TOPICAL REVIEW

How clean is clean: a review of the social science of environmental cleanups

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Abstract

Environmental cleanup may involve decontaminating an area affected by a radiological release, containing an oil spill, or remediating a Superfund site or brownfield. It is a key component of how environmental agencies work to protect public health and the environment. There are many publications on technical protocols for cleanup and waste disposal. Additionally, there has been much social science work on the social problems of environmental contamination. However, social science research on cleanup itself has been much more scattered across disciplines and incidents. To date, there has not been a comprehensive review of the social factors that affect cleanup processes and outcomes. Such social factors may include cultural worldviews that shape stakeholder perspectives on ‘how clean is clean’ and social relationships among stakeholders. This article fills this gap by providing an interdisciplinary literature review of the social science of environmental cleanup. Three principal themes emerged from the 97 articles that met selection criteria: effects on cleanup worker health, public engagement and decision-making, and societal benefits of cleaned-up sites. The review points to areas where further research is needed. For example, there is a lack of mixed methods and interdisciplinary engagement within the literature. Additionally, few articles compare cleanup situations. There is also a need for further investigation into specific social science topics such as labor practices, gender, race, and power relationships. To address these gaps, we argue for the development of a comprehensive framework or model as well as the exploration of broader questions complicating cleanups. Overall, this area of research has significant potential to benefit environmental cleanup policy and practice worldwide, while advancing social theory about people and the environment.

1. Introduction and background

Cleaning up toxic contaminants and hazardous waste is a cornerstone of environmental protection in the United States (US) and abroad. In the US, there are 1345 sites on the Superfund National Priority List (NPL) and an estimated 450 000 contaminated brownfields properties. Approximately 53 million people (17% of the US population) live within 3 miles of a Superfund site (EPA 2015), making cleanups vital to public health. Environmental cleanup is also part of emergency response to oil spills, industrial and transportation accidents, and homeland security threats. In this paper, ‘cleanup’ refers to any part of the assessment, characterization, containment, removal, remediation, and waste disposal of chemical, biological, and radiological materials. Some hazardous waste sites, such as Love Canal and Warren County, North Carolina, play important roles in the history of US environmental policy and environmental justice. Others, such as historic industrial buildings contaminated with mercury or residential yards with high levels of lead in the soil, may not be nationally renowned yet still pose a risk to human health and require an extensive and costly cleanup.

Table 1 shows the range of situations included as environmental cleanup for the purposes of this analysis. It follows US Environmental Protection Agency
(EPA) categorizations and US policy approaches to provide consistency. Other countries may use slightly different categorizations (e.g. megasites, polluted sites), policy approaches (e.g. soil protection policies), and funding sources. The overarching goal of environmental cleanup is to protect human health and the environment, but there are differences among statutory requirements for achieving this goal. Each situation involves specific terminologies, activities, and phases. The term remediation refers to long-term actions at Superfund and brownfield sites to remove contaminants from different environmental media. Techniques include capping hazardous waste sites, dredging sediments in water bodies, and bioremediating using microbes to treat contaminated soil or groundwater on site. The term decontamination, in contrast, is more commonly used in emergency response when a substance is released that poses an ‘imminent and substantial threat’ to public health or the environment (40 CFR 300 1994). Decontamination refers to the inactivation, immobilization, or reduction of contaminants from a surface. For example, rooms containing Bacillus anthracis (the bacterium that causes anthrax) can be fumigated with chemicals to inactivate the spores. Surfaces contaminated with radiological materials can undergo physical or chemical decontamination. Responses to smaller release incidents are called removal actions. After an oil spill from an overturned truck, for example, contaminated soils are removed to be treated and disposed of elsewhere.

The cleanup situations in table 1 differ in several respects: the cause of contamination, materials handled, statutory authority, institutions involved, steps followed, funding stream, and future reuse. This diversity of cleanup situations is one indication of the complex social and political dynamics involved. Environmental and public health agencies, tribes, industry, private contractors, and community groups all play roles. Actions and timelines vary, as do the threat to human health, public engagement, and cost. Different cleanup situations use different criteria for cleanup standards. Superfund sites are cleaned to national standards, for example, whereas brownfields rely on state standards.

