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Resource Equivalency Methods for Assessing Environmental Damage in the EU

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Contents

Acronyms and Abbreviations

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CVM	contingent valuation method
CWA	Clean Water Act
DSHYs	discounted service hectare-years
ELD	Environmental Liability Directive
EU	European Union
HEA	habitat equivalency analysis
HPF	habitat production foregone
HRC	habitat replacement cost
NCCP	Natural Community Conservation Planning
NOAA	US National Oceanic and Atmospheric Administration
NRDAR	natural resource damage assessment and restoration
OPA	Oil Pollution Act
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PRP	potentially responsible party
PSRPA	Park System Resource Protection Act
REA	resource equivalency analysis
REMEDE	Resource Equivalency Methods for Assessing Environmental Damage in the EU
TVE	Total Value Equivalency
US	United States
VEA	value equivalency analysis

1. Introduction

1.1 Objectives

In the United States (US) and in Europe, various environmental laws have been enacted to provide for compensation for damage to natural resources. Quantifying the environmental damage and required environmental remediation requires the application of economic, ecological and legal principles. Generally, two approaches have been used to calculate the amount of required compensation: determining the monetary value of the damages; and calculating the amount of natural resource remediation or restoration needed to compensate for the harm. When a monetary valuation approach is used, the value of the loss is used to define the scope of remediation needed to complement and compensate for the damage.[1] When a resource equivalency approach is used, the benefits of remediation projects are scaled to be equivalent to the damage. Recent European Union (EU) Directives covering environmental compensation state a preference for resource equivalency approaches over monetary valuation.[2,3] In this document, we review the state-of-the-art resource equivalency methods used in the US

1.2 Conceptual Basis

When natural resources are damaged by releases of hazardous chemicals or physical destruction of the environment, actions can be undertaken to remediate the resources and to compensate the public for the loss of those resources during the time that the resources are impaired. In the US, such actions are referred to as primary and compensatory *restoration*. In the language of the Environmental Liabilities Directive (ELD), the equivalent terms are primary, complementary, and compensatory *remediation*.

In the US, equivalency methods are used to determine the type and amount of remediation needed to make the public whole for past, current, and anticipated future losses related to an incident.[4] Three main approaches to resource equivalency commonly are applied in the US: service-to-service, resource-to-resource, and value-to-value approaches. The objective of each of these methods is to determine the appropriate amount of complementary and/or compensatory remediation necessary to fully compensate the public for an environmental damage.

The result of an equivalency analysis can be expressed in monetary units, area of required remediation, numbers of individual organisms that must be replaced (such as fish or birds), or units of recreational use, such as user-days that must be replaced to compensate for the loss of recreational use. The key to equivalency methods is determining a unit of measure of damage that can describe losses over time and can be matched to the benefits of remediation over time. These methods can be applicable to scale remediation in advance of an event (*ex ante* remediation), such as to determine the

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1. An example of monetary valuation used to assess damages in the US was the Exxon Valdez spill, where it was determined that the public valued the loss of those resources at $2.8 billion (Carson et. al, 2003).

2. See, for example, the Environmental Liability Directive, the Wild Birds Directive, and the Habitats Directive (European Union 1979, 1992, 2004).

3. Throughout this document, we use terms as presented in the ELD. The term *damage* means a measurable adverse change in a natural resource or measurable impairment of a natural resource service which may occur directly or indirectly (ELD Article 2.2). In the US, the equivalent term is injury. The term *remediation*, as used in the ELD, is equivalent to the term *restoration*, as used in US laws and guidance. Therefore, primary remediation in the ELD is equivalent to primary or baseline restoration in the US, and complementary and compensatory remediation in the ELD are equivalent to compensatory restoration in the US

4. Under the ELD, the focus will be on current and future losses, since the directive is not retroactive to past events.

amount of mitigation necessary in the context of the Habitats and Wild Birds Directives, and after an event (*ex post* remediation), as in the case of the ELD.

1.3 Development of Equivalency Methods in the US

In the US, environmental damages initially were expressed in economic terms, primarily using non-market economic valuation approaches. Non-market valuation focuses on measuring the value of goods and services that are not commonly traded in economic markets. Economists have developed or adapted a number of methods to measure the value of non-market goods and services. These methods include travel cost, hedonic, contingent valuation, and conjoint analysis (choice modelling).

Travel cost, an approach developed in the 1940s, uses the cost an individual is willing to pay to travel to a recreational site as a proxy for a market price. Under conditions where environmental damage causes a reduction in recreational activity (such as the lost opportunity to fish) and the proposed remediation action creates or improves recreational fishing opportunities, this method can be used to estimate the value lost because of the damage and the value gained because of the proposed remediation projects.

Hedonic analysis builds on the understanding that often the value for a good can be divided into component parts. For example, everything else held equal, a larger house with more bedrooms will cost more than a smaller house with fewer bedrooms. Environmental quality is another factor that influences the value of homes. All else held equal, a home near a contaminated site will cost less than one some distance away. The difference in housing costs provides an estimate of the loss in value because of the contamination. This loss in value could then be expressed as the value that a remediation action must create to compensate the public for environmental harm.

Both the travel cost and hedonic methods use “revealed preference” information about people’s behaviour to estimate value. The contingent valuation method (CVM) and conjoint analysis use “stated preference” methods to estimate value. For both methods, individuals are questioned directly about how they value the prevention of a specific environmental damage and the implementation of proposed restoration projects. Conjoint analysis typically provides more choices to individuals than CVM, but otherwise the approaches are similar.

Each of these four methods is a value-to-cost equivalency approach: the value of a loss is used to scale the remediation. That monetary value is then collected and used to undertake remediation.

Because of dissatisfaction with the difficulties of non-market valuation approaches and with value-to-cost compensation, alternative service-to-service equivalency methods were developed in the US in the 1990s. Under this alternative paradigm, if services provided by public resources are lost, the public theoretically can be made whole through replacement of the same or similar services. Services provided by natural resources include both human and ecological functions. Examples of services to humans include fishing, hunting, boating, hiking, bird watching, flood control, shoreline storm protection, and enjoyment of a healthy and functioning natural environment. Services to ecosystems and other ecological resources include habitat for food, shelter, and reproduction; organic carbon and nutrient transfer through the food web; energy transfer through the food web; biodiversity and maintenance of the gene pool; food web and community structure; prevention of the spread of exotic or disruptive species; and natural succession processes. Under the service-to-service equivalency approach, remediation is scaled so that the service gains provided through remediation equal the service losses caused by the environmental harm.

The method initially developed to implement this service-to-service approach is called habitat equivalency analysis (HEA). By scaling remediation based on units of habitat rather than money, the services provided by habitats (which can include human use and ecosystem services) can be adequately replaced, regardless of the cost of the replacement.

The first cases in which HEA was used, in about 1990, were straightforward incidents of physical destruction, such as where a vessel grounding destroyed sea grass or coral reef habitat. The destruction was clearly delineated, and habitat was essentially eliminated in the footprint of the impact. The date of the destruction was well defined, and estimates of the time required for the habitat to recovery naturally and with intervention were calculated based on existing information. The resulting estimate of loss was expressed in lost hectare-years of habitat. Remediation of an equivalent amount of the same type of habitat was identified as an appropriate compensation for the loss.

These early applications of service-to-service equivalency were innovative developments in two main ways: they extended and formalized the conceptualization by Freeman (1993) of the environment as an asset that provides a flow of services, and they focused the measure of damages as the scale of remediation projects necessary to compensate for harm over time. One of the key benefits of HEA is that it allows users to bypass the evaluation of economic damages resulting from natural resource damage and to proceed directly to remediation. In addition, HEA explicitly creates a connection between units of services lost because of damage and units of services gained through remediation, when the services provided by proposed remediation actions are of similar type, quality, and value as the services lost.

HEA is appropriately applied when the service of the damaged area is ecologically similar to the service that will be provided by the replacement habitat. HEA is more complicated to apply when the services provided by the remediation action are not the same type or quality as those lost. Such instances are discussed in greater detail in Section 5.

By the mid-1990s, HEA began to be applied to cases of increasing complexity. In particular, it was applied to cases in which chemical contaminants harmed the environment, but the harm was not so clearly complete as a physical damage that wholly eliminated habitat features. Chemical contaminants can have acute, chronic, or sub-lethal effects on organisms; they can vary over space; and they can persist for long periods of time. These complications required advances in thinking about how to match the scale of the remediation projects to the scale of the damages. In addition, HEA began to be applied in cases where the harm originally began long ago (such as at old mine sites), and where the baseline condition (the condition absent the release or incident in question) is difficult to quantify or describe. State-of-the-art approaches to handling such complications are described in Sections 4 and 5.

As the use of HEA expanded, cases arose where the damage was more appropriately measured in numbers of individuals lost, such as birds or fish, than in habitat units. In such cases, the remediation was scaled to provide equivalent numbers of replacement individuals, on the theory that the replaced individuals would compensate for the full suite of ecological and human use services lost. This application of resource-to-resource scaling came to be called resource equivalency analysis (REA). The methods of REA are fundamentally the same as for HEA, but the units of quantification differ.

