Ecological Resource Value, Remediation Options, and Impacts: Functional Remediation at Hanford Site - 17226

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ABSTRACT

Governmental agencies, Tribes, regulators, resource trustees and other stakeholders are interested in understanding the risk to the environment from remediation and restoration, particularly at large DOE sites with complex remediation tasks lasting decades. While each remediation project has the usual environmental impact assessment that include risk to eco-receptors, a piece-meal approach to examining the effect of remediation does not provide an overview of remaining tasks that would aid in sequencing these tasks. The Consortium for Risk Evaluation with Stakeholder Participation (CRESP) developed a risk methodology for Hanford Site that included ecological resources between 2014 and 2015. The ecological methodology included a comparison of the value of on-site resources with the ecoregion, with state and federal threatened and endangered species, and with rare and unique habitats. Potential remediation options for particular evaluation units were used in conjunction with the resource level values to determine the risk of remediation of ecological resources. The methodology developed for Hanford Site also considered functional remediation (e.g. number of trucks, personnel, heavy equipment), initiating events (e.g. earthquakes, volcanos) and future land use. These factors were combined to rate the risk to ecological resources on a scale of not-discernible to very high. In this paper seven evaluation units (waste sites requiring remediation) were evaluated to explore the efficacy of the methodology to provide useful information on the comparative risk for decommissioning and waste management sites. The evaluation of resource levels was based on prior site information, state and federal data bases, and field investigations. The final determination of a risk rating for each evaluation unit depended upon both quantitative data, field experience, and professional judgement. It provides a method that can be applied to many remediation sites within a large DOE facility such as Hanford, as well as across the DOE complex. This will provide information for sound decision-making with stakeholder participation, and will allow DOE to reassure stakeholders that they are protecting human and ecological health on the Hanford Site.

INTRODUCTION

Protecting environmental, ecological and eco-cultural resources is one of the current missions of the Department of Energy (DOE). Since the late 1940s and 1950s ecological resources have been protected at DOE Sites because of security concerns and as support for the federal governmental sustainability mandate [1]. Preservation of natural resources is particularly important on large DOE sites that have unique habitats, such as the Carolina Bays at the Savannah River Site (SRS), sagebrush-steppe at Idaho National Laboratory (INL), and shrub-steppe at Hanford Site [2, 3]. Carolina Bays are limited and their numbers are dwindling outside of SRS, and at the other sites the habitat is decreasing rapidly in their respective ecoregions. In the northwest, many of the climax ecosystems have been developed for agriculture (e.g. around Hanford and INL) because of the availability of irrigation. The massive development of agriculture has eliminated much of the native vegetation in these regions, making the DOE protected lands some of the only remaining, undisturbed ecosystems.

Many different stakeholders are interested in the protection of ecological resources, including federal and state regulatory and resource agencies, Tribal agencies, natural resource trustees, and the general public. Ecological resources are an important component of Native American cultural resources (eco-cultural [4]), and many medicinal, cultural, and religious activities depend upon the health and well-being of ecological resources. DOE needs a methodology that would lead to resource sustainability on their sites. Assuring governmental agencies, Tribal Nations and the public that DOE is protecting human and ecological health is an important aspect of DOE's mandate. To do so requires consistent methodologies that can be used complex-wide, as well as being consistent across a given DOE site.

DOE sites, such as Hanford, have a large remediation task, with many different units requiring cleanup over decades. The cleanup at Hanford will take decades, requiring continual modification of milestones, considerations, and methods. Since there are many remediation sites that will take decades to complete, the question of consistency in evaluating the risk to ecological resources and eco-cultural resources is key to assuring stakeholders that these resources are being protected now and into the future. Consistent implementation of methods is essential for sustainability both within and among sites.

The objective of this paper is to use functional remediation [5] to explore the efficacy of this methodology to provide useful information on the comparative risk for decommissioning and waste management sites. Six waste sites (or units) at Hanford Site are used as case studies. This paper is an outgrowth of the Hanford Site-wide Risk Review Project, conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP [6]). Our overall methods for the ecological component of the assessment adapted an existing methodology that includes using established levels for the value of ecological resources [7], on-site field work to ground-truth these resource evaluations, the possible effects of functional remediation and existing remediation options for each evaluation unit. This paper explores the applicability of functional remediation to determine effects to specific waste remediation units, called evaluation units in this paper. Functional remediation is described briefly below; a fuller description can be found in Burger et al. [6].