Cleanups take place everywhere from tribal lands to private residences on time scales of days to decades. During cleanups, stakeholders with existing social and power relationships engage in new ways. Stakeholders may not all use the same technical terms or even speak the same language. They may have competing ideas about health risks at a site, when is it clean enough, what does ‘clean’ even mean, and what constitutes appropriate post-cleanup land use (Fowlkes and Miller 1982, Interstate Technology and Regulatory Council ITRC 2002, Franco and Bouri 2010), and cost-benefit analysis (Hamilton and Viscusi 1999). Many studies are specific to a particular site such as Chernobyl in the Ukraine (Petryna 1995, Smith 2005) or Hanford in the United States (Gray and Becker 1993, Gephart 2003). To date, however, there has not been a comprehensive review of the social, economic, institutional, political, and cultural factors that affect cleanup processes and outcomes. Such a review is necessary to begin to develop an overarching framework to explain the social dynamics of environmental cleanup.

To fill this knowledge gap, we conducted a systematic, interdisciplinary literature review of the social science of environmental cleanups. The purpose of the review was to understand the current state of this literature and to identify key social variables that affect cleanup activities and outcomes. The review covered publications from anthropology, archeology, economics, environmental justice, environmental management, epidemiology, human geography, policy, public health, psychology, science and technology studies (STS), and sociology. Three common areas of investigation emerged from the review: physical and mental health of cleanup workers, public engagement in decision-making, and evaluation of societal benefits of cleanups.

The review should be of interest to social scientists, environmental scientists, and technical experts involved in cleanup decisions. It provides a baseline synthesis of scientific knowledge about the social dynamics of environmental cleanups. It also identifies research gaps, including a lack of cross-disciplinary fertilization and uneven coverage and comparison of cleanup situations. Overall, the review supports the development of an interdisciplinary systems framework for analyzing environmental cleanups and evaluating societal benefits.

2. Methods

2.1. Overview

This article uses a systematic literature review method, which involves article search and selection protocol, a defined research question or hypothesis, and a quantitative summary of results (Grant and Booth 2009, Singh 2017). It differs from systematic review methods from the clinical health literature in two respects. It provides a numerical analysis of article metadata but does not do a statistical analysis of article results (e.g. effect size) (Singh 2017). Instead, it uses a qualitative thematic synthesis or critical review to analyze the literature (Hart 1998, Thomas and Harden 2008, Grant and Booth 2009). Qualitative analysis is appropriate because this is exploratory research to identify social variables, not test a specific hypothesis. Figure 1 shows a preferred reporting items for systematic review and meta-analysis (PRISMA) diagram of the systematic search and selection process used (Moher et al 2009).
Literature sources included peer-reviewed journal articles, books, book chapters, e-books, and gray literature such as government agency reports. We included articles for review if the following criteria applied: (1) they use theories and/or methods from a social science discipline; (2) they address one or more social dimensions of environmental cleanups; (3) they were published in the last 25 years (1992–2017); (4) they meet quality control criteria (see below); and (5) they are written in English.