In 1996, the US National Oceanic and Atmospheric Administration (NOAA) formalized the use of HEA in environmental regulations. Subsequently, HEA became the most common equivalency scaling method. It has been used to scale compensatory remediation in such diverse habitats as Florida coral reefs, salmon habitat in the Northwest, and estuarine wetlands in south Texas. Currently, there are many HEAs or REAs ongoing in the US

Legal Background of Equivalency Methods in the US

In the US, the legal framework for environmental protection includes the common law principles of nuisance, trespass, toxic tort, negligence, public trust, and *parens patriae* (parent of the country), as well as numerous local, state, and federal statutes, regulations, and ordinances. The primary US federal statutes that address environmental impacts through response and remediation actions are the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Oil Pollution Act (OPA), the Clean Water Act (CWA), and the Park System Resource Protection Act (PSRPA). These statutes provide for response to oil spills and releases of hazardous substances, clean up of contamination in the environment, physical destruction of resources, and compensation through remediation for public losses caused by releases.

The last of these three provisions, compensation, is the basis for natural resource damage assessment and restoration (NRDAR) programs in the US These programs ensure that the polluter (responsible party) – and not the American taxpayer – pays for the loss of natural resources and the associated remediation costs. When the release (or a response to the threat of a release) of oil or hazardous substances harms public land or other natural resources, and when response actions will not fully restore the affected resources, trustees of the public's natural resources can seek compensation from the potentially responsible party (PRP) to remediate the resources. Calculation of damages for the NRDAR cases was the developing grounds for equivalency scaling.

In the early 1990s, HEA was applied to a number of sea grass damage claims in the Florida Keys National Marine Sanctuary. Two of these assessments were challenged in US Courts on the applicability of HEA as a reliable method. The conclusions from both court rulings strongly supported the admissibility of HEA as an appropriate method to determine compensatory remediation project scale when the primary category of lost on-site services pertains to the ecological/biological function of an area; when feasible remediation projects are available that provide services of similar type, quality, and comparable value to those that were lost; and when sufficient data to perform the HEA are available or cost-effective to collect.

Another federal program that scales remediation is wetland mitigation. Section 404 of the CWA regulates dredging and filling in navigational waters of the US Provisions of Section 404 have led to programs to prevent the net loss of wetlands. Where wetlands are lost or impaired, equivalency scaling is often used to determine how many hectares of wetlands, and of what type and quality, must be either banked or restored as mitigation to offset the loss.

By the mid- to late 1990s, a variety of other mitigation applications evolved that used a similar service-to-service or resource-to-resource scaling framework to offset anticipated impacts. Mitigation banking for planned impacts to wetlands, and conservation banking for planned impacts to species of concern became more common. Both of these uses allowed for remediation actions to occur prior to impacts.

1.4 Overview of Application of HEA/REA

The technical approach for HEA/REA is presented in a series of published articles (e.g., Peacock, 1999; NOAA, 2000). All of the resource equivalency approaches are formalized in the following equation:

$$\left[\sum_{t=0}^{B} \mathrm{V}^{j} * \rho_t * \left\{\left(b^j - x_t^j\right)/b^j\right\}\right] * J = \left[\sum_{t=I}^{L} \mathrm{V}^{p} * \rho_t * \left\{\left(x_t^p - b^p\right)/b^j\right\}\right] * P$$

[_____] [_____]
Losses Gains

where *t* refers to time (in years):

t = 0, injury occurs
t = B, injured habitat recovers to baseline
t = C, time the claim is presented
t = I, habitat replacement project begins to provide services
t = L, habitat replacement project stops yielding services

and where:

V^j is the annualized per unit value of the services provided by the injured habitat (without injury)

V^p is the annualized per unit value of the services provided by the replacement habitat

x_t^j is the level of services per hectare provided by the injured habitat at the end of year *t*

b^j is the baseline (without injury) level of services per hectare of the injured habitat

x_t^p is the level of services per hectare provided by the replacement habitat at the end of year *t*

b^p is the initial level of services per hectare of the replacement habitat

ρ_t is the discount factor, where $\rho_t = 1/(1+r)^{t-C}$, and *r* is the discount rate for the time period
J is the number of injured hectares
P is the size in hectares of the replacement project that equates the losses with the gains from remediation.

This formulation implies four important points about HEA/REA:

1. Holding all else constant, losses from damages and gains from remediation accrue over different time periods, and ecological services gained from remediation conducted in the future are less valuable to the public than ecological services available today. To make past or current and future losses and gains comparable, calculations are made that discount the quantities of service from past or future years to present-day terms ("present value"). HEA calculations typically incorporate a discount rate of 3%, which has the effect of compounding past service loss and discounting future service loss compared to the present value (this issue is discussed further in Section 3.4).

2. The amount of services provided by the resources at a damaged area and a remediation site may be different. In reality, most impacts do not completely eliminate habitat (or biota), and most remediation actions do not create a completely new and functioning habitat (or biota). In

addition, habitat functions are complex, and ecosystem processes are interrelated. To accommodate this complexity, common practice includes estimating the percentage of services lost and gained using a single attribute of service or function called a metric. The metric used must be measured using the same attribute on the loss and gain sides of the equation, and it should be useful to discern relative differences in the quality and quantity of services provided by the baseline, damaged, and compensatory habitats.

3. The value to society of a given habitat type is constant over time. Alternatively, one might argue that increasing development may lead to a shortage of some resources or habitat types (e.g., urban wetlands), and thus increase the value of the loss in the future and make its damage more costly today. Resource equivalency does not directly allow for this change in preferences; use of a non-constant discount rate could indirectly allow for such preferences to be considered (see Section 3.4).

4. Habitat and resource equivalency approaches assume that the public's utility loss can be compensated in the aggregate through remediation or replacement of equivalent resources, whatever that may cost (see Flores and Thacher, 2002; Zafonte and Hampton, 2007).

HEA and REA are considered to be appropriate for scaling remediation when (1) a common metric can be defined that reflects the services damaged by the impacts and gained through remediation, (2) the landscape context of the damaged and remediated habitats are sufficiently similar that the remediation will supply similar services, and (3) sufficient data on HEA/REA input parameters exist or are cost-effective to collect. When these conditions are not fulfilled, the HEA/REA process is unlikely to result in appropriate remediation. As with all models, a lack of input data limits the validity of the outputs. In Section 3, we discuss the issue of estimating service losses and gains, data useful to estimate input parameters, and the choice of metrics.

When remediation of the same or similar resources or services is not technically feasible (e.g., habitat or organisms of similar type and quality are not available), is undesirable (e.g., if enhancing habitat or number of organisms nearby will increase exposure of wildlife to toxic substances), or is excessively expensive, HEA/REA may not be appropriate. In such cases, compensatory actions that provide resources and services of different type or quality than those injured may be preferred. In these cases, the value-based scaling methods discussed earlier may provide a better basis for selecting and scaling remediation activities.

2. Equivalency Models

Several approaches to performing equivalency analysis have been developed. These approaches can be categorized as follows:

HEA is used to scale damages (debits) and the benefits of remediation (credits) through units of habitat. For example, the impacts of a given incident are calculated in terms of discounted-hectare-years that describe the aerial extent of harm over time. Remediation credits also are calculated in terms of discounted-hectare-years that describe the ecological services that will accrue during and following remediation. Recent advances in HEA methods enable treatment of partial service losses, impacts from multiple stressors, and inclusion of scalars that reflect differential productivity or scarcity of different habitat types.

REA is used to scale debits and credits through resource-specific units other than habitat area. For example, numbers or biomass of fish have been used as the basis for REA evaluations. The **habitat replacement cost (HRC)** analysis (Allen et al., 2005) is a variant of REA. In this analysis, impacts to marine fish species at different life stages are expressed in terms of age-1 (one year old) juvenile equivalents, and remediation is scaled based on the amount of habitat creation needed to produce a similar number of age-1 equivalents. A variant of the HRC was developed in California, US, by Raimondi (2006). Termed the **habitat production foregone (HPF)** method, this approach involves using fisheries population models to describe impacts in terms of fractional mortality rates. This fractional mortality rate then is multiplied by the area over which impacts have occurred to scale remediation. More recently, REA has been applied to water damages, where remediation is scaled in terms of groundwater and surface water volume or flow.

Value equivalency analysis (VEA is implemented in situations where remediation of similar habitats or resources is either infeasible or undesirable. VEA is used to scale impacts with complementary/compensatory remediation actions based on stated preference measures of individuals' values.

2.1 Conducting Equivalency Analysis

HEA and REA are conceptually similar and involve performing generally similar types of analyses. VEA requires different methodological approaches, because it relies on stated preference measures of societal value. As such, it is conceptually similar to the economic valuation approaches described in Section 2.2. More detail about VEA applications can be found in Breffle and Rowe (2002), Breffle et al. (2005), and Lazo et al. (2005).

Conducting a HEA or REA involves three main steps:

1. Quantify the effects of environmental damage in terms of the extent and degree of lost resources or services (whether ex-ante or post-ante)

2. Identify and evaluate remediation options in terms of the quantity and quality of service or resource replacement anticipated to be provided

3. Scale the remediation to compensate for the lost resources or services over time.

The required information and input parameters include:

Start year. On the impact side, this is the year in which losses began, or the year in which the calculation of losses begins. On the remediation side, this is the year in which remediation actions and benefit are expected to begin.

End year. On the impact side, this is the year in which losses end – either the resources recover naturally or recover as a result of response actions. Sometimes there is no expected end year because resources are not expected to recover. On the remediation side, this is the last year in which the credit from the remediation project is summed.

Spatial extent. On the impact side of a HEA, this is the area of habitat impacted. On the remediation side, this is the unit area to be remediated.

