HANFORD NATURAL RESOURCE DAMAGE ASSESSMENT
INJURY ASSESSMENT PLAN

Hanford Natural Resource Trustees

U.S. Department of Energy

U.S. Department of the Interior

U.S. Department of Commerce

State of Washington

State of Oregon

Yakama Nation

Confederated Tribes of the Umatilla Indian Reservation

Nez Perce Tribe

DRAFT

November 15, 2012

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LIST OF EXHIBITS

LIST OF ACRONYMS

ALE	Arid Lands Ecology
ANN	Artificial Neural Network
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPC	Contaminant of Potential Concern
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CWA	Clean Water Act
DAP	Data Acquisition Plan
DMP	Data Management Plan
DMS	Data Management System
DOE	U.S. Department of Energy
DOI	Department of the Interior
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FS	Feasibility Study
HEIS	Hanford Environmental Information System
HH&E	Human Health and Environment
HLAN	Hanford Local Area Network
HNRTC	Hanford Natural Resource Trustee Council
IAP	Injury Assessment Plan
MC	Markov chain
MOA	Memorandum of Agreement
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Adiminstration
NPL	National Priorities List
NPT	Nez Perce Tribe
NRD	Natural Resource Damage
NRDA	Natural Resource Damage Assessment
OU	Operable Unit
PAS	Pre-assessment Screen
PNNL	Pacific Northwest National Laboratory
QA	Quality Assurance
QAP	Quality Assurance Plan

QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QMP	Quality Management Plan
RCDP	Restoration and Compensation Determination Plan
RCBRA	River Corridor Baseline Risk Assessment
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RM	River Mile
SDWA	Surface Drinking Water Act
SOPs	Standard Operating Procedures
TCP	Traditional Cultural Property
TEDF	Treated Effluent Disposal Facility
TNC	The Nature Conservancy
TP	Transition Probability
TWG	Technical Working Group
UCWSRI	Upper Columbia White Sturgeon Recovery Initiative
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
WCH	Washington Closure Hanford
WDFW	Washington Department of Fish and Wildlife

EXECUTIVE SUMMARY

This Injury Assessment Plan is intended to describe the Hanford Trustees' current understanding of the studies necessary to determine and quantify contaminant-related injury to Hanford Site natural resources and to assess associated service losses.

The identified studies, which are summarized in Exhibit ES-1, include efforts to carefully evaluate existing information as well as efforts designed to generate new information relevant to natural resource injury determination and quantification.

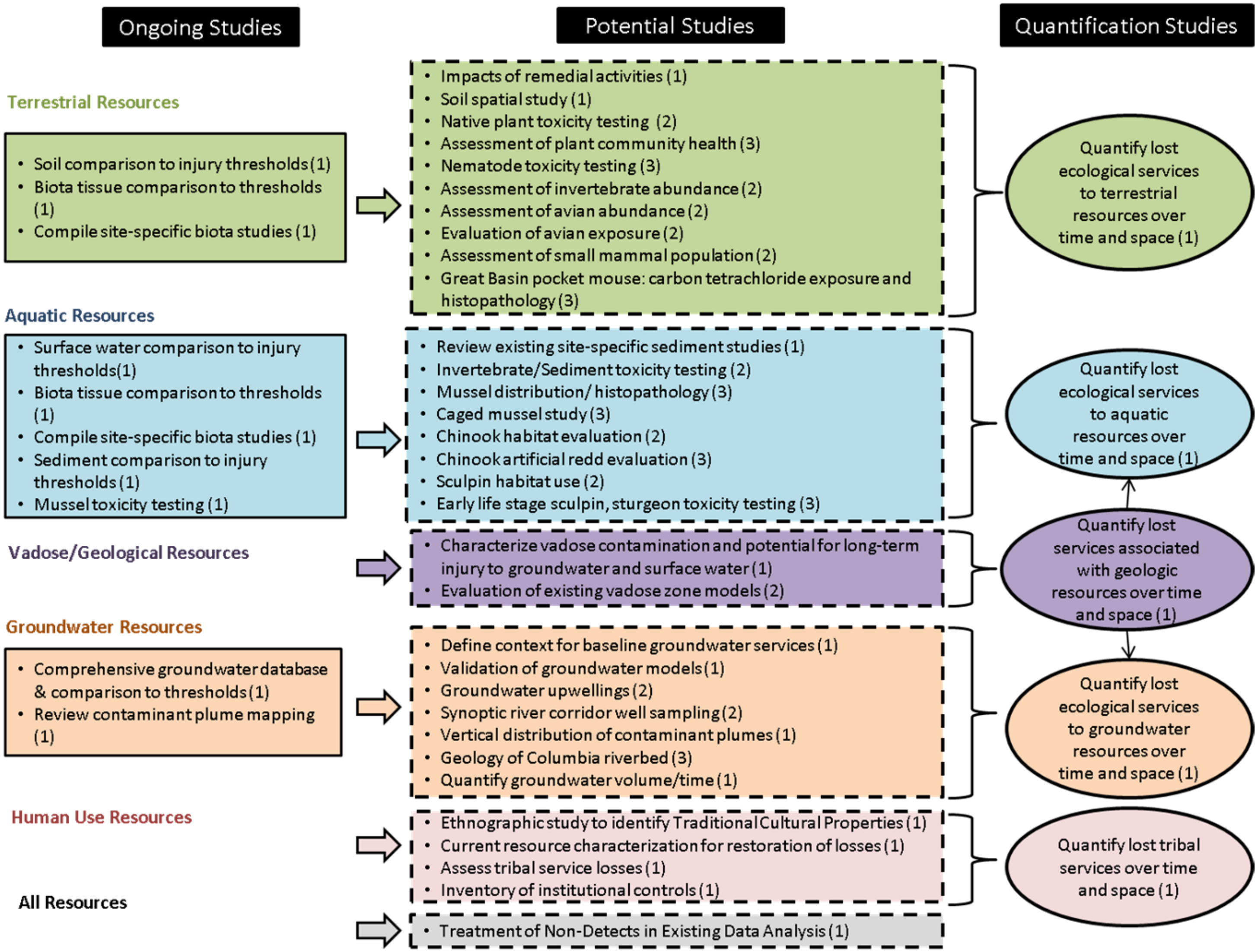
The Trustees have selected these studies and produced this document as part of their duties in connection with the ongoing Hanford natural resource damage assessment (NRDA). The following paragraphs describe the purpose and need for a NRDA, identify opportunities for public involvement, describe the identity and role of the Trustees (who work on behalf of the public), provide more information about NRDA, and briefly summarize the events and general processes undertaken by the Trustees that resulted in the selection of the indicated studies.

PURPOSE AND NEED

Public lands, waters, air, and living resources are held in trust for the benefit of all people and future generations. Since the 1970s, the U.S. Congress has enacted a number of statutes to protect and manage the natural resources that belong to all Americans. Certain of these statutes designate natural resource Trustees. These Trustees serve as stewards of natural resources on behalf of the public, identifying potential natural resource injuries and restoring resources when they are threatened or harmed by releases of hazardous substances. In the case of Hanford, designated Trustees include several Federal agencies as well as states and tribes.

Since 1943, activities on the Hanford Site in south-central Washington have resulted in the widespread release of a large volume of radiological and other hazardous contaminants into the environment. Cleanup of the Site began around 1989 and will continue for several more decades. While cleanup efforts continue, the Hanford Natural Resource Trustees are conducting a natural resource damage assessment.

EXHIBIT ES-1 SUMMARY OF INJURY ASSESSMENT STUDIES



Note: The numbers in parentheses indicates the priority group of each study, as described in the text. Additional potential studies may be added to this list.

The goal of the NRDA is to restore, replace, or acquire the equivalent of natural resources that have been injured as a result of the release of hazardous substances.

> Trustees undertake natural resource damage assessments on behalf of the public. The purpose of these assessments is to define the scope and scale of natural resource restoration required to make the public whole for natural resource injuries and associated service losses.

As defined by the Department of the Interior's (DOI) regulations implementing the damage assessment provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the purpose of this Plan is to outline the approach the Hanford Trustees will take to assess injuries to natural resources stemming from releases of Site-related hazardous substances. The development of a Plan is intended to ensure that the natural resource damage assessment is conducted in a planned and systematic manner and at a reasonable cost (43 CFR § 11.30(b)). This Injury Assessment Plan describes ongoing and anticipated studies designed to evaluate past, current, and future natural resource injury and associated losses of resource services. Ultimately, the information collected through implementation of this Plan will inform the scope and scale of restoration activities needed to make the public whole for natural resource injuries and associated service losses.

This Plan describes the Trustees' current understanding of the studies necessary to determine and quantify injury to Site resources and resource services. The studies have been initially grouped into three general prioritization categories (nearer-term, middle-term, and longer-term). The exact timing of studies has not been determined and will depend on a number of considerations including but not limited to available funding. The DOI regulations also provide that an assessment plan may be modified as new information becomes available (43 CFR Section 11.33 (e)). Implementation of initial studies may result in the addition of studies to the current list, and may deprioritize others.

PUBLIC INVOLVEMENT

The DOI regulations provide that an assessment plan, as well as any significant subsequent revisions that may be made to it, be made available for review and comment by potentially responsible parties, other natural resource trustees, other affected Federal, state, or tribal agencies, and any other interested members of the public for a period of at least 30 calendar days, with reasonable extensions granted as appropriate (43 CFR §11.32(c) and (e)).

The Trustees are interested in receiving feedback on this Injury Assessment Plan. To facilitate this process, the Trustees are asking the public to review the Assessment Plan and provide feedback on the proposed approach and studies. Comments should be submitted by December 31, 2012. These comments will help the Trustees plan and conduct an assessment that is scientifically valid, cost effective, and that incorporates a broad array of perspectives. To that end, the Trustees request that you carefully consider this plan and provide any comments you may have.

Modifications to the Assessment Plan documents may occur at any time during the Assessment phase as new and additional information becomes available. Such modifications may result in additional need for public notification and opportunities for comment. Minor modifications could result in public notification, but need not result in delay of the implementation of those modifications pending public comment (43 C.F.R. § 11.32(e)).

Commenters are encouraged to submit electronic comments to Larry.Goldstein@ecy.wa.gov. Comments can also be sent via U.S. mail to:

Mr. Larry Goldstein
Hanford Natural Resource Trustee Council Chair
Washington State Department of Ecology
Nuclear Waste Program
PO Box 47600
Olympia, WA 47600

For more information, please visit www.hanfordnrda.org.

THE HANFORD TRUSTEES

Designated Federal, state, and tribal entities are authorized to act as Trustees of natural resources on behalf of the public.[1] In this role, Trustees may assess and recover damages for natural resource injuries resulting from the release of hazardous substances to the environment to ensure that the services that would have been provided by the injured resources but for Hanford Site-related contamination are restored, and the public made whole. Natural Resource Trustees for the Hanford Assessment Area include:

- U.S. Department of Energy (DOE);
- U.S. Department of the Interior (DOI) through U.S. Fish and Wildlife Service;
- U.S. Department of Commerce through the National Oceanic and Atmospheric Administration;
- State of Washington, through the Washington Department of Ecology, in consultation with the Washington Department of Fish and Wildlife;
- State of Oregon, through the Oregon Department of Energy;

[1] More specifically, CERCLA as amended (42 U.S.C. 9601 *et. seq.*), the Oil Pollution Act of 1990 (OPA), 33 U.S.C. 2701 *et. seq.*, and the Federal Water Pollution Control Act (the "Clean Water Act" (CWA)), as amended (33 U.S.C. 1251 *et. seq.*), authorize the Federal government, states, and Indian tribes to recover, on behalf of the public, damages for injuries to, destruction of, or loss of natural resources belonging to, managed by, appertaining to, or otherwise controlled by them (42 CFR §9607(f)(1); 9601(16)). Under the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), when there is injury to, destruction of, loss of, or threat to the supporting ecosystems of natural resources, the Trustees are also authorized to act (40 CFR Subpart G § 300.600).

- Confederated Tribes and Bands of the Yakama Nation (Yakama Nation);
- Confederated Tribes of the Umatilla Indian Reservation (CTUIR); and
- The Nez Perce Tribe.

The Trustees have formed the Hanford Natural Resources Trustee Council (HNRTC), a collaborative working group chartered to address natural resources injured by Hanford Site releases of hazardous substances. The Trustees have established several Technical Working Groups (TWGs) that provide technical expertise and guidance to the Council.

The party responsible for discharges and releases of oil or hazardous substances at this site (i.e., the “responsible party”) is DOE. DOE is also responsible for site remediation; in addition, as noted above, DOE is a Trustee. The Trustees have agreed to follow a cooperative assessment process, as recommended by the DOI Natural Resource Damage Assessment regulations; meaning that DOE and the other Trustees are jointly and collaboratively conducting the assessment, including development of this Plan.

NATURAL RESOURCE DAMAGE ASSESSMENT VS. REMEDIATION

Following the release of a hazardous substance that resulted in injury to a natural resource or resources, CERCLA provides an avenue by which the affected sites and resources can be remediated and restored. “Remediation” and “restoration” represent two related, but distinct processes under CERCLA.

Remediation and/or cleanup activities are risk-based. They are designed to reduce current and future risks to public health and the environment to acceptable levels. At Hanford, remediation activities are overseen by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology.

> “Remediation” and “restoration” represent two related, but distinct processes under CERCLA.

In contrast, restoration – the focus of the natural resource damage assessment process – is designed to restore injured natural resources to their “baseline” condition, defined as the conditions that would have existed in the assessment area (over time) absent the release of the hazardous contaminants in question. Achieving a risk-based cleanup goal (remediation) does not necessarily return injured natural resources to their baseline condition. However, Trustees are directed in the DOI regulations to take cleanup activities and outcomes into account — and whenever possible coordinate with the remedial process — in order to enhance the cost-effectiveness of proposed restoration activities.

THE NRDA PROCESS

Section 301(c) of CERCLA provides the statutory authority for natural resource Trustees to assess and recover damages resulting from the "injury to, destruction of, or loss of natural resources resulting from the release of oil or hazardous substances." Injury assessment planning represents one step within the multi-phased framework of natural resource damage assessments. As noted above, the ultimate goal of the assessment is to restore (or replace) injured natural resources and services lost due to the release of hazardous substances. To achieve this goal, Trustees must complete a number of interim steps which are outlined within the DOI regulations, and can be divided into three sequential phases. These phases are presented graphically in Exhibit ES-2, and are described below.

In the **Pre-Assessment Phase**, a review of readily available information is conducted that allows the authorized official to make an early decision on whether a natural resource damage assessment can and should be performed. During this phase, the Trustees determine whether an injury has occurred and if a pathway of exposure exists.[2] The pre-assessment phase is a pre-requisite to conducting a formal assessment. The Hanford Trustees have completed this process and confirmed that a formal assessment of injuries to resources on the Site is warranted.

Development of the present injury assessment plan, indicated by a red outline in Exhibit ES-2, is the first step within the **Assessment Phase** of a natural resource damage assessment.[3] There are two primary components of the Assessment Phase: planning and implementation. First, the Trustees must write a plan, or series of plans, to ensure that the assessment is performed in a planned and systematic manner, and that the methodologies selected can be conducted at a reasonable cost.[4] Second, the Plan is implemented.

This report represents the Trustees' current plan for injury assessment. It focuses on studies to be undertaken as part of injury determination and injury quantification phases of the assessment. It does not include studies associated with the damage determination phase—i.e., it does not include efforts aimed at identifying the appropriate amount of compensation, expressed either in dollars or in terms of actions to be taken to restore natural resources and the services they provide, associated with any potential injuries. The Trustees will develop one or more additional planning documents when appropriate to describe efforts to be undertaken as part of damage determination. In addition, the Trustees may make modifications to this Plan over time to reflect new information and/or

[2] "Injury" is generally defined in the regulations as a measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge of oil or release of a hazardous substance" (43 CFR 11.14(v)).

[3] In addition to the assessment documents and steps listed in Exhibit ES-2, the Trustees have commissioned a Preliminary Economic Determination, which uses existing information to estimate the scale and scope of injury and damages at the Hanford Site. This document and the process of its development informed this damage assessment plan.

[4] The U.S. Department of the Interior NRDA regulations at 43 CFR 11 require that the Trustees perform either a Type A or Type B assessment. Type A assessments are assessments performed using the CERCLA Type A Natural Resource Damage Assessment Model for Coastal and Marine Environments. Type B assessments employ alternative methodologies for damages determination. In the case of Hanford, the Trustees are conducting a Type B assessment.

analyses as they become available. Future assessment planning documents will be developed that provide more technical details for particular studies (e.g., detailed sampling and analysis plans, statistical approaches). The implementation of studies generally described in this Injury Assessment Plan, and to be described in more detail in study-specific work plans, ultimately will result in the identification and quantification of injury to natural resources resulting from hazardous contaminant releases from the Site.

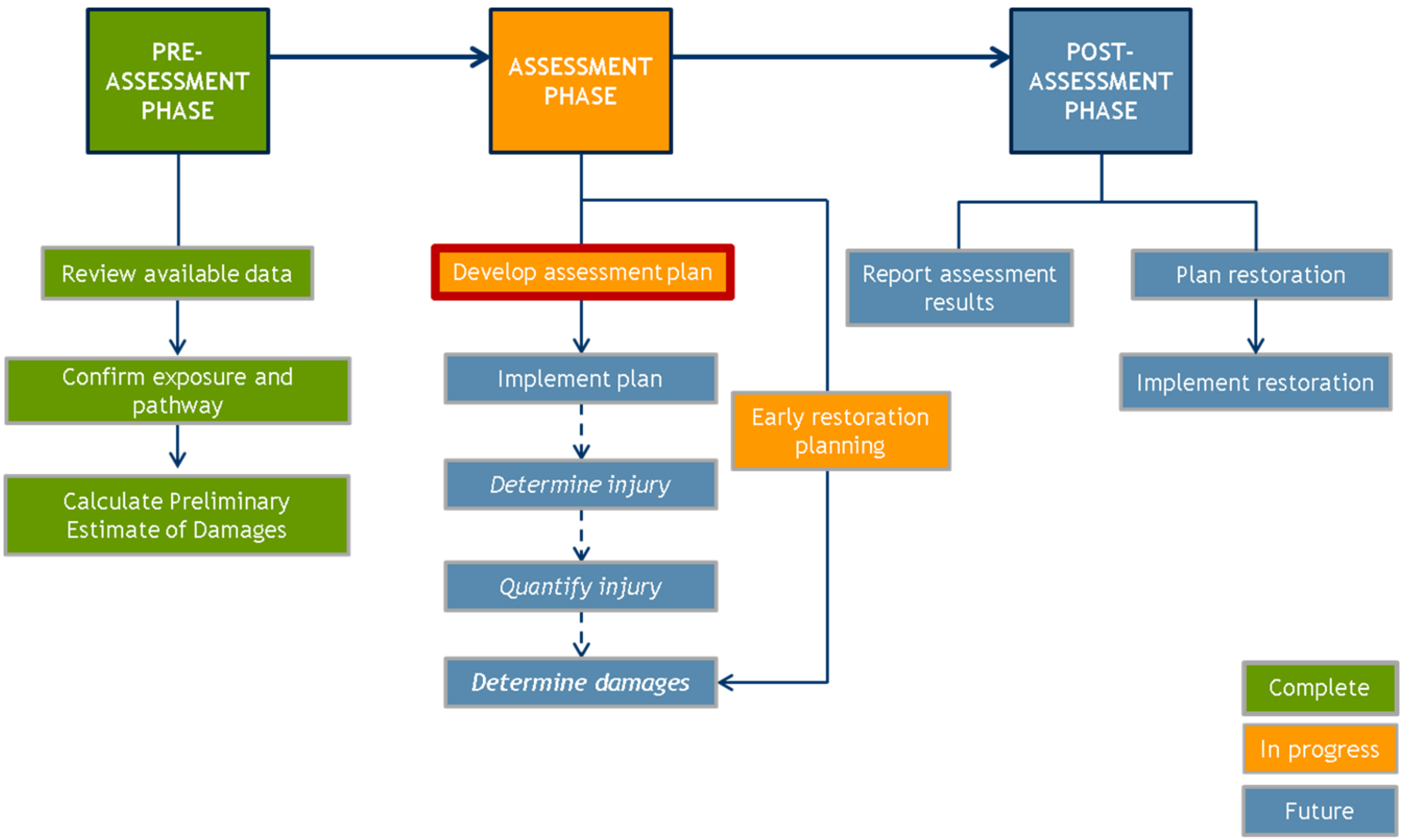
The DOI NRDA regulations state that a Restoration Compensation and Determination Plan (RCDP) shall be part of the Assessment Plan (43 CFR 11.81(d)(1)). The RCDP is a document that lists a reasonable number of possible alternatives for restoration, rehabilitation, replacement, and/or acquisition of equivalent resources and their related services; that selects one of the alternatives, and provides a rationale for the alternative (43 CFR 11.81(a)). The DOI NRDA regulations, however, allow Trustees to defer development and public release of a RCDP after completion of injury determination or quantification phases if existing data are not sufficient to develop a RCDP at the time that the overall assessment plan is released (43 CFR 11.81(d)(1). The Hanford Trustees believe there is insufficient information to complete a RCDP at this time, and have chosen to develop a RCDP later in the assessment process.

After completing injury determination and quantification (including pathway determination), the damage determination planning and implementation will follow. Subsequent to damage determination, the Trustees enter the **Post-Assessment Phase.** As part of this phase, the Trustees will prepare: 1) a Report of Assessment detailing the results of the Assessment phase; and 2) a Restoration Plan that is based upon the RCDP and describes how natural resources and the services they provide will be restored.

The Trustees note that although the various phases and steps of a natural resource damage assessment are set forth as a sequential process within the DOI NRDA regulations, in practice evaluations for different natural resources may occur at different rates: for some categories of injury the Trustees may choose to proceed through the steps in a sequential order; in others the availability of existing information or the ability to establish reasonable assumptions may allow the Trustees to take an alternative, but still sound approach to establish the scale and scope of required restoration.

In addition, the Trustees may from time to time identify early restoration opportunities—i.e., chances to commence with a restoration project before the assessment has proceeded completely through earlier phases. Because these opportunities may be short-lived in duration, the Trustees may agree to pursue them and to estimate restoration credits for such projects that could eventually be used to offset the final tally of environmental liabilities.

EXHIBIT ES-2 PHASES OF THE NATURAL RESOURCE DAMAGE ASSESSMENT PROCESS



SITE HISTORY, NATURAL RESOURCES, AND INJURY ASSESSMENT PLAN DEVELOPMENT

ACTIVITIES LEADING TO CONTAMINANT RELEASE

In 1943, the United States established the 586 square mile Hanford Site as the Hanford Nuclear Reservation to produce nuclear materials for national defense.[5] In addition to producing the materials needed for nuclear weapons, Site activities produced significant quantities of waste containing hazardous chemicals and/or radioactive materials.[6] The Federal government managed these wastes by storing them on land and by releasing them into ponds and ditches.[7] Over time, many of these production facilities have leaked contaminants onto the land and into the air and water, including into the Columbia River.[8] The production facilities, which included nine nuclear reactors and associated processing facilities (Poston *et al.* 2010), are now considered "closed" (not operational) and are being decommissioned and cleaned up by DOE, which is currently the Federal agency responsible for overall management of the Site.[9]

CONTAMINANTS OF POTENTIAL CONCERN

At Hanford, the list of contaminants known to have been used and released from the Site is extensive. The Hanford Trustees have identified a suite of contaminants on which to focus this assessment. The Trustees have reviewed a number of information sources in assembling this list, including but not limited to site risk assessments (e.g., CRCIA 1998, DOE 2011a, b), contaminant data for onsite underground tanks (e.g., Gephart 2003b) and major groundwater plumes (e.g., DOE 2011c), reports on historic and current releases (e.g., Hall 1991), and Site contaminant databases. Although the Trustees' work in this area is ongoing and subject to further refinement, the preliminary list of contaminants of potential concern (COPCs) is presented in Exhibit ES-3.

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[5] Tri-Party Agreement, Article VI, Part 23 (A).

[6] Tri-Party Agreement, Article VI, Part 23 (D) and http://www.hanford.gov/page.cfm/HanfordsPresentMission

[7] http://www.hanford.gov/page.cfm/HanfordsPresentMission

[8] Statement added by Trustees, in part supported by http://www.hanford.gov/page.cfm/HanfordsPresentMission and the Cleanup Progress at Hanford Factsheet.

[9] Tri-Party Agreement, Article VI, Part 24 (E).

EXHIBIT ES-3 PRELIMINARY LIST OF CONTAMINANTS OF POTENTIAL CONCERN

RADIOISOTOPES	ORGANICS	INORGANICS
Americium-241 Carbon-14 Cesium-137 Cobalt-60 Europium-152 Gadolinium-152 Iodine-129 Neptunium-237 Plutonium-239/240 Potassium-40 Radium-226, Ra-228 Strontium-90 Technetium-99 Thorium-232 Tritium Uranium-233/34/35/38 Zirconium-93 Total rad dose	1-2 Dichloroethane 1,4 Dioxane 2,4,6 Trichlorophenol Acetonitrile Benzo(a)pyrene Carbon tetrachloride Chlorodane Chloroform Cyanide DDT/DDE Dichloromethane Glyphosate Hydrazine Hexone PCBs Tributyl Phosphate Trichloroethylene (TCE) Total Petroleum Hydrocarbons/PAHs Vinyl chloride	Antimony Arsenic Barium Boron Cadmium Chromium (includes Cr6+) Cobalt Copper Fluoride Lead Manganese Mercury Molybdenum Nitrate Nickel Phosphate Selenium Silver Strontium Uranium Vanadium Zinc

RESOURCES OF CONCERN

Natural resources of concern include all Trust resources within the assessment area, including groundwater, surface water, sediment, soil, plants, insects and other invertebrates, fish, amphibians, reptiles, birds, and mammals.[10] The Hanford Site has unique terrestrial and aquatic ecosystems that are home to 40 species of mammals (Fitzner and Gray 1991), over 200 species of birds (TNC 1999), and a large variety of amphibians, reptiles, and invertebrates (Fitzner and Gray 1991). Rare plant surveys conducted by The Nature Conservancy confirm the Site is a critical area for the conservation of rare shrub-steppe, riparian and aquatic plants. At least 725 individual plant species have been identified on the Site (Sackschewsky and Downs 2001), 13 of which are listed by Washington State as threatened or endangered (Poston *et al.* 2010). The adjacent Columbia River also supports a number of economically and culturally important fish species including the Chinook salmon, coho salmon, steelhead, white sturgeon and Pacific lamprey.

The Chinook salmon species is managed by population according to spawning location and timing of spawning. There are seventeen populations of Chinook that are considered to be “substantially reproductively isolated” and that are managed in divisions known as Evolutionarily Significant Units (ESUs). Two Chinook ESUs currently occur within the

[10] Available information does not indicate that the air resource itself has been subject to injury due to releases from the Hanford Site. For the purposes of this Plan, air is considered as a pathway for contamination.

Hanford Reach: (1) the Upper Columbia River (UCR) summer/fall run Chinook, and (2) the UCR spring Chinook.

The fall run Chinook naturally spawn in the Hanford Reach, as do fall run steelhead trout (Federally threatened) (Duncan *et al.* 2007). Spring-run Chinook, which pass through the Hanford Reach to their spawning grounds, are listed as Federally endangered.

HUMAN USES OF NATURAL RESOURCES

Historically, the lands making up the Hanford Site were home to several mid-Columbia Indian Tribes and bands, including ancestors of the present-day Wanapum, Yakama, Nez Perce, Cayuse, Umatilla, and Walla Walla people. The Site continues to have tremendous cultural and religious significance for local tribes. Non-tribal historical and present uses of the Site include recreation (e.g., fishing, hunting, birding) and agriculture. The Wanapum and Yakama Tribes continue to fish in the Columbia River, including spring and fall fishing near Horn Rapids Dam and from Vernita Bridge to Wanapum Dam (Leah Aleck, personal communication, 2012).

> "The most appropriate way to understand our cultural values is to view our cultural practices conducted today on our landscape. They reflect a complex tradition showing high regard for the land. There isn't a daily activity of a traditional lifestyle that doesn't have oral traditions telling how the activity is part of the land and plays a role in taking care of the land" (*Nez Perce 2010*).

The release of hazardous contaminants from Hanford Site operations has impacted people's use of natural resources, and the well-being they derive from such uses. Changes in human use due to the presence of contaminants may result in the need for specific restoration actions to restore the scale and quality of human uses of natural resources of particular concern to the Trustees or losses in tribal services as a result of injury to natural resources.

ABOUT THE PROPOSED STUDIES

Purpose of Studies

It is well-established that natural resources have been injured as a result of release of hazardous contaminants from Hanford, as described in Chapter 5. Thus, the Trustees' intent in designing this Injury Assessment Plan, and in selecting the studies identified therein, is to lay out a path by which the scope and scale of injury to natural resources can be understood and restoration may be planned and scaled appropriately.

The Plan as currently written represents the Trustees' best understanding of the studies that may be necessary to robustly identify and quantify injury to Site natural resources and their services. Inclusion of a study within this Plan does not guarantee that it will be undertaken, and studies not included within the Plan may be deemed necessary at a later date. **The Plan does not limit in any way the extent and nature of studies that may be undertaken in the course of the Assessment.** Rather, it provides a starting point from which the Trustees will begin to prioritize study efforts and implement the Injury Assessment process.

In developing this Plan, the Trustees have considered available information on the nature and extent of hazardous contaminants in the environment resulting from releases from Hanford operations. The Trustees have also considered information that can be used to establish the level of past, current, and likely future natural resource injuries and service losses resulting from these releases. There is, however, a great deal of uncertainty as to the potential for long-term future natural resource injuries and service losses that could result from sources of contamination at the Site that currently may not be well-characterized. There is also a great deal of uncertainty regarding the likely nature and effectiveness of future remedial actions in addressing these sources of contamination. For example, there are several existing sources of hazardous contaminants in the vadose zone (or deep soils above the groundwater) in the Central Plateau of the Hanford Site (Chronister 2011, DOE 2010a). These sources may not be remediated as part of the ongoing Site cleanup. As such, additional injuries and lost services associated with these contaminants may occur in the future that may not be foreseen or reliably quantified in the context of this injury assessment plan. DOE notes that ecological risk assessments, additional site characterization, and remedial investigation/feasibility studies will be performed and are intended to assure remedial actions are protective of human health and the environment.

Study Selection

A number of Trustee efforts have led to the selection of the particular studies included in this Plan. The Trustees have been meeting since 1993, and more recently on a monthly basis to discuss Hanford assessment activities. There are six technical working groups (TWGs) that focus on more technical analyses including the aquatic, terrestrial, groundwater, human use, restoration, and source and pathway TWGs. Specifically, the Hanford TWGs have conducted preliminary analyses of geo-coded sediment and fish contaminant data to determine resources at risk, developed a number of species profiles, which summarize and evaluate historical contaminant data on a Hanford species of concern, conducted research on contaminant sources and resource use of several ponds and ditches on Hanford, evaluated groundwater contaminant plume maps, and began developing the Hanford Natural Resource Restoration Plan which addresses early restoration and restoration project evaluation criteria.

The Trustees held a number of workshops and expert panels to explore different methods for injury assessment as well as key questions on the effects of contamination at Hanford. Workshop and panel topics included data management, quality assessment, ecosystem service valuation, human use services and service flows in natural resource damage assessments, compiling toxicity thresholds, injury to aquatic biota in the Hanford Reach, groundwater contaminant upwellings, the integration of groundwater and vadose zone analyses, and the effects of radionuclides on biota at Hanford.

With contractor support, the Trustees have completed a number of large technical analyses including a compilation and evaluation of natural resource information and historical contaminant concentrations from the Hanford Site, an analysis and summary of key data gaps, and a preliminary estimate of injury at the Site. Together, these analyses have helped the Trustees to evaluate existing information and identify injury studies that will fill data gaps and allow the Trustees to determine and quantify injury at the Hanford Site.

Nature of Studies

This Injury Assessment Plan presents an array of potential studies to identify the scope and scale of injury and services losses to natural resources. Ultimately, these studies are intended to help the Trustees select the appropriate scope and scale of restoration projects that will restore site natural resources to their baseline condition – i.e., a condition in which the injured natural resource provides all of the services that would have been provided absent natural resource injury – and compensate the public for any lost services that occurred while natural resources were in an injured state. The identified studies fall generally within four categories:

1. **Use of existing data to identify potential injury to site resources.**

   Since the Hanford Reservation was established in 1943, a tremendous volume of environmental data has been collected both at the Site and from adjacent lands and waterways. These data present a valuable source of information on the past and recent condition of site resources, and they will be used, to the extent possible, to help evaluate occurrence and magnitude of potential injury to site resources. Studies that may be undertaken in this regard include the comparison of existing data measuring concentrations of contaminants in various media to selected injury thresholds, and compilation of the results of toxicity testing that has been conducted on-site for non-assessment purposes.[11]

2. **Collection of new data to determine injury to site resources, including changes in natural resource services.**

   Preliminary analysis of existing site data indicates that those data alone will not be sufficient to fully characterize contamination and injury to site resources. For example, sampling of soil has largely been limited to specific geographic areas immediately around the operational units, and most data have been collected for specific purposes, potentially limiting its utility for Natural Resource Damage Assessment. In addition, comparison of existing data to published thresholds may not, in itself, be enough to demonstrate injury under the law.[12] Collection of new data to fill existing gaps, or to answer questions raised through the analysis of existing data, will represent a significant proportion of studies conducted under the Injury Assessment.

3. **Use of existing or newly collected data to identify the pathways of exposure of site resources to hazardous releases.**

[11] An "injury threshold" is a concentration of a contaminant found in a given media type or resource which has been demonstrated (e.g., in the peer-reviewed scientific literature) to cause a "…measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource" (43 CFR 11.14(v)).

[12] An exception may be in the case where the published threshold is based on a site-specific study.

Responsible parties are only liable for injury due to contamination that can be positively linked to their own hazardous releases. However, for some contaminants, upstream or otherwise offsite sources may be contributing to the contamination identified in site resources. Studies of this nature are primarily focused on demonstrating a direct link between on-site activities and observed contamination, or identifying that portion of identified injury for which the responsible party can be held accountable.

4. **Use of existing or newly collected data to quantify injury to site resources, including changes in natural resource services.**

   Determination that injury has occurred does not provide sufficient information to allow for the selection and scaling of restoration projects needed to restore that resource's services to their baseline condition. Once injury is identified, the Trustees must evaluate the scope and scale of that injury and the degree of natural resource services loss. These studies will evaluate the type of injury that has occurred, and quantify that injury, providing information so that restoration may be selected and scaled appropriately.

Study Timing / Relative Prioritization

To help guide future assessment efforts, the Trustees have grouped the proposed studies into three informal categories. The assignation of a study to a particular category (and, therefore, the expected relative prioritization of the study) is based on Trustee judgments about a variety of factors including but not necessarily limited to: cost effectiveness; technical study sequencing requirements; studies that, in the Trustees' view, may be more likely to demonstrate injury; studies most likely to contribute to the selection and scaling of restoration alternatives; and/or studies anticipated to address principal concerns of the public. Based on these types of considerations, the Trustees have grouped the studies in this plan into three categories:

1. Nearer-term priorities,
2. Middle-term priorities, and
3. Longer-term priorities.

The first category, nearer-term priorities, includes studies that are presently ongoing, and studies the completion of which are prerequisites for subsequent work or that are expected to generate information of significant use in refining future study designs. The second category of studies is expected to include studies that may be more likely to identify injuries, studies anticipated to address principal concerns of the public, and/or studies that are expected to contribute the most towards informing the selection and scaling of restoration alternatives. The third category includes studies that depend on the prior completion of other efforts, and those that are presently expected to be subject to more difficult technical issues. Exhibit ES-1 lists the studies identified in this plan and indicates their current relative priority group (i.e., 1, 2, or 3) in parentheses after each study.

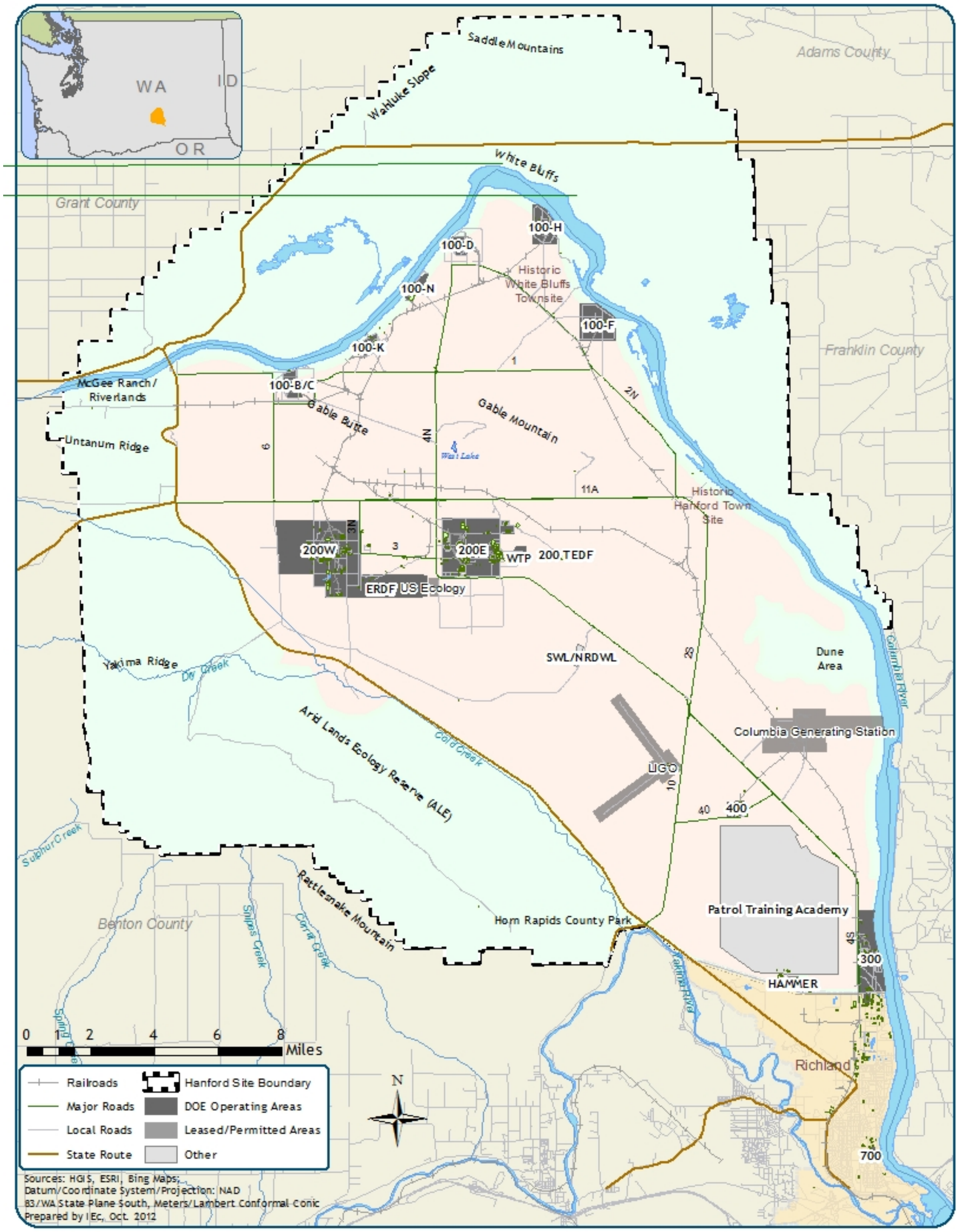
CHAPTER 1 | INTRODUCTION

The Hanford Site is located in south-central Washington State near the City of Richland – approximately 150 miles southwest of Spokane and 200 miles southeast of Seattle. The Site covers 586 square miles (375,000 acres) and includes an area now designated as the Hanford Reach National Monument (Exhibit 1-1).

The Site has had restricted public access since 1943, "providing a buffer for areas currently used for storage of nuclear materials, waste treatment, and waste storage and/or disposal" (Duncan 2007). This restricted access has allowed the area to serve as a refuge for native plants and animals that were once far more common in the region (USFWS 2008). At present, the Site is surrounded primarily by agricultural lands. The U.S. Department of Energy (DOE) and the U.S. Fish and Wildlife Service (FWS) each manage portions of the Site.

The Hanford Site is home to nine decommissioned nuclear reactors and associated processing facilities. From 1944 until 1987 these reactors produced plutonium for use in the United States' atomic weapons program. The processes required to transform raw uranium into plutonium generated billions of gallons of liquid waste and millions of tons of solid waste. Radioactive wastes were piped to underground tanks, contaminated liquids and cooling water were pumped to ditches and ponds, and contaminated water discharged from the reactors was released to nearby soils and the Columbia River (Gephart 2003b). Major contaminants released to soil and groundwater include metals (e.g., chromium), organics (e.g., carbon tetrachloride), and radionuclides (e.g., cesium, tritium, strontium-90, technetium-99, uranium, and plutonium) (Hartman *et al.* 2001). Most radionuclides released to the Columbia River were short-lived; however, some longer-lived radionuclides such as cobalt-60, strontium-90, cesium-137, uranium-238, and plutonium-238, -239, and -240 were also released to the River (Gephart 2003b).

EXHIBIT 1-1 HANFORD SITE



In May 1989, DOE, the U.S. Environmental Protection Agency (EPA), and Washington State signed the Hanford Federal Facilities Agreement and Consent Order (also known as the Tri-Party Agreement), and in November, 1989, the Hanford Site was listed on the

National Priorities List (NPL).[13] Remedial actions have been ongoing since the early 1990s. Cleanup actions are conducted by DOE, with support and oversight from EPA and the Washington Department of Ecology.

Radionuclides, metals, and organics released to on-Site ditches, ponds, and soil have leached into groundwater beneath the Site. Along with contaminants discharged directly to the Columbia River, these hazardous substances (also generally referred to as contaminants in this Plan) have been transported downstream via surface water, sediments, and floodplain soils. Since the 1950s, Site natural resources have been monitored as part of various risk assessments and monthly and annual environmental reporting requirements. Thousands of soil and sediment samples, as well as millions of groundwater samples are documented in the Hanford Environmental Information Systems database, confirming exposure of sediments, soils, groundwater, and biota to contaminants such as chromium, mercury, strontium-90, and technetium-99. In addition, EPA conducted fish surveys in the Columbia River from 1996-1998, and documented elevated levels of metals and organic contaminants in Hanford Reach fish compared to other areas of the Columbia River basin (EPA 2002a).

Releases of hazardous substances to the environment may cause injury to natural resources. Injury is generally defined in the Department of the Interior (DOI) regulations for Damage Assessment under CERCLA as:

> "a measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge of oil or release of a hazardous substance. As used in this part, injury encompasses the phrases "injury", "destruction" and "loss". Injury definitions applicable to specific resources are provided in Sec. 11.62 of this part." (43 CFR 11.14(v))

Natural resources or resources are defined in the DOI regulations under CERCLA as:

> "land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States...any State or local government, any foreign government, any Indian tribe, or if such resources are subject to a trust restriction or alienation, any member of an Indian tribe. These natural resources have been categorized into the following five groups: Surface water resources, ground water resources, air resources, geologic resources, and biological resources." (43 CFR 11.14(z))

When injury to natural resources is suspected, Federal law authorizes government officials, acting as natural resource trustees, to enter into a Natural Resource Damage

[13] "The *National Priorities List* (NPL) is the list of national priorities among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. The NPL is intended primarily to guide the EPA in determining which sites warrant further investigation" (EPA 2012c).

Assessment (NRDA) process. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[14] and the Federal Water Pollution Control Act, also known as the Clean Water Act (CWA),[15] authorize the Federal government, states, and Indian tribes to recover, on behalf of the public, damages for injuries to natural resources belonging to, managed by, appertaining to, or otherwise controlled by them. Under the authority of CERCLA and the CWA, the U.S. Department of the Interior (DOI) issued regulations to guide trustees in the assessment of natural resource injuries and damages and to plan and implement actions to restore, replace, or rehabilitate natural resources injured or lost as a result of the release of a hazardous substance, and/or to acquire the equivalent resources (collectively referred to as “restoration”; 42 U.S.C. § 9601 et seq. (CERCLA); 43 CFR Part 11).

The DOI regulations under CERCLA define restoration or rehabilitation as:

> “actions undertaken to return an injured resource to its baseline condition, as measured in terms of the injured resource’s physical, chemical, or biological properties or the services it previously provided, when such actions are in addition to response actions completed or anticipated, and when such actions exceed the level of response actions determined appropriate to the site pursuant to the NCP.” (43 CFR 11.14(ll))

The remainder of this Chapter describes the following:

- Trusteeship: the Hanford Trustees and their role and coordination;
- Overview of the Natural Resource Damage Assessment process;
- Assessment activities at Hanford;
- Public participation;
- Schedule for injury assessment; and
- Plan organization.

1.1 TRUSTEESHIP

The natural resource trustees for the Hanford Site (together, Trustees) include:

- The U.S. Department of Energy;
- The U.S. Department of the Interior through the Fish and Wildlife Service;
- The U.S. Department of Commerce through the National Oceanic and Atmospheric Administration (NOAA);
- The State of Washington through the Washington Department of Ecology in consultation with the Washington Department of Fish and Wildlife;
- The State of Oregon through the Oregon Department of Energy;

[14] As amended, 42 U.S.C. §§ 9601, et seq.

[15] As amended, 33 U.S.C. §§ 1251, et seq.

- The Confederated Tribes and Bands of the Yakama Nation (Yakama Nation);
- The Confederated Tribes of the Umatilla Indian Reservation (CTUIR); and
- The Nez Perce Tribe.

In 1993, DOE, DOI, the State of Washington, the State of Oregon, the Yakama Nation, CTUIR, and the Nez Perce Tribe formed the Hanford Natural Resource Trustee Council (HNRTC), a collaborative working group chartered to address natural resources affected by Hanford Site releases of contaminants. In 1996, these Trustees signed a Memorandum of Agreement (MOA) "intended to help coordinate decisions and actions made by the trustees pursuant to their legal authority to address natural resources impacted by Hanford Site releases of contaminants." NOAA began participating in the Hanford Trustee Council in 1997.

The Hanford Trustees have adopted a statement of guiding principles for protection of natural resources on the Hanford Site. These principles state, in broad terms, the Trustees' expectations for cleanup and future uses of the Hanford Site as they relate to natural resource restoration, and also Trustee goals for restoration of injured natural resources. Three broad goals are articulated in the principles document (Guiding principles for protection of natural resources Draft 4, March 11, 2011):

1) Achieve a cleanup of the site sufficient to avoid or minimize residual injuries to natural resources and the services they provide to people and ecosystems.
2) Achieve cost-effective restoration of the site. One way to achieve this will be to coordinate assessment restoration with post-cleanup revegetation and mitigation activities where practicable.
3) Post-cleanup land use decisions should not constrain, or preclude, effective natural resource damage assessment restoration. (HNRTC 2011)

1.2 THE NATURAL RESOURCE DAMAGE ASSESSMENT PROCESS

The ultimate goal of the natural resource damage assessment process is to restore, replace or acquire the equivalent of natural resources injured due to the release of hazardous substances, and to compensate the public for any loss of services that occurs while natural resources are in an injured state (43 CFR 11.80(b)).[16] The Trustees must determine the scope and magnitude of damages, that is, the cost for restoration of injured natural resources and/or compensation for lost services.[17]

The DOI regulations under CERCLA define services as:

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[16] The regulations are not mandatory. However, they "must be followed by Federal or State natural resource trustees in order to obtain the rebuttable presumption contained in section 107(f)(2)(C) of CERCLA" (50 CFR Part 11). A rebuttable presumption is an assumption accepted by a court until disproved. The regulations state that the results of an assessment performed by a Federal or State natural resource trustee according to the NRDA regulation shall be accorded the evidentiary status of a rebuttable presumption under CERCLA.

[17] Note that the responsible party may also choose to undertake restoration activities directly.

> "the physical and biological functions performed by the resource including the human uses of those functions. These services are the result of the physical, chemical, or biological quality of the resource." (43 CFR 11.14 (nn))

The DOI regulations can be divided into three sequential phases in the assessment of damages: pre-assessment, assessment, and post-assessment.

Pre-Assessment Phase

In the pre-assessment phase, a review of readily available information is conducted that allows the authorized official to make an early decision on whether a natural resource damage assessment can and should be performed. During this phase, the Trustees determine whether an injury has occurred and a pathway of exposure exists. The pre-assessment phase is a prerequisite to conducting a formal assessment.

The Hanford Trustees completed the pre-assessment phase of the assessment in 2009 with the release of the Pre-assessment Screen (PAS) for the Site, in accordance with 43 CFR 11.23-11.25. Yakama Nation and the Confederated Tribes of the Umatilla Indian Reservation each released a PAS in 2006 and 2007 respectively. The PAS determined there was a reasonable probability of making a successful claim for damages for injuries to natural resources. Specifically, the PAS concluded:

- Releases of hazardous substances have occurred;
- Natural resources for which the Trustees may assert trusteeship under CERCLA and/or the CWA may have been adversely affected by the discharge or release of hazardous substances;
- The quantity and concentration of the released hazardous substances are sufficient to potentially cause injury to natural resources;
- Data sufficient to pursue an assessment are readily available or likely to be obtained at a reasonable cost; and
- Response actions may not sufficiently restore, replace, or provide compensation for injured natural resources without further restoration action.

Therefore, the Trustees determined that further investigation and assessment is warranted.

Assessment Phase

This is the current phase of the Hanford assessment. This Injury Assessment Plan describes studies to determine and quantify injury (components 1 and 2 below).

There are three main components of the Assessment Phase (Exhibit 1-2):

1) **Injury Determination**: Determine "whether an injury to one or more of the natural resources has occurred; and that the injury resulted from the discharge of oil or release of a hazardous substance based upon the exposure pathway and the nature of the injury" (43 CFR 11.61(a)(1)).

2) **Injury Quantification**: "quantify for each resource determined to be injured and for which damages will be sought, the effect of the discharge or release in terms of the reduction from the baseline[18] condition in the quantity and quality of services…provided by the injured resource" (43 CFR 11.70(a)(1)).

3) **Damage Determination**: Estimate "the monetary damages resulting from the discharge of oil or release of a hazardous substance" (43 CFR 11.80(a)(1)), typically presented in a Restoration and Compensation Determination Plan (RCDP) (43 CFR 11.80(c)).

