Application of Field Evaluations of Ecological Resources at Hanford and Other DOE Sites for Consistency of Resource Protection and Sustainability - 16404

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ABSTRACT

Remediation and management of contaminated facilities, soil, sediment and biota is an essential element of the DOE-EM mission for site completion, contaminant footprint reduction, and protection of human health and the environment. Protecting ecological resources is an integral part of protecting human health because people are part of the ecosystem and rely on ecological resources for food, fiber, clean air and water, recreational, aesthetic, and cultural values. Evaluation and management require understanding the past and current conditions, as well as protecting, preserving, and enhancing ecological resources. Understanding past and current resources includes evaluation of individual and population health within a local and regional context. The objective of this research is to describe a field method of evaluating ecological resources, based on work at the Hanford Site, which can be applied to sustainability of ecological resources as another mandate of DOE. This requires objective methods to characterize and evaluate resources spatially, within a context of local and regional importance.

The DOE complex is large, diverse, and multi-state. The habitats and ecological resources are diverse, and the relative importance of ecological resources to the local ecosystem, region, and human communities varies. Large and diverse sites such as Hanford, Idaho National Laboratory, Los Alamos, hold resources of substantial importance to local and regional ecosystems, as well as to the ecology and cultural values of Tribes and other residents. However, other smaller sites (e.g. Oak Ridge, Brookhaven) also hold key ecological resources to local and regional ecosystems, cultures, and economics. Understanding the relative importance of ecological resources on each remediation site at different spatial scales, within and among DOE-EM sites is critical to management, stewardship, and ensuring sustainability for generations to come.

Without a standardized methodology it is difficult to develop sound remediation and management plans to protect human health and the environment. The Ecological Evaluation of Resources described in this paper is part of the Consortium for Risk Evaluation with Stakeholder Participation’s (CRESP) Risk Review Project on the Hanford Site. It is an independent assessment based of on-site field evaluations that encompasses evaluations of site resources in comparison to the Columbia

Basin Ecosystem prior evaluations made by DOE, the States of Washington and Oregon, Nature Conservancy and Tribes. The on-site field evaluations are the focus of the current paper. The on-site field evaluation methodology was developed to update existing information on habitat values in light of changing landscape features (edge, patch size and shape, connectivity) and the current presence of invasive species. Both aspects change with time, especially given that remediation of remediation units changes the landscape. That is, every time there is a remediation and restoration of an operable unit (remediation site) on a DOE site, it changes the adjacent landscape (and ecological resources). The changes are greater where new roads were built to access a remediation site, staging areas constructed, and as a function of the size and time-frame for the remediation.

Since ecological resources form a continuum across the landscape, and activities from remediation on a given site can affect those on adjacent areas, we evaluated resources both on the remediation site itself, and on a buffer equal to the largest diameter of the remediation site. The field evaluation methodology developed at Hanford Site makes use of existing resource level maps (DOE/RL-96-32 2013) and field surveys and measurements of current vegetation and habitat conditions to evaluate potential ecological impacts associated with cleanup activities at the evaluation unit. Additional information used in the ecological resource evaluations include current Endangered and Threatened Species distribution data (both state and federal), aerial imagery, locations of waste sites and infrastructure, and species and habitats of special concern.

We suggest that the field methodology developed for the Hanford Site could be used across the DOE complex to evaluate ecological resources. This would provide DOE-EM with a common data base to make long-term decisions about the protection and sustainability of resources on the DOE complex, and would provide Tribes and the public with information on ecological resources on DOE sites. Such information could be provided in a web-based format which DOE, regulators, Tribes, and the public could easily access.

INTRODUCTION

Remediation and restoration of contaminated facilities, soil, and sediment are part of the DOE-EM mission for site completion, contaminant footprint reduction, and protection of human health and the environment. Protecting ecological resources requires determining the status of ecological resources on units still remaining to be remediated, within the context of different spatial scales from the immediate contiguous habitats, those in adjacent sites, and local landscapes up to ecoregion scale. Understanding the relative importance of ecological resources spatially on each DOE site, and among DOE sites is important for DOE’s long-term mission of management, stewardship, and ensuring sustainability for generations to come. Without a standardized methodology it is difficult to develop sound remediation and management plans to protect human health and the environment. Finally, evaluating ecological resources on those sites where DOE-EM is still responsible for remediation may aid in prioritizing remediation schedules to minimize damage to ecological resources.