Functional Remediation

DOE and other agencies conducting remediation on contaminated sites have a full range of methods to remove, stabilize, or store radionuclides and other contaminants on their sites. In some cases, storage or stabilization is temporary, and in others it is permanent. These methods include soil or sediment removal, capping, pump and treat, and natural attenuation, among others. Functional remediation involves defining the different components of remediation. The components are described regardless of the remediation type, and one or more of them make up the sum of remediation activities employed during a given remediation task (e.g. whether it is soil removal, capping, or some other method). The functional remediation components, with their ecological effects are listed in TABLE I below.

TABLE I. Effects from functional remediation types on ecosystems. Functional remediation types increase in intensity from top to bottom, and effects increase from left to right. If 'Yes' is capitalized that indicates the effect is high. The target area = evaluation unit (EU); Buffer = the area around the target area (after Burger et al. [6]).

	Dis-place mobile wildlife	Kill less mobile wildlife	Kill algal mat	Kill native plants	Spread exotic seeds	Kill soil inverte-brates	Pack soil	Remove seed bank	Remove all living system
Personnel traffic through non-EU area	Yes	Yes	Yes	NA	NA	NA	NA	NA	NA
Personnel traffic through EU	Yes	Yes	Yes	NA	NA	NA	NA	NA	NA
Car, pick-up trucks in buffer	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	NA

Car, pick-up truck in EU	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	NA
Trucks on roads through buffer	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA	NA
Trucks on roads and pads in EU	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA
Heavy equipment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA
Heavy wide hoses	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA
Drill rigs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA
Construct buildings[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA
Caps other contain-ments	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA
Soil Removal	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Contamin-ation	Yes	No [b]	?[b]	?[c]	NA	Yes[b]	NA	Maybe[a]	?[c] NA
Dust suppres-sion	Yes	NA	Yes	Yes	Yes	Yes[b]	Some[c]	NA	NA
Plant control	Yes	NA	Som e	NA	Yes	Yes	Some[c]	Maybe[d]	NA

a. Similar effects with demolishing buildings
b. May kill sensitive species
c. May have this effect if very high and above effects thresholds
d. Depends on the frequency of heavy truck traffic

The above table indicates that with increasing use of heavy equipment and permanent fixtures on the site (e.g. hoses, drills, buildings), the ecological effects increase. It is not the type of remediation, but the functional components that result in ecological damage. This table simplifies the effects; there are clearly others that occur. Hoses and other objects on the ground prevent movement of small animals, as well as contributing to loss of available space for plants and animals.

The last three in the table are different in that they are either in-place contamination, or are maintenance activities to reduce fires (plant control, tumbleweeds), or depress dust. For most of the Hanford Site the contamination is insufficient to cause identified and documented effects.

METHODS

The Hanford Site (586 square miles (about half the size of Rhode Island)), located in the State of Washington, has mainly a shrub-steppe habitat, with the riparian corridor along the Columbia River being one of the valued, unique habitats [7, 8]. The Hanford Site includes a significant portion of the shrub-steppe habitat in the Ecoregion [9, 10, 11]. The natural stressors on shrub-steppe are fire, exotic/alien species, snowmelt, landscape changes, and succession. Succession is the natural progression or changes of vegetation types from early stages (after a perturbation such as a fire or flood) to climax vegetation (shrub-steppe on the Hanford Site [7]). All systems face anthropogenic forces, and ecosystems on the Hanford Site face anthropogenic forces as well, such as DOE development activities, fire suppression, infrastructural changes, and remediation. Generally less than 10% of the Hanford Site was developed to support its nuclear mission, and the rest is relatively undisturbed. However, fire (that can be both natural and anthropogenic) has the great potential to burn large areas of shrub-steppe. A 2000, fire burned most of the shrub-steppe habitat on the Fitzner-Eberhardt Arid Lands Ecology Reserve [10]

The CRESP team developed the functional remediation categories, and also collected field data, analyzed data, and rated the risks [11]. When all the data were assembled, we developed tables of the value of the ecological resources (from a low of 1 to a high of 5) endangered or threatened species, the known remediation types to be employed at each unit evaluated, and the functional remediation categories, and from that data, we arrived at a rating (with justification). Since the same team performed all the steps, consistency was maintained. The rating scale ranged from not-discernible (0) to very high risk that there would be injury to endangered and threatened species and unique habitats [11].

