Risk to Ecological Resources from Delaying Decommissioning and Waste Management: conceptualization and examples from the Hanford Site - 17156

Joanna Burger*,**, Michael Gochfeld*, **, David Kosson****, James Clarke****, Christian Jeitner** and Taryn Pittfield**

*Rutgers University, **CRESP

***Pacific Northwest National Laboratory, ****Vanderbilt University

ABSTRACT

Ecological evaluation is essential for remediation, restoration, and future land-use decisions for contaminated lands, and forms a basis for many management practices. Ecological evaluations or assessments can also be used to examine the efficacy of remediation and restoration methods, providing valuable data to plan and improve future restoration. Assessments can examine past activities, current conditions, and *the* effects of future remediation or restoration. In general, ecological evaluations have not been used to assess the effects of delaying remediation. Yet for complicated situations, such as at Hanford Site, where there are dozens of remediation sites still to be completed, understanding the effects of delaying remediation on ecological and eco-cultural resources adds measurably to making sound sequencing decisions. Ecological evaluations are inherently complex compared to human health risk assessment because there are hundreds of species, composing a great number of communities and ecosystems. Ecosystems are dynamic, undergoing changes in response to predictable environmental conditions (succession), as well as unforeseen events. Further, ecosystems respond to remediation and restoration actions, even when they are on adjacent areas. Conducting evaluations of the risk to ecological resources must account for the dynamic nature of ecosystems, and for the dynamic, changing landscape that results from remediation on nearby areas. The approach will provide information for sound decision-making with stakeholder participation. This project was partially funded by CRESP through the Department of Energy (DE-FC01-95EW55084),

INTRODUCTION

The Department of Energy (DOE) has one of the largest environmental management tasks in the U.S., involving the cleanup of radiological and other contaminants at several large sites. Government agencies, non-governmental organizations, Tribes, public policy makers, and the public are interested in the health and well-being of humans and the environment, especially before, but also during and after remediation. Understanding the risk to ecological resources, and especially eco-cultural resources, is a critical component of planning for remediation. While protecting human health involves considerations of workers, co-located workers, and the public on site, at the fence-line and beyond [1], it still involves one species. Risks to human health are often considered in relation to a "clean" environment. In contrast, ecosystems have hundreds or thousands of species, especially considering biota living in the soil and sediment. Further, environmental protection involves not only individual and populations of organisms, but the integrity of communities and ecosystems, which may in themselves, be vulnerable or endangered.

At its simplest level, environmental assessment (or environmental evaluations) involves the identification of federal threatened and endangered species [2]. The Endangered Species Act provides legal protection and promotes recovery efforts for plants and animals that are listed, and some suggest that habitats where these species live are protected as well. Many states similarly have lists of endangered and threatened species [3]. The United States Fish and Wildlife Service also lists candidate species, which include those species that are potentially at risk, but require a final assessment and evaluation before undertaking the challenge of the formal listing process. Many states list "species of special concern" which require more information to determine their status. Some may be at risk of becoming threatened, in the absence of protection or management. In addition to consideration for individual species, some DOE sites have vulnerable or unique habitats that are at risk [4, 5]. These habitats are usually limited in number or area and may be fragmented. They often contain threatened or endangered species, and may host endemic species (those that are very limited in range [6]).

Assessment and monitoring of ecological resources, and those that are critical for cultural pursuits, are on-going tasks. They are especially important for large DOE sites with many different and overlapping remediation units. Where funds or personnel are limited, DOE must make decisions about which projects to pursue, when to pursue them, and how to sequence the remaining remediation tasks. This paper discusses the risk of delaying remediation on ecological receptors, both generally and for some of the remediation evaluation units at the Hanford Site.

Although the entire Hanford Site is important to Tribes and others, the Columbia River is particularly important. The associated riparian zone and upland habitat provides goods (e.g. fish) and services (recreation, water for agriculture) to Northwesterners and the Nation. Delaying remediation and decommissioning of nuclear reactors and other on-site buildings can have consequences for ecological resources, as well as for cultural resources that depend upon the health and well-being of eco-receptors and ecosystems (e.g. sacred places, vision quests, view sheds [7]).