The five selection criteria allowed for inclusion of a diversity of publication types covering multiple disciplines, institutions, and countries. We excluded articles that provide a descriptive account of social conflict during a cleanup but do not use social theory or methods to analyze it. For example, our search returned technical assessments and reports about specific sites, but many of them did not have clear connections to social theory or employ social science research methods (e.g. interviews, surveys), so they were excluded from the analysis. We also excluded articles that address the social impacts of contamination but not decontamination. We limited the search to publications within the last 25 years to capture work published on cleanup actions under US environmental laws (e.g. Comprehensive Environmental Response,
| Cleanup category         | Definition                                                                 | Examples                                                                 | Cleanup steps                  | Statutory authority | Funding                      |
|-------------------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------|-------------------------------|---------------------|------------------------------|
| Emergency response      | Response to oil spills, chemical, biological, radiological releases, and large-scale national emergencies. | • Natural disaster (medical waste, household hazardous waste, orphan containers, flood debris)  
  • Oil spill  
  • Train derailment  
  • Chemical spill | • Removal assessment  
  • Removal action | • CERCLA  
  • SARA  
  • Clean Water Act  
  • National Contingency Plan  
  • Oil Pollution Act  
  • Stafford Act  
  • Presidential Directives | • Stafford Act  
  • Oil Spill Liability Trust Fund |
| Superfund sites/NPL sites | Uncontrolled or abandoned sites or properties where hazardous waste or other contamination is located. A contaminated site is generally considered a ‘Superfund site’ if the federal government is or plans to be involved in cleanup efforts. Note: NPL sites are those on the NPL; Superfund sites can be proposed or deleted from the list. | • Lead  
  • Asbestos  
  • Dioxin  
  • Radiation  
  • Agriculture runoff  
  • Heavy metals  
  • Industrial spill  
  • Excludes coal mines | • Preliminary assessment/site investigation  
  • NPL site listing  
  • Remedial investigation/feasibility study  
  • Records of decision  
  • Remedial design/remedial action  
  • Construction completion  
  • Post-construction completion  
  • NPL deletion  
  • Site reuse/redevelopment | • CERCLA  
  • SARA  
  • EPA grants  
  • Technical Assistance Grants Program  
  • Superfund Job Training Initiative  
  • Superfund  
  • Cost recovery | |
| Cleanup category | Definition | Examples | Cleanup steps | Statutory authority | Funding |
|------------------|------------|----------|---------------|---------------------|---------|
| State sites      | Sites addressed by state, not EPA | All types of contaminants | - Depends on state | - State environmental laws | ・ Tax credits |
| Resource Conservation and Recovery Act (RCRA) corrective action | Treatment, storage and disposal facilities regulated under RCRA may have releases into the environment that require cleanup. | - Hazardous waste | - Flexible may include: | ・ RCRA | ・ State funding |
| | | - Solid waste | - Initial site assessment | ・ Hazardous and Solid Waste Amendments (HSWA) | ・ Responsible parties |
| | | - Injection wells | - Site characterization | | |
| | | - Landfills | - Interim actions | | |
| | | | - Evaluate remedial alternatives | | |
| | | | - Implement remedy | | |
| | | | - Track process | | |
| | | | - Long-term care | | |
| Underground storage tank sites (USTs) | Sites that contain contamination from petroleum products or Superfund hazardous substances released from underground storage tanks. | - Petroleum containers | - Site characterization/assessment | ・ RCRA | ・ Leaking Underground Storage Tank Trust Fund |
| | | - Underground pipelines | - Corrective action | ・ Solid Waste Disposal Act | |
| | | - Hazardous chemicals | - Site closure | ・ Energy Policy Act of 2005 | |
| | | - Not septic tank, fuel container <1100 gal. | | | |
| Federal facilities | Properties owned or operated by the US government that may contain environmental contamination from unexploded ordnance, radioactive waste, or other hazardous substances. | - Military munitions | - Depends on site | ・ RCRA | ・ Superfund |
| | | - Unexploded ordnance | - Some federal facilities may be Superfund sites and follow Superfund steps. | ・ HSWA | ・ Department of Defense (DOD) |
| | | - Hazardous chemicals | | ・ Safe Drinking Water Act | ・ Department of Energy (DOE) |
| | | - Federally owned wastewater treatment facilities | | ・ Clean Air Act | |
| | | | | ・ Clean Water Act | |
| | | | | ・ Oil Pollution Act | |
Compensation and Liability Act (CERCLA), Superfund Amendments and Reauthorization Act (SARA)), as well as homeland security incidents and technological disasters. We limited articles to English publications to avoid misinterpretations that could affect data quality. The articles had to be research articles, not book reviews, commentaries, or policy documents.

2.2. Quality control
We evaluated the articles according to a checklist of nine quality standards: focus, verity, integrity, rigor, soundness, applicability and utility, clarity and completeness, uncertainty and variability, and evaluation and review (EPA 2003, 2013). We evaluated gray literature sources according to these standards. If sources did not meet at least six of the nine quality standards, we did not include them. Because peer-reviewed sources such as books and journal articles are already evaluated by a similar system, we presumed that they met quality standards. We did assess the applicability of each source and the appropriate use of social science theory and methods for all articles, which served as another layer of quality assessment.