RESULTS

In this section, we use examples of evaluation units at Hanford Site that represent different types of clean-up tasks (e.g. D & D, legacy sites, operating facilities, tank farms) to illustrate the efficacy of using functional remediation types to inform risk to ecological systems from remediation. Each will be described separately, with effects and unique conditions or effects. The list was chosen to demonstrate different aspects of evaluations. The full list can be found in the CRESP report [11]. The following data are applicable to the actual remediation phase activities.

Legacy Site: PUREX cribs and trenches (LS-9) – Multiple remediation actions (TABLE II).

Total acreage: 39

% level 3 resources or above in EU: 18

% level 3 resources or above in buffer: 46

Remediation plan: Multiple options

Risk Rating during cleanup: low to medium

TABLE II. Functional Remediation and Rationale for Risk Rating at Purex.

Remediation type	Functional remediation	Effects
Dust suppression	Light to heavy vehicles	Leads to soil compaction, which depresses plant growth and decreases the abundance and diversity of soil invertebrates, as well as the abundance of snakes and other burrowing animals. There are some native grasses, and there are patches of native Gray Rabbitbrush (*Ericameria nauseosa*) and native Bluegrass (*Poa secondo*) that should be protected.
Dust suppression	Increased water	Increased water can change the plants that can live there, allowing less drought tolerant species to move in, and can foster invasive species. The site already contains some introduced Cheatgrass (*Bromus tectorum*).
Barriers (e.g. caps)	Increased car and truck traffic	Activities have to potential to disrupt or kill state sensitive species (Piper's Daisy, *Erigeron piperianus*). Such species are very hard to restore once their populations have been disrupted. Traffic in buffer area can kill native species. Increased traffic can directly kill sensitive plants and animals, as well as causing soil compaction.
Remove, treat and dispose	Increased car and truck traffic	Carries seeds or propagules, kills native species, causes soil compaction, and can disrupt Piper's Daisy populations.
Remove, treat and dispose	Increases in heavy equipment	Wide-scale soil compaction killing invertebrate communities and preventing burrowing animals to use the habitat. Birds and other animals on this site may avoid areas with high levels of noise (e.g. Pocket Gopher *Thomomys talpoides*, Lark Sparrow *Chondestes grammacus*).
Remove, treat and dispose	Pumps, and hoses	Provide barriers for movement of small animals, increases ambient noise preventing some birds from breeding.
Remove, treat and dispose	Soil removal	Increased activity of trucks and personnel cause the greatest damage by increased noise and activity; soil compactions destroys soil invertebrates, and complete soil removal removes the seed bank as well as all living organisms. Would remove all the native plants and animals, and remove the state sensitive Piper's Daisy.

This evaluation unit was selected because there are multiple remediation actions that will be employed (allowing for an understanding of the range of possible ecological effects), and both the EU and the buffer area have considerable resources at a resource level of 3 and above. This indicates that the resources are important ecologically, having state species of concern and a range of native grasses and forbs. Because of the quality and quantity of high level resources, all of the remediation options have some ecological consequences, but soil removal has the greatest potential to remove native shrub-steppe habitat. While natural succession and restoration of sagebrush and rabbitbrush is possible (assuming nearby presence of these species to all rapid recovery), it is far more difficult to establish populations of the sensitive Piper's Daisy.

Legacy Site: U Plant Cribs and Ditches – Uncertain remediation plans (TABLE III).

Total acreage: 316

% level 3 resources or above in EU: 4

% level 3 resources or above in buffer: 33

Remediation plan: uncertain plans, but options range from cap or treat in place to remove, treat and dispose. Thus, there is uncertainty in effects to ecological receptors. Possible effects are given below.

Risk Rating during cleanup – Low to medium

TABLE III. Functional Remediation and Rationale for Risk Rating at U Plant Cribs and Ditches.