METHODS

A literature review was performed to identify refereed and grey literature dealing with the Hanford Site, ecological resources, including relevant DOE documents. The general effects of delaying remediation of ecosystems were examined in terms of the usual succession of ecosystem types when exposed to natural stressors (drought, fire, rainfall). Specific examples from the Hanford Site are given to illustrate the effects of delaying remediation. Maps of the Hanford Site that indicate remediation tasks still to be completed, and DOE documents, were used to understand the relative timing of cleanup at the site overall.

The Hanford Site has mainly a shrub-steppe habitat, with an important riparian corridor along the Columbia River [Fig. 1, [8. 9]]. The shrub-steppe habitat on the Hanford Site represents a significant portion of this habitat in the Columbia Basin Ecoregion [9]. The main natural stressors on this habitat are fire, exotic/alien species, landscape changes, and succession. Succession is the natural progression or changes of vegetation types from early bare earth stages (after a perturbation such as a fire or flood) to climax vegetation (shrub-steppe on the Hanford Site [8]). In addition, ecosystems on the Hanford Site face anthropogenic forces, such as DOE development activities, infrastructural changes, and remediation including soil removal. While generally less than 10% of the 586 square miles (1500 square kilometers) Hanford site was developed to support its nuclear mission, fire has a great potential to burn large areas. The rapid spread of alien Cheatgrass (*Bromus tectorum*), provides a fuel to allow rapid spread of fire, regardless of cause. In 2000, a fire burned most of the shrub-steppe habitat on the Fitzner-Eberhardt Arid Lands Ecology Reserve [10], and a fire in 2016 burned much of Rattlesnake Mountain (A. Bunn, Unpubl. data).