Data on the spatial distribution, importance or value of ecological resources on different units within each DOE site will help DOE decision-making in four important ways: 1) protection of ecological resources on site during remediation, 2) providing information to prioritize remediation schedules and optimizing timing to reduce damage to ecological resources, 3) selection of restoration and revegetation plans, and 4) contributing to the mission of long-term stewardship and sustainability of ecological resources. All benefit from formalized methods to evaluated resources spatially, within a context of local and regional importance.

The DOE complex is large, diverse, and multi-state, the resources are diverse, and the relative importance of ecological resources to the ecosystem, ecoregion, and human communities varies among sites. Large and ecologically diverse sites hold resources that might be of critical importance to local and regional ecosystems, but this cannot be fairly stated without having metrics for evaluation. Further, the ecological resources on site have recreational and cultural value to Tribes, ecotourists, naturalists, and other residents. Additionally, other smaller sites also hold key ecological resources that are important to local and regional ecosystems, cultures, and economics (e.g. Brookhaven).

DOE sites have protected unique habitats that have been eradicated or degraded outside the boundaries of the sites. These include the Arid Lands Reserve (Hanford), shrub steppe (INEL), Carolina bays (SRS), and Long Island pine barrens (Brookhaven), However, even on large sites, habitats are vulnerable to degradation and fragmentation, by the very industrial and testing activities, that allowed the sites to be protected beginning in the mid-20th century.

The objective of this paper is to briefly describe a field method of evaluating ecological resources, based on work at the Hanford Site, and suggest approaches and methods to implement it at other large DOE sites with important ecological resources. A long-term goal is to develop an ecological method that can be applied across and beyond the DOE complex to provide consistency in the evaluation of ecological resources. This works fits within a context of environmental assessment and management to protect and enhance ecological resources, protect human health within an ecological context, and ensure cultural health and well-being.

Ensuring the health of ecological resources requires understanding the diversity, status, and changes in natural resources, which range from populations of individuals of a single species to whole ecosystems. The U.S. Endangered Species Act [1] provides legal protection for plant and animal species listed as threatened or endangered. While being on the Endangered Species List results in legal protection, the Act also affords some protection for the habitat of listed species, the so-called "umbrella effect". States also have lists of threatened and endangered species, and many also list species of special concern. We also pay attention to candidate species that are being considered for listing as well. Evaluating potential impacts to endangered, threatened, and species of special concern is paramount when determining ecological risks, and is particularly of interest to federal and state natural resource regulators, as well as Tribal agencies.

Species, however, exist within a habitat that is part of a complex ecosystem. Resource managers now recognize the importance of habitat protection, particularly for vulnerable habitats, which often contain endangered or threated species. Vulnerability is a key aspect for ecological risk assessment or evaluation, and managers (and legal entities) are both concerned about sensitive or unique ecosystems [2]. Vulnerable habitats are usually most at risk, limited in quantity or extent, and often contain one or more endangered species, endemic species (species that occur only in those areas), or threatened species assemblages (e.g migrant songbirds, breeding frogs, hibernating snakes). Unique habitats are those that are rare both locally and regionally. Such habitats are limited and often fragmented, and any decreases in quantity or declines in quality could have severe consequences.

Thus an important part of ecological valuation for sites requiring remediation is acquiring site-specific information on the frequency and spatial extent of Listed Species (federal, state, Tribal), and knowing the frequency and extent of rare and unique habitats. In this paper we suggest that having valuations of these two imperatives for the remaining remediation units on as many DOE sites as possible will aid both local and headquarters in making informed decisions that concern ecological resources on their sites. Further, the information will provide assurance to regulators, natural resource trustees, Tribes, and the public that DOE is fulfilling its mission of protecting environmental and human health on their sites.

METHODS

Our overall protocol was to assess the available biological and ecological information for the Hanford Site, consider previous resource evaluations, and then to develop a methodology for rapid on-site ecological resource evaluation that could be applied to existing remaining remediation units. Assessing the available information for the Hanford Site included an extensive review of the refereed literature about valuation of resources [3,4], resources and ecosystems on the Hanford Site [5-9], ecological resources in the region and eco-region evaluations [10,11], drivers in the system (i.e. fire [12-13]), state and federal resource evaluations [14-16], and DOE’s contractors [17,18], as well as information about other DOE-EM sites [19].