Remediation type	Functional remediation	Effects
Dust suppression	Light to heavy vehicles	Leads to soil compaction, which depresses plant growth and decreases the abundance and diversity of soil invertebrates. Soil compaction can decrease the abundance of snakes and other burrowing animals.
Dust suppression	Increased water	Increased water can change the plants that can live there, allowing less drought tolerant species to move in. Excess water can drown out some vegetation, and allow invasive species to move in.
Barriers (e.g. caps)	Increased car and truck traffic	Carry seeds or propagules of non-native plant species, which in turn decreases the abundance and diversity of native plants. Traffic in buffer area can kill native species. Increased traffic can directly kill sensitive plants and animals, as well as causing soil compaction.

Remove, treat and dispose	Increased car and truck traffic	Carry seeds or propagules, kill native species, cause soil compaction
Remove, treat and dispose	Increases in heavy equipment	Wide-scale soil compaction killing invertebrate communities and preventing burrowing animals to use the habitat. Birds and other animals may avoid areas with high levels of noise.
Remove, treat and dispose	Pumps, and hoses	Provide barriers for movement of small animals, increases ambient noise preventing some birds from breeding.
Remove, treat and dispose	Soil removal	Increased activity of trucks and personnel cause the greatest damage by increased noise and activity; soil compactions destroys soil invertebrates, and complete soil removal removes the seed bank as well as all living organisms.

Because remediation options have not been determined, it was necessary to examine the potential range of remediation options. Thus, the potential effects during remediation vary from low to medium. The ratings also take into account the level of resources on the EU, and on the buffer lands. For the U Plant cribs and ditches, there were few high-quality resources on the EU, but there were 33% on the buffer area.

Operating facility: Canister Storage Building (CSB, OP-5) – No remediation decisions (TABLE IV)

Total acreage: 43

% level 3 resources or above in EU: 0

% level 3 resources or above in buffer: 32

Remediation plan: No decisions made, but remediation options include removal of facilities.

Risk Rating during active cleanup: non-discernible to Low

TABLE IV. Functional Remediation and Rationale for Risk Rating at Canister Storage Building.

Remediation type	Functional remediation	Effects
Remediation type	Functional remediation	Effects

Demolition and removal	Trucks and heavy equipment	Truck and heavy equipment traffic could compact soil in the buffer if new laydown or roads are required; constant traffic could provide noise and disturbance to animals in the buffer where there are resources at level 3 and above.
Demolition and removal	Removal of buildings	Removal of any buildings could reduce nesting sites for birds, roosting sites for migratory birds, and perch/hunting sites for raptors, as well as habitat for bats.

This EU illustrates a different situation in that there is no decision on remediation, but the buildings require addressing. Closure includes spent fuel dry storage pad, and 95% of the site is covered with buildings, surrounded by bare soil. There is also an understory of the exotic Cheatgrass. This is a restricted area. There are no level 3 to 5 resources on the EU itself, but there are significant resources on the buffer, which accounts for the risk rating of low during remediation. In the past Black-tailed Jackrabbits, a Washington State candidate species, occurred in the area. Although not observed in the present field surveys, there is still the potential that is occurs. The low rating is due to the resources on the buffer.

Tank Farms: A-AX Tank Farms (TF-5) - Tank Retrieval and Removal (Table V)

Total acreage: 128

% level 3 resources or above in EU: 21

% level 3 resources or above in buffer: 27

Remediation plan: Not complete, Tank retrieval and removal of all equipment and contaminated soil

Risk Rating during cleanup – Low to medium

TABLE V. Functional Remediation and Rationale for Risk Rating at AX Tank Farms.

Remediation type	Functional remediation	Effects
Natural attenuation monitoring	Cars, trucks and personnel	On site activities can bring in invasive species, trample sensitive plants, and cause small amounts of compaction (decreasing soil invertebrate communities). Activity can introduce invasive species and seeds to the sensitive, high quality resources in buffer.
Capping	Cars, trucks, some	On-site activity can trample and kill sensitive plants, cause mobile animals to leave, and heavy equipment

	heavy equipment	can cause compaction, eliminating soil invertebrates and burrowing animals.
Demolition and Soil removal	All the categories of traffic, including soil removal	On-site activity can trample and kill sensitive plants and animals, and complete removal of soil removes the seed bank and sets the habitat back to the beginning successional stage. If no nearby seed bank and plants remain, succession to a shrub-steppe habitat will be much delayed.