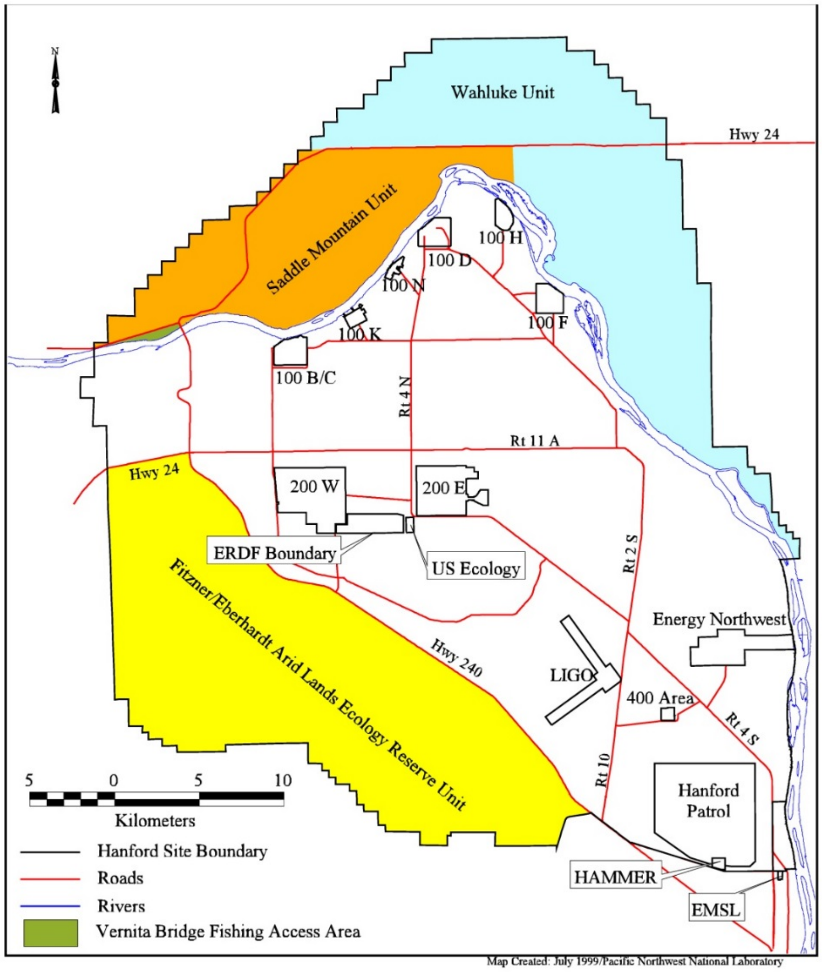

Figure D.2 Hanford Site Facilities and Land Use Areas (ERDF = Environmental Restoration Disposal Facility, LIGO = Laser Interferometer Gravitational-Wave Observatory, HAMMER = Hazardous Materials Management and Emergency Response Training Center, EMSL = Environmental Molecular Sciences Laboratory; *Energy Northwest formerly was the Washington Public Power Supply System)

Fig. 1. Hanford Site Facilities Map (Appendix D) [9].

RESULTS

Assessment of the presence, abundance, and ecology of species, populations and communities is required to understand the effects of remediation, and the effects of delaying remediation on ecological health and well-being. Although in the past risk assessors sometimes assumed that protecting human health protected ecological health, this is not true, particularly for remediation sites where the physical disruption of “cleanup” may cause the greatest harm to ecosystems [6, 11]. For Hanford and other contaminated sites, the differences must be considered.

We define here several terms that are used throughout the paper (TABLE I)

TABLE I. Definitions of terms used throughout the results and discussion.

Term	Definition
Community (ecological)	A group of species (plants and animals) that reside in the same defined area, and may or may not interact.
Population (eco-receptor)	Members of the same species (e.g. bats, deer, sagebrush) that reside in the same, defined area (usually capable of interacting).
Recovery	The ability of a degraded ecosystem or habitat to return to its previous ecosystem type with appropriate structure and function.
Remediation unit	A spatial unit, facility, or building that is slated for decommissioning and cleanup to a specified state.
Resource Level	The relative value of ecological resources, from 0 (no value, usually paves or no ecological resources) (0) to very high (5), defined as federally endangered and threatened species and unique habitats. These were initially defined by DOE [9] and modified and adapted by CRESP [12].
Risk rating	A rating of the potential injury or risk to ecological resources, from no discernible effect to very high (irreparable damage).
Succession	The natural progression of a habitat or ecosystem from bare earth to one that occurs naturally on a specific site, given the regional geology, physiognomy and climate.

Assessment Differences between Human and Ecological Health

Evaluating the effects of delaying remediation on ecological receptors first involve recognizing the differences between human risk evaluations and ecological risk evaluations (TABLE II). While human risk assessment is usually given the most attention, environmental protection also is important because it too is mandated by laws and regulations, as well as DOE orders [2, 13], and needs to be performed as well.

TABLE II. Differences between assessing human and ecological health, and their possible effects on remediation (and sequencing of cleanup).

Characteristic	Human effects	Eco-receptors and effects
Number of species	1	Hundreds to thousands
Populations	Populations of people	Each species has populations that interact and affect one another

Communities	Towns and cities	Communities have hundreds of species from one cell organisms to large animals (e.g. that can compete or prey on others
Life cycle	Baby – adult	Many different life cycles that require a mix of habitats.
Longevity	Only for humans (up to 100+)	Longevity of biota varies from minutes and hours to centuries
Activity pattern	Diurnal	Some species are diurnal (most birds), some crepuscular (coyotes), some are nocturnal (owls).
Seasonality	People are present all year on site (workers and the pubic on highways).	Some species are sedentary, and others migrate. Some species are on site but hibernate in the winter (e.g. snakes).
Horizontal space	People can be active throughout the Hanford Site, and have been at different historical periods	Species are limited to specific environmental conditions, and do not occur on every location (e.g. some species are limited to the riparian zone, some to different elevations on Rattlesnake Mountain.
Vertical space	People are active on the surface or in/on the Columbia River.	Eco-receptors live in the soil, sediment, surface, and in the air
Use of human structures	People work in all active buildings, and are involved in decommissioning and demolition.	Some eco-receptors live in abandoned buildings (e.g. bats nesting on the outside of pump houses; snakes can get into buildings; swallows nest on some pump houses at Hanford).