For each of these components, the Trustees undertake a planning effort, then a subsequent implementation effort. First the Trustees must write a plan, or series of plans, to ensure that the assessment is performed in a systematic manner and that the methodologies selected can be conducted at a reasonable cost (43 CFR 11.30(b)). This Injury Assessment Plan ("Plan") describes the Trustees' current approach to preparing for and implementing the injury assessment phase of the NRDA (i.e., injury determination and quantification). After injury quantification is completed, the Trustees will establish the amount of money (or damages) required to compensate for the quantity of injuries to natural resources resulting from the discharge of hazardous substances (i.e., the amount of monies needed to restore, replace, or acquire the equivalent of lost services). Note that damage determination activities are not addressed in the Plan, and will be described in a subsequent RCDP, as mentioned above.[19]

Keep in mind that this Plan includes only injury assessment studies (i.e., those associated with injury determination and quantification), and does not address potential activities associated with the damage determination phase.

This Plan is intended to summarize ongoing and proposed studies that have been or will be used to evaluate Site-related contamination and corresponding effects of contamination on natural resources and resource services (Exhibit 1-2). The Trustees may make modifications to this Plan over time to reflect new information and/or analyses as they become available (43 C.F.R. §11.32(e)). In addition, future injury assessment planning documents will be developed that provide more technical details for particular studies (e.g., detailed sampling and analysis plans, statistical approaches). Consistent with the DOI NRDA regulations, Plan documents will be made available for public review and comment (43 C.F.R. §11.32(c)); see Public Participation section below).

[18] According to the DOI regulations, baseline is "… the condition or conditions that would have existed at the assessment area had the discharge of oil or release of hazardous substance under investigation not occurred." (43 CFR 11.14(e))

[19] The RCDP typically includes a number of possible alternatives for restoration, rehabilitation, replacement, and/or acquisition of equivalent resources. This Plan may also include the criteria used to select the Trustees preferred alternative and the methodologies selected for estimating cost or valuation of natural resource injuries to calculate damages. After public review and finalization of the Restoration and Compensation Determination Plan is complete, the Plan is implemented.

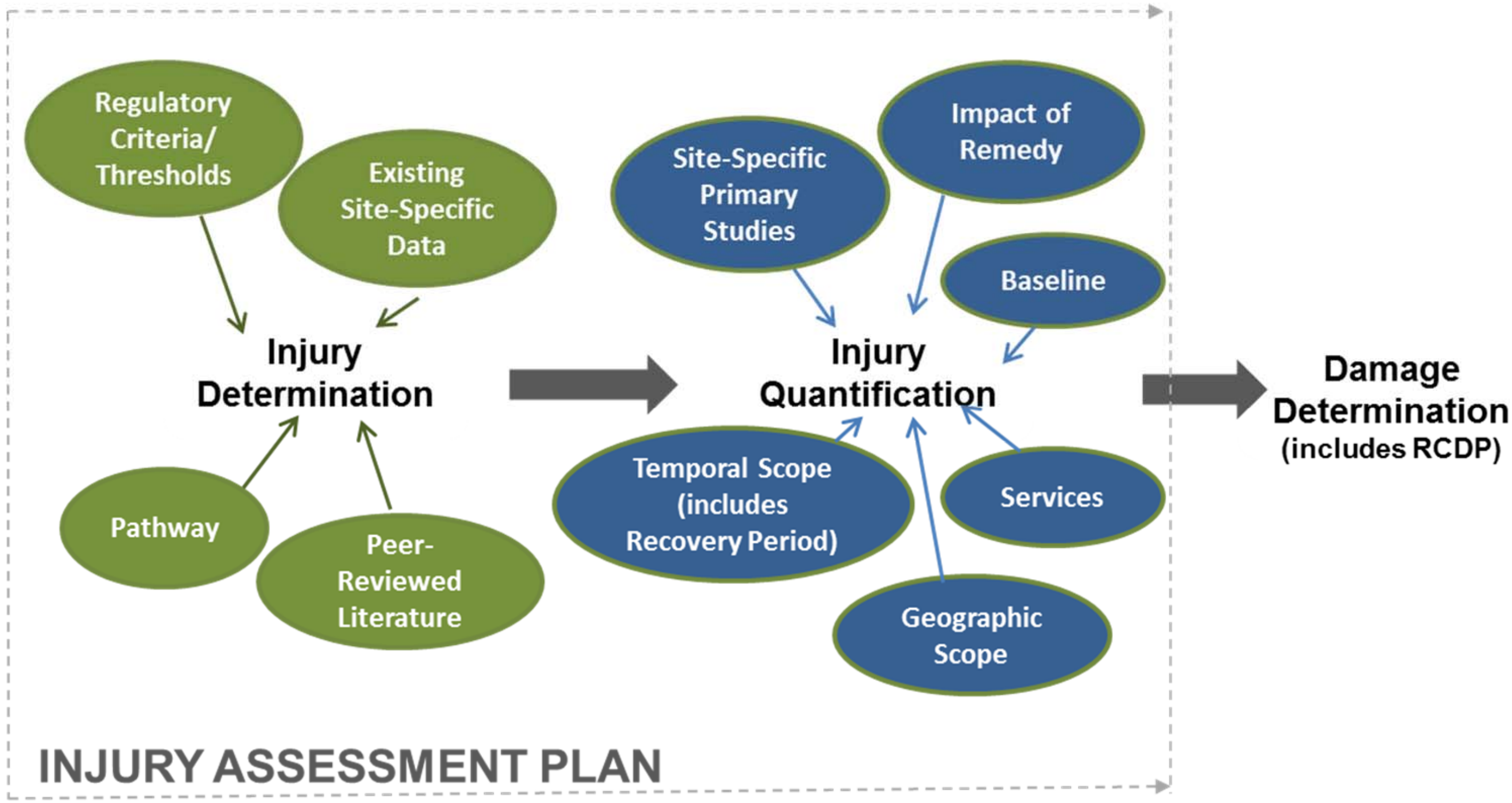
As part of the assessment planning process, the Trustees must also decide to conduct either a simplified assessment ("Type A") or a comprehensive assessment ("Type B"). The Type A procedures, which use minimal field observations in conjunction with computer models to generate a damage claim, are limited by the regulations to the assessment of relatively minor, short duration discharges or releases in coastal or marine environments or in the Great Lakes. Alternatively, Type B procedures allow for a range of scientific and economic methodologies to be used for Injury Determination, Quantification and Damage Determination. For this site, the Trustees concluded that the use of Type B procedures is appropriate based on the following determinations: (1) the release did not occur in a coastal, marine, or Great Lakes habitat, (2) the nature of the release and resource exposure to contaminants is long-term and spatially and temporally complex, (3) substantial site-specific data already exist to support the assessment, and (4) additional site-specific data can be collected at reasonable cost. As such, in accordance with the natural resource damage assessment regulations the Trustees have confirmed that at least one of the natural resources identified as potentially injured has in fact been exposed to the released hazardous substances (43 CFR 11.33-11.35) (See Chapter 5).

Study implementation will take place in a phased manner, reflecting factors including, but not necessarily limited to, the availability of funding and prioritization (e.g., collection of ephemeral data before the opportunity to collect it is lost, priority implementation of studies that may generate information relevant to the design of other studies, efficiencies gained by integrating studies into other ongoing data collection activities, etc.).

Post-Assessment Phase

As part of this phase, the Trustees prepare: 1) a Report of Assessment detailing the results of the Assessment phase (i.e., the results of injury studies described in this Plan as well as the results of any subsequent damage determination studies); and 2) a Restoration Plan, based upon the RCDP created as part of the damage determination phase described above, which describes how awarded monies will be used.

EXHIBIT 1-2 ASSESSMENT PHASE COMPONENTS



1.3 ASSESSMENT ACTIVITIES AT HANFORD

SUMMARY

Under the MOA described above, in the early years of Council, the Trustees focused much of their effort on the review of and providing technical assistance on ecological risk assessments and other cleanup activities being conducted on the Hanford Site, such as those associated with the Central Plateau cleanup, the River Corridor Closure Project and the Groundwater Project. In addition, during the pre-assessment phase, various Trustees developed their own PASs, including two for the 1100 Area (HNRTC 2000, Nez Perce 2000), as well as Site-wide PAS reports (CTUIR 2007, Ridolfi 2006). In 2007, the Trustees decided to proceed with a phased assessment approach and begin the assessment phase in parallel with ecological risk assessments.

In 2008, a contractor was hired to begin the injury assessment planning process including development of a list of potentially injured natural/cultural resources and defining the focus and scope of the injury assessment. This initial planning was completed in 2009. Since that time, assessment planning activities have continued, including development of this injury assessment plan. The current status of the assessment process at Hanford is outlined in Exhibit 1-3.

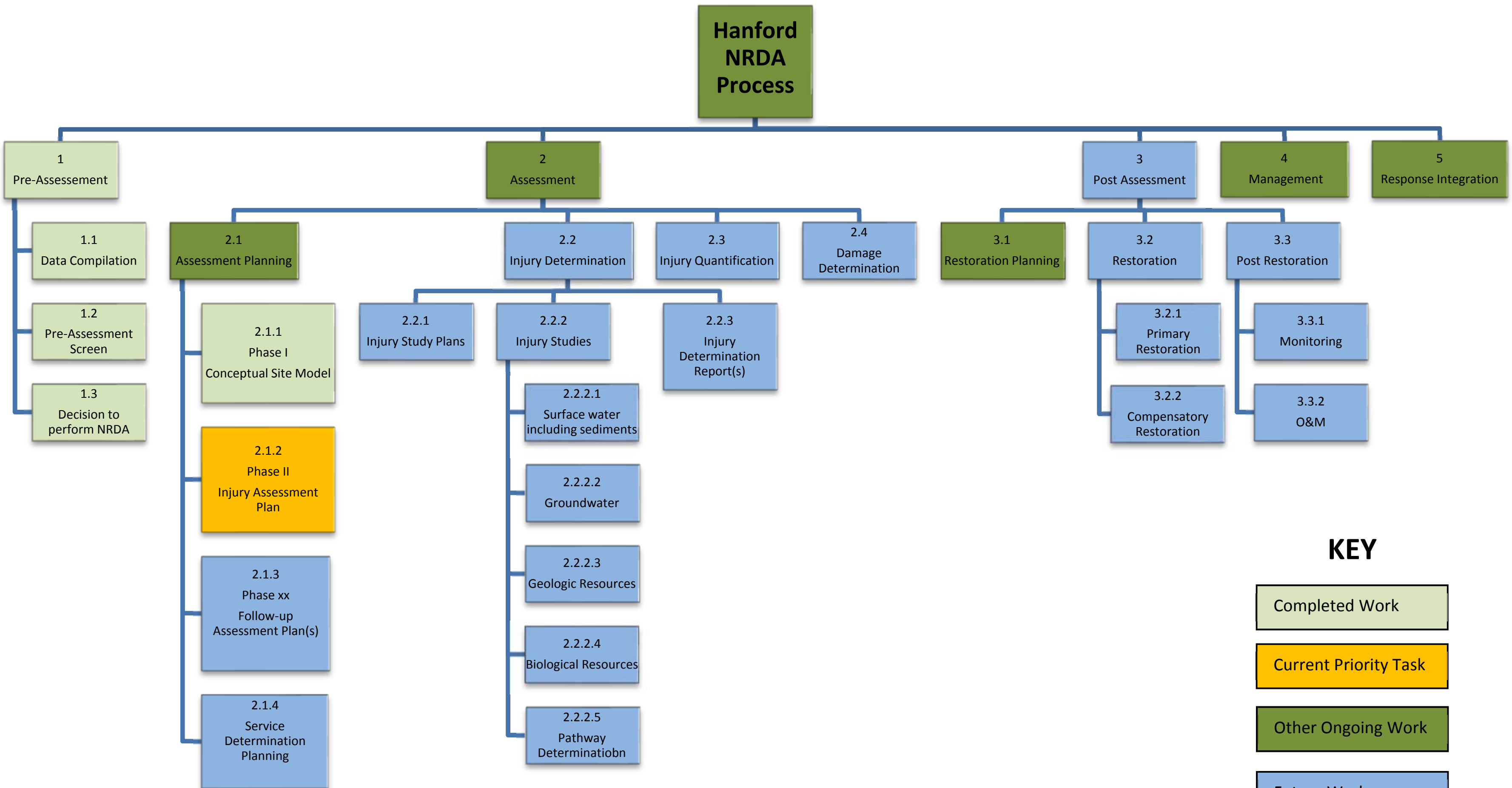
When available, updated information about assessment activities at the Hanford Site is posted at:

- http://www.hanford.gov/page.cfm/HNRTCHistory
- http://www.hanfordnrda.org/

USE OF AVAILABLE DATA

Analysis of existing data by Hanford Trustees is already underway, including preliminary pathway determination and injury determination efforts. To the extent possible, the Hanford Trustees anticipate using existing information to inform the assessment process. Such information includes data and information collected as part of site investigation and remediation. Going forward, the Hanford Trustees anticipate evaluating existing information and data prior to undertaking additional data collection as part of the assessment process, to better understand where additional information would assist in determining and quantifying injury and, ultimately, determining damages and required restoration. Such efforts are likely to inform the need for and extent of any additional primary research or study(ies) to support the assessment.

EXHIBIT 1-3 SUMMARY OF THE NATURAL RESOURCE DAMAGE ASSESSMENT PROCESS AT HANFORD



COORDINATION WITH SITE REMEDIAL ACTIVITIES

It is important to understand that remediation (i.e., cleanup) and NRDA are separate but related programs. *Remediation and/or response* activities, usually overseen by EPA or state environmental agencies, are intended to reduce present and future risks to public health and the environment. In contrast, *natural resource damage* claims compensate the public for past, present, and future injuries to natural resources and the services they provide.

The Trustees recognize the importance of coordinating efforts to meet assessment and remedial objectives as effectively and efficiently as possible. As noted above, the Trustees have focused, and continue to focus, significant effort in providing comments on and recommendations relating to the ecological risk assessments and other cleanup activities being conducted on the Hanford Site.

COOPERATION WITH THE RESPONSIBLE PARTY

Under CERCLA, the parties responsible for releases of hazardous substances may be invited to participate cooperatively in the assessment and restoration planning process (43 CFR 11.32(a)(2)). Cooperative assessments can act to reduce duplication of effort, expedite the assessment, and accomplish resource restoration earlier than might otherwise be the case. For this Site, the primary party responsible for discharges and releases of oil or hazardous substances is the Federal Government, represented by DOE, which, as noted above, is also a Trustee and member of the Hanford Trustee Council along with other Federal Trustees. The Hanford Trustee Council has agreed to follow a cooperative assessment process.

GEOGRAPHIC SCOPE

The assessment area is defined in the DOI regulations as

> *the area or areas within which natural resources have been affected directly or indirectly by the discharge of oil or release of a hazardous substance and that serves as the geographic basis for the injury assessment* (43 CFR 11.14(c)).

Existing data indicate that the exposure and potential impacts from contaminants of potential concern (COPCs) released from the Site may be affecting natural resources in the aquatic and terrestrial habitats of the Hanford Site (including the National Monument), and the adjacent portion of the Columbia River and associated floodplain (the Hanford Reach). Although the evaluation of natural resource damage (NRD) injuries is not limited to a specific geographic area, it is reasonable to develop an understanding of the nature, spatial extent and severity of injuries on the Hanford Site before determining whether the geographic scope of the assessment should be expanded to other, off-site areas.

TEMPORAL SCOPE

The date at which quantification of injuries will begin will depend on the type of natural resource injury. For instance, some natural resource injuries and subsequent damages may be assessed in a manner that allows for separate estimation of damages pre- and post-December 11, 1980 (in accordance with the passage of CERCLA). In those cases, the Trustees will focus their efforts on estimating damages for the post-December 11, 1980 period. In other cases, injuries and damages may be less clearly divisible over time. In these cases, the Trustees may choose to assess damages for the entire time period of injury. For example, cultural losses may be assessed beginning when tribal members began noticing changes in their environment, and may continue indefinitely. In either case, information available from pre-1980 may be used by the Trustees in understanding baseline conditions as well as injuries and damages post-1980.

Injuries will be quantified, and damages calculated, through the expected date of resource recovery to baseline (note that some injuries may be considered permanent if baseline conditions are not expected to be reestablished). The rate of recovery will be determined based on information related to remedial and restoration activities, natural attenuation, and resource recoverability.

1.4 PUBLIC PARTICIPATION

The Trustees intend to work with the general and tribal publics during this assessment and restoration process and encourage active public participation. Public participation is a required component of the Plan's development process. Specifically:

> *The authorized official must make the Assessment Plan available for review by any identified potentially responsible parties, other natural resource trustees, other affected Federal or State agencies or Indian tribes, and any other interested member of the public for a period of at least 30 calendar days, with reasonable extensions granted as appropriate. The authorized official may not perform any type B procedures described in the Assessment Plan until after this review period (43 CFR 11.32(c)(1)).*

The Hanford Natural Resource Damage Assessment website, available at http://www.hanfordnrda.org, provides updated information to the public regarding the status of the assessment and restoration process and opportunities for public involvement. Interested individuals may also sign up for the Hanford natural resource damage assessment Listserve, through which they will be notified about the release of key documents and of milestones within the assessment.

PUBLIC REVIEW AND COMMENT

During the assessment process, the Trustees have and will produce and release for public comment several key documents. The public will be notified of opportunities for public comment through the Hanford Listserve, media releases, and mailings that will be distributed to key stakeholders.

This Plan, as well as any significant subsequent revisions which may be made to it, will be available for review and comment by interested members of the public for a period of at least 30 calendar days, with reasonable extensions granted as appropriate (43 CFR 11.32(c) and (e)).

Commenters are encouraged to submit electronic comments to Larry.Goldstein@ecy.wa.gov. Comments can also be sent via U.S. mail to:

Larry Goldstein
Hanford Natural Resource Trustee Council Chair
Washington State Department of Ecology
Nuclear Waste Program
PO Box 47600
Olympia, WA 47600

Comments on this Plan must be submitted in writing to the Hanford Trustee contact listed above within 45 days of the publication of the Federal Register Notice of Availability.

As mentioned above, modifications to Assessment Plan documents may occur at any time during the Assessment Phase as new and additional information becomes available (43 CFR 11.32(e)). Such modifications may result in additional need for public notification and opportunities for comment. Significant modifications (e.g., resource-specific study plan amendments) or additions to this Plan will also be made available for review by any interested members of the public for a period of at least 30 calendar days, with reasonable extensions granted as appropriate, and will be appended to this Plan. Non-significant modifications may also be made available for review, but implementation of such modifications need not be delayed as a result of the review. For more information regarding completed, ongoing, planned, and proposed Site-specific studies see Chapter 7.

1.5 SCHEDULE FOR INJURY ASSESSMENT

The Trustees do not yet have a firm schedule for the completion of the injury assessment phase of this natural resource damage assessment. However, as mentioned above, study implementation will take place in a phased manner, reflecting factors including, but not necessarily limited to, the availability of funding, prioritization of studies, and remedial alternatives. Other variables that may affect the schedule of the injury assessment phase include public comment on this Plan and environmental conditions (e.g., weather and flooding) that could restrict ancillary study plan(s) implementation.

1.6 PLAN ORGANIZATION

This Plan provides relevant background information and describes the Trustees' approach to the first two major steps in the assessment process: 1) injury determination, and 2) injury quantification. The third major step, damage determination, including restoration alternatives selection and scaling, will be assessed in a separate plan at a later date.

The remainder of this document contains the following chapters:

- **Chapter 2 - Background Information:** This chapter provides an overview of the history of the Hanford Site including natural history, tribal presence at Hanford, land use and development, and Federal government operations, and Hanford operations and sources of contaminants, hazardous substance releases, and COPCs.

- **Chapter 3 – Natural Resources**: This chapter includes a description of the Hanford Site natural resources and a discussion of potential ecological service losses associated with contaminant releases from Hanford Site operations and rate of recovery of services.
- **Chapter 4 – Human Uses**: This chapter provides a description of Hanford tribal and non-tribal human use services and associated potential service losses.
- **Chapter 5 – Confirmation of Exposure and Injury Assessment Process**: This chapter provides a description of data confirming exposure of Hanford resources to contaminants; a description of the injury determination process including a discussion of primary pathways and fate and transport of contaminants; and a description of the injury quantification process including a discussion of baseline and the quantification of ecological, groundwater, human use, and remediation-related impacts.
- **Chapter 6 – Injury Assessment: Regulatory Definitions**: This chapter includes relevant DOI regulatory definitions for injury determination, pathway determination, and injury quantification.
- **Chapter 7 – Injury Assessment: Studies**: This chapter includes descriptions of injury assessment studies that are currently proposed to support assessment of ecological injuries, groundwater injuries, and human use service losses.
- **Chapter 8 – Quality Assurance Management**: This chapter provides a discussion of the Quality Assurance Plan including project management, a description of the quality system, data generation and acquisition, assessment and oversight, and data validation and usability.

CHAPTER 2 | BACKGROUND INFORMATION

This chapter provides an overview of the Hanford Site's history, including key components of the Site's natural and cultural landscapes. Topics include the site's major natural features, tribal presence, land use/development, and Federal government operations, including an overview of releases of hazardous substances. Subsequent chapters provide more detail on certain topics: Chapter 3 provides information on the Site's natural resources, while Chapter 4 describes human uses of these natural resources.

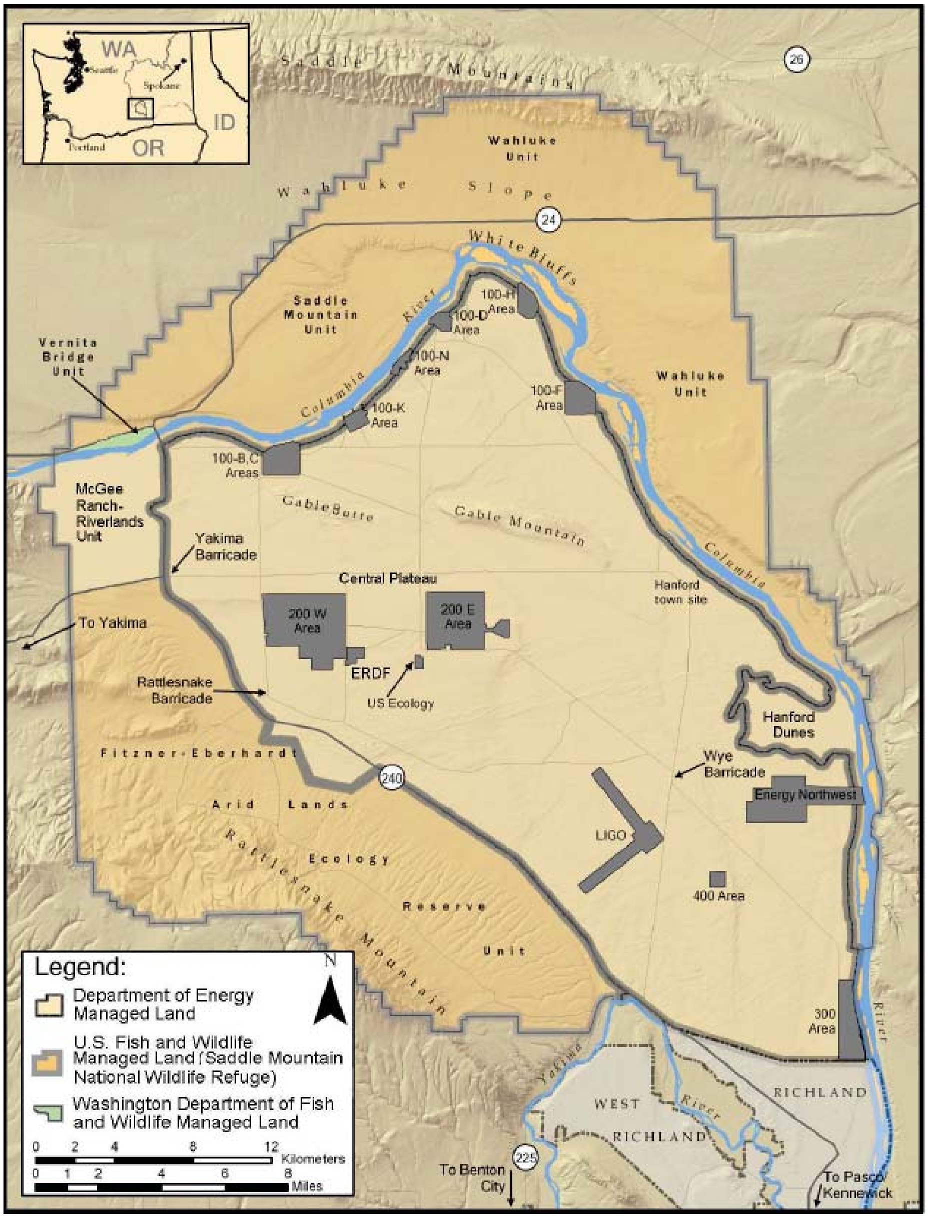
2.1 SITE HISTORY

MAJOR LANDSCAPE FEATURES AND SETTING

The Hanford Site consists of Central Hanford and the Hanford Reach National Monument (Exhibit 2-1). The Columbia River flows east thorough the northern part of the Site and then turns south towards Richland. The Yakima River meets the Columbia River at Richland. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge are major landforms on the Site's southwestern and western sides, while Saddle Mountain is to the north. Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Kennewick, Pasco, and Richland (the Tri-Cities), West Richland, and Benton City are the nearest population centers and are located south-southeast of the Hanford Site.

The Hanford Site includes a number of significant natural features, such as the Hanford Dunes—the only active dunefield within the State of Washington—along with Gable Mountain and Gable Butte in Central Hanford (TNC 2003). The Fitzner-Eberhardt Arid Lands Ecology (ALE) Reserve, officially recognized as a valuable site for scientific study in 1967 due to its rich and relatively undisturbed native shrub-steppe habitat, is on the southwest boundary of Hanford. Additionally, the McGee Ranch-Riverlands Unit, managed by DOE, contains the biologically diverse Umtanum Ridge area and some intact shrublands (TNC 2003).

EXHIBIT 2-1 CENTRAL HANFORD AND THE HANFORD REACH NATIONAL MONUMENT



Source: Poston *et al*. 2010

TRIBAL PRESENCE

For thousands of years before the Hanford Site was established, indigenous peoples used the natural resources of the area for hunting, fishing, gathering plants, and conducting religious ceremonies (Yakama 2010; NPT 2010; CTUIR 2012; DOE 2007a). Ancestors of the present day Nez Perce, Cayuse, Umatilla, Walla Walla, Yakama, Wanapum, and Colville fish for salmon; hunt deer, elk, sheep and rabbit; and collect and gather roots, seeds and berries. Natural resources are gathered primarily during spring to fall for foods, medicines, and materials for shelters and tools. Temporary camps are located at fishing sites along the River or in upland areas where resources are available.

Traditionally, the Yakama, Umatilla, and Nez Perce follow a seasonal round of subsistence where hunting, fishing, and gathering harvest is based on seasonal availability of these resources. Many families spent much of their time in the mountains during the summer and in the valley during the winter. The seasonal round is best described as a return to a specific area for the purpose of gathering resources: food, medicinal, or otherwise (NPT 2010). Rather than following a resource wherever it occurs, a seasonal round is “a return to an area to gather resources based on prior knowledge or experience” (NPT 2010). Thus, the ritual of returning to a site daily, seasonally, or annually, was critical to the culture, and the ability to sustain the culture, of these peoples. The three tribes documented this cultural knowledge of subsistence resource use through their Tribal Narratives (NPT 2010; CTUIR 2012; Yakama 2010), which are available in the Administrative Record.

Each Tribal Narrative describes the Columbia River as being culturally and economically central to the culture of these tribes. The CTUIR characterizes the regional importance of the Columbia River Plateau as follows:

> “The Columbia River flows through what was a cultural and economic center for the Plateau communities. The indigenous communities were part of the land and its cycles, and the land was part of them. The land and its many entities and services provided for all their needs: hunting and fishing, food gathering, and endless acres of grass on which to graze their horses, commerce and economy, art, education, health care, and social systems. All of these services flowed among the elements of the natural resources, including humans, in continuous interlocking cycles. These elements and relationships form the basis for the unwritten laws or Tamanwit that were taught by those who came before, and are passed on through generations by oral tradition in order to protect those yet to arrive. The ancient responsibility to respect and uphold these teachings is directly connected to the culture, the religion, and the landscape of the Columbia Plateau. The cultural identity, survival, and sovereignty of the native nations along the Columbia River and its tributaries are still maintained by adhering to, respecting, and obeying these ancient unwritten laws here in this place along the Nch’i-Wana, or Big River” (CTUIR 2012).

In its “Perspective at Hanford,” the Nez Perce describes the historical use of the Hanford Site and surrounding areas as follows:

> "Use of the Hanford site and surrounding areas by tribes was primarily tied to the robust Columbia River fishery. Tribal families and bands lived along the Columbia either year round or seasonally for catching, drying and smoking salmon. Past associated activities included gatherings for such events like marriages, trading, ceremonial feasts, harvesting, fishing, and mineral collection" (NPT 2010).

The Yakama Nation also emphasizes the Columbia River's importance:

> "Native Americans of the Columbia River Basin, including members of the Yakama Nation, depend on the Columbia River, known as *Nch'i-wa'na* ('Big River') for their livelihood. The spring Chinook salmon is considered a 'first food,' celebrated with a feast each spring to recognize the availability and abundance of food at the start of each growing season (ERWM personal communication, 2006-2007; Relander, 1986). In addition to dependence on fish as a major part of their diet for both nutritional and cultural health, the Yakama also depend on hunting local wild animals and birds for food and materials. They are also extremely dependent on the rich abundance and variety of wild plants, from above and below ground, which are used for food and medicine and some of which are also celebrated as 'first foods'" (Yakama Nation, 2010).

The Treaties of 1855

The Confederated Tribes of the Umatilla Indian Reservation[20] observe that "when Lewis and Clark and subsequent traders arrived in the Hanford area during the early 1800s, Native Americans were living in numerous villages along the Columbia River, including from the mouth of the Yakima River to Priest Rapids" (CTUIR 2012). Less than 50 years later, under separate treaties signed in 1855, the Confederated Tribes and Bands of the Yakama Indian Nation,[21] the CTUIR, and the Nez Perce Tribes, as well as numerous other tribes in the Columbia River Basin, ceded control of millions of acres of land to the United States in exchange for establishment of reservations set up for the exclusive use and benefit of those tribes. The Yakama and CTUIR treaties included ceding control of the area occupied by the present Hanford Site, but reserving rights to hunt, gather, fish, and other activities upon open and unclaimed land. These treaties all include similar language recognizing tribal rights to natural resources as follows:

> "the exclusive right of taking fish in the streams running through and bordering said reservation is hereby secured to said Indians, and at all other usual and accustomed stations in common with citizens of the United States, and of erecting suitable buildings for curing the same; the privilege of hunting, gathering roots and berries and pasturing their stock on unclaimed lands in common with

[20] Cayuse, Umatilla, and Walla Walla Tribes.

[21] The Yakama, Palouse, Pisquouse, Wenatshapam, Klikatat, Klinquit, Kow-was-say-ee, Li-ay-was, Skin-pah, Wish-ham, Shyiks, Oche-chotes, Kah-milt-pah, and Se-ap-cat tribes and bands were joined by their treaty agreement under the name "Yakama" (Treaty with the Yakama, 1855).

> citizens, is also secured to them" (Treaty with the Walla Walla, Cayuse, and Umatilla Tribes in 1855).

Thus, the Yakama Nation, the CTUIR, and the Nez Perce Tribe all retain rights to fish, hunt, gather, pasture livestock, and erect structures in the usual and accustomed areas currently occupied by the Hanford Site. We note that the Wanapum People did not sign a treaty with the United States and are not a Federally-recognized Tribe; however, the Wanapum People were historical residents of what would become the Hanford Site and their interests in the area have been acknowledged by the State of Washington (CLUP).

The Tribes note that in establishing these treaties, the U.S. Government and the Treaty did not "give" the indigenous people the rights to fish, hunt, and gather foods and medicines. Rather, the Treaty of 1855 recognized pre-existing indigenous rights that these peoples have held and exercised since time immemorial (CTUIR 2012). In the Treaty, "ancestors reserved those rights in order to ensure that the Tribes' future generations would be able to maintain and exercise their traditions and customs, obtain foods and medicines, and retain that part of their identity that is associated with the specific lands and resources at Hanford. Because cultural identity is tied to specific lands and landscapes, every acre has its own unique importance and cannot necessarily be interchanged with another acre if the first acre is lost or injured" (CTUIR 2012).

Federal Trust Responsibility

The Tribes note that, in addition to rights they maintain under existing treaties, the U.S. government also has a responsibility to manage lands held in trust, as well as resources held in trust, for the benefit of tribes. As stated by CTUIR:

> "Though often difficult to define, the federal Indian trust doctrine is considered a "cornerstone" of federal Indian law.[22] Federal courts have clarified that certain kinds of assets can be held by the United States in trust for Indian tribes and, generally, the United States must properly manage and protect those resources held in trust for tribes.[23] Regardless of the difficulty in defining the trust responsibility, it is clear that the United States has charged itself with moral obligations of the highest order in its conduct towards Indian tribes."[24]

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[22] *See Dep't of the Interior v. Klamath Water Users Protective Ass'n*, 532 U.S. 1, 11 (2001) ("The fiduciary relationship has been described as 'one of the primary cornerstones of Indian law,' and has been compared to one existing under a common law trust, with the United States as trustee, the Indian tribes or individuals as beneficiaries, and the property and natural resources managed by the United States as the trust corpus.") *See also* Cohen, Felix S., *Handbook of Federal Indian Law* at 220 (Michie Bobbs-Merrill 1982) (trust relationship as one of the primary "cornerstones" of Indian law).

[23] Morisset, Mason D., *Recent Developments in Defining the Federal Trust Responsibility* (April 1999) (http://www.msaj.com/papers/43099.htm) (accessed July 5, 2012).

[24] *Seminole Nation v. United States*, 316 U.S. 286, 296-297 (1942) (stating that Federal government is "more than mere contracting partner" with tribes and has "charged itself with moral obligations of the highest responsibility and trust"); *Pyramid Lake Paiute Tribe of Indians v. Morton*, 354 F. Supp. 252, 256 (indicating that the Federal government's conduct toward tribes should "be judged by the most exacting fiduciary standards").

> "In such cases where the federal government has a trust responsibility for a specific tribal resource, the government must assume the obligations of a trustee as in a typical, non-Indian fiduciary relationship. These principles include: 1) preserving and protecting the trust property; 2) informing the beneficiary about the condition of the trust resource; and 3) acting fairly, justly and honestly in the utmost good faith and with sound judgment and prudence.[25] *United States v. White Mountain Apache Tribe* recognizes that the fundamental common law duty of a trustee is to maintain trust assets and applies that principle in the context of the Indian trust doctrine.[26] In a typical fiduciary relationship the trustee must always act in the interests of the beneficiary and the Indian trust doctrine is no different.[27] The federal government can and should act on behalf of an Indian tribe if it is within its legal authority to do so" (CTUIR 2012).

OTHER LAND USE/DEVELOPMENT

Lewis and Clark were the first Euro-Americans to visit the Columbia Basin in 1805 (DOE 2007a; Gard 1992). By 1840, the area around Hanford had been mapped by the Army Corps of Topographical Engineers, laying the groundwork for settlers and development (Gard 1992). In 1856, cattle ranchers began making their way to the Columbia River Valley (Gard 1992). By the early 1880's, settlers were abundant, much of the natural bunchgrasses in the region had been overgrazed, and much of the livestock lost due to lack of available feed (Gard 1992). In response, ranchers began to build small dams and irrigation systems in order to grow alfalfa as food for cattle (Gard 1992). Just after the turn of the century, new irrigation and water companies were developed, new canals and ditches were constructed, and desirable land adjacent to the canals were procured for farming (Gard 1992). Soon, the area was growing strawberries, root crops, fruit trees, onions, and barley in addition to alfalfa (Gard 1992).

Archaeological resources from thousands of years of indigenous occupation as well as the early settlement period are scattered over the Hanford Site, and include gold mining features along riverbanks, homestead remains, agricultural equipment and fields, ranches, and irrigation features (DOE 2007a). Identified traditional cultural places associated with early settlement and farming include home sites and townsites, orchards, fields, and places of former community activities (e.g., swimming hole and town square).

In 1943, the Federal government acquired the Hanford Site for the Manhattan Project. At this time, Native Americans were still living at Hanford in accordance with traditional beliefs and practices, and were among those evicted when the U.S. government took control of the area (CTUIR 2012). Livestock grazing has "presumably been prohibited on the unit since about 1950, although active enforcement was apparently sporadic until the

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[25] *See Assiniboine and Sioux Tribes v. Board of Oil and Gas Conservation*, 792 F.2d 782, 794 (9th Cir. 1986); *Trust*, 89 C.J.S. §§ 246-62; Morisset, *Recent Developments in Defining the Federal Trust Responsibility*, *supra* note 3.

[26] 537 U.S. 465, 475 (2003)

[27] *Covelo Indian Community v. FERC*, 895 F.2d 581, 586 (9th Cir. 1990).

1970s" (TNC 2003) Incidences of trespass grazing by sheep continue to be reported occasionally along the western edge of the Site (TNC 2003).

> "In May 2000, 175,000 acres of the Hanford Site surrounding Central Hanford was designated as the Hanford Reach National Monument by proclamation of President William J. Clinton. DOE continues to have administrative jurisdiction over Monument lands, is the primary manager for some portions of the Monument, and cooperates with USFWS in comanagement of other Monument Lands. Five management units of the Hanford Reach National Monument—the Fitzner-Eberhardt Arid Lands Ecology Reserve, the McGee Ranch– Riverlands Unit, the Saddle Mountain Unit, the Wahluke Unit, and the River Corridor Unit—encircle Central Hanford, which remains under DOE management" (TNC 2003).

FEDERAL GOVERNMENT OPERATIONS

Site Operational History

The Hanford Site was the world's first nuclear production facility. The site location was originally selected due to its remoteness, available electrical power from the Grand Coulee Dam, a functional railroad, a cool, flowing water source (the Columbia River), and the availability of sand and gravel for construction (Poston 2010). Construction of nuclear facilities at the Site began in 1943 as part of the Manhattan Project, a secretive World War II government program with the goal of manufacturing an atomic bomb. Extraordinary measures were taken throughout the World War II era to ensure that progress continued on an accelerated schedule, often resulting in unprecedented scientific risks being taken and unorthodox means to acquire land and resources (DOE 2002).

In the over 40 years of nuclear operations, a total of nine reactors were constructed for the production of plutonium for national defense purposes. In 1943, DOE constructed the Site's first three reactors (reactors B, D, and F). Of these, B Reactor was the world's first industrial scale plutonium production reactor, and manufactured the plutonium used in the Trinity Test and Nagasaki atomic bombs.

After World War II, Hanford's objective was shifted to nuclear production for the Cold War, and the Site underwent an extensive expansion phase including the construction of the DR and H complexes in the late 1940s. Construction of the C Reactor began in 1950, less than a mile from B Reactor, so that the two could share utilities, services, and facilities. The two reactors in the 100-K area were larger than all of their predecessors, and construction of these reactors began in 1953. The last reactor, N Reactor, was completed in 1963. All nine reactors were decommissioned by the late 1980s, although additional testing facilities (in the 400 Area, specifically) remained active until the early 1990s.

DOE operational and research areas on the Hanford Site include the 100, 200, 300, 400, and 1100 Areas (has since been transferred to Port of Benton), described below and shown in Exhibit 2-1. The 600 Area designation encompasses all areas not included within the 100, 200, 300, 400 or 1100 Areas.

- The **100 Areas,** consisting of six operable units, are where the nine plutonium-producing reactors were located;
- The **200 Area**, split into the East and West portions, includes facilities for chemical separation and extraction and plutonium finishing. It also houses dozens of underground storage tanks (known as "tank farms") that store highly contaminated radioactive waste, byproducts of the plutonium extraction process;
- The **300 Area**, where nuclear fuel fabrication and development were performed;
- The **400 Area**, located just north of the 300 Area, houses the Fast Flux Test Facility, a reactor that was designed to test and research various types of nuclear fuel.
- The **1100 Area** included an area just north of Richland and a non-adjacent area on the Arid Lands Ecology Reserve. The portion near Richland contained offices associated with administration, maintenance, transportation, and materials procurement and distribution, waste sites, French drains, underground tanks, and a sand pit. The portion on the Arid Lands Reserve is a former missile base and control center. Remedial actions selected for the 1100 Area have been completed and the site was delisted from the NPL in 1996 (DOE 2011d).[28]

The process areas were designed to have structural redundancy so that each could function as an independent unit. Each contained its own facilities for operations, support, administration, security, health, communication, utilities, and waste disposal, the ultimate goal being the uninterrupted production of weapons-grade plutonium (DOE 2002).

Presently, the DOE Richland Operations Office, the Office of River Protection, and the DOE Office of Science and their contractors jointly manage cleanup, treatment, disposal, and research in the central portion of the Hanford Site in what has become the world's largest environmental remediation project (Poston 2010).

The buffer zone of the Site was established as a national monument in 2000 in order to protect rare resources, specifically, unimpounded portions of the Columbia River and areas of shrub-steppe ecosystem (Poston 2010). Units of the Hanford Reach National Monument are managed by DOE, FWS, and Washington Department of Fish and Wildlife.

National Priorities List (NPL) Designation

Nuclear fuel production activities, disposal practices, and releases at Hanford resulted in the Site qualifying for inclusion on the EPA's NPL. In anticipation of Hanford's inclusion on the NPL, in May 1989, DOE, EPA, and Washington State Department of Ecology signed the Hanford Federal Facility Agreement and Consent Order or Tri-Party

[28] The 1100 Area land and facilities have been transferred to the Port of Benton. However, DOE maintains institutional controls, as required by DOE 1996, *Superfund Final Closeout Report, U.S. Department of Energy 1100 Area*, and EPA/ROD/R10-93/063, *Record of Decision for the USDOE Hanford 1100 Area Final Remedial Action*.

Agreement, which established a legal framework and schedule for cleanup, and designated a lead regulatory agency (either EPA or Washington State Department of Ecology) for each operable unit.

On November 3, 1989, Hanford was added to the NPL as four separate sites: the 100 Area, 200 Area, 300 Area, and 1100 Area.[29] In order to coordinate response actions, each of these sites is further subdivided into operable units (OUs), based on geographic area, common waste sources, and natural resource type (soil and groundwater contamination are addressed in separate OUs). Additionally, waste management units have been identified throughout the Hanford Site; these units, based on waste disposal practices, are much smaller than operable units and are grouped among the four NPL sites (DOE 2006a).

Ongoing and planned cleanup work at Hanford is expected to address, but will not be limited to, more than 50 million gallons of highly contaminated liquid waste in 177 underground storage tanks, 2,300 tons of spent nuclear fuel, 12 tons of plutonium in various forms, approximately 25 million cubic feet of buried or stored solid waste, and approximately 270 billion gallons of groundwater contaminated above drinking water standards (and occurring over an area of approximately 80 square miles), more than 1,700 waste sites, and approximately 500 contaminated facilities.

Additional summary information describing the four Hanford NPL sites and the current status of remediation efforts is provided in Appendix A. More detailed information can be found at http://www.hanford.gov/.

2.2 OVERVIEW OF RELEASES OF HAZARDOUS SUBSTANCES

Between fuel fabrication in the 300 Area, fuel irradiation in the 100 Area, and fuel processing and plutonium recovery in the 200 Area, operations at Hanford resulted in the release of many hazardous substances, including radionuclides as well as other inorganic and organic contaminants (Ballinger and Hall 1991).

300 AREA

The 300 Area supported the first step of the plutonium production process, fuel fabrication, as well as research and development activities. Construction of fuel fabrication facilities began in 1943 and fuel fabrication operations began in 1944 (Ballinger and Hall 1991). Fuel fabrication consists of molding and encapsulating uranium in metallic alloy cladding so that it can be used as nuclear fuel in reactors (DOE 2008). Once the fuel was fabricated, it was transported to the 100 Areas for irradiation in the nuclear reactors (DOE 2011b).

Operations in the 300 Area generated both solid and liquid waste. While there is some evidence of air emissions associated with fuel fabrication and research activities in the 300 Area, these air emissions were relatively minor (Stratus 2009). Before 1973,

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[29] Remedial actions selected for the 1100 Area have been completed and the site was delisted from the NPL in 1996 (DOE 2011d).

operators at the Hanford Site stored solid waste and debris generated by 300 Area operations in solid waste burial grounds in the 300 Area. After 1973, these burial grounds were no longer used as waste was transported to other Hanford Site burial grounds (DOE 2008).

Contaminated liquid wastewater generated in the 300 Area was deposited in surface impoundments such as unlined ponds and trenches located in the 300 Area. These liquid wastes were primarily contaminated with uranium from the fuel fabrication process, and the ponds and trenches are now “suspected to be the primary source of uranium in the groundwater beneath the 300 Area” (DOE 2008). Evidence suggests that these underground storage tanks leaked hazardous substances to the subsurface, possibly further contributing to soil and groundwater contamination (Stratus 2009).

The 300 Area fuel fabrication operations ended in 1988 after the final nuclear reactor shut down (Ballinger and Hall 1991). Today, the “300 Area contains solid waste disposal sites, burn pits, ash pits, catch tanks, cribs, drains fields, dumping areas, foundations, French drains, injection wells, laboratories, process sewers, ponds, process facilities, radioactive process sewers, storage areas, storage tanks, surface impoundments, trenches, and unplanned releases” (DOE 2011b). Remediation operations in the 300 Area are ongoing.

100 AREA

Once nuclear fuel was fabricated in the 300 Area, it was transported to the 100 Area for irradiation in the nuclear reactors. From 1943 to 1963, over the course of three post-World War II production capability expansions and the peak years of plutonium production, nine nuclear reactors were built in the 100 Area (Gerber 2001). Eight of these nuclear reactors (the B, C, KW, KE, D, DR, H, and F Reactors) were single-pass reactors that relied upon water withdrawn from the Columbia River to cool the reactors before returning the water to the river. The ninth reactor (the N Reactor) “recirculated purified water through the reactor core in a closed-loop cooling system” (DOE 2008). These nuclear reactors used fabricated fuel to produce weapons grade plutonium via nuclear reactions. The closed-loop N Reactor, unlike the other reactors, acted as a dual-purpose reactor that also produced electrical power (Ballinger and Hall 1991).

Operations in the 100 Area produced contamination in the form of air emissions, solid wastes, and liquid wastes. Sources of air emissions in the 100 Area included stacks related to the nuclear reactors, as well as incinerators and open burn pits. Airborne emissions from the stacks primarily occurred in the 1940s and 1950s before the introduction of filtration systems in the 1960s (although ongoing radionuclide air emissions are still released at low levels from some Hanford operational sites, the emissions are permitted and regulated by Washington State and inventoried annually (DOE 2010b)). Radioactive waste generated in the 100 Area was divided into “soft waste (combustibles) and hard waste (greater than 99% metallic)” (DOE 2011b). Soft wastes with less potent radioactive contamination were buried in the 100-F Area, burned in open pits, or incinerated in the 100-K Area (DOE 2011b). For soft wastes that were burned, the open burn pits and incinerator operations resulted in the airborne release of "radionuclides, organics, metals, and other hazardous substances" (Stratus 2009). Hard wastes generated in the 100 Area were disposed of in burial grounds or, for highly contaminated radioactive wastes, transported to the 200 Area for burial. In addition, irradiated fuel from N reactor was stored in canisters in the K basins located in the 100 Area after N reactor was closed (Stratus 2009).

Liquid wastes generated in the 100 Area were primarily related to the waters used to cool the nuclear reactors. For the closed-loop N Reactor, the highly contaminated liquid effluent resulting from cooling operations "was discharged to trenches and cribs near the river" (DOE 2008). For the eight single-pass reactors, water was withdrawn from the Columbia River, sent to treatment facilities for purification, passed through the reactors, and then sent to retention basins to cool and "allow for decay of short-lived radionuclides" (DOE 2008). From there, most of the water was returned to the Columbia River, while portions of highly radioactive water were diverted to surface impoundments, including trenches, cribs, and French drains (DOE 2008). The effluent water sent to the Columbia River was often discharged at high temperatures, with traces of hazardous substances such as radionuclides, chromium, and other hazardous substances (Stratus 2009). Although a change in the water treatment process in 1961 reduced radioactive contamination in the discharge water, this pathway of contamination continued until the last single-pass reactor was shut down in 1971 (Ballard and Hall 1991).

An additional issue linked to the single-pass reactors was sodium dichromate contamination of groundwater resources; sodium dichromate was used as a corrosion inhibitor and it likely migrated to groundwater via unplanned releases of reactor coolant water (DOE 2011b). Significant amounts of chromium contamination also resulted from inadvertent discharges of sodium dichromate spilled in the handling process, when granular dichromate was mixed in batches to create solutions for mixture into cooling waters. The solutions were delivered to treatment plants via pipeline, rail car, truck, and other methods, the process of which may have resulted in additional spills. There is likely an ongoing source of chromium contamination from a dichromate transfer station in the 100-D Area (Qafoku *et al.* 2011).

More highly contaminated water was diverted to surface impoundments such as trenches, cribs, and French drains. This water was frequently contaminated with radioactive isotopes such as cesium, strontium, and iodine, which led to contamination of the soil and the underlying groundwater (DOE 2011b).

The eight single-pass reactors were shut down between 1964 and 1971 and the closed-loop N Reactor was shut down in 1988 (Ballinger and Hall 1991). Following the cessation of reactor operations, remediation activities for the burial grounds, retention basins, groundwater resources, and other contamination sites commenced and are ongoing (DOE 2008).

200 AREA

Following irradiation in the 100 Area, fuel elements were transported to the 200 Area for processing and separation of the irradiated fuel. These processing operations were designed to extract plutonium from the irradiated fuel by dissolving irradiated "fuel elements with acids and then chemically [separating] the plutonium isotopes from the liquefied materials" (DOE 2008). Five separation plants (T, B, U, REDOX, and PUREX) were constructed in the 200 Area between 1944 and 1952 (Ballinger and Hall 1991). This final processing step in the plutonium production process produced significant amounts of contamination, primarily in the form of air emissions and liquid wastes.

When nuclear operations first began in 1944, 200 Area stacks for the chemical separation plants generated large quantities of airborne emissions, including radioactive and non-radioactive hazardous substances (i.e., iodine-131, volatile organic compounds (VOCs), nitrate compound particulates, and gaseous ammonia) (Stratus 2009). Although these emissions were reduced in the late 1940s and early 1950s through a series of iterative improvements to the filtration devices on these stacks (Ballinger and Hall 1991), some significant releases continued into the 50s including large releases of ruthenium from 1952 to 1954 (Selby and Soldat 1958). In fact, several retired facilities continue to produce minor emissions, which are regulated and permitted by the State of Washington. As of 2009, the 200 Areas released nine different radionuclides, totaling 2.14 E-03 Ci (DOE 2010b).