The development of our methodology was based on our combined ecological field experience at Hanford Sites, other DOE sites, and other ecological sites in several states. Most of the authors have had over 25 years of ecological field experience each. We then propose approaches and methods to apply the methodology (described briefly here) [20] to other large DOE sites.

RESULTS

Evaluation Method Assumptions

The on-site field methodology required some assumptions, which included: 1) There were a number of remaining remediation sites on Hanford, 2) a reasonable boundary could be drawn around each site where any remediation activities would likely occur, 3) Some information about ecological resources on site existed, and was developed over the years by federal, state, and tribal natural resource agencies, non-governmental organizations (e.g. Nature Conservancy), contractors, and university and other scientists. These will be discussed briefly below.

The first assumption needs no justification – everyone in the DOE-EM complex knows that Hanford has a number of very extensive remediation tasks to remove, stabilize or contain legacy nuclear and chemical contamination in a wide variety of conditions, containers, structures, lagoons, and in the soil and groundwater.

The second assumption is valid for Hanford. PNNL was able to designate the appropriate boundaries around the remaining remediation sites. Evaluating risks to ecological resources also involves establishing the area of direct impact, which we defined as the Evaluation Unit (EU). The boundaries for the EUs at Hanford were drawn as a polygon around the area expected to be directly impacted by the remediation. The EU boundary was assumed to represent the estimated boundary or extent of potential habitat removal (e.g. complete soil and vegetation removal) or direct disturbance due to remediation. That is, at the extreme or worse-case scenario, remediation might involve the complete removal of soil (down to varying depths), with removal of associated soil invertebrates, vegetation, and animals using the site.

On-site Field Method Paradigm

The initial decisions for a field evaluation were determining area around a remediation unit that needed to be evaluated, determining the relevant spatial scale for evaluation beyond the immediate study site, and identifying other site-specific considerations should needed consideration. We determined that the buffer area around the evaluation unit (EU) should be equal to the widest diameter of the EU.

Valuing ecological resources is a difficult task, and we were fortunate that several years of thought and experience of State, Federal, Tribal and Non-Governmental Organizations (NGO) ecologists and managers had developed a ranking system for ecological resources based mainly on vegetation types (DOE/RL-96-32 2013). These valuations were developed based on field work, as well as knowledge of threatened and endangered species, threatened habitats, and habitats critical to threatened and endangered species, and species of special concern (for ecological, economic or cultural reasons). The definitions of resource value are given in Table I.

TABLE I. Resource Levels Used in Valuation of Ecological Resources (after DOE/RL-96-32; DOE/RL-96-32, 2013 [8,9].

Resource Level	**Definition**
0	Paved or highly developed with facilities
1	Resources are in habitats where DOE is not required to complete habitat replacement, but habitat could be restored there. There may be common native plants and animals, as well as stands of non-native plants or abandoned agricultural fields
2	Resources include migratory birds and state monitored plants and animals, as well as upland stands of shrub over-story, non-native plants, and some steppe stands that co-occur with non-native plants
3	Resources include state sensitive or candidate plants and animals that may have cultural importance
4	Resources include state threatened or endangered species, federal candidates, upland stands with native climax shrub over-story and native grass understory, and wetlands and riparian habitats
5	Resources includes not only federally–listed species, but sensitive habitats. Irreplaceable habitats included cliffs, lithosols, dune fields, ephemeral streams and vernal ponds, as well as Fall Chinook Salmon and Steelhead spawning areas

We include here one of the resource maps for the Hanford Site to provide an idea of the level of assessment that exists for Hanford, and a goal for other sites (Figures 1 and 2).

