Stakeholder Value-Linked Sustainability Assessment: Evaluating Remedial Alternatives for the Portland Harbor Superfund Site, Portland, Oregon, USA

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EDITOR’S NOTE:
This is 1 of 5 articles generated from the Portland Harbor Sustainability Project (PHSP). The Portland Harbor Superfund site is one of the “mega-sediment sites” in the United States, comprising about 10 miles of the Lower Willamette River, running through the heart of Portland, Oregon. The primary aim of the PHSP was to conduct a comprehensive sustainability assessment, integrating environmental, economic, and social considerations of a selection of the remedial alternatives laid out by the US Environmental Protection Agency. A range of tools was developed for this project to quantitatively address environmental, economic, and social costs and benefits based upon diverse stakeholder values. In parallel, a probabilistic risk assessment was carried out to evaluate the risk assumptions at the core of the remedial investigation and feasibility study process.

ABSTRACT
Regulatory decisions on remediation should consider affected communities’ needs and values, and how these might be impacted by remedial options; this process requires that diverse stakeholders are able to engage in a transparent consideration of value trade-offs and of the distribution of risks and benefits associated with remedial actions and outcomes. The Stakeholder Values Assessment (SVA) tool was developed to evaluate remedial impacts on environmental quality, economic viability, and social equity in the context of stakeholder values and priorities. Stakeholder values were linked to the pillars of sustainability and also to a range of metrics to evaluate how sediment remediation affects these values. Sediment remedial alternatives proposed by the US Environmental Protection Agency (USEPA) for the Portland Harbor Superfund Site were scored for each metric, based upon data provided in published feasibility study (FS) documents. Metric scores were aggregated to generate scores for each value; these were then aggregated to generate scores for each pillar of sustainability. In parallel, the inferred priorities (in terms of regional remediation, restoration, planning, and development) of diverse stakeholder groups (SGs) were used to evaluate the sensitivity and robustness of the values-based sustainability assessment to diverse SG priorities. This approach, which addresses social indicators of impact and then integrates them with indicators of environmental and economic impacts, goes well beyond the Comprehensive Environmental Response, Compensation and Liability Act’s (CERCLA) 9 criteria for evaluating remedial alternatives because it evaluates how remedial alternatives might be ranked in terms of the diverse values and priorities of stakeholders. This approach identified trade-offs and points of potential contention, providing a systematic, semiquantitative, transparent valuation tool that can be used in community engagement. Integr Environ Assess Manag 2018;14:43–62. © 2017 The Authors. Integrated Environmental Assessment and Management published by Wiley Periodicals, Inc. on behalf of Society of Environmental Toxicology & Chemistry (SETAC)

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INTRODUCTION
Remediation and restoration approaches should be designed with community expectations for the final site uses in mind (ITRC 2006; Woodford 2010; ECA 2012; Kapustka et al. 2016). In the United States, such thinking is supported by a US presidential executive memo (Donovan...
et al. 2015), which directs that human needs (supported by ecosystem services) must drive regulatory decisions. The memo directs that consideration of “affected communities’ needs,” and how these might be impacted, must underlie decision making. Therefore, there is a need to integrate a consideration of community and stakeholder expectations, priorities, and vulnerabilities into assessments of remedial options.

However, incorporating such thinking into regulatory decision making faces challenges. Although US Environmental Protection Agency (USEPA) guidance for sustainability considerations has recently moved from recommending best management practices (BMPs) that optimize selected remedies (USEPA 2015a) to guidance on remedy selection (Woodford et al. 2016), the focus remains on Green and Sustainable Remediation (GSR) or footprint reduction, rather than on a fuller consideration of sustainability. The National Research Council concluded that regulatory programs such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) (CERCLA 1980), with risk reduction as their primary objective, have not generally given full consideration to all 3 sustainability pillars (environmental, social and economic) (NRC 2011, 2014), and that there is a need for more tools to address sustainability and stakeholder values in decision making. The USEPA acknowledges that public participation is an essential aspect of its decision-making process, allowing them “to obtain and consider a range of views on the issue being assessed, as well as on management options” (USEPA 2014b). They further acknowledge that “effective public involvement (including key stakeholders and communities) can enhance the deliberative process and improve the content of the Agency’s decisions…consistent with sustainability principles” (USEPA 2014b).

The USEPA (2014a) states that it seeks to move “beyond the foundation of traditional regulatory approaches to environmental protection…seeking to build sustainability into our day-to-day operations.” They provide increasing guidance on sustainability (Fiksel et al. 2012), stakeholder outreach (USEPA 2013a), and environmental justice (McConville 2013) considerations within a range of their programs, but frameworks and guidance on their integration into remedial decision-making programs such as CERCLA are lacking.

Harclerode et al. (2015) discussed the state of the practice for integrating the social dimension—community impact and values—into remedial decision making, invoking a range of emerging approaches, case studies, and tools for this rapidly evolving field; an international Sustainable Remediation Forum (SuRF) working group is currently developing further guidance. A recent effort by the USEPA to integrate early stakeholder outreach into decision making in the Tittabawassee River Floodplain, Midland, Michigan (USEPA 2013b) demonstrated innovation by seeking repeated interactions with a broad range of stakeholders, creating a clear mental model of decisions and trade-offs, framing questions in terms of an articulation of values rather than positions, and communicating back to the community on what was heard and how it was used in decision making, but links between stakeholder views and remedial alternatives remained qualitative.

“Community acceptance” is the final modifying criterion for CERCLA (USEPA 1989), but all impacts of remedial options (environmental, economic, and social) affect communities, and thus sustainability principles require that stakeholder priorities be considered and balanced in terms of all impacts. Communities must decide what values they wish to maintain, but tools to quantify and integrate this criterion into the decision-making process in a transparent manner are limited. In their final feasibility study (FS) for the Portland Harbor Superfund Site (the “Site”), Portland, Oregon, USA, the USEPA provided a qualitative table rating remedial alternatives in terms of CERCLA criteria (USEPA 1989), but no quantitative basis for the cost-effectiveness of each alternative or link to stakeholder values was presented (USEPA 2016b).

There is a need to develop broad-based, transparent, quantitative (or semiquantitative) frameworks to evaluate and communicate the stakeholder value-linked costs and benefits of remedial alternatives to inform balanced decision making. This paper presents such a framework, using the Site as a case study.

BACKGROUND

The Site encompasses about 10 miles of the Willamette River immediately downriver of downtown Portland, Oregon and is contaminated with PCBs, dioxins, PAHs, metals, and DDT, DDD, and DDE (DDx) from more than 100 y of agricultural, urban, wartime, industrial, combined sewer overflow, and storm water inputs. The Site, considered a “mega-sediment site” by the USEPA, affects residents, businesses, tribes, recreation, and wildlife (PHNRTC 2012); there is considerable contention over the best approach for remediation at the Site (e.g., Sallinger 2012; CAG 2015; Fricano et al. 2015; McDonough 2015; ODEQ 2015; Ward 2015). The remedial alternatives include combinations of remediation technologies—dredging, capping, enhanced natural recovery (ENR), in situ treatment, and monitored natural recovery (MNR); they differ in the proportion and relative extent to which each technology is applied at the Site. Alternative A is the “no action” option and is considered the baseline alternative for this analysis. The active alternatives evaluated as part of the present study range in cost from about US$642 million to almost $2.2 billion and may require up to 13 y of construction. The USEPA-preferred remedial option in the Proposed Plan (PP) was Alternative I (a more extensive alternative, F modified [F Mod], was selected in the Record of Decision [ROD] [USEPA 2017]; because this occurred after the present study, Alternative F Mod is not evaluated here).