Service loss. For a HEA, this is the degree of loss experienced by the area defined by the spatial extent. A complete loss is described as 100% service loss; a loss that does not eliminate the human use or ecological services provided by the habitat can be characterized as some percentage less than 100. Service loss can vary over time, and if resource condition improves with time, it can go to 0%. For a REA, this can be numbers of individuals lost, or, if the loss is a sub-lethal effect on organisms, it can be expressed as a loss of viability, as in years of lifespan or number of offspring.

Service gain. For a HEA, this is the amount of benefit expected to derive from a remediation project. Once a project is implemented, benefits begin to accrue, but full services might not be expected until some time in the future. Service gain could be 100% if entirely new habitat is created, or it could be some percentage less if actions merely enhance the services of habitat that already exists. The amount of service gain is estimated relative to baseline conditions, or the conditions of the impacted area had the impact not occurred. For a REA, this can be numbers of individuals to be gained, or, if the gain is in terms of health or viability, it can be expressed as an increase in lifespan or expected number of offspring.

Baseline conditions. Baseline conditions are the conditions that would exist if the incident (spill, release, physical damage) did not or does not occur. Baseline conditions are used to compare to existing or anticipated conditions to evaluate the type and amount of resources or services lost as a result of the damage, or gained as a result of complementary or compensatory remediation.

Metric. This is not an input parameter per se, but the unit of measure of the service loss and gain. See Section 3.2 for details.

Trajectory. This also is not an input parameter per se, but a description of the time course of service loss or gain (degradation rate or recovery rate). On the impact side, this is the service loss for each unit area impacted each year from the start date to the end date. For a REA, it is the number of individuals impacted (and degree of impact) each year. On the credit side, this is the service gain for each unit of area remediated each year between the start year and the end year. For REA, it could be the number of individuals or additional life span generated by the project each year.

Discount rate. Current practice in the US is to use a constant 3% rate. There are situations in which different discount rates, or variable discount rates, might be appropriate.

Base year. This is the year used for the present value calculations.

The major steps and use of the input parameters are detailed in the sections that follow.

2.2 Quantifying Damage

The first step involves estimating the quantity of the damage, which for HEA is the spatial and temporal extent of the damage, and the degree of the harm. The spatial extent might be straightforward, in that the damage might involve physical degradation that is easily delineated. In more complicated cases, the spatial extent might be affected by processes of environmental chemical fate and transport, such as transport of more- or less-harmful degradation products into a wider area over time, or cascading biological effects that take place in far removed locations, such as with migratory species. For REA, the quantity of the damage can be expressed as numbers of organisms directly harmed (killed or impaired), but it may also include indirect effects, such as offspring foregone, or prey or food chain biomass forgone.

The temporal extent of the damage might initiate with a specific spill, release, or incident, or, depending on the circumstances, with a date of passage of a statute or regulation.[5] If adverse effects or losses are ongoing and are expected to continue in the future, this temporal component is included in evaluating the present value of the damage. Often, estimates must be made about the effectiveness of any ongoing response actions or anticipated ability of the resource to recover without intervention. In these cases, comparison to similar events or sites can offer support to assumptions about future degree of harm and recovery rates.

The most difficult part of HEA/REA often involves the estimation of the degree or quality of loss associated with the environmental harm (and, in step 2, the degree or quality of service gain associated with the remediation). Common practice includes estimating the percentage of services lost and gained using a single attribute of service or function called a metric. Multiple measures of the injured or replacement habitat can be evaluated, but in HEA, the multiple measures typically are aggregated into a single measure that relates to the overall percent service loss due to the injury.

The metric used should be the same attribute on the loss and gain sides of the equation, and it should be useful to discern relative differences in the quality and quantity of resources or services provided by the harmed and compensatory habitats. Examples of single-attribute metrics include:

- Measures of vegetation density, cover, or biomass, if vegetation is key to supporting wildlife and other functions or services provided by the injured habitat. Depending on the type of services believed to have been lost, the vegetation measure might be percent cover of desirable, dominant, or essential vegetation species; above-ground biomass of the dominant vegetation (for grasslands or wetlands); density of seedlings (in areas where seedling recruitment is important); or an index of vegetation structural diversity (if the injury has caused a simplification of the structure of the habitat.

- Habitat use-days, if an injury has reduced the availability of habitat such that fewer birds or other wildlife can occupy the habitat for essential needs, such as nesting. This measure might involve field surveys, such as bird point counts during key seasons, in affected and reference areas.

- For REA, organism densities, biomass, counts of individuals lost, or an index of the ability of the remaining individuals to reproduce or maintain a population equivalent to the baseline condition. Such an index might take into account sex ratio, age class distribution, or seasonality effects.

- Categories of service loss assigned based on the degree of exceedance of toxicity thresholds (see, for example, Cacela et al., 2005). This approach might involve compiling dose-response

[5.] The ELD does not allow governments to seek compensation for incidents that occurred before April 30, 2007, but in the future, it is possible that remediation could be delayed relative to an incident that occurs some time after passage of relevant laws and regulations in the EU.

information from the literature or site-specific studies, and developing an estimate of service loss as a function of increasing contaminant concentration in soil, sediment, surface water, or biological tissues. Data or examples that link concentrations in media to adverse effects are helpful in supporting this approach. An example of this approach is a degree of exceedance of a threshold: if a threshold concentration in water or sediment is exceeded by >10 times, the service loss to the habitat might be 100% (depending on the specifics of the toxicity data used to derive the threshold). If the threshold is exceeded by >5 to 10 times, the service loss might be 50% or some other lesser amount, depending on toxicological details.

Multiple measures of service provision include published or accepted indices of environmental health, as well as indices developed for specific incidents and HEA applications. For example:

- Indicators of rangeland health used by the US Departments of Agriculture and Interior are commonly used to aggregate a dozen or so attributes related to soil stability, hydrologic function, and the capacity of grasslands to support characteristic functional and structural communities important for grazing livestock or wildlife. The aggregate score indicates the current and anticipated future condition of the land to provide ecological and human use services.

- A series of decision rules based on numerous risk indicators, such as degree and frequency of exceedance of toxicity thresholds or aquatic life standards, evidence of population shifts or reductions, evidence of loss of functional groups or biogeochemical pathways. With a set of tailored decision rules, the degree service loss is assumed to increase with an increasing number of indicators, or rules, satisfied. Such decision rules are typically developed on a case-by-case basis and are site- and incident-specific.

There is no single objective standard for determining which metric should be used to estimate service losses at damaged sites and replaced services at remediation sites. Metrics used for capturing service losses are often based on site-specific ecological attributes that are assumed to correlate well with services. For example, standing above-ground biomass in a grassland could be used as a surrogate for net primary productivity; abundance of keystone species could be used as a surrogate for ecosystem health. Other considerations taken into account in selecting the measurement unit of the damage include the type of damage (e.g., physical, chemical), the scale of the damage (e.g., area, timing, anticipated duration), and, perhaps most importantly, the nature of the remediation available for compensation, since the same metric must be used to estimate the scope of the remediation.

The outcome of HEA is sensitive to the choice of metric used to quantify lost and replaced services. For a case study of HEA in a salt marsh, Strange et al. (2002) found that different metrics of ecological services (e.g., above-ground biomass, soil nitrogen, density of infauna) resulted in more than threefold differences in alternative HEA remediation requirements. Because all habitats and natural resources provide a variety of ecological services, a single metric will never capture all potential services that have been lost. Therefore, the choice of a metric is perhaps the single-most important consideration for adequate remediation scaling. Selection of an appropriate metric is usually done in close consultation with biologists, ecologists, or other relevant environmental scientists. Selection of a metric and gathering and analysis of data to inform the estimation of service loss (and gain) using the metric are part of the cost of damage estimation.

2.3 Quantifying Gains

On the gain side of the equivalency equation, quantifying the benefits of potential remediation projects requires developing a similar set of information as for quantifying damage. Remediation projects that have the potential to provide services of comparable type and quality to those that were damaged must be identified. The anticipated timing and degree of productivity of the remediation actions must be evaluated in terms of the chosen metric, and the anticipated productivity should be

compared to the total amount of services that would have been provided by the damaged site had the damage not occurred.

During this step, several possible remediation alternatives are developed, where an alternative can consist of a single action or a combination of actions that could potentially restore, rehabilitate, or replace the equivalent of the damaged natural resources or services. The alternatives are evaluated using criteria such as those described below, and a preferred alternative is selected, fully described in terms of timing and degree of anticipated gains, and the actions are costed. The implementation cost includes capital components of the preferred alternative, and future operation, maintenance, and monitoring costs.

Remediation projects are often conducted on-site or as close as possible to the location of the damaged resource. However, if there is a reasonable resource connection, or if administrative factors intervene, remediation actions at a location that is geographically removed from the site of the injury may be appropriate. For example, if remediation of a damaged resource requires actions in a breeding or rearing ground to enhance a wildlife population affected by the event, the remediation action may be best located far from the site of the event.