The tank farms are important because the characterization (or lack thereof) of the quantity and quality of radionuclides and other contaminants is critical to understanding the possible risk to ecological resources. The risks to ecological resources for the tank farms are similar among the farms because the risks from contamination are similar, what differs is the amount and extent of each resource level, and whether the high-quality resources are located adjacent to the tank farms themselves. While there is generally little activity around the tank farms currently, there is limited truck traffic that can carry in the seeds or invasive species.

D & D: Final Reactor Disposition (DD-3) – Planned Remediation (TABLE VI)

Total acreage: 156

% level 3 resources or above in EU: 57

% level 3 resources or above in buffer: 39

Remediation plan: Remove, treat and dispose

Risk Rating during cleanup – High to very high

The final dispositions of the six discrete reactor buildings currently “cocooned” in the 100 area along the Columbia River are important to a wide range of stakeholders, especially Native Americans who consider that the structures impair their eco-cultural values. Each reactor was cocooned, and is surrounded by disturbed ground, which resulted from previous demolition and remediation activities. The few vegetation patches around the reactors generally have the invasive Cheatgrass and Russian Thistle (*Salsola tragus*). The long-term plan of dismantling, treating and disposing of the reactors poses risks to ecological receptors because: 1) the EU and buffer areas include some of the riparian zone along the Columbia River, 2) physical disruptions have the potential to affect the riparian zone and the river, 3) physical disruption may introduce exotic species to a delicate riparian zone, and 4) radionuclides or contaminants could be released to the surface, and reach the riparian zone or the Columbia River. These considerations have led to final disposition of the reactors being relegated to relatively late in the overall remediation plan for the Hanford Site.

TABLE VI. Functional Remediation and Rationale for Risk Rating at Final Reactor Disposition.

Remediation type	Functional Remediation	Effects
Monitoring	Cars and trucks	Potential to introduce exotic species (on tires and boots), including Cheatgrass. Carry seeds and small invertebrates (e.g. insects, into sensitive areas.
Stabilize and remove reactor facilities	Trucks and heavy equipment	Introduction of exotic species, trampling of native species, and changes in the ratio of native to exotic species in affected areas (which could include the riparian zone along the Columbia River). Will cause compaction of work areas, as well as laydown areas, which will destroy or degrade invertebrate communities, and habitat for burrowing animals (especially snakes).
Stabilize and remove reactor facilities	Widen roads	Infringement on native ecosystems, allowing invasive species to obtain a foothold, direct destruction of plants in the area used for larger roads. Disruption of soil invertebrate communities with the road building.
Stabilize and remove reactor facilities	Dust suppression	Increases in water use to suppress dust will affect the abundance and diversity of native and exotic plants, and because of the grade to the Columbia River, may adversely affect the riparian zone (one of the highest rated ecological areas on the Hanford Site).
Stabilize and remove reactor facilities	Demolition	Release of dust and possible contaminants, requiring additional dust suppression with increased adverse effects. Some birds and other animals use structures for roosting, nesting and hunting perches, and these will be destroyed. Bird activity included an active Red-tailed Hawk (*Buteo jaamaicensis*) nest on building 105c, and a Great Horned Owl (*Bubo virginianus*) nest on building 105-H. The 105-F building has a large bat roost (boxes have been attached to the building).
Stabilize and remove reactor facilities	Soil removal	Soil removal under the reactors could result in the release of radionuclides or other contaminants to the sensitive riparian zone and the Columbia River. Soil removal can result in blowing sand, which can harm adjacent riparian zones, and result in increased silting in the sensitive salmon spawning areas in the Columbia River.

Stabilize and remove reactor facilities	Contamination abatement	The potential for contamination below the reactors and vadose zone may require considerable excavation, exposing the upland areas, riparian zone, and the Columbia River (with potential for associated effects on benthic and other organisms.