In addition to airborne releases, the chemical processing of irradiated fuel in the 200 Area produced significant quantities of liquid waste. Less contaminated liquid wastes were primarily disposed of in "liquid waste receiving sites (i.e., ponds, cribs, trenches, reverse wells, ditches, and cribs)" (DOE 2008). These wastes percolated into the soil column and eventually migrated to groundwater resources, resulting in contamination of the vadose zone and groundwater (DOE 2008). More highly contaminated wastes were neutralized and directed to underground storage tanks in the 200 Area via underground pipes. Initially, the underground storage tanks were arranged in twelve groups, or tank farms, that collectively included 149 single-shell tanks (Ballinger and Hall, 1991). In the tanks, heavier components settled out of solution, forming sludge. Because tank space was limited, though, Hanford operators would discharge the remaining liquid effluent to the soil column via the waste receiving sites, making room for additional highly contaminated waste (Stratus 2009). Over time, environmental monitoring efforts discovered that the single-shell tanks were leaking. This prompted the construction of 28 double-shell tanks in the 200 Area, and drainable liquid wastes were pumped from the single-shell tanks to the double-shell tanks to prevent further leakage and contamination. Many of the 149 single-shell tanks, however, still contain highly contaminated non-drainable wastes, and remain a risk of future releases (DOE 2009). It is now believed that 67 out of 149 single-shell tanks leaked (Gephart 2003b). Between the storage tank leaks and the liquid waste discharges to the soil column, the 200 Area released significant quantities of radionuclides (e.g., cesium-137, iodine-129, strontium-90, uranium, and tritium), as well as inorganic and organic chemicals (e.g., nitrate, sodium, phosphate, sulfate, ammonia, carbon tetrachloride, and sodium dichromate), which have contaminated the underlying groundwater (DOE 2008).

OTHER RELEASES

In addition to hazardous substances generated and released in the course of managed Site operations, there have been "numerous episodic events at the Site, such as overland flow, spills, leaks, explosions and wildfires that may have resulted in the release of hazardous substances into the environment" (Stratus 2009). Examples of these releases include the following.[30]

- 1948: In October of this year, a large liquid waste pond in the 300 Area failed, resulting in "the release of 14.5 million gallons of uranium-contaminated water" into the Columbia River (Stratus 2009). It is estimated that "12 to 16 pounds of elemental uranium entered the Columbia River" (*ibid*).
- 1949: To test the usefulness of atmospheric sampling for radioisotopes indicative of fuel processing, Hanford operators bypassed stack filters on the chemical separation plants and released radioactive gases, including 11,000 curies of iodine-131 and xenon-133. This experiment was known as the "Green Run" (Gephart 2003b).
- 1953: "An unintentional chemical reaction resulted in the violent ejection of metal waste spray from a vault in one of the tank farms in the 200 Area...The volume released was unspecified but should not have exceeded the 15,000 gallon storage capacity of the vault. The contamination spread to the southeast, and covered the eastern half of the tank farm" (Stratus 2009).
- 1956: "500 gallons of metal waste overflowed the 241-UR-151 diversion box at the northeast corner of the U tank farm. In the same year, tank U-104 leaked an estimated 55,000 gallons of metal waste" (Stratus 2009).
- 1966: In the 100 Area, a spill "released 140,000 pounds of sodium dichromate, much of which reached the Columbia River, as a result of a storage tank transfer pump malfunction at the 183-C Building" (Stratus 2009).
- 1969: In the 200 West Area, "approximately 2,600 gallons of cesium-137 recovery process feed solution leaked... It is estimated that 11,300 curies of cesium-137, 18.3 kilograms of uranium, and 5.01 curies of technetium-99 were released to the subsurface" (Stratus 2009).
- 1997: "Leachate tanks at the ERDF leaked approximately 190 liters (50 gallons) of contaminated leachate" (Stratus 2009).
- 2003: "Approximately 757 liters (200 gallons) of diesel fuel leaked from a 242-S Facility tank on January 22, 2003. Contaminated soil was excavated and moved to a remediation area" (Stratus 2009).

[30] The official listing of all unplanned releases at the Hanford Site is available in the Hanford Site Waste Management Units Report (last updated February 2012), available at http://www.hanford.gov/files.cfm/DOERL-88-30_R21.pdf.

- 2007: "Approximately 322 liters (85 gallons) of radioactive waste spilled from Tank 241-S-102 at the S Tank Farm on July 27, 2007" (Stratus 2009).

HANFORD SITE HAZARDOUS SUBSTANCES

Hanford Site operations have resulted in releases of hundreds of different hazardous substances. The Hanford Trustees have been engaging in an effort to identify those contaminants likely to be of greatest concern in the context of this natural resource damage assessment. Towards that end, the Trustees have examined a number of sources of information, including but not limited to information in Site risk assessments (e.g., CRCIA 1998, DOE 2011a, b), information on chemicals in the underground tanks (e.g., Gephart 2003b), in major groundwater plumes (e.g., DOE 2011c), data on releases (e.g., Hall 1991), and chemical measurements in Site databases. The Trustees' work in this area is ongoing, and their preliminary focused list of hazardous substances (Exhibit 2-2) is subject to refinement in the future.

EXHIBIT 2-2 PRELIMINARY ASSESSMENT-FOCUSED LIST OF HAZARDOUS SUBSTANCES

RADIOISOTOPES	ORGANICS	INORGANICS
Americium-241 Carbon-14 Cesium-137 Cobalt-60 Europium-152 Gadolinium-152 Iodine-129 Neptunium-237 Plutonium-239/240 Potassium-40 Radium-226, Ra-228 Strontium-90 Technetium-99 Thorium-232 Tritium Uranium-233/34/35/38 Zirconium-93 Total radiological dose	1-2 Dichloroethane 1,4 Dioxane 2,4,6 Trichlorophenol Acetonitrile Benzo(a)pyrene Carbon tetrachloride Chlordane Chloroform Cyanide DDT/DDE Dichloromethane Glyphosate Hydrazine Hexone PCBs Tributyl Phosphate Trichloroethylene (TCE) Total Petroleum Hydrocarbons/PAHs Vinyl chloride	Antimony Arsenic Barium Boron Cadmium Chromium (includes Cr6+) Cobalt Copper Fluoride Lead Manganese Mercury Molybdenum Nitrate Nickel Phosphate Selenium Silver Strontium Uranium Vanadium Zinc

Different hazardous substances have the potential for different types of adverse effects to natural resources. Effects on biota may include (but are not limited to) genotoxicity, carcinogenicity, reproductive impairment, behavioral impairment, immunotoxicity, endocrine disruption, disruption of other physiological functions, and/or lethality, depending on the degree of exposure and the sensitivity of the exposed organism.

Different life stages of a given species may experience differential degrees of exposure and may also be differentially sensitive to a given exposure. In addition, exceedances of certain standards (e.g., promulgated water quality standards and criteria) can constitute an injury under DOI's NRDA regulations. Natural resources (e.g., surface waters, sediments, soils, groundwater, air, biota) can also be considered as injured if exposure to hazardous substances in those natural resources results in injury to other natural resources.

Providing a detailed description of the potential effects of the full suite of hazardous substances under consideration is beyond the scope of this assessment plan; however, Appendix B contains a series of ecotoxicity summaries for a subset of these including uranium, plutonium, cesium-137, iodine-129, strontium-90, technetium-99, tritium, PCBs, mercury, chromium (including hexavalent chromium), and carbon tetrachloride.

CHAPTER 3 | HABITATS, NATURAL RESOURCES AND ASSOCIATED ECOLOGICAL SERVICES

The Hanford Site lies in the semi-arid Pasco Basin of the Columbia Plateau in southeastern Washington State (USFWS 2008). The Site is situated along the banks of the longest continually flowing stretch of the Columbia River (the Hanford Reach), and is home to one of the largest areas of native shrub-steppe habitat remaining in the state. The Hanford Site's unique terrestrial and aquatic ecosystems are home to forty species of mammals, over two hundred species of birds, and a large variety of amphibians, reptiles, and invertebrates. Furthermore, rare plant surveys conducted by The Nature Conservancy confirm the Site is a critical area for the conservation of rare shrub-steppe, riparian and aquatic plants (TNC 2003). The Hanford Reach of the Columbia River also supports a number of economically and/or culturally important fish and mollusk species such as the Chinook salmon (including the endangered Upper Columbia spring-run Chinook), coho salmon, sockeye salmon, steelhead (a Federally-listed threatened species), Pacific lamprey (a Federal Species of Concern), bull trout (threatened), white sturgeon, land snail, freshwater snail, Columbia pebblesnail, freshwater Limpet shortface lanx, and the California floater.

This chapter provides information characterizing Site habitats, describes the Site natural resources (as defined by the DOI natural resource damage assessment regulations) found within those habitats, and summarizes the ecological services these resources typically provide, as well as a preliminary determination of the time required for injured resources to once again provide these services (i.e., the "recovery period") (human use services provided by these resources are described in Chapter 4). A number of earlier reports describe the Hanford Site's natural resources in more detail.[31] This Assessment Plan does not attempt to re-create or supplant those efforts, but rather summarizes key subjects useful in placing the proposed assessment studies into a historic and ecological context.

3.1 AQUATIC HABITATS

COLUMBIA RIVER

The Columbia River is the fourth largest river in the contiguous United States as measured in terms of flow, and is the dominant surface water resource at the Hanford Site (Burk *et al.* 2007). The river forms the northern and eastern boundary of the Site, flowing east and then turning south. The Hanford Reach, the portion of the river most closely associated with the Hanford Site, is approximately 51 miles long, extending from Priest Rapids Dam (River Mile (RM) 397) to McNary Pool (RM 346; USFWS 2008).

[31] See, for example, Downs *et al.* 1993, Burk *et al.* 2007, and Fitzner and Gray 1991.

The Hanford Reach "is the last non-impounded, non-tidal segment of the Columbia River in the United States" (Burk *et al.* 2007) and "contains significant riparian habitat that is otherwise rare within the Columbia River system" (National Park Service 1994 as cited in USFWS 2008).

Hydrology

Burk *et al.* (2007) provides the following description of the river's hydrology.

> "Flows through the Hanford Reach fluctuate significantly and are controlled primarily by releases from three upstream storage dams: Grand Coulee in the United States, and Mica and Keenleyside in Canada. Flows in the Hanford Reach are directly affected by releases from Priest Rapids Dam; however, Priest Rapids operates as a run-of-the-river dam rather than a storage dam. Flows are controlled for purposes of power generation and to promote salmon egg and embryo survival.[32] …
>
> Columbia River flows typically peak from April through June during spring runoff from snowmelt and are lowest from September through October. As a result of daily discharge fluctuations from upstream dams [i.e., Priest Rapids dam], the depth of the river varies over a short time period. River stage changes of up to 3 m (10 ft) during a 24-hr period may occur along the Hanford Reach (Poston *et al.* 2006). The width of the river varies from approximately 300 m (1,000 ft) to 1,000 m (3,300 ft) within the Hanford Reach. The width also varies with the flow rate, which causes repeated wetting and drying of an area along the shoreline."[33]

Burk *et al.* (2007) states "Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood control/water-storage dams upstream of the Hanford Site." There are no Federal Emergency Management Agency (FEMA) floodplain maps for the Hanford Reach because FEMA maps developing areas, while lands adjacent to the Hanford Reach are primarily under Federal control (*ibid.*). However, assessments of the Reach's flood potential, including a scenario of potential dam failures, have been made and are summarized by Burk *et al.* (2007).

Columbia River Habitat Types

The Columbia River includes a variety of riparian habitats, including riffles-pools (areas with graded geomorphic attributes of riffles and pools), gravel bars, backwater sloughs, and shorelines.[34] Pacific Northwest National Laboratory (PNNL) has collected spatial

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[32] The Vernita Bar Agreement (signed in 1988 and expanded in 2004, by the U.S. DOE, Federal and state agencies, tribal governments, and public utility districts in Grant, Chelan, and Douglas counties) was created to prevent redds (salmon nests) from being left high and dry when river flows fluctuate to meet peak power demands.

[33] The flow rate varies from year to year, which affects the development and extent of vegetation in nearshore areas.

[34] A riffle is a section of a streambed characterized by shallow, steep slopes and fast moving water broken by the presence of rocks and boulders, and are typically at cross over locations. A pool is a reach of a stream characterized by deep, low velocity water and a smooth surface, and typically has a greater depth of flow and slope of the bed than that of riffles, often located at the outside of meander bends. (http://www.streamnet.org/glossarystream.html). A backwater slough is a

information on substrate type (including sediments, sand, gravel, and large boulders), and in 2002, PNNL developed more detailed spatial information about nearshore substrates from Vernita Bridge to the 300 Area (Downs *et al.* 2004).

The Hanford Reach includes several slack water areas, including the White Bluffs slough (between 100-H and 100-F Areas), the F Area slough (about 1 mile downstream of the 100-F Area), and the Hanford slough at the old Hanford townsite (Weiss and Mitchell 1992). These areas are generally depositional, and typically include more vegetation than erosional areas. A number of fish species also use slack water areas as nursery habitat.

Some contaminants adhere to sediment and tend to be transported along with sediments; consequently, sediment depositional areas can serve as sinks for certain types of contaminants. Biota that live on or in these sediments, or that derive part of their food from sediment-associated food webs, may receive an increased exposures to these contaminants.

SPRINGS AND STREAMS

Downs (2007) states:

> "Springs are found on the slopes of the Rattlesnake Hills along the western edge of the Hanford Site (DOE 1988). There is also an alkaline spring at the east end of Umtanum Ridge (Hall 1998). Rattlesnake and Snively springs form small surface streams. Water discharged from Rattlesnake Springs flows in Dry Creek for about 3 km (1.6 mi) before disappearing into the ground (Figure 4.4-1). Cold Creek and its tributary, Dry Creek are ephemeral streams within the Yakima River drainage system in the southwestern portion of the Hanford Site. These streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. When surface flow occurs, it infiltrates rapidly and disappears into the surface sediments in the western part of the Site. The quality of water in these springs and streams varies depending on the source. However, they are up-gradient of Hanford waste sites and groundwater contamination plumes."

Jamison (1982) provides additional information about Rattlesnake Springs, noting that it begins "from ground seepage and is subsequently fed by small ground springs along its course, flows for approximately 3 km… before disappearing into the ground." Biota present at the spring include algae, cattails and sedges, and watercress (*ibid.*). Invertebrates are also present, although "the number of species present is highly dependent on the size of the winter floods" (*ibid.*).

PONDS AND DITCHES

There are a number of ponds on the Hanford Site, some of which were created as a result of water releases through trenches from processing facilities. Some of the major ponds

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an inlet off of another waterway; as defined in Alaska Statute AS 41.17.950, it "(A) has sluggish flow, is warm in summer, and is typically only connected to the main stem or a side channel at one end of the water body; (B) carries river current only under high water conditions; and (C) may have only a seasonal connection to the main stem or side channel."

include Gable Mountain pond, U-pond, B-pond, S-pond, T-pond, Westlake, and associated ditches. Contaminated ponds have been decommissioned, filled, and covered with soil.

Gable Mountain pond was one of "the most significant and extensively studied" ponds onsite (Jamison 1982). Gable Mountain pond was much larger than many other Hanford ponds and supported an abundance of plant life which provided food and shelter for wildlife. Vegetation, primarily cattails and rushes, were the predominant biota type associated with these ponds (*ibid.*). Table 7-4 in Jamison (1982) lists major taxa identified at these ponds. Decommissioning of Gable Mountain pond was completed in 1988, and the water table beneath the pond declined more than three feet between 1979 and 1989 as wastewater discharges ceased (Newcomer 1990).

The B-pond system included a series of ponds used for disposal of liquid effluent from past Hanford production facilities starting in 1945 (Barnett *et al.* 2000). In 1994, some of the ponds were closed, leaving only the main pond and a portion of one of the ditches as the currently regulated facility (*ibid*). Minor contamination in groundwater and soil has been detected at the site, and levels of gross alpha and gross beta radiation and specific conductance are monitored semi-annually (*ibid*).

West Lake is a natural feature recharged from groundwater, the B-pond system, and two 300 Area Treated Effluent Disposal Facility (TEDF) disposal ponds – Gable Mountain and U-pond (Burk *et al.* 2007).[35] There are also several natural vernal ponds near Gable Mountain and Gable Butte (Hall 1998 as cited in Burk *et al.* 2007). West Lake "has not received direct effluent discharges from Site facilities; rather, its existence is caused by the intersection of the elevated water table with the land surface in the topographically low area. Water levels of West Lake fluctuated with water table elevation, which were influenced by wastewater discharge in the 200 Areas. The water level and size of the lake has been decreasing over the past several years because of reduced wastewater discharge" (*ibid.*).

3.2 TERRESTRIAL HABITATS

SHRUB-STEPPE

The upland terrestrial habitat on the Hanford Site consists primarily of shrub-steppe, considered to be some of the highest quality of this habitat type remaining in the State of Washington (Burk *et al.* 2007).

A variety of specific shrub-steppe habitats exist on-site, each defined by the dominant shrub and grass species at a given location (Downs *et al.* 1993). For example, the healthy, intact shrub-steppe habitat at Hanford is characterized by an overstory dominated by big sagebrush (*Artemisia tridentata*) and an understory of bunchgrasses and forbs. On the Columbia River Plain, habitat is usually dominated by big sagebrush and non-native cheatgrass (*Bromus tectorum*), or a mixture of cheatgrass and native bunchgrasses (e.g.,

[35] Although the waste disposal ponds were used by wildlife, they are mentioned for completeness and are not themselves considered to be a natural resource.

Sandberg's bluegrass (*Poa secunda*), Indian ricegrass (*Achnatherum hymenoides*)) (Downs *et al.* 1993).

Microbiotic crusts, which are formed primarily by algae, lichens, and mosses, serve a number of important ecological functions as a component of the shrub-steppe ecosystem. These functions include soil stability, erosion protection, nitrogen fixation, and nutrient contribution, as well as increasing water infiltration, seedling germination, and plant growth (Burk *et al.* 2007).

The shrub-steppe habitat of Hanford provides a variety of important functions for the biota described later in this report including foraging, nesting, burrowing, and hunting habitat, as well as cover (Burk *et al.* 2007).

Remaining shrub-steppe habitat in Washington is threatened by a number of factors including soil disturbance (e.g., due to overgrazing), development, invasive species, and wildfires (Washington Native Plant Society 2008). Because of its importance to a number of wildlife species, and the scarcity of the habitat type, the State of Washington considers shrub-steppe habitat to be a priority habitat, and DOI identifies the native shrub and grassland steppe in Washington and Oregon as an endangered ecosystem (USFWS 2011c).

SAND DUNES

The sand dune habitat found at Hanford is distinctive due to its atypical association with a shrub-steppe habitat. Dune habitat is dynamic, ranging from 2.5 acres to several hundred acres in size (U.S. Department of the Army 1990 as cited in Burk *et al.* 2007). Areas of sand dunes are found in several locations on the Hanford Site including along the shoreline in the area north of the Energy Northwest complex, near the 100-F area and westward to the area north of Gable Mountain, and along the eastern border of the Site. Fire has also resulted in the formation of temporary dunes along State Route 240 (Burk *et al.* 2007).

Predominant vegetation in the dune areas includes shrubs such as bitterbrush (*Purshia tridentata*) and gray (*Ericameria nauseosa*) and yellow rabbitbrush (*Chrysothamnus viscidiflorus*), with an understory of forbs and grasses including Indian ricegrass, scurfpea (*Psoralidium lanceolatum*), needle-and-thread grass (*Hesperostipa comata*), and thickspike wheatgrass (*Elymus lanceolatus*) (Burk *et al.* 2007). Dunes are known to support several plant species of concern, and thus are considered to be a sensitive habitat. The gray cryptantha (*Cryptantha leucophaea*), an ESA Species of Concern and Washington State sensitive plant species, grows in sandy soils in a variety of locations across the Columbia River Plain, and is likely distributed across the dune habitat at Hanford (Downs *et al.* 1993).

Dunes also provide habitat for burrowing owls (*Athene cuncularia*), coyotes (*Canis latrans*), and mule deer (*Odocoileus hemionus*) (Burk *et al.* 2007). In addition, the bitterbrush that grows in sandy soils is considered to be an important forage resource for mule deer (Downs *et al.* 1993). A 2003 study of biodiversity by The Nature Conservancy found that several of the invertebrate fauna found in sand dunes at Hanford are extremely limited outside of the Hanford Site (TNC 2003).

The Hanford Dunes are reported to be the only active non-coastal dunefield in the State of Washington although other dune areas exist (TNC 2003).

WHITE BLUFFS

The White Bluffs are located on the northern shoreline of the Columbia River from RM 376 to RM 356 (Burk *et al*. 2007). The tops of the bluffs are dominated by Indian ricegrass, while the slopes are dominated by shrubs including greasewood (*Sarcobatus vermiculatus*) and spiny hopsage (*Grayia spinosa*) (Burk *et al.* 2007). The bluffs are home to at least two species of sensitive plants – Geyer's milkvetch (*Astragalus geyeri Gray*), recognized as a sensitive species by the State of Washington and White Bluffs bladderpod (*Lesquerella tuplashensis*), recognized respectively as sensitive and threatened by the State of Washington (Sackschewsky and Downs 2001). The White Bluffs bladderpod is additionally a Candidate for listing under the ESA.

The bluffs provide perching, nesting and escape habitat for a number of bird species existing on the Hanford Site, including the prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo regalis*), cliff swallow (*Hirundo pyrrhonota*), bank swallow (*Riparia riparia*), rough-winged swallow (*Stelgidopteryx serripennis*), Canada goose (*Branta canadensis*), and bald eagle (*Haliaeetus leucocephalus*). The bluffs are known to provide habitat for at least one Federal Species of Concern, the peregrine falcon (*Falco peregrinus*) (Burk *et al.* 2007).

COLUMBIA RIVER ISLANDS

The total area of island habitat within the Hanford Reservation is 4.74 square kilometers (Hanson and Browning 1959). Islands within the main channel of the Hanford Reach, including Locke Island, Wooded Island, and others, provide important habitat for a variety of plant, mammalian and avian species. The shoreline of the island is dominated by willow (*Salix spp*.), poplar (*Populus spp.*), Russian olive (*Eleagnus angustifolia*), and mulberry (*Morus alba*) (Burk *et al.* 2007). Plants species populating the interior of the islands include buckwheat, lupine (*Lupinus spp*.), mugwort (*Artemisia lindleyana*), thickspike wheatgrass, giant wildrye (*Leymus cinereus*), yarrow (*Achillea millefolium*), and cheatgrass (Warren 1980). The islands are used for resting, nesting, and escape by a variety of waterfowl and shorebirds, including the Canada goose, American white pelican (*Pelecanus erythrorhynchos*), California gull (*Larus californicus*), ring-billed gull (*Larus delawarensis*), and Forster's tern (*Sterna forsteri*). There has also been documented use of the islands by mule deer for birthing, and by coyote for hunting (Burk *et al.* 2007).

Slumping of the White Bluffs has caused accelerated erosion of Locke Island, which is of great concern due to the cultural significance of the island and potential losses of cultural resources (Bjornstad 2006). Eroding sediments may also be sources of contamination and may be reducing the suitability of important salmon habitat in the Columbia River (Mueller and Geist 1999).

BASALT OUTCROPS, SCARPS, AND SCREES

A number of features on the Hanford Site support lithosol habitats or stony soils.[36] The tops and slopes of Rattlesnake Mountain, Umtanum Ridge, Yakima Ridge, Saddle Mountains, Gable Butte, and Gable Mountain are all characterized by basalt outcrops, scarps (cliffs), screes (loose rock at the base of cliffs or on slopes), and thin, rocky soils. Diverse plant communities can establish on these stony soils, typically dominated by short shrubs and grasses (Sackschewsky and Downs 2001).

Outcrops support some plants, including thyme buckwheat (*Eriogonum thymoides)*, and Sandberg's bluegrass (Burk *et al.* 2007). Areas with higher elevation, including habitat on Rattlesnake Mountain, typically support greater plant diversity than lower elevations (Downs *et al.* 1993). Most of the scarps and screes occur on Umtanum Ridge, and are nearly devoid of vascular plants (Downs *et al.* 1993). However, on north-facing slopes some small islands of stabilized substrate develop, and can support squaw currant (*Ribes cereus*), bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg's bluegrass, and forbs in early spring when moisture is available (Downs *et al.* 1993). Hoover's desert parsley (*Lomatium tuberosum*), an ESA Species of Concern, is confined to steep scree slopes. Additionally, the shrub steppe immediately adjacent to the basalt outcrops of Umtanum Ridge and Juniper Springs are known to support other plant species of concern (Downs *et al.* 1993).

The unique geomorphology of basalt outcrops, scarps, and screes provide habitat for rattlesnakes (*Crotalus viridis*), woodrats (*Neotoma cinerea*), and other burrowing animals (Burk *et al.* 2007). Scarps on Umtanum Ridge, Rattlesnake Mountain, and Gable Butte provide nesting sites for prairie falcons and, historically, for ferruginous hawks (*Buteo regalis*); rock wrens (*Salpinctes obsoletus*), chukars (*Alectoris chukar*), and poorwills (*Phalaenoptilus nuttallii*) also nest on scarps and scree habitats (Downs *et al.* 1993).

ABANDONED FIELDS/DISTURBED AREAS

Past agricultural development, livestock grazing, and wildfires have created extensive areas of disturbed habitat that are dominated largely by non-native species. Additionally, contaminant releases and associated remedial activities have created disturbed areas. These disturbed areas are concentrated around operational areas, and impact the distribution, movement, and extent of natural resources on the Hanford Site.

Dominant species in abandoned fields and disturbed areas include cheatgrass, tumble mustard (*Sisymbrium altissimum*), jagged chickweed (*Holosteum umbellatum*), and Russian thistle (*Salsola kali*) at low elevations. At higher elevations, such as the Snively Ranch in the Rattlesnake Hills, native black rye (*Secale cereale*) is still dominant (Downs *et al.* 1993). Similar species are found in areas that have been disturbed by grazing and wildfire.

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[36] Lithosol is defined by Sackschewsky and Downs 2001 as gravelly, rocky, talus soils associated with basalt outcrops and cliffs.

3.3 NATURAL RESOURCES

Pursuant to 43 CFR 11.14(z), natural resources are defined as:

> *land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States…any State or local government…These natural resources have been categorized into the following five groups: surface water resources, groundwater resources, air resources, geologic resources, and biological resources.*

This Plan focuses on abiotic and biological resources in the aquatic, riparian, and terrestrial habitats described above, and the ecological and human uses of those resources. Air, soil, and groundwater are exposed to Site-related contaminants and transport those contaminants to other resources (e.g., surface water, sediment, the hyporheic zone where groundwater and surface water mix, and biota). Within the aquatic habitat, surface water and sediment are the base of the aquatic ecosystem. The invertebrate community (e.g., mussels, crayfish, stoneflies) supports multiple species of fish, including special status fish, which vary depending on the microhabitat (e.g., riffle or pool). Other organisms that rely on aquatic invertebrates as prey include amphibians and reptiles, migratory and non-migratory birds, and multiple small mammals, such as several species of bats including the Hoary bat (*Lasiurus cinereus*) and Pallid bat (*Antrozous pallidus*). The invertivorous fish community is in turn preyed upon by piscivores such as the smallmouth bass (*Micropterus dolomieui*), bald eagle, great blue heron (*Ardea herodias*), and river otter (*Lutra canadensis*). The terrestrial habitat supports a wide array of species as well, including an invertebrate community (e.g., spiders, beetles, moths, and grasshoppers) reliant on soil for protection, food, etc.; several species of breeding songbirds; and several species of small mammals. Additionally, larger fauna such as mule deer, Rocky Mountain elk (*Cervus elaphus*), coyote, badger (*Taxidea taxus*), and black-tailed jackrabbit (*Lepus californicus*) utilize the shrub-steppe and grassland habitat.

SURFACE WATER RESOURCES

Surface water resources are defined as:

> *The waters of the United States, including the sediments suspended in water or lying on the bank, bed, or shoreline and sediments in or transported through coastal and marine areas (43 C.F.R. § 11.14(pp)).*

At the Hanford Site, surface water and sediment resources are found in all of the aquatic habitats described above (see section 3.1 on Aquatic Habitats). Surface water and sediment sources at the Site include:

- the Columbia River;
- springs on Columbia River riverbanks and Rattlesnake Springs;
- ponds and lakes, including West Lake;
- streams, including Cold Creek and Dry Creek; and,
- the Yakima River abutting the southernmost extent of the site.

The Columbia River is the predominant surface water resource at Hanford. While the Columbia defines the northern and eastern boundaries of the Site, the Yakima River also abuts the southern extent, and Cold Creek flows along the Site's southwestern edge.[37] Also prevalent, are a series of waste water ponds north of the Columbia within the National Monument. A map of significant surface water features at Hanford is provided below (Exhibit 3-1).

GEOLOGIC RESOURCES

Geologic resources are defined as:

> *Those elements of the earth's crust such as soils, sediment, rocks, and minerals…that are not included in the definitions…of surface water resources (43 CFR Section 11.14 (s)).*

The Hanford Site lies within the Pasco Basin, part of the larger Columbia Basin or Columbia Plateau. Relatively low-relief due to river and stream sedimentation filling in synclinal valleys and basins between the anticlinal ridges of the Yakima Fold Belt within the past several million years, the surface topography has been modified by Pleistocene cataclysmic flooding, Holocene eolian activity, and landsliding (Burk *et al.* 2007). Cataclysmic floods during the Pleistocene eroded sediments and scoured basalt bedrock, creating branching flood channels, giant current ripples, ice rafted erratics, and giant flood bars, which can all be found on the Hanford Site (Burk *et al.* 2007).

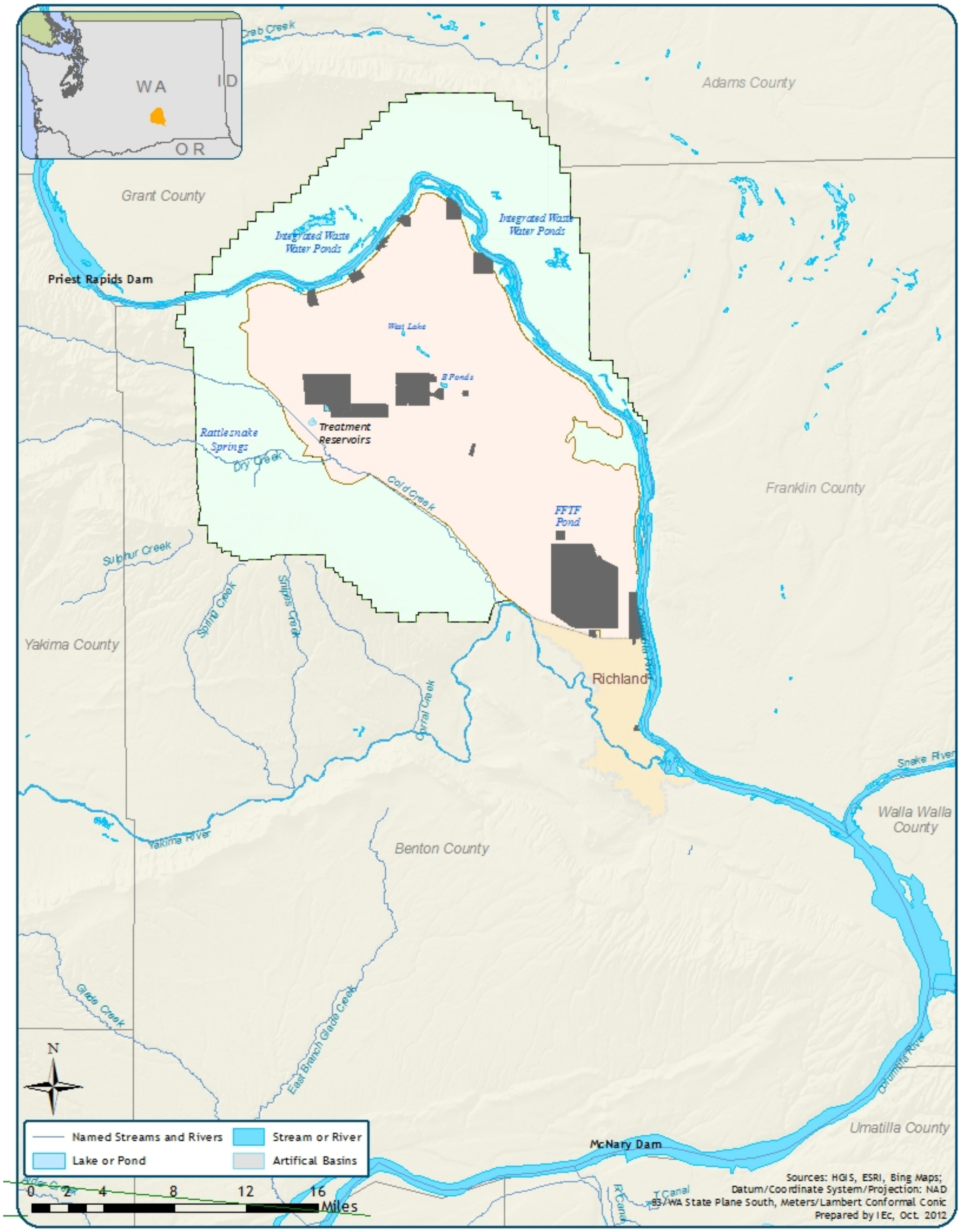
The Site consists of a layered depositional model, with basalt bedrock in the deepest (oldest) layer, overlain by Ringold formation sediments, Cold Creek sediments, and with Hanford formation sediments as the top (youngest) layer. However, these layers have been complicated by the method of deposition, and later by the removal of some of the sedimentary units (DOE 2011c). A description of each of the stratigraphic layers, from oldest to youngest, and additional information on some of these complications is provided in DOE 2011c.

Surface Soil

Of particular concern for this natural resource damage assessment are the soils in the suite of terrestrial habitats described above (i.e., shrub-steppe, sand dunes, white bluffs, Columbia River islands, basalt outcrops, scarps, scree, and, in particular locations, agricultural or disturbed habitat). Soils have been directly exposed to contaminants, and also act as a pathway of contaminants to terrestrial biota (see Chapter 5 for more details).

[37] For additional detail regarding surface water resources, see section 3.1 on Aquatic Habitats, above.

EXHIBIT 3-1 SURFACE WATER FEATURES ON HANFORD SITE



Vadose Zone Soil

In addition to the soils described above, Trustees are investigating injury to soils within the vadose zone at the Site – that is, the geologic resources that extend from the surface of the ground to the water table. The Hanford Site vadose zone ranges in thickness from less than one meter near the Columbia River to over 50 meters on the Central Plateau (DOE 2011c).

Moisture consistently moves through the vadose zone to groundwater. Prior to the mid-1990s, the major source of moisture was liquid discharges from the Site; currently, the major moisture sources include precipitation and water used for dust suppression during remediation. The rate of deep drainage from the vadose zone into the groundwater (i.e., the migration path and time required for a contaminant to pass through the vadose zone) depends on hydraulic, physical, and chemical conditions in the soil, total soil moisture content, the total amount of water available, recharge rates, depth to the water table, and the presence of vegetation (Burk *et al.* 2007, Freeman *et al.* 2001). However, since precipitation is fairly low at Hanford, annual infiltration is limited but over time can be an important driving force for transport of near-surface contaminants.

GROUNDWATER RESOURCES

Groundwater resources are defined as:

> *Water in a saturated zone or stratum beneath the surface of land or water and the rocks or sediments through which groundwater moves. It includes groundwater resources that meet the definition of drinking water supplies (43 CFR Section 11.14 (t)). Drinking water supply means any raw or finished water source that is or may be used by a public water system, as defined in the SDWA [Safe Drinking Water Act], or as drinking water by one or more individuals (43 CFR Section 11.14 (o)).*

As described in Burk *et al*. (2007), "groundwater at the Hanford Site originated as either recharge from rain and snowmelt, or from excess irrigation, canal seepage, and wastewater disposal." Additionally, seasonal bank recharge from the Columbia River is an important source of groundwater on Site. Most of the Hanford groundwater eventually discharges into the Columbia River, although some may be brought to the surface through wells or evaporation and transpiration in areas where the water table is shallow (Burk *et al.* 2007).

The groundwater on the Hanford Site is found in both an upper unconfined sedimentary aquifer system and a deeper basalt confined or semi-confined aquifer system (DOE 2011c, Burk *et al.* 2007). Although parts of the unconfined aquifer are semiconfined or confined, the entire suprabasalt aquifer system is interconnected site-wide (DOE 2011c, Burk *et al.* 2007). Unconfined aquifer groundwater typically flows from recharge zones near the western part of the Site towards the Columbia River on the eastern and northern boundaries of the Site. The Yakima River near the southwest boundary of the Hanford Site is a source of recharge (DOE 2011c). Recharge rates vary across the Site, due to changes in vegetation and soil type, and range from 1.5 millimeters per year in natural shrub-steppe areas to 52 centimeters per year in un-vegetated areas (DOE 2011c).

Recharge rates can also be artificially supplemented from Hanford wastewater disposal operations. To-date an estimated 1.68 x 10^{12} liters of wastewater have been discharged to disposal ponds, trenches, and cribs, increasing the water table elevation during operating years (DOE 2011c). Discharges in the Central Plateau caused groundwater mounding as high as 20 meters during peak operations (Stratus 2009). However, Hanford Site wastewater discharges have declined steadily in volume over the years, from approximately 14 billion liters in 1990 to 0.33 billion liters in 2010. Subsequently, the water table has been declining in most areas since 1980; Central Plateau levels have decreased to approximately 11 meters (Stratus 2009). Groundwater levels have also declined across the Site since non-permitted discharges to unlined ponds ceased in 1996 (DOE 2011c).

The confined/semi-confined aquifer system is located within the Columbia River Basalt Group. Most of the water in basaltic aquifers comes from precipitation and stream flow, and the groundwater generally flows toward the Columbia River; in some places, groundwater flows toward semi-confined areas where groundwater flows upward from the basalt into the overlying unconfined sedimentary aquifer system. This upward flow occurs in areas where the basalt is not completely confined and where there is an upward hydraulic gradient between the basalt and the overlying unconfined sedimentary aquifer system. Such upward gradients have been detected at several areas of the Site, due in part to significant declines in the unconfined water table as wastewater disposals ceased over the past 20 years.

Interactions between Groundwater and the Columbia River

The groundwater system at Hanford is highly influenced by the Columbia River flow system, and there is a dynamic zone of interaction where groundwater mixes with river water (DOE 2011c). This situation occurs in the 100 and 300 Areas, where during the high river stage, river water moves into the riverbank, overlaying the groundwater and mixing with it (Peterson and Johnson 1992). As the river water levels fall, the water flows back towards the river. Additionally, groundwater enters the Columbia River through a number of upwellings. Although the nature and extent of groundwater upwelling is unclear, upwelling locations have been identified within the 100 and 300 areas within the Hanford Reach (Hulstrom and Tiller 2010; Hulstrom 2010). A number of contaminants in these upwellings have been documented at levels exceeding water quality standards, including hexavalent chromium, nitrate, and uranium (Hulstrom 2011).

These interactions between groundwater and surface water can affect contaminant concentrations and cause varying hydraulic gradients by river-stage fluctuations. The effects of groundwater and surface water interaction on contaminant concentrations depends on a number of key variables such as flow patterns in the zone of interaction, the location of groundwater discharge, and the degree and timing of dilution prior to discharge into the riverbed substrate and the free stream (Peterson and Connelly 2001).[38]

[38] Additional information on the interaction of groundwater and the Columbia River can be found in FLUOR 2008, Lee *et al*. 1997, Peterson and Johnson 1992, and Peterson and Connelly 2001.

BIOLOGICAL RESOURCES

Biological resources are defined as:

> *Those natural resources referred to in section 101(16) of CERCLA as fish and wildlife and other biota. Fish and wildlife include marine and freshwater aquatic and terrestrial species; game, nongame, and commercial species; and threatened, endangered, and State sensitive species. Other biota encompass shellfish, terrestrial and aquatic plants, and other living organisms not otherwise listed in this definition (43 CFR Section 11.14 (f)).*

The biological resources potentially exposed to releases from the Site include, but are not limited to, aquatic and terrestrial plants, aquatic and terrestrial invertebrates, reptiles and amphibians, fish, birds, and mammals that utilize the aquatic and terrestrial habitats described above. The following sections provide a brief description and inventory of the biological resources present on the Hanford Site. Additional information on the specific species documented on the Hanford Site is available in Appendix C and in other sources (e.g., Gray and Dauble 1977, Fitzner and Gray 1991, Downs *et al.* 2004, CRICIA 1998, TNC 1999, TNC 2003, Burk *et al.* 2007, USFWS 2008, and information from the Hanford Site Environmental Monitoring and Compliance Project presented in Downs *et al.* 1993 and the annual Hanford Site Environmental Monitoring Reports).[39]

Aquatic and Riparian Plants

Hundreds of plant species have been documented on the Hanford Site (Sackschewsky and Downs 2001). Aquatic plants are typically found in the narrow riparian areas along the Columbia River, which consist "of a number of forbs, grasses, sedges, reeds, rushes, cattails, and deciduous trees and shrubs. Much of the riparian zone has also been successfully invaded by exotic plant species" (Sackschewsky and Downs 2001). Dominant vegetation includes mulberry (*Morus alba*), willow, Siberian elm (*Ulmus pumila*), Northern wormwood (*Artemisia campestris*), sweet clover (*Melilotus spp.*), and reed canarygrass (*Phalaris arundinacea*) (DOE 2007a). Burk *et al.* (2007) provides a list (see Table B1) of riparian vegetative species in the area, based on Sackschewsky and Downs (2001). TNC (1999) identified rare riparian community plants in riverine emergent wetlands.

In the Hanford Reach, phytoplankton consists predominantly of diatoms (Weiss and Mitchell 1992), but green algae, blue-green algae, red algae, and dinoflagellates have also been found (Burk *et al.* 2007). Populations are heavily influenced by Priest Rapids dam and the changing water levels (Burk *et al.* 2007). Many of the free-floating algae species in the Hanford Reach are derived from the periphyton. The phytoplankton and periphyton community make up the base of the aquatic food web and are an important food source for many herbivores such as immature insects.

[39] These lists show many, but not all, species present at the Hanford Site. Note that inclusion of a species in this assessment plan does not imply an obligation on the part of the Trustees to evaluate it, nor does omission of a species preclude the Trustees from evaluating potential injury to that species.

Macrophytes are "sparse in the Columbia River because of strong currents, rocky bottom, and frequently fluctuating water levels" (Burk *et al.* 2007), and are most prevalent in the slack water areas (Weiss and Mitchell 1992). Where present, macrophytes provide food, shelter, and breeding areas for fish. Weiss and Mitchel (1992) provide a list of macrophyte species present in the Hanford Reach.

Terrestrial Plants

The terrestrial vegetative communities on the Hanford Site are dominated by shrubs and steppe grasses. The shrub-steppe communities that once covered over 200,000 square miles of the American West have been largely eliminated or fragmented as a result of agricultural development and urbanization. The Hanford Site, with hundreds of documented plant species, represents one of the last relatively undisturbed tracts of this plant community remaining (Sackschewsky and Downs 2001).

Terrestrial plant community type (i.e., dominant shrub and grasses) is determined by climatic conditions, topographic conditions, soil type and depth, and land disturbance history. Big sagebrush is the dominant shrub in the majority of shrub-steppe plant communities found at Hanford. Other common species include grey rabbitbrush (*Chrysothamnus nauseosus*), green rabbitbrush (*Chrysothamnus viscidiflorus*), antelope bitterbrush (*Purshia tridentata*), spiny hopsage (*Grayia spinosa*), and black greasewood (*Sarcobatus vermiculatus*). Communities in which shrub species dominate are typically associated with an understory of grasses and forbs. Common grass species include Sandberg's bluegrass (*Poa secunda*), cheatgrass (*Bromus tectorum*), needle-and-thread grass (*Hesperostipa comata*), bluebunch wheatgrass (*Pseudoroegnaria spicata*), Indian ricegrass (*Oryzopsis (=Achnatherum) hymenoides*), saltgrass (*Distichlis stricta*), and Idaho fescue (*Festuca idahoensis*) (Sackschewsky and Downs 2001). At higher elevations, Sandberg's bluegrass is replaced by bluebunch wheatgrass, Cusick's bluegrass (*Poa cusickii*), hawk's beard (*Crepis atrabarba*), and Idaho fescue become more abundant, and three-tip sagebrush (*Artemisia tripartita*) is found at the highest elevations (Downs *et al.* 1993).

Of the 725 plant species documented at Hanford, approximately 20 percent are non-native. A number of noxious weeds have successfully established and displaced native forbs, including rush skeletonweed (*Chondrilla juncea*) and several species of knapweeds. Areas that have been disturbed by activities such as cultivation, fire, grazing, or construction activities are typically dominated by exotic annual species such as cheatgrass, tumble mustard (*Sisymbrium altissimum*), and Russian thistle. Past fires, such as the major fire in the year 2000 which consumed much of the shrub-steppe habitat in the ALE Reserve, have greatly contributed to altering the plant community – allowing non-native species to invade and significantly influence the Hanford habitat (Burk *et al.* 2007). The introduction of cheatgrass in particular has also resulted in significant alterations to distribution and abundance of native plants (Sackschewsky and Downs 2001).

A number of plant species whose populations are considered to be of concern by the Federal government and the State of Washington occur on the Hanford Site, such as Columbia milkvetch (*Astragalus columbianus*), Columbia yellowcress (*Rarippa* *columbiae*), and Hoover's desert parsley (*Lomatium tuberosum*). Although no plant species is currently listed as threatened or endangered under the ESA, two plant species are currently candidates for listing, Umtanum Desert buckwheat (*Eriogonum codium*) and White Bluffs bladderpod.

Terrestrial Invertebrates

Between 1994 and 1999, The Nature Conservancy conducted an insect inventory at Hanford that resulted in at least 1,536 species-level terrestrial invertebrate identifications, including identification of 43 previously unknown taxa. At the time of publication, researchers anticipated that after identification of all remaining samples the inventory would result in a total of over 2,000 species identified. Of those species identified during the survey, 142 were identified in the State of Washington for the first time, making Hanford the only known location for these species in Washington State (TNC 1999). The authors of this study attribute the high diversity of insect species on the Hanford Site to the size, complexity, and relatively undisturbed quality of the shrub-steppe habitat.

Biomass estimates indicate that the major taxonomic groupings at the Hanford Site are *Coleoptera* (beetles), *Hymenoptera* (ants, bees and wasps), and *Lepidoptera* (moths and butterflies) (Downs *et al.* 1993).

Two species, the Columbia River tiger beetle (*Cicindela columbica*) and the silver-bordered fritillary butterfly (*Boloria selene atrocostalis*) are listed as Candidate species by the State of Washington (Appendix C).

Aquatic Invertebrates

TNC (1999) conducted a limited reconnaissance survey and identified 52 taxa of aquatic invertebrates, including 21 not previously documented in the Hanford Reach. This discovery brought the total number of identified aquatic invertebrate taxa to 145 (*ibid.*). The study also investigated aquatic invertebrates in Hanford Reach tributaries and spring streams.

TNC (2003) continued the work of TNC (1999), surveying and compiling existing records of aquatic invertebrates in the Hanford Reach and other area locations. The authors conclude that over the past 50 years a variety of changes have occurred in the Hanford Reach: "*Ephemeroptera* (mayfly) diversity has increased; *Plecoptera* (stoneflies) have disappeared; *Trichoptera* (caddisfly) diversity and abundance remain high; *Odonata* (dragonflies and damselflies), *Hemiptera* (true bugs), *Lepidoptera* (butterflies and moths) and *Coleoptera* (beetles) are rare; and *Diptera* (fly) diversity remains relatively constant." The Pacific crayfish (*Pacifasticus leniusculus*) population "appears to be robust" and the introduced Asiatic clam (*Corbicula fluminea*) "appears to be extremely abundant" (*ibid.*).

Mueller *et al.* (2011) evaluated the species, distribution, and densities of native freshwater mussels in the Hanford Reach. Four species of native mussels were identified, of which the western and Oregon floaters (*Anodonta kennerlyi* and *Anodonta oregonensis*) were most abundant. The California floater (*Anodonta californiensis*), though it is listed as a Federal Species of Concern and State Candidate species, was the next most abundant, while the formerly-abundant western pearlshell (*Margaritafera falcata*) appears to have been extirpated.

In addition to the California floater, two additional species, the Giant Columbia River spire snail (*Fluminicola (*also known as *Lithoglyphus) columbiana*), and the shortfaced lanx (*Fisherola nuttalli*), are of special conservation concern (Appendix C).

Reptiles and Amphibians

A variety of reptiles and amphibians are found in and around the Hanford Site. However, Fitzner and Gray (1991) note that distribution and abundance of these species is poorly understood. Nine unique species of reptiles have been identified at Hanford (Fitzner and Gray 1991). The most common reptile species is the side-blotched lizard (*Uta stansburiana*) (Downs *et al.* 1993). The short-horned lizard (*Phrynosoma douglassi*), sagebrush lizard (*Sceloporous graciosus*) (an ESA Species of Concern and Candidate for State listing), striped whipsnake (*Masticophis taeniatus*) (a Washington State Candidate for listing) and desert nightsnake (*Hypsiglena torquata*) are also documented, though infrequently and the painted turtle was once commonly found on the Site (Fitzner and Gray 1991). The Gopher snake (*Pituophis melanoleucus*), yellow-bellied racer snake (*Coluber constrictor*), and western rattlesnake (*Crotalus viridis*) are commonly found on the Site (Burk *et al.* 2007).

Hanford is also home to a small number of native and non-native amphibians. Fitzner and Gray (1991) report that the Great Basin spadefoot (*Scaphiopus intermontana*), and Woodhouse's toad (*Bufo woodhousei*) are considered to be common in riparian areas. TNC (1999)'s survey reported these species and also the tiger salamander (*Ambystoma tigrinum*) and bullfrog (*Rana catesbeiana*). The western toad (*Bufo boreas*) has also been previously documented at the Site (TNC 1999, Burk *et al.* 2007), is listed as a Species of Concern under the ESA, and is a Candidate for State listing.

Fish

The Hanford Reach supports 45 fish species spanning 12 families, five of which are represented by only one species, and one of which (*Petromyzontidae*) includes two local species (Burk *et al.* 2007 as based on Gray and Dauble 1977). Fish species with the greatest economic importance include salmon (Chinook (*Oncorhynchus tshawytscha*), sockeye (*Oncorhynchus nerka*), and coho (*Oncorhynchus kisutch*)), and steelhead trout (*Oncorhynchus mykiss*) (DOE 2007a). Both the fall Chinook salmon and steelhead trout spawn in the Hanford Reach (Jamison 1982). Furthermore, "since 1962, the Hanford Reach spawning population has represented about 15 to 20% of the total fall Chinook escapement to the river. The destruction of other main-stem Columbia River spawning grounds by dams has increased the relative importance of the Hanford Reach spawning area" (*ibid.*).