To estimate gains, process models or population models can be used to estimate the trajectory of benefits anticipated given alternative remediation actions. For example, for the Blackbird Mine Chinook salmon restoration, NOAA developed detailed life-stage survival models to estimate the benefits of habitat improvements and supplementing with hatchery-reared juvenile fish on adult spawning densities (Chapman et al., 1998). For the Coeur d'Alene River basin HEA, Lipton et al. (2004) developed population response models to estimate the benefits of habitat improvements on trout populations. For the North Cape oil spill off Rhode Island, NOAA developed a HEA using metrics for American lobsters (McCay et al., 2003a), bivalves (focusing on surf clams) (McCay et al., 2003b), endangered piping plovers (Donlan et al., 2003), a variety of seabirds (Sperduto et al., 2003), and a variety of organisms in a representative food chain (McCay and Rowe, 2003).

A remediation-based damage estimate is typically developed as follows:

- Establish evaluation criteria for evaluating remediation options for the damage.
- Develop a list or database of potential remediation options.
- Summarize the remediation proposals into categories of actions.
- Apply the evaluation criteria to identify categories or potential remediation actions that meet pass-fail criteria, and then rank the remaining categories or remediation actions.
- Choose appropriate metrics for comparing priority remediation options with damages caused by the event.
- Develop information about unit costs for priority remediation actions. Costs should account for the implementation and administration of the action, as well as operation, maintenance, and monitoring expenditures required to ensure that the project provides the benefits incorporated in the equivalency analysis.

Evaluation criteria are designed to satisfy any requirements or preferences imposed by relevant statutes, regulations, and agency mandates or preferences. Some examples of criteria that define or express preferences might include:

- Does the proposed acquisition or remediation project have a high likelihood of successfully protecting or restoring high-quality natural features, unique features, or valuable ecosystem services?

- Are the natural features at the site threatened by impending human activities that can be prevented by the completion of this project?
- Does the site have a completed natural area plan or remediation plan that includes inventory, management, and monitoring?
- Does the completion of the project contribute to increased connectivity between existing natural areas or protecting interior habitats in existing designated natural areas?
- Is there broad local support for the proposed project?
- Is the proposed project a good value for the funding requested?
- Does the project build partnerships among resource managers or demonstrate collaboration?
- Is the site important for the protection or remediation of natural resources on adjacent lands?
- Does the project provide or improve opportunities for public uses for stewardship, education, or recreation compatible with resource protection and remediation goals?

As resource managers develop project evaluation criteria, they can define how each criterion will be interpreted in evaluating proposed projects to support a transparent project selection process. Table 1 presents example criteria that have been used in the US to focus the evaluation of alternatives. A full prioritization and selection of alternatives requires deliberation by all involved parties during the assessment process.

Table 1: Example evaluation criteria

Criterion	Interpretation
Initial screening criteria	
▸ Address resources injured by hazardous substances, or services lost as a result of damages	▸ Projects are evaluated with regard to whether they restore, rehabilitate, replace, or acquire the equivalent of injured natural resources and services.
▸ Comply with applicable/relevant laws and regulations	▸ Projects must be legal.
▸ Protect public health and/or safety	▸ Projects must not jeopardize public health and/or safety.
▸ Coordinate with planned response actions	▸ Projects must not conflict with planned response actions and will not be undone or harmed by response actions.
▸ Be technically feasible	▸ Projects must have a high likelihood of success.
▸ Minimize collateral injury	▸ Projects must not cause additional natural resource damage, service loss, or environmental degradation; or collateral damages that may be caused are minimal compared to benefits achieved.
▸ Be acceptable to the public	▸ Projects must meet a minimum level of public acceptance; projects must not create a public nuisance.
▸ Reduce exposure of natural resources to hazardous substances	▸ Primary remediation projects should reduce exposure to hazardous substances and reduce the volume, mobility, and/or toxicity of hazardous substances.
▸ Reduce the volume, mobility, and/or toxicity of hazardous substances	

Table 1: Example evaluation criteria	
Criterion	**Interpretation**
Detailed evaluation criteria	
▸ Restore or preserve the type of natural resources damaged	▸ Projects should improve the quality of the resource that was or will be damaged (e.g., groundwater, terrestrial habitat) through remediation or preservation actions.
▸ Preserve threatened natural communities that are unique, of high quality, or connected to such areas	▸ Projects designed to protect resources through acquisition or conservation easements should protect high quality or unique resources or establish viable buffers against future development around such areas.
▸ Target a resource or service that is unable to recover, or that will require a long time to recover naturally	▸ Projects should target resources/services that will be slow to recover without remediation action (e.g., > 25 years).
▸ Address remediation of "preferred" resources or services	▸ Resource managers may develop a list of priorities based on the resource types injured and degree of damage.
▸ Use established, reliable methods/technologies known to have a high probability of success	▸ Projects should use appropriate, proven, and successful techniques. Experimental methods, research, or unproven technologies can be given a lower priority, if appropriate.
▸ Be cost-beneficial	▸ Projects should have a high ratio of expected benefits to expected costs relative to other projects that benefit the same resource.
▸ Have low costs associated with long-term operation, maintenance, and monitoring	▸ Costs should be reasonable given the benefits expected.
▸ May be scaled to appropriate level of resource damage or loss	▸ Projects should be amenable to scaling to provide remediation of appropriate magnitude. Small projects that provide only minimal benefit relative to the damaged resources or services, or overly large projects that cannot be appropriately reduced in scope, are less favoured.
▸ Provide benefits that can be measured for success evaluation	▸ Projects should produce benefits that can be quantified to measure success
▸ Be consistent with regional planning and administratively feasible	▸ Projects should not be inconsistent with regional planning (e.g., supportive of species recovery plans); projects must be administratively feasible.
▸ Generate collateral benefits	▸ Projects that benefit more than one damaged resource or service or that provide secondary or cascading benefits to ecological resources and economic benefits are given priority.
▸ Enhance the public's ability to use, enjoy, or benefit from the environment	▸ This may be considered either an evaluation criteria or a collateral benefit, depending on the goals of the parties involved.
▸ Aim to achieve environmental equity and/or environmental justice	▸ The environmental equity or justice of a project is the degree to which the project benefits the individuals most affected by the damage. Projects that benefit the low-income segments of the human population that often suffer the most from pollution are favoured.
▸ Provide ecological and/or economic benefits to a	▸ Projects that provide the greatest good will be favoured. To the degree that a bigger project results in greater good,

Table 1: Example evaluation criteria	
Criterion	**Interpretation**
comprehensive area or population	bigger projects are better.
▸ Provide benefits sooner	▸ Projects that will achieve full expected results sooner than the resource would achieve the result through natural recovery, and sooner than other projects that benefit the same resource, are favoured. The sooner equivalence is achieved, the better.
▸ Provide long-term benefits	▸ Projects that will persist will be favoured over short-term projects.
▸ Provide benefits not being provided by other remediation projects being planned/implemented/funded under other programs	▸ Preference is given to projects that are not already being implemented or have planned funding under other programs.

2.4 Scaling Remediation

The final step in implementing HEA is determining the scale, or quantity, of the remediation project(s) to implement so that, over time, the discounted flow of services from the remediation projects is equal to those lost in the impacted area.

To accomplish this, an appropriate discount rate must be selected. When the HEA/REA is developed to address lost public resources over time, it is correct to apply the "social discount rate." This social discount rate is the rate at which society as a whole would be willing to trade services or natural resources across different time periods. The social discount rate is based on the idea that current consumption of natural resources is preferred to future consumption. There are two components to the social discount rate: a relative weighting of current versus future generations, sometimes called a utility adjustment; and a "consumption" adjustment. The consumption adjustment accounts for the relative scarcity of the resource during the period it is being provided. If in the future, the relative scarcity of the good increases (e.g., there are fewer wetland hectares), then to provide the same level of public benefit, less of the good needs to be provided today. A unit of wetlands in the future is relatively more important than current conditions. This would imply a relatively lower discount rate in the future when compared to a constant quantity of the good available.[6]

The argument for a non-constant discount rate is often discussed in the context of public expenditures (see, for example, Dasgupta, 2006). To date, a consumption adjustment to reflect relative future scarcity (or abundance) has not been applied, but such an adjustment may be made in future cases.

The scale of the necessary remediation projects is determined by first identifying the per unit net present value of the remediation project, and then dividing the total discounted lost services by this amount. Table 2 demonstrates how the HEA debit would be calculated for 1 hectare of land with a constant service loss of 50% from 2004 to 2009. The total HEA debit for this hectare is calculated in units of "discounted service hectare-years" (DSHYs). This unit takes into account the area and the time course and level of service loss, and the 3% discount rate. In the present year, in this case, 2007, the

6. The opposite effect occurs when calculating the damage with a lower discount rate. The amount of future damage measured in today's terms will increase when a lower discount rate is used because that damage is relatively more costly to incur today.

present value factor equals one. For years before 2007, the present value factor is higher than one, and for years after the base year, the present value factor is lower than one. The total HEA debit for this hectare, for the period 2004-2009, is 3.05 DSHYs.

Table 2: Example of HEA debit calculations. This example assumes 1 hectare of land with a 50% service loss during 2004-2009.

Year	Percent service loss	Present value factor[a]	Debit[b] (DSHYs)
2004	50%	1.09	0.55
2005	50%	1.06	0.53
2006	50%	1.03	0.52
2007 (base year)	50%	1.00	0.50
2008	50%	0.97	0.49
2009	50%	0.94	0.47
Total			**3.05**

a. Present value factor = 1 / (1+ discount rate)$^{(\text{year - base year})}$.
b. Debit is calculated by multiplying percent service loss by present value factor.
Note: the discount rate = 3% and the present value year = 2007.