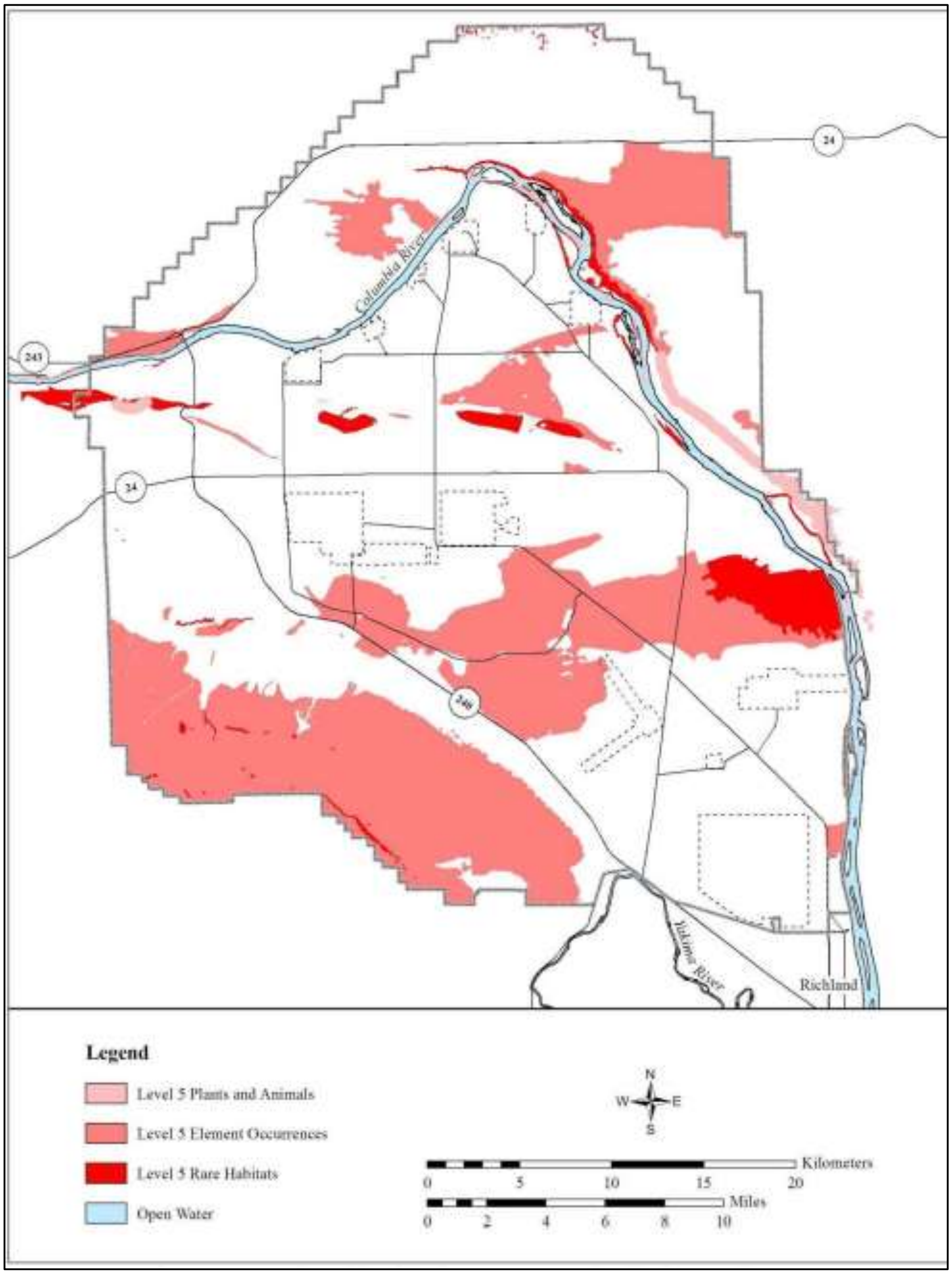

Fig. 1. Resources classified as Level 5 by Hanford (From Figure 5.2, page 5.13) [3].