As is standard practice in CERCLA, USEPA (2016a) evaluated remedial options (B, D, E, I, F, and G, in order of increasing extent) relative to Alternative A, the “no action” alternative (Alternative C was not evaluated in the PP, having
been eliminated by the USEPA in earlier phases). To be consistent with the context of the FS, the current project evaluated the impacts of Alternatives B, D, I, E, and F relative to A (Alternative G, full removal, was not evaluated in the present study). As in the PP and FS, alternatives were evaluated in the context of remediation alone (not restoration), using, where possible, technical specifications and risk values from the PP (USEPA 2016a).

METHODS

The focus of the present project was to assess the stakeholder values–based sustainability of a range of remedial alternatives proposed by the USEPA in their FS (USEPA 2016a). The project described here evaluated the social costs and benefits of a range of remedial options, linking aspects of remedial alternative technical specifications to metrics of impacts on stakeholder or community values and priorities. In brief, remedial alternatives were scored on the basis of metrics of remedial alternative technical specifications (e.g., time, volumes dredged or disposed of, footprint, projected risk reduction), which were linked to impacts on stakeholder group (SG) values (4 for each pillar of sustainability, called SG Values in this paper). Metric and value scores were weighted on the basis of diverse SG priorities, generating a range of stakeholder value–linked sustainability scores (Figure 1 illustrates the conceptual approach).

A Microsoft Excel®-driven calculation tool, the Stakeholder Values Assessment (SVA) tool (SEA and AECOM 2016), was developed specifically for the present project, building on and adapting from several methods reviewed or used on other decision-making projects (MWOEW 1995; Johnston et al. 2002; Linkov et al. 2006; Apitz 2008; Linkov 2014), including the Architecture, Engineering, Construction, Operations, and Management (AECOM) CERCLA-linked Environmental Impact and Benefit Assessment (EIBA) calculation tool (AECOM 2016). The SVA tool scores and aggregates multiple lines of evidence of risks and benefits to selected endpoints, and then uses the output to identify trade-offs between SG Values resulting from different alternatives under consideration (an assessment of social costs and benefits).

Step 1: Develop indicators for 12 generic stakeholder values

The present paper develops indicators in 3 areas—environmental quality, economic viability, and social equity—that might be impacted by Portland Harbor remediation. One can view the concept of social equity as all-encompassing, under the premise that all impacts (positive and negative) of remedial options can be seen as social impacts, but it is
useful to distinguish these 3 broad areas or “pillars.” A coherent set of criteria to inform a decision should be (Burgman 2005):

1) exhaustive (allow a clear delineation between alternatives),
2) cohesive (alternatives that rank higher on 1 criterion should be preferred),
3) clear (linked to decisions, in scientific terms and in the minds of decision makers),
4) not redundant (avoiding bias and double-counting), and
5) relevant (meaningful to the actual decision process).

Thus, although the literature presents a vast range of potential indicators for the 3 pillars of sustainability, indicators for this framework were selected for use considering the above criteria. A range of sediment-specific sustainability assessment frameworks (Ellis and Hadley 2009; SuRF-UK 2011; Vivian et al. 2011; SMOCS 2013; Linkov 2014) was reviewed to identify sustainability indicators (see Tables S-0-1 to S-0-3 in the Supplemental Data); these indicators were evaluated in terms of the criteria listed above as well as in terms of their relevance to Portland Harbor remedial impacts.

After review, a list of 12 SG Values, 4 for each pillar of sustainability (environmental quality, economic viability, and social equity; Tables 1–3, respectively) was generated. All quantifiable and project-relevant indicators identified in the review either are reflected in values in this list or are considered in the metric set that is used to quantify the SG Values (see Step 4: Link stakeholder values to metrics). These SG Values are the indicators under which metrics of sustainability are aggregated in the SVA tool. The choice of 4 SG Values for each pillar was in part based upon this review—many case studies had 3 to 6 indicator categories for each pillar and some were combined or eliminated, but having the same number of indicators for each pillar also simplifies calculations and comparisons when the data are aggregated.

In selecting terms to describe the SG Values, the challenge was to build a conceptual framework that links measurable metrics of impact to value terms that resonated with the public and reflected value statements made by the community. This simplifying terminology, developed in discussion with a range of SGs, at times sacrifices technical precision for simplicity. For example, the term “habitat” makes sense ecologically only in the context of a species or guild of species, and “resilience” means something different to an ecologist than it does in the context of a remedial alternative’s resilience to disaster and change, but these were deemed the best aggregating terms, balancing technical precision and community understanding.

One indicator type not addressed by most of the frameworks reviewed was the technical aspect of remedial options such as time to completion, permanence, effectiveness, and implementability. However, these aspects are included as CERCLA criteria (USEPA 1989) and also proved to be a major concern expressed in community meetings and stakeholder documents. Thus, they were deemed to be important issues to regulators and the community, and therefore were included in one of the SG Values considered in the social equity pillar, termed “SOC-3: Acceptable Remedy.” This is not to be confused with the CERCLA-modifying criterion “community acceptance”; impacts on other social as well as environmental and economic values that might also affect community acceptance are addressed in the other SG Values.

Step 2: Identify stakeholder groups for Site

In this work, “stakeholders” are defined as any individual or group that can affect or is affected by the decision being made (Cundy et al. 2013). Assessing the social equity impacts of remedial alternatives requires a consideration of the values of as diverse a range of affected SGs as possible (Cundy et al. 2013), ideally not only focusing on potentially responsible parties (PRPs) and regulators, but also on the under-represented sectors of the community that do not have a strong voice. This helps the evaluation to avoid bias. Large SGs and nongovernmental organizations (NGOs) can support and represent broad communities, but when such groups seek to speak with one voice, a diversity of viewpoints may be masked. Unengaged subjects, due to a lack of resources, interest, or awareness, may not have their needs and values addressed unless a special effort is made to identify and consider them.

To address this issue, a broad-based online and in-person review of Site SGs was carried out to identify and build an SG database. More than 280 separate SGs were identified, including regional businesses and industries upstream, near, or dependent on the river (including PRPs); neighborhood, community, and tribal groups; recreational and other clubs and associations; environmental, social justice, and other NGOs; media; and local, regional, state, and federal government entities, each with its own focus and priorities. (See Supplemental Data Figure S1.)