HEA credits for service gains are calculated similarly. Table 3 demonstrates how HEA credits would be calculated for 1 hectare of land with a service improvement that increases to 50% over baseline values during a 5-year time period, from 2009 to 2013. This example also uses 2007 as the present value year. The HEA credit for this hectare from 2009 to 2013 is 1.31 DSHYs.

Table 3. Example of HEA credit calculations. This example assumes 1 hectare of land with a service gain increasing to 50% over baseline service levels from 2009 to 2013.

Year	Percent service gain	Present value factor[a]	Credit[b] (DSHYs)
2009	10%	0.94	0.094
2010	20%	0.92	0.183
2011	30%	0.89	0.267
2012	40%	0.86	0.345
2013	50%	0.84	0.419
Total			**1.31**

a. Present value factor = 1 / (1+ discount rate)$^{(\text{year - base year})}$.
b. Credit is calculated by multiplying percent service gain by present value factor.
Note: the discount rate = 3% and the present value year = 2007.

To get the amount of credit that would be needed to offset the loss in the example above (3.05 DSHYs) within a 5-year period, 2.3 hectares of remediation would be required (i.e., 3.05 DSHYs ÷ 1.31 DSHYs/hectare restored = 2.33 hectares). Alternatively, if the project continued to provide a 50% service gain beyond 2013, a single hectare would accrue enough credit to offset the 3.05 DSHYs of loss by 2018.

The results of the HEA or REA can be presented in terms of the amount and type of required remediation, or in terms of the cost of implementing the required remediation. Unit costs include the total cost of the required scale of remediation, including implementation, administration, operation, maintenance, and monitoring expenditures required to ensure that the project provides the benefits incorporated in the equivalency analysis.

3. Case Studies

In this section, case studies of HEA, REA, and VEA applications are presented. These case studies were selected to illustrate specific recent advances or innovative techniques for quantifying losses and gains, and approaches to overcoming analytical challenges such as the treatment of multiple contaminants released by multiple parties over a long time, jurisdictional challenges such as distributional impacts and cross-boundary issues, biological equivalency challenges such as trades across habitat for compensation, and challenges associated with determining baseline conditions.

The case studies presented in the pages that follow include:

- An illustration of the use of regional population models of factors influencing population declines of salmon to estimate the effect of a specific chemical impact on population decline, and of remediation projects on population enhancement. The case study of the Blackbird Mine, Idaho, US, details an approach to discerning complicated baseline conditions (additional stressors) from conditions caused by the impact in question, and the effect of the ongoing stressors (unrelated to the impact) on the anticipated gains to be provided by remediation.

- A description of the use of empirical, site-specific field data to estimate impacts of mining on aquatic biota, and the impacts of habitat restoration on aquatic biota. This case study of the Coeur d'Alene River aquatic biota equivalency analysis is provided as an example of the level of detail of data that might be desirable to conduct a REA. Where detailed data are available, estimates of service loss and gain can be made with greater assurance, and REA is more likely to estimate the "right" amount of remediation necessary to offset the damage.

- A method developed to cope with multiple contaminants from multiple industrial sources that varied over time and space. Equivalency methods become more complicated when the source of the impact is complicated (i.e., multiple stressors), and when the distribution of the stressor in the environment is non-uniform, poorly characterized, or entirely unknown. In addition, if the combined effect of the multiple contaminants on biota is unknown, assigning service loss to a cocktail of contaminants is quite difficult. This case study of a HEA for Commencement Bay, Tacoma, Washington, US, describes a method developed to handle such complexity. The method was extended to assist in assigning liability and responsibility for remediation costs among the multiple contributors to the impact.

- An example of a case in which service-to-service and resource-to-resource methods were inappropriate, and instead, a value-to-value scaling method was most appropriate. Providing remediation with the same or very similar services impacted in the Fox River/Green Bay, Michigan, US, was not feasible or desirable, or was too expensive. Remediation that provided similar resources but of a different type and quality than those impacted was needed. A public survey was used to determine how much of one kind of remediation has equivalent value to different amounts of other kinds of remediation.

- A description of an approach to estimating the benefit of protecting existing resources and services as a form of remediation. Often, conservation of existing habitat is proposed as compensation for impacted habitat. If the offered habitat already provides services, then protecting it in the future might provide no added benefit. If, however, a change in future condition is possible, then the benefit (or anticipated service gain) of a project can be modelled probabilistically. An example from the south-western US is provided.

- A hybrid of HEA and REA is HRC analysis. HRC is used to compare losses of organisms caused by an environmental impact with the costs of sufficient habitat remediation to produce organisms to the level necessary to offset the losses. This method might be needed when an actual remediation

project is not identified, but categories of suitable projects can be costed to ensure that sufficient funding is provided to achieve equivalency. This case study is also an example of an *ex ante* estimation of damages, assigning compensation in advance of anticipated damages.

- An *ex ante* version of equivalency scaling, in which anticipated losses are estimated and offset in advance as mitigation. Mitigation banking and conservation banking are conducted in the US to halt the loss of wetlands and species of special concern that are threatened by development. While such planned offsets can encourage (or fail to discourage) poor development practices, they can have substantial value for proactive resource management.

Additional Guidance and Discussion of HEA/REA/VEA

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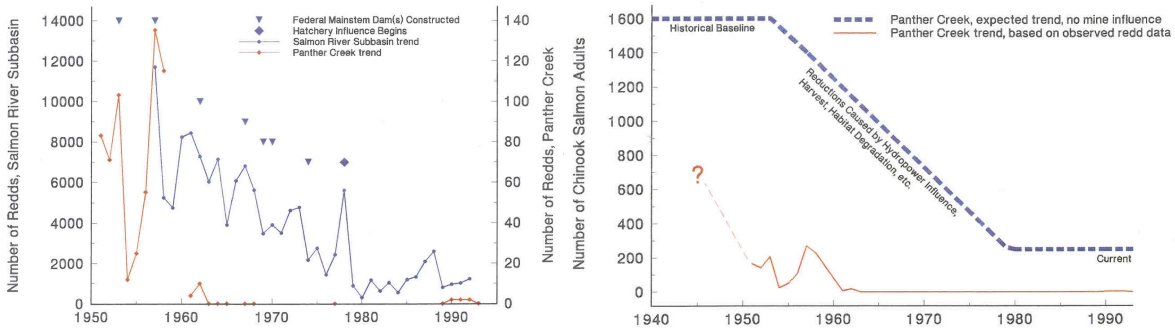
Salmon Remediation at the Blackbird Mine, Idaho, US:
A Case Study in using Regional Population Models to Differentiate Mining Impacts

The Blackbird Mine was a copper-cobalt mine that began operations in the late 19th century and ceased by 1982. Metal-contaminated water from mine tunnels, waste rock piles, and an open pit drained into Panther Creek, a major tributary to the Salmon River. Panther Creek historically supported substantial runs of Chinook salmon, steelhead, and other resident trout. By the early 1960s, these fish had been eliminated from Panther Creek because of contamination from the mine.

Damages were determined using REA. Numbers of naturally spawning Chinook salmon were used as the metric for service loss from Panther Creek. This species was chosen because of its cultural and economic importance and its role in providing a nutrient base for the stream (Chapman et al., 1998). Baseline spawning density (the density that Panther Creek should support absent contamination from the mine) was derived though counts of returning adults in nearby reference drainages, and on run-reconstruction modelling that took into account survival at numerous life stages. The modelling was complicated by the numerous additional stressors that confront these anadromous fish during a life cycle. Panther Creek Chinook salmon migrate as yearlings over 1,600 km to the Pacific Ocean, where they mature. At age 3 to 4, they return to their natal stream to spawn. The journey to and back from the ocean involves passage through eight major hydroelectric dams. At each dam, a certain level of morbidity or mortality occurs, reducing the survival rate of passing populations.

The present value of the damage was calculated based on lost production (number of lost spawning Chinook salmon) since 1981 (the date of passage of CERCLA), continuing through 2005, when water quality was assumed to return to baseline conditions as a result of ongoing response actions at the mine. The estimated loss was calculated as 200 adult Chinook salmon spawning in Panther Creek each year between 1980 and 2005. Using a base year of 1995 and a discount rate of 3%, the number of spawning Chinook salmon required for compensation was calculated, and then the number of juveniles that would be required to reach the adult goal was calculated.

Both complementary and compensatory remediation projects were identified. Projects included actions to increase the productivity and carrying capacity of Panther Creek and the productivity of nearby creeks. Replacement requirements took into account hatchery supplemented "plants" of juveniles and survival at all life stages, based on estimates generated using a salmon life-cycle model. To achieve the necessary production of spawning Chinook salmon in Panther Creek, the responsible parties agreed to clean up the mine site and restore water quality; restore, enhance, and create anadromous and resident salmonid habitat in impacted and out of-basin streams; and fund a hatchery operation to support the reintroduction of Chinook salmon.



Comparisons of observed trends in redds (spawning nests), returning adults, and modelled expected trends in returning adults, absent contamination in Panther Creek.

Trout Remediation in the Coeur d'Alene Basin, Idaho, US:
A Case Study in Resource Equivalency using Empirical Measures of Fish Density

The Coeur d'Alene River Basin was the site of more than a century of releases of cadmium, lead, zinc, and other heavy metals from mine waste rock and tailings to area creeks, rivers, floodplains, wetlands, and lakes. Aquatic resources in the Coeur d'Alene Basin have been degraded by releases of hazardous substances from mining and mineral processing operations.