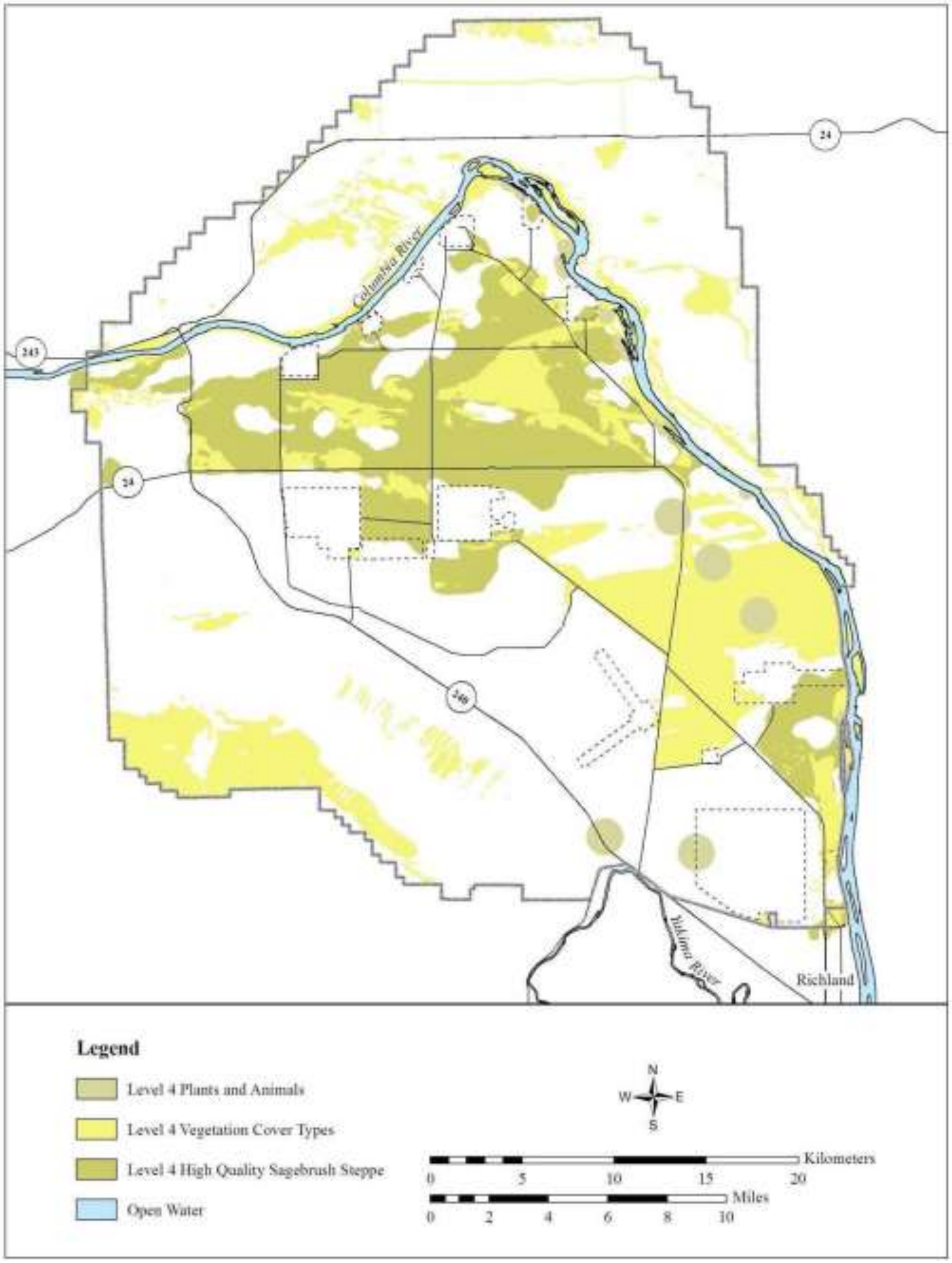

Fig 2. Map of DOE's (2013) evaluation of Level 4 species and unique or rare habitats (Figure 5.3, page 5.14) [3].

The steps for the on-site field methodology for evaluating risks to ecological resources on Hanford involved the steps outlined in Table II.

TABLE II. Steps in the Field Methodology to Evaluate Ecological Resources on the Hanford Site.

Steps	Description	Personnel
Determine remediation boundaries	Although remediation units may be defined, the actual footprint of activity needs to be defined, including laydowns	PNNL
Determine buffer size	For ecological resources, areas adjacent to remediation site will be affected, and this area needs to be defined and justified	Rutgers and PNNL, other scientists and authors
Determine resource value scale	Determine a scale, define the scale, and the assessment metrics	Modified the existing resource values (0-5; DOE/RL 96-32 [9]
Field visual survey of EU	Visual survey within EU boundary by experienced biologists (transects where needed) to determine % of each resource value/EU (using resource descriptions [9]).	PNNL and Rutgers scientists
GIS and field reconnaissance Survey of buffer	The original resource valuation maps [9] were compared to current value of buffer, and additions made	PNNL
Determine resource value of EU and buffer	In the laboratory, use GIS and field observations to determine the percent of each resource level in every EU	PNNL
Opportunistic wildlife observations	All personnel in the field recorded observations of wildlife	PNNL and Rutgers scientists
Existing data bases	Search any existing data bases for occurrence of wildlife of interest (e.g. known threatened or endangered species, species of concern)	PNNL
Final Field Value Sign-off	Discussion to assure accuracy, consistency	Rutgers, PNNL, and other scientists

This procedure allowed all personnel (as well as stakeholders) to be assured that the process was accurate and consistent, and that all personnel had an opportunity to note unusual ecological observations that might indicate future value.