Step 3: Identify stakeholders’ priorities

If remedial options are to be selected and optimized based on community values and priorities, these can be elicited using communication and outreach (USEPA 2013a) in a range of tools such as surveys, collaborative and interactive workshops, and other structured approaches, or inferred based upon a review of community statements and documents; each of these approaches has strengths and weaknesses (Linkov et al. 2006; Harclerode et al. 2015). In the present project, SG priorities were primarily determined using an inferred values approach based upon a broad-based review of SG statements about what is important to them in Web pages and documents. This approach has the advantage of allowing a breadth not possible when collecting elicited values. This review also integrated the results of 2 outside surveys (SCI 2015; DHM 2016) that elicited stakeholder views on some of the values considered here and elicited SG Value statements made in public meetings organized by other groups.
| SG Value       | Conceptual basis of scoring and metrics | Relevance to balanced decision making | Metric label | Metric | Measurement basis, notes |
|---------------|----------------------------------------|--------------------------------------|--------------|--------|--------------------------|
| Fish & Wildlife (ENV-1) | Degree of risk reduction at the end of construction and over the long term, degree of increased risk during construction | Ecological impacts an important regulatory driver of cleanup, also of great concern to many stakeholders | ENV-1a | 1a. Residual risk, T0 (end of construction) | Based on average of 1) average reduction in SWACs on a site-wide basis following construction for the focused COCs; 2) RAO 5: Hazard Index–Direct Contact, equal to the sum of the HQs for PCBs, total PAHs, DDx, BEHP, chlordane, Pb, and Hg; and 3) RAO 6: Hazard Index–Consumption, equal to the sum of the HQs for 4,4-DDE, PCBs, HxCDF, PeCDF, TCDD, and TCDF. |
|                | satisfactory                             |                                       | ENV-1b | 1b. Downstream risk | Based on total mass exiting the study area for each alternative (total kg PCB), adjusted for AECOM years (McNally et al. this issue). Note: This metric is based on Anchor QEA (2012) because the USEPA (2016a) does not address. |
|                | satisfactory                             |                                       | ENV-1c | 1c. Reliance on controls | Proportional to total acres of cap, in situ treatment, ENR, and MNR. Assume reliability of ICs and engineering controls is inversely proportional to the area of technologies that leave contamination on site. Although Alternative A does not have technology assignments, all contamination is left on site; therefore, the total PH study area is used to score Alternative A. |
|                | satisfactory                             |                                       | ENV-1d | 1d. Construction risk | Based on construction time (AECOM years; McNally et al. this issue). Set to zero because this seems duplicative of ENV-1b. |
|                | satisfactory                             |                                       | ENV-1e | 1e. Residual risk, T45 | Based on Year 45 PCB SWAC, site-wide, from Table 9.3.1-1 (Anchor QEA 2012). |
| Habitat (ENV-2) | Relative impact on habitat during remediation; gain, loss, or enhancement of habitat due to or after remediation | Reflects mid- to long-term impacts during and after construction, may reflect benefits when restoration is part of a scenario under consideration | ENV-2a | 2a. Nearshore habitat | Inversely proportional to % overlap of active remediation to nearshore habitat area above –15 ft elevation. |
|                | satisfactory                             |                                       | ENV-2b | 2b. Benthic habitat | Based on acres of active remediation. |
|                | satisfactory                             |                                       | ENV-2c | 2c. Shoreline habitat | Based on GIS overlap of active remedy (dredge, cap, treatment, and ENR) with shoreline. |
| Resilience (ENV-3) | Net impact on local flooding risk; vulnerability to extreme events and climate change | There is increasing scrutiny on the climate impact and resilience of any development or action | ENV-3a | 3a. Flood risk | Based on net volume removed, assuming greater river capacity reduces flood risk. |
|                | satisfactory                             |                                       | ENV-3b | 3b. Vulnerability in place | Inversely proportional to total acres of caps, in situ treatment, ENR, and MNR. Assigned A as 100% MNR. |

(Continued)
### Table 1. (Continued)

| SG Value | Conceptual basis of scoring and metrics | Relevance to balanced decision making | Metric label | Metric | Measurement basis, notes |
|----------|----------------------------------------|-------------------------------------|--------------|-------|--------------------------|
| Low Impact Remedy (ENV-4) | Remedial option air emissions, energy, water, and landfill consumption | GSR endpoints are the main focus, currently, for USEPA sustainability considerations | ENV-4a | 4a. Air emissions | Based on SiteWise\(^c\) emissions, NO\(_x\), SO\(_x\), PM\(_{10}\), and GHG.\(^b\) |
|            |                                        |                                     | ENV-4b | 4b. Energy consumption | Based on SiteWise energy use.\(^b\) |
|            |                                        |                                     | ENV-4c | 4c. Water consumption | Based on SiteWise water use.\(^b\) |
|            |                                        |                                     | ENV-4d | 4d. Hazardous landfill use | Based on SiteWise hazardous landfill use.\(^b\) |
|            |                                        |                                     | ENV-4e | 4e. Nonhazardous landfill use | Based on tons disposed in nonhazardous landfills.\(^a\) |
|            |                                        |                                     | ENV-4f | 4f. Volume of sediment treated | Based on volume sediment treated, high values.\(^a\) |
|            |                                        |                                     | ENV-4g | 4g. Contaminant mobilization | Based on total mass exiting the study area for each alternative (total kg PCB), adjusted for AECOM years. Note: this metric is based on Anchor QEA (2012) because USEPA (2016a) does not address. |

BEHP = bis(2-ethylhexyl) phthalate; CoCs = contaminants of concern; DDx = DDT, DDD, and DDE; ENR = engineered natural recovery; FS = feasibility study; GHG = greenhouse gas; GIS = geographic information system; GSR = Green and Sustainable Remediation; HQ = hazard quotient; HxCDF = hexachlorinated dibenzofurans; IC = Institutional Controls; PeCDF = pentachlorinated dibenzofurans; MNR = monitored natural recovery; NO\(_x\) = oxides of N; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; PH = Portland Harbor; PM\(_{10}\) = particles with a diameter between 2.5 and 10 µm; RAO = remedial action objective; SG = stakeholder group; SO\(_x\) = oxides of S; SWAC = spatially weighted average concentration; TCDD = tetrachlorodibenzodioxin; TCDF = tetrachlorodibenzo-furan; T0 = time at end of construction; T45 = time 45 y after construction begins; USEPA = US Environmental Protection Agency.

\(^a\)USEPA 2016a.

\(^b\)McNally et al. this issue.

\(^c\)NAVFAC 2015.

\(^d\)USEPA 2016a.
| SG Value     | Conceptual basis of scoring and metrics                                                                 | Relevance to balanced decision making                                                                 | Metric label | Metric | Measurement basis, notes                                                                 |
|-------------|---------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------------|--------|--------------------------------------------------------------------------------------------|
| Economic   | Modeling of regional economic impact of remedial expenditure and financing                            | Regional economic impact of large-scale remediation is often ignored or miscommunicated                 | ECON-1a      | 1a.   | Based on GRP impacts — REMI model, used upper and lower limits of GRP estimates from local business, local government and mixed scenarios, scored and averaged. |
| vitality    |                                                                                                        |                                                                                        |              | 1b.   | Based on “illustrative qualitative impacts of disruption” discussion using professional judgment from stakeholder surveys. |
| (ECON-1)    |                                                                                                        |                                                                                        |              | 1c.   | Based on GIS overlap analysis of active overlap with beach/park areas. Note: Fishing not considered because no good metric or evidence of economic impact could be found. |
| Jobs        | Modeling of regional employment impact of remedial expenditure and financing                          | Regional employment impact of large-scale remediation is often ignored or miscommunicated              | ECON-2a      | 2a.   | Based on REMI model, used upper and lower limits of job estimates from local business, local government and mixed scenarios, scored and averaged. |
| (ECON-2)    |                                                                                                        |                                                                                        |              | 2b.   |                                                                                              |
| Infrastructure | Effects on traffic, utilities, river, shoreline, and navigational infrastructure                    | Communities and businesses may be disrupted for many years in a large-scale project                  | ECON-3a      | 3a.   | Proportional to total volume handled, assuming larger remedies will require greater local equipment inputs and regional disposal; regional, not Willamette; trucks from Colombia. |
| (ECON-3)    |                                                                                                        |                                                                                        |              | 3b.   | Inversely proportional to adjusted construction times, with the assumption that quicker is more desirable (>70% of those surveyed support a treatment which is <7 y, but this preference is more reflected in the social scoring of this). |
| Cost        | Capital and long-term costs; costs per unit risk reduction or contaminant removal                    | Stakeholders who may be paying for options (PRPs, businesses, taxpayers) may consider “bang for the buck” an important criterion, if explicitly communicated | ECON-4a      | 4a.   | Based on total capital costs, adjusted using AECOM costing tool. |
| Effectiveness | (ECON-4)                                                                                               |                                                                                        |              | 4b.   | Inversely related to the need for long-term maintenance and monitoring. Based on number of acres that require |