Damage calculations for aquatic biota habitat services provided by surface water, fish, and other aquatic biota were based on the cost of replacing the ecological services that should have been provided by the degraded surface water over time. Remediation actions to replace habitat for fish provided a means of calculating replacement costs for both surface water and aquatic biota services. Remediation alternatives considered included physical habitat enhancements in nearby streams that would enhance fish spawning, rearing, and adult survival.

Service losses from contamination and gains from habitat enhancement were scaled using trout population density as the metric. Detailed fish population surveys had been conducted previously in the approximately 70 km of impacted streams and in reference streams, so the degree and temporal and spatial extent of the loss of trout were well documented. Trout population response to water quality improvement was modelled based on empirical data from a range of stream reaches of differing water quality to take into account the anticipated effect of planned cleanup actions on future population trends in the impacted area.

Trout population densities from 47 sites in area streams that ranged from relatively pristine to degraded physical habitat were used to model service gains anticipated to result from off-site habitat remediation actions. A range of remediation project types (e.g., channel reconfiguration to restore natural sinuosity and hydrodynamics, woody debris placement for enhancement of habitat complexity, road relocation for reduction of sediment loading) was investigated and the costs of implementing the alternatives were calculated based on representative unit costs. The total replacement cost was calculating by scaling the amount of replacement to the quantity of damage. The scaling accounted for both the loss relative to baseline conditions, and supplemental replacement necessary to compensate for the services during the time from the release until the attainment of remediation to baseline conditions. Depending on the type of remediation project and the implementation period assumed, the cost of compensatory remediation ranged from $64.4 to $177.9 million (2004 dollars).

Loss of trout services due to surface water injury			
Reach	**Area (m^2)**	**Density ($fish/m^2$)**	**Baseline density ($fish/m^2$)**
Canyon Creek	82,268	0	0.055
Ninemile Creek	34,870	0	0.122
South Fork Coeur d'Alene	461,932	0.020	0.118

Example remediation/improvement project opportunities				
	1st-2nd order streams		**3rd-4th order streams**	
Basin	**Miles needing rehabilitation**	**Current and targeted fish density (#/100 m^2)**	**Miles needing rehabilitation**	**Current and targeted fish density (#/100 m^2)**
Benewah	7.16	10, 20	3.62	0.6, 20
Evans	1.17	10, 20	2.42	0.6, 20
Lake	4.57	10, 20	3.56	0.6, 20

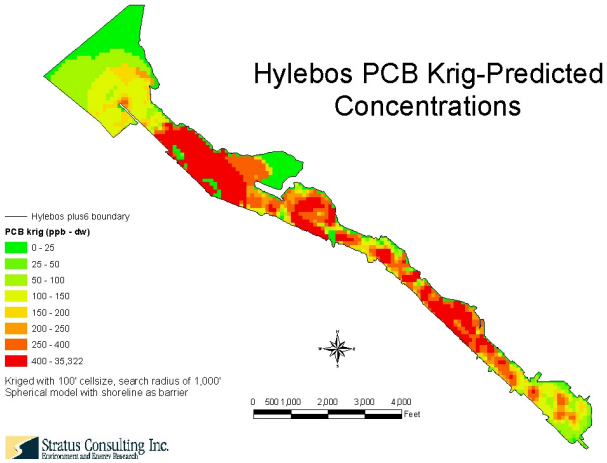
Habitat Remediation, Commencement Bay, Washington, US:
A Case Study in Habitat Equivalency Analysis in a Contaminated Urban Estuary

Commencement Bay is a heavily industrialized bay near Tacoma, Washington. Hylebos Creek flows into the head of the Hylebos Waterway of Commencement Bay. Contaminants of concern in sediments and tissues of aquatic biota of the bay include copper, lead, mercury, zinc, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other chlorinated hydrocarbons.

The Hylebos Waterway HEA quantified damages in areas where sediments contained contaminants at or above concentrations defined as toxic effect thresholds (Wolotira, 2002). Ecological services were assumed to be lost when an organism or organisms were likely to be harmed by the presence of a specified concentration of a contaminant. The ecological service losses associated with the thresholds (and higher concentrations) were mapped using sediment concentration data collected from the bay. Service loss was calculated for each sampling location and each contaminant. Service loss associated with a given contaminant ranged from a maximum of 20% if only benthic invertebrate thresholds were exceeded, to a maximum of 80% if fish thresholds were exceeded.

Service loss from multiple contaminants was calculated sequentially as a proportionally weighted total service loss. Therefore, if the contaminant of greatest concern caused a 50% reduction in habitat services, and the contaminant of next greatest concern caused a 30% reduction (from 50% services), the remaining service provision was 35%, rather than 20% (i.e., it was not calculated as a simple sum of service loss).

Another important application of the HEA was to allocate liability to individual responsible parties (EcoChem and Geosphere, 2002). For most chemicals, the allocation was based on the source and pathway information that linked industrial site and release activities to chemical footprints mapped in the bottom sediments of the bay. This approach was appropriate for the many clearly defined areas of contamination (hot spots) located immediately offshore or in very close proximity to a site likely to be the source of the chemical. For areas of well mixed contamination in the bay, and areas where industrial source locations of similar character were closely spaced along the shoreline, the allocation was based on the probable mass loading of the chemical from each potential source to the bay. Each potential source was assigned a percentage of the mass loading of each contaminant, and the loss associated with the spatial footprint was distributed to each potential source based on the calculated percentage.



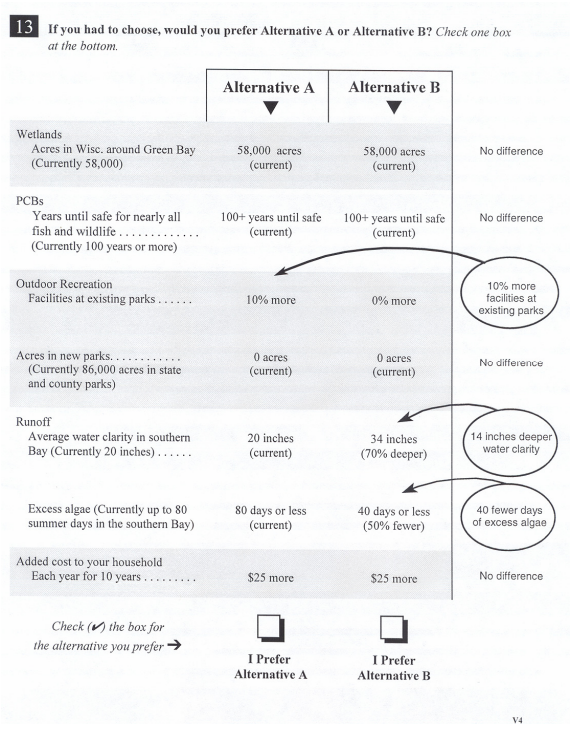
Ecological Remediation, Fox River/Green Bay, Michigan, US:
A Case Study in Value Equivalency Analysis

The most innovative VEA (value-to-value equivalency analysis) that currently sets the stand for state of the art is the Fox River/Green Bay Total Value Equivalency (TVE) (Breffle and Rowe, 2002; Breffle et al., 2005; Lazo et al., 2005). Natural resource injuries resulting from releases of PCBs to the Lower Fox River/Green Bay from pulp and paper mills included harm to birds and fish, and damages related to reduction in recreational fishing opportunities and enjoyment.

For many of the damages, providing remediation with similar services was considered to be technically infeasible, was undesirable, or was economically implausible (e.g., dredging a bay approximately the area of Luxembourg). Therefore, remediation that provided similar resources but of a different type and quality than those damaged was needed. The VEA determined public preference across a range of remediation programs. A survey describing four natural resource remediation programs and variations in program levels being considered was administered to the public. Respondents to the survey were questioned about preferences about the programs and levels by varying the program mixes and levels across stated preference choice questions, and examining choices made, mathematical models (random utility models) determined how much of one kind of remediation has equivalent value to different amounts of other kinds of remediation.

The survey results allowed for scaling of remediation programs that provide equivalent value to the service flow losses. The results identified combinations and areas of wetland remediation projects, projects that reduce pollutant runoff and increase water clarity in Green Bay, and projects to enhance exiting park facilities that were equal in value to the ongoing losses related to PCB contamination, under three remediation scenarios.

The total valuation approach involved a high degree of community outreach and involvement. Hundreds of people were convened for focus groups to prepare the survey, and hundreds more were surveyed. The process resulted in a high degree of stakeholder "buy-in" for the proposed compensatory remediation. The public's value for lost services and for restored services was the common metric used to determine equivalency. The approach avoided difficulties related to actual measurement or estimation of service losses and expected gains, by going directly to the issue of what people care about.