Ecological and Eco-cultural Protection of Resources at the Hanford

While ecologists and ecological risk assessors mainly study the effects of natural or anthropogenic stressors on ecosystem structure and function, it is equally important to recognize that healthy functioning eco-receptors and ecosystems are important contributors to the value of cultural resources (= eco-cultural resources, [14]. This leads to the conclusion that the disruption of ecosystems on culturally-sensitive areas should be minimized, which may involve careful sequencing of remediation activities to reduce the total time of remediation on any one section of the Hanford Site. For example, salmon fishing is an important cultural value of the Tribes that use the Columbia River [15, 16], as well as to other Northwesterners, so reducing the total time that remediation is being conducted during the salmon runs should be an important sequencing decision (where possible). This may involve conducting several remediation projects at once at different reactor or other sites near the river, suspending remediation activities during prime salmon fishing, or other methods suggested by Tribes and other stakeholders.

Succession and Remediation

Any perturbation can set succession back to an earlier stage. For example, a hot fire can destroy all above-ground vegetation and damage some root systems. Remediation can have a similar effect if heavy vehicles and other activities kill, degrade, or remove vegetation. Soil removal, as occurred at some of the reactor sites (e.g. 100D and 100C areas at Hanford) removes all organisms, including soil invertebrates; it also removes the seed bank (viable seeds remaining in the soil) that is necessary for an ecosystem to recover naturally. The type, degree, and spatial-temporal extent of remediation affects the extent and spatial-temporal pattern of succession. Succession is a necessary part of recovery of a damaged or degraded ecosystem. Restoration can aid in improving the rate and extent of succession, but it is always better to preserve existing ecosystems that to rely on restoration. Restoration does not always work, and has not yet proven successful at Hanford. Ecosystems facing extreme conditions, such as fire, drought or harsh temperatures, are more vulnerable to disruptions and recover less quickly.

Conceptual Considerations

Many DOE sites, including the Hanford Site, contain endangered, threatened and iconic species as well as unique habitats that should be preserved [4, 5]. Some, such as Hanford Site, also contain very valuable geological formations of cultural value (e.g. Rattlesnake Mountain). On most DOE sites, less than 10% of the area ever contained facilities or was disrupted. These valuable habitats exist because of DOE protection and management, yet remediation may threaten them because of physical disruption, degradation, and soil removal. Much of the Hanford Site was agricultural (orchards) prior to DOE occupation [17].

The trajectory of ecosystem health on DOE lands is diagrammed below (Fig. 2). The damage to ecosystems on non-production areas mainly occurred during construction and operation of the facilities, which ceased following the Cold War in 1989. Where there was continued activity nearby, ecosystem recovery may have been non-existent or low. However, where there was no activity, ecosystems recovered from previous land use (agriculture, orchards) and DOE activities (e.g. construction of roads), and have reverted through success to shrub-steppe (the regional biome). Succession is the orderly process of vegetation changes from bare ground to the vegetation type that is dominant given the geology, geophysical processes and climate of the region. For the Hanford Site, the climax biome is shrub-steppe. The Hanford Site contains some of the most natural, undisturbed shrub-steppe in the Columbia River Basin Ecoregion [17]. Remediation will have the effect, depending on the degree and extent of remediation, of setting succession back to an earlier stage, thus requiring years to return to its present condition.