(Continued)
Table 2. (Continued)

| SG Value | Conceptual basis of scoring and metrics | Relevance to balanced decision making | Metric label | Metric | Measurement basis, notes |
|----------|----------------------------------------|--------------------------------------|--------------|--------|--------------------------|
|          | institutional controls – sum of acres of capping and ENR<sup>c</sup> (CDF not included in estimates). Landfill maintenance included in tipping fees. Scored based on sum of capping and ENR but not dredging/capping or in situ treatment. |
| ECON-4c  | 4c. Cost-effectiveness (T0)             | Based on the % reduction in SWAC (T0)<sup>e</sup> divided by millions of US$ adjusted cost.<sup>b</sup> |
| ECON-4d  | 4d. Cost effectiveness (T45)            | Based on % reduction in SWAC (T45)<sup>e</sup> divided by millions of US$ adjusted cost.<sup>b</sup> Note: Based upon Anchor QEA (2012). |
| ECON-4e  | 4e. Net environmental benefit           | Based on benefit points per billion US$ in CERCLA-linked IEBA.<sup>b</sup> |

AECOM = Architecture, Engineering, Construction, Operations, and Management; CDF = confined disposal facility; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980; ENR = engineered natural recovery; FS = feasibility study; GIS = geographic information system; GRP = gross regional product; IEBA = environmental impact-benefit assessment; PRP = potentially responsible party; REMI = Regional Economic Models, Inc.; SWAC = spatially weighted average concentration; T0 = time at end of construction; T45 = time 45 y after construction begins.

<sup>a</sup>Harrison et al. this issue.
<sup>b</sup>McNally et al. this issue.
<sup>c</sup>USEPA 2016a.
<sup>d</sup>SCI 2015.
<sup*e</sup>Anchor QEA 2012.
| SG Value                        | Conceptual basis of scoring and metrics | Relevance to balanced decision making                                                                 | Metric label | Metric               | Measurement basis, notes                                      |
|--------------------------------|-----------------------------------------|--------------------------------------------------------------------------------------------------------|--------------|----------------------|-----------------------------------------------------------------|
| Quality of Life & Recreation (SOC-1) | Time and extent of remedial option, impacts on neighborhoods and access | Many communities have concerns about the impacts of large projects on their quality of life; these impacts are localized, so there may be social justice concerns at play as well | SOC-1a       | 1a. Quality of life  | Impact on quality of life is proportional to volume of sediment removed and total construction time. Short-term indicator of impacts during construction. |
|                                |                                         |                                                                                                        | SOC-1b       | 1b. Recreation: water quality | Assumed to be proportional to construction time; impacts should abate when construction complete. Based on AECOM adjusted construction times. |
|                                |                                         |                                                                                                        | SOC-1c       | 1c. Other water recreation | Based on GIS overlap analysis; overlap of active footprint with beach/park areas. |
|                                |                                         |                                                                                                        | SOC-1d       | 1d. Access to river     | Based on GIS overlap analysis; Overlap of active remedy (dredge, cap, treatment and ENR) with shoreline (total active shoreline) (City of Portland, non-business areas). |
| Community Values (SOC-2)       | Stakeholder involvement; amenability to re-use, communication of uncertainty, impacts on sites of cultural importance | These issues are important for social justice, and in most social and community outreach guides, but are rarely quantitatively addressed | SOC-2a       | 2a. Stakeholder involvement | Based on professional judgment based upon USEPA involvement of stakeholders in process. Inform (2), consult (4), involve (6), collaborate (8), empower (10). Not sensitive to specific remedies. |
|                                |                                         |                                                                                                        | SOC-2b       | 2b. Amenability to re-use | Aggregate score considering stigma reduction, recreation/fishing, Native American views, in-water re-use. Did not score for re-uses on shore such as hiking, biking as remedial plans do not address restoration. Details in Supplemental Data. |
|                                |                                         |                                                                                                        | SOC-2c       | 2c. Communication of uncertainty | Judgment based upon review of public outreach process by USEPA and various stakeholder groups. In public meetings, and in documents. Not sensitive to specific remedies. |
|                                |                                         |                                                                                                        | SOC-2d       | 2d. Archaeological sites | Based on archeological and culturally sensitive sites in internal review of available maps by qualified AECOM archaeologist. Semiquantitative. |
| Acceptable Remedy (SOC-3)      | Mass of contaminants removed, degree of risk reduction, relative difficulty of remedies, construction time | Stakeholder groups can differ significantly in what they consider important in an acceptable remedy | SOC-3a       | 3a. Permanence        | Based on mass of PCBs removed and reduction of mobility of hazardous substances. |
|                                |                                         |                                                                                                        | SOC-3b       | 3b. Effectiveness      | Based on human health and ecological risk reduction, a score based upon the relative permanence of remedies, and the extent to which institutional controls will be required. |
|                                |                                         |                                                                                                        | SOC-3c       | 3c. Implementability   | Based upon qualitative comparative scoring tables, 2 points for each quartile of implementability symbol; |

(Continued)
Table 3. (Continued)

| Social equity |
|----------------|
| **SG Value** | **Conceptual basis of scoring and metrics** | **Relevance to balanced decision making** | **Metric** | **Metric label** | **Measurement basis, notes** |
| | | | | | full black circle = 8, half black = 4, all white circle = 0, A scored as 10. |
| | | | | SOC-3d | 3d. Socially optimal construction time |
| | | | | SOC-3e | 3e. Time-effectiveness |
| **Health & Safety (SOC-4)** | Worker safety, long-term risk reduction, increased risks during construction | Regulations may focus on long-term risk reduction while neglecting (often much higher) risks to workers and, at times, short- to mid-term increases in exposure due to construction | SOC-4a | 4a. Worker safety |
| | | | | SOC-4b | 4b. Human health risk |
| | | | | SOC-4c | 4c. Fish consumption risk (short term) |

AECOM = Architecture, Engineering, Construction, Operations, and Management; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980; FS = feasibility study; GIS = geographic information system; PCBs = polychlorinated biphenyls; RAO = remedial action objective; SWAC = spatially weighted average concentration; T0 = time at end of construction; T45 = time 45 y after construction begins; USEPA = US Environmental Protection Agency.

*aUSEPA 2016a.  
*bAECOM 2016.  
*cMcNally et al. this issue.  
*dUsing Cundy et al. 2013 categories.  
*eSCI 2015.
An online review of documentary evidence addressed Site SG viewpoints on Portland Harbor remediation. Although the assessment boundaries of the present study focus on remediation alone (in line with USEPA PP), only a limited range of SGs formally commented on this process. To identify values and priorities of a wider range of SGs, documents that identified SG viewpoints on restoration, planning, and development were also reviewed. Because this framework addresses technical scoring of remedial options separately from the community priority-based value weighting, SG statements about how they prioritize values such as recreation, jobs, and health do not necessarily need to be linked to comments on remediation plans. The SG “value statements,” ranging from a single word to 1 or more paragraphs, provided qualitative evidence of SG priorities (SEA and AECOM 2016). Value statements were drawn from more than 500 documents and records such as

1) SG Web pages (mission statements or other linked pages),
2) produced literature (news articles, journal articles, reports, fliers, brochures),
3) interviews,
4) extracts from third-party surveys (SCI 2015; DHM 2016),
5) written comments to or by the USEPA,
6) notes or transcriptions from public meetings and forums, and
7) notes from neighborhood and business group meetings.