Sport anglers also value the white sturgeon (*Acipenser transmontanus*), native mountain whitefish (*Prosopium williamsoni*), smallmouth bass, crappie (*Pomoxis spp*.), catfish (*Ictalurus punctatus*), walleye (*Sander vitreus*), and perch (*Perca flavenscens*) (Jamison 1982). The Pacific lamprey (*Lampetra tridentata*), a Federal Species of Concern, travels through the Hanford Reach and has great cultural value to area tribes (Close 2000).

Of the species documented in the Hanford Reach, six are considered by the Federal and/or State government to be of particular conservation concern (bull trout (*Salvelinus confluentus*), leopard dace (*Rhinichthys flacatus*), mountain sucker (*Catastomus platyrhynchus*), river lamprey (*Lampetra ayresi*), spring-run Chinook (*Oncorhynchus tshawytscha*), steelhead). Additionally, Spring-run Chinook salmon are listed as endangered under the ESA, while bull trout and steelhead are both listed as threatened (Appendix C).

Birds

Surveys conducted between 1994 and 1999 documented 221 species of birds on the Hanford Site, bringing the total of known avian species at Hanford to 258 (TNC 1999). A number of reports including Ennor (1991), Fitzner and Gray (1991), and Landeen *et al.* (1992) provide inventories of birds that have been documented breeding, wintering, or migrating through the Hanford Site. Downs *et al.* (1993) focuses in particular on summarizing information regarding species of particular conservation concern.

Ferruginous hawks, red-tailed hawks (*Buteo jamaicensis*), and Swainson's hawks (*Buteo swainsoni*) are commonly observed nesting on the Hanford Site, and feed primarily on small to medium-sized mammals (Downs *et al.* 1993). Other raptors commonly found breeding on Site include the Northern harrier (*Circus cyaneus*) and burrowing owl. Other common species at Hanford include sage sparrows (*Artemisiospiza belli*), western meadowlark (*Sturnella neglecta*) (the most abundant bird of the Columbia River plain shrub-steppe), and a wide variety of songbirds including the eastern kingbird (*Tyrannus tyrannus*), horned lark (*Eremophila alpestris*), barn swallow (*Hirundo rustica*), black-billed magpie (*Pica hudsonia*), common raven (*Corvus corax*), American robin (*Turdus migratorius*), European starling (*Sturnus vulgaris)*, white-crowned sparrow (*Zonotrichia leucophyrys*), dark-eyed junco (*Junco hyemalis*), red-winged blackbird (*Agelaius phoeniceus*), house finch (*Haemorhous mexicanus*), and house sparrow (*Passer domesticus*) (Landeen *et al.* 1992). Game bird species present on the Hanford Site include the mourning dove (*Zenaida macroura*), California quail (*Callipepla californica*), ring-necked pheasant (*Phasianus colchicus*), Hungarian partridge (*Peridix perdix*), and chukar partridge (*Alectoris chukar*) (Downs *et al.* 1993).

Thirty-nine species of native birds within the Columbia Basin Ecoregion that are considered to be shrub-steppe dependent have been documented at Hanford. In addition, eight species of regional management concern that breed in steppe or shrub-steppe habitats were documented by Saab and Rich (1997) breeding at Hanford, including black-throated sparrow (*Amphispiza bilineata*), sage sparrow, sage thrasher (*Oreoscoptes montanus*), Brewer's blackbird (*Euphagus cyanocephalus*), Brewer's sparrow (*Spizella brewen*), lark sparrow (*Chondestes grammacus*), loggerhead shrike (*Lanius ludovicianus*), and western meadowlark (TNC 1999).

Eighteen species of birds documented on the Hanford Site are of special conservation concern, including the American white pelican (*Pelecanus erythrorhynchos*), the peregrine falcon, and the greater sage grouse (*Centrocercus urophasianus*), which is a Candidate for ESA listing (Appendix C).

Mammals

Approximately forty species of mammals have been identified as certain or potential residents of the Hanford Site (Fitzner and Gray 1991; Appendix C). The Great Basin pocket mouse (*Perognathus parvus*) and deer mouse (*Peromyscus maniculatus*) are the most abundant species on the Site (Downs *et al.* 1993), and are important prey for snakes, coyotes, raptors, badgers, and other species. The Northern pocket gopher (*Thomomys talpoides*) is also considered to be abundant (Fitzner and Gray 1991) though it is not commonly observed by humans (Downs *et al.* 1993).

Three lagomorph species – Nuttall's cottontail (*Sylvilagus nuttallii*), white-tailed jackrabbit (*Lepus townsendii*) and black-tailed jackrabbit (*Lepus californicus*) - are currently found at Hanford.

Four species of ungulates have been reported at Hanford. Elk and mule deer are both observed commonly on Site, while white-tailed deer (*Odocoileus virginianus*) are only occasionally documented. Researchers documented several pronghorn antelope (*Antilocapra americana*) sightings between 1978 and 1981, but the species has since been considered extirpated from the Site.

Four families of carnivores are represented at Hanford. The coyote, the sole representative of the family *Canidae*, is the most abundant large carnivore on-site (Downs *et al.* 1993). Bobcats (*Lunx rufus*) represent the *Felidae* family at Hanford, and are generally associated with rock outcroppings and canyons. Six species of the *Mustelidae* family occur at Hanford, with the badger and striped skunk (*Mephitis mephitis*) being the most abundant, according to Fitzner and Gray (1991).[40] Minks (*Mustela vison*), short-tailed weasels (*Mustela ermiea)*), long-tailed weasels (*Mustela frenata*), and river otters have also been documented on Site, though less commonly. Raccoons (*Procyon lotor*) represent the *Procyonidae* family at Hanford (Fitzner and Gray 1991). None of these species has been studied extensively on Site.

Two species of shrew, the vagrant shrew (*Sorex vagrans*) and the Merriam's shrew (*Sorex merriami*), have been documented at Hanford, though both are considered to be uncommon (Fitzner and Gray 1991). The Townsend's ground squirrel was also once common across the Site (Fitzner and Gray 1991).

Bats are well-represented at Hanford. Six species of bats have been observed on the Site, and several, including the pallid bat (*Antrozous pallidus*) and two species of myotis bats (*Myotis spp*.) are frequently associated with buildings in the 100 and 200 Areas.

Of the mammalian species that have been documented at Hanford, five are of special conservation concern, including the black-tailed jackrabbit, white-tailed jackrabbit, Merriam's shrew, Townsend's ground squirrel (*Spermophilus townsendii*), and Washington ground squirrel (*Spermophilus washingtoni*). The Washington ground squirrel is also a Candidate for ESA listing.

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[40] Although Fitzner and Gray (1991) list badgers as being common to the Site, Downs *et al.* (1993) suggest that their population size is unknown.

AIR

Air resources are defined as: "*those naturally occurring constituents of the atmosphere, including those gases essential for human, plant, and animal life*" (43 C.F.R. § 11.14(b)). Although injury to air is sometimes assessed in the context of a natural resource damage assessment, the atmosphere is generally considered to be a pathway for the movement and re-suspension of contaminants by which other natural resources may be exposed to hazardous substances. Operations at Hanford are known to have emitted hazardous substances. At this time, the Trustees are focusing on air as a pathway, but may consider formally addressing injury to this resource in the future.

3.4 ECOLOGICAL SERVICES

Each of the natural resources described above provides a variety of ecological services. (Human use services, including tribal connections to Site natural resources, are described in Chapter 4). According to the DOI regulations, services are defined as:

> *…the physical and biological functions performed by the resource including the human uses of those functions. These services are the result of the physical, chemical, or biological quality of the resource* (43 CFR 11.14 (nn)).

For example, rivers provide habitat for numerous aquatic plant and animal species. Riverbanks and riparian habitats provide protective cover, spawning, and nursery habitat for aquatic and terrestrial biota, aid in nutrient cycling, maintain hydrologic flows, and improve water clarity by promoting sedimentation of particulate matter. Phytoplankton and zooplankton serve as prey for aquatic invertebrates and help to cycle nutrients in aquatic habitats. Salmon also contribute to nutrient cycling—their post-spawning carcasses provide an influx of nutrients to the Columbia River ecosystem. Fish, amphibians, and reptiles help to control insect populations and serve as prey for higher trophic level organisms, such as birds and mammals. Terrestrial habitat provides nesting and denning habitat for a suite of species, as well as flood control during storm events.

The resources described in this chapter are ecologically interdependent and provide interdependent services (43 CFR 11.71(b)(4)). For example, Safriel and Adeel (2005) describe the interactions of dry land natural resources and their services, for example:

- "[S]oil formation and soil conversion are key supporting services of dryland ecosystems, the failure of which is one of the major drivers of desertification";
- Nutrient cycling "supports the services of soil development and primary production through the breakdown of dead plant parts (thus enriching the soil with organic matter) and the regeneration of mineral plant nutrients… Unlike non-drylands, where soil microorganisms are major players in nutrient cycling, macrodecomposers such as termites, darkling beetles (*Tenebrionidae*),[41] and other invertebrates (many of which are soil dwellers) that are less water-sensitive become important for nutrient cycling"; and

[41] Darkling beetles are present at the Hanford Site (Rogers *et al*. 1978).

- "The numerous dryland plant species of different growth forms jointly provide a package of services through their ground cover and structure, which provide the drylands' most important services of water regulation and soil conservation… [and] In many arid and semiarid areas, this biodiversity of 'vegetation cover' and biological soil crusts is linked to a diversity of arthropod species that process most of the living plant biomass, constituting the first link of nutrient cycling."

These and other services sustain a functioning ecosystem by supporting essential hydrological, geomorphological, and ecological processes.

3.5 PRELIMINARY DETERMINATION OF RECOVERY PERIOD

Existing data indicate that natural resource services have been lost due to Site-related contamination. As described in the DOI NRDA regulations, this Plan includes a preliminary estimate of the time needed for affected natural resources to recover (43 CFR 11.31(a)(2)). This recovery period is "either the longest length of time required to return the services of the injured resource to their baseline condition [*i.e.*, the condition in which they would have been had the release not occurred] or a lesser period of time selected by the authorized official and documented in the Assessment Plan" (43 CFR 11.14(gg)).

Recovery period estimates must be based on the best available information and, where appropriate, may be based on cost-effective models. More specifically, information may come from one or more of the following sources, as applicable: published studies on the same or similar resources; the experience of managers or resource specialists with the injured resource or with similar discharges elsewhere; and field and laboratory data from the assessment and control areas (43 CFR 11.73(c)(1)).

In estimating recovery times, Trustees consider factors such as ecological succession patterns in the area; the growth or reproductive patterns, life cycles, and ecological requirements of biota involved, including their reaction or tolerance to the hazardous substance involved; the bioaccumulation and extent of hazardous substances in the food web; and the chemical, physical, and biological removal rates of the hazardous substance from the media involved, including the nature of any potential degradation or decomposition products (43 CFR 11.73(c)(2)).

For example, some contaminants released from the Site are expected to have extremely high persistence in Site media. Site activities resulted in the discharge of over 200,000 kg of uranium to the ground in the 200 and 300 Areas (Corbin *et al*. 2005 as cited in Zachara *et al*. 2007). These actions created large groundwater plumes of uranium, and at least one such plume "continues to grow in size" (Hartman *et al*. 2007 as cited in Zachara *et al*. 2007). Uranium does not decay over appreciable timeframes: the U-238 isotope[42] makes up the large majority by mass of natural uranium and has a half-life of about 4.5 billion years, whereas U-234 and U-235 have half-lives of approximately 240,000 years and 700

[42] An isotope is defined as a nuclide of an element having the same number of protons but a different number of neutrons. Nuclide is a general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom (http://www.epa.gov/radiation/glossary/index.html).

million years, respectively (ATSDR 1999). These lengthy half-lives indicate that uranium's specific activity is relatively low compared to radionuclides with shorter half-lives. However, if not physically removed, it will persist for a very long time; and, uranium is also chemically toxic.

Overall, the soil and groundwater beneath Hanford contain approximately 1.8 million curies of radioactivity as of 2000 (Gephart 2003).[43] Furthermore, contamination of groundwater from single-shelled tanks has been substantial and is ongoing; sixty-seven tanks have or are suspected to have leaked up to 1 million gallons of waste (DOE 2010).

Radionuclides and other contaminants including hexavalent chromium have been released to the Columbia River, particularly between 1944 and 1971 (Gephart 2003). Groundwater travel time from the 200 Area to the river is uncertain but likely ranges from a few years to several decades. Travel times for contaminants subject to retardation by ion exchange and adsorption could be on the high end of that range, such as uranium, strontium-90, and chlorinated hydrocarbons. Over time, high flow rates in the Columbia River have diluted contaminant concentrations in water and sediment in the Hanford Reach and total discharge of groundwater into the River ranges from 0.08 to 2.8 cubic meters per second (0.001 percent of the average Columbia River flow). However, the variability in discharge rates along the River are not well known (DOE 2011c). Additionally the influx of contaminants from groundwater is ongoing, and as long as that persists, it may adversely affect exposed biota, particularly those with life stages associated with river sediments and those exposed in areas of groundwater upwelling.

The potential for ongoing exposure to river biota is therefore at least as long as the groundwater travel time. Preventing contaminated groundwater from reaching the Columbia River is one of the main cleanup goals (DOE 2010). As part of Hanford's 2015 Vision, DOE, EPA and the Washington Department of Ecology hope to prevent contamination from reaching the River by 2015 by decommissioning, deactivating, decontaminating, and demolishing more than 235 facilities, remediating over 300 waste sites, and sending approximately 4.6 million tons of waste and debris to the Hanford Environmental Restoration Disposal Facility. These types of actions will shorten the time required for resources to recover to their baseline condition.

As mentioned, some Hanford contaminants may persist for thousands of years, including those with long half-lives such as the uranium isotopes, plutonium-239 (half-life of 24,100 years), and technetium-99 (half-life of 211,000 years), and carbon tetrachloride, a persistent contaminant in groundwater at Hanford. Based on an evaluation of the existing literature documenting the limited natural degradation rates of many Site contaminants and their resulting persistence in the environment, the Trustees' preliminary determination of the recovery period is that it will likely be at least hundreds of years before recovery will be achieved.

[43] This figure does not include contained wastes, such as those in tank farms. In total, it is estimated that about 430 million curies of human-made radioactivity remain on site (as of 2000) (Gephart 2003).

CHAPTER 4 | NATURAL RESOURCE HUMAN USE SERVICES

4.1 NATURAL RESOURCE SERVICES PROVIDED TO TRIBAL COMMUNITIES

In addition to the suite of ecological services described in Chapter 3, trust natural resources in the study area also provide a wide range of human use services. The release of hazardous contaminants from Hanford Site operations has potentially impacted people's use of natural resources, and the well-being they derive from such uses. Measures of the change in human use of a natural resource can be used to quantify natural resource injury (i.e., quantifying the loss in services provided by natural resources to humans), and can support selection and scaling of specific restoration actions to restore the scale and quality of human uses of natural resources. This section describes natural resource services provided to tribal and non-tribal communities that will be considered by the Trustees in conducting the Hanford injury assessment.

Indigenous peoples inhabited the landscape that became the Hanford Site from time immemorial. In the mid-19th century, various tribes in the region reserved rights to access the Hanford Site for traditional use purposes through Treaties with the United States. These traditional uses include the right to access natural resources at this site. Native Americans were still living in accordance with traditional beliefs and practices at Hanford when the Site was established in 1943, and were among those evicted when the U.S. government took control of the area (CTUIR 2012). After that time, little to no access was granted to indigenous groups for many years. More recently, increased, but still limited, access has been allowed. For example, today Native Americans use resources and conduct religious ceremonies in accessible areas at the Site (Yakama PAS). Note that the Federal government maintains a special trust relationship with Indian tribes pursuant to various treaties, statutes, Executive Orders, judicial decisions and other legal instruments. Inherent in the relationship is an enforceable fiduciary responsibility to the Yakama Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Tribe, to protect their rights and resources. (R. Jim, Yakama Nation).Indigenous peoples may utilize natural resources to an extent and in ways that are different from the general population (Harper *et al.* 2002, Nadasdy 2003, Turner 2005). In addition, the role that natural resources play in the culture of these indigenous communities may differ from that of the general population. "Culture" in this context encompasses the lived experiences and all of the material and spiritual relationships that indigenous peoples have with all of the elements of the natural world. Drawing on published anthropological research, *culture* in the context of this Plan incorporates *practice*, which consists of the everyday activities of the people on the land. As stated by the Nez Perce,

> "The most appropriate way to understand our cultural values is to view our cultural practices conducted today on our landscape. They reflect a complex tradition showing high regard for the land. There isn't a daily activity of a

> traditional lifestyle that doesn't have oral traditions telling how the activity is part of the land and plays a role in taking care of the land" (Nez Perce 2010).

The Yakama Nation underscores the importance of the Hanford Site and environs as follows:

> "The Yakama subsistence lifestyle, including fishing, hunting, and plant gathering; use of traditional foods, medicines, and materials; sweathouse use, feasts, and other cultural practices, depends upon safe, unrestricted access to clean natural resources in the Hanford Assessment area year round in perpetuity" (Yakama 2010).

In general, natural resources and associated ecosystem services provide cultural services including, but not limited to, provisioning, regulating, cultural, and supporting services to tribal members. Thus, cultural service loss can encompass adverse changes in three broad areas of a tribe's natural resource-based cultural practices, including, but not limited to: (1) Tribal economies (in terms of food, money, and livelihoods, etc.); (2) Tribal knowledge (languages, values, teachings, etc.); and (3) Tribal spiritual values (ceremonies, sacred histories, places, etc.).

As a result of differences in the nature and extent of services tribal members and their communities derive from the environment – and differences in the way in which changes in these services affect indigenous communities — it may be necessary to describe and quantify service losses for tribal communities separately from service losses to the general public. Given these differences, specific restoration actions may also be required to fully compensate the public for losses in indigenous community services.[44] Exhibit 4-1 provides a preliminary matrix of natural resources, ecosystem services associated with these resources, and examples of tribal uses of these resources at Hanford. This list is not intended to be all-inclusive; identification of specific sites or uses is not intended to

> "[P]rominent landforms such as Rattlesnake Mountain, Gable Mountain, and Gable Butte, as well as various sites along and including the Columbia River, remain sacred. American Indian traditional cultural places within the Hanford Site include, but are not limited to, a wide variety of places and landscapes: archaeological sites, cemeteries, trails and pathways, campsites and villages, fisheries, hunting grounds, plant gathering areas, holy lands, landmarks, important places in Indian history and culture, places of persistence and resistance, and landscapes of the heart (Bard 1997). Because affected tribal members consider these places sacred, many traditional cultural sites remain unidentified." (*Hanford Site National Environmental Policy Act (NEPA) Characterization (2007) and CTUIR (2012)).*

[44] Any Federal undertaking that has the potential to affect Federally-listed (and/or eligible for listing) cultural resources, including Traditional Cultural Properties (TCP), must be evaluated, as mandated under the National Historic Preservation Act (NHPA) Section 106. Such actions would include restoration decisions associated with NRDA. As such, identification of TCPs within Federal jurisdiction must first occur, as mandated under NHPA Section 110 within the area of potential affect for the Federal undertaking.

undervalue other areas and uses that are not listed. In addition, Trustees continue to work to refine and expand this matrix. Recognizing that this matrix is a simplification of a complex association of tribal values with natural resources, it is intended to illustrate and classify the critical links that exist between natural systems and tribal uses at Hanford. As such, it provides context for understanding the range and complexity of tribal uses of and values for this site and its resources, and for the studies proposed in Chapter 7 to address tribal lost use. This exhibit is organized according to "Natural Resource Categories," which include resources that are likely to have been injured at Hanford: surface water, groundwater, geologic resources, biological resources, and air. For each type of natural resource, there are several "Ecosystem Service Categories," as defined by the Millennium Ecosystem Assessment and National Academy of Sciences (Millennium Ecosystem Assessment 2005). These categories are: cultural and amenity, provisioning, regulating, and supporting and habitat.[45] For each category, there are multiple "Associated Tribal Services" that are beneficial and of value to tribal members.[46] Finally, for each tribal service, examples are listed of "Specific Tribal Uses" at Hanford. The Tribal Narratives (which can be found in the Administrative Record) articulate in more detail the specific tribal uses of resources at Hanford.

As noted in Exhibit 4-1, specific physical areas at the Hanford Site carry particular cultural importance to the Yakama, CTUIR, and Nez Perce. As stated in the Hanford Site National Environmental Policy Act (NEPA) Characterization (Duncan 2007) and reiterated by CTUIR (2012),

> "prominent landforms such as Rattlesnake Mountain, Gable Mountain, and Gable Butte, as well as various sites along and including the Columbia River, remain sacred. American Indian traditional cultural places within the Hanford Site include, but are not limited to, a wide variety of places and landscapes: archaeological sites, cemeteries, trails and pathways, campsites and villages, fisheries, hunting grounds, plant gathering areas, holy lands, landmarks, important places in Indian history and culture, places of persistence and resistance, and landscapes of the heart (Bard 1997). Because affected tribal members consider these places sacred, many traditional cultural sites remain unidentified" (Duncan 2007).

Despite the fact that many sites are not identified, as of 1997, over 1,500 cultural resource sites and isolated finds, as well as 531 buildings and structures[47] have been documented on the Hanford Site (Duncan 2007). Such sites include pit house villages, open campsites, spirit quest monuments (rock cairns), hunting camps, game drive complexes, and quarries in nearby mountains and rocky bluffs; hunting/kills sites, and small

[45] Ecosystem services that are market-mediated (i.e., can generally be monetarily valued) include provisioning, regulating, and supporting services; while those that are generally non-market-mediated include cultural/amenity services, such as subsistence, recreation, education, ceremonial, and artistic services (Chan *et al.* 2011).

[46] Service benefits that are generally market-mediated include employment, material, activity, and aesthetic benefits; while those that are generally non-market-mediated include benefits associated with place/heritage, spiritual, inspiration, knowledge, existence/bequest, option, social capital/cohesion, and identify (Chan *et al.* 2011).

[47] These figures include a small number of sites from early settlers and the Manhattan Project Era.

temporary camps near perennial sources of water (Duncan 2007). Forty-nine cultural resource sites have been listed on the National Register of Historic Places, most of which are associated with Native American sites (Duncan 2007).

EXHIBIT 4-1 HANFORD TRIBAL SERVICES MATRIX

NATURAL RESOURCE CATEGORIES[1]	ECOSYSTEM SERVICE CATEGORIES[2]	ASSOCIATED TRIBAL SERVICES[3]	EXAMPLES OF SPECIFIC TRIBAL USES[3, 4]
Surface water (includes sediment and hyporheic zone)	Cultural & Amenity	Water supply (subsistence, ceremonial, spiritual)	Life-giving source
			Drinking water (feasts)
			Sweat lodge purification
		River features (subsistence, ceremonial)	Sweat lodge sites
			Fishing camp sites
			Coyote Rapids (spiritual site)
	Provisioning	Water supply	Drinking water (daily)
			Bathing, cleaning water
	Regulating	Water purification	Clean water (less disease)
		Flood control	Stable shoreline (fishing/gathering area)
		Climate regulation	Stable climate (maintaining habitat for species collected)
	Supporting & Habitat	Aquatic/riparian habitat for sacred plants/animals	Plant/animal collection for subsistence food, medicine, materials, ceremony
		Key species habitat	Salmon and other fish
Groundwater (includes springs and seeps)	Cultural & Amenity	Water supply (subsistence, ceremonial, spiritual)	Life-giving source
			Drinking water (feasts)
			Sweat lodge water (e.g., Rattlesnake Ridge springs)
	Provisioning	Water supply	Drinking water (daily)
			Bathing, cleaning water
	Regulating	Water security	Clean water availability
Geologic (includes surface soil, vadose zone, dust, and rocks)	Cultural & Amenity	Spiritual sites, sacred grounds, landmarks and landscape features, traditional use areas	Burial Grounds
			Archeological sites
			Mooli Mooli
			Gable Butte
			Gable Mountain
			Rattlesnake Mountain
			Columbia River Islands
			White Bluffs
			Other spirit quest areas

NATURAL RESOURCE CATEGORIES[1]	ECOSYSTEM SERVICE CATEGORIES[2]	ASSOCIATED TRIBAL SERVICES[3]	EXAMPLES OF SPECIFIC TRIBAL USES[3, 4]
			Sweat Lodges along river
			Sweat lodge rocks
			Solitude, quiet, dark for meditation and ceremony; spiritual connection to Mother Earth
			Cultural/religious ceremonies, feasts, traditional uses
		Traditional ecological knowledge, information, education, observation, language, inspiration, community cohesion, heritage	Historical places, names, songs, stories, calendar
			Language, linguistic landmarks, mnemonics
			Cultural recognition / association
			Heritage, multi-generational ties
			Treaty rights education
			Environmental restoration/stewardship education/jobs
			Traditional Cultural Properties (TCPs)
			Scenic vistas, recreational experience, trails
			Social-economic opportunities
			Areas for barter, trade, reciprocity
	Provisioning	Raw materials (subsistence, medicinal, sacred)	Rocks and clay for building material
			Soil to white-wash buildings
			Clay for mud baths
			Ground (dirt floor) for sweat lodge
			Ground (dirt floor) for ceremonies, dancing
			Soil for healing wounds
		Ornamental use (spiritual, artistic)	Clay for pottery
			Soil to clean hides
			Soil to make paints
	Regulating	Erosion control	Stable soils, dust reduction
		Nutrient cycling	Fertile soils (habitat for foods collected)
	Supporting & Habitat	Terrestrial habitat for sacred plants/animals	Plant/animal collection for subsistence food, medicine, materials
		Key species habitat	Elk/deer and other wildlife

NATURAL RESOURCE CATEGORIES[1]	ECOSYSTEM SERVICE CATEGORIES[2]	ASSOCIATED TRIBAL SERVICES[3]	EXAMPLES OF SPECIFIC TRIBAL USES[3, 4]
Biological (includes aquatic, riparian, and terrestrial wildlife, birds, fish, shellfish, invertebrates, plants, fungus, microbes)	Cultural & Amenity	Traditional ecological knowledge, information, education, observation, language, inspiration, community cohesion, heritage	Wildlife, hunting information and skills
			Fish, fishing information and skills
			Plant identification, gathering information
			Traditional foods and medicines knowledge
			Nutrition, health education
			Cultural recognition / association
			Treaty rights education
			Environmental restoration & stewardship education and careers
			Materials for barter, trade, reciprocity
			Aesthetics, existence, viewing, ecotourism
	Provisioning	Gathered foods and medicines (subsistence, healing, sacred)	Hemp, chokecherry, balsamroot as examples
			Berry A, Berry B, …
			Herb A, Herb B, …
			Roots A, Root B, ….
			Pine tea, sage (medicine)
			Fir, willow, flowers used in sweat lodges
		Hunted and fished animals (clothing/blankets, subsistence, healing, sacred)	Deer
			Elk
			Rabbit
			Other wildlife
			salmon
			Other fish
		Raw materials (sacred, subsistence use, shelter)	Plant parts for fishing poles
			Salmon drying racks
			Cedar bark for baskets
			Tule for mats
			Plant and animal parts for sweat lodge
			Wood for burning (fuel, sweat lodge)
			Wood for buildings
		Ornamental use (spiritual, artistic)	Animal parts (hide) for clothing, shoes
			Animal parts (bones, teeth, shells) for jewelry
			Plant/animal parts for hats, pigments/dyes

NATURAL RESOURCE CATEGORIES[1]	ECOSYSTEM SERVICE CATEGORIES[2]	ASSOCIATED TRIBAL SERVICES[3]	EXAMPLES OF SPECIFIC TRIBAL USES[3, 4]
	Regulating	Biological control	Infestation control
			Predator/prey population control
		Waste treatment	Nutrient cycling
	Supporting & Habitat	Biodiversity, food web	Culturally important species
			Interdependent species
Air	Cultural & Amenity	Information, education, observation, language	Viewshed
	Provisioning	Clean air supply	Respiration
	Regulating	Climate regulation	Stable air patterns

Notes:

1. Natural resources potentially injured at Hanford, as listed in DOI regulations, include surface water/sediment, groundwater, geologic resources, biological resources, and air.
2. Ecosystem services are the benefits to ecosystem functions, including provisioning, regulating, supporting, and cultural services; listing of these ecosystem services is not necessary to demonstrate the direct link between injured resources and tribal lost services, but illustrates the interconnectedness of ecosystem health and human services.
3. Sources of information include: Human Use Technical Working Group (TWG) Services Matrix and Publics Matrix; and Tribal Narratives provided by CTUIR, Nez Perce, and Yakama Nation.
4. Specific uses reflect tribal values associated with subsistence, culture, education, preservation, health and well-being, recreation, and business/economic services.
5. Note that some of these services may not change as a result of natural resource injury, but are referenced to provide a broad overview of the services provided by these resources.

4.2 NON-TRIBAL HUMAN USE SERVICES

There are a variety of non-tribal human uses that may have been impacted by the presence of contaminants from Hanford Site operations. In particular, the Trustees have considered past, current, and potential future impacts to recreation (both water-based and land-based) and social welfare changes due to changes in agriculture in the Hanford region (i.e., changes in producer or consumer surplus associated with agricultural products). The Trustees have also considered the nature, extent, and timing of past, present, and expected future resource use limitations due to institutional controls associated with the presence of hazardous contaminants at the Site.

Based on review of existing information, the Trustees are proposing a study to fully describe the past, current, and future geographic and temporal scope of contaminant-related institutional controls which could impact human use of natural resources at the Site. This study is described in Chapter 7.

At this time the Trustees are not proposing additional study of the effect of site releases on agricultural behaviors or a detailed study of recreational behavior. Below we summarize the information on which these determinations were based.

RECREATION

Assessment Area Recreational Opportunities

Hanford Reach National Monument

Hanford Reach National Monument currently provides the public with access to over 57,000 acres of land (USFWS 2011a). The Monument lands support a variety of recreation ranging from wildlife-dependent recreational activities such as hunting, to water-based recreational activities such as boating. This section provides an overview the most commonly pursued recreational activities, including discussion of where the activities occur, when they occur, and what factors influence recreational demand for them.

- **Fishing**: With the Hanford Reach being the last free flowing stretch of the Columbia River in the United States, it has become a very popular recreational fishing resource among fishermen in the Pacific Northwest. The Reach provides excellent fishing opportunity for anglers who wish to pursue sport fishing for fall Chinook salmon, steelhead, sturgeon, whitefish, and small-mouth bass (USFWS 2008). Most fishing occurs from motorized boats, though there is also some fishing done from non-motorized boats and from the river banks. The peak fishing seasons for some species, and especially for fall Chinook salmon, can feature heavy congestion at boat launches both within and downstream of the Monument (USFWS 2008). In addition to angler effort in the river, there is also a small amount of angler effort that occurs in the WB-10 ponds of the Wahluke Unit, which are part of the Columbia Basin Irrigation Project.
- **Hunting**: The Monument offers visitors the opportunity to hunt a variety of mammalian and avian species in riparian and shrub-steppe habitats during the fall and winter hunting seasons. The species open to hunting on the Monument are deer, elk, goose, duck, coot, dove, snipe and all upland game birds (USFWS

2011b). For the Monument, areas open or potentially open to hunting include all or portions of the Ringold Unit, Saddle Mountain, Wahluke, and Columbia River Corridor (USFWS 2002 & USFWS 2011b). Non-waterfowl hunting includes the Saddle Mountain Unit, the Ringold Unit, part of the Wahluke Unit, and all areas of the Columbia River Corridor Unit that are downstream of the Saddle Mountain National Wildlife Refuge (USFWS 2002 & USFWS 2011b).

- **Boating**: The Hanford Reach stretch of the Columbia River Corridor Unit offers opportunities for recreational participants to pursue both motorized and non-motorized boating. While boating in the Reach is primarily driven by angling demand, an increasing number of visitors are pursuing boating for alternative purposes such as scenery and wildlife observation (USFWS 2008). Visitors can also participate in boating-related recreation activities such as water-skiing, personal watercraft use (i.e., jet skiing), and commercial tours of the river. There are three main boat-launching areas on the Monument and several boat-launching areas downstream, including one near the Ringold Fish Hatchery, that have the potential to provide access to the Monument.[48] With boating being primarily driven by angling demand, peak boating seasons closely mirror the peak fishing seasons, with heavy congestion occurring at boat launches during the summer sturgeon season and the fall Chinook salmon and steelhead season (USFWS 2008).
- **Wildlife Observation and Photography**: The four publicly accessible units of the Monument offer significant opportunities for visitors to view and photograph nature. The Monument offers a diverse range of scenic habitats and provides a home to over 240 bird species and more than 40 mammal species throughout the year (USFWS 2008).
- **Environmental Education and Interpretation**: The Monument does not have any formal educational or interpretive programs at this time; however, USFWS accommodates these activities as well as scientific research on the Monument when practical. Schools, nature appreciation groups, and research groups can access the Monument for field trips or biological research projects, and the Arid Lands Ecology Reserve Unit "provides unique settings for other research-oriented projects including an observatory and an underground gravitational research lab" (USFWS 2002).
- **Horseback Riding, Biking, Swimming, Camping, and Hiking**: All of these activities occur on the Monument, consistent with resource management restrictions. Though camping is technically prohibited on the Monument, an exception is that some camping does occur upstream of the Vernita Bridge, especially during peak fishing seasons (USFWS 2008).

Downstream of Hanford Reach National Monument

Downstream of the Monument, the Columbia River continues to provide recreational opportunities. Several miles downstream of the Monument is the McNary Dam; this dam

[48] The downstream boat launches are discussed in the downstream recreation review below.

creates a reservoir-environment in the Columbia River that is known as “Lake Wallula.” Information available for recreation activities that occur downstream of the Monument along Lake Wallula is provided by the U.S. Army Corps of Engineers’ (USACE) Natural Resource Management System (NRMS). Though the NRMS was discontinued after 1999, the database does provide comprehensive information for visitation data through 1999. This section will review recreation information to the extent that it is available.

A host of recreation sites are available along Lake Wallula, including parks, beaches, boat launches, a visitor information center, and a National Wildlife Refuge. Collectively, these recreation sites allow recreation users to pursue activities similar to those that occur on Hanford Reach National Monument.

- **Fishing:** The downstream portion of the Columbia River between the Monument and the dam provides opportunity for anglers pursuing sport fish and attempting to avoid the fishing season congestion that occurs in parts of the Hanford Reach.
- **Hunting:** McNary National Wildlife Refuge, specifically the Wallula Unit, Peninsula Unit, the Two Rivers Unit, and the Burbank Slough Unit, provides hunting opportunities to recreational users of the Lake Wallula area (USACE 2011b).
- **Boating:** With boating congestion in some stretches of the Hanford Reach during peak fishing seasons, Lake Wallula provides important recreational resources both in terms of available boat launch facilities and additional area open to boating.
- **Wildlife Observation and Photography, Camping, Horseback Riding, Hiking, Biking, and Swimming:** Several Lake Wallula recreation sites offer year-round opportunities to pursue wildlife observation and birding. Recreational users can observe a diverse range of species and habitats at these sites. Several recreational sites in the Lake Wallula area offer seasonal or year-round camping (USACE 2011b). These sites also offer day-use areas with amenities such as picnic benches and recreational opportunities such as hiking or biking, so campers have ample opportunity to participate in a diverse range of recreational activities. Equestrians can use the Lewis and Clark Commemorative Trail and designated trails on the McNary National Wildlife Refuge. The Lake Wallula area offers plentiful opportunities for hiking in a diverse range of environments. Bicycling can be pursued on roads throughout the Lake Wallula area, and two recreation sites particularly single out bicycling as a popular recreational pursuit: Chiawana Park and Hood Park **(**USACE 2011b**).** Several Lake Wallula recreation sites offer visitors the opportunity to swim in the Columbia River **(**USACE 2011b**).**

Contaminant Effects on Recreation

Impacts of contamination on recreational opportunities can manifest in a variety of ways, ranging from fish consumption advisories, to hunting advisories, to closures of sites and facilities. Under DOI’s NRDA regulations, to the extent that contamination causes changes to available services in terms of recreational quality, public access, and recreation demand, these changes may be compensable (43 CFR 11.71(e)).

To examine how contamination may be affecting human use recreation at the Monument and downstream of the Monument, this section reviews available contamination information for the region as it pertains to recreational activities, recreational quality, and public access.

- **Cleaned up sites:** For the Hanford Reach National Monument, the Rattlesnake, Saddle Mountain and Wahluke Units had been historically contaminated from activities related to the Hanford Site. These locations have since been cleaned up and are now able to "support unrestricted use" (EPA *et al.* undated).[49]
- **Saddle Mountain Lakes:** There is evidence that the Saddle Mountain Lakes, in the Saddle Mountain National Wildlife Refuge, suffer from contamination due to the presence of "DDT-related compounds" (EPA *et al.* undated). This water body is part of the Columbia Basin Irrigation Project, and as such, is potentially exposed to non-Hanford contamination sources. Because Saddle Mountain National Wildlife Refuge is managed for research and education-related activities, and is therefore closed to most public access, this contamination does not pose significant loss of recreational resources. However, the USFWS may wish to open Saddle Mountain pond in the future.
- **Columbia River Shoreline:** There are "hot spots" of contamination along the Columbia River shoreline due to activities related to the Hanford Site. Most of the shoreline of the Hanford Site is accessible to visitors up to the mean high water mark, "except in those areas where reactor and reactor-related cleanup is ongoing" (EPA *et al.* undated). Contamination of the shoreline includes contaminated groundwater in locations near the former reactor sites. Water quality sampling has determined that groundwater underlying the stretch of river between river mile 363 and river mile 356 is contaminated above drinking water standards due to contamination from central Hanford (EPA *et al.* undated). This contaminated groundwater can enter the river through seeps and springs, and although it is unlikely that visitors could ingest enough water to be harmful, it is best not to consume water from the Columbia River within the Hanford Reach National Monument (EPA *et al.* undated).[50] However, as of 1996, the Columbia River Systems Operation Review found that "no water quality problems affecting recreational suitability are known to exist in the Hanford Reach" of the Columbia River (USACE 2011a).
- **Biota Monitoring Program:** The US Department of Energy (USDOE) "maintains a comprehensive environmental monitoring system" on the Hanford Site and in the Hanford Reach National Monument (EPA *et al.* undated). This monitoring system tests game species, including waterfowl and fish, for evidence of contamination. Results from the monitoring program indicate that "consumption of wildlife and fish harvested from the Monument does not pose a threat to humans" (EPA *et al.*

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[49] This designation by the EPA does not necessarily preclude injury under DOI NRDA regulations.

[50] Washington State has designated the Columbia River in this area as Class A (i.e., suitable for raw drinking water); and the USFWS advice relates to the Hanford Site shoreline only.

undated); except for wildlife in the Saddle Mountain Lakes, as noted above, which are potentially exposed to offsite contamination.

- **'Class A' Designation:** According to the 2008 Comprehensive Conservation Plan and Environmental Impact Statement, Washington State rates the water quality of the Hanford Reach stretch of the Columbia River as "Class A". Class A waters are suitable for essentially all uses, including raw drinking water, primary-contact recreation, and wildlife habitat" (USFWS 2008). Note that the "Current Uses and Restrictions at Hanford Reach National Monument" document produced by the US Fish and Wildlife Service, mentioned above, refers only to the shoreline of Hanford Reach, as possibly contaminated above safe drinking water standards.
- **USGS Measurements:** To measure the Hanford Site's contribution to contamination of the Hanford Reach and Columbia River waters downstream of the Reach, it is important to analyze water quality upstream of the Hanford Site as well as downstream of the Site. In 2002, the USGS measured a limited set of water quality parameters at stations upstream and downstream of the Monument. While this sampling effort was limited and did not test for all Hanford potential contaminants of concern, results indicated that water quality parameters such as total dissolved solids and dissolved oxygen "were well within EPA standards" (USFWS 2008). Further, "there were no statistically significant differences between upstream and downstream samples for these parameters" (USFWS 2008).
- **Ongoing DOE Monitoring:** The US Fish and Wildlife Service coordinates with the USDOE environmental monitoring system and factors the results of this program into determining regulations pertaining to public access of the Monument. At present, "a visitor will not be exposed to elevated levels of Hanford derived contaminants which could become a health issue unless they access specific areas illegally or perform activities that are prohibited on the [Monument]" (EPA *et al.* undated). Thus, DOE believes that, as long as visitors are following USFWS regulations when pursuing recreational activities on the Monument, they will not be exposed to contaminants at levels that pose a human health risk.
- **Closed areas on Hanford Site.** Much of the Hanford Site remains closed to visitors, precluding recreational activities in these areas. An inventory of the nature and geographic scope of institutional controls related to hazardous contaminant releases that could impact past, present, or future human uses of the Site is one of the studies described in Chapter 7.

Conclusion on Lost Recreational Services

The Trustees have identified the potential for loss in recreational opportunities, or the values the public holds for such activities, associated with the release of hazardous contaminants from Hanford Site operations. For example, it is possible that some anglers, hunters and other recreators in the region avoid or otherwise modify their behavior due to concern about contaminants in this area. However, the Trustees are unaware of any studies conducted to-date that have identified such impacts on recreator behavior. As such, and given the limited scope of these impacts combined with public access to numerous substitute opportunities and sites, the Trustees are not currently proposing further study. As a result, no studies of recreator behavior are proposed in this Plan.

However, as mentioned above and given the potential that some recreators and other members of the public could be restricted from use of natural resources due to site-related institutional controls related to hazardous substance releases, the Trustees are proposing a study to inventory the nature and extent of such controls (see Chapter 7). This information may form a measure of the scale of lost human use of the Hanford Site, or may identify the need for a more focused study of lost human use of the Site.

AGRICULTURE

Agriculture is one of the key industries in the State of Washington, with the food and agriculture industry accounting for 160,000 jobs and contributing 12 percent of the state's economic output (WSDA 2011a). The state's 39,500 farms produced $8.25 billion in agricultural output in 2010 (USDA 2011). Further, it is estimated that "each dollar of farm gate receipts has a multiplier effect of 2 to 3 times throughout the state's economy," meaning that the 2010 receipts of $8.25 billion resulted in total economic impacts for the State of Washington ranging from $16.5 billion to $24.75 billion (WSDA 2009).[51] In 2009, for the four Washington counties identified in the Final Comprehensive Conservation Plan and Environmental Impact Statement (USFWS 2008), Franklin County produced $467 million worth of crops on 891 farms, Grant County produced $1.19 billion worth of crops on 1,858 farms, Adams County produced $344 million worth of crops on 272 farms, and Benton County produced $526 million worth of crops on 1,630 farms (WSDA 2011b).

In terms of agricultural commodity groups, the top five products of Washington's agricultural industry (with 2010 gate receipts in parentheses) are apples ($1.44 billion), milk ($950 million), wheat ($925 million), potatoes ($654 million), and cattle ($568 million) (WSDA 2011b). For the Washington counties surrounding the Hanford Site, Franklin County agricultural production focuses on potatoes, apples and hay; Grant County farm production focuses on apples, cattle, and potatoes, Adams County farm production focuses on potatoes, wheat, and apples, and Benton County farm production focuses on potatoes, apples, and grapes (WSDA 2011b).

Additionally, West Lake, now classified as a waste site under CERCLA, was historically a source of good quality water for livestock. Currently, West Lake and its basin is a contaminated and highly saline habitat, most likely because of the evaporation of water from the pond and the accumulation of dissolved solids during Hanford operations (Burk *et al.* 2007).

The Trustees have applied available information to determine if releases of contaminants from Hanford Site operations have impacted the value of farm products or farm land in study region. The Trustees found no evidence that farm products from this region have been reduced in value, or that significant acreages of agricultural lands have been

[51] Gate receipts are the price of the product as sold by a farm.

rendered inarable due to the presence of contaminants from Hanford. Thus, no studies of injuries to agricultural services are included in this Plan.

CHAPTER 5 | CONFIRMATION OF EXPOSURE AND INJURY ASSESSMENT PROCESS

This chapter provides a brief overview of the exposure of natural resources to contaminants of potential concern (COPCs) at the Hanford Site and the subsequent injury assessment process. As the available information on these subjects is vast, this report does not attempt to comprehensively characterize all relevant information but rather aims to broadly and generally characterize the state of knowledge on these topics, while meeting the requirements of assessment plan content as set forth in 43 CFR 11.31.

5.1 CONFIRMATION OF EXPOSURE

The DOI's NRDA regulations require that at least one of the natural resources identified as potentially injured "has in fact been exposed to the released substances" (43 CFR11.37(a)). A natural resource has been exposed to hazardous substances if "all or part of [it] is, or has been, in physical contact with… a hazardous substance, or with media containing… a hazardous substance" (43 CFR 11.14(q)). The regulations also state that "whenever possible, exposure shall be confirmed by using existing data" (43 CFR 11.37(b)(1)). This Plan confirms that a variety of potentially injured resources have been exposed to multiple contaminants of potential concern, including radionuclides, metals, and organic compounds.

A substantial body of information demonstrates past and ongoing exposure of the Hanford Site's natural resources to contaminants of concern; much of the information has been documented in the Yakama Nation and CTUIR's pre-assessment screens (Ridolfi 2006, CTUIR 2007). The scale of documented releases of contaminants to the air, soil, surface water, and groundwater is, on its face, sufficient evidence of exposure. Furthermore, vast datasets have documented the past and, in some cases, ongoing presence of Site contaminants in Site media. Examples of data confirming exposure of surface water, sediment, groundwater, geological, and biological resources to Site-related contaminants are described below.

SURFACE WATER

Contaminated liquid wastes were discharged directly into the Columbia River during Hanford operations starting in 1944, when B Reactor operations began (Hall 1991). Uranium from the 300 area was released to the river due to seepage and dike failures. Additionally, reactor effluent water released to the River contained radioactive contaminants such as zinc-65, chromium-51, iodine-131, tritium, cesium-137, and strontium-90 (Hall 1991).

Surface water samples collected from the 100 and 300 areas of the Hanford Reach of the Columbia River in the 1990s and 2000s have exceeded the 0.006 mg/L EPA Drinking

Water Standard (DWS) for antimony and the 0.005 mg/L DWS for cadmium (Industrial Economics and Ridolfi 2012).

SEDIMENT

Two lines of evidence confirm exposure of sediments to Site-related contaminants. First, sediment samples collected along the shoreline of the Columbia River adjacent to Hanford contained concentrations of radioactive contaminants including cobalt, strontium, cesium, europium, and plutonium higher than at upstream (i.e., reference) locations (Cooper and Woodruff 1993, as cited in Gephart 2003b). Second, a suite of contaminants in assessment area sediment frequently exceed concentrations above which adverse effects on biota are likely. For example, average chromium concentrations in the 1990s and 2000s range from approximately 12 mg/kg to over 40 mg/kg in the 100 and 300 areas of the Columbia River and downstream of the Site. These levels exceed sediment quality guidelines, indicating the potential for adverse impacts on benthic invertebrates (MacDonald *et al.* 2000).[52] Concentrations of antimony, barium, cadmium, dieldrin, lead, PCBs, and zinc in riverine sediment also exceeded sediment quality guidelines (Industrial Economics and Ridolfi 2012).

GEOLOGICAL (SOIL)

As described above, contaminated liquid and solid wastes were released directly to Hanford Site soils in ditches, trenches, cribs, and storage tanks. Soils beneath Hanford have been estimated to contain 1.8 million curies of radioactivity and 100,000 to 300,000 tons of chemicals (Gephart 2003b).[53]

In the 2011 Site monitoring report, soil samples from locations near facilities and operational areas generally had higher radionuclide concentrations than samples from more distant locations, and were significantly higher than concentrations at offsite locations (DOE 2011d). In addition, hexavalent chromium levels exceed published concentrations indicating adverse effects to earthworms. For example, average hexavalent chromium concentrations in the 100-BC, 100-K, 100-DH, and 200 areas exceed the 0.34 mg/kg, ecological soil screening level protective of soil invertebrates (LANL 2008, as cited in DOE 2011b).[54]

GROUNDWATER

Hazardous substances released to soils have leached into the groundwater at the Hanford Site. Since the early 1950s, groundwater samples have been collected and analyzed from hundreds of groundwater monitoring wells across the Site. Major groundwater contaminants include carbon tetrachloride, hexavalent chromium, cyanide, iodine-129,

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[52] The cited thresholds are used for illustrative purposes. This injury assessment plan includes a study comparing contaminant concentrations in sediments with literature-based adverse effects thresholds, and threshold selection is part of that effort.

[53] The full extent of soil and sediment contamination due to transport in air and deposition is unknown. See the potential for long-term injury study in Chapter 7.

[54] The cited threshold is used for illustrative purposes. This injury assessment plan includes a study comparing contaminant concentrations in soils with literature-based adverse effects thresholds, and threshold selection is part of that effort.

nitrate, strontium-90, trichloroethene, tritium, and uranium. These plumes have a combined area in excess of 186 km^2 (DOE 2011c). Remedial activities are in place for some, but not all locations. For instance, pump-and treat systems, as well as a soil-vapor extraction system, continue to remove contaminants from the groundwater and vadose zone beneath the 200 areas (DOE 2011d). Furthermore, contaminants have not only reached groundwater but have moved laterally with groundwater into the Columbia River (DOE 2011c).

Some examples of exceedances reported in the most recent DOE annual monitoring report include chromium exceedances of the EPA Drinking Water Standard of 100 µg/L in parts of the 200 West, 100-K, and 100-D areas as well as hexavalent chromium exceedances of the Washington State cleanup standard of 48 µg/L and the aquatic water quality criterion of 10 µg/L in almost all of the 100 areas. In the 100-NR-2 operable unit, strontium-90 concentrations exceeded EPA's DWS of 8 pCi/L, manganese concentrations exceeded the 50 µg/L DWS in several wells, and total petroleum hydrocarbon is a contaminant of concern for a CERCLA interim action (DOE 2011c). Additionally, in the 100-FR-3 operable unit, nitrate concentrations have been documented in excess of the 45 mg/L drinking water standard (DOE 2011c).

Additionally, upwellings in the Hanford Reach of the Columbia River introduce groundwater contaminants to the River and to aquatic biota. Although the nature and extent of groundwater upwelling contamination is unknown, upwelling samples have documented hexavalent chromium, strontium-90, tritium, and uranium concentrations in excess of drinking water standards (Hulstrom and Tiller 2010).

BIOLOGICAL

A number of studies have documented the exposure of biota to Site-related contamination. Efforts to-date have focused mainly on vegetation, fish, and mammals. For example, the 2010 Hanford Site Environmental Report reported elevated levels of radionuclides in vegetation samples collected near Hanford facilities compared to off-site locations (DOE 2011d). The 2002 EPA fish contaminant survey documented contamination due to metals, pesticides, PCB congeners, dioxins, and furans in white sturgeon from the Hanford Reach (EPA 2002a).[55] In addition, small mammals have been analyzed for contamination, including radiological contamination, and preliminary Trustee analysis suggests that levels of mercury, PCBs, and uranium in mice collected near operational areas exceeded adverse effect concentrations from the literature.[56] Additionally, strontium-90 was detected in rabbits, deer, and elk (DOE 2011d, Price 1988).