APPLICATION TO OTHER DOE SITES

Many of the DOE sites have large land holdings, with many different habitats and species. They have endangered and threatened species, and unique ecosystems [20 and references therein]. Initially a local committee should be established of DOE, regulators, and resource trustees to oversee the process, assigning personnel to accomplish each task. Some will require longer to complete than others, especially the definitions of resource levels, and the field evaluations if no previous GIS data exist for the site.
We are thus suggesting that a similar procedure could be applied at the other DOE sites. Because the other sites will not have a valuation system already established, in Table III we have amplified our suggestions for application at other sites.

These are suggestions based on many years of experience at Hanford, other DOE sites, and ecological research in general. But every DOE site is different, and this methodology should be adapted to each specific site, bearing in mind the importance of consistency across sites.

TABLE III. Application of the Field Methodology to Other DOE Sites.

Steps	Description	Approach Application
Determine remediation boundaries	Although remediation units may be defined, the actual footprint of activity needs to be defined, including laydowns	DOE and regulators need to determine remediation sites and appropriate boundaries.
Determine buffer size	For ecological resources, areas adjacent to remediation site will be affected, and this area needs to be defined and justified	DOE, regulators and biologists need to discuss the most relevant buffer size for the DOE significant habitats on site
Determine resource value scale	Determine a scale, define the scale, and the assessment metrics	A committee of DOE, regulators, resource trustees and biologists need to establish a scale, which can be modelled after the existing resource values (0-5; DOE/RL 96-32 [9]
Field visual survey of EU	Visual survey within EU boundary by experienced biologists (transects where needed) to determine % of each resource value/EU (using resource descriptions [9]).	Depending upon time, scope and funding, transect surveys need to be completed of the EU and buffer areas by biologists familiar with the rating scale and the rare, endangered and threated species and habitats of the region
GIS and field reconnaissan	The original resource valuation maps [9] were compared to current value	Since original resource maps will not exist, the same procedure as above needs to be followed.

ce Survey of buffer	of buffer, and additions made	
Determine resource value of EU and buffer	In the laboratory, use GIS and field observations to determine the percent of each resource level in every EU	For most sites, this will involve analyzing the field data to determine the percent of each rank type in each EU and buffer
Opportunistic wildlife observations	All personnel in the field recorded observations of wildlife	Appropriate data sheets need to be developed to allow all field personnel to record important wildlife observations. In addition, refereed and grey literature needs to be searched for expected or known wildlife of concern.
Existing data bases	Search any existing data bases for occurrence of wildlife of interest (e.g. known threatened or endangered species, species of concern)	Many of the DOE sites were once National Environmental Research Parks (NERPS) and these data bases should be searched for important plant and wildlife sightings and information.
Final Field Value Sign-off	Discussion to assure accuracy, consistency	Because this process is time-consuming and new to most sites, multiple resource meetings with different agencies, scientists, interest groups and the public will be essential to ensure that all parties feel that ecological resources are being protected by the process.

DISCUSSION

Hard decisions at Hanford

Evaluating the risks from any management, remediation, or restoration project must involve defining the geographical extent of the project, valuing the resources that are present on the site, defining the remediation or management actions, and determining how the actions will affect the resources on site. In this paper we focus on the field assessment of ecological resources.

The hardest decisions were deciding whether to evaluate only the remediation site (EU) or also evaluate a buffer, what evaluation scale to use, how the scale should be modified, and how to conduct the field evaluations. Each will be discussed below:

Some ecological resources around the EU may be affected by actions within the EU due to personnel or vehicular traffic, introduction of invasive species, altered drainage, or disruption of ecological patches (including creating more edge). We decided that a buffer around the actual EU is essential to adequately evaluate risk to ecological resources from remediation, restoration, or other management actions. Thus, a second boundary outside the EU was established to evaluate indirect effects and assess the remediation in relation to adjacent landscape features. This polygon was centered on the EU and encompassed a circular area with a radius 1 times the maximum width (diameter) of the EU and is referred to as the adjacent landscape buffer. While this is arbitrary, we felt that the area was sufficient to assess potential affects to adjacent habitat.