Where no documentation could be found to determine the priorities of an SG, they were qualitatively identified (+/−reflecting whether something was assumed to be a priority) using general local knowledge and professional judgment. The resultant “value map” provides an evidence base for the diverse priorities of Portland SGs; what is critical to 1 group may be of little interest to another. However, all SG Values (see Step 1) were prioritized by some SGs, thus all should be considered in a broad discussion of remedial impacts.

Step 4: Link stakeholder values to metrics

In the present project, SG Values were linked to quantifiable indicators or metrics of impact, used to score each remedial alternative based upon the remedial alternative technical specifications. A total of 49 metrics were quantified and aggregated into 1 or more of the 12 indicator value groups (SG Values). Tables 1 to 3 summarize the metrics used to evaluate the SG Values in each pillar, and the basis or source of the data used to quantify the metrics; details are in Section 4 of the Supplemental Data. Where an SG Value has more than 1 metric, this can represent different aspects of impacts on the same SG Value. For instance, “SOC-4: Health & Safety” has metrics that address short-term risks to workers (“SOC-4a: Worker safety”) and the public during remediation (“SOC-4c. Fish consumption risk [short term]”) and longer-term risk after remediation (“SOC-4b. Human health risk”).

Step 5: Score and weight metrics

For each remedial alternative under consideration, metrics were scored on the basis of inputs from a range of project assessments: CERCLA-linked EIBA (AECOM 2016; McNally et al. this issue), economic assessment (NERA 2016; Harrison et al. this issue), Portland Harbor 2012 Draft FS (Anchor QEA 2012), 2016 USEPA FS and PP (USEPA 2016a, 2016b), and stakeholder and value mapping (SEA and AECOM 2016). The data input table for these metric calculations is listed in Supplemental Data Table S-0-4.

For each alternative, a risk or benefit score was calculated for each metric, in terms of the relative desirable or undesirable impact on SG Values. The SVA metrics were scored from −10 (most undesirable outcome, such as maximum toxic emissions) to +10 (most desirable outcome, such as maximum toxicity reduction), based on the range of values for the remedial options under consideration. As with other multicriteria frameworks, the purpose of scoring all indicators on a common scale (i.e., −10 to +10) is to allow for the comparison of disparate values, measured in a range of units, on the same basis. Thus, alternative-specific values for a given metric (e.g., cubic years [cy] in landfill, percent spatially weighted average concentration [SWAC] reduction) are scaled based on the range of values for all alternatives. For example, a metric of “ENV-1: Fish & Wildlife” is “ENV-1b: Downstream risk.” The basis of quantification for this impact is the total mass, in kilograms, of PCBs exiting the study area for each alternative (Anchor QEA 2012). Alternative A, by definition, has 0 kg mobilized PCBs, while the most extensive alternative, F, is predicted to mobilize 93 kg of PCBs during construction (Anchor QEA 2012). Thus, alternatives are proportionately scored for this metric by scaling the kilograms PCB mobilized for all Alternatives based upon 0 mobilization being scored as 0 and the maximum mobilization, 93 kg, getting a score of −10 (a maximum undesirable impact). It should be noted that there are no positive scores for this metric because contaminant release is an undesirable impact. Alternatives B, D, I, and E, then, with mobilizations of 30, 40, 50, and 60 kg, respectively, receive submetric scores of −3.2, −4.3, −5.4, and −6.4. Details of the basis, assumptions, approach, and results for all metric scores can be found in Section 4 of the Supplemental Data.

Where possible, metrics for endpoints should be standard, quantitative, logically and clearly linked to (and correlating with) the SG Values, as well as being relevant and sensitive to the remedial alternatives under consideration (MWOEW 1995; Johnston et al. 2002). The most relevant lines of evidence should also be given more weight than less relevant ones when data are aggregated (Germano 1999). To address this, metric relevance weights (MRWs) were calculated for each metric, in a method adapted from weight-of-evidence approaches (MWOEW 1995; Johnston et al. 2002; Apitz 2008). (See Supplemental Data Section S4-1.)
Step 6: Aggregate metrics into SG Value and pillar scores

The SG Value scores \( (V_r) \) were calculated as the relevance-weighted average, of the metric scores for a given SG Value:

\[
V_r = \left( \frac{\sum (M_i \times MRW_i)}{\sum MRW_i} \right),
\]

where \( M_i \) is the score assigned for each metric, \( MRW_i \) is the metric’s MRW (as described in Step 5), and \( \sum MRW_i \) is the sum of the MRWs for all value metrics. For instance, the SG Value score for “ENV-1: Fish & Wildlife” is the weighted average of the metric scores “ENV-1a: Residual Risk, T0 (end of construction),” “ENV-1b: Downstream Risk,” “ENV-1c: Reliance on Controls,” and “ENV-1e: Residual Risk, T45” (“ENV-1d: Construction Risk” was not used in the present case study because it was duplicative of ENV-1b, but can be used when that metric is not quantifiable). So, for Alternative B, the score for ENV-1 (see Table 4) is

\[
(3 \times 6.6) + (3 \times -3.2) + (3 \times 0.3) + (3 \times 3.2)/(3 + 3 + 3) = 3.2
\]

The pillar (i.e., environmental quality, economic viability, and social equity) scores were calculated as the average of the SG Value scores for a given pillar:

\[
P_r = \left( \frac{\sum (V_r)}{4} \right).\]

Where \( V_r \) is the score assigned for each SG Value. For example, the pillar score for “ENV: Environmental Quality” for a given alternative is the average of its scores for “ENV-1: Fish & Wildlife,” “ENV-2: Habitat,” “ENV-3: Resilience,” and “ENV-4: Low Impact Remedy.” For Alternative B, the value (Table 4) is calculated as

\[
\left( \frac{(3.2 + (-3.9) + 0.4 + (-4.5))}{4} \right) = -1.2.
\]

Full details of weightings, metric scores, and calculations for every alternative, metric, value, and pillar are in Supplemental Data Section 4.

Step 7: Sensitivity analysis

The methods described thus far aggregate metrics to SG Values and SG Values to pillars, treating all metrics and SG Values as equally important to the overall sustainability. However, not all SGs have the same priorities; for instance, some may value time-effectiveness more than cost, or uncontaminated fish over time-effectiveness. Thus, metric and SG Value scores were weighted on the basis of the inferred priorities of different representative SGs, to evaluate the impact on overall sustainability scores. This analysis had 2

| Pillar label | Pillar name | A (baseline) | B | D | E | I | F |
|--------------|-------------|--------------|---|---|---|---|---|
| ENV          | Environmental quality | 0.0 | -1.2 | -1.6 | -1.9 | -1.7 | -2.7 |
| ECON         | Economic viability | 0.0 | -0.6 | -2.3 | -3.7 | -3.3 | -7.5 |
| SOC          | Social equity | 0.9 | 0.4 | -0.2 | -1.1 | -0.7 | -3.5 |