[55] Note that, some of the contaminants studied in the EPA survey may not be entirely attributable to Hanford operations.

[56] The cited exceedances are noted for illustrative purposes. This injury assessment plan includes a study comparing contaminant concentrations in biotic tissues with literature-based adverse effects thresholds, and threshold selection is part of that effort.

5.2 INJURY DETERMINATION

As described above, natural resources within the assessment area have been and continue to be exposed to both historical pollution and the continuing release of contaminants to Site resources. This chapter demonstrates injury to trust resources resulting from this contamination, which motivates and provides additional weight of evidence for studies proposed in Chapter 7.

Determination of injury to natural resources consists of documentation that there is: (1) a viable pathway for the released hazardous substance from the point of release to a point at which natural resources are exposed to the released substance, and (2) that injury of site-related resources (i.e., surface water, sediment, soil, groundwater, biota) has occurred as defined in 43 C.F.R. § 11.62.

PATHWAY

The DOI NRDA regulations define ‘pathway’ to be “the route or medium through which oil or a hazardous substance is or was transported from the source of the discharge or release to the injured resource” (43 CFR 11.14(bb)), and indicate that pathway may be determined “by either demonstrating the presence of the oil or hazardous substance in sufficient concentrations in the pathway resource or by using a model that demonstrates that the conditions existed in the route and in the oil or hazardous substance such that the route served as the pathway” (43 CFR 11.63(a)(2)). The regulations identify several methods for establishing pathway if existing information is not adequate for this purpose.

During the pathway determination phase, the Trustees will document how Site-related contaminants move through the environment. Specifically, the movement of contaminants from the source (i.e., the Site) to the environment will be determined. The pathway determination phase will also establish how contaminants move into the food web and then from one species to another.

In general, natural resources can be exposed to hazardous substances through both abiotic and biotic pathways. Abiotic components of pathways include processes such as volatilization, evaporation, aeolian transport, infiltration, runoff, flooding, and irrigation. Biotic pathways include dermal contact; respiration and inhalation; ingestion of food, water, or soils; uptake from soils by plants; decomposition of plants and animals; and the distribution of hazardous substances by the physical movement of biota (biotic vectors). For example, contaminated soils may expose groundwater through infiltration mechanisms, or the air through aeolian transport. Contaminated groundwater may enter the hyporheic zone and then expose surface water and sediments, which may in turn lead to the exposure of aquatic biota.

Response actions also may inadvertently facilitate contaminant transport. For example, pump and treat and re-injection systems that are designed to treat a specific contaminant may inadvertently transport and disperse other contaminants (e.g., tritium; Peterson *et al.* 2002).

The Trustees have developed a preliminary conceptual site model (Stratus 2009) that identifies and describes numerous pathways through which contaminants released on-site could injure natural resources and adversely impact the ecological and human use services they provide. In addition, data showing Site-related contaminants in surface water, sediment, groundwater, soils, plants, invertebrates, fish, birds, and mammals within the assessment area (as described above) support this assertion.

Conducting assessment studies specifically to address pathway issues is most important in circumstances where the source of contamination observed in the study area is not obvious (e.g., releases from some combination of multiple entities, general anthropogenic activities, and/or natural sources). At Hanford, site activities clearly are the sole or predominant source of much of the observed contamination. That said, for certain hazardous substances, natural and/or offsite anthropogenic sources likely contribute to some extent. Several studies in this assessment plan are designed to help Trustees better understand the extent of these contributions. In particular, this plan includes several studies in which contaminant concentrations in various media are compared to thresholds. These studies include an analysis of baseline concentrations (i.e., the concentrations that would be present but for Hanford Site-related releases).

In addition, this assessment plan includes a study to assess the spatial distribution of patterns in surficial soils, which in combination with information on significant aerial releases and historic wind patterns, will help Trustees better identify areas more/less likely to have been exposed to potentially injurious contaminant concentrations. This assessment plan also includes an exposure study for wild terrestrial birds. Many studies include measurements of contaminants in site media and/or in the tissues of site organisms. All these studies will contribute to the Trustees' understanding of the pathways through which natural resources may have been exposed to Hanford Site contaminants. As assessment activities progress, the Trustees may or may not decide to pursue additional studies to support the establishment of a pathways between Hanford Site releases and natural resources.

DETERMINING INJURY

Injuries to trust resources, as defined in the DOI NRDA regulations at 43 C.F.R. §11.62, generally fall into three categories.

- The first category establishes injury based on the exceedance of regulatory standards or criteria. This may include exceedance of established standards (e.g., water quality standards) or the existence of advisories limiting/banning the consumption of contaminated biota (e.g., fish consumption advisories).
- The second category establishes injury based on adverse changes in an organism's viability. Changes in viability that constitute injuries include: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including impaired reproduction), and physical deformations.
- The third category establishes injury to a natural resource when concentrations of a hazardous substance are sufficiently high in that natural resource to cause injury to another natural resource.

Chapter 6 provides additional details on the regulatory definitions of injury for each trust resource.

The Trustees have identified a set of natural resources found within the assessment area on which to focus this assessment. Resources were chosen based on their relative and/or cumulative importance to the healthy functioning of the ecosystem, abundance within the assessment area, and the feasibility of conducting COPCs exposure and/or toxicity studies on each resource. As described in the following sections, at this time the Trustees are evaluating potential injury to surface water, sediments, soils, various biota associated with these resources, and groundwater. This list of resources may be modified as assessment activities proceed and additional information becomes available.

For each selected resource, the Trustees will gather existing information about past, present, and predicted future concentrations of COPCs and compare these data to known criteria, standards, guidance values, or other thresholds that, if exceeded, indicate that injury to the resource exists or is likely to exist. In addition, the Trustees will review existing site-specific community structure and toxicity studies for biota. The Trustees will review these studies in the context of the natural resource damage assessment and use the findings to determine whether injury has occurred or is likely to occur in any portion of the study area.

As part of this effort, the Trustees will assess whether sufficient data exist to adequately characterize injury to Trust resources. "Adequacy" in this context means the data provide a sound and sufficient basis to characterize injuries for purposes of establishing the scale and scope of required restoration. As described in the preceding section, studies have determined that Site-related contaminants are transported via surface water, groundwater, and air flow, and bioaccumulative contaminants are transported through a complex food web. Although considerable past effort has been undertaken to describe contaminant exposure across many resources, for some resources the available data are limited. For example, the spatial distribution of soil data in terrestrial habitats on-site may be insufficient to characterize the extent of contamination. As such, the Trustees have identified additional studies, described in Chapter 7, which are intended to fill in data gaps associated with characterizing the extent of contamination.

5.3 INJURY QUANTIFICATION

Once it has been determined that natural resources have been injured, quantification of that injury is undertaken to establish a basis for scaling restoration and determining damages. Injuries to natural resources can be quantified in terms of the actual measured loss of the specific resource(s), and/or the services that the injured resource would have provided had the release not occurred.[57] Ecological services include the services provided by natural resources, such as "food and fresh water… the climate and the air we breathe" (Millennium Ecosystem Assessment 2005).

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[57] The Trustees may choose to quantify injury in units of resource, where the services provided by those resources are understood to be related to the scale of the available resource or where it is not feasible or cost-effective to quantify the human use or ecological service loss.

As described in the DOI regulations:

> "In the quantification phase, the extent of the injury shall be measured, the baseline condition of the injured resource shall be estimated, the baseline services shall be identified, the recoverability of the injured resource shall be determined, and the reduction in services that resulted from the discharge or release shall be estimated." (43 CFR 11.70(c))

Injury quantification will consider the effect of remedial activities in the assessment area on the return of injured natural resources to their baseline condition.

BASELINE

In order to quantify injuries, the baseline conditions of the affected resources and associated services must be established. Baseline is "the condition or conditions that would have existed at the assessment area had the discharge of oil or release of the hazardous substance under investigation not occurred" (43 C.F.R. 11.14(e)). As required by the DOI regulations, the Trustees anticipate determining "the physical, chemical, and biological baseline conditions and the associated baseline services for injured resources at the assessment area" (emphasis added) and quantifying injury based on a reduction in these services (43 C.F.R. 11.72(a)).

Baseline conditions may be established based on the review of historical, pre-release data and information, or on reference locations that exhibit similar physical, chemical and biological conditions as the assessment area, excluding contamination (43 C.F.R. 11.72). The fact that releases of hazardous substances have occurred within the assessment area prior to the establishment of regular or standardized approaches for the collection of physical, chemical and biological data may necessitate the use of suitable reference locations in lieu of historical data for purposes of baseline determination.

In general, the characterization of baseline conditions will take place within the context of specific injury studies. For instance, studies that compare contaminant measurements in site media to thresholds will include an evaluation of what baseline concentrations would likely have been but for the Hanford Site releases. In particular, "upgradient" locations may be used for characterization of surface water and groundwater baseline conditions, and background soil concentrations could be used to establish baseline for geological resources. Field studies of biota, and studies using site media, will consider baseline through examination of suitable reference areas, and experimental laboratory studies (e.g., spiked exposure toxicity studies) will consider baseline through the use of control experiments.

"Baseline" also incorporates the ecosystem and human use services that would be provided by natural resources but-for injury (holding all other factors constant). For example, an aquifer that was not potable prior to contamination would have a different baseline condition than one that was potable. In this example, the injury assessment would consider the baseline level of human use services that would have been provided but for the release of hazardous substances.

ECOLOGICAL INJURY QUANTIFICATION

As described in Chapter 3, each trust resource provides a variety of ecological services, ranging from protective cover to nutrient cycling, food web sustainability to flood control. The Trustees currently propose to quantify injury to natural resources within assessment area aquatic and terrestrial habitats on a habitat basis, considering changes in injury over time. For example, the Trustees may apply habitat equivalency analysis (HEA), a commonly applied, well-accepted method that involves quantification of losses over space and time that is specifically identified in the DOI NRDA regulations (43 CFR 11.83(c)(2)). Quantification of ecological losses will focus on endpoints that are considered the most biologically relevant (i.e., endpoints that most directly impact a resource's ability to function and provide services) such as growth, reproduction, and survival of biota, but may also include evaluation of other measures of health and organism viability.

The Trustees note that injuries to certain resources may be quantified individually (e.g., resources which are unique or of special concern, such as locally rare, threatened or endangered species, or require that restoration be scaled based on individual quantification of injuries, etc.). The Trustees are in the process of identifying whether any such resources have been impacted by exposure to Site-related contamination.

GROUNDWATER INJURY QUANTIFICATION

The DOI regulations provide guidance on the steps to follow in quantifying groundwater injury (43 CFR 11.71). In addition to determining a volume of injured groundwater, the Trustees will also quantify, "…the effect of the discharge or release in terms of the reduction from the baseline condition in the quantity and quality of services … provided by the injured resource…." (43 CFR 11.70). In terms of services provided, all waters and uses must meet the standard for "committed use" and all uses must be "…reasonably probable, not just in the realm of possibility. Purely speculative uses of injured resources are precluded from consideration in estimating damages" (43 CFR 11.84).

In the context of damage assessment, a range of hydrological metrics have been used to quantify injury, representing proxy measures for the services provided by groundwater. For example, groundwater can be quantified either as a "stock" or a "flow." These metrics include the three dimensional volume of the plume(s) combined with measures of porosity, the volume previously extracted, and calculated or modeled sustainable or "safe" yield (the amount of water that can be withdrawn from a given aquifer without depleting it over time). Because groundwater provides a range of services, the particular metric chosen to quantify services will relate to the types of services the Hanford Trustees understand to be adversely affected.

In some cases quantification of the volume of injured groundwater over time may not be necessary to establish damages and scale restoration. For example, a plume may effectively preclude groundwater use in a community. In such a case the loss in services is insensitive to the particular plume dimensions. Specifically, the DOI regulations at 11.71 state that "The effects of a discharge or release on a resource may be quantified by directly measuring changes in services provided by the resource, instead of quantifying changes in the resource itself." This approach is stated as being valid when three conditions hold:

> "(1) The change in the services from baseline can be demonstrated to have resulted from the injury to the natural resource;
> (2) The extent of change in the services resulting from the injury can be measured without also calculating the extent of change in the resource; and,
> (3) The services to be measured are anticipated to provide a better indication of damages caused by the injury than would direct quantification of the injury itself." (43 CFR 11.71(f))

Once the volume of injured groundwater has been quantified (if necessary), the next step in the injury quantification process is to consider what, if any, services have been impacted by the release of hazardous substances. This step is necessary since the goal is to restore, replace or acquire the equivalent of injured natural resources and the services they provide to their baseline condition. The scope of services that may have been lost as a result of groundwater injury will depend on a variety of factors, including baseline quality, hydrological limitations that could impact the usability of the resource, policy and regulatory limitations unrelated to the release of a hazardous contaminant, access limitations, regional water supply and demand balances, etc. For example, a plume may exist in an area that requires residences to hook-up to a public water supply (i.e., precludes private wells) for reasons unrelated to the presence of a plume. In some cases the information required to develop an inventory of lost services will exist. In others, it may be necessary to conduct primary research to determine the extent to which service flows have been lost as a result of injury to groundwater resources.

Injuries Resulting From Exposure of Other Natural Resources to Contaminated Groundwater

Under the DOI regulations, injury to groundwater can be demonstrated based on concentrations of hazardous substances sufficient to cause injury to surface water, air, geological or biological resources. While this definition of injury may be applicable in a range of cases, some trustees choose to evaluate groundwater as a pathway, and quantify the injuries resulting from groundwater contamination as losses to the exposed resources (rather than the groundwater itself). For example, where groundwater transports contaminants to surface water, exposing fish to those contaminants, injury could be assessed as service losses incurred by fish. The Trustees are still evaluating which methodology is most appropriate for this Site.

Addressing Contamination of the Vadose Zone and Geological Resources

As described in Chapter 3, the movement of moisture in the Hanford vadose zone is the primary driving force for the migration of Site-related contaminants to groundwater (Burk *et al.* 2007). While moving through the vadose zone, contaminants can become "stuck" (i.e., adsorbed and/or absorbed by the soil matrix), then releasing to groundwater over an extended period of time (Freeman *et al.* 2001).

The DOI regulations list geologic resources (i.e., soil) as a separate category of natural resources, and suggest quantification of injury to such resources in terms of "[t]he volume of geologic resources that may act as a source of toxic leachate." (43 CFR 11.71 (k)(3)) Thus, while trustees can choose to assess injuries and damages to the vadose zone, in practice vadose zone contamination has been treated by trustees as a pathway and reservoir of contaminants. The Trustees are in the process of reviewing existing information to determine which methodology is most appropriate for this Site.

Existing Data and/or Primary Research

Whether existing data will be sufficient to complete a groundwater damage assessment for the Hanford Site is yet to be determined. For example, depending on the approach followed and information obtained regarding service losses, it may turn out that precise determination of plume dimensions or other characteristics will not be required. Currently, the Trustees are working with USGS to review the DOE Hanford plume maps to determine if the maps are sufficiently accurate for assessment purposes.

LOST HUMAN USE SERVICES QUANTIFICATION

As described in Chapter 4, a variety of human uses are thought by the Trustees to have been affected by the presence of contaminants released from Hanford operations. At this time the Trustees are focusing on human use losses to tribal communities; due to the nature of public access and resource availability at Hanford, non-tribal human use losses are expected to be relatively modest, and are therefore not included in this Plan.

"Tribal lost services" refer to a loss in natural resource services of importance to a tribal Trustee entity or members, for which separate natural resource restoration actions are likely to be needed. As stated in Chapter 4, as a result of differences in the nature and extent of services tribal members and their communities derive from the environment -- and differences in the way in which changes in these services affect indigenous communities— it may be necessary to describe and quantify service losses for tribal communities separately from service losses to the general public. That is, specific restoration actions may be required to fully compensate the public for losses in indigenous community services.

The techniques available to assess changes in tribal member uses of the environment in the context of natural resource damage assessment are less well-developed (and have been applied less frequently) than the techniques used for other categories of natural resource services. As a result, damage assessments involving tribal lost use of natural resources have generally relied on similar methods as applied to other service categories (modified and supplemented to reflect unique circumstances of tribal member use), or on methods applied to assess other impacts on tribal cultures (e.g., land claims, cultural impact assessment, etc.).

Examples of such methods, which have been applied to measure service losses to indigenous communities in the context of natural resource damage assessment include but are not limited to:

- **Assessment of changes in cultural services.** This includes assessment and analysis of changes in levels of traditional knowledge, cultural practices, and relationships resulting from shifts in the use of natural resources caused by the presence of hazardous contaminants. Such an analysis is generally based on applied anthropological and ethnographic approaches.
- **Direct assessment of loss of resource use.** This can involve application of revealed preference techniques, user surveys, existing data, etc. For example, assessment of the number of individuals who previously utilized a site, the nature and frequency of that use, substitution or alternative behaviors, and the expected recovery period for the activity.
- **Habitat and resource equivalency.** This involves the use of resource-based measures to quantify the level of service loss under the assumption that ecological service losses are a proxy measure of cultural service losses.
- **Stated preference.** This involves the use of surveys to elicit tribal attitudes and preferences towards an injured resource.

These approaches may be used in combination to assess changes in services resulting from the release of hazardous contaminants to the environment. Each of these approaches, all of which are available to the Hanford Trustees, is discussed in greater detail below.

Assessment of Changes in Cultural Services

One approach for conducting cultural service loss assessment is to inventory and evaluate existing documentary record related to tribal uses of and services provided by natural resources. This would include consideration of all of the relevant information held by the participating tribal communities that can be located and accessed from other archives. These sources would include scientific reports and academic studies on historic tribal use and traditional cultural context; tribal environmental philosophy and ethnographic descriptions of land and river-based practices; newspaper and media reports on environmental and health issues affecting the communities; studies on the health and social status of the communities; transcripts of oral narratives, etc.

The goal of this type of assessment is to evaluate and organize the existing information so that it can be analyzed in ways that are supported by, and consistent with, the criteria and ethics of standard social science research practice, the conventions of the best strategies of community-based participatory research, and the most advanced ethnographic approaches. The ultimate objective is to gain as complete an understanding as possible (using documentary sources) of the community and its interactions with the natural environment and how these behaviors have changed over time and in response to the presence of hazardous contaminants.[58] In this context, primary documents would be given

[58] Cultural changes can impact a community in terms of time; social cohesion; the intergenerational transfer of knowledge and identity and of the speaking/use of indigenous languages; their economic self-sufficiency; and even the maintenance of the population on the territory. For example, in a recent assessment a tribal trustee developed seven cultural indicators affected by changes in ecosystem services over time. These indicators relate to water, fishing, and the use of the river; horticulture, farming, and basket-making; medicine plants and healing; hunting and trapping; well-being of children, youth

priority as they provide more validity than secondary sources as meaningful indicators of change and service flow interruption. Ultimately, all of the materials in the available record could be assessed for their relative contribution to the objectives of the work: understanding the nature and scope of interruptions to ecosystem service flows within the affected communities due to the presence of hazardous contaminants. The goal is to produce an assessment record that meets the needs of the natural resource damage assessment process and is sound and valid from a social scientific perspective, but is also consistent with the communities' values and traditions to assure that the results are accepted.

Although this approach draws heavily on the existing evidentiary base, it also involves identification and consideration of data gaps. Where appropriate and required, primary research efforts such as oral history research, can be applied to focus on gathering information directly from people who had used and who continue to use the natural resources and to ask them directly how their knowledge of environmental contamination affected their cultural practice.

The principal strengths of the applied indigenous community research methodology includes utilization of existing information to the fullest extent possible; applying approaches to organization and review of available information that are well-accepted; recognizing the complex relationship between indigenous communities and natural resources; explicitly considering baseline factors; and enhancing the probability of community acceptance of the results. The principal weaknesses involve the time and cost to implement the work, the need for information that may be considered confidential or proprietary, and the challenge of quantifying results such that they can be used to support restoration scaling using evidence that is typically qualitative in nature.

Direct Assessment of Loss of Resource Use

Some impacts on tribal uses of natural resources may be relatively limited in geographic scope and/or temporal scope. Others may be of a magnitude that may not warrant a substantial research effort, or may be very well-defined (e.g., the loss of access to a culturally significant area for a limited period of time). In these cases direct assessment of lost use can provide a basis for assessing service losses.

The strengths of this approach are its simplicity: the direct measure of changes in use to establish service losses, the ability to control for baseline factors in the assessment, and the fact that the information required to conduct such an assessment is generally available with limited additional effort. The principal disadvantage is the failure of the approach to see changes recognizing the complex relationship between indigenous communities and natural resources.

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and family; food security and sustainable livelihoods; and transmission of community knowledge to future generations. For each of the indicators, measures of ecosystem impairment were causally linked (where relevant) to cultural injury or interruption of resource services.

Habitat and Resource Equivalency

Resource equivalency methods may be used to define the level of service losses that have resulted from the release of hazardous contaminants, serving as proxy measures for cultural service losses. In such cases a biological measure of resource injury (such as the presence of phytotoxicity) is assumed to provide a better indication of lost services than direct measures of changes in a tribal member's behavior.

The benefit of a habitat or resource-based approach to scaling cultural losses is that it is relatively easy to conduct, can be explicitly designed to address baseline issues, and avoids potential confidentiality issues. The principal weaknesses is that the service loss measures developed are not a direct measures of the change in services but an estimate based on the contaminant concentration levels, and the method may fail to address the complex relationship between indigenous communities and natural resources.

Stated Preference

Stated preference approaches involve the application of public opinion surveys to elicit information from individuals regarding their use of a resource, and/or attitudes and preferences towards an injured resource or restoration strategy. For example, the Trustees may use a survey to understand the frequency with which tribal members fish or hunt, the species they target, consumption rates, etc. Such surveys might be applied as a direct approach to service loss quantification, or might be combined with the approaches discussed above.

In a few cases stated preference methods have been applied to directly assign economic values to foregone cultural use (Duffield 1999). That is, these studies provide economic measures of the value of lost services, without necessarily defining the nature and extent of the loss of use or cultural harm.

The strength of the stated preference methods is the ability to pose to a respondent any hypothetical alternative scenario (i.e., the method is not limited to observing behaviors under limited actual conditions). While more flexible than revealed preference approaches, stated preference surveys can be costly and time consuming to administer, and may not be consistent with tribal policies or values. As a result, researchers often look to apply revealed preference methods to assess changes in human use of natural resources, since such methods are generally less controversial and pose fewer challenges. Revealed preference studies, however, typically address a narrower set of values than stated preference.

Combination Approaches

As noted above, the approaches outlined above may be conducted independently, or combined in order to assess tribal lost use services.

As noted in Chapter 7, within this Plan the Trustees will consider a study that relies on existing information to define the type and scale of tribal lost use, and based on that study determine if additional research is needed to support injury quantification.

REMEDIATION-RELATED IMPACTS

As described in Appendix A, extensive remediation has taken place on the Hanford Site since the early 1990s when cleanup became the Hanford mission. These remedial activities include but are not limited to the removal of contaminated soils which involves disposal of wastes, backfilling, and revegetation, groundwater pump and treat systems, demolition of inactive facilities, groundwater monitoring, and the transfer and remediation of liquid tank wastes. Hanford remediation has focused on cleaning up the solid and liquid wastes, decontaminating and demolishing facilities, and preventing groundwater contamination from reaching the Columbia River.

Adverse impacts to natural resources as a result of remediation-related activities are compensable under the DOI regulations. For instance, on the Hanford Site, remediation equipment staging areas and waste disposal areas have resulted in the loss of habitat and ecological services. The use of trucks and the creation of roads to provide access to demolition and de-contamination sites as well as the destruction of plants and soil resources when contamination is removed have resulted in the temporary loss of ecological services.

Chapter 7 provides a list of proposed studies that may be called for to complete the Injury Assessment. This set of studies includes an assessment of the nature and extent of injury resulting from remediation-related activities. The analysis will be conducted based on an assessment of the extent of lost habitat services, described over time (e.g., number of acres of habitat services lost, for some period of time).

CHAPTER 6 | DEFINITION OF INJURY

As described in Chapter 5, one essential component of injury assessment is the determination of injury. Because the Trustees are conducting this natural resource damage assessment effort in accordance with the DOI regulations at 43 CFR Part 11, they plan to "determine that an injury has occurred based upon the definitions provided in this section for surface water, groundwater, air, geologic, and biological resources" (43 CFR 11.62(a)). These definitions are identified below.

6.1 SURFACE WATER

Surface waters include both waterways and waterbodies as well as their associated bed and bank sediments. Injury to surface water "has resulted from the discharge of oil or release of a hazardous substance if one or more of the following changes in the physical or chemical quality of the resource is measured:

(i) Concentrations and duration of substances in excess of drinking water standards as established by sections 1411–1416 of SDWA, or by other Federal or state laws or regulations that establish such standards for drinking water, in surface water that was potable before the discharge or release;

(ii) Concentrations and duration of substances in excess of water quality criteria established by section 1401(1)(D) of SDWA, or by other Federal or state laws or regulations that establish such criteria for public water supplies, in surface water that before the discharge or release met the criteria and is a committed use, as the phrase is used in this part, as a public water supply;

(iii) Concentrations and duration of substances in excess of applicable water quality criteria established by section 304(a)(1) of the CWA, or by other Federal or state laws or regulations that establish such criteria, in surface water that before the discharge or release met the criteria and is a committed use, as that phrase is used in this part, as a habitat for aquatic life, water supply, or recreation. The most stringent criterion shall apply when surface water is used for more than one of these purposes;

(iv) Concentrations of substances on bed, bank, or shoreline sediments sufficient to cause the sediment to exhibit characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act, 42 U.S.C. 6921; or

(v) Concentrations and duration of substances sufficient to have caused injury as defined in paragraphs (c), (d), (e), or (f) of this section to ground water, air, geologic, or biological resources, when exposed to surface water, suspended sediments, or bed, bank, or shoreline sediments" (43 CFR 11.62(b)(1)).

Under DOI's NRDA regulations, the bed, bank, and shoreline sediments, including suspended sediments, are also considered to be part of the surface water resource. The Trustees intend to evaluate the concentrations of chemicals of potential concern in sediments to assess the degree to which these substances may be causing adverse effects to exposed aquatic species.

The DOI NRDA regulations define injury to surface water sediments in several ways. In general, these sediments are determined to be injured when:

a) Concentrations of substances on bed, bank or shoreline sediments are sufficient to cause the sediment to exhibit characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act, 42 U.S.C. 6921 (43 CFR 11.62(b)(1)(iv)); or

b) Other natural resources (for example, biological resources) become injured as a consequence of exposure to the sediments (43 CFR 11.62(b)(1)(v)).

6.2 GROUNDWATER

Injury to groundwater "has resulted from the discharge of oil or release of a hazardous substance if one or more of the following changes in the physical or chemical quality of the resource is measured:

(i) Concentrations of substances in excess of drinking water standards, established by sections 1411–1416 of the SDWA, or by other Federal or state laws or regulations that establish such standards for drinking water, in ground water that was potable before the discharge or release;

(ii) Concentrations of substances in excess of water quality criteria, established by section 1401(1)(d) of the SDWA, or by other Federal or state laws or regulations that establish such criteria for public water supplies, in ground water that before the discharge or release met the criteria and is a committed use, as the phrase is used in this part, as a public water supply;

(iii) Concentrations of substances in excess of applicable water quality criteria, established by section 304(a)(1) of the CWA, or by other Federal or state laws or regulations that establish such criteria for domestic water supplies, in ground water that before the discharge or release met the criteria and is a committed use as that phrase is used in this part, as a domestic water supply; or

(iv) Concentrations of substances sufficient to have caused injury as defined in paragraphs (b), (d), (e), or (f) of this section to surface water, air, geologic, or biological resources, when exposed to ground water" (43 CFR 11.62(c)(1)).

6.3 GEOLOGIC

Soils are geologic resources. Injury to these resources occurs "if one or more of the following changes in the physical or chemical quality of the resource is measured:

(i) Concentrations of substances sufficient for the materials in the geologic resource to exhibit characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act, 42 U.S.C. 6921;

(ii) Concentrations of substances sufficient to raise the negative logarithm of the hydrogen ion concentration of the soil (pH) to above 8.5 (above 7.5 in humid areas) or to reduce it below 4.0;

(iii) Concentrations of substances sufficient to yield a salt saturation value greater than 2 millimhos per centimeter in the soil or a sodium adsorption ratio of more than 0.176;

(iv) Concentrations of substances sufficient to decrease the water holding capacity such that plant, microbial, or invertebrate populations are affected;

(v) Concentrations of substances sufficient to impede soil microbial respiration to an extent that plant and microbial growth have been inhibited;

(vi) Concentrations in the soil of substances sufficient to inhibit carbon mineralization resulting from a reduction in soil microbial populations;

(vii) Concentrations of substances sufficient to restrict the ability to access, develop, or use mineral resources within or beneath the geologic resource exposed to the oil or hazardous substance;

(viii) Concentrations of substances sufficient to have caused injury to ground water, as defined in paragraph (c) of this section, from physical or chemical changes in gases or water from the unsaturated zone;

(ix) Concentrations in the soil of substances sufficient to cause a toxic response to soil invertebrates;

(x) Concentrations in the soil of substances sufficient to cause a phytotoxic response such as retardation of plant growth; or

(xi) Concentrations of substances sufficient to have caused injury as defined in paragraphs (b), (c), (d), or (f), of this section to surface water, ground water, air, or biological resources when exposed to the substances" (43 CFR 11.62(e)).

6.4 BIOLOGICAL

Injury to biological resources occurs "if concentration of the [hazardous] substance is sufficient to:

(i) Cause the biological resource or its offspring to have undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations; or

(ii) Exceed action or tolerance levels established under section 402 of the Food, Drug and Cosmetic Act, 21 U.S.C. 342, in edible portions of organisms; or

(iii) Exceed levels for which an appropriate state health agency has issued directives to limit or ban consumption of such organism" (43 CFR 11.62(f)).

The methods used to determine injury to a biological resource need to satisfy several acceptance criteria:

(i) "The biological response is often the result of exposure to oil or hazardous substances. This criterion excludes biological responses that are caused predominately by other environmental factors such as disturbance, nutrition, trauma, or weather. The biological response must be a commonly documented response resulting from exposure to oil or hazardous substances.

(ii) Exposure to oil or hazardous substances is known to cause this biological response in free-ranging organisms. This criterion identifies biological responses that have been documented to occur in a natural ecosystem as a result of exposure to oil or hazardous substances. The documentation must include the correlation of the degree of the biological response to the observed exposure concentration of oil or hazardous substances.

(iii) Exposure to oil or hazardous substances is known to cause this biological response in controlled experiments. This criterion provides a quantitative confirmation of a biological response occurring under environmentally realistic exposure levels that may be linked to oil or hazardous substance exposure that has been observed in a natural ecosystem. Biological responses that have been documented only in controlled experimental conditions are insufficient to establish correlation with exposure occurring in a natural ecosystem.

(iv) The biological response measurement is practical to perform and produces scientifically valid results. The biological response measurement must be sufficiently routine such that it is practical to perform the biological response measurement and to obtain scientifically valid results. To meet this criterion, the biological response measurement must be adequately documented in scientific literature, must produce reproducible and verifiable results, and must have well defined and accepted statistical criteria for interpreting as well as rejecting results."

Additionally, injury determination must:

"be based upon the establishment of a statistically significant difference in the biological response between samples from populations in the assessment area and in the control area. The determination as to what constitutes a statistically significant difference must be consistent with the quality

> assurance provisions of the Assessment Plan. The selection of the control area shall be consistent with the guidance provided in §11.72 of this part."

Several specific biological responses already determined to meet the above criteria are identified in the regulations, and can be found at (43 CFR 11.62(f)(4)). These responses include the following (paraphrased):

(i) *Category of injury—death*. Five biological responses for determining when death is a result of exposure to the discharge of oil or release of a hazardous substance meet the acceptance criteria.

  (A) Brain cholinesterase (ChE) activity

  (B) Fish kill investigations

  (C) Wildlife kill investigations

  (D) *In situ* bioassay

  (E) Laboratory toxicity testing

(ii) *Category of injury—disease*. One biological response for determining when disease is a result of exposure to the discharge of oil or release of a hazardous substance has met the acceptance criteria.

  (A) *Fin erosion.*

(iii) *Category of injury—behavioral abnormalities.*

  (A) Clinical behavioral signs of toxicity.

  (B) Avoidance.

(iv) *Category of injury—cancer.* One biological response for determining when cancer is a result of exposure to the discharge of oil or release of a hazardous substance has met the acceptance criteria.

  (A) Fish neoplasm

(v) *Category of injury—physiological malfunctions.* Five biological responses for determining when physiological malfunctions are a result of exposure to the discharge of oil or release of a hazardous substance have met the acceptance criteria.

  (A) Eggshell thinning

  (B) Reduced avian reproduction

  (C) Cholinesterase (ChE) enzyme inhibition

  (D) Delta-aminolevulinic acid dehydratase (ALAD) inhibition

  (E) Reduced fish reproduction

(vi) *Category of injury—physical deformation.* Four biological responses for determining when physical deformations are a result of exposure to the discharge of oil or release of a hazardous substance have met the acceptance criteria.

(A) Overt external malformations

(B) Skeletal deformities

(C) Internal whole organ and soft tissue malformation

(D) Histopathological lesions.

6.5 AIR

Injury to air resources occurs “if one or more of the following changes in the physical or chemical quality of the resource is measured:

(i) Concentrations of emissions in excess of standards for hazardous air pollutants established by section 112 of the Clean Air Act, 42 U.S.C. 7412, or by other Federal or state air standards established for the protection of public welfare or natural resources; or

(ii) Concentrations and duration of emissions sufficient to have caused injury as defined in paragraphs (b), (c), (e), or (f) of this section to surface water, ground water, geologic, or biological resources when exposed to the emissions.”

6.6 LINKING INJURY STUDIES TO DOI REGULATIONS

The injury assessment studies that are currently proposed to support assessment of ecological injuries, groundwater injuries, and human use service losses are described in detail in Chapter 7. The exhibit below outlines the specific DOI natural resource damage assessment regulations associated with each study.

EXHIBIT 6-1 LINKING INJURY ASSESSMENT PLAN STUDIES TO DOI NATURAL RESOURCE DAMAGE ASSESSMENT REGULATIONS

INJURY/DAMAGES DETERMINATION/QUANTIFICATION APPROACH	DOI NRDA REGULATIONS INJURY DEFINITION	DOI NRDA REGULATIONS DEFINITION COMPONENTS
SURFACE WATER AND SEDIMENTS		
Comparison of surface water data to injury thresholds	Threshold exceedances 43 CFR 11.62(b)(1)	Hazardous contaminant concentrations are in excess of applicable water quality criteria 43 CFR 11.62(b)(1)(i-iii)
Comparison of sediment data to effects thresholds		Contaminant concentrations sufficient to cause injury to groundwater, soil, or biota when exposed to sediments 43 CFR 11.62(b)(1)(v)
Review of Hanford sediment and pore water toxicity studies		
Benthic invertebrates: sediment toxicity testing		
SOILS		
Comparison of soil data to effects thresholds	Sufficient to cause injury 43 CFR 11.62(e)	Concentrations in the soil of substances sufficient to cause a toxic response to soil invertebrates 43 CFR 11.62(e)(9)
Soils geospatial evaluation		
Review of Hanford soil toxicity studies		Concentrations sufficient to cause injury to other resources when exposed to the substances 43 CFR 11.62(e)(11)
Nematode toxicity testing		Concentrations sufficient to cause injury to other resources when exposed to the substances 43 CFR 11.62(e)(11); concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i) Statistical significant difference in mortality between population samples and controls 11.62(f)(4)(i)(E).
Native plant toxicity testing		Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i); statistical significant difference in mortality between population samples and controls 11.62(f)(4)(i)(E); and/or concentrations in the soil of substances sufficient to cause a phytotoxic response 43 CFR 11.62(e)(10)
VADOSE/GEOLOGICAL		
Characterize vadose zone contamination and potential for long-term injury to groundwater and surface water	Sufficient to cause injury 43 CFR 11.62(e)	Concentrations sufficient to cause injury to other resources when exposed to the substances 43 CFR 11.62(e)(11)
GROUNDWATER		
Developing comprehensive database and comparison to injury thresholds	Injury to groundwater, threshold exceedances 43 CFR 11.62 (c)(1) Quantify injury in terms of the reduction from baseline services 43 CFR 11.70-11.73	Concentrations in excess of water quality criteria and drinking water standards 43 CFR 11.62(c)(1)(i-iii)
Groundwater upwellings		Concentrations sufficient to cause injury to biological resources when exposed to groundwater 43 CFR 11.62(c)(1)(iv)
Define the legal, political, and economic environment for baseline services provided by groundwater		Baseline services determination 43 CFR 11.72
Review of contaminant plume mapping		Determining areal extent of hazardous substances in water or geologic materials within the assessment area 43 CFR 11.71(i)(1)
Vertical distribution of contaminant plumes		Determining vertical extent of released substances 43 CFR 11.71(i)(2)
Geology of Columbia riverbed		Quantifying injured groundwater 43 CFR 11.71(i) and concentrations sufficient to cause injury to biological resources when exposed to
Synoptic sampling of river corridor wells		

INJURY/DAMAGES DETERMINATION/QUANTIFICATION APPROACH	DOI NRDA REGULATIONS INJURY DEFINITION	DOI NRDA REGULATIONS DEFINITION COMPONENTS
		groundwater 43 CFR 11.62(c)(1)(iv)
Evaluation of existing vadose zone models		Quantifying injured groundwater 43 CFR 11.71(i) and Source and pathway and injury quantification
Validity, limitations to existing Hanford groundwater models		Quantifying injured groundwater 43 CFR 11.71(i)
Quantify injured groundwater volume and time dimensions		
BIOTA		
Comparison of biological tissue data to adverse effects thresholds	Concentrations sufficient to cause injury to biota 43 CFR 11.62(f)(1-4)	Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i)
Assessment of plant community health		Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i) and/or statistical difference between assessment area and control areas 43 CFR 11.62(f)(3)
Assessment of terrestrial invertebrate abundance		
Mussels: Distribution, abundance, and histopathology		
Prickly sculpin habitat use		
Assessment of avian abundance and diversity		
Small mammal population assessment		
Mussels: Toxicity testing		Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i) and/or statistical significant difference in mortality between population samples and controls 11.62(f)(4)(i)(E)
Early life stage sculpin and white sturgeon toxicity testing		
Chinook salmon artificial redd evaluation		Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i) and/or statistical significant difference in mortality between in situ populations and controls 11.62(f)(4)(i)(D)
Mussels: Caged (*in situ*) study		
Chinook salmon spawning habitat evaluation		Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i); to cause avoidance 43 CFR 11.62(f)(iii)(B); and/or groundwater upwelling contamination sufficient to cause injury to biota 43 CFR 11.62(b)(v) and 11.62(c)(iv)
Great Basin pocket mouse: carbon tetrachloride and histopathology		Concentrations sufficient to cause adverse changes in viability 43 CFR 11.62(f)(1)(i); statistical difference between assessment populations and control populations 11.62(f)(3); and/or physical deformations 11.62(f)(4)(vi)
Evaluation of exposure in Hanford Site avian speciessite	Determination of exposure pathways 43 CFR 11.63	Establish pathway 43 CFR 11.63(a-f)
Impacts of remedial activities	Recoverable damages include any increase in injuries as a result of response actions 43 CFR 11.15(1)	NA
HUMAN USE		
Inventory of institutional controls related to the release of hazardous contaminants	Quantification of service reductions 43 CFR 11.71	In quantifying changes in natural resource services, services include provision biological resources, recreation, and other products or services used by humans 43 CFR 11.71(e)
Assess tribal service losses		
Current resource characterization		

INJURY/DAMAGES DETERMINATION/QUANTIFICATION APPROACH	DOI NRDA REGULATIONS INJURY DEFINITION	DOI NRDA REGULATIONS DEFINITION COMPONENTS
ALL RESOURCES		
Quantification of lost aquatic , terrestrial, groundwater, and human use services	Quantify injury in terms of the reduction from baseline services 43 CFR 11.70-11.73	Quantifying lost natural resource services 43 CFR 11.71(a)

CHAPTER 7 | INJURY ASSESSMENT STUDIES

7.1 INTRODUCTION

In order to advance the injury assessment process, the Trustees plan to undertake a series of studies that will inform both determination and quantification of injury to natural resources resulting from Site-related contamination. Damage determination studies to provide information to help the Trustees identify and scale restoration to address natural resource injuries, including the cost of such restoration, will be addressed in a separate Restoration and Compensation Determination Plan to be developed at a later date (in accordance with 43 CFR 11.81).

This chapter describes the studies that the Trustees are presently undertaking or are considering at this time. The selected efforts represent the Trustees' best understanding of the studies that may be necessary to identify and quantify injury to site natural resources and their services. The Plan is not intended to limit other studies that may be undertaken in the course of the assessment, but represents the current best judgment of the Hanford Trustees regarding the types of studies that are needed to advance the assessment. The Trustees recognize that other studies may become necessary or advisable, as the assessment proceeds. For instance, focused pathway studies may be needed to the extent that the Trustees identify uncertainties regarding the source of specific contaminants associated with identified injuries. The Trustees may also choose to evaluate specific natural resources in greater detail. For example, the Pacific lamprey is a species of exceptionally high cultural value to indigenous peoples in the region, as are many other natural resources. As new information becomes available during the course of this assessment the Trustees may choose to pursue additional assessment activities.

Note that the inclusion of a study within this Plan does not guarantee that it will be undertaken -- the Hanford Trustees may determine that some of these efforts are not needed, or may have lower priority -- and studies not included within the Plan may be deemed necessary at a later date as more information becomes available. For example, some studies may not be needed if reasonable assumptions can be made, balancing the cost of additional research or sampling against the expected gain in information from a particular study. As such, this Plan provides a starting point from which the Trustees will begin to prioritize study efforts and implement the injury assessment process. As these efforts progress and additional information is generated, the Trustees may modify this Plan, and may provide amendments to this Plan for public review and comment.

EFFORTS TO DATE

A number of Trustee efforts have led to the selection of the particular studies included in this chapter. The Trustees have been meeting since 1993, and more recently on a monthly basis to discuss Hanford assessment activities. There are six technical working groups (TWGs) that focus on more technical analyses including the aquatic, terrestrial, groundwater, human use, restoration, and source and pathway TWGs. Specifically, the Hanford TWGs have conducted preliminary analyses of geo-coded sediment and fish contaminant data to determine resources at risk, developed a number of species profiles, which summarize and evaluate historical contaminant data on a Hanford species of concern, conducted research on contaminant sources and resource use of several ponds and ditches on Hanford, evaluated groundwater contaminant plume maps, and began developing the Hanford Natural Resource Restoration Plan which addresses early restoration and restoration project evaluation criteria.

The Trustees held a number of workshops and expert panels to explore different methods for injury assessment as well as key questions on the effects of contamination at Hanford. Workshop and panel topics included data management, quality assessment, ecosystem service valuation, human use services and service flows in natural resource damage assessments, compiling toxicity thresholds, injury to aquatic biota in the Hanford Reach, groundwater contaminant upwellings, the integration of groundwater and vadose zone analyses, and the effects of radionuclides on biota at Hanford.

With contractor support, the Trustees have completed a number of large technical analyses including a compilation and evaluation of natural resource information and historical contaminant concentrations from the Hanford Site, an analysis and summary of key data gaps, and a preliminary estimate of injury at the Site. Together, these analyses have helped the Trustees to evaluate existing information and identify injury studies that will fill data gaps and allow the Trustees to determine and quantify injury at the Hanford Site.

INJURY STUDIES

The initial focus of injury determination and quantification activities will entail the evaluation of existing data. Some data evaluation efforts are underway: for example, the Trustees have begun examining contaminant data in the Hanford Environmental Information System

Quality Assurance

The Trustees recognize the importance of data quality, including the need to both understand and document the quality of existing data as well as ensuring the quality of newly generated data. Work plans for individual studies will include Quality Assurance Project Plans that will describe data quality-related measures that will be undertaken as part of study implementation. Chapter 8 provides more information on quality assurance management in the context of this natural resource damage assessment.

(HEIS) database.[59] Future efforts will focus on a more comprehensive evaluation of available contaminant concentration data and other information. This approach will ensure that the Trustees utilize the substantial amount of existing data on the nature and extent of contamination.

The availability of such a large volume of existing information, however, presents challenges in data management, and in recognition of these challenges, the Trustees have developed a Quality Management Plan (HNRTC 2011b) and a Data Management Plan (HNRTC 2011a). The purpose of these documents, and of data and quality management activities in general, is to establish and adhere to a methodology governing the collection, collation, evaluation and management of all environmental data and related information to help ensure the integrity of the data, such that the data collections and applications undertaken by the Trustees are of known and acceptable quality, are scientifically valid and legally defensible.

In addition to evaluating existing information, the Trustees have identified a number of potential studies to provide new information to support injury determination and quantification. These studies are summarized in Exhibit 7-1 and ES-1, and described below in more detail. These studies address aquatic resources, terrestrial resources, groundwater, human use, and data management.

Identification of Traditional Cultural Properties at Hanford

Before field studies or other studies undertaken at the Hanford Site begin, Traditional Cultural Properties (TCPs) must be identified. Any Federal undertaking that has the potential to affect Federally-listed (and/or eligible for listing) cultural resources, including TCPs, must be evaluated, as mandated under the National Historic Preservation Act (NHPA) Section 106. TCPs cannot be discovered through archaeological or historical research alone. The existence and significance of such locations can only be ascertained through interviews with knowledgeable users of the area or through other forms of ethnographic research.

Studies of environmental media (i.e., groundwater, soils, sediment) generally focus on comparisons of observed and forecast future contaminant concentrations with injury or effects thresholds. Human use studies focus on understanding the likely extent of institutional controls related to contaminant releases that may limit public use of the site, as well as understanding the manner and extent to which contaminants have affected tribal use of the site and services derived from natural resources at the site. Proposed studies of biota are intended to examine the ecological impacts to native species and communities due to exposure to hazardous contaminants released from site operations.

[59] Existing databases include, but are not limited to, HEIS, the Columbia River Component historic database, the Columbia River Component Data Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River, the River Corridor Baseline Risk Assessment GiSdT database, and the Near-Field Monitoring Program's collection effort, reported through the Environmental Release Summary.

The range and types of biota studies are particularly varied. Consistent with DOI NRDA guidance, they include laboratory and field studies; these two categories each have advantages and disadvantages. Field studies have a distinct advantage in that they comprehensively reflect the cumulative effects of contaminants present at a site, however complex those mixtures may be. Because field studies examine biota under natural conditions, these organisms are also exposed to other natural stressors (food foraging, predators, disease, temperature fluctuations, etc.). Organisms may be more sensitive to contaminants when faced with such natural stressors. However, natural systems are typically highly variable, making it difficult to detect differences in organisms or populations in a study area as compared to reference areas, even if such differences exist. Field studies have other limitations. Obtaining adequate sample sizes can be challenging, depending on the study organism and endpoint(s). In addition, even if effects are observed in a field study, it can be difficult to persuasively determine the causality of the effect: site contaminants could be responsible, or arguably, other site-specific factors (differences in habitat type, prey availability, predator pressure, disease prevalence) may contribute to, or could be responsible for, the observed effects.

In contrast, laboratory studies address causality directly. For example, spiked exposure studies (i.e., studies in which biota are exposed to a specific level of a contaminant) can demonstrate that specific contaminants cause specific effects, albeit under controlled, laboratory conditions. Laboratory studies are limited in that they do not fully mimic field conditions. Also, testing all contaminant combinations or exposures that may occur under field conditions is frequently not technically or financially possible.

In situ studies and laboratory toxicity studies that use site media combine features of both lab and field studies. *In situ* experiments expose organisms to actual site mixtures of contaminants under actual field conditions (e.g., variable water flow and temperatures, parasite exposure, etc.) but may not fully replicate field conditions—for instance, organisms are frequently protected from predation by virtue of being caged. Laboratory toxicity experiments with site media expose organisms comprehensively whatever site-specific, potentially complex mixture of contaminants is present, but they do so under conditions that are controlled in other ways (e.g., temperature, food availability, etc.).

Because the various types of potential biotic injury studies have different—and often complementary-- advantages and disadvantages, the Trustees have selected a variety of approaches to evaluate injury.

In all cases, individual study plans will be developed by the Trustees and principal investigators prior to study implementation. These individual study plans will detail the approaches to be followed, including actions to assure data quality. These study plans will undergo peer review, to provide assurance that the study designs will provide the information required by the assessment.

To help guide future assessment efforts, the Trustees have grouped the proposed studies into three priority categories. The assignation of a study to a particular category is based on Trustee judgments regarding: cost effectiveness; technical study sequencing requirements; likelihood of demonstrating injury; likely contribution to the selection and scaling of restoration alternatives; and/or anticipated concerns of the public. The three categories are:

(1) Nearer-term priorities,

(2) Middle-term priorities, and

(3) Longer-term priorities.

The first of these—the nearer-term priorities—includes studies that are presently ongoing as well as studies that are prerequisites for subsequent work, and studies that are expected to generate information of significant use in refining future study designs. The second category of studies is expected to include those that are more likely to identify injuries, are anticipated to address concerns of the public, and/or are expected to contribute the most towards informing the selection and scaling of restoration alternatives. The third category includes studies that depend on the prior completion of other efforts, and those that are presently expected to present more difficult technical issues.

As noted previously, both the conduct and timing of these studies will depend on the specific needs of the assessment, resource and funding limitations, and other factors.