On-site Field assessments were essential to provide up-to-data valuations of the ecological value of both the EU and the buffer area. A visual survey was conducted within the EU boundary by experienced shrub-steppe ecologists who have worked in the habitat for many years. Biologists assembled the information from field survey, reconnaissance, and spatial analyses of resource availability to provide a subjective evaluation of potential effects on habitat connectivity in the vicinity of the EU. That is, for each EU and the buffer area, we determined the percent of the habitat that fell into each habitat value category (from 0 to 5). This methodology results in a field report for each EU, which can then be used to rate relative risk to ecological resources based on the value of the resources, and other considerations (e.g. remediation type, presence of contamination).

Additional information used in the ecological evaluation included: 1) current Endangered and Threatened Species (Federal and State lists) distribution data (including species with "candidate" status), 2) priority habitats as defined by Washington Department of Fish and Wildlife, 3) available current aerial imagery, locations of Hanford Site waste units, and infrastructure spatial data, and 4) available information about species of concerns, including data previously collected by contractors. We were able to compare the status and trends of different habitat types on Hanford, compared with the Columbia basin ecoregion. This information may not be available at other sites.

Hard decisions at other DOE sites

There will be many hard decisions at the other sites, including which remediation sites to evaluate, how large to make the buffer, who should be on the committee to set a rating scale (ecological resource rating scale based on unique and rare plant and animal communities), what approval or consensus process such a committee needs, who should conduct the evaluations once a rating scale is developed, and at what level the field evaluations should occur.

Our final two recommendations are that it would be useful for DOE headquarters to convene a committee to develop and refine this methodology, and any methodology developed should be monitored periodically for changes. Application of this methodology is an iterative process, requiring evaluation of success and failures, as the process of remediation and restoration at Hanford EUs continues. Periodic monitoring of restored and adjacent habitat, periodic ground and aerial surveys of habitat integrity, mapping (and control) of invasive species, survival and spread of listed species, are all necessary to apply, perpetuate, and validate the proposed methodology. Dissemination of the methodology across the DOE complex and to other relevant agencies will be desirable.

CONCLUSIONS

Environmental remediation, restoration, and stewardship require information on the resources present, and the relative ecological and cultural value of these resources in terms of species, ecosystems, and the goods and services they provide. The first step in understanding ecological resources involves an inventory of the resources present, and a ranking of those resources. An understanding of ecological resources is especially important for the Department of Energy because its complex is large, diverse, contains important and unique resources, and protection of human health and the environment is part of its mission. This paper provides a field method of evaluating ecological resources that can be used complex-wide. The method involves 9 steps that can be applied at all DOE sites The method involves determining boundaries of individual remediation sites, determining an appropriate buffer size around each site, determining a resource value scale, conducting a field visual survey of the environmental unit (EU), conducting GIS and field reconnaissance, determining resource value of the EU and its buffer, reporting any wildlife observations while in the field, utilizing existing data when appropriate, and providing a final field value for each EU. Different sites will have different information on the ecological resources on their site, which may include GIS information of unique species or habitat locations, distribution of federal and state endangered and threatened species, and recent occurrences of species of special concern. Before implementation of the method each site needs to identify the federal and state regulators and resource personnel that will direct the process, and oversee its implementation. Consistency across DOE sites will allow headquarters and the public to understand the relative presence and value of ecological resources across the complex, providing support for remediation, restoration, and stew

REFERENCES

[1] Endangered Species Act (ESA). Public Law-205, as amended, 16USC 1513 et seq. (1973) Available: http://www.epw.senate.gov/esa73.pdf

[2] J.L. Downs , W.H. Rickard, and C.A Brandt. Habitat types on the Hanford Site: wildlife and plant species of concern, PNL-8942, UC-702. Pacific Northwest National Laboratory, Richland, WA. (1993).

[3] M.J. Scott, C.A. Brandt, A.L.Bunn, D.W. Engel, P.W. Eslinger, T.B. Miley, B.A Napier, E.L. Prendergast, L.A. and Nieves. Modeling long-term risk to environment and human systems at the Hanford nuclear Reservation: scope and findings from the Initial Model. *Environmental Assessment,* 35, 84-98 (2005).