Mean sustainability score: 0.3

| SG Value label | SG Value name | A (baseline) | B | D | E | I | F |
|----------------|---------------|--------------|---|---|---|---|---|
| ENV-1          | Fish & Wildlife | 0.0 | 3.2 | 3.3 | 3.4 | 3.4 | 3.0 |
| ENV-2          | Habitat       | 0.0 | -3.9 | -5.3 | -6.7 | -6.0 | -10.0 |
| ENV-3          | Resilience    | 0.0 | 0.4 | 1.1 | 2.3 | 1.9 | 6.1 |
| ENV-4          | Low Impact Remedy | 0.0 | -4.5 | -5.4 | -6.6 | -6.2 | -10.0 |
| ECON-1         | Economic Vitality | 0.0 | -2.7 | -4.0 | -5.6 | -5.2 | -10.0 |
| ECON-2         | Jobs          | 0.0 | -2.6 | -3.9 | -5.5 | -5.0 | -10.0 |
| ECON-3         | Infrastructure | 0.0 | -2.1 | -3.8 | -4.9 | -4.7 | -7.9 |
| ECON-4         | Cost-Effectiveness | 0.0 | 4.8 | 2.5 | 1.1 | 1.5 | -2.1 |
| SOC-1          | Quality of Life & Recreation | 0.0 | -2.9 | -4.3 | -5.9 | -5.1 | -10.0 |
| SOC-2          | Community Values | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.0 |
| SOC-3          | Acceptable Remedy | 3.6 | 3.5 | 2.9 | 2.0 | 2.2 | -0.1 |
| SOC-4          | Health & Safety | 0.0 | 0.9 | 0.2 | -0.8 | -0.3 | -3.7 |

SG = stakeholder group.

*Giving all metrics and SG Values equal weight.
objectives: 1) to demonstrate the use of the SVA tool to address SG-specific priorities and communicate trade-offs in terms of these priorities, and 2) to evaluate the sensitivity and robustness of SVA-based assessment of the remedial alternatives to differing SG priorities.

Value mapping, meeting notes, surveys, discussions, and reviews provided evidence for the priorities of a set of representative SGs. Metrics and SG Values were assigned SG-specific weights based upon evidence of whether they were unimportant (0) to critically important (5) to an SG; SG priority-specific weights ($W_{mSG_i}$) are developed for the SG Values and metrics; details on the SG-specific weighting approach can be found in Supplemental Data Section 4.

The intent here is to illustrate how trade-offs are affected when differing priorities are considered, not to speak for the selected SGs. Thus, a diverse set of plausible SG Value and metric weightings were applied, considering representative SGs for which we have documentation on their priorities. As well as considering equal weighting, representing the diverse priorities and SGs of the Portland Harbor community, for comparison, 5 representative SGs were identified for this purpose:

- Community Forum (CF): Based upon community values elicited by USEPA at a Site community outreach meeting called “St John’s Community Café,” in July 2015 (USEPA 2015b). This forum sought to identify broad-based community values.
- Community Comments (CC): Based upon value statements in presentations, public comments and questions by community groups and members of the public at meetings hosted by USEPA on the Site cleanup plans. These were open to all members of the public, but several documents and meetings had the same set of presenters and commentators.
- City Survey (CS): Based on results from the City of Portland’s Bureau of Environmental Services online consultation with Portland residents to better understand their opinions and values regarding the cleanup (DHM 2016). This survey focused on some, but not all, of the SG Values considered in the present paper.
- Business Group (BG): Based on value statements in documents commenting on the 2015 USEPA FS (LWG 2015), interviews (e.g., Harrison et al. this issue), and BG statements and presentations at public meetings.
- Tribal Groups (TG): Based on value statements made in presentations and documents provided by or on behalf of tribal groups (e.g., CAG 2015; Fricano et al. 2015; ODEQ 2015; Ward 2015). The Yakama Nation has been particularly active at public meetings.

The SG-weighted SG Value scores were calculated as the MRW- and SG-weighted average ($V_{SG,r}$), the weighted average of the metric scores for a given SG Value

$$V_{SG,r}(value\ weighted) = \left(\sum \left(M_i \times MRW_i \times W_{mSG_i}\right)\right)/\left(\sum MRW_i \times \sum W_{mSG_i}\right)W_{vSG_i} \quad (3)$$

where $M_i$ is the score assigned for each metric, MRW, is the metric MRW (see Step 5), and $W_{mSG_i}$ and $W_{vSG_i}$ are the SG-specific metric and value SG weighting (0-5 depending on how important it is to the SG), respectively. These scores are similar to those in Equation 1, but the SG weightings allow for differing priorities for different SGs.

**RESULTS AND DISCUSSION**

**Metric scores**

Metrics feeding into a specific SG Value may not follow the same trends from smaller to larger remedies. For example, for the SG Value “ENV-4: Low Impact Remedy,” the metrics scores for “ENV-4d: Hazardous Landfill Use” and “ENV-4f: Volume of Sediment Treated” are at the same high value for all alternatives except A, the no-action alternative (Figure 2), because all remedies under consideration remove the same volume of highly contaminated (hazardous) material. On the other hand, air, energy, water, and nonhazardous landfill use all increase as the total volumes of sediment removed increase, and thus their metric scores increase (Figure 2). Similarly, for the “SOC-3: Acceptable Remedy” SG Value, “SOC-3a: Permanence” metric scores increase substantially and “SOC-3b: Effectiveness” scores increase somewhat for more extensive remedies, whereas “SOC-3c: Implement-ability” and the time-dependent metrics decrease for more extensive remedies (Figure 3). Unlike most metrics, which score 0 for Alternative A, the “SOC-3c: Implement-ability” score for A, based upon the USEPA (2016a) assessment, has a score of 10, resulting in a positive score for the no-action alternative.

For the SG Value “ENV-1: Fish & Wildlife,” removal or containment of contaminated sediments results in substantially reduced residual risks immediately after construction ($T = 0$) and in the longer term ($T = 45$), relative to no action (A), with some increase in benefit score for more extensive options (Figure 4). This benefit is, however, increasingly offset in the short- to midterm (due to undesirable impacts from remediation-induced contaminant mobilization for the larger alternatives.

Some metrics are insensitive to the remedial alternatives under consideration. For example, for the SG Value “SOC-2: Community Values,” the metrics “SOC-2a: Stakeholder Involvement” and “SOC-2c: Communication of Uncertainty” have the same value for each alternative because these are a function of the entire process, rather than of a particular alternative. Although it is possible to design a process that is more or less responsive to these priorities, communication approaches within the CERCLA process addressed all alternatives in the same manner. Details of metric scoring, and graphs for all metrics and values can be found in Supplemental Data Section 4.

**Stakeholder group value and pillar scores: Equal weighting**

As described in Step 6, the individual metric scores were aggregated using weighted averages to generate scores for SG Values and pillars. For some SG Values such as “ECON-1: Economic Vitality,” “ECON-1: Jobs,” and “ECON-3:...
Infrastructure, “all active alternatives have negative scores, with the more extensive alternatives having the lowest SG Value scores (Table 4, and the “all” columns of Figure 5). For example, for “ECON-4: Low Impact Remedy,” the SG Value scores are negative for all alternatives other than the baseline (see Table 4, and the “all” columns of Figure 5). These metrics, evaluated using SiteWise™ (see McNally et al. this issue, for more detailed discussion), reflect those parameters that are the focus of most GSR assessments; larger remedies cause more emissions and use more resources. In other cases, the alternatives result in a mix of positive and negative impacts to SG Values; in the case of “SOC-4: Health & Safety,” for example, Alternative B has a much higher “Health & Safety” score than does Alternative A due to the long-term

![Figure 2](image2.png)

**Figure 2.** Metric scores for the SG Value ENV-4: Low Impact Remedy. SG = stakeholder group. Note: Indicator scores for Alternative A are all 0, so are not visible on graph.