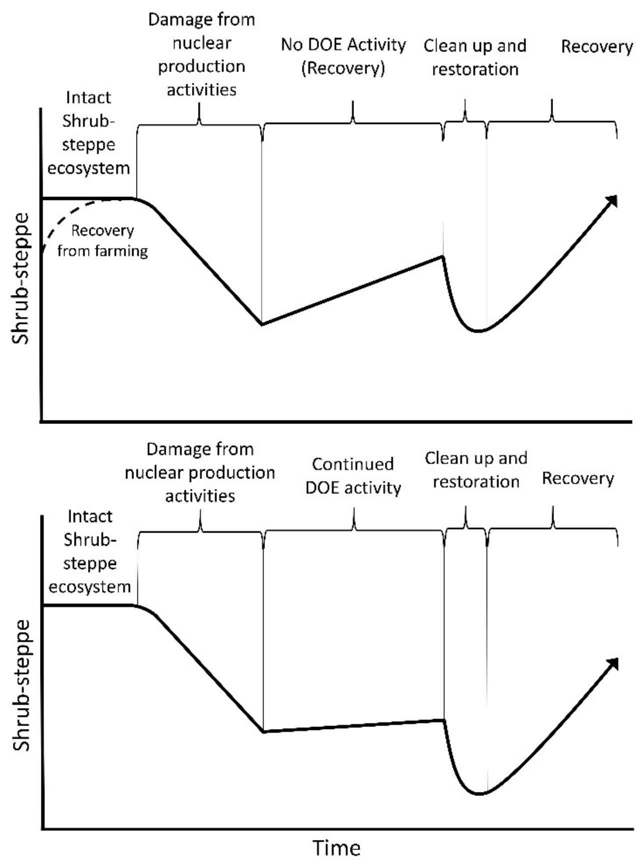

Fig. 2. Representation of the effect of nuclear production on ecological resources, and recovery either when there is no further DOE activity (top), or continued activity (bottom). When there is no or little DOE activity after the initial disruption due to nuclear production, the resources recover. Physical remediation has the potential to disrupt the systems, requiring ecosystems to once again recover.

Some of the land near the Columbia River was agricultural, including apple orchards, when the Hanford Site was taken over by the federal government in 1943. These agriculture lands had long-before replaced the shrub-steppe habitat. When used for agriculture, the soil was not as disturbed as the activities that accompanied the construction of buildings, underground tanks, trenches and other structures. Further, agriculture does not destroy the seed bank, except for the surface soils. Thus, the cessation of agriculture quickly results in succession toward the ecological climax community in areas surrounding the Hanford industrial development.

Succession and the Effects of Delaying Remediation

For a large site such as Hanford, it is impossible to conduct all remediation activities at once, and the range of considerations that enter decisions about sequencing and delaying remediation are varied and many. From an ecological perspective, if remediation is going to occur, it is best for it to occur earlier rather than later because: 1) delaying remediation means existing ecosystems have longer to recover from the initial and on-going nuclear production activities, 2) physical disruption of these recovering ecosystems may also increase contamination, and 3) remediating earlier rather than later will allow succession to begin earlier, and the ecosystem to recover sooner to a functioning system that provides goods and services to both eco-receptors living within the system and to people. Delaying remediation also provides a longer period for exotic plants to become invasive. Thus, for eco-receptors, delaying remediation means that post-cleanup recovery (natural succession) is delayed (Fig. 3).