2.3. Literature search and analysis
We conducted keyword searches in the following databases: ScienceDirect, Springer, ProQuest, AnthroSource, Web of Science, our institutional library catalog, and Google Scholar. This search strategy covered a wide range of publications in social science, environmental science, homeland security, risk analysis, and other related areas. We also found sources via snowballing, i.e., using citations in articles already retrieved. Keywords used to search include place names, contaminants, social science concepts, and cleanup actions (see table 2). Searches included alternative spellings, e.g., cleanup, clean-up, clean up. Keyword strings varied depending on the database’s topical focus and search capability.

Since many of the searches turned up technical and engineering articles outside the scope of this review, a quick reading of the source’s title and abstract ascertained its possible relevance. We recorded the number of relevant hits in an Access® database. For sources that made it through this first round of selection, we entered bibliographic information into an Access® database and EndNote® library. We searched bibliographic databases until article saturation was achieved, that is, additional keyword searches failed to turn up new relevant articles.

The second step of the review was to acquire and read a full-text version of each source. We eliminated some articles at this step because of access limitations. We evaluated full-text articles for compliance with the five selection criteria described above. To reach agreement on source selection, we each ranked the articles on a one-to-three compliance scale: (1) did not meet the criteria; (2) met some but not all; (3) met all criteria. We totaled the rankings for each source and then discussed sources that ranked below a seven out of nine to reach consensus on whether they should be included. At this stage, we evaluated gray literature sources using the quality control standards described above.

The third and final stage of the review process involved a close textual reading of the selected articles and thematic evaluation of article contents. We recorded research notes in EndNote® for each article’s topic, research methods, cleanup situation, and main argument. We then created mind maps to identify major themes and conducted a thematic synthesis of article content (Hart 1998, Thomas and Harden 2008). We also conducted a quantitative analysis of article metadata using NVivo®. We coded metadata for each source by geographic location in which the research took place, phase of cleanup addressed, type of

| Table 2. A list of keywords and search strings used in the literature search. |
|---------------------------------|---------------------------------|
| Actor network theory decontamination | Hazardous waste cleanup |
| Anthrax/Amerithrax | How clean is clean |
| Anthrax/Amerithrax and decontamination | Libby, Montana |
| Bikini atoll/ Marshall Islands | Livestock carcass disposal |
| Biosafety | Love Canal |
| Biosecurity | Love Canal and remediation |
| BP/ Deepwater Horizon | Milwaukee (Cryptosporidium outbreak) |
| Brownfield | Minot, North Dakota |
| BSE | Mitigation |
| Chemical spill | Nuclear |
| Chemical spill and clean-up | Nuclear waste disposal |
| Chernobyl | Oil spill |
| Chernobyl and social impacts | Oil spill and clean-up |
| Clean-up | Oil spill and cleanup and social impacts |
| Cleanup and radiation | Oil train derailment/Lac-Mégantic |
| Clean-up and social effects | Pensacola, Florida—Mt. Dioxin Plague |
| Clean-up and toxic spill | Radiological |
| Clearance | Remediation |
| Community | Rocky flats |
| Construction | Social impacts and cleanup |
| Cost | Social impacts and decontamination |
| Decontamination | Social stigma |
| Disaster and clean-up | Superfund and clean-up |
| Ebola and social stigma | Superfund, CERCLA |
| Endicott, NY—IBM | TB sanatorium |
| Foreign animal disease threat | Three Mile Island |
| Fukushima and remediation | Three Mile Island and cleanup |
| Fukushima, Japan | Toxic spill |
| Gold King Mine | Vieques, Puerto Rico |
| Hanford | World trade center and clean-up |
| Hanford and cleanup | |
| Hansen’s disease/leper colony | |
contaminant, discipline, and methodology. We then tabulated these metadata categories.