EXHIBIT 7-1 OVERVIEW OF INJURY ASSESSMENT STUDIES

RESOURCE / USE	STUDY	STATUS	CATEGORY	GENERAL APPROACH
AQUATIC				
SURFACE WATER	Comparison to injury thresholds	Ongoing	1	Comparison of observed surface water concentrations to regulatory water quality criteria
SEDIMENT	Comparison to effects thresholds	Ongoing	1	Comparison of sediment concentrations to literature-based adverse effects thresholds and guidelines to inform understanding of the potential severity and magnitude of effects
AQUATIC BIOTA (GENERAL)	Comparison to effects thresholds – tissues	Ongoing	1	Compare site-specific contaminant data in biota tissue to literature-based adverse effects thresholds to inform understanding of potential severity and magnitude of effects
	Review of Hanford sediment and pore water toxicity studies	Potential	1	Evaluate results of existing studies of toxicity to trust resources to identify evidence of injury
BENTHIC INVERTEBRATES	Sediment toxicity testing	Potential	2	Evaluate toxicity of Site sediments to benthic invertebrates
MUSSELS	Distribution, abundance, and histopathology	Potential	3	Collect data on mussel community health; determine correlations between community metrics, habitat quality, and presence of contaminants; assess histopathological endpoints
	Toxicity testing	Ongoing	1	Evaluate toxicity of a sub-set of contaminants to mussels, including native and sensitive species
	Caged (*in situ*) study	Potential	3	Evaluate direct toxicity of contaminants in surface water and sediment to mussels *in situ*
FISH	Chinook salmon spawning habitat evaluation	Potential	2	Compare habitat characteristics and contaminant concentrations, including chromium, at known and potential spawning locations to determine whether contamination influences spawning site selection and avoidance
	Chinook salmon artificial redd evaluation	Potential	3	Assess effects of chromium-contaminated, and other contaminated groundwater upwellings on salmon development, using artificial redds
	Prickly sculpin habitat use	Potential	2	Estimate relative abundance and density of sculpin; evaluate population size/age structure in areas exposed to contaminated groundwater versus reference sites
	Early life stage sculpin and white sturgeon toxicity testing	Potential	3	Expose early life stage sculpin and sturgeon in the laboratory to waterborne chromium and other contaminants

RESOURCE / USE	STUDY	STATUS	CATEGORY	GENERAL APPROACH
AQUATIC RESOURCES	Quantification of lost aquatic ecological services	Potential	1	Compile aquatic resource information and analyze to quantify lost services
TERRESTRIAL				
SOIL	Comparison to effects thresholds	Ongoing	1	Compare concentrations of contaminants in soil with literature-based toxicity thresholds to inform potential severity and magnitude of effect
	Geospatial evaluation	Potential	1	Geospatial evaluation of patterns in soil data to identify areas more/less likely to have been exposed to potentially injurious contaminant concentrations, and areas where additional sampling may be useful
TERRESTRIAL BIOTA (GENERAL)	Comparison to effects thresholds - tissues	Ongoing	1	Compare site-specific contaminant data in biota tissue to literature-based adverse effects thresholds to inform potential severity and magnitude of effect
	Review of Hanford soil toxicity studies	Potential	1	Evaluate results of existing studies on soil toxicity to identify evidence of injury
PLANTS	Native plant toxicity testing	Potential	3	Evaluate potential phytotoxic effects of Site soils
	Assessment of plant community health	Potential	3	Compare health of plant communities at Hanford Site to suitable reference locations
INVERTEBRATES	Nematode toxicity testing	Potential	3	Evaluate the suitability of site soil as a habitat for biota
	Assessment of terrestrial invertebrate abundance	Potential	2	Assess abundance and (possibly) diversity of species/species groups across contaminant gradients; examine correlations between metrics and measures of contaminant exposure
BIRDS	Assessment of avian abundance and diversity	Potential	2	Assess abundance and diversity of birds across contaminant gradients using visual and auditory metrics; examine correlations between metrics and measures of contaminant exposure
	Evaluation of exposure in Hanford Site avian species	Potential	2	Evaluate exposure of avian species to contaminants
MAMMALS	Small mammal population assessment	Potential	2	Identify impacts of contaminant exposure on small mammal community population
	Great Basin pocket mouse: carbon tetrachloride and histopathology	Potential	3	Evaluate effects of carbon tetrachloride exposure on small burrowing mammals at Hanford Site
TERRESTRIAL RESOURCES	Impacts of remedial activities	Potential	1	Compilation of information describing the general type, timing, location, and spatial extent of activities; estimation of severity of impacts on

RESOURCE / USE	STUDY	STATUS	CATEGORY	GENERAL APPROACH
				habitat
	Quantification of lost terrestrial ecological services	Potential	1	Compile terrestrial resource information and analyze to quantify lost services
VADOSE/GEOLOGICAL				
GEOLOGICAL RESOURCES	Characterize vadose zone contamination and potential for long-term injury to groundwater and surface water due to contaminants that have been released to the vadose zone	Potential	1	Utilize available information and model outputs to develop an understanding of the likely nature, extent, and timing of natural resource injury, and lost services that could occur as a result of vadose zone contamination.
	Evaluation of existing vadose zone models	Potential	2	Assess ability and limitation of existing models to quantify vadose zone contamination flux
GROUNDWATER				
GROUNDWATER RESOURCES	Developing comprehensive database and comparison to injury thresholds	Ongoing	1	Create a comprehensive Hanford groundwater database for Trustee use in injury determination and quantification; use information in database to compare observed groundwater concentrations to regulatory water quality criteria
	Review of contaminant plume mapping	Ongoing	1	Evaluate methods and results of current groundwater contaminant plume mapping at Hanford
	Define the legal, political, and economic environment for baseline services provided by groundwater[60]	Potential	1	Describe services provided by groundwater at Hanford Site under baseline conditions; analyze how these services have been impacted by contaminants
	Validity and limitations to existing Hanford groundwater models	Potential	1	Verify validity of existing Hanford groundwater models in quantifying currently injured groundwater, as well as understanding of past and future nature and extent of groundwater contamination.
	Groundwater upwellings	Potential	2	Characterize distribution, frequency, and volumetric flow rate of contaminant upwellings in Columbia River, as pathway to potential injury to biota

[60] This study to define the legal, political, and economic environment of baseline groundwater services should be done prior to other groundwater studies.

RESOURCE / USE	STUDY	STATUS	CATEGORY	GENERAL APPROACH
	Synoptic sampling of river corridor wells	Potential	2	Sample selected river corridor wells at varying river stages to determine impact of river stage on groundwater depth readings
	Vertical distribution of contaminant plumes	Potential	1	Construct monitoring wells in key areas for sampling to identify depth of significant plumes
	Geology of Columbia riverbed	Potential	3	Drill boreholes on river islands, develop seismic and electromagnetic profiles, and perform geophysical surveys to determine the presence of plumes near and beneath the river as well as ongoing potential for contaminant migration
	Quantification of injured groundwater volume and time dimensions	Potential	1	Quantify groundwater affected by contaminant release across Site
HUMAN USE				
TRIBAL USE	Ethnographic study to identify Traditional Cultural Properties	Potential	1	Identify Traditional Cultural Properties at the Hanford Site
	Assess tribal service losses	Potential	1	Identify service losses to tribal use not accounted for in other studies
	Current resource characterization to allow for restoration of lost tribal services	Potential	1	Characterize and monitor contaminant concentrations in natural resources to verify potential for restoration of tribal services
INSTITUTIONAL **CONTROLS**	Inventory of institutional controls related to the release of hazardous contaminants, and description of associated limits on human use of the site	Planned	1	Inventory the nature and geographic scope of institutional controls related to hazardous contaminant releases that could impact past, present or future human use of the site.
ALL RESOURCES				
DATA MANAGEMENT	Treatment of non-detects in studies analyzing existing data	Potential	1	Evaluate a variety of options for handling non-detect sample results within each analysis.

7.2 AQUATIC RESOURCES

The Hanford Site has a lengthy operational and remedial history, and as part of that history, a number of ecological, toxicological, and other studies have produced information of potential use in the injury assessment. The studies included in this Injury Assessment Plan build on available information from past efforts and are intended to address key data gaps and/or remaining uncertainties. The following paragraphs briefly describe such prior research in order to characterize the larger scientific context into which the proposed studies will fit.

OVERVIEW OF EXISTING SITE AQUATIC RESOURCE DATA

Available information about the Hanford Site's aquatic natural resources that is of most relevance to a natural resource damage assessment includes but is not limited to: (a) measurements of hazardous substances in site media (surface water, pore water, sediments) and in the tissues of aquatic organisms, (b) information about species presence/absence at various locations; (c) results of toxicity testing of specific biota with site media and site contaminants, (d) (e) population and community investigations, and (e) other research exploring potential contaminant-related effects at the Site (e.g., reproductive studies, histopathological evaluations, biota condition assessments, behavioral assessments, etc.).

Measurements of Hazarous Substances

The Trustees have identified at least seven partially overlapping databases that contain many measurements of concentrations of hazardous substances in site media and biotic tissues. The Hanford Environmental Information Systems (HEIS) database contains the largest numbers of samples of soils, surface water, biota, and groundwater, while other databases contain larger numbers of sediment and pore water samples. HEIS continues to be developed, and HEIS may eventually serve as the repository for virtually all site sampling efforts, past and ongoing. A substantial effort has been underway within this past year to add more data to HEIS; as this effort progresses, it may become increasingly less necessary to rely on other compilations of contaminant information. In addition to HEIS, databases with information on aquatic samples include: (a) the Columbia River Component historic database, (b) the Columbia River Component Data Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River (WCH 2011), and (c) the River Corridor Baseline Risk Assessment GiSdT database.

Although the number of measurements of contaminants in site abiotic and biotic media is large, many challenges remain in effectively using these data in the context of an assessment. These challenges include but are not limited to: the variety of sampling efforts (and associated sampling objectives) associated with the datasets; the need to understand quality assurance issues associated with the various datasets; analytic issues associated with non-detect values; and the absence of sample characterization information in many cases (e.g., sampling depths and geographic coordinates). Studies that rely on this information (e.g., those involving comparisons of measured concentrations with thresholds) will need to address these issues during the detailed study design and implementation stages.

Toxicity Testing

Trustees frequently include toxicity testing among site assessment activities. Some such testing has been conducted: in particular, the River Corridor Baseline Risk Assessment (DOE 2011b) presents the results of site-specific toxicity tests with site media. RCBRA tests include assessments of sediment toxicity to pak choi, and to the amphipod *Hyalella azteca*, as well as assessments of pore water toxicity to the daphnid *Ceriodaphnia dubia* and to the frog *Xenopus laevis*. The results of these efforts provide information that may be valuable in the context of an assessment; however, preliminary review of the approach and results suggests that they may have important limitations associated with their use (see discussion in “Benthic Invertebrates: Sediment Toxicity Testing”). Altogether, the Trustees plan to undertake additional review of the RCBRA’s toxicity testing results and may pursue additional toxicity testing of site media, as described in “Benthic Invertebrates: Review of Hanford Toxicity Studies” and “Benthic Invertebrates: Sediment Toxicity Testing”.

Species Distribution and Population/Community Characterization Information

In a natural resource damage assessment, Trustees may choose to evaluate species distributions and population or community metrics to evaluate the extent to which hazardous substances may have affected biota at this level of ecological organization.

Some information on these topics is available: for example, Mueller *et al.* (2001) presents the results of a mussel survey of the Hanford Reach, documenting the species composition, densities, and distribution of native freshwater mussels along the Benton County shoreline of the Hanford Reach. The authors found several shells of the western pearlshell but concluded that “the species appears to be largely absent from its historical range” (Mueller *et al.* 2011). Based in part on this study’s results, the Trustees believe that additional mussel work may be useful in identifying the potential sensitivity of native unionid species to site contaminants in the laboratory and under field conditions (see “Mussels: Distribution, Abundance, and Histopathology”, “Mussels: Toxicity Testing”, and “Mussels: Caged (*in situ*) Study”).

The River Corridor Baseline Risk Assessment (DOE 2011b) presents community-level information on aquatic communities, which was gathered using a rock basket deployment technique. Baskets were deployed in association with three groundwater plumes (chromium, uranium, and strontium-90) as well as at locations between the areas of most direct plume influence, and at reference locations. The authors conclude that “For most RCBRA study sites, results for aquatic community measures were as high as or higher than upstream reference sites with similar habitat characteristics.” The Trustees have reservations about the defensibility of this conclusion and in the future may choose to more formally and carefully review both the study design and its results. The Trustees may also choose to conduct additional benthic invertebrate community health assessment (e.g., using different geographic scope and/or sample sizes, different technical methods, and/or using more sophisticated statistical approaches to more carefully control for confounding factors). However, at the current moment, such a study represents a lower priority effort and is not included in the Injury Assessment Plan at present.

DOE's Ecological Monitoring and Compliance Project (EMC), which until 2011 was managed by Pacific Northwest National Laboratory (PNNL) and is now managed by Mission Support Alliance (MSA), includes information on aquatic species locations including but not limited to salmon and steelhead redd counts, amphibian occurrences including call responders, and clam counts. For purposes of natural resource damage assessment, this information may be useful in identifying likely locations of biota in the event that future field studies on these species are pursued, but it is not likely to be useful for direct injury determination purposes as the program has not been designed to definitively identify species absence, or to quantify population-level metrics such as abundance.

Other authors have also developed and/or compiled general information on aquatic species presence at the Hanford Site (e.g., Fitzner and Gray 1990, CRCIA 1998, TNC 1999, TNC 2003, Duncan 2007).

Histopathological Investigations

The Trustees may examine organisms for evidence of physiological injuries including but not limited to histopathological impacts. Some site-specific histopathology information on aquatic biota has been collected in recent years, although most study efforts appear to be subject to certain limitations. For example, PNNL's databases include histology information for certain biota collected between 2002 and 2005 (i.e., 3 bass, 1 adult bullfrog, 1 tadpole bullfrog, 3 suckers, 830 clams, 33 sculpin, 68 crayfish, and 7 whitefish). The Trustees have not identified reports that describe the sampling methods, sampling design, and/or discuss the results.[61]

Larson *et al.* (2008) describes a November 2003 to February 2005 *in situ* investigation on exposure of the (non-native) Asiatic clam, *Corbicula fluminea*, to contaminants in the 300 Area. Growth, survival, and tissue conditions were evaluated at two nearshore locations, one of which was associated with contaminated groundwater upwelling, and the other was an upstream reference location. The authors did not identify any effects of contaminant exposure; however, growth overall was poor (negative), which the authors attribute to the type of tubing in which the clams were contained. The study's results may not be representative of results under natural conditions.

DOE (2011b) discusses results of sampling in 2006 and 2007 for mussels, sculpin, juvenile suckers, and for Asian clams *in situ*:

- In mussels, the authors found statistically increased observations between study site versus reference site organisms, in two of the 20 measurements: digestive cell vacuolation severity and degraded mantle condition. This study was limited to six study sites and three reference sites.
- In sculpin, the authors found statistically increased fish length and weight among study site versus reference area fish. The authors also found four out of 22

[61] The Hanford Site Environmental Report for Calendar Year 2003 (Poston *et al.* 2004) states that other than radiological results in clams, "Analyses for other species and biological components were still under development when this report was prepared." Subsequent annual environmental reports also do not appear to present the results of this sampling.

histopathological measurements to differ between study and reference sites: the number of liver parasites and the number of muscle granulomas was higher among site fish, and the number of encysted parasites in gills and kidneys were higher among reference fish.

- In Asian clams (a non-native species), the authors found statistically increased observations between study site versus reference site organisms, in two of the 19 measurements: the incidence of digestive system epithelial cell shedding, and reproductive system follicle cyst presence. These clams were exposed *in situ* for periods of 3 or for 7 to 8 months.

Finally, as part of a white sturgeon workshop, Kiser (2010) preliminarily reports histology information associated with several tissues from 30 white sturgeon, including 25 from the Hanford Reach and five from a reference area above Wanapum Dam. External and internal anomalies were observed in about 15 percent of all sturgeon, including reference area fish. Tissue histopathology also indicated abnormalities in all fish sampled, including those from the reference area. The observed histopathology was consistent with a chronic viral, bacterial, or chemical stressor. Gonadal observations include inflammation, degeneration, and oocyte necrosis, potentially indicating reproductive impairment. Metal concentrations were “generally low” except for mercury; radionuclide concentrations were “infrequently” detected and were “near detection limits” (*ibid*.). Concentrations of total DDT and PCBs were elevated within the study area fish tissues. The workshop’s conclusions include that, despite the long lifespan of the species and its potential for exposure to higher past contaminant concentrations, “There is considerable uncertainty regarding the likelihood of detecting historical histological impacts [on white sturgeon].”

Additional Investigations

Additional site-specific field research on potential contaminant-related effects to aquatic and aquatically-linked biota include:

- **A 2005 pilot study on bullfrog and Woodhouse’s toad malformations** in animals from two Hanford Reach slough/backwater pools. The authors found a “relatively low” rate of malformations (Poston *et al.* 2006).
- **Canada geese reproduction.** Fitzner *et al.* (1991) note that nearly four decades of research on the nesting ecology and behavior of this species have been conducted. Fertility rates in the 1950s and 1960s found reproductive rates “as high or higher than in areas not supporting nuclear operations.” Simmons *et al.* (2010) summarizes Canada goose research at Hanford, concluding that radiological dose rates were “well below applicable guidelines” and that maximum concentrations of a variety of other metals “met or fell below existing toxicological benchmarks, suggesting minimal risk… from exposure.”
- **Great blue heron reproduction.** Despite heavy metal concentrations, Tiller *et al.* (2005) found that in 1996, reproductive health of *A. herodias* nesting along the Hanford Reach to be one of the highest reported in the United States. The authors note that there has been a decline in the numbers of active nests from 94

in 1983 to 37 in 1999, attributing this change to increased human activity near nest trees, wind toppling of trees used as nesting sites, and low subadult/survival ratios (Rickart and Tiller 2003 as cited in Tiller *et al.* 2005).

- **Chinook salmon behavior.** Chinook salmon may be avoiding areas of groundwater upwelling within the Hanford Reach. For example, Geist (2000) reports that spawning salmon used areas of hyporheic upwelling where the specific conductance indicated a surface water source of the upwelling, whereas they did not use hyporheic discharge zones where the source was ground water. (Dissolved oxygen was higher in the surface water discharge areas, but concentrations in both areas were higher than levels needed for egg/alevin survival. Contaminant concentrations were not measured.)

The findings of Geist (2000) are among those suggesting that additional research on Chinook salmon is appropriate for the Hanford assessment (e.g., see "Fish: Chinook Salmon Spawning Habitat Evaluation" and "Fish: Chinook Salmon Artificial Redd Evaluation").

IMPLICATIONS OF EXISTING DATA FOR INJURY ASSESSMENT

Given the description above of available information on contaminant exposure and potential aquatic injuries, the following injury assessment studies have been identified to fill important data gaps. Phase 1 priorities for aquatic injury assessment focus on organizing the information necessary to better understand aquatic resource exposure and to help guide work plan development for later stages of the injury assessment. Phase 1 priorities therefore include estimating the level and extent of surface water, pore water, sediment and aquatic biota tissue contamination, estimating baseline contaminant concentrations in site media, and reviewing the existing sediment and pore water ecotoxicity testing studies. Phase 2 and 3 priorities encompass further efforts that would help the Trustees refine their understanding of potential aquatic injuries. In particular, Phase 2 and 3 efforts include but are not limited to: conducting additional laboratory toxicity testing, gathering information about population and community attributes, conducting *in situ* assessments to evaluate the effects of exposure to site media on aquatic biota, and collecting information on the health of aquatic biota.

SURFACE WATER: COMPARISON TO INJURY THRESHOLDS

Objectives: (1) To determine injuries to surface water resources based on comparisons of measured and/or modeled concentrations of Site COPCs to regulatory water quality standards or criteria. (2) To identify COPCs that may be most strongly associated with potential injuries (e.g., by virtue of having a greater magnitude and/or exceedance of effects thresholds). (3) To identify locations with higher or lower levels of exposure to hazardous substances, to help inform site selection in potential future injury studies.

Need/Rationale: Surface water is a key natural resource, providing habitat to numerous aquatic biota as well as providing services to humans. Contaminant concentrations in excess of certain levels (e.g., Washington State water quality standards) generally indicate that an injury has occurred under DOI's NRDA regulations (43 CFR 11.62(b)(1)(i) through (iii); see Chapter 6).[62]

Comparing contaminant concentrations in surface waters to regulatory water quality standards or criteria is a cost-effective and widely used approach to evaluate potential surface water injuries. Furthermore, making comparisons can also help document the existence of a pathway between sources of releases and receptors, and/or may suggest that additional field or lab studies on certain biological receptors/locations/contaminant combinations may be appropriate.

Approach: The study will focus on the Hanford Reach of the Columbia River and appropriate reference locations. The first component of this task will involve assembling and evaluating available surface water and pore water data, and incorporating it into the Trustees' natural resource damage assessment database in accordance with the Data Management Plan and the Quality Assurance Management Plan (HNRTC 2011a, 2011b). Although many measurements of surface water COPCs are available, a comprehensive assessment database has not been developed.

The Trustees will also determine the water quality criteria and standards (e.g., Federal drinking water standards, state water quality criteria) against which sample concentrations will be evaluated.

This study will include an evaluation of baseline conditions, which will include to the extent possible a characterization of the concentration ranges of hazardous substances expected to be present in surface waters but for Hanford Site releases. As part of this evaluation, contaminants will be identified as having one or more of the following origins: natural sources, Hanford Site operations, and/or other anthropogenic sources.

SEDIMENT: COMPARISON TO EFFECTS THRESHOLDS

Objectives: (1) To determine potential past, current, and future injuries to sediment resources based on comparisons of measured sediment COPC concentrations to regulatory standards and literature-based effects thresholds. (2) To identify COPCs that may be most strongly associated with potential injuries (e.g., by virtue of having a greater magnitude and/or exceedance of effects thresholds). (3) To identify locations with higher or lower levels of exposure to hazardous substances, to help inform site selection in potential future injury studies.

Need/Rationale: Sediments provide essential habitat for aquatic plants, mussels and other invertebrates, and fish (e.g., species such as salmon use the river bed as spawning habitat). Comparing sediment contaminant concentrations to appropriate adverse impact thresholds is a cost-effective, widely used approach to identify potential sediment injuries.

[62] Chapter 6 provides complete definitions of injury to natural resources, including injury determination. Exceedances of certain concentration thresholds is a key component of these definitions but is not the only requirement that must be satisfied.

Although comparing measured concentrations to literature-based thresholds is not generally, in itself, sufficient to determine injury in accordance with the DOI regulations,[63] such analyses can inform the Trustees' understanding of the nature and extent of potential injury. For example, within the context of a cooperative assessment, such comparisons can provide a basis for reaching agreement on injury determination and/or quantification assumptions. These comparisons can also help document the existence of a pathway between sources of releases and receptors, and/or may suggest that additional field or lab studies on certain biological receptors/locations/contaminant combinations may be appropriate. They may also provide help identify those COPCs that may be the largest drivers of injury (e.g., based on the magnitude and/or extent of threshold exceedances).

Approach: The study will focus on the Hanford Reach of the Columbia River and appropriate reference locations. The first component of this task will involve assembling and evaluating available data, and incorporating it into the Trustees' natural resource damage assessment database in accordance with the Data Management Plan and the Quality Assurance Management Plan (HNRTC 2011a, 2011b). Although many measurements of sediment COPCs are available, a comprehensive assessment database has not been developed.

The second component of this study requires identification of adverse effects thresholds—i.e., Site-specific and/or generic values from the literature—against which the Trustees will compare contaminant concentrations from the database described above. Potential thresholds identified to date include Washington State sediment quality criteria, as well as literature-based sediment quality guidelines. Building off the preliminary work done by the Trustees, and supplemented by additional literature and/or the results of toxicity testing, the Trustees will develop sediment thresholds for each COPC.

This study will include an evaluation of baseline conditions, which will include to the extent possible a characterization of the concentration ranges of hazardous substances expected to be present in Hanford Reach sediments but for Hanford Site releases. As part of this evaluation, contaminants will be identified as having one or more of the following origins: natural sources, Hanford Site operations, and/or other anthropogenic sources.

AQUATIC BIOTA: COMPARISON TO EFFECTS THRESHOLDS - TISSUES

Objectives: (1) To determine potential past, current, and future injuries to aquatic biota based on comparisons of measured tissue COPC concentrations to literature-based effects thresholds. (2) To identify COPCs that may be most strongly associated with potential biotic injuries (e.g., by virtue of having a greater magnitude and/or exceedance of effects thresholds). (3) To identify species and/or locations with higher or lower levels of exposure to hazardous substances, to help inform site selection in potential future field studies of aquatic biota.

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[63] Chapter 6 provides complete definitions of injury to natural resources, and sediments are considered to be part of the surface water resource (43 CFR 11.14(pp)). Injury to sediments is most commonly determined when sediments are sufficiently contaminated to have caused injury to other natural resources (43 CFR 11.62(b)(1)(v)).

Need/Rationale: Biologic resources, including aquatic organisms, are trust resources that provide a suite of essential ecological services. Comparison of COPC tissue concentrations to appropriate adverse impact thresholds is a cost-effective, widely used approach to identify potential biological injuries. With certain exceptions, comparisons of measured concentrations in tissues to thresholds is not usually in itself sufficient to determine injury in accordance with the DOI regulations;[64] nevertheless, such analyses can inform the Trustees' understanding of the nature and extent of potential biological injuries. Within the context of a cooperative assessment, these kinds of comparisons can provide a basis for reaching agreement on injury determination and/or quantification assumptions. These studies can also help document the existence of a pathway between sources of releases and receptors, and/or may suggest that additional field or lab studies on certain biological receptors/locations/contaminant combinations may be appropriate. They may also provide help identify those COPCs that may be the largest drivers of injury (e.g., based on the magnitude and/or extent of threshold exceedances).

Approach: The study will focus on the Hanford Reach of the Columbia River and appropriate reference locations. The first component of this task will involve assembling and evaluating available data, and incorporating it into the Trustees' natural resource damage assessment database in accordance with the Data Management Plan and the Quality Assurance Management Plan (HNRTC 2011a, 2011b). Although measurements of COPC concentrations in biota exist, a comprehensive assessment database has not been developed. Therefore, the Trustees will create a database, ensuring that data are normalized, contain location information where possible, and are presented in consistent units (e.g., convert radiological concentrations to internal radiological dose estimates). This effort may also identify species of interest for which additional data collection may be warranted.

The second component of this study requires identification of adverse effects thresholds—i.e., Site-specific and/or generic from the literature—against which the Trustees will compare contaminant concentrations from the database described above. Building off preliminary work done by the Trustees, and supplemented by additional literature and/or results of toxicity testing, the Trustees will develop injury thresholds for COPCs and species/species guild of potential concern.

This study will include an evaluation of baseline conditions, which will include to the extent possible a characterization of the concentration ranges of hazardous substances expected to be present in selected Hanford Reach biota but for Hanford Site releases. As part of this evaluation, contaminants will be identified as having one or more of the

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[64] Chapter 6 provides complete definitions of injury to natural resources. Injury to biological resources can occur when concentrations of hazardous substances exceed action or tolerance levels established under the Food, Drug, and Cosmetic Act (43 CFR 11.62(f)(1)(ii), or when concentrations exceed levels for which an appropriate state health agency has issued directives to limit or ban consumption of an organism (43 CFR 11.62(f)(1)(iii)). However, no such consumption limits or bans have been issued, and for many Hanford Site COPCs, no action or tolerance levels have been established. For these and other reasons, the Trustees expect that this study will focus on comparing COPC tissue concentrations with literature-based adverse effects thresholds, in particular those associated with potential injuries to biota as defined in 43 CFR 11.62(f)(1)(i)).

following origins: natural sources, Hanford Site operations, and/or other anthropogenic sources.

AQUATIC BIOTA: REVIEW OF HANFORD SEDIMENT AND PORE WATER TOXICITY STUDIES

Objective: To determine what conclusions may be drawn with respect to injury determination and quantification for sediments and sediment-associated biota based on existing sediment and pore water toxicity testing data.

Need/Rationale: Sediment and pore water toxicity testing are a common components of natural resource damage assessments, undertaken to determine the extent to which sediments are injured by virtue of causing injury to other natural resources (see 43 CFR 11.62(b)(1)(v)). This effort focuses on the toxicity of Hanford Reach sediments to benthic invertebrates. Some contaminants adhere to sediments particularly, and sediment-associated invertebrates are an important part of many freshwater food webs. Reliance on existing information can be a cost-effective way to determine injury, and thus the Trustees propose to evaluate existing testing approaches and results to determine whether available data are of sufficient quantity and quality to meet assessment needs.

Approach: Documentation of reduced survival, growth, reproduction or other adverse effects arising from exposure of biota to hazardous substances in Site sediments relative to reference sediments is an injury under DOI NRD regulations. The benthic community is a key natural resource, forming the base of the aquatic food chain. Sediment toxicity testing has been undertaken in the past at Hanford. For example, DOE (2011b) reports the results of testing of 49 nearshore aquatic sites, and states that 28-d bioassays with *H. azteca* found reduced survival at study sites compared to reference sites, and that *C. dubia* exposed to pore water collected under “low river flow” conditions experienced reduced reproduction compared to reference sites. However, the Trustees have identified limitations associated with these previous studies (see “Invertebrate Sediment Toxicity Testing” below). Therefore, this study will involve a significantly more detailed and rigorous review of available information, documenting, compiling and summarizing these and potentially other studies undertaken at Hanford that evaluated the toxicity of Site sediments to biota. This effort will also include a careful review of these results from an NRD perspective. This work will involve evaluation of test acceptability, assessment of test relevance, and determination of adequacy of spatial coverage. It may also involve re-evaluation of test information using alternate approaches (e.g., alternate statistical analyses), and as appropriate, will result in developing conclusions on the interpretation of existing data in the context of injury determination and quantification for natural resource damage assessments.

BENTHIC INVERTEBRATES: SEDIMENT TOXICITY TESTING

Objective: To evaluate the toxicity of sediments from the Hanford Site to selected benthic invertebrates.

Need/Rationale: This effort will support an injury determination to benthic invertebrates and associated sediments (e.g., see 43 CFR 11.62(b)(1)(v)), and may inform injury quantification efforts. Measurements of contaminants in the tested sediments will also contribute to the Trustees' pathway determination for sediments and associated biota. As noted previously, collecting river sediments and subjecting them to toxicity testing using standardized test organisms is a common component of many natural resource damage assessments. Some COPCs adhere to sediments, and the sediment-associated invertebrates that may be exposed to sediment-associated COPCs are an important part of many freshwater food webs.

The River Corridor Baseline Risk Assessment (RCBRA DOE 2011b) reported the results of some Site-specific toxicity tests with Site media, including sediments and pore waters. However, there are some key limitations of the data presented in DOE 2011b. For example, there are potential concerns with the control data in the 28-day *H. azteca* tests. In sediment toxicity testing using *H. azteca*, the negative control samples should achieve over 80 percent survival (Ingersoll *et al.* 2008) and such criteria are also often applied to reference sediment samples (MacDonald *et al.* 2012); however, Figure 6-35 in DOE (2011b) indicates that at least some reference site samples did not meet this criterion, and, hence, data from certain locations may not be relevant for evaluating sediment toxicity. A closer evaluation may help explore the extent to which this issue may or may not affect a determination about overall test acceptability. In addition, longer tests, such as the 42-day reproduction tests in amphipods, tend to represent a more sensitive endpoint than 28-day tests examining survival and growth. Lastly, the *C. dubia* pore water bioassays exposure duration was limited to seven days, and therefore, potential effects of longer-term exposures are unclear.

The Trustees are interested in conducting additional aquatic invertebrate sediment toxicity testing, designed to ensure appropriate, comprehensive site selection to reflect the diversity of habitat and contamination regimes present, and to use longer-term exposures to more thoroughly explore the potential for chronic effects.

Approach: The specific approach to this study will be defined by the Trustees and the principal investigators in a detailed work plan. However, at this time the Trustees believe that the target organisms could include amphipods (*H. azteca*) in 42-day tests, and midges (*Chironomus dilutis*) in 53 to 60-day tests. Endpoints could include survival, growth, biomass, and reproduction. In addition, it may be desirable to evaluate the viability of F1 amphipods and midges produced by the exposed F0 generation. The results of such tests have, in some cases, supported the development of injury thresholds that are more protective than those based on survival or biomass evaluated in short-term toxicity tests (e.g., 10-d for midge and 28-d for amphipods).

Sediment characteristics, including contaminant concentrations in sediments and pore waters, will also be measured. As part of these efforts, the Trustees will need to select appropriate reference locations from which the baseline condition of sediment resources can be established. Where contaminant concentrations are to be measured, investigators should select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

MUSSELS: DISTRIBUTION, ABUNDANCE, AND HISTOPATHOLOGY

Objectives: To collect information on mussel community health, and to determine whether correlations exist between these metrics and either habitat characteristics or measures of exposure to contaminants.

Need/Rationale: This study results will help the Trustees determine whether native mussels in the Hanford Reach have been injured due to exposure to Site contaminants in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(3), and the extent of such injury. Measurements of contaminants in the site media will also contribute to the Trustees' determination of exposure pathways to these receptors.

Mussels provide freshwater ecosystems with a wide range of important ecological services. Not only do they serve as a food resource for aquatic and terrestrial predators, they also filter particulate matter from the water column, improving water quality. Their shells provide biogenic habitat, and their nutrient excretion supports the benthic invertebrate community (Spooner and Vaughn 2006). Mussels are also indicators of the ecological health of surface water communities. Their immobile nature (as adults) helps ensure that their status reflects local environmental conditions. In addition, mussels require suitable host fish for parts of their life cycle. The ability of mussels to thrive in a particular area therefore may provide an indirect indication of the status of the host fish community.

The Hanford Reach mussel community has undergone significant change. Mueller *et al.* (2011) evaluated the species, distribution, and densities of native freshwater mussels in the Hanford Reach. Four species of native mussels were identified, of which the western and Oregon floaters (*Anodonta kennerlyi* and *Anodonta oregonensis*) were most abundant. The California floater (*Anodonta californiensis*) was the next most abundant, while the formerly-present western pearlshell (*Margaritafera falcata*) appears to have been extirpated, although this species was formerly abundant. This species has also been in decline regionally (WCH 2008, Appendix F)). Potential causes of decline include (but may not be limited to) physical/chemical habitat alterations, thermal stress, availability of host fish, competition with non-native species, and the presence of contaminants. Pauley (1961, 1967, 1968) (as cited in Ingersoll *et al.* 2012) found high levels of pedunculated tumors in *Anodonta* in the Hanford Reach. As summarized in Ingersoll *et al.* (2012), chromium in the groundwater in the vicinity of the 100-D area has exceeded 50,000 µg/L, and recent measurements of chromium upwelling into the middle of the Columbia River from groundwater have exceeded 100 µg/L.

Approach: The Trustees will design a study that will examine mussel community characteristics (potentially including abundance, diversity, and age structure) in areas within the Hanford Reach thought to be potentially influenced by contaminant plumes from upwelling groundwater, as well as in reference areas. Semi-quantitative or quantitative sampling methods may be employed. Both live and dead unionids will be targeted for collection. Collected mussels may be subject to histopathological analysis (i.e., to identify lesions, tumors, or other deformities).[65]

Live animals not retained for histology, contaminant measurements, or for use as voucher specimens, will be returned to their collected location. Sediment and pore water samples will also be collected for purposes of environmental and contaminant characterization, and habitat characteristics will be documented. Where contaminant concentrations are to be measured, investigators should select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

MUSSELS: TOXICITY TESTING

Objectives: The objectives of this study (Ingersoll *et al.* 2012) are to:

- Determine the sensitivity of a native mussel (*M. falcata*) to hexavalent chromium relative to a related commonly tested freshwater mussel surrogate (*Lampsilis siliquoidea*) in water-only exposures;
- Evaluate the sensitivity of *M. falcata* and *L. siliquoidea* to hexavalent chromium in combination with other stressors (uranium, nitrate, and thermal stress) in water-only exposures;
- Determine the concentration of hexavalent chromium in water-only exposures in which these mussels are adversely affected, as defined under DOI's NRDA regulations (see 43 CFR 11.62(f)(1)(i) and 11.62(f)(4)(i)(E)).

Need/Rationale: This study results will help the Trustees determine whether native mussels in the Hanford Reach have been injured due to exposure to hexavalent chromium alone or in combination with other stressors, and will potentially help the Trustees quantify any identified injury.

As noted above, mussels are sentinels of freshwater community health, and Hanford Site contaminants may have played a role in alterations to this community over the years. Toxicity testing has the potential to identify clear cause-effect linkages between contaminant/stressor exposure and effects. Available information suggests that one site contaminant, hexavalent chromium, can have adverse effects on some freshwater mussels. In particular, the sensitivity of juvenile mussels (*Anodonta imbecillis*) to chromium has been tested and the 96-h median lethal effect concentration (LC50) was found to be 39 μg/L in relatively soft water and 618 μg/L in relatively hard water (Keller and Zam 1991 as cited in Ingersoll *et al.* 2012). When combined with mercury, the chromium 48-h LC50 was lowered from 295 μg/L to 170 μg/L (*ibid*.).

[65] As noted previously, DOE (2011b) reported results of a limited investigation of mussel histopathology, assessing six study sites and three reference sites. The authors found statistically increased observations between study site versus reference site organisms, in two of the 20 measurements: digestive cell vacuolation severity and degraded mantle condition. The Trustees will consider the design and evaluation of the DOE (2011b) histopathological study in more detail as part of determining whether, and how, to conduct additional mussel histopathological evaluations in the context of this broader mussel study effort.

Approach: The first step in this study involves methods development, focusing on the collection and culture of *M. falcata.* If these efforts are sufficiently successful, acute toxicity testing with *M. falcata* and *L. siliquoidea* will proceed, with chromium alone or with chromium along other stressors representative of the Site.

Should acute toxicity tests demonstrate one or more of the secondary stressors in combination with hexavalent chromium to be synergistic or additive to hexavalent chromium toxicity, chronic toxicity tests with hexavalent chromium and those stressors will then be performed with either *M. falcata* or *L. siliquoidea*. The choice of which of the two mussel species in which to conduct subsequent, chronic studies will be determined based on the success in propagating or conducting toxicity tests with *M. falcata*, which is the preferred species.

MUSSELS: CAGED (*IN SITU*) STUDY

Objectives: To determine whether *in situ* exposure to the Hanford Reach environment adversely affects the health of unionid mussels.

Need/Rationale: Depending on the results of previous mussel research, the Trustees may pursue this *in situ* study using native and/or surrogate unionids, to support a determination of injury to mussels (e.g., see 43 CFR 11.62(f)(1) and 11.62(f)(4)(i)(D)).. *In situ* studies allow for the exposure of organisms to site conditions, including the physical, chemical, and biological stressors normally present at a site, but do so in a controlled manner that allows for real-time comparisons of effects on selected species of a known life stage and initial condition. Measurements of contaminants in the site media will also contribute to the Trustees' determination of exposure pathways to these receptors. If pursued, this study may support a quantification of injury to mussels by helping identify areas where site conditions are/are not adequate for mussels.

Approach: Native and/or surrogate unionid mussel species may be employed. The selected species will be deployed in appropriate enclosures, to locations within the Hanford Reach thought to be potentially influenced by contaminant plumes from upwelling groundwater. Mussels will also be deployed in reference areas for comparative purposes. Potential endpoints include survival, growth, histopathological condition, and contaminant uptake (i.e., tissue chemistry). Sediment and pore water samples will also be collected for purposes of environmental characterization. Habitat characteristics will also be documented.

FISH: CHINOOK SALMON SPAWNING HABITAT EVALUATION

Objective: The purpose of this study is to examine whether contaminants are influencing Chinook spawning habitat selection in the Hanford Reach.

Need/Rationale: Chinook salmon are considered to be injured to the extent that their behavior is altered by the presence of contaminants (e.g., see 43 CFR 11.62(f)(1)). In addition, areas of sediments/groundwater upwelling that are contaminated to the extent that salmon avoid them, are also determined to be injured (see 43 CFR 11.62(b)(v) and 11.62(c)(iv)). It is anticipated that this study will help determine injury to these resources and may also provide information useful in quantifying these injuries (e.g., the size of the affected areas), if present. Measurements of contaminants in the site media will also contribute to the Trustees' determination of exposure pathways to this species.

Chinook salmon are a species of exceptionally high ecological and human use value and are a high priority for the Trustees. Chinook salmon are known to seek out specific types of habitat for purposes of spawning. Redd locations are routinely monitored within the Hanford Reach, and site-specific models have been developed to identify the characteristics of Chinook salmon spawning habitat in the Hanford Reach (e.g., Geist and Dauble 1998, Geist *et al.* 2000, Geist *et al.* 2006). These models have identified water depth, velocity, substrate, and slope as important discriminators of spawning habitat.

In addition to these habitat characteristics, research has suggested that certain other variables also differed between spawning and no-spawning reaches: in particular, "the permeability, specific discharge, and vertical hydraulic gradient were all higher in [the] spawning reach than in [the] non-spawning reach" of the Columbia River (Geist *et al.* 2006).

Groundwater upwelling, in particular, may influence habitat use by Chinook salmon, and a behavioral change due to contaminants is considered an injury under DOI's regulations (43 CFR 11.62(f)(1)). For example, Geist (2000) reports that spawning salmon used areas of hyporheic upwelling where the specific conductance indicated a surface water source of the upwelling, whereas they did not use hyporheic discharge zones where the source was groundwater. Dissolved oxygen was higher in the surface water discharge areas, but concentrations in both areas were higher than levels needed for egg/alevin survival. Contaminant concentrations were not measured; however, it is possible that contaminants in upwelling groundwater may be rendering some otherwise suitable spawning habitat undesirable.

Of note, chromium is a known contaminant in Hanford Site groundwater. DeLonay *et al.* (2001) found Chinook parr to be able to detect and avoid water with low concentrations of chromium, and also found that the parr spent less time in waters with higher concentrations of chromium. Laboratory-based avoidance constitutes an injury under DOI's NRDA regulations (43 CFR 11.62(f)(iii)(B)); of note, however, this effect was depended on water hardness. Farag *et al.* (2006) found exposure of juvenile Chinook salmon to concentrations of 120 µg/l or more were associated with impaired growth, while exposure to concentrations of 266 µg/l were associated with reduced survival.

Approach: Potentially suitable spawning habitat (e.g., as identified in existing models) in the Hanford Reach will be identified. Known redd locations will be compared with these areas of potentially suitable habitat, and from these comparisons, study locations will be selected. The selected locations will include areas of previously-known spawning as well as areas without a known spawning history. Contaminant concentrations in all study areas, including concentrations in upwelling groundwater, will be measured, as will other habitat characteristics thought to be important in salmon habitat spawning site selection. This may involve revising existing habitat use models to determine whether their performance in predicting redd locations is improved when contaminant measurements are included. Where contaminant concentrations are to be measured, investigators should select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious. The Trustees note that prior to implementation of this study, it may be necessary to gather more information, such as generating data to refine existing substrate maps.

FISH: CHINOOK SALMON ARTIFICIAL REDD EVALUATION

After the evaluation of Chinook salmon spawning habitat discussed above, the Trustees may pursue an *in situ* study using artificial redds.

Objective: This study's objective is to ascertain the effect of exposure to contaminants n upwelling groundwater on Chinook salmon eggs and alevins.

Need/Rationale: If salmon do not consistently avoid areas with contamination (e.g., if upwelling of contaminated groundwater is intermittent and does not occur during redd site selection), salmon eggs may be subject to contaminant exposure from sediments and upwelling groundwater, and may be injured from this exposure (e.g., see 43 CFR 11.62(f)(1) and 11.62(f)(4)(i)(D)). This study will, therefore, also support a determination of injury to salmon, and inform injury and quantification. Measurements of contaminants in the site media will also contribute to the Trustees' determination of exposure pathways to this species. **Approach:** Artificial Chinook salmon redds will be constructed at sites with habitats possessing characteristics thought to be favorable for spawning. These sites should include areas with recent spawning activity as well as areas without known recent spawning activity. Areas of suspected groundwater upwelling will be specifically targeted. Fertilized eggs will be placed in Vibert boxes within the artificial redds. Redds will be monitored for endpoints including but not necessarily limited to hatching success, fry survival, and growth. Non-contaminant related habitat characteristics will be documented, as will measures of contaminant exposure, and upwelling of surface or groundwater.

FISH: PRICKLY SCULPIN HABITAT USE

Objective: To estimate the relative abundance, density, and age structure of sculpin, in areas exposed to contaminated groundwater compared to reference locations.

Need/Rationale: This study will support an injury determination for sculpin, a forage fish occupying a ecological niche distinctly different from those occupied by other species proposed for evaluation in this assessment plan, and will provide data that will inform injury quantification in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(3). Measurements of contaminants in the site media will also contribute to the Trustees' determination of exposure pathways to this species.

The prickly sculpin is a suitable fish to study in part because it can serve as a surrogate for other species of conservation concern. For example, the mottled sculpin (*Cottus bendirei*) is a Federal species of concern and is listed on Oregon Biodiversity Information Center's list (Kagan and Christy 2010). In addition, sculpins have been used as indicators of stream health (Besser *et al.* 2007, Yeardley 2000). Sculpins are bottom dwellers and typically remain close to the substrate (Brown 2005). Adult sculpin build nests of eggs on the underside of rocks in the fast-moving streams in which they live. Once the eggs hatch, the fry drop to the bottom of the nest (Brown 2005). At this time, the fry still have a yolk sac and are about five mm long. The adult male sculpin tending the nest continues to fan the fry, aerating the eggs and keeping them free of silt, until the yolk sacs are absorbed, about two weeks after hatching (Brown 2005). The fry then disperse and grow into juveniles. Consequently, both the adults and early life stage fish have the potential for significant exposure to contaminants in sediments or in upwelling groundwater.

Some studies have found sculpin to move tens of meters or less over the course of a month or more (Petty and Grossman 2004, Petty and Grossman 2010). As a small fish with a limited home range, sculpin are likely to be exposed to COPCs for greater periods of time and will reflect the local conditions more precisely than species with larger ranges (Besser *et al.* 2007, Van Verst *et al.* 1998). Sculpin can be used to demonstrate the worst-case exposure for fish in a given area and can be used to estimate exposure to fish-eating biota (Van Verst *et al.* 1998). Sculpins have also been reported to be more sensitive to certain metals than are salmonids and other larger fish (Besser *et al.* 2007).

Some information on Hanford Reach sculpin has been collected: The River Corridor Baseline Risk Assessment (DOE 2011b) reports the collection, through electrofishing, of sculpin in nearshore fine sediments and gravel-pebble substrate areas. Sculpin were caught at 26 locations thought to be affected by contaminated groundwater plumes and seven areas thought to be unaffected by site contamination. These fish were subject to disease and histopathological evaluations[66] as well as contaminant analysis (liver and kidneys), weight, and length measurements. The authors found four out of 22 measurements to differ between study and reference sites: the number of liver parasites and the number of muscle granulomas was higher among site fish, and the number of encysted parasites in gills and kidneys were higher among reference fish.

Approach: Potentially suitable sculpin habitat will be identified. These areas are expected to be nearshore, as sculpin are often (but not always) found at depths of less than 0.5 meters (Hendricks 1997, Becker 1983). Electrofishing will be used to capture fish. Sculpin will be quickly identified as to species, measured and weighed. Habitat information will also be documented, including measurements of prey availability as research has suggested this to be an important factor affecting sculpin presence (Petty and Grossman 1996), as will contaminant concentrations in site media. The Trustees may choose to use a mark-recapture model to estimate population size. The Trustees may also elect to phase this study to better understand the ability of the study to achieve its objectives, prior to deciding to proceed with a full-scale implementation effort.

FISH: EARLY LIFE STAGE SCULPIN AND WHITE STURGEON TOXICITY TESTING

Objectives: To determine the sensitivities of a representative sculpin species and the white sturgeon to waterborne site contaminants including chromium, both alone and in combination with other stressors (e.g., uranium and nitrate).

[66] Disease and physiological deformations are injuries in accordance with 43 CFR 11.62(f)(1)(i); histopathological effects are specifically noted as an injury in 43 CFR 11.62(f)(vi).

Need/Rationale: This study will help evaluate the extent to which chromium, and potentially other stressors associated with the Hanford Site, may injure sculpin and/or sturgeon in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(4)(i)(E).. As a laboratory study, it is suited towards identifying the causality of potential injuries.

As noted previously, adult and early life stage sculpin live in close proximity to sediments. Early life stages of fish are frequently among the most sensitive to contaminant exposure, and in the Hanford Reach, chromium or other contaminants in upwelling groundwater may be reaching areas where sculpin spawn. In addition, sculpin have been reported as being more sensitive to certain metals than are salmonids and other larger fish, and have been extirpated from some streams due to elevated metal concentrations (Besser *et al.* 2007, Kunz *et al.* 2005, Dorts *et al.* 2010, Allert *et al.* 2005).

The white sturgeon's life cycle also puts eggs and larval stages in close association with sediments: after fertilization, eggs remain attached to the substrate for approximately seven to 11 days before hatching, dependent upon water temperature (UCWSRI 2002, Wydoski and Whitney 2003). Hatched larvae leave the substrate during a swim-up phase, which lasts approximately five to six days, during which time they are dispersed. After dispersal, larvae seek shelter in substrate and remain hidden for approximately 20 to 25 days until their yolk-sac is absorbed. Upon absorption of their yolk-sac, young white sturgeon emerge from the substrate to seek food (UCWSRI 2002). It may be that during these early life stages, fertilized sturgeon eggs and larvae are exposed to contaminants in upwelling groundwater.

Approach: Standard methods are available for both sculpin and white sturgeon toxicity testing methods. Sculpin will be field-collected, and adults spawned in the laboratory to provide embryos and/or fry for use in toxicity testing. Standard methods (e.g., ASTM E1241) will be used to conduct toxicity tests. For white sturgeon, fertilized eggs can be obtained from hatchery sources, and alevins and fry can be used in standard toxicity tests. Toxicity testing will include exposure to chromium alone or with chromium along other stressors representative of the Site. Chronic exposure tests may be preferred, as these are considered to more closely reflect field conditions.

AQUATIC RESOURCES: QUANTIFICATION OF LOST AQUATIC ECOLOGICAL SERVICES

Objective: The objective of this study is to quantify the ecological services aquatic resources have lost in the past and may lose in the future as a result of Site-related contamination.

Need/Rationale: In order to determine the scale and type of restoration actions required to compensate the public, the Hanford Trustees will need to understand the scale and scope of lost services.

Approach: This study involves two phases. The first phase consists of compiling information obtained from the aquatic resource studies mentioned above. This information will likely include the degree to which sample concentrations exceed identified injury thresholds, toxicity information on the adverse effects of varying levels of contamination, as well as ecological information (e.g., the abundance or distribution of aquatic species, habitat usage by species of concern). The second phase consists of analyzing the compiled data in order to quantify the geographic and temporal scope of ecological services aquatic resources have lost in the past and may lose in the future due to Site-related contamination. This will involve developing a relationship between contaminant concentrations and the severity of corresponding adverse effects on aquatic resources. The relationship will likely be based on literature information and data from site-specific studies on the toxicity of contaminants of concern as well as information on habitat usage, species abundance, and species diversity. Site-specific contaminant concentrations will then be compared to the developed relationship in order to determine the extent to which Site aquatic resources have been injured (i.e., determine the estimated service loss).

7.3 TERRESTRIAL RESOURCES

The Hanford Site has a lengthy operational and remedial history, and as part of that history, a number of ecological, toxicological, and other studies have provided information of potential use in the injury assessment. The studies included in this Injury Assessment Plan build on available information from past efforts and are intended to address key data gaps and/or remaining uncertainties. The following paragraphs briefly summarize key data that have resulted from past investigations of the Site's terrestrial resources and are intended to generally characterize the larger research context into which the proposed studies will fit.