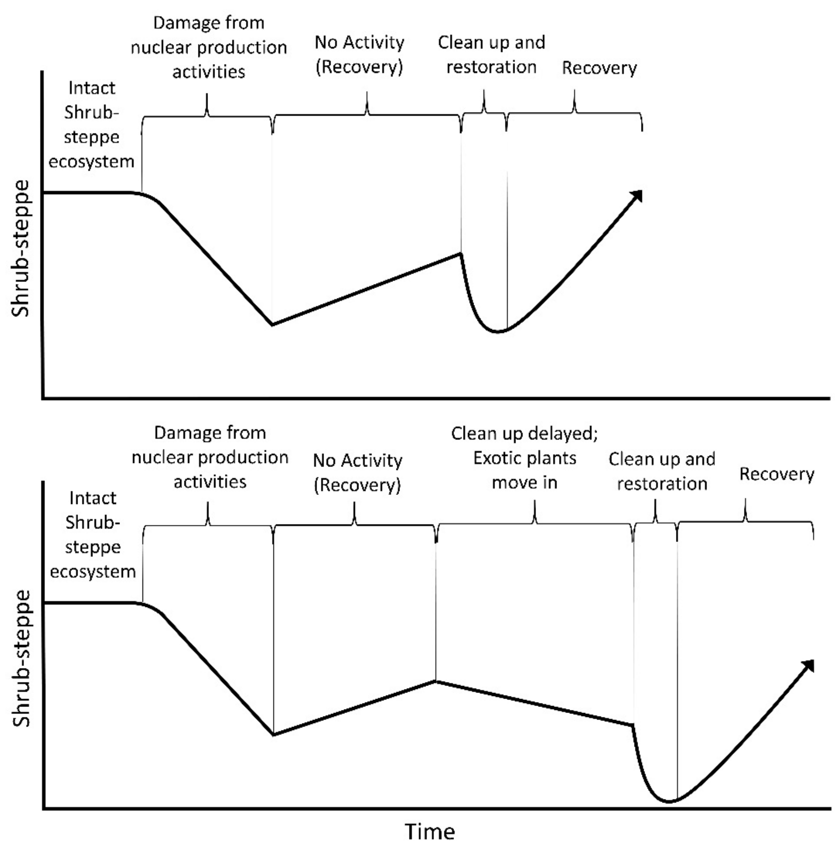

Fig. 3. Representation of the effects of delaying remediation on recovery of the climax community at the Hanford Site (e.g. shrub-steppe). If remediation is going to occur, it is better to complete it as soon as possible so that there is not continued invasion by exotic species.

However, the sequencing of remediation, and delays in remediation interact for remediation units (sites or areas slated to be remediated at the same time) that are close together or contiguous. If, for example, there are three to four such units in one continuous area, remediating them all at once reduces the time of total disturbance. Remediating them sequentially increases the disruption time, and remediating them sequentially with periods of inactivity in between increases the disruption time markedly. That is, in the latter case, the remediation units begin to recover following remediation, but this recovery is disrupted when the next unit is remediated.

Ecological Evaluations, Succession, and Delaying Remediation

Understanding the full effects of delaying remediation on ecosystems requires not only understanding succession on the site, but the relative ecological value of the resources on the remediation unit (and adjacent units). That is, if all the remediation units have been developed with parking lots, buildings, cribs, trenches and other structures, the ecological resources are non-existent, thus delaying remediation on one or more of these sites will not adversely affect ecological resources (because there are none).

If the ecological resources on remediation sites are intermediate (e.g. resource level 3 or below [9]), then careful consideration should be given to the sequencing of remediation on adjacent sites so that the resources are not disrupted for long periods of time. However, if the ecological resources on a remediation unit are 4 or 5 (e.g. state and/or federally endangered or threatened species, unique or rare habitats), then considerable attention should be given to sequencing and to delayed remediation. Such habitats include riparian habitats along the Columbia River. Longer periods of remediation at particular units, and longer time periods of inactivity (allowing ecosystem recovery to progress), will lead to greater disruptions of ecological resources, and longer total recovery periods (Fig. 4).