[4] T. Teder, M. Moora, E. Roosaluste, K. Zobel, M. Partel, U. Koljalg, M. and Zobel. Monitoring of biological diversity: a common-ground approach. *Conservation Biology*, 21, 313–317 (2007)

[5] DOE/RL-96-32 Rev.1. Hanford Site Biological Resources Management Plan, U.S. Department of Energy, Richland, Washington. (2013). Available: http://www.hanford.gov/files.cfm/DOE-RL-96-32-01.pdf

[6] J.P. Duncan, K.W. Burk, M.A. Chamness, R.A. Fowler, B.G. Fritz, P.L. Hendrickson, E.P. Kennedy, G.V. Last, T.M. Poston, and M.R. Sackschewsky.. Hanford Site National Environmental Policy Act (NEPA) Characterization, PNNL-6415 Rev.18, Pacific Northwest National Laboratory, Richland, WA. (2007).

[7] DOE/RL 96-32. Hanford Site Biological Resources Management Plan, Appendix D: Hanford's biological resources: geographic information system-based resource maps, species of concern data tables, and their technical basis. U.S. Department of Energy, Richland, Washington. Available at: http://nerp.pnnl.gov/docs/brmap/BRMaP.pdf. (2001a).

[8] DOE/RL 96-32. Hanford Site Biological Resources Management Plan, Appendix C: Hanford biological resources in a regional context. U.S. Department of Energy, Richland, Washington. Available at: http://nerp.pnnl.gov/docs/brmap/BRMaP.pdf (2001b).

[9] DOE/RL-96-32. Hanford Site Biological Resources Management Plan, Revision D (2013).

[10] J.M Omernik. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers,* 77, 118-125. (1987).

[11] J.M. Omernik. Perspectives on the nature and definition of ecological regions. *Environmental Management,* 34, 527-538. (2004)

[12] R.C. Roos, A.R. Johnson, J.G. Caudill, J.M. Rodriguez, J .W. and Wilde Post-fire revegatation at Hanford. HNF-42601-FP, Rev O. Department of Energy, Richland, WA. (2009).

[13] J.M. Azerrad, K.A. Divens, M.F. Livingston, M.S. Teske, H.L. Ferguson, and J.L. Davis. Site-specific management: how to avoid and minimize impacts of development to shrub-steppe. Washington Department of Fish and Wildlife, Olympia, Washington. Available: http://wdfw.wa.gov/publications/01335/wdfw01335.pdf. (2011).

[14] E. Rodrick and R. Milner. Management recommendations for Washington's priority habitats and species. Washington Department of Wildlife, Olympia Washington. Available: http://wdfw.wa.gov/publications/00029/ (1991).

[15] United States Fish and Wildlife Service. Rare, threatened, or endangered Species: Hanford Reach. Available: http://www.fws.gov/refuge/Hanford_Reach/Wildlife_Habitat/Rare_Species.html (2014).

[16] United States Fish and Wildlife Service. Hanford Reach National Monument: Comprehensive Conservation Plan and Environmental Impact Statement. U.S. Fish and Wildlife Service. Available: http://www.fws.gov/uploadedFiles/Region_1/NWRS/Zone_2/Mid-Columbia_River_Complex/Hanford_Reach_National_Monument/Documents/final-ccp.pdf. (2008).

[17] J.M Becker and M.A. Chamness. 2011 Annual Ecological Survey: Pacific Northwest National Laboratory Site, PNNL-21164. Pacific Northwest National Laboratory, Richland, WA. Available: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21164.pdf. (2012).

[18] C. McAllister, H. Beckert, C. Abrams, G. Bilyard, K. Cadwell, S. Friant, C. Glantz, R. Maziaka, and K. Miller. Survey of ecological resources at selected U.S. Department of Energy sites, DOE/EH-0534. Pacific Northwest National Laboratory, Richland Washington. Available: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/29/015/29015260.pdf(1996).

[19] J. Burger, M.A. Carletta, K. Lowrie, K.T. Miller, and M. Greenberg. Assessing ecological resources for remediation and future land uses on contaminated lands. *Environmental Management,* 34, 1-10. (2004).

[20] J. Burger J, M. Gochfeld, J. Salisbury, and A. Bunn. An approach to evaluating and monitoring ecological resources for sustainability on DOE remediation sits: Hanford as a cast study. Phoenix, Arizona, March 14-20, 2015. Waste Management Symposium, Waste Management Proceedings. (2015).