Although the reactors are similar in some respects, and all are located in the 100 area along the Columbia River, each has unique characteristics, which should be taken into account when remediation plans are finalized. The loss of roosting and breeding sites, particularly for bats, needs to be addressed. Monitoring and survey work on the bats is required to assess whether the species present are state or federally endangered, or represent an important component of the Washington State bat population (either breeding or migrants). The 100 area and associated riparian zone contain some of the highest plant species diversity on the Hanford Site (excluding Rattlesnake Mountain). Areas 100-H and 100-N are located within ¼ mile of the Columbia River shore, and thus have significant level 3 and above resources that are important ecologically and to Tribal Nations and many other stakeholders.

DISCUSSION

The intent of this paper was to explore how the components of remediation (e.g. functional remediation) can be used to evaluate the risk to ecological receptors on the Hanford Site, and secondarily to demonstrate how they could be used at other DOE sites. The analysis revealed several considerations that managers, ecologists, and waste site works need to take into account when planning remediation of contaminated sites:

1. Ecological evaluations should be completed before remediation options are determined, plans are developed, and remediation is implemented.
2. Lack of clear remediation plans makes it difficult to determine the effects on eco-receptors and ecosystems.
3. Removal of structures and buildings removes nesting, roosting, and hunting perch habitats for many birds.
4. Any remediation activities can result in the introduction of exotic plants and their seeds.
5. The physically most disruptive methods (e.g. soil removal) have the greatest adverse effects on eco-receptors and ecosystems.
6. While the effects of functional remediation types are general, the effects to eco-receptors and habitats are site-specific.
7. Functional remediation acknowledges that it is the components of remediation that determine the ecological effects, and not simply the name of specific types.

8. Functional remediation makes it possible to examine the effects of specific activities, which in combination under any remediation type (e.g. pump and treat, demolition, soil removal), are responsible for the ecological effects.

The functional remediation types described [5] were developed for the Hanford Site, and we expect that there may be some additions that are unique for different DOE sites. Many of the DOE sites in the western United States are in relatively dry habitats where the kinds of effects from functional remediation types are similar. However, the DOE sites in the east, such as Oak Ridge and the Savannah River Site, are in wetter areas with forests, lakes, and ponds. Thus, the effects to those areas from any given functional remediation would differ. For example, in eastern hardwood and coniferous forests, even a few personnel, cars and trucks will bring in seeds of both native and non-native species, increasing the potential for shifts in species diversity and abundance of the understory of forests, which in turn shifts the diversity of soil invertebrates. Similarly, heavy equipment would not only cause soil compaction of soil, decreasing the diversity and abundance of soil invertebrates, but the compaction could cause large ruts and even producing temporary or permanent ponds.

One aspect of functional remediation types requiring further consideration is the time required for cleanup activities. The effects on ecological receptors from different functional remediation activities increase the longer the period of exposure. Large trucks and heavy equipment on a site for 2 months are likely to have fewer effects than the same equipment active on site for 2 to 3 years. Such exposure provides more time to bring in seeds of invasive species, cause greater compaction, and to kill more plants, soil invertebrates and other organisms. Partly the latter is due to the seasonality of species; many species are active only during the warmer months; some move deeper in the soil (some invertebrates), some migrate away from the area (e.g. some insects, birds, mammals), and some have life cycles that make them less vulnerable at some periods of the year (e.g. some butterflies and other insects).

Another aspect of functional remediation types that can affect the extent and magnitude of effects is the spatial extent of remediation. When remediation occurs over a wide geographical area, the effects are going to be greater than when the remediation area is small. Partly this is because any injury that occurs cannot be repaired as easily by natural succession because the seed bank, and the animals that would repopulate the area, are too far away. Large remediation areas have a large edge area where effects on buffer lands can occur. Further, understanding the spatial extent of remediation becomes especially important for the final disposition of Hanford's reactors because they are located close to the riparian zone and the Columbia River.

CONCLUSIONS

Functional remediation allows public policy makers, DOE managers, workers and contractors, and the public to fairly assess the effects on ecological systems of specific components of remediation. This will identify species, communities, or specific habitats at risk from different components of remediation, and allow managers to triage negative impacts. Likewise, Tribes and stakeholders can compare the effects of limited remediation, versus large-scale demolition and soil removal.

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