13 **If you had to choose, would you prefer Alternative A or Alternative B?** *Check one box at the bottom.*

	Alternative A ▼	Alternative B ▼	
Wetlands Acres in Wisc. around Green Bay (Currently 58,000)	58,000 acres (current)	58,000 acres (current)	No difference
PCBs Years until safe for nearly all fish and wildlife . . . . . (Currently 100 years or more)	100+ years until safe (current)	100+ years until safe (current)	No difference
Outdoor Recreation Facilities at existing parks	10% more	0% more	10% more facilities at existing parks
Acres in new parks. . . . . (Currently 86,000 acres in state and county parks)	0 acres (current)	0 acres (current)	No difference
Runoff Average water clarity in southern Bay (Currently 20 inches)	20 inches (current)	34 inches (70% deeper)	14 inches deeper water clarity
Excess algae (Currently up to 80 summer days in the southern Bay)	80 days or less (current)	40 days or less (50% fewer)	40 fewer days of excess algae
Added cost to your household Each year for 10 years	$25 more	$25 more	No difference
Check (✓) the box for the alternative you prefer →	☐ I Prefer Alternative A	☐ I Prefer Alternative B	

V4

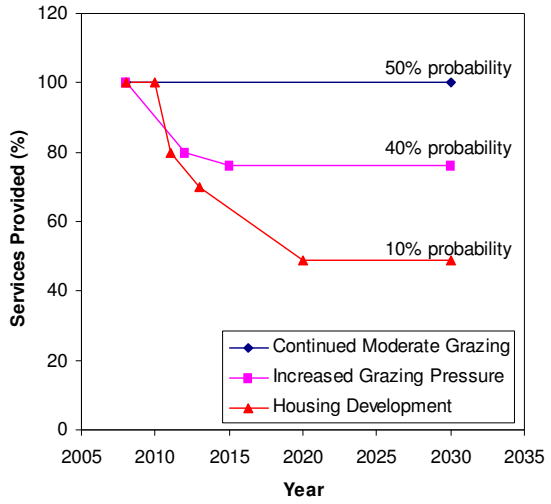
Grassland Remediation in the South-western US:
A Case Study in Quantifying the Benefits of Conservation

As part of an ongoing attempt at settlement of natural resource damage claims at a site in the south-western US, adverse effects of contaminants on terrestrial (grassland) habitat were quantified using an index of rangeland condition. The index takes into account soil stability, erosion susceptibility, and plant cover, diversity, and productivity. These characteristics are important determinants of the ability of the grassland to provide ecological services such as habitat for wildlife.

The existing condition of the affected grassland was partially attributable to contamination from the responsible party, and partially to historical over-grazing by livestock. A map of contaminant concentrations in soil was overlaid on a map of rangeland condition scores. Where contaminant concentrations exceeded a defined threshold based on potential for phytotoxicity, the rangeland condition score was compared to the rangeland condition score of uncontaminated grassland. The percentage difference in score was used as the metric of service loss. The percent service loss was calculated for each hectare of contaminated land, and the loss was summed across all hectares and discounted (at 3%) from 1980 through 2005.

A remediation project involving land transfer for conservation purposes was proposed for remediation. The land currently provides a certain level of habitat services, so an hectare-for-hectare replacement ratio was considered inappropriate. A rangeland condition score was estimated for the land proposed for transfer, and a "perfect" rangeland condition score was assumed to be achievable if livestock grazing were discontinued for 20 years. The recovery rate was based on evidence from a bordering parcel on which grazing was discontinued 20 years ago. The potential service gain anticipated from the land transfer and change in management was modelled as a probabilistic function of future land uses and conditions. Future fates of the land include no change in use, increased grazing and degradation of habitat services, and development into residential community (substantial loss of habitat services). Each fate was assigned a percent probability based on anticipated rates of housing development and recent changes in land value in the area. This "variable future baseline" approach allows for expression of uncertainty in expected gains from remediation.

The most likely scenario for the land (50% probability assigned) was no change in the existing moderate grazing pressure. This was considered to be the baseline condition. However, there was a chance that grazing pressure might increase and degrade the services provided (40% probability assigned) or that the land might be sold to a housing developer (10% probability assigned). Each scenario was modelled (see figure to right) to incorporate the potential effect on the future baseline trajectory.



Marine Fisheries Remediation, Pilgrim Nuclear Generation Facility, Massachusetts, US: A Case Study in Habitat Replacement Cost Analysis to Scale Remediation using Fisheries Population Analysis

A HRC analysis compares losses of organisms caused by an environmental impact with the costs of sufficient habitat remediation to produce organisms to the level necessary to offset the losses (Strange et al., 2004; Allen et al., 2005). Using HRC analysis, the damage is quantified by estimating total losses, habitat requirements of habitat-limited species are identified, and the habitat remediation measures likely to be most effective at producing these species are identified. Next, estimates of the expected increases in the production of each species in the habitats of interest are developed. The required scale of habitat remediation for each species is determined by dividing losses by the corresponding estimate of production in the restored habitat. Then the total amount of all remediation alternatives required to replace all losses is determined. Finally, the costs of implementing the remediation is estimated.

Pilgrim is a 670-MW nuclear power plant that uses water from Plymouth Bay, Massachusetts, as a coolant. As water is drawn into the facility, aquatic organisms are entrained into the plant or are impinged on screens across the intake pipes. The area surrounding the Pilgrim facility supports many habitats, including open sandy and rocky bottoms, seagrass beds, salt marshes, tidal mud flats, sandy beaches and dunes, coastal ponds, and open water.

Damage to fishery resources was estimated using biological monitoring data reported by the facility. The data consisted of records of impinged and entrained organisms sampled at intake structures and included organisms of all life stages, from newly laid eggs to mature adults. These sampling counts were converted to standardized estimates of the annual numbers of fish impinged and entrained expressed as numbers of age-1 equivalents.

HRC analysis was used to estimate the costs of the type and amount of habitat remediation that would be required to offset impingement and entrainment losses that would occur if engineering-based alternatives were not put in place. Application of the HRC method to the Pilgrim facility used published biological data wherever possible. Where published data were unavailable or insufficient to address HRC needs, unpublished data from knowledgeable resource experts were used.

The total cost for preferred remediation alternatives was determined by multiplying the required scale of implementation for each remediation alternative by the unit cost for that alternative. For each remediation alternative, the scale of implementation was based on the amount of remediation required to offset losses of the single species requiring the greatest amount of remediation. The remediation needs of all species preferring that habitat were not summed because the habitat benefits each of the species simultaneously. The costs of each scaled remediation activity were then summed to determine the total cost necessary to offset all Pilgrim losses.

Ex-Ante Conservation Banking: Overview

A conservation bank is a parcel of habitat that is managed for the protection of sensitive species and used to offset future impacts to these species occurring on nonbank lands. The protection of species in conservation banks generates conservation "credits" that can be used to mitigate species impacts, or "debits." Developers of conservation banks can use a variety of strategies to enhance species, including preserving existing habitat, restoring habitat function in degraded areas, and creating habitat.

Carlsbad Highlands, the first conservation bank in the US, was dedicated in 1995 in San Diego County, California (Anonymous, 1995). At the time, the State of California issued formal guidance that established the need for permanent protection of all land in the bank: a resource management plan; guarantees of funding for operation, maintenance, and long-term management; assessment of bank credits with reference to baseline conditions at the site; and processes for award of bank credits (Wheeler and Strock, 1995).

The initial incentive for conservation banking in California was to help implement the state's Natural Community Conservation Planning (NCCP) Program, which was developed to protect coastal sage scrub habitat for the threatened California gnatcatcher and other species. Under the NCCP Program, conservation banks were expected to provide long-term protection of habitat and to offer land developers economic incentives for habitat protection through purchase of mitigation credits. Mitigation requirements resulted from the California Environmental Quality Act, which requires mitigation if a proposed activity will "substantially diminish habitat for fish, wildlife, or plants," and from state and federal endangered species acts.

In 1996, the California Department of Fish and Game and the US Fish and Wildlife Service jointly issued a "Supplemental Policy Regarding Conservation Banks Within the NCCP Area of Southern California." The policy noted that the "the number of conservation banks that are established will be regulated by the 'free market' . . . not by the wildlife agencies." The policy also noted that "[o]nly in-kind mitigation (same habitat and species) will be permitted unless . . . the wildlife agencies determine that the bank achieves regional conservation goals" (US Fish & Wildlife Service and California Department of Fish and Game, 1996). By 1999, more than 20 conservation banks had been developed in California (Environmental Defense, 1999).

Conservation banks are usually authorized through a formal conservation bank agreement between the bank owner and a regulatory agency. The agreement specifies the number of conservation credits established for use in the bank, the number of hectares or individuals of a species that pertain to each credit, restrictions on land use of the bank, procedures for sales and transfers of conservation credits, requirements for monitoring and annual reports, and provisions for default among any of the parties. Agreements may also specify required land management activities to be undertaken by the bank owner.

When the land used for a conservation bank is not in immediate danger of development, the credits provided by the bank essentially result in a net loss of habitat. The habitat destruction or modification is authorized contingent upon the purchase of conservation credits, but the bank is not actually providing any new or additional habitat beyond existing habitat in the area. The bank does, however, guarantee protection of that habitat in perpetuity. Banks that restore habitat or actively manage habitat types that would otherwise be lost through neglect more clearly provide a near-term benefit to endangered species that most likely equals or exceed the loss from habitat destruction.

4. Discussion and Summary

HEA/REA, and to a lesser degree, VEA, are used commonly in the US, but users still face challenges implementing these methods. Some of the technical challenges include distributional impacts associated with cross-boundary compensation; cross habitat compensation; the incorporation of complex metrics and models for quantification of service losses and gains; issues related to multiple contaminants from multiple sources; and determination of baseline conditions. We discuss these further below.

4.1 Distributional Impacts and Cross-Boundary Compensation

As currently practiced, HEA and REA do not explicitly account for potential distributional impacts. Because their focus is on habitat or resources, the location of the damaged area and remediation sites are considered only to the degree that the remediated habitats or resources are similar, which often means as close to the site of the damage as practicable. In practice, the competent authorities account for potential distributional impacts during the identification and evaluation of potential remediation projects. Projects that are closer to the damaged site typically are favoured over projects that are farther away.