OVERVIEW OF EXISTING SITE TERRESTRIAL RESOURCE DATA

Available information about the Hanford Site's terrestrial natural resources that is of most relevance to a natural resource damage assessment includes but is not limited to: (a) measurements of hazardous substances in soils and in the tissues of terrestrial organisms, (b) information about species presence/absence at various locations; (c) results of toxicity testing of specific biota with site media and site contaminants, (d) population and community investigations, and (e) other research exploring the potential for contaminant-related effects at the Site (e.g., reproductive studies, histopathological evaluations, biota condition assessments, behavioral assessments, etc.).

Measurements of Hazarous Substances

As noted previously, the Trustees have identified at least seven partially overlapping databases that contain many measurements of concentrations of hazardous substances in site media and biotic tissues. The Hanford Environmental Information Systems (HEIS) database contains the largest numbers of samples of soils and biota. HEIS continues to be developed, and HEIS may eventually serve as the repository for virtually all site sampling efforts, past and ongoing. A substantial effort has been underway within this past year to add more data to HEIS; as this effort progresses, it may become increasingly less necessary to rely on other compilations of contaminant information. In addition to HEIS, databases with information on terrestrial natural resources include: (a) the Columbia River Component historic database, (b) the Columbia River Component Data Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River (WCH 2011), and (c) the River Corridor Baseline Risk Assessment GiSdT database.

A review of the entries in these databases suggests that, of the non-domestic terrestrial biota, mammals (e.g., mule deer, cottontail rabbit, black-tailed jackrabbit, mouse species) have been the most frequently sampled. Information on contaminant concentrations in wild terrestrial birds appears to be particularly sparse (recognizing that some measurements are available for pheasant and quail). The limited availability of exposure information on a broader range of wild avian species is a key factor behind the Trustees' inclusion of the study "Birds: Evaluation of Exposure to Hanford Site Avian Species."

The number of measurements of contaminants in site soils is large; however, many challenges remain in effectively using these data, as well as the terrestrial biota data, in the context of a natural resource damage assessment. Challenges include but are not limited to: the variety of sampling efforts (and associated sampling objectives) associated with the datasets; the need to understand quality assurance issues associated with the various datasets; analytic issues associated with non-detect values; and the absence of sample characterization information in many cases (e.g., sampling depths and geographic coordinates). Studies that rely on this information will need to address these issues during the detailed study design and implementation stages.

Species Distribution and Population/Community Characterization Information

In a natural resource damage assessment, Trustees may choose to evaluate species distributions and population or community metrics to evaluate the extent to which hazardous substances may have affected biota at these levels of ecological organization.

Some information on these topics is available: for example, the River Corridor Baseline Risk Assessment (DOE 2011b) reports community assessment results for terrestrial vegetation and for small mammals. While these data are potentially useful for assessment purposes, preliminary Trustee review has identified important limitations associated with these efforts. For example, the upland plant community comparisons are limited to remediated areas and reference sites; furthermore, site selection was intentionally biased towards sites with an established vegetative community (to ensure an adequate sample collection for contaminant analysis purposes). The scope of a natural resource damage assessment is not limited to remediated locations or to areas where recovery may be better. Community evaluations of unremediated locations, without a bias towards higher ecological quality sites, is important so that Trustees can better understand the extent to which Hanford contaminants in site soils may be affecting or may have affected terrestrial communities.

The RCBRA's small mammal community results also warrant careful scrutiny. This study's primary objectives did not encompass characterizing small mammal community parameters in detail. Only a single campaign's worth of data were collected, which—as recognized by DOE (2011b) —significantly limits the study's ability to characterize population or community attributes. For more discussion on these topics, see "Plants: Assessment of Plant Community Health" and "Mammals: Small Mammal Population Assessment").

DOE's Ecological Monitoring and Compliance Project (EMC) has also included the collection information on terrestrial species. Until 2011, the EMC Project was managed by Pacific Northwest National Laboratory (PNNL) and now is managed by Mission

Support Alliance (MSA). The collected information primarily includes observations of species locations and dates; it includes but is not limited to species such as elk, deer, eagles, sage sparrows, and raptors (e.g., nest locations). For purposes of natural resource damage assessment, this information may be useful in identifying likely locations for biota in the event that future field studies on these species are pursued, but it is not likely to be useful for direct injury determination purposes as the program has not been designed to definitively identify species absence, or to quantify population-level metrics such as abundance.

Other authors have also developed and/or compiled general information on terrestrial species presence at the Hanford Site (e.g., Fitzner and Gray 1991, Downs *et al.* 1993, TNC 1999, Sackschewsky and Downs 2001, and Duncan 2007).

Considering the needs of the injury assessment and limitations on available information, this assessment plan includes studies such as "Invertebrates: Assessment of Terrestrial Invertebrate Abundance", "Birds: Assessment of Avian Abundance and Diversity", and "Mammals: Small Mammal Population Assessment," which are intended to help fill data gaps with respect to terrestrial species population/community characteristics at Hanford.

Toxicity Testing

Trustees frequently include toxicity testing among site assessment activities. Some such testing has been conducted with site media. For example, the River Corridor Baseline Risk Assessment (DOE 2011b) presents the results of soil toxicity tests on Sandberg's bluegrass and on the nematode, *C. elegans*. The results of these efforts provide information that may be valuable in the context of a natural resource damage assessment; however, preliminary review of the approach and results suggests that they also are subject to the same types of limitations as noted above for the RCBRA vegetative and small mammal community data, most especially their focus on testing soils from remediated locations and from areas with healthier vegetative communities.

Altogether, the Trustees plan to undertake additional review of the RCBRA's toxicity testing results and may pursue additional toxicity testing of site media, as described in "Terrestrial Biota: Review of Hanford Toxicity Studies", "Invertebrates: Nematode Toxicity Testing," and "Plants: Native Plant Toxicity Testing" below.

Histopathological Investigations

The Trustees may examine organisms for evidence of physiological injuries including (but not limited to) histopathological impacts. Site-specific information on histopathology of terrestrial species appears to be limited. One such study is an assessment of adult male mule deer reproductive health. In particular, in response to observations of adult male deer with atypical antlers, Tiller *et al.* (1997) conducted research that found these deer to have infertile, atrophied testicles. The authors stated that radiation, natural aging, infectious agents, and genetics were ruled out as causes, while other stressors including heavy metals, herbicides/pesticides/insecticides were unlikely to be causative agents. Plant and fungal toxins were not evaluated.

The study "Mammals: Great Basin Pocket Mouse – Carbon Tetrachloride and Hisopathology" is intended to provide histopathological data on a species that, has a burrowing mammal, has a very different life history than the mule deer, and that may be particularly exposed to carbon tetrachloride in Hanford Site soils.

Additional Investigations

DOE (2011b) evaluated reproduction in cliff swallows, eastern kingbirds, and western kingbirds, but the authors note that predation was sufficiently high as to render interpretation impossible.

In the future, the Trustees may choose to pursue additional avian assessment studies; however, to inform any such potential future research, the Trustees intend to first complete the study “Birds: Evaluation of Exposure to Hanford Site Avian Species.”

IMPLICATIONS OF EXISTING DATA FOR INJURY ASSESSMENT

Given the description above of available information on contaminant exposure and potential terrestrial injuries, the following injury assessment studies have been identified to fill important data gaps. Phase 1 priorities for terrestrial injury assessment focus on organizing the information necessary to better understand aquatic resource exposure and to help guide work plan development for later stages of the injury assessment. Phase 1 priorities therefore include estimating the level and extent of soil and terrestrial biota tissue contamination, estimating baseline contaminant concentrations in soils and biotic tissues, conducting a geostatistical spatial analysis of soil data contaminant concentrations, reviewing the existing soil ecotoxicity testing studies, and assessing the impacts of site remedial activities. Phase 2 and 3 priorities encompass further efforts that would help the Trustees refine their understanding of potential terrestrial injuries. In particular, Phase 2 and 3 efforts include but are not limited to: conducting additional laboratory toxicity testing, gathering information about terrestrial population and community attributes, gathering additional exposure data where gaps are evident, and collecting information on the health of terrestrial biota.

SOILS: COMPARISON TO EFFECTS THRESHOLDS

Objective: (1) To determine potential past, current, and future injuries to soil resources and terrestrial biota based on comparisons of measured soil COPC concentrations to literature-based effects thresholds. (2) To identify COPCs that may be most strongly associated with potential injuries (e.g., by virtue of having a greater magnitude and/or exceedance of effects thresholds). (3) To identify locations with higher or lower levels of exposure to hazardous substances, to help inform site selection in potential future studies.

Need/Rationale: Soils are a key natural resource, providing habitat to numerous terrestrial species. Comparison of contaminant concentrations in soils to appropriate adverse impact thresholds is cost-effective approach commonly undertaken to evaluate the likelihood and potential severity of injury to soils. While comparisons of measured concentrations in soils to thresholds is not, in itself, sufficient to determine and quantify injury in accordance with the DOI regulations, such analyses inform the Trustees’ understanding of the nature and extent of potential injury. Within the context of a cooperative assessment, these kinds of comparisons can provide a basis for reaching agreement on injury determination and/or quantification assumptions. These studies can also help document the existence of a pathway between sources of releases and receptors, and/or may suggest that additional field or lab studies on certain biological receptors/locations/contaminant combinations may be appropriate.

Approach: The study will focus on the Hanford Site and appropriate reference locations. The first component of this task will involve assembling and evaluating available data, and incorporating it into the Trustees' natural resource damage assessment database in accordance with the Data Management Plan and the Quality Assurance Management Plan (HNRTC 2011a, 2011b). Although data on soil concentrations exist, a comprehensive database is not currently available.

The second component of this study requires identification of adverse effects thresholds—i.e., Site-specific and/or generic values from the literature, against which the Trustees will compare contaminant concentrations from the database described above. Building off the preliminary work done by the Trustees, and supplemented by additional literature and/or the results of toxicity testing, the Trustees will develop injury thresholds for each COPC.

This study will include an evaluation of baseline conditions, which will include to the extent possible a characterization of the concentration ranges of hazardous substances expected to be present in Hanford Site soils but for Hanford Site releases. As part of this evaluation, contaminants will be identified as having one or more of the following origins: natural sources, Hanford Site operations, and/or other anthropogenic sources.

SOILS: GEOSPATIAL EVALUATION

Objectives: (1) To identify which surficial soils of the Hanford Site are either more or less likely to have been exposed to potentially injurious contaminant concentrations, and (2) to identify areas where additional soil sampling may be necessary to adequately characterize surficial soil contamination for natural resource damage assessment purposes.

Need/Rationale: The Trustees are concerned that available documentation of releases of hazardous substances associated with Site operations may not be complete. They are specifically concerned about the potential for past aerial emissions to have resulted in the contamination of surficial soils, which may in turn expose biota. The Trustees wish to better understand how comprehensive available information is with respect to surficial soil contaminant concentration measurements, and to evaluate whether—considering typical wind patterns, for example—the spatial extent of sampling is sufficient to have likely identified areas of concern from an assessment perspective. This study will also contribute to the Trustees' determination of exposure pathways to soils.

Approach: The Trustees will work closely with a geostatistician and potentially with additional experts to evaluate available surficial soil contaminant concentration data. The exact approach to be used will be selected by the principal investigator(s) in close coordination with the Trustees, but may include:

- Exploratory analyses of available soil data for visual evaluation of spatial patterns, as well as confirmation of known and potential source locations;

- Global and local, directional and omni-directional variogram analyses of selected soil data for determining spatial correlations along specific directions of interest, such as those aligned with dominant wind directions;
- Estimation techniques designed to identify "hot spots" (i.e., contiguous areas with expected contaminant concentrations in excess of specific thresholds based on selected tolerable errors and/or confidence), such as areas with sparse data situated downwind of dominant wind directions, as confirmed by directional variograms as well as contiguous areas with expected contaminant concentrations below specific thresholds, but upper confidence concentrations in excess of specific thresholds based on selected tolerable errors and/or confidence.

Any "hot spot" areas, if identified, might be reasonable sites to target in field studies of terrestrial biota. Similarly, locations where soil sampling data are sparse but where typical wind patterns , as confirmed by directional variograms, suggest that aeolian transportation may have been more likely, could be identified as priority areas for additional soil sampling, to ensure that significant areas of potential terrestrial contaminant exposure and injury are not overlooked.

The study will manly focus on surficial soils for two reasons: first, because surficial soil concentrations will drive exposures for most terrestrial biota, and second, because aerially deposited contaminants are more likely to be present in the more surficial strata. Of note, however, the need to categorize soil samples by depth may present a technical challenge. In the largest two Hanford Site soil databases identified (i.e., HEIS and GiSdT), sampling depth information is not specified for roughly 80 percent of the soil samples. It may be possible to determine approximate depths of samples through use of sampling method information and/or coordination with the entities responsible for the original sample collection. The appropriateness and reliability of such approximations would be evaluated during the exploratory and variogram analyses of investigated soil data.

Finally, the Trustees recognize that this effort will be informed by an understanding of the locations and general types of known aerial contaminant releases: this knowledge may suggest that specific analysis of the spatial patterns of particular contaminants in particular areas should be prioritized, e.g., given priority to directional variogram analyses of soil data in certain parts of the Site. However, the focus of this analysis will be on drawing conclusions based on available measurements of hazardous substances in surficial soils, rather than reconstructing the history of the Site's aerial emissions.

TERRESTRIAL BIOTA: COMPARISON WITH INJURY THRESHOLDS - TISSUES

Objectives: (1) To determine potential past, current, and future injuries to terrestrial biota based on comparisons of measured tissue concentrations of COPCs to literature-based effects thresholds. (2) To identify COPCs that may be most strongly associated with potential biotic injuries (e.g., by virtue of having a greater magnitude and/or exceedance of effects thresholds). (3) To identify species and/or locations with higher or lower levels of exposure to hazardous substances, to help inform site selection in potential future field studies of aquatic biota.

Need/Rationale: Biologic resources, including terrestrial organisms, are trust resources that provide a suite of essential ecological services. Comparison of COPC tissue concentrations to appropriate adverse impact thresholds is a cost-effective, widely used approach to identify potential biological injuries. While comparisons of measured concentrations in tissues to thresholds is not, in itself, sufficient to determine and quantify injury in accordance with the DOI regulations,[67] such analyses can inform the Trustees' understanding of the nature and extent of potential injury. Within the context of a cooperative assessment, these kinds of comparisons can provide a basis for reaching agreement on injury determination and/or quantification assumptions. These studies can also help document the existence of a pathway between sources of releases and receptors, and/or may suggest that additional field or lab studies on certain biological receptors/locations/contaminant combinations may be appropriate. They may also provide help identify those COPCs that may be the largest drivers of injury (e.g., based on the magnitude and/or extent of threshold exceedances).

Approach: This study will focus on the Hanford Site and appropriate reference areas. The first component of this task will involve assembling and evaluating available data, and incorporating it into the Trustees' natural resource damage assessment database in accordance with the Data Management Plan and the Quality Management Plan (HNRTC 2011a, 2011b). Although data on contaminant concentrations in biota exist, a comprehensive database is not currently available. The Trustees are presently creating a database, ensuring that data are normalized, contain location information where possible, and are presented in consistent units (e.g., convert radiological concentrations to internal radiological dose estimates). This effort may also identify species of interest for which additional data collection may be warranted.

The second component of this study requires identification of adverse effects thresholds, Site-specific and/or generic from the literature, against which the Trustees will compare contaminant concentrations from the database described above. Building off the preliminary work done by the Trustees, and supplemented by additional literature and/or results of toxicity testing, the Trustees will develop injury thresholds for COPCs and species/species guild of potential concern.

This study will include an evaluation of baseline conditions, which will include to the extent possible a characterization of the concentration ranges of hazardous substances expected to be present in selected Hanford Site biota but for Hanford Site releases. As part of this evaluation, contaminants will be identified as having one or more of the following origins: natural sources, Hanford Site operations, and/or other anthropogenic sources.

[67] Chapter 6 provides complete definitions of injury to natural resources. Injury to biological resources can occur when concentrations of hazardous substances exceed action or tolerance levels established under the Food, Drug, and Cosmetic Act (43 CFR 11.62(ii), or when concentrations exceed levels for which an appropriate state health agency has issued directives to limit or ban consumption of an organism (43 CFR 11.52(iii)). However, no such consumption limits or bans have been issued, and for many Hanford Site COPCs, no action or tolerance levels have been established. For these and other reasons, the Trustees expect that this study will focus on comparing COPC tissue concentrations with literature-based adverse effects thresholds, in particular those associated with potential injuries to biota as defined in 43 CFR 11.62(f)(i)).

TERRESTRIAL BIOTA: REVIEW OF HANFORD SOIL TOXICITY STUDIES

Objective: To determine what conclusions may be drawn with respect to injury determination and quantification for terrestrial biota, based on existing toxicity testing data.

Need/Rationale: Soil toxicity testing is a common component of natural resource damage assessments, undertaken to determine the extent to which soils are injured by virtue of causing injury to other natural resources (see 43 CFR 11.62(e)(11)). This effort focuses on the toxicity of Site-specific terrestrial biota. Reliance on existing information can be a cost-effective way to determine injury, and Trustees are well-served to evaluate existing testing approaches and results to determine whether available data are of sufficient quantity and quality to meet assessment needs.

Approach: Documentation of reduced survival, growth, reproduction or other adverse effects arising from exposure of vegetation and/or other biota to hazardous substances in Site soils relative to reference soils is an injury under DOI NRD regulations. Terrestrial soils are a key natural resource, providing habitat for plants and invertebrates that form the base of the terrestrial food chain.

Soil toxicity testing has been undertaken at Hanford. For example (as summarized in Exhibit 7-2), DOE (2011b) reports the results of testing of Sandberg's bluegrass to determine whether remediated waste sites presented an ecological risk to the growth and development of this native grass species. DOE (2011b) also reports the results of 24-hour toxicity tests examining the effects of remediated site and reference soils on the nematode, *C. elegans*. In both sets of experiments, study sites were selected from amongst 85 remediated waste sites documented to have been cleaned up to Interim Record of Decision requirements, representing a mix of minimally disturbed sites as well as highly disturbed sites remediated with backfill.

Some preliminarily identified limitations on these efforts are described below (in "Plants: Native Plant Toxicity Testing" and "Invertebrates: Nematode Toxicity Testing"). This study will involve a significantly more detailed and rigorous review of available information, documenting, compiling and summarizing these and potentially other studies undertaken at Hanford that evaluated the toxicity of Site sediments to biota.

This study will compile and summarize studies undertaken at Hanford that evaluated the toxicity of Site soils to biota. The results of these studies will be carefully reviewed from an NRD perspective. This work should involve evaluation of test acceptability, assessment of test relevance, and determination of adequacy of spatial coverage. It may also involve re-evaluation of test information using alternate approaches (e.g., alternate statistical analyses). The results of this analysis will provide a basis for recommending additional studies that will fill critical data gaps.

PLANTS: NATIVE PLANT TOXICITY TESTING

Objective: To evaluate the toxicity of soils from the Hanford Site to key native plant species.

Need/Rationale: As noted previously, collecting site media and subjecting them to toxicity testing using standardized test organisms is a common component of many natural resource damage assessments. To the extent soil toxicity is shown to exist in such testing, it provides evidence supporting an injury determination to both plants and site soils (e.g., see 43 CFR 11.62(f)(1)(i), 11.62(f)(4)(i)(E), and 11.62(e)(11)). Measurements of contaminants in the tested soils will also contribute to the Trustees' determination of exposure pathways. Study results may inform injury quantification efforts as well.

Healthy plants and plant communities are a critical requirement for proper ecosystem function. Plants are the base upon which the terrestrial food web is structured. Injury to the foundation of the food web can disrupt the interactions between all subsequent trophic levels, fundamentally changing the dynamics of the ecosystem. Thus, the health of the ecosystem as a whole is closely tied to the health of the vegetative community. Plants also serve other important ecosystem functions as nesting habitat and cover, which many other terrestrial species depend upon for survival and reproduction.

Plants are subject to contaminant exposure both through direct contact and uptake or absorption of soil-bound contaminants, as well as through exposure to radiation emitted by contaminated soil. Exposure to contaminants can affect germination, growth, and other endpoints. Standard toxicity tests have been developed and widely used to identify how site-specific contaminated media affects these endpoints as compared to media collected from reference sites and/or artificial media.

The RCBRA (DOE 2011b) includes results of toxicity testing of Sandberg's bluegrass (*Poa secunda*, a native species) to selected site soils. This effort falls short of meeting Trustee assessment needs for several reasons. First, testing in upland areas was limited to seven upland *remediated* waste sites plus three reference sites;[68] however, the scope of a natural resource damage assessment is not limited to remediated locations. For assessment purposes, toxicity testing of unremediated locations is important so that Trustees can better understand the extent to which Hanford contaminants in site soils may be affecting terrestrial plants. Evaluating unremediated areas may also inform Trustees about possible past impacts to vegetative communities at sites prior to their remediation.

The RCBRA's site selection method further reduces the utility of the bluegrass toxicity testing results for a natural resource damage assessment. Specifically, the selection of upland sites was intentionally biased towards areas of good ecological recovery –i.e., areas with an established vegetative community. This bias was intended to ensure adequate vegetative sample collection for contaminant analysis. However, this study design choice makes it impossible to fully understand the extent to which Hanford

[68] Sandberg's bluegrass toxicity testing also included soils from eight riparian "study" sites and eight "rare plant" sites, as well as three riparian reference sites (DOE 2011b).

contaminants in site soils may be affecting native plants: areas with poorer recovery may have soils with greater phytotoxicity but were not tested.

Finally, and independent of the previous considerations, the number of sites evaluated is small, particularly given the large number and disparate history of waste sites and contamination regimes at Hanford. Overall, the scale of the study effort may not be sufficiently comprehensive to adequately characterize the potential phytotoxicity of Hanford vegetation to site soils. For all these reasons, the Trustees believe that additional soil toxicity testing of vegetation is warranted.

Approach: After evaluating available toxicity test data generated and collected for the Hanford Site Risk Assessments from an NRD perspective, additional toxicity tests may be warranted. Ideally, this study could include a diversity of sites representing off-site control sites, remediated sites, and those where cleanup actions have not yet been implemented. The sites should also represent the likely range of contaminant conditions and mixes to which flora have been exposed over the years.

Study elements are expected to include the identification of test species, the selection of test media (soil) across a range of contaminant concentrations, the use of appropriate control growth media, and the measurement of endpoints. Endpoints may include seedling survival, seedling height, tissue chlorosis and necrosis, numbers of leaves, above- and below-ground biomass, and photosynthetic activity, among others. Soil properties will also be measured. Where contaminant concentrations are to be measured, investigators will take care to select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

PLANTS: ASSESSMENT OF PLANT COMMUNITY HEALTH

Objective: To evaluate the health of the plant communities across the Hanford Site in comparison to suitable reference locations.

Need/Rationale: This study will support an injury determination to Hanford Site plants and may inform injury quantification efforts to this community in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(3). Measurements of contaminants in site soils and plant tissues will also contribute to the Trustees' pathway determination for these natural resources.

As noted previously, healthy plants and plant communities are a critical requirement for proper ecosystem function. Toxic substances have the potential to reduce cover and to cause changes in plant community structures. Contamination can result in significant changes to the composition and health of plant communities.

The RCBRA (DOE 2011b) included a plant cover and diversity survey; however, this effort falls short of meeting Trustee assessment needs for several reasons.

First, RCBRA community evaluations in upland areas focused on 20 *remediated* sites and 10 reference sites;[69] however the scope of a natural resource damage assessment is not limited to remediated locations. For assessment purposes, Trustees are interested in understanding the extent to which Hanford contaminants in site soils may be affecting terrestrial plant communities. Evaluating unremediated areas may also inform Trustees about possible past impacts to vegetative communities at sites prior to their remediation.

The RCBRA's site selection method further reduces the utility of the vegetative community testing results for a natural resource damage assessment. Specifically, the selection of upland sites was intentionally biased towards areas of good ecological recovery –i.e., areas with an established vegetative community. This bias was intended to ensure adequate vegetative sample collection for contaminant analysis. However, this study design choice makes it impossible to fully understand the extent to which Hanford contaminants in site soils may be affecting native plants: areas with poorer recovery may have soils with greater were excluded from the study.

Finally, and independent of the previous considerations, the number of sites evaluated is modest, particularly given the large number and disparate history of waste sites and contamination regimes at Hanford. Overall, the scale of the study effort may not be sufficiently comprehensive to adequately characterize the potential phytotoxicity of Hanford vegetation to site soils. For all these reasons, the Trustees believe that additional soil toxicity testing of vegetation is warranted.

Approach: The Principal Investigator(s) responsible for detailed study design will consider in detail the results of the DOE (2011b) plant community work as well as other relevant information as part of developing a carefully-designed survey of plant community health. The study will provide information relevant to evaluating the extent to which plant communities may have been affected by contaminant releases from Hanford. The Trustees will measure the occurrence, composition, and density of plant cover at (and near) an appropriate number of operational and other contaminated areas, and in suitable reference areas. Samples may be gathered to measure contaminant concentrations in tissues and soils, and/or for genetic analysis to evaluate measures of genetic damage consistent with radiation exposure. Soil properties will also be measured.

Ideally, the selected sites should also represent the likely range of contaminant conditions and mixes to which flora have been exposed over the years. Where contaminant concentrations are to be measured, investigators should select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

INVERTEBRATES: NEMATODE TOXICITY TESTING

Objectives: To evaluate the toxicity of soils from the Hanford Site to selected nematodes.

[69] Plant communities in riparian areas were also assessed, at eight "study" sites, eight "rare plant" sites, and three reference sites.

Need/Rationale: As noted previously, collecting site media and subjecting them to toxicity testing using standardized test organisms is a common component of many natural resource damage assessments. To the extent soil toxicity is shown to exist, it provides evidence supporting an injury determination to both nematodes and site soils (e.g., see 43 CFR 11.62(f)(1)(i), 11.62(f)(4)(i)(E), and 11.62(e)(11)). Measurements of contaminants in site soils will also contribute to the Trustees' pathway determination for soils and soil-associated biota. Study results may inform injury quantification efforts as well.

The nematode is a ubiquitous roundworm that lends itself well to soil toxicity testing, and a standard toxicity test, ASTM E2172-01, is widely used for expressly this purpose. The availability of information on this organism, of a standard test for toxicity, and ease of study make the nematode an ideal potential soil toxicity test organism.

DOE (2011b) includes results of toxicity testing of the nematode *C. elegans* to selected site soils. DOE (2011b) did not identify statistically significant differences in survival between nematodes exposed to upland study site soils and those exposed to reference site soils; however, the tested upland sites were limited to 20 remediated waste sites and 10 reference sites.[70] Importantly, the scope of a natural resource damage assessment is not limited to remediated locations. Toxicity testing of unremediated locations is important if Trustees are to understand the extent to which terrestrial invertebrates may be (or may have been) affected by the Site's releases of hazardous substances.

Approach: After evaluating available toxicity test data from an NRD perspective, as recommended previously, additional toxicity tests may be warranted. Ideally, this study could include a diversity of sites representing off-site control sites, remediated sites, and those where cleanup actions have not yet been implemented. The selected exposure regimes should also represent the likely range of contaminant conditions and mixes to which terrestrial invertebrates have been exposed over the years, to the extent possible. The testing could potentially include longer exposures (to be more representative of chronic conditions), and/or might include both lethal and sub-lethal endpoints, such as survival, reproductive success, movement, and/or feeding (Sochová *et al.* 2006). Where contaminant concentrations are to be measured, investigators will take care to select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

INVERTEBRATES: ASSESSMENT OF TERRESTRIAL INVERTEBRATE ABUNDANCE

Objective: To evaluate the abundance of certain terrestrial insects, and potentially spiders, across one more gradients of contamination at Hanford, and examine correlations between these metrics and measures of contaminant exposure. Invertebrate community diversity may also be assessed.

[70] DOE (2011b) also reports the results of *C. elegans* soil toxicity testing at 11 riparian sites adjacent to known contaminated media, seven riparian sites located between operational areas, and three riparian reference sites.

Need/Rationale: This study will support an assessment of injury to terrestrial invertebrates in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(3). Measurements of contaminants in site soils and terrestrial invertebrates will also contribute to the Trustees' pathway determination for these natural resources.

A healthy invertebrate community is fundamental to a healthy ecosystem. Terrestrial invertebrates are prey for small mammals and birds and provide essential ecological services (e.g., pollination). Invertebrate macro-decomposers, such as darkling beetles (*Tenebrionidae*) provide essential nutrient-cycling services in dry land areas (Safriel and Adeel 2005). Møller and Mousseau (2009) reported negative relationships of the abundance of spiderwebs, grasshoppers, dragonflies, bumblebees, and butterflies with background radiation exposure.

Approach: A survey of insect health will evaluate the extent to which insect abundance may have been affected by contaminant releases from Hanford. The Trustees will measure the abundance of insects an appropriate number of operational and other contaminated areas, and in suitable reference areas. Physical samples may be gathered to measure contaminant concentrations in tissues and soils, and/or for genetic analysis to evaluate measures of genetic damage consistent with radiation exposure. Invertebrate sampling may include above- and/or below-ground measures, and could include visual standard point counts, soil sample collection with subsequent processing/sieving and organism identification, pitfall traps, and/or other methods. Habitat characteristics (e.g., soil properties, litter, vegetation characteristics) will be documented at survey sites, as will other information (e.g., external radiation levels).

Ideally, the selected sites should represent the likely range of contaminant conditions and mixes to which terrestrial insects have been exposed over the years. Where contaminant concentrations are to be measured, investigators should select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

BIRDS: ASSESSMENT OF AVIAN ABUNDANCE AND DIVERSITY

Objective: To evaluate the abundance[71] and diversity of terrestrial birds, across one or more gradients of contamination at Hanford and examine correlations between these metrics and measures of contaminant exposure.

Need/Rationale: This study will support an assessment of injury to the avian community, in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(3). Measurements of contaminants in site soils will contribute to the Trustees' pathway determination for these natural resources.

A healthy bird community is also fundamental to a healthy ecosystem. Møller and Mousseau (2007) found relationships between species richness, abundance, and population density of forest birds—particularly those eating soil invertebrates—in relation to Chernobyl radiation. Møller and Mousseau (2010) reported negative

[71] In this context, the common English term "abundance" is intended to encompass any of several potential measures of population size, including abundance, relative abundance, or occupancy.

relationships of the abundance of birds with background radiation exposure, reporting that of the taxa evaluated, birds and mammals showed the strongest effects of radiation exposure. Birds in particular "appear to be the most efficient indicator of low-level radiation" (*ibid*.).

Approach: A survey of bird community status will evaluate the extent to which the avian community may have been affected by contaminant releases from Hanford. The Trustees will measure the abundance of birds in an appropriate number of operational and other contaminated areas, and in suitable reference areas. Specific methods may include line transects or point counts, documenting birds through visual and auditory means. Physical samples may be gathered to measure contaminant concentrations in soils. This study may also include the collection and genetic analysis of bird tissue samples to evaluate measures of genetic damage consistent with radiation exposure. Habitat characteristics will be documented at survey sites, as will other information (e.g., time of day, weather, radiation levels).

Ideally, the selected sites should represent the likely range of contaminant conditions and mixes to which terrestrial insects have been exposed over the years. Where contaminant concentrations are to be measured, investigators should select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

BIRDS: EVALUATION OF EXPOSURE TO HANFORD SITE AVIAN SPECIES

Objective: To evaluate the exposure of selected avian species to Hanford Site contaminants, as indicated through measurements of contaminants in eggs.

Need/Rationale: Birds can be exposed to contaminants in the environment through direct digestion of contaminated media (e.g., water) or, more often, through dietary pathways (i.e., consumption of contaminated food items), yet relatively few direct measurements of contaminants in wild avian tissues are available. Data are especially few for terrestrial birds. This study will contribute to the establishment of a complete pathway between contaminant sources and avian receptors in accordance with 43 CFR 11.63, and may suggest future lines of inquiry with respect to injury assessments of particular species. Focusing on eggs is particularly appropriate, as early life stages tend to be the most susceptible to the effects of many contaminants.

Surveys conducted between 1994 and 1999 documented 221 species of birds on the Hanford Site, bringing the total of known avian species at Hanford to 258 (TNC 1999). Of note, not all documented species breed onsite, and it is only onsite breeders that would be investigated in this study.

Approach: Bird egg analysis can provide a direct indication of contamination to which an organism has been exposed. For this study, the principal investigator(s) will select a suite of bird species based upon criteria including the species' life histories, the technical feasibility of egg collection, and the anticipated abundance of nests onsite and at reference locations. To the extent possible (e.g., without inflicting undue mortality on the population), sufficient numbers of eggs of each species will be collected to allow for statistically rigorous analysis of concentrations of multiple COPCs. Eggs will be collected from a diversity of nests located across areas in various conditions to allow for comparison between locations (e.g., remediated areas, un-remediated areas, and reference areas).

Eggs will be tested for selected COPCs, likely focusing on both lipophilic organic contaminants (as these may be maternally deposited into the yolk), as well as metals that are expected to partition preferentially to shells. Detection limit and sample volume restrictions may result in the need to composite eggs within nests prior to analysis, and will likely limit the total number of contaminants that can be analyzed within a given sample.

We note that depending on the species and COPCs, it may also be appropriate to collect blood and/or feather samples, as recommended by the principal investigators.

MAMMALS: SMALL MAMMAL POPULATION ASSESSMENT

Objectives: To evaluate the abundance[72] of one or more small mammalian species, across one or more contaminant gradients at Hanford, and to evaluate correlations between measures of contaminant exposure and population metrics.

Need/Rationale: This study will inform an injury determination for one or more small mammalian species in accordance with 43 CFR 11.62(f)(1)(i) and 11.62(f)(3). Measurements of contaminants in site soils and mammalian tissues will also contribute to the Trustees' pathway determination for these natural resources.

Small mammals serve an important ecological role in food webs, commonly consuming plants and sometimes invertebrates, thereby filling the role of a primary (or secondary) consumer. Small mammals may themselves be prey to carnivorous mammals and predatory birds. Møller and Mousseau (2010) reported negative relationships of the abundance of mammals with background radiation exposure, reporting that of the taxa evaluated, mammals and birds showed the strongest effects of radiation exposure.

Significant differences in relative abundance, or occupancy, between un-remediated affected sites and control sites can be indicative of a population-level injury to a species.[73] Although difficult to demonstrate in upper-trophic level species with expansive home-ranges, population-level impacts may be more readily identified in smaller mammals that can be easily collected and studied in the field, and that are associated with a small home-range. The RCBRA (DOE 2011b) collected small mammals for the purpose of comparing tissue concentrations in study sites versus references sites. However, this study was designed to support exposure studies in mid-trophic level and broad-ranging species, rather than to identify population-level impacts to small mammals between sites. Further, as recognized by DOE (2011b), the availability of only a single campaign's worth of data collection for the small mammal community significantly limits its usability

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[72] In this context, "abundance" is intended to encompass any of several potential measures of population size, including abundance, relative abundance, or occupancy.

[73] Of note, injury can be determined at the individual organism level: the DOI NRDA regulations do not require injury at the population level to be present in order for an injury determination to be made.

in drawing conclusions on population-level endpoints such as relative abundance, occupancy, or density. One candidate species for this population assessment is the Great Basin pocket mouse. This mouse, primarily an herbivore, is an important native species that serves as prey for many species of animals. As a burrowing mammal, it may be exposed to contaminants present below the surface, and it is the most abundant small mammal found at the Hanford Site (Downs *et al.* 1993). Other mammalian species may also be considered.

Samples may be gathered to measure contaminant concentrations in tissues and soils, and/or for genetic analysis to evaluate measures of genetic damage consistent with radiation exposure. Habitat characteristics will be documented at survey sites, as will other information (e.g., external radiation levels).

Approach: The Principal Investigator(s) responsible for detailed study design will consider in detail the results of the DOE (2011b) small mammal community work as well as other relevant information as part of developing a multi-season field study. This study will examine differences in abundance and density, relative abundance, and/or occupancy of this species between various sites including partially or completely remediated sites, sites where remediation has not yet begun, and suitable reference areas. Study methods may include traps, canine scent surveys, and/or other approaches.

MAMMALS: GREAT BASIN POCKET MOUSE - CARBON TETRACHLORIDE AND HISTOPATHOLOGY

Objective: To evaluate whether Hanford Site Great Basin pocket mice may have been injured as a result of exposure to carbon tetrachloride.

Need/Rationale: This study will inform an injury determination for the Great Basin pocket mouse, a common burrowing mammal found at the Hanford Site in accordance with 43 CFR 11.62(f)(1)(i), 11.62(f)(3), and 11.62(f)(4)(vi). Measurements of contaminants in site soils will also contribute to the Trustees' pathway determination for soils and associated mammals.

As a burrowing mammal, the Great Basin pocket mouse may be more likely than other animals to be exposed to carbon tetrachloride, one of the soil-associated site COPCs. Carbon tetrachloride's primary toxic effect in mammals is hepatotoxicity, causing liver tumors and general liver damage.

Approach: This study will include collecting Great Basin pocket mice from areas known or thought to be subject to higher levels of carbon tetrachloride, as well as from reference areas, to determine whether mice from contaminated locations have a higher incidence of pathology of the liver (and potentially other organs). It is recommended that contaminant levels, including carbon tetrachloride, be simultaneously collected. Because carbon tetrachloride is subject to "rapid clearance from exposed organisms" (ASTDR 2005), measurements of the exposure of mice to this contaminant may be more accurately made through evaluation of levels in site media rather than in tissues.

TERRESTRIAL RESOURCES: IMPACTS OF REMEDIAL ACTIVITIES

Objective: To identify and quantify impacts to terrestrial habitats associated with Site remediation activities.

Need/Rationale: This effort will support the determination and quantification of injury associated with those remedial activities that address Site contamination, in accordance with 43 CFR 11.15(1).[74]

Approach: Quantifying injury to the terrestrial habitat due to site remedial activities will require the Trustees to identify, organize, and summarize extensive information related to several parameters. Specific questions to be addressed with this study include:

- What remedial activities have occurred on site that have generated injuries that are recoverable under CERCLA? Such site activities are likely to include but may not be limited to: landfill construction (for hazardous materials), road development, borrow pit use, and capping, all of which are actions likely to result in temporary or permanent adverse impacts to terrestrial habitat.
- Where are or have these activities been located, and what is the spatial extent of the disturbed or injured habitat? As part of this question, Trustees will consider ancillary disturbance that may have occurred away from the remediation site itself (e.g., associated borrow pits, or roads leading to the site).
- When did remediation of the site begin, and when is full recovery of the habitat's services expected to be restored?
- What was the condition of the site prior to restoration (i.e., what level of services was it providing) and what is the anticipated condition when restoration is complete?

As part of this study, it will also be important to evaluate the likely severity of the identified remedial activities on the affected area(s). Close collaboration with DOE will be important to ensure the accuracy and completeness of information on which this analysis will rely. The Trustees propose to use HEA (discussed in Chapter 5) to quantify these injuries.

TERRESTRIAL RESOURCES: QUANTIFICATION OF LOST TERRESTRIAL ECOLOGICAL SERVICES

Objective: The objective of this study is to quantify the ecological services terrestrial resources (soil and terrestrial biota) have lost in the past and may lose in the future as a result of Site-related contamination.

Need/Rationale: In order to determine the scale and type of restoration actions required to compensate the public, the Hanford Trustees will need to understand the scale and scope of lost services.

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[74] In particular, Trustees may recovery injuries "that are reasonably unavoidable as a result of response actions taken or anticipated."

Approach: This study involves two phases. The first phase consists of compiling information obtained from the geologic and terrestrial biota studies mentioned above. This information will likely include the degree to which sample concentrations exceed identified injury thresholds, toxicity information on the adverse effects of varying levels of contamination, as well as ecological information (e.g., the abundance or distribution of terrestrial species, species community health). The second phase consists of analyzing the compiled data in order to quantify the geographic and temporal scope of ecological services terrestrial resources have lost in the past and may lose in the future. This will involve developing a relationship between Site-related contaminant concentrations and the severity of adverse effects experienced by terrestrial resources as a result of the contamination. The relationship will likely be based on literature information and data from site-specific studies on the toxicity of contaminants of concern as well as information on habitat usage, species abundance, and species diversity. Site-specific contaminant concentrations will then be compared to the developed relationship in order to determine the extent to which Site terrestrial resources have been injured (i.e., determine the estimated service loss).

7.4 VADOSE/ GEOLOGIC RESOURCES

Remedial activities began on the Hanford Site in the early 1990s. These activities have focused on groundwater and soil contamination in the Columbia River corridor. After remedial activities are complete in the river corridor, the focus will switch to the Central Plateau and contamination in the 200 Areas. The majority of Hanford's solid waste burial grounds and underground liquid waste storage tanks are found in the 200 Areas; hence, there is significant vadose (deep soils) contamination in this area. The vadose zone includes soil resources between the surface soils (which are assessed as part of the terrestrial resources described above) and the groundwater resources (described below). Vadose zone soils, and other geological resources, are typically assessed by Trustees as a source and pathway for contamination to groundwater and aquatic resources. Due to the significant volume of contaminants currently present in the Hanford vadose zone, and the potential for these contaminants to injure groundwater and aquatic resources, we include vadose zone/geological resources as a separate resource category to be addressed in the assessment.

Deep vadose zone contamination poses some of the most difficult remediation challenges for the protection of groundwater at the Hanford Site (Chronister 2011).Recently, Hanford officials have been working to integrate groundwater and vadose zone remedial activities and adopt a holistic cleanup approach (Goswami 2011). However, the potential for vadose contamination to impact groundwater resources and ultimately move towards the Columbia River is not well characterized. The study described below is intended to characterize contamination in the vadose zone and the potential for injury due to vadose contamination, based on existing information and models.

OVERVIEW OF EXISTING SITE VADOSE ZONE DATA

Available information on the Hanford Site's vadose zone resources that is of most relevance to the injury assessment includes (a) measurements of hazardous contaminants in the vadose zone, and (b) information on the stratigraphy and geology of the vadose zone.

Measurements of Hazardous Substances and Geology of Vadose Zone

Numerous studies have been conducted at the Hanford Site to characterize the stratigraphy and geology of the vadose zone as well as contamination in the vadose zone. Vadose zone soil data are collected and monitored using geophysical logging of boreholes and soil-vapor monitoring (Hartman 2000). The quantity, location, and movement of vadose contamination and moisture are documented through the borehole monitoring (Hartman 2000). The Groundwater/Vadose Zone Integration Project established a Characterization of Systems Task to organize a set of data, parameters, and conceptual models that could be used to estimate contaminant migration and impacts in the vadose zone. Freeman *et al.* 2001 provides a catalog of data sources describing hydraulic properties important in characterizing the vadose zone. Gee and Ward (2001) found that the transport of a vadose zone plume was controlled by distinct horizontal sedimentary layers at the six and 12 meter depths, and that a change from coarse to fine sand caused significant lateral spreading of the plume. Conceptual models of the vadose zone need to include two- or three- dimensional aspects of transport to adequately capture vadose transport (Gee and Ward 2001).

Vadose zone monitoring and sampling has continued in recent years with carbon tetrachloride soil vapor monitoring in the 200 West Area, tank farm vadose characterization, borehole sampling in C Tank Farm, surface geophysical exploration in part of the S Tank Farm, and geophysical logging as described in the 2010 Monitoring Report (DOE 2011c). More recently, a new operable unit has been created for the deep vadose zone (200-DV-1) to allow for a centralized focus and systematic approach to the challenges presented by the contamination in the deep vadose zone (DOE 2010a). In addition, a site-wide groundwater and vadose zone project was planned by Washington State Department of Ecology Nuclear Waste Program to expedite cleanup of soil and groundwater to be implemented from July, 2011 through June, 2013 (Goswami 2011). The main objectives of the project include developing site-wide groundwater and vadose zone strategy, policy, and integration, deep vadose zone science and technology, and site-wide well installation, monitoring, and decommissioning.

IMPLICATIONS OF EXISTING DATA FOR INJURY ASSESSMENT

Given the information above on the level of existing relevant vadose zone data, the following injury assessment studies have been identified to fill data gaps. Phase 1 priority for the assessment of vadose zone (geologic) resources focuses on characterizing vadose zone contamination and the potential for long-term injury to groundwater and surface water resources due to contaminants that have been released to the vadose zone, as described below. The phase 2 priority study in this section encompasses efforts to evaluate current vadose zone models.

CHARACTERIZING VADOSE ZONE (GEOLOGIC RESOURCE) CONTAMINATION AND THE POTENTIAL FOR LONG-TERM INJURY TO GROUNDWATER AND SURFACE WATER DUE TO CONTAMINANTS THAT HAVE BEEN RELEASED TO THE VADOSE ZONE

In developing this Injury Assessment Plan the Trustees have considered available information on the nature and extent of hazardous contaminants in the environment resulting from releases from Hanford operations. The Trustees have also considered information that can be used to establish the level of past, current, and likely future natural resource injuries and service losses resulting from these releases. There is, however, a great deal of uncertainty as to the potential for long-term future natural resource injuries and services losses that could result from sources of contamination at the site that are not well-characterized. There is also a great deal of uncertainty regarding the likely nature and effectiveness of future remedial actions in addressing these sources of contamination.

In particular, despite current uncertainty, it is estimated that a substantial portion of the hazardous substance inventory at the Hanford Site remains in the vadose zone, so understanding this potential injury is of great importance. For example, there are several existing sources of hazardous contaminants in the vadose zone in the Central Plateau of the Hanford Site (DOE 2011c, Chronister 2011, Goswami 2011). These sources of potential injury may not be fully removed as part of the ongoing site cleanup, pending final cleanup decisions.

Objective: The purpose of this study will be to utilize available information and model outputs to develop an understanding of the likely nature, extent, and timing of natural resource injury, and lost services that could occur in the long-term future. The output of this effort will be subject to significant uncertainties, which should be described in the resulting white-paper and briefing.

Need/Rationale: The Trustee Council will need to determine the expected duration of ongoing injuries, as well as the potential that additional injury could occur in the future, as a result of ongoing sources of contaminants that are not being addressed by ongoing or planned remedial activities. Based on this information, the Trustees may be able to make assumptions about the nature, extent, and timing of future injury, or will identify the need for additional studies to define the nature and extent of such injury.

Approach: A team will be assembled to develop a whitepaper for presentation to the Trustee Council on this topic. This whitepaper will describe (1) significant sources of contaminants in the vadose zone and other geological resources that are not currently addressed by ongoing or planned remedial activities; (2) what is known about the potential future fate of these contaminants; (3) what the likely fate of these contaminants implies for future injury to groundwater resources and the environment of the Columbia River. No new data collection or modeling will be conducted as part of this effort.

EVALUATION OF EXISTING VADOSE ZONE MODELS

Objective: The objective of this study or expert panel is to assess the ability and limitation of currently used models to quantify vadose zone contamination flux in order to determine whether the models can be used to accurately predict the impact of vadose contamination on groundwater resources.

Need/Rationale: A variety of models are used by DOE to quantify contamination flux in the vadose zone. Verifying the accuracy of these models may allow the Hanford Trustees to make an informed decision on whether to rely on the results of the models to help estimate the quantity of injured groundwater in the vadose zone and the impact vadose zone contamination may have on groundwater resources.

Approach: Contamination in the vadose zone is an important component in determining groundwater injury at the Hanford Site due to the threat vadose zone contamination poses to the underlying groundwater resource. An independent evaluation of the models used at Hanford to quantify contamination flux in the vadose zone could provide additional information on the validity of these models, and the re-modeling of vadose zone contamination using three-dimensional models could strengthen understanding of the Hanford vadose zone.

The purpose of this study is to perform an independent assessment of Hanford vadose zone models. A limited-area field experiment within the 200 East Area was conducted to study vadose zone contamination; water was injected into the vadose zone and migration tracked with boreholes. The movement of the injected water was analyzed by comparing simulated distributions of the water using three different simulation tools: 1) upscaling, 2) cokriging/artificial neural network (ANN), and 3) transition probability (TP)/Markov chain (MC) to observe spatial and temporal evolution of the moisture plume. Since moisture retention and unsaturated hydraulic conductivity measurements are sparse, these methods are used to model moisture flow. However, this field injection experiment was very limited in area and volume, and therefore provides data on the unsaturated zone specific only to the zone of the experiment, which represents a miniscule portion of the total Site vadose zone impacted by Site contaminants. Additional vadose zone injection tests and simulations at different locations within the Site will provide information on the quantitative hydraulic properties of the vadose zone across the Site. Such experiments will be relatively costly and time-consuming; therefore, a cost/benefit analysis should be done to determine the net value of such tests. It will be useful to compare the physical hydraulic properties of the previous injection test zones to other important vadose zone areas of the Site (i.e., grain size distribution, saturated hydraulic conductivity, and porosity).

7.5 GROUNDWATER

The Hanford Site has a lengthy operational and remedial history, and as part of that history, a number of existing groundwater studies provide information of potential use in the injury assessment. The studies included in this Injury Assessment Plan either review or build on available information from past efforts and are intended to address key data gaps and/or remaining uncertainties.

Several of the groundwater studies described below could be very costly to conduct. As such, to provide information to support a decision on whether to undertake such studies, the Trustees propose to firm complete an analysis of the legal, political, economics, and hydrological contexts which define the baseline for groundwater at the Hanford site. This will include developing a general understanding of the scope and scale of services that may have been lost. This understanding will inform the decision to conduct additional groundwater characterization efforts. In addition, in some cases the Trustees may reach a determination that the information which would be provided by a study will be limited; in those cases, the Trustees may choose to rely on reasonable assumptions in place of values or information developed through primary research.

To provide context for the proposed groundwater injury studies, the following paragraphs briefly summarize key data that have resulted from past investigations of the Site's groundwater resources and are intended to generally characterize the larger research context into which the proposed studies will fit.

OVERVIEW OF EXISTING SITE GROUNDWATER RESOURCE DATA

Available information about the Hanford Site's groundwater resources that is of most relevance to the injury assessment includes but is not limited to: (a) measurements of hazardous substances in groundwater and the vadose zone, (b) measurements of the areal and vertical extent of groundwater contamination, including groundwater plume maps, (c) measurements of aquifer porosity, adsorption effects and matrix diffusion effects, and (d) information on the extent of groundwater upwellings in the Columbia River.

Measurements of Hazardous Substances

As noted previously, the Trustees have identified at least seven partially overlapping databases that contain many measurements of concentrations of hazardous substances in site media. The Hanford Environmental Information Systems (HEIS) database contains the largest numbers of samples of groundwater and soils. HEIS continues to be developed, and HEIS may eventually serve as the repository for virtually all site sampling efforts, past and ongoing. A substantial effort has been underway within this past year to add more data to HEIS; as this effort progresses, it may be possible to rely less on other compilations of contaminant information. In addition to HEIS, databases with information on groundwater resources include the Columbia River Component historic database and the River Corridor Baseline Risk Assessment GiSdT database.