![Figure 3](image3.png)

**Figure 3.** Metric scores for the SG Value SOC-3 Acceptable Remedy. SG = stakeholder group. Note: Where metric scores are at or near 0, they are not visible on graph.
risk reduction as a result of remediation, but this benefit is gradually offset by medium-term human health and safety risks due to construction risks and contaminant mobilization for the more extensive alternatives. The trade-offs reflected in the “ROC-3: Acceptable Remedy” metrics (Figure 3), result in positive SG Value scores for most alternatives, decreasing to a small negative score for Alternative F (Table 4, and the “all” columns of Figure 5). The high “ROC-3c: Implementability” and time-dependent metric scores for Alternative A result in a high positive “ROC-3: Acceptable Remedy” value score for Alternative A; this is a result of scoring consistency for scoring across alternatives, but means that Alternative A has nonzero scores for this SG Value. “ROC-2: Community Values” has similar aggregated values for all alternatives because most metrics for this SG Value are insensitive to remedial approach, with a small positive score for Alternative A, due

Figure 4. Metric scores for the SG Value ENV-1: Fish & Wildlife. SG = stakeholder group. Note: Indicator scores for Alternative A are all 0, so are not visible on graph.

Figure 5. SG Value scores for Alternatives B, D, E, I, and F, all representative stakeholder groups (SGs). SG Values based upon SG-weighted metrics. All = equal weighting (as in Table 4), not SG priority weighted; BG = business groups; CC = community comments; CF = community forum; CS = community survey; TG = tribal groups.
to the “SOC-2a: Stakeholder Involvement” metric score. For “ENV-3: Resilience,” the most aggressive alternatives have the highest scores.

Active remediation has economic, environmental, and social impacts, when compared to the no-action baseline (Alternative A). The main drivers of cleanup, the protection of ecological and human health, show clear benefits from remediation when one compares, for example, Alternative A (no action) to Alternative B. However, when all metrics are weighted equally, this benefit is offset by undesirable risks to ecological and human health, as well as to other environmental, economic, and social SG Values, for the most extensive remedies; the overall magnitude of the undesirable impacts is much greater for the more extensive alternatives (Table 4, and the “all” columns of Figure 5; details in Supplemental Data).

Overall, these results indicate that the net benefits (positive scores; those above the axis in Figures 2–5) for each alternative are progressively offset by increasing undesirable impacts (negative SG Value scores; those below the axis in Figures 2–5) as one moves to the larger alternatives. Thus, the sum of the SG Value scores is increasingly negative for the more aggressive, extensive remedial options (Figure 6).

This is not to suggest that the highly aggregated indicator of net benefit score is the best, or only, indicator of relative sustainability; it is used here as one point of comparison. All approaches that seek to develop a similar scoring scale for very dissimilar parameters (i.e., any multicriteria decision tool) involve choice and compromise. Indicator development always requires a balance between complexity and clarity; decisions should be based upon a careful consideration of many parameters—trade-offs between individual parameters as well as aggregated indicators—to provide a broader picture of the consequences of alternatives.

**Value and pillar scores: SG weighted sensitivity analysis**

When metrics and SG Values are weighted differently depending on the priorities of a particular SG, there is still a clear ranking of net SG Value scores, with progressively lower net scores for the more aggressive alternatives (Figure 6). This pattern is consistent across all groups; however, there are some differences depending upon the representative SG considered. The first 4 SGs (from the left) in Figures 5 and 6—“all,” CF, CC, and CS—reflect different approaches to inferring priorities of the broader community, rather than specific SGs (see Supplemental Data Section 6). At the CF (USEPA 2015b), stakeholders expressed broad-based priorities and concerns, but with somewhat lower priorities for “externalities” such as those reflected in metrics for the SG Values “ENV-4: Low Impact Remedy” and “ECON-4: Cost Effectiveness.” For instance, no concern was expressed for air, water, and land use, nor for containing costs. The CCs reflect some similar priorities, but expressed more concern for the social SG Values and “ECON-4: Cost Effectiveness” and less over “ECON-3: Infrastructure” and “ECON-2: Jobs,” slightly changing some SG Value scores but not the relative net scores for the alternatives. Similarly, the CS, which focused on aspects of permanence, effectiveness, and cost-effectiveness, put greater weights on metrics of these SG Values (the weighting scheme places a constant, moderate weight on SG Values and metrics not directly mentioned), but the same relative net scores. Together, these 4 SGs can be seen as a partial evaluation of the uncertainty around inferred community priorities.
Business groups put more emphasis on issues such as implementability and cost, and less on the social values (other than “SOC-3: Acceptable Remedy”), but the net scores fell within the range of the broader community scores.

The last representative SG, TGs, on the other hand, resulted in markedly different SG Value scores than did the other SGs. Given the strong stated preferences by the TGs for permanence by extensive removal and their focus on multigenerational goals, their scores differ from the other groups, with highest “SOC-3: Acceptable Remedy” score for the most extensive option and much lower negative scores for many SG Values because the tribes have stated that short-term impacts associated with active remediation are not relevant. However, because there was some stated concern by the tribes for some remediation impacts, including jobs, downstream impacts on fish, and recreation and habitat, the net scores (Figure 6) still decrease, though to a lesser extent, for the most aggressive alternatives.

The effect of differing priorities can be evaluated by comparing specific SG Value scores for 2 representative SGs. The TG gives low priority to short-term impacts, resulting in a weight of 1 for “ECON-3: Infrastructure” with only a weight of 2 for two metrics and 0 for the others, while BG gives a weight of 5 to the SG Value and nonzero weights for most of the metrics (see Supplemental Data Sections 5 and 6). This results in an ECON-3 score of only –6.3 for Alternative F for TG (F:TG in Figure 5), and a much larger negative score of –35.8 for BG (F:BG in Figure 5). Similarly, the strong TG focus on permanence and effectiveness, but none on implementability or time-effectiveness means that the TG “SOC: Acceptable Remedy” score for Alternative B (16.1) is lower than that for Alternative F (21.2), whereas the opposite is true for BG (20.5 and 3.2, respectively), due to their weighting of the offsetting metrics reflecting implementability and time-effectiveness.

However, with the exception of TG, the sum of the SG Values with positive benefits (the bars above the zero line in Figure 5) shows a slight decrease for the more extensive alternatives. Most of the SG Values that have overall positive scores (“ENV-1: Fish & Wildlife,” “SOC-4: Health & Safety,” “SOC-3: Acceptable Remedy,” “ECON-4: Cost-Effectiveness,” and “SOC-2: Community Values”) are scored using metrics with both positive and negative values; the trade-offs between these metrics are reflected in their overall SG Value scores. For all SGs, there are increased negative scores for the more extensive alternatives. For each stakeholder-weighted group, the net negative impacts increasingly outweigh the benefits as the alternative becomes more aggressive.

For all SGs other than TG, the differences in net scores between Alternatives B and D and between Alternatives E and F are much greater than the variability between SG-specific scores for a given alternative, though the cross-SG net scores for Alternatives I and E, and to a lesser extent, D, overlap. On the other hand, although there is a clear decreasing trend in TG net scores for the more extensive alternatives, the net score for Alternative F, based on TG priorities, overlaps with those for Alternatives D and I based upon other SG priorities, illustrating the importance of short-term impacts in the overall scores.

**CONCLUSIONS**

Regardless of the weighting approach used, the overall SG Values-based sustainability score of the Site remedial alternatives can be ranked as Alternative B > Alternative D ≡ Alternative I ≡ Alternative E >> Alternative F.