There were limitations to this systematic literature review. The review addresses the social dimensions of cleanup, which is only a subset of the social impacts of contamination. The bibliographic databases searched might not contain all relevant publications. While the review did include non-US materials, the search and selection protocol used did not require international representation and may not have captured all international publications. For example, the databases used to find gray literature may not contain reports published in other countries. Alternatively, a source may have been in a database but not discoverable using the keywords selected. The term Superfund originates from US policy and may not be applicable elsewhere. An article framed around social theory might not use the technical language of decontamination. The review only included sources available via institutional library holdings and interlibrary loan agreements, which were limited. The English language criterion may have excluded relevant materials written in Russian, Japanese, and other languages. Because this research does not conduct a statistical analysis of article data, results are not skewed by not including every article published on a topic, as with quantitative reviews (Thomas and Harden 2008, Singh 2017). Our search did reach conceptual saturation, that is, it captured the range of concepts found in the literature (Thomas and Harden 2008).

3. Results and synthesis

3.1. The landscape of the literature
A total of 97 relevant articles was analyzed. Figure 2 shows the distribution of sources by publication year. The year 2007 has the greatest number of publications \((n = 11)\), while 1994, 1988, and 2000 have none. There is a slight increase in coverage since 2000, but no apparent trend in peaks and valleys. For example, only two of the articles from the early 2000s analyze cleanup after the 9/11 attack on the World Trade Center, even though that incident involved a huge cleanup effort from the US. Given the wealth of remediation, removal, and decontamination activity in the US and elsewhere, finding only 97 relevant sources suggests that environmental cleanup may not be a popular topic in the social sciences.

Of the 97 sources found, 75 refer to specific case studies. The most common case studies are Chernobyl \((n = 10)\), the Exxon Valdez oil spill \((n = 7)\), and the Deepwater Horizon oil spill \((n = 5)\). These case studies illustrate the predominance of social science analysis of emergency response to disasters. Figure 3 also highlights this trend. Most of the cleanup situations found in the literature are emergency response \((n = 48)\) or Superfund sites \((n = 35)\). Cleanups of brownfields and federal facilities are less well represented, as are smaller scale emergency response situations.

Figure 4 shows the distribution of cleanup situations that the articles analyze. The literature includes sites in United States, Belgium, Ukraine, China, England, Japan, South Korea, Liberia, Spain, Sweden, Finland, Canada, and Italy. There is none to limited coverage of cleanups in Africa, Latin America, Australia, and Asia.

The case studies analyze 18 Superfund sites in the US: Amchitka Island, Alaska; City of Bloomington, Indiana; RSR Corporation Site, Dallas, Texas; Emmell’s Septic Landfill, New Jersey; Endicott, New York; Fresno Municipal Sanitary Landfill, California; Central
Chemical in Hagerstown, Maryland; Gowanus Canal, New York; Hanford, Washington; Los Alamos National Laboratory, New Mexico; Love Canal, New York; Middlefield-Ellis-Whisman, California; Tar Creek, Oklahoma; Rentokil Inc., Virginia; Rocky Flats, Colorado; Shell Oil Co dumpsite on the Swinomish Reservation, Washington; Three Mile Island, Pennsylvania; and Waukegan Harbor, Illinois.

The literature covers different phases of cleanups: pre-cleanup, during cleanup, and post-cleanup. Fifteen sources address the pre-cleanup phase, ten sources address the cleanup itself, and 30 sources address post-cleanup. Forty-two sources address multiple phases. The articles do not all delineate phases in the same way, nor does their terminology correspond exactly to the steps listed in table 1, which impeded comparison of the case studies.

The articles come from seven academic disciplines: anthropology, economics, human geography, policy and management, public health and medicine, sociology, and STS. They use a wide range of research methods, e.g. interviews, surveys, focus groups, and economic modeling. The most common methods are secondary analysis of existing data \( (n = 24) \) and interviews \( (n = 21) \). Figure 5 shows the distribution of academic disciplines and method type. To analyze methodological differences, we used four main method categorizations: qualitative, quantitative, mixed methods, secondary analysis. By mixed methods, we mean any study that combines quantitative and qualitative methods (Merriam and Tisdell 2015). By secondary analysis, we mean any study that reviewed the data or findings of other studies. The academic areas with the most representation in the literature are policy and...
management (n = 28), public health and medicine (n = 25), and anthropology (n = 20). There is a near-even split between studies using qualitative (n = 33) and quantitative methods (n = 35). Far fewer studies use mixed methods (n = 6) such as integrating quantitative survey data with qualitative interviews or combining economic modeling with participant observation. As we will discuss later in this paper, the lack of mixed methods may be a result of limited cross-disciplinary engagement on this topic.