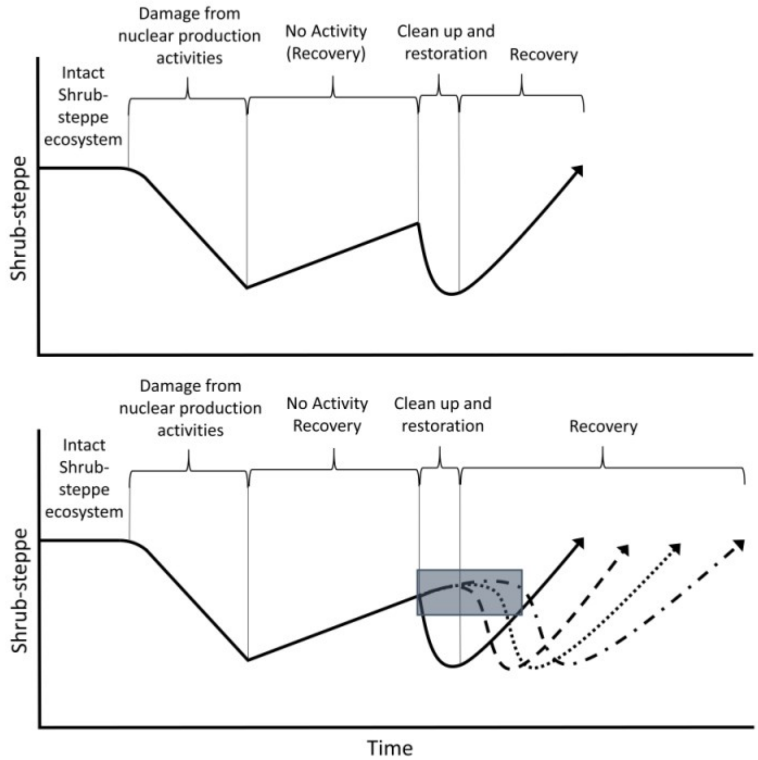

Fig. 4. The effect on ecological resources is minimized by conducting remediation at the same time in adjacent or nearby evaluation units (top). When remediation tasks are complete at different times in adjacent sites, it prolongs the period of disruption, and the total time that the contiguous ecosystems can recover. The shaded area in the bottom graph shows the period of cleanup and total disruption on nearby evaluation units.

DISCUSSION

Risk Balancing: Radionuclides and other Contaminants vs Physical Disruption

For ecological resources, there is a trade-off between the benefits of removing contamination to reduce any possible adverse effects from radiation or other contaminants, and leaving it in place to avoid disruption of existing functioning ecosystems. Obviously, the decision is easy when the risk to humans or eco-receptors from the contaminants is clear and can be demonstrated, such as remediation in the 200 area on Hanford. It may also be clear when pollutant levels are so low as to provide a *de minimus* effect on humans or any eco-receptor. However, ecological and human health risk assessments are required to demonstrate this, and for eco-receptors, this means controlled laboratory experiments to demonstrate no effect level for sensitive species or life stages (e.g.

for benthic species and salmon [17]), including those of eco-cultural value. If there is no risk to eco-receptors from contaminants, then removal does not reduce risk, but physical disruption during remediation can cause great risks to eco-receptors. This paper does not address the risks from radionuclides or other contaminants, but rather focuses on the physical remediation activities that can cause disruption.

Sequencing and Delaying Remediation

Given that specific remediation options have been determined through the appropriate methods (fulfilling CERCLA and RCRA requirements), the question for ecologists becomes how to sequence cleanup tasks for individual remediation units in a manner to decrease the risk to species, communities and ecosystems. There are three overarching conclusions described in this paper: 1) the greatest risk to eco-receptors and ecosystems comes from physical disruptions during remediation (assuming there is little risk from contaminants on site), 2) if remediation is going to occur, and involves physical disruption, it is best to sequence (and delay remediation) on adjacent remediation units such that all physical disruptions occur in as limited a time as possible, and 3) if remediation is going to occur, it is best to implement cleanup sooner rather than later because it provides longest period of time for ecosystems to recover (whether or not the site involves restoration).

CONCLUSIONS

Many different considerations, other than risk to ecological systems, enter into the decisions about sequencing and delaying remediation. Thus, perhaps the most useful ecological advice is to sequence (regardless of the timing) remediation activities such that remediation units that are adjacent to each other are remediated at the same time (or as close as possible) to reduce the total time any given spatial area is exposed to physical disruption. Secondly, ecological damage can be reduced by decreasing the number and size of laydown areas by using the same laydowns for adjacent remediation units.

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