Recently, there has been discussion about the need to explicitly account for potential distributional impacts of the chosen location for the remedial actions (Flores and Thacher, 2002; Hampton and Zafonte, 2003, 2004). The discussion focuses on two key issues: compensation is provided to the public through the provision of natural resources or services; and the location of the provided resources/services determines who is adequately compensated.

An example of this issue was the very contentious remediation selection process in the North Cape Oil Spill in Rhode Island along the eastern seaboard of the US Ruddy ducks were injured by the spill. The best compensatory remediation actions were determined to be protection of nesting habitat that occurs primarily in the “prairie pothole” region of the central US, some 2,000 km west of the spill location. Transfer of remediation dollars out of the State of Rhode Island highlighted the issue of potential asymmetric distributional impacts.

Distributional impacts will be a reoccurring theme in EU applications of HEA/REA under the ELD. Transboundary pollution events are likely, opportunities for cost-effective and biologically effective remediation may be limited, and discussions about the suitability of compensation by remedial actions in one member state (or non-member state) for harm in another are likely to be common. Species that migrate pose particular problems since the location most suitable for compensatory action might be very distant from the location of the impact. These cross-boundary compensation issues may be contentious and pose interesting challenges for demonstrating equivalency of resources, services, and values.

4.2 Cross Habitat Compensation

In some cases, resource managers have allowed for damage to one habitat or species to be offset with remedial actions in another. Such trading happened in Commencement Bay. The trustees determined that remedial actions should focus on the improvement and creation of near-shore inter-tidal marsh, rather than in deeper water habitats. This compensation framework required the development of a very complex relationship between the services provided by inter-tidal marsh and submerged sediments. Ultimately, decisions came down to a number of adjustments to the type and quality of services provided by each habitat. Future efforts can be made to more directly translate across habitat types.

In an ongoing case in the south-western US, groundwater was impacted by contaminant releases. A project to replace groundwater in a degraded alluvial aquifer was proposed. The project would ultimately restore an alluvial aquifer and associated riparian zone along an ephemeral creek. The gain associated with the project was calculated as the quantity of groundwater to be replaced in the aquifer, plus the quantity (of the replaced water) consumed through transpiration by the riparian vegetation community expected to develop as a result of the elevation of the water table. In this way, the value of restoring a water cycle in the area was incorporated. The benefit of the water in creating valuable habitat in an arid region was translated from a riparian habitat to a volume of water essential to sustain that valuable habitat. While in a wetter region this might be considered "double counting" of water, in this arid region, the riparian vegetation will slow the transport of water out of the valley (relative to an unvegetated wash). This longer residence time is considered a significant benefit. Such a cross habitat transfer can be useful where one impact resource is a key component of another highly desirable resource.

4.3 Complex Metrics

As HEA and REA are applied to more complex damage scenarios, the estimation of service loss estimation and attribution becomes more complicated. In many cases, the harm resulting from an incident occurs across numerous species and levels of ecological organization. The harm may have cascading effects on ecological communities, future generations, human use services, and other resources or services. A metric for each type of harm could be developed and quantified independently, but not all of the resources and services harmed are independent, and a summation of such calculations might over-compensate for the harm. Combining metrics into an index of loss (or gain on the restoration side) has been attempted, but such indices are difficult to validate, even qualitatively. The development of complex metrics continues to mature in the US, and will undoubtedly be an issue for application of HEA/REA under the ELD.

4.4 Complex Models of Recovery and Future Baseline

Incorporation of complex biological models to evaluate injury and natural recovery is becoming more common in REA applications. Modelling of bird kills, particularly kills resulting from oil spills, has become increasingly sophisticated as existing data on species sensitivity to oiling, carcass recovery rates, and carcass search efficiency have become more complete and accurate. Models used in estimating birds at risk and birds killed as a result of recent spills on the western coast of the US (Ford et al., 2000, 2002; Ford, 2002) include consideration of carcass counts from aerial, boat, and shoreline surveys; bird body size and its relation to susceptibility to hypothermia resulting from oiling; bird body size and its relation to probability of carcass recovery; proportion of the total area affected that could have been effectively searched for carcasses (accessibility issues); and modelled spill trajectories. Some of the models have also taken into account effects of modelled mortality and morbidity on breeding populations in current and subsequent years.

Complex biological models are becoming more common in modelling effects on a range of biota and ecological scales. The fish population models described in the Blackbird Mine and Coeur d'Alene River examples are examples of this increasing level of biological sophistication in HEA and REA. In the south-western US, complex models were developed to estimate the number of migratory and resident birds that visited toxic ponds over a 25-year period, and that would have succumbed to lethal or sub-lethal toxic effects. Estimates of bird behaviour and regional migratory population sizes year-to-year were used on both loss and gain sides to estimate the benefits of providing alternative stopover sites as compensatory remediation.

This variable future baseline modelling described in the grassland remediation case study is likely to be increasingly important, and possibly increasingly sophisticated, in the situations where the proposed remediation action is intended to prevent a future loss of habitat or species. The chance that the

action is truly necessary to prevent the loss is unknown, and may depend on many factors at a range of spatial and temporal scales. Development scenarios, climate change and other global change scenarios (e.g., species invasions), and anticipated changes in law, regulation, and policy controlling development or conservation, all contribute to the potential future benefits of protecting land or resources.

For example, if potential climate change impacts might reduce habitat availability or suitability (e.g., reduced rainfall in an already arid region, sea level rise in a coastal area that eliminates critical habitat), and preservation of refuge lands now might mitigate potential effects on wildlife in the future, then the anticipated effects and timing of such a need can be modelled probabilistically. If future scenarios were not taken into account, and the assumption was made that since the land currently provides habitat, a remediation action that only protects the existing habitat does not provide a gain of resources or services. It merely protects existing services. However, if those services are assumed to be increasingly at risk of loss with time, the project can be credited with an increasing level of anticipated service gain over time.

4.5 Multiple Contaminants from Multiple Sources

Often multiple contaminants from multiple sources contribute to the overall damage in an area. In addition, multiple physical stressors can exacerbate contaminant effects. If the sources of the multiple contaminants (and/or physical impacts) are all responsible parties and involved in the environmental action, issues of partial attribution may arise. In addition, a complex metric, as discussed in Section 5.3, might be needed to quantify loss. If the sources of the multiple stressors are not all responsible parties, then the stressors that contribute to the baseline or background condition of the resource must be taken into account.

Cases of mixed contamination from multiple industrial sources are very common. The case study of Commencement Bay is an example of an attempt to partition contribution to injury to assign responsibility for compensation. Where responsible parties are willing to settle individually for a portion of the remediation costs, developing a method for attributing partial responsibility is critical.

4.6 Characterizing Baseline Conditions

In the US, the characterization of baseline conditions, or the condition of the resource absent the incident in question, is often one of the most challenging aspects of quantifying a loss. Baseline condition must take into account all of the stressors on an ecosystem that existed (or would have existed) and that influence the quality of the resources and services provided. In the US, where the industrial influence typically spans at most 100 to 150 years, effects of historical land use can be difficult to incorporate in determining baseline and causality. In Europe, where land use effects may span many centuries, characterization of baseline conditions may be even more confounding.

Baseline conditions typically are described or estimated using one or more of three approaches, depending on data availability:

1. Before and after sampling
2. Comparison to conditions at a reference site
3. Modelling to estimate the delta associated with the incident.

In some locations, baseline data might be available from the scientific literature, in agency files, or through inspection of other existing maps, images, studies, or other sources of information about a location before an incident. In cases where remediation is to be determined ex ante, baseline data collection can be well planned and executed in advance. Results of sampling conducted after the incident can be compared to earlier data to determine differences related to the incident.

Often, data characterizing conditions before the incident are unavailable or inadequate for use in quantifying the conditions. In such instances, a reference area or areas that resemble the damaged area in terms of relevant environmental attributes (and recreational or economic attributes, if appropriate) can be sampled to characterize baseline conditions. Selection of appropriate reference areas can be contentious, and must be done with care and typically in consultation with ecological, biological, and physical scientific experts who have knowledge of the ecosystems in question. The reference site or sites can be used to provide a reasonable range of expected conditions, against which existing conditions at a damaged site are compared.

When baseline data and reference sites are unavailable or inadequate, modelling approaches can be used. Models that allow users to estimate conditions by changing certain input variables related to the incident can be applied to subtract the effect of the incident. Modelling approaches, like reference sites, can be contentious, and might involve numerous experts to develop acceptable input scenarios.

4.7 Summary

In this report, we review state of the art applications of resource equivalency methods in the US Equivalency methods such as HEA and REA are widely used in the US to quantify environmental damage and the amount of environmental remediation required to compensate for the damage. We describe the conceptual and mathematical basis for equivalency methods and basic methods for conducting an equivalency analysis. In addition, we discuss case studies that provide examples of specific applications, and an idea of the site-specific tailoring that must be done for each case to ensure that an appropriate scale of remediation is achieved. Finally, we discuss several key technical challenges in the US that may be of concern in the EU.

Additional details about the application of equivalency methods in the EU will be developed as part of the REMEDE toolkit. The REMEDE toolkit will also reflect any official guidance through the EU, and through transformation of the ELD into national law in member states.

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