A review of the entries in these databases indicates that existing groundwater samples are distributed across the Site but concentrated around the operational areas (100, 200, and 300 areas). The number of measurements of contaminants in site groundwater is large; however, challenges remain in effectively using these data in the context of the injury assessment. These challenges include but are not limited to: variations in sampling efforts (and associated sampling objectives) associated with the datasets; the level of quality assurance associated with the various datasets; analytic issues associated with non-detect values; and the absence of readily available sample characterization information in some cases (e.g., sampling depths and geographic coordinates). Studies that rely on this information (e.g., those involving comparisons of measured concentrations with thresholds) will need to address these issues through careful study design and implementation.

Measurements of Areal and Vertical Extent

Groundwater resources on Site have been monitored since the late 1940s. Samples are collected monthly, quarterly, or semiannually in wells near regulated waste units, and less frequently from wells farther away from waste sites and operational areas (Hartman 2000). Thousands of samples have been collected from hundreds of monitoring wells, piezometers, and aquifer tubes, distributed across the Site.

The Department of Energy uses groundwater sampling data along with knowledge of Site hydrogeology, waste disposal practices, and chemical characteristics to develop groundwater contaminant distribution maps. These maps are presented in the annual groundwater monitoring reports. Contaminant plume maps have been delineated over the past 30 years, based on information from thousands of samples. However, in many places, there are gaps of two miles or more between wells. Thus, when sampling data are mapped and interpreted for delineating plume boundaries, interpolated concentration contours may be subject to large uncertainty in some locations. The Hanford Trustees are currently working with the USGS to review existing plume maps and estimate their accuracy for assessment purposes (see the "Review of Contaminant Plume Mapping" study described below).

Plume area is one of several parameters needed to reliably estimate the volume of contaminated groundwater; another important parameter is the vertical distribution of plumes. Limited data exists on the vertical extent of plumes. Within the past two to three years, multiple-depth samples have been collected in numerous wells in the Central Plateau (200 Areas) and in the 100 Areas along the Columbia River. Data on the vertical distribution of strontium-90 in the 100-N operable unit, nitrate in 200-BP-5 unit, numerous contaminants in the 200-UP-1 unit, carbon tetrachloride and technetium-99 in the 200-ZP-1 unit, and uranium and trichloroethene in the 300 area is reported in the 2010 Annual Monitoring Report (DOE 2011c). However, data gaps remain pertaining to contaminants and locations which have not yet been characterized, the available data are based on a limited number of wells, and the wells have not been sampled for long enough to establish reasonable temporal trends.

Porosity, Adsorption, and Matrix Diffusion Effects

As part of groundwater monitoring at the Hanford Site for the past 30 years, hundreds of reports have been produced describing the results of hydrogeologic investigations. The Department of Energy used a groundwater model used in the 200 Areas for evaluating potential remediation options, which estimated a 15 percent effective porosity (Central Plateau Version 3 MODFLOW Model, ECF-Hanford-10-0371, 2010). Additionally, Cole *et al.* 1997 reports effective porosity values estimated from specific yields obtained from well-aquifer tests in the range of approximately one to 40 percent, laboratory measurements of porosity ranging from 19 to 41 percent, and tracer tests indicating porosities ranging from one to 25 percent.

Some dissolved contaminants, particularly cations such as strontium-90, adsorb to aquifer mineral grain surfaces. This phenomenon can significantly increase the potential for continued contamination of the groundwater as the adsorbed contaminants dissolve into the water. There has been considerable work at Hanford addressing adsorption processes. For instance, distribution coefficients (i.e., the ratio of concentrations at equilibrium) for a number of contaminants including uranium and strontium-90 are reported in Cole *et al.* 1997.

Additionally, molecular diffusion of dissolved contaminants into low-permeability clay/silt lenses and layers can affect contaminant migration patterns. This process, referred to as matrix diffusion, has an effect similar to that of adsorption/desorption in slowing contaminant migration and delaying remedial actions, such as pump-and-treat systems. Unlike adsorption, matrix diffusion impacts all dissolved contaminants in a similar manner.

Information on Extent of Upwellings

The Trustees have particular interest in the current and expected future movement of contaminated groundwater to the Columbia River. There are a number of known upwelling locations, where Hanford groundwater releases into the Columbia River. As part of the Remedial Investigation of Hanford Site Releases to the Columbia River, surface water, pore water, and sediment samples were collected from 2008 through 2010 to help characterize groundwater upwellings (Hulstrom and Tiller 2010). Upwelling locations were located and mapped using conductivity and temperature measurements. Upwellings were found to be non-uniformly distributed and varied by water depth, season, and proximity to the shoreline (Hulstrom and Tiller 2010). Sampling results also documented hexavalent chromium, strontium-90, tritium, and uranium concentrations in excess of water quality guidelines in both nearshore and offshore locations. However, sampling effort was limited, and further study may be necessary to determine the potential adverse effects from contaminated groundwater upwellings (see “Groundwater Upwelling” study below).

IMPLICATIONS OF EXISTING DATA FOR INJURY ASSESSMENT

Given the information above on the level of existing relevant groundwater data, the following injury assessment studies have been identified to fill important data gaps. Phase 1 priorities for groundwater injury assessment focus on organizing the information necessary to estimate the level and extent of groundwater contamination and the associated restoration requirements, including reviewing existing contaminant maps, reviewing groundwater models, determining the vertical extent of certain plumes, defining the context of baseline groundwater services, and quantifying contaminated groundwater. Phase 2 and 3 priorities encompass further efforts that would help the Trustees refine their understanding of potential groundwater injuries including characterizing the interaction between groundwater and the Columbia River and the impact of vadose zone contamination.

DEVELOPING A COMPREHENSIVE DATABASE AND COMPARISON TO INJURY THRESHOLDS

Objectives: (1) To create a comprehensive groundwater database; (2) to determine injuries to groundwater resources based on comparisons of measured and/or modeled concentrations of Site COPCs to regulatory water quality standards or criteria; (3) to identify COPCs that may be most strongly associated with potential injuries (e.g., by virtue of having a greater magnitude and/or exceedance of effects thresholds); and, (4) to identify locations with higher levels of hazardous substances, to help inform site selection in potential future injury studies.

Need/Rationale: Groundwater is a key natural resource, providing services to humans and serving as a pathway for the movement of contaminants to other resources. Contaminant concentrations in excess of certain levels (e.g., EPA maximum contaminant levels) generally indicate that an injury has occurred under DOI's NRDA regulations (43 CFR 11.62(c)(1)(i) through (iv); see Chapter 6).[75]

A comprehensive database will allow the Hanford Trustees to compare the influence of well location and depth on contaminant plume concentration data in order to make an informed decision on the reliability of well sampling data for use in drawing contaminant plume maps.

In addition, comparing contaminant concentrations in groundwater to regulatory water quality standards or criteria is a cost-effective and widely used approach to evaluate potential groundwater injuries. Furthermore, making comparisons will also contribute to the Trustees' determination of exposure pathways between sources of releases and receptors.

Approach: The study will focus on groundwater beneath the Hanford Site, groundwater upwellings in the Hanford Reach of the Columbia River, and appropriate reference locations. The first component of this task will involve assembling and evaluating available data, and incorporating it into the Trustees' natural resource damage assessment database in accordance with the Data Management Plan and the Quality Assurance Management Plan (HNRTC 2011a, 2011b). Although many measurements of groundwater COPCs are available, a comprehensive database for use in damage assessment has not been developed. Developing a comprehensive groundwater database involves gathering and organizing data records and information on groundwater wells, depth, and associated contaminant concentrations. Much of the groundwater data is available in HEIS, and could be collected from HLAN (with QA/QC of the metadata), but this task will involve determining if the HEIS database is comprehensive and sufficient for injury assessment purposes. This database will also allow the Trustees to analyze the impact of well data quality including well siting, construction, and screened interval location, on the sampling and modeling of contaminant plumes to ultimately decide if well data meets injury assessment needs.

The Trustees will also determine the water quality criteria and standards (e.g., Federal drinking water standards, state water quality criteria) against which sample concentrations will be evaluated.

Lastly, this study will require an evaluation of baseline conditions, which will include a characterization of the concentration ranges of hazardous substances expected to be present in groundwater but for Hanford Site releases. As part of this evaluation,

[75] Chapter 6 provides complete definitions of injury to natural resources, including injury determination. Exceedances of certain concentration thresholds is a key component of these definitions but is not the only requirement that must be satisfied.

contaminants will be identified as having one or more of the following origins: natural sources, Hanford Site operations, and/or other anthropogenic sources. In some cases this determination will require new analysis; in other cases available information will be sufficient to make a baseline determination.

REVIEW OF CONTAMINANT PLUME MAPPING

Objective: To review and evaluate existing contaminant plumes, including determining whether the contaminant plume map generation method(s) being used by the DOE and contractors is sufficiently accurate for groundwater injury assessment purposes as defined under 43 CFR 11 as well as whether additional plume maps need to be generated.

Need/Rationale: An assessment of the DOE plume maps is underway and will allow the Hanford Trustees to determine the need for a study to generate revised contaminant plume maps. If DOE plume maps are deemed appropriate for assessment purposes, the Hanford Trustees will be able to use these maps to move forward in assessing the quantity of injured groundwater. If the plume maps are not deemed appropriate for assessment purposes, the Trustees can begin to assess the need for an additional study to map plumes; this might involve the development of an alternative groundwater plume model to estimate various plumes' full extent and volume which would incorporate information on wells, contaminant data, and hydrostratigraphy that are deemed appropriately representative of the Site.

Approach: The Trustees, through the USGS, are evaluating the methods and results of current groundwater contaminant plume mapping at Hanford used to prepare illustrations and ancillary information presented in the annual Hanford Site Groundwater Monitoring and Performance Reports. As a critical part of the evaluation, USGS will independently regenerate groundwater contaminant plume maps, areas, and volumes from original monitoring and hydrogeologic data; evaluate the uncertainty of the original data; and determine the sources of uncertainty in the data that most substantially influence uncertainty in plume maps, areas, and volumes. Once this effort is complete, the Trustees can determine whether the current maps are appropriate for the natural resource damage assessment and whether any additional maps need to be drawn.

DEFINE THE LEGAL, POLITICAL, AND ECONOMIC ENVIRONMENT FOR BASELINE SERVICES PROVIDED BY GROUNDWATER

Objective: The objective of this study is to describe the services that will be provided by groundwater at the Hanford Site under baseline conditions and how these services have been impacted by the release of hazardous contaminants.

Need/Rationale: An understanding of the baseline services provided by groundwater at the Hanford Site, in the context of political, legal, and economic setting is necessary to determine how the services have been affected by the release of contaminants. Once the baseline services and how services have been affected has been determined, the Trustees will be able to identify and scale appropriate restoration projects to restore or replace those lost services. As noted above, this information will also help support decisions regarding the value and need for additional groundwater injury studies.

Approach: This study should be undertaken prior to other groundwater studies, in order to provide the necessary context on groundwater baseline services which will help scope subsequent studies. This study will involve the development of a white paper that describes the services that will be provided by groundwater at the Hanford Site under baseline conditions, and how those services have been impacted by contamination. The paper should address the full range of services, including use, non-use, and in situ services. This paper should also address the institutional, policy, legal, economic, and hydrological factors that define how groundwater will have been used absent contamination.

VERIFYING VALIDITY AND LIMITATIONS TO HANFORD GROUNDWATER MODELS

Objective: To verify the validity of Hanford groundwater models, to support a quantification of groundwater injuries.

Need/Rationale: A variety of models are used by DOE to estimate current, past, and future injured groundwater. Verifying the accuracy and validity of these models may allow the Hanford Trustees to make an informed decision on whether to rely on the results of the models to help estimate the quantity of injured groundwater on Site.

Approach: In a natural resource damage assessment, injury to groundwater resources can be quantified in physical units, such as an annual sustainable yield, a flux, or as a volume. Models frequently play a critical role in this quantification: data on past contaminant levels may be few or absent (but may be approximated through models), and models are also necessary to estimate future concentrations. Groundwater computer models have been applied at the Hanford Site to examine and simulate groundwater flow patterns, water budgets, aquifer responses to hydraulic stresses, migration of contaminant plumes, and the performance of groundwater remediation systems. These models are helpful in interpolating hydrogeologic conditions between wells, conducting sensitivity analyses regarding data gaps, prioritizing future data gathering steps, testing remediation alternatives, and in assessing exposures and groundwater injury under various assumed scenarios. In general, MODFLOW (a groundwater flow modeling code), coupled with a contaminant transport code, and STOMP are the modeling codes generally used at Hanford.

Since these models are essential in estimating contaminant plume volumes, an independent assessment of the groundwater models used at Hanford will provide additional validation of the current assumptions, parameters, and application of the models including what they should not be used for, and if the models are being used and applied appropriately. This validation process could be accomplished through the use of an expert panel. Note that the panel may require a significant amount of time to review existing information and to come to a consensus opinion.

GROUNDWATER UPWELLINGS

Objective: To characterize the distribution, frequency, and volumetric flow rate of a few known contaminant upwellings in the Columbia River in order to assess the potential for exposure pathways and injury to aquatic biota.

Need/Rationale: Defining the distribution, frequency, and volume of a few known contaminant upwellings in the Columbia River will allow the Hanford Trustees to estimate the potential adverse effects to aquatic biota in the River, in accordance with 43 CFR 11.62(c)(iv) , as well as the need for further study.

Approach: Groundwater upwellings in the Columbia River can adversely or beneficially affect aquatic biota, depending on contaminant levels in the upwelling water. However, the nature, extent, frequency, and volume of these upwellings in not well known. Hanford Site groundwater upwellings have been studied through pore water sampling as well as sediment and surface water sampling, the results of which can be found in the Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, WCH-380 (Hulstrom and Tiller 2010). An assessment of groundwater upwelling pore water data is presented in the Data Quality Assessment Report for the Remedial Investigation of Hanford Site Releases to the Columbia River, WCH-381 (Hulstrom 2010). Samples were taken from the 100-B/C, 100-K, 100-N, 100-D, 100-H, 100-F, Hanford townsite, and 300 Area to characterize groundwater upwellings, and upwellings were found in all study areas (Hulstrom and Tiller 2010). However, groundwater upwellings were not uniformly distributed across the study areas and changed with water depth, season, and proximity to the shoreline (Hulstrom and Tiller 2010).

Although the above mentioned sampling of pore water, surface water, and sediment has provided information on chromium upwellings in the Columbia River, questions remain on the distribution, frequency, and volumetric flow rates of upwellings and past estimates could be strengthened based on new information. Improvements to the digital elevation model for the Columbia River channel, new detail on the stratigraphy near the river, and riverbed pore water sampling results could be used to further the accuracy of chromium upwelling estimates. Additionally, more precise measurements of net gains or losses in river discharge rates along the reaches impacted by Site groundwater could also further Trustee understanding of Hanford upwellings. A chromium upwellings study could more accurately characterize the spatial and temporal distribution of known upwellings, area and resources influenced by the known seeps, as well the frequency of seepages.

The Trustees may also elect to phase this study to better understand the ability of the study to achieve its objectives, prior to deciding to proceed with a full-scale implementation effort.

SYNOPTIC SAMPLING OF RIVER CORRIDOR WELLS

Objective: To sample selected river corridor wells at varying river stages to determine the influence of river stage on groundwater depth readings.

Need/Rationale: Understanding the effect of river stage on groundwater depth readings will allow the Hanford Trustees to decide whether well readings near the river are accurate and appropriate for use to estimate plume maps and pathways near and beneath the river for the purposes of groundwater injury determination and quantification.

Approach: The Columbia River stage changes drastically within short time periods and could affect groundwater well readings. Understanding the relationship between groundwater depth and river stage will help to determine the reliability of groundwater data for developing plume maps, and whether the river stage and therefore timing of groundwater sampling significantly affects groundwater plume estimates. Samples will be taken from multiple wells within one hour and from wells at high, middle, and low river stages to determine the impact of the river on well water levels.

VERTICAL DISTRIBUTION OF CONTAMINANT PLUMES

Objective: To construct additional multi-depth monitoring wells in key areas of several of the major plumes and to sample the wells for several years in order to obtain information on the vertical depth of the significant plumes to inform injured groundwater volume calculations.

Need/Rationale: Information on the vertical depth of many major plumes on the Hanford Site is lacking. This study will provide additional information on the vertical depth of contaminant plumes, useful information used to estimate the volume of contaminant plumes for injury assessment.

Approach: One of the major uncertainties in assessing injured groundwater volumes on Site is the sparseness of vertical sampling data within all of the significant contaminant plumes. There are a limited number of samples from different depths within some areas of plumes in the 200 West, 200 East, 300-FF-5, 100-HR-3, and 100-NR-2 operational units (as described in the 2010 Groundwater Monitoring Report, DOE 2011c). However, vertically spaced sampling has been done only since 2009, which is insufficient temporal coverage, as well as spatial coverage to enable accurate delineation of three-dimensional plume configurations. Without adequate three-dimensional data, assumptions must be made regarding plume boundaries which can result in over-estimates of injured groundwater volumes. Additional collection of spatial and temporal plume thickness data will increase the accuracy of plume volume estimates. This will likely require construction of several more multi-depth monitoring wells at key areas of several plumes, and an additional period of sampling of the multi-depth wells for a number of years. Installation and monitoring of several more multi-depth monitoring wells will be highly costly.

GEOLOGY OF COLUMBIA RIVER BED

Objective: The objective of this study is to characterize the geology of the Columbia River bottom in order to determine the potential impact of plumes near and beneath the river and contaminant upwellings in the River, as well as the potential for contaminants to migrate into groundwater on the non-Hanford side of the River.

Need/Rationale: Information on the geology of the Columbia River will allow the Trustees to more accurately map groundwater plumes near the River as well as determine any potential for groundwater plumes to affect riverine resources or locations on the non-Hanford side of the River (i.e., the Trustees will be able to more accurately determine the scale and scope of groundwater injury near the River). However, groundwater upwelling characterization (described in the upwelling study above) may provide adequate information for assessment purposes; thus, this study is a lower priority for the Trustees and may need to be re-evaluated after the upwelling is completed.

Approach: The geologic stratigraphy of the Columbia River bottom is not well known. Faults and other geologic structures can offset the hydrostratigraphic units, complicating interpretation of groundwater flow under the river. Drilling boreholes on river islands, seismic and electro-magnetic profiles, and geophysical surveys across the River could define the river bed stratigraphy, provide information to compare hydrostratigraphy and bank geology, provide information for correlating and interpreting geology between wells, and aid in the interpretation of groundwater flux and riverine upwellings. Measurement of hydraulic heads beneath the River bed will help define three-dimensional hydraulic gradients under the River.

QUANTIFY INJURED GROUNDWATER VOLUME AND TIME DIMENSIONS

Billions of gallons of contaminated wastes have been discharged on the Hanford Site, resulting in contaminated groundwater above drinking water standards. The groundwater on Site provides a range of services, which have been impacted due to the contamination. The metric chosen to quantify these losses depends on the type of services affected.

Objective: The objective of this study is to quantify injured Hanford groundwater resources.

Need/Rationale: The Trustees will need to understand the quantity of injured groundwater in order to determine the scale of lost services and the types of restoration projects required to restore those losses.

Approach: This study requires an understanding of the range and type of services impacted by groundwater contamination on the Hanford Site. Once these services are identified, the quantity of injured groundwater can be calculated using a stock volume, flux volume or sustainable yield approach as appropriate. Once the injured groundwater is quantified, and the Trustees have an understanding of groundwater baseline, the scale of lost services and type of required restoration projects can be determined.

7.6 TRIBAL USE

As noted in Chapter 4, there are a range of tribal use services provided by natural resources that may have been impacted by releases from Hanford Site operations. While there is a large amount of available information on indigenous peoples use of the site (e.g., information which is used to inform decisions on whether remedial actions will disturb culturally important sites), the Trustees are unaware of any studies that have been done to assess the impacts of the presence of hazardous contaminants on current tribal use of natural resources. This information will be required to complete service quantification for this category of lost use. This information will inform the Trustees understanding of the scale and scope of benefits of potential primary restoration, as well as the scale and scope of any required compensatory restoration. In addition, while there are numerous ongoing efforts to characterize the nature and extent of contamination at the site (see below), the Trustees believe that a more focused effort to determine if additional characterization would allow for greater use of site resources by tribal community members is needed.

ETHNOGRAPHIC STUDY TO IDENTIFY TRADITIONAL CULTURAL PROPERTIES AT HANFORD

Objective: This study will identify Traditional Cultural Properties (TCPs) within the Federal government's jurisdiction of the Hanford assessment area. Any Federal undertaking that has the potential to affect Federally-listed (and/or eligible for listing) cultural resources, including TCPs[76], must be evaluated, as mandated under the National Historic Preservation Act (NHPA) Section 106. Such actions could include assessment and restoration decisions associated with natural resource damage assessments. As such, identification of TCPs must first occur, as mandated under NHPA Section 110. Therefore, this study will be conducted to identify TCPs within the "area of potential effect" (APE) for the assessment, which is a Federal undertaking at Hanford. This effort will support assessing Tribal Lost Services and making decisions regarding the scale and scope of primary and compensatory restoration.

Need/Rationale: In compliance with NHPA Sections 106 and 110, DOE must identify the properties within their jurisdiction that qualify for listing as cultural resources in the National Register. While archeological sites may not be affected by the injury assessment, TCPs could be affected by the decisions made within the process. TCPs are generally eligible under any (or all) of the following three criteria (of four total):

> The Trustees recognize that multiple activities and actions at the Hanford Site may trigger requirements under the NHPA: in particular, actions outside of the NRDA may generate the need for information on TCPs. The Trustees acknowledge that NRDA may or may not be the correct legal and financial structure within which to pursue these activities, and that further discussions are needed to determine the best method to accomplish the work. That acknowledged, the Trustees have included this study in the this Plan in recognition of the importance of TCP identification, and to note that the natural resource damage assessment may provide an opportunity to systematically address concerns regarding the impacts of site operations and cleanup, including the assessment and subsequent restoration actions, on TCPs.

- Property is associated with events that have made a significant contribution to the broad patterns of our history.
- Property is associated with the lives of persons significant to our past.

[76] For further definition, refer to the National Park Service National Register (NR) Bulletin 38 (Guidelines for Evaluating and Documenting Traditional Cultural Properties).

- Property has yielded or may be likely to yield information important in prehistory or history.

A property (TCP) must maintain integrity, which is "the ability of a property to convey its significance" (NR Bulletin 15). There are seven aspects of integrity: location, design, setting, material, workmanship, feeling, and association. If a project compromises or may compromise any of these characteristics that give a property significance, it is considered to be adversely affecting the property.

The association of a TCP with the traditional belief system and culture of a Native American group is a characteristic that gives it significance. "A traditional cultural property then, can be described generally as one that is eligible for inclusion in the national register because of its association with cultural practices or beliefs of a living community that (a) are rooted in that communities history, and (b) are important in maintaining and continuing cultural identity of the community" (NR Bulletin 38). TCPs are culturally significant for a number of reasons for Native American groups: locational setting (including associated natural resources such as water, soil, plants, etc.), feeling, and association. By not fully restoring a TCP or installing institutional controls (e.g., when leaving contamination in place) that prohibit the Affected Tribes from utilizing the TCP, the association, setting, and feeling have been adversely effected. Adverse effects to TCPs must be mitigated.

Approach: TCPs cannot be discovered through archaeological or historical research alone. The existence and significance of such locations can only be ascertained through interviews with knowledgeable users of the area or through other forms of ethnographic research (NR Bulletin 38).

This study to identify TCPs is needed to determine if any properties that are within the project area (the entire Hanford site) will be adversely affected by the injury assessment and other related NRD activities. This study must be conducted by a trained professional meeting Secretary of Interior Standards.

ASSESS TRIBAL SERVICE LOSSES

As discussed in Chapter 4, there are a range of services provided by natural resources to tribal communities. These services may have been diminished in quality, or interrupted, by the presence of contaminants released by Hanford operations. As a result, specific restoration actions may be required to address these service losses. In Chapter 5, we discuss several approaches that could be used to assess the nature and extent of tribal service losses associated with contaminant releases. This information could be used to support Trustee decision-making regarding the scale and scope of primary and compensatory restoration.

Objective: This study is intended to identify natural resources and the nature and extent of services that they provide which are important to the health, welfare, economy, tradition, and cultural integrity of tribal members in the assessment area. Tribal lost services will then be assessed by selecting and implementing appropriate approach(es) to fill data gaps and determine Tribal service loss associated with Hanford contaminant releases. This information ultimately will be used to support decision-making regarding the scale and scope of potential primary and compensatory restoration for lost tribal use services.

Need/Rationale: Natural resources in the Hanford assessment area provide many services to tribal members in ways that are distinct from the general public, including social, cultural, spiritual, medicinal, recreational, and subsistence services, uses, and values. Examples include collecting sacred or medicinal plants; participating in subsistence and ceremonial fishing, hunting, and gathering; conducting ceremonial drinking, bathing, and sweating; and using sacred grounds for meetings, ceremonies, and spiritual recognition. The lives of tribal members are intricately linked to the natural resources in the assessment area; when one or more resource, such as surface water, plants or animals, is contaminated by the releases of hazardous substances, the ability of the environment to support subsistence and traditional uses can be diminished.

> "The Yakama subsistence lifestyle, including fishing, hunting, and plant gathering; use of traditional foods, medicines, and materials; sweathouse use, feasts, and other cultural practices, depends upon safe, unrestricted access to clean natural resources in the Hanford Assessment area year round in perpetuity" (*Yakama, 2010*).

The resources that are used by tribal members, particularly those that support the cultural integrity and continuity of each Tribe, must be identified, including those that would have existed and been used by tribal members in the absence of Hanford releases. Compilation of existing materials and a critical review of the documentary record will identify what data are most useful and necessary for the injury assessment to identify the link between Hanford contaminants, injured resources, and service losses. During this process, the Tribes will propose and then undertake approaches they deem appropriate for collecting additional information and assessing changes in the use of natural resources by tribal members that have occurred as a result of the presence of contaminants from Hanford operations. This effort will distinguish changes in natural resource services to Tribes at the Hanford site that are unrelated to contaminant releases from those that are the result of the presence of contaminants.

Approach: Tribal Trustees will collectively or independently develop and implement individual study plan(s) to: 1) review available information related to tribal services, 2) assess the nature and extent of tribal lost services, and 3) develop information to determine the appropriate scope and scale of restoration options to restore such losses. This effort will need to address confidentiality of tribal information. The following specific tasks will be identified in the individual study plan(s), which may be customized according to the needs of each Tribe:

- Identify, compile, and review existing literature and historical data as they relate to natural resources and associated tribal services now and prior to Hanford contaminant releases (i.e., baseline), including historical reports, scientific papers, oral histories, etc.

- Evaluate the compiled information and determine what sensitive information shall not be released, what information is necessary for assessing tribal service loss (and may require data sharing agreements), and what information is still missing that will help link Hanford contaminants to injured resources and changes in tribal behaviors and services. This effort will result in identification of the information needed (and data available) to assess the nature and extent of tribal lost services and restoration selection and scaling.
- Evaluate and select sound approach(es) to fill gaps and assess tribal lost services, while protecting confidential information.

Following these plans, one or more studies will be implemented to assess tribal lost services due to the release of contaminants, as distinct from other factors that have led to changes in tribal use of resources over time, and identify restoration options and scaling.

CURRENT RESOURCE CHARACTERIZATION TO ALLOW FOR RESTORATION OF LOST TRIBAL SERVICES

Tribal community member use of natural resources at the Hanford Site may be limited by concerns over exposure to hazardous contaminants. While numerous efforts are ongoing to characterize the nature and extent of contamination at the Site (discussed below), the scope of these efforts (geographic, temporal, resource specific) may not be sufficient for tribal community members to make informed decisions regarding their use of resources at the Site. As such additional monitoring and sampling may be needed to allow for restoration of lost services.

As noted, a variety of programs are in place to characterize the nature and extent of contamination in Hanford Site resources, including:

- **Environmental Surveillance Project.** Part of Mission Support Alliance's Public Safety and Resource Protection program, this project monitors the concentrations of radionuclides and chemical and metal contaminants in environmental media including air, surface water, sediment, soil, natural vegetation, agricultural products, fish, birds, and mammals. Monitoring occurs on the Hanford Site, as well as at several offsite locations. External radiation levels are also monitored. Data from this program are reported regularly in the annual Hanford Site Environmental Monitoring Reports (MSA 2012a). Currently, the annual budget for this project is approximately $2,100,000 (DOE 2012c).
- **Soil and Groundwater Remediation Project.** Managed by the CH2M HILL Plateau Remediation Company (CHPRC), this project includes sampling and monitoring of groundwater and soil on-site to characterize distribution of contamination and evaluate the effectiveness of remediation activities (CHPRC, 2012; Poston *et al.* 2010).
- **Drinking Water Monitoring Project.** This program conducts routine monitoring of drinking water supplies on the Hanford Site to ensure compliance with the Safe Drinking Water Act (Poston *et al.* 2010).

- **Biological Control Program.** The biological control program was established to limit the environmental impact of radioactively contaminated or otherwise undesirable plants and animals. As part of this program, radiological surveillance is done to help characterize the extent and distribution of contaminated biota and soil (Poston *et al.* 2010).
- **Near-Facility (Near Field) Environmental Monitoring.** This program monitors environmental media, as well as external radiation levels, around DOE facilities that have released, or have the potential to release, radioactive or hazardous contaminants. Monitored sites include areas around nuclear facilities (e.g., 100-N reactor and the Plutonium Finishing Plant), and waste storage and disposal facilities (e.g., burial grounds and trenches). Resources monitored include soil, air and vegetation (Poston *et al.* 2010). Although this monitoring is currently managed under the Environmental Surveillance Project, historically the annual budget for this monitoring was approximately $500,000 (DOE 2012c).
- **Washington State Department of Health Hanford Environmental Radiation Oversight Program.** This Department of Health program's primary responsibility is providing oversight of DOE monitoring programs designed to characterize the impact of releases of radiation on the public and the environment. The program is itself not intended to provide comprehensive characterization of site contamination, but rather to independently verify the characterization work being done by DOE. Results of the program's work are published annually in a Data Summary Report (WDOH 2012). Currently, the annual budget for this oversight program is approximately $764,000 (DOE 2012c).
- **Hanford Long-Term Stewardship Program.** This program was established to manage DOE's post-cleanup obligations. One of the key activities of the program will be the surveillance and maintenance of physical remedies and institutional controls to ensure continued protection of human health and the environment (DOE 2010b).
- **CERCLA Five-Year Reviews.** The five-year review process required under CERCLA calls for additional characterization of sites where contaminants remain at levels that preclude unrestricted use of an area. Additionally, it will evaluate the effectiveness of completed remedies to determine if those remedies continue to be protective of the public and the environment. These reviews will be conducted by the Hanford Long Term Stewardship Program (DOE 2010b).
- **Ecological Monitoring Project.** Part of Mission Support Alliance's Public Safety and Resource Protection program, this project monitors the abundance, condition, and distribution of biota on the Hanford Site. Note that this program is focused on population-level conditions of biotic resources, rather than concentrations of contaminants within individual specimens (MSA 2012b).

In addition to the established long-term monitoring programs described above, several recent and on-going efforts have included comprehensive characterization of the Hanford Site and its resources. These efforts include:

- **Remedial Investigation of Hanford Site Releases to the Columbia River:** Samples collected between 2008 and 2010 (and approximate sample numbers reported in the Columbia River Component [CRC] database) included aquifer tubes (3,000), pore-water (400), surface water (600), sediment (1,200), soil (100), and fish (1,000) (DOE 2010c).
- **River Corridor Baseline Risk Assessment (RCBRA):** Samples collected as part of the RCBRA (and approximate sample numbers reported in the Guided Interactive Statistical Decision Tools [GiSdT] database) included soil/sediment (9,500), surface water, including seeps, springs, aquifer tubes, and pore-water (3,500), groundwater (13,000), and biota (200) (Neptune and Company Inc. 2009).

This study will consider these existing characterization efforts, assuring that additional characterization is not duplicative of these efforts.

Objective: There are a number of ongoing efforts to characterize and monitor contaminant concentrations within the Hanford study area. This study will define how to better organize and present this information for use by the tribal publics as well as the general public. It will also identify where additional characterization of contaminant concentrations would allow for restoration of tribal lost services. This effort will require close coordination with tribal community members and resource managers to fully understand tribal concerns and information needs.

Need/Rationale: A significant concern of the tribal Trustees for natural resources at Hanford is an absence of sufficient characterization of contaminant concentrations in natural resources. This information is needed by tribal resource managers to inform decisions by tribal members who are interested in utilizing resources at Hanford, but want to assure that these uses are safe.

Approach: Following response actions and/or primary restoration efforts, characterization of natural resources will be required to monitor the safety of the natural resources and to allow for restoration of tribal services. Some of this characterization is already taking place, but additional actions may be needed. This additional characterization would include organization of existing information, as well as gathering of additional information on the nature and extent of residual contamination and condition of injured resources. The scope and scale of characterization required to restore tribal use of the site needs to be determined and compared against information from existing characterization efforts (e.g., determine what media to monitor, where to monitor (and density of samples), and frequency and duration of sampling).

In addition to any monitoring plans associated with remedial activities and long-term stewardship plans, which rely heavily on the expectation of institutional controls, additional characterization may be undertaken by the Tribes to verify whether tribal use services can be confidently resumed. This effort would include developing Sampling and Analysis and Quality Assurance Project Plans, conducting field sample collection and laboratory analysis activities for all resource types in terrestrial, riparian, and aquatic zones, and conducting adaptive management, as necessary.

The factors that will need to be determined in this study are:

- Do existing sampling and characterization efforts provide enough information and the right type of information to inform tribal member use?
- How would this information be better assessed and presented for use by tribal members in making decisions about resource use? What is the most effective means to communicate this information to the public?
- What additional information is needed? Over what time period?
- What is the most cost-effective means to obtain additional characterization information?

7.7 OTHER HUMAN USES

As discussed in Chapter 4, based on review of existing information, the Trustees are proposing a study to fully describe the past, current, and future geographic and temporal scope of contaminant-related institutional controls which could impact human use of natural resources at the site. At this time the Trustees are not proposing additional study of the effect of site releases on agriculture or a detailed study of recreational behavior. While this information exists, it has not been compiled in a manner sufficient for injury quantification.

INVENTORY OF INSTITUTIONAL CONTROLS RELATED TO THE RELEASE OF HAZARDOUS SUBSTANCES, AND DESCRIPTION OF ASSOCIATED LIMITS ON HUMAN USE OF THE SITE

Objective: To determine the extent to which institutional controls at the Hanford site, past, current, and expected future, are related to the release of hazardous contaminants. To define the geographic scope and nature of these controls, and describe the types of human uses that may be impacted.

Need/Rationale: The primary source of non-tribal lost human use opportunities at the Hanford site will be associated with institutional controls made necessary by the presence of hazardous contaminants released from site operations. These controls may relate to areas of the site that will be subject to access restrictions, as well as limitations on the use of specific resources (e.g., groundwater). These restrictions may result in quantifiable injury. Based on this study, the Trustees will be able to determine if additional analysis of the likely change in the scale and scope of human use of the site from baseline conditions is called for.

Approach: An inventory of institutional controls will be developed. These controls will be screened to determine if they are related to the presence of a hazardous contaminant released from Hanford operations. A set of maps will be developed that presents these controls, for past, present and expected future conditions. Once this inventory is completed, the nature of any expected change in human use will be described.

7.8 ALL RESOURCES

TREATMENT OF NON-DETECTS IN STUDIES ANALYZING EXISTING DATA

Initial data evaluations conducted by the Trustees to date have determined that a substantial number of available records identifying contaminant concentrations in various media in key sites databases (specifically, HEIS) are identified as "non-detects." The value that is reported for records that are identified as non-detects is dependent upon the type of reporting limit reported by the lab that conducted the analysis. Values reported may be the Adjusted Reporting Limit, Estimated Quantitation Limit, Instrument Detection Limit, Method Detection Limit, Practical Quantitation Limit, or Required Detection Limit (DOE 2007b). Occasionally the value may simply be reported as "0" or some number < 0.

While it is not necessarily clear from the record documentation what value specifically is reported for each record, we can generally assume that the actual concentration of the contaminant in question is something less than the value reported. The issue of non-detects becomes particularly problematic in cases where the value being reported exceeds a selected injury threshold, numerically suggesting injury although the analyte was not detected. Initial data evaluations have identified this situation in a number of media/contaminant pairings, including antimony in sediment, mercury in fish tissue, and chromium in soil. Alternately, if a detection limit exceeds an identified injury threshold, a reported value (e.g., if listed as zero) may suggest an absence of injury, even though the actual analyte's concentration may have exceeded an injury threshold.

Records identified as "non-detects" represent valuable historical information that cannot be replicated. Thus, the Trustees prefer not to simply remove these data from the analysis but rather wish to identify the most appropriate treatment of these. Although it can be tempting to simply use the reported value or use some proportion of the detection limit, for most applications, "substitution" approaches have been severely critiqued (e.g., Helsel 2010).

Objective: Determine the most appropriate way to treat samples identified as non-detects within analyses that rely upon historical data, and develop recommendations for additional data collection efforts.

Need/Rationale: Because of the substantial number of contaminants measured as non-detects, the Trustees need to develop a method to both utilize these data and reduce uncertainty in data analyses.

Approach: For each study that relies upon the analysis of historical data, the Trustees will evaluate a variety of options for handling non-detect sample results within each analysis. As a detailed analysis of non-detect samples for every media type and contaminant in each individual study area will not be feasible, the Trustees may prioritize detailed evaluations of non-detects in cases where:

- The extent of non-detects included within the group of samples to be analyzed is substantial (e.g., > 30 percent of available samples); and/or,

- The reported value of non-detect samples frequently exceeds the lowest identified injury threshold for a given contaminant/media type pairing (e.g., the vast majority of PCB sediment samples are non-detects and the reported values are above injury thresholds); and/or,
- The detection/reporting/quantitation limit value (where known) exceeds the lowest identified injury threshold for a given contaminant/media type pairing; and/or,
- Other evidence (e.g., toxicity testing results) indicates that injury to a specific resource due to a given contaminant is likely.

Evaluation of existing samples identified as non-detects may also indicate that additional data collection is warranted to adequately characterize the present state of the resource. In these instances, investigators will take care to select laboratory methods whose detection limits are sufficiently low such that the lowest detectable concentration of a contaminant does not exceed levels that have been identified as injurious.

CHAPTER 8 | QUALITY ASSURANCE MANAGEMENT

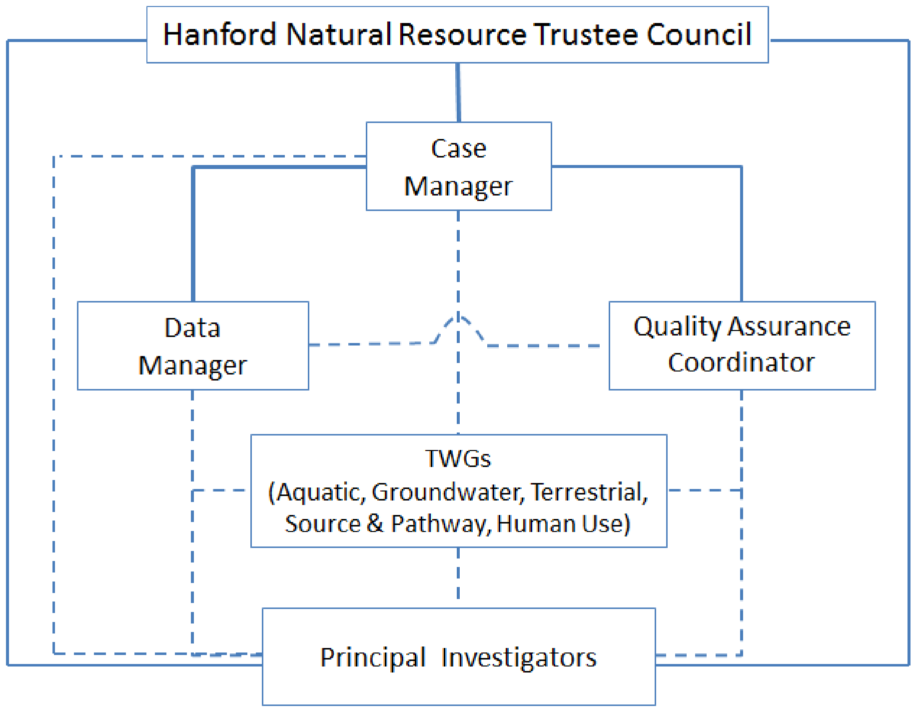
The DOI NRDA regulations require the Trustees to develop a Quality Assurance Plan (QAP) that "satisfies the requirements listed in the NCP and applicable EPA guidance for quality control and quality assurance plans" (43 CFR 11.31(c)(2)). The Trustees recognize the importance of data quality: many of the management decisions involved in accomplishing the Hanford natural resource damage assessment ultimately require the use of environmental data. The collection, compilation, evaluation and reporting of environmental data are necessary to perform the functions of the assessment. It is necessary that the origin and quality of the data used to make these decisions is properly documented so that data gaps may be identified; assessments of the severity, location and extent of injury are accurate; and thus, appropriate decisions may eventually be made as to the needed type and scale of restoration actions.

The Hanford Trustees have developed a Quality Management Plan (QMP) in order to document the Trustees Quality Systems and to provide a blueprint for how the Trustees will plan, implement, and assess its Quality Systems for work performed by or on behalf of the Hanford Trustees. Consistent with EPA (2001), the Trustees' QMP (HNRTC 2011b) presents the organizational structure, functional responsibilities of management and staff, lines of authority, and required interfaces for those planning, implementing, and assessing all activities conducted under the assessment. The following paragraphs summarize key elements of this Quality Management Plan, including the requirement that natural resource damage assessment work plans include project-specific Quality Assurance Project Plans (QAPPs).

8.1 PROJECT MANAGEMENT

Exhibit 8-1 shows the quality assurance management organization for the Hanford natural resource damage assessment.

EXHIBIT 8-1 QUALITY ASSURANCE MANAGEMENT ORGANIZATION FOR THE HANFORD NATURAL RESOURCE DAMAGE ASSESSMENT



Solid lines – formal lines of authority
Dashed lines – advisory/coordination

The Trustees have overall program management responsibilities for the natural resource damage assessment including data quality management. The Case Manager is responsible for the management and communication of specific quality assurance activities with advisory input from the Technical Working Groups (TWGs). TWGs also work closely with Principal Investigators in the technical design of work plans to help ensure that these documents meet the Trustees' needs. The Data Manager is responsible for assembling documents and data collected in support of the assessment (both current and historical) in an accessible and complete format for assessment purposes. Principal Investigators are responsible for project-specific design and implementation of the quality assurance/quality control (QA/QC) activities. The Quality Assurance Coordinator oversees QA program implementation, contributing to the work plan development, data review, and documentation processes. Specific responsibilities of the Hanford Quality Assurance Coordinator include:

- Annually reviewing the Hanford natural resource damage assessment QMP, revising it if changes are necessary, and obtaining appropriate document approvals.
- Overseeing the verification and validation of the historical and newly acquired data for the Hanford assessment.
- Identifying and delegating responsibility for responding to specific QA/QC needs, and ensuring timely answers to requests for guidance or assistance including interpretation of the Quality Management Plan and providing guidance on compliance.
- Ensuring that all work plans, Quality Assurance Project Plans, and standard operating procedures (SOPs) are technically reviewed and approved prior to collection and/or analysis of environmental data.
- Ensuring that problems and deficiencies identified in technical audits and data assessments are resolved.

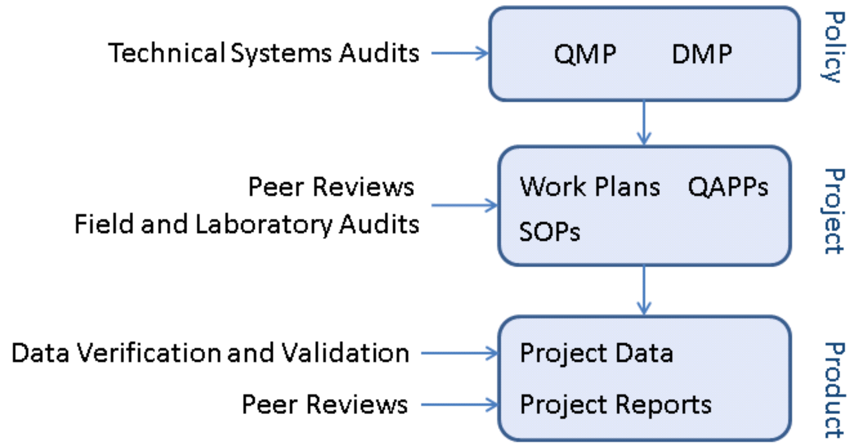
8.2 QUALITY SYSTEM DESCRIPTION

The goal of the Quality System is to ensure that the acquisition and use of environmental data, whether historical or generated under the oversight of the Hanford Trustees, includes sufficient up-front planning and review to ensure data quality is adequate to meet project goals. In order for any data to be useful for the natural resource damage assessment, the data must be of known and documented quality: it must have sufficient supporting documentation such that data users can evaluate whether the data meet their needs. This is achieved by ensuring that adequate quality assurance tools are used throughout the entire data collection and assessment process from initial planning through data usage. The tools used in the Quality System include:

- The Trustees' Quality Management Plan (HNRTC 2011b);
- The Data Management Plan (HNRTC 2011a);
- Work plans including associated Quality Assurance Project Plans that may be developed to support assessment activities;
- Standard Operating Procedures;
- Peer reviews;
- Technical systems audits;
- Field and laboratory audits; and
- Data verification and validation.

Exhibit 8-2 depicts the relationships of these tools to one another. The Technical Working Groups, Data Manager, QA Coordinator, Principal Investigators and appropriate staff participate in and are responsible for the creation and implementation of each of these tools.

EXHIBIT 8-2 COMPONENTS OF THE QUALITY SYSTEM



Quality system components shall be consistent with, and supportive of, project objectives (e.g., they will have a graded approach as described in EPA 2001a). In other words, the level of application of quality system controls to an environmental data program can vary according to the intended use of the results and the degree of confidence needed in the quality of the results. For example, if historical data are being used to support planning for additional sampling, the degree of review and documentation may be less than the degree of review and documentation if historical data are to be used for injury determination.

Specifically, it is the responsibility of the QA Coordinator working with the TWG leads and Principal Investigators to ensure that the following objectives are achieved.

- All environmental data used and generated are of known and acceptable quality for the intended use. The data quality information developed with all environmental data is documented and available within the Data Management System (DMS).
- If new data are to be collected, the intended uses of the data are defined before the data collection effort begins so that appropriate QA measures can be applied to ensure a level of data quality commensurate with the project data objectives. The determination of this level of data quality takes into account the prospective data needs of secondary users. The assigned level of data quality, specific QA activities, and data acceptance criteria must be explicitly described in each individual Quality Assurance Project Plan.
- The general audit and data review procedures are stated during the planning process for the acquisition and use of any data used in the assessment process. The audits and data assessments should be documented and provided with the final data reports.

8.3 DATA GENERATION AND ACQUISITION

NEW DATA GENERATION ACTIVITIES

All Hanford assessment projects that involve the generation of new environmental data (activities that involve the measurement, monitoring or collection of physical, chemical, or biological data) are required to document all aspects of their project's sampling design, sample collection, analysis, quality control, and data management activities in a work plan. Work plans should generally include, but are not necessarily limited to, the following elements:

- Cover page with title and date;
- Signatory page (including the Principal Investigator(s) and QA Coordinator);
- Background/introduction;
- Study measurement endpoints;
- Sampling design strategy (e.g., numbers and types of samples, sampling locations, sampling timing, and identification of analyses that will be conducted on the samples);
- Detailed methods, including new, study-specific SOPs or references to SOPs;
- A description of the statistical methods to be used in interpreting results;
- Provisions for health and safety, as applicable;
- Descriptions of all permissions needed to conduct the study (e.g., collection permits, paperwork documenting approval for work on-site at Hanford); and
- References.

Accompanying the work plan must be a study-specific QAPP that describes the methods for documenting and assessing environmental data, QA, QC, and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria. The QAPP should follow the EPA guidelines for QAPP preparation (EPA 2002b).

These work plans must be peer-reviewed, signed by the Principal Investigator(s) and the QA Coordinator, then approved by the Hanford Trustee Council. The QA Coordinator shall ensure appropriate QA/QC measures are included in all technical guidance documents. The Principal Investigator and the QA Coordinator are jointly responsible for the proper use of these documents, which is ensured through the training and audit processes. The Case Manager provides higher-level oversight to ensure documents are consistent with overall Trustee priorities.

HISTORICAL DATA ACQUISITION AND USE

If a historical dataset is identified that may be useful for formulating or performing a study, the request for potential inclusion of the dataset in the Trustees' DMS will be made through the development and submittal of a Data Acquisition Plan (DAP) as described in the Data Management Plan (HNRTC 2011a). Once implementation of the DAP has been approved by the Hanford Trustees, the dataset(s) will be obtained, reviewed by the QA Coordinator, and assigned a QA Category, as described in the Trustees' Quality Management Plan (HNRTC 2011b).

Reports relying on historical data shall describe the data review procedures undertaken as part of report development, as well as the results of those efforts (i.e., whether or not specific data sets were included/excluded from use). The QA Coordinator shall advise as to the appropriate nature and type of data review procedures for use in connection with specific efforts.

8.4 ASSESSMENT AND OVERSIGHT

The appropriate type of assessment activity for particular projects will be determined during the planning process. Assessment tools include technical systems audits, laboratory and field audits, peer reviews, and data verification and validation. For evaluating particular activities, the work plan will describe the appropriate assessment tool and identify personnel responsibilities.

Data quality verification, validation, and assessment shall be consistent with *EPA Guidance on Environmental Data Verification and Data Validation (QA/G-8)* (EPA 2002c).

The QA Coordinator determines if appropriate actions have been implemented in response to assessment findings. The QA Coordinator, in a timely manner, determines the effectiveness of responses to assessments and maintains the documentation and correspondence relating to assessments and actions. Following any assessment event, the QA Coordinator prepares a written summation of needed changes and actions and then presents this summation in a timely manner to the Case Manager.

8.5 DATA VALIDATION AND USABILITY

The purpose of data validation is to verify that the data are of known quality, are technically valid, are legally defensible, satisfy project objectives, and are usable for their intended purpose. Work plan Quality Assurance Project Plans shall describe the criteria that should be used for accepting, rejecting, or qualifying project data. Understanding the extent of validation of historic data is integral to evaluating their usability for natural resource damage assessment purposes and is an important aspect of the categorization of historical data described above. Overall, data quality verification and validation shall be consistent with *EPA Guidance on Environmental Data Verification and Data Validation (QA/G-8)* (EPA 2002c).

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