3.2. Worker health

One of the prominent themes in the literature is the analysis of short- and long-term impacts on the physical and mental health of cleanup workers. The articles document health problems among workers involved in the containment, removal, and remediation of toxic contaminants. They focus on notable case studies such as the 9/11 attacks on the World Trade Center, Deepwater Horizon oil spill, and Chernobyl and Fukushima nuclear disasters. The number of cleanup workers exposed to health risks is significant, particularly in large disasters. Over 800 000 ‘liquidators’ worked with radiologically contaminated materials at Chernobyl between 1986 and 1989 alone (Bay and Oughton 2005). Formal measures of the number of cleanup workers may not even include residents, business owners, and others who initiate work on their own (Allen 2007).

The most common and longest studied aspect of worker health is cancer, followed by mental health and other aspects of physical health. The articles document that cleanup workers suffer from high rates of cancer (Bebeshko and Bobyliva 2002, Bay and Oughton 2005), prevalence of post-traumatic stress disorder and depression (Allen and D’Elia 2015, Bromet 2014, Laidra et al 2015, Horn et al 2016, Maeda and Oe 2015, Viel et al 1997, Zvolensky et al 2015), substance abuse (Bromet 2014, Laidra et al 2015), and respiratory diseases (Herbstman et al 2005). Many of these studies are retrospective, reviewing health data collected years before the analysis; or longitudinal, analyzing worker cohorts many years after a disaster (Bebeshko and Bobyliva 2002, Chernobyl Forum 2005, Eglite et al 2009).

While the studies use primarily epidemiological methods, this body of work also illuminates the broader social context of cleanup work. We highlight three aspects of this social context here. First, the articles raise concerns about workplace safety, i.e. protective gear, training, and information (Suárez et al 2005, Allen 2007, Wheeler et al 2007). Second, they touch on issues of environmental justice and ethics. They note that vulnerable populations, including prison inmates and immigrants, are unequally burdened with cleanup tasks and consequently exposed to greater health risks (Koo et al 1995, D’Andrea and Reddy 2013, Laidra et al 2015). Finally, the literature highlights the problem of stigma against people involved in cleanup activities (Bay and Oughton 2005, Chernobyl Forum 2005, Schneider 2012, Magill et al 2013, Bromet 2014, Pellechia et al 2015). For example, Chernobyl liquidators were ostracized from their communities because people feared that radiation exposure was somehow contagious (Bay and Oughton 2005, Chernobyl Forum 2005, Bromet 2014).

3.3. Decision-making and public engagement

A second common theme found in the articles is decision-making and public engagement. These studies establish the necessity of public engagement by illuminating the social and political dimensions of technical cleanup decisions (e.g. Frickel 2012). Technical decisions made throughout cleanups include:

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**Figure 5. Methods used within the sources (n = 97) divided by discipline.**

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where to sample for contaminants,
how to analyze samples,
how to set and meet quality control standards for data collection and analysis,
what is the extent of contamination,
which removal and remediation techniques to use,
what cleanup levels to set,
whether cleanup has achieved the desired reduction in contamination and health risks,
where and how to dispose of the waste,
what ongoing monitoring is necessary, and
what types of post-cleanup land use are appropriate.

In addition, specific cleanup situations may require their own decisions. In the US, for example, CERCLA law requires determinations about whether to list a site on the NPL and when a site is clean enough to warrant deletion from the list.

The studies indicate that public views shape cleanup decisions as much as experts’ technical determinations do. Moreover, lay and technical perceptions of risk often differ. Jorgensen (2016) observes that decisions about radiological cleanup depend on how affected people understand and tolerate risk. In a review of Superfund cleanup activities at the US Department of Energy’s (DOE) Hanford Site, Gray and Becker (1993) argue that decisions have been driven more by public anxiety and politics than by scientific data. Affected communities may not accept agencies’ technical determinations about health risks, remediation techniques, and cleanup levels. Instead, they apply socially contextual determinations of their own.