Representative SGs with disparate priorities were identified on the basis of the value-mapping exercise. The SVA tool is sensitive to various stakeholder inputs—the SG Value and pillar scores change in response to different SG priorities, identifying trade-offs, opportunities for optimization, and sources of potential disagreement. For most of the representative SG priorities used in the sensitivity analysis, outputs were similar, with differences in priorities offsetting one another. For TGs, which discounted most short-term remediation impacts, net negative impact scores were, unsurprisingly, lower.

However, the relative rankings between alternatives were robust; when a broad range of positive and negative impacts of large-scale remediation is considered, regardless of the weighting approach used, the overall relative sustainability rankings of the remedial alternatives remained the same. The present work focused on inferred rather than elicited stakeholder priorities; results might differ if other stakeholders were directly engaged, but stakeholder priorities were evaluated using a range of approaches, providing similar results.

It is clear that many stakeholders who do engage in the CERCLA process have a primary focus on a single or narrow set of remedial impacts. In fact, the vast majority of comments received on the PP focused on a desire for more extensive sediment removal; this resulted in an ROD (USEPA 2017; developed after the present study) with more aggressive removal than those evaluated here. In theory, scenarios could be run using the SVA tool in which a single-issue SG could weight a single (or a few) SG Values heavily and set other weights to 0. This would, however, essentially collapse the sustainability assessment to a single- or narrow-issue assessment not unlike a stand-alone risk assessment or narrow cost assessment. One of the premises of the present work was that there are many SG Values and priorities which are affected by remedial activities that not all decision frameworks consider or stakeholders are aware of. The focus of the present work is to broaden the analysis beyond single issues in a systematic, transparent manner, using USEPA-generated data in the FS. To do this, the scoring of technical aspects of remedial design was carried out separately from the weighting based upon SG priorities. If done correctly, this should be able to separate a consideration of how stakeholders prioritize various values from their opinions about the planned remediation.

Model outcomes can also be affected by the selection of indicators and the scoring approach. Indicators and scoring approaches were selected on the basis of a review of the literature (NRC 1997, 2001; Driscoll et al. 2002; Cura et al. 2004; Linkov et al. 2006; Ellis and Hadley 2009; SuRF-UK...
This social sustainability assessment suggests that all of the remedial options evaluated (Alternatives B, D, E, I, and F) have environmental, economic, and social impacts, and that these impacts differ across the remedial alternatives. The results of the present study indicate that the relatively small incremental increase in permanence and risk reduction for the more extensive options is more than offset by the increased impacts to other SG Values. The net SG Values—based sustainability scores (i.e., the sum of the negative and positive scores) show a clear pattern, with progressively lower net scores for the larger and more expensive alternatives. Alternatives B and D had the highest net scores in terms of social costs and benefits when the diverse priorities of stakeholders vested in Portland Harbor are considered, with lower net scores for the more extensive alternatives.

The 3 pillars of sustainability can and should be evaluated within the existing CERCLA framework for remedy decisions; the consideration of threshold criteria ensures “strong” sustainability (Adams 2006) in which environmental considerations are not compromised in trade-off consideration. In the Superfund process, the need for “strong sustainability” is addressed by the fact that the CERCLA criteria “Overall protection of Human Health and the Environment” and “Compliance with ARARs” are threshold criteria—no remedial alternative that fails to meet these criteria can be selected (USEPA 1989). Other criteria, the balancing and modifying criteria, are then used to select among options that meet the threshold criteria. In the PP (USEPA 2016b), the USEPA determined that Alternatives B and D did not meet these threshold criteria (based on interim targets). The basis of the USEPA ROD was not clear given that the selected remedy (F mod) was a combination of Alternatives F and B (USEPA 2017).

The present study, using the risk assessment and remedial alternative technical specifications from the PP, suggests that the social costs of remediation are more extensive for Alternatives E and I and far outweigh the incremental increase in risk reduction. However, the PP and ROD did not evaluate long-term risk reductions for the alternatives due to uncertainty in transport models; they looked at only Time 0 results immediately post-remediation without consideration of natural system recovery and ongoing source control. Thus, there is significant uncertainty about relative contributions of recontamination from upstream, or natural recovery, over time, and thus in the long-term risk reductions achievable by the remedial options. It should also be noted that there can be considerable uncertainty in risk models, depending on the amount of available site-specific data and knowledge of local physical processes; this can result in substantial uncertainty in risk assessments (von Stackelberg et al. 2008). The age of the data used to establish baseline risks and the conservatism of the risk assumptions introduce uncertainty about the relative ability of remedial alternatives to meet threshold criteria (see Ruffle et al. this issue). Given these concerns, although there is a clear benefit from removing the most contaminated sediments, the selection of a very aggressive remedial option, even if in response to public pressure, risks sacrificing significant and fairly certain negative impacts in exchange for small and uncertain gains in risk reduction (Wenning et al. 2006).

For Portland Harbor, as with other contaminated sediment sites, risks, benefits, and costs are not borne equally in terms of time, space, stakeholders, or demographics. These issues should be kept in mind when the trade-offs described in the present report are considered, because it is important in environmental decision making to consider the needs, demographics, and vulnerabilities of a diverse population (SEA and AECOM 2016).

The Portland Harbor Sustainability Project sought to develop a framework that can be used as an aid to environmental decision making for complex sediment remedies, integrating the results from all 3 pillars—environmental quality, economic viability, and social equity—into a common framework that allows one to consider potential community values-based trade-offs among the remediation alternatives. Our quantitative assessment of remediation alternatives in the context of SG Values is extensive, new, and robust, and it advances the incorporation of sustainability considerations. We believe this approach provides a tool that can be used to optimize final remediation approaches for the Site, and for decision making at other sites, considering broad-based impacts on stakeholders. Although inferred SG priorities were used in the present case study, the model is designed to integrate stakeholder priorities elicited using other approaches such as surveys, interviews, and workshops; this approach should be applied in future applications.

The application of a sustainability framework to complex environmental decisions is consistent with recommendations from the NRC to USEPA (NRC 2011, 2014) and recent US executive directives, requiring that federal decision making should consider community needs and how they are affected (Donovan et al. 2015). The use of a framework that guides stakeholders to consider the extent to which they prioritize impacts to all (rather than just a narrow subset) of their values would also provide for a more balanced public comment process, less subject to single- or narrow-issue lobbying.

The application of sustainability makes sense for complex environmental issues, but ideally it should be considered earlier in the decision process and involve more stakeholder engagement, to develop a desirable set of options. For this approach to be most useful in optimizing sustainable options, a wide range of remedial options—with a broad range of potential risk reductions—should be evaluated, to identify the point at which additional adverse impacts overwhelm the additional gains. Identification of the risks and benefits of most interest to stakeholders also can support negotiation and optimization of alternatives under consideration, support collaborative design of more sustainable options, and help inform the design of a long-term monitoring plan that addresses community values.
The goal for large, complex projects should be to envision a sustainable approach from the beginning of a project with collaborative input from a large group of stakeholders. An informed, transparent, and balanced decision-making process will enable selection of a remedy that more stakeholders can support earlier in the process.

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Data Accessibility—Most data used are from USEPA documents, with exceptions and data source noted. Most calculation tools used are described in the other papers of this special series (or supplemental materials) to the extent that they can be replicated. Economic calculations are carried out (as described in companion paper) under license using a commercial model, REMI; this is not open access. Please email corresponding author Sabine Apitz at drsea@cvrl.org with any questions about data.

SUPPLEMENTAL DATA

Supplemental Data (1 file) provides detailed information on the data sources, assumptions, and calculation approaches (including stakeholder weighing approach) for the Stakeholder Values Assessment (SVA) tool. This extensive material is provided to encourage transparency, and potential adaptation to other sites.

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