The articles further suggest that agencies’ setting of technical standards itself has socio-political dimensions. Standards are set amid scientific debates tied to institutional power dynamics. Auer (2010), for example, describes negotiations between Finland and Sweden concerning tests to measure organochlorines in water. He argues that advances in testing technology in fact increased confusion in these negotiations, and warns that science and technology do not guarantee consensual decision-making.

The articles highlight trust as a critical social dimension of decision-making (Raimond 2001, Gephart 2003, Allen 2007, Cheong and Hazelwood 2015). Lack of trust in environmental officials undermined public trust in the information agencies provided following Hurricane Katrina, particularly when agencies appeared to undervalue local knowledge (Allen 2007). A long history of secrecy and concealment at former nuclear weapons production sites impedes public trust in cleanup activity at these sites (Raimond 2001, Gephart 2003). A lack of trust also exacerbated emergency responders’ problems communicating with residents of Grand Isle, Louisiana, an insular community, during the Deepwater Horizon oil spill (Cheong and Hazelwood 2015).

The articles examine how decisions about future reuse of a site shape risk determinations and cleanup actions. They argue that present and future risks from existing contamination, remediation actions, and residual contamination following remediation must be balanced and considered in decision-making (Gochfeld et al 2007). They point out that when goals and options are not well defined, cleanup is hampered by uncertainty (Gray and Becker 1993). Recognizing these limitations, Beling et al (2007) suggest that Superfund processes allow for contingency planning.

Finally, the articles underscore the importance of public engagement to decision-making, even for technical decisions (Raimond 2001, Pellecchia et al 2015). The need to build consensus, share power, and establish trust is a recurring theme (e.g., Raimond 2001, Allen 2007, Jorgensen 2016). Ferris (1993) argues that cleanup solutions are more enduring at sites with higher community participation. Dukes (2007) posits that contaminated sites are an opportunity to build cumulative knowledge by including the public in deliberative, adaptive decision-making. Authors also point to challenges encountered during public engagement. For example, communities are not homogenous and may have internal socioeconomic and power inequalities. Participatory outreach may not reach all affected stakeholders (Miller 2016). Additionally, contamination incidents can exacerbate community divisions (Raimond 2001).

3.4. Evaluating societal benefits of cleanup
A third theme in the social science literature is evaluation of the broader societal benefits of cleanup. The articles found by this review primarily evaluated economic benefits in the form of housing value. The majority use hedonic pricing models to analyze local property values. Hedonic pricing is a revealed preference method that associates an increase in housing value after cleanup with the amenity value of living in an uncontaminated place. The articles apply hedonic pricing to housing around Superfund sites in the US (Kiel 1995, McClusky and Rauser 2003, Chattopadhyay et al 2005, Messer et al 2006, Noonan et al 2007, Greenstone and Gallagher 2008, Gamper-Rabindran and Timmins 2011, 2013). A few studies apply it to other cleanup situations, e.g. along nuclear waste transport routes (Gawande and Jenkins-Smith 2001), and near hazardous waste sites not on the NPL (Ketkar 1992, Ihlanfeldt and Taylor 2004). This method also provides a way of measuring stigma associated with site discovery, listing, and other cleanup actions (Kiel 1995, McClusky and Rauser 2003, Messer et al 2006). Post-cleanup housing values can be compared to pre-cleanup values to
determine whether stigma is overcome (Gamper-Rabindran and Timmins 2011, 2013).

We note methodological differences among the articles in their selection of regression models and datasets, radial distance of properties from a site (e.g. one mile, three miles), spatial unit of analysis (e.g. census tract, census block), type of property (e.g. owner-occupied housing, commercial), and timeline (e.g. after construction complete, after deletion). The authors also came to differing conclusions about the societal benefits of cleanups. The majority agrees that property values do increase after cleanup (Ketak 1992, Ilhanefldt and Taylor 2004, Chattopadhyay et al 2005, Gamper-Rabindran and Timmins 2011, Gamper-Rabindran and Timmins 2013). However, the amount of the estimated increase varies greatly, as do authors’ interpretations of these numbers. Noonan et al (2007) posit that while direct impacts on housing are minimal, there may be positive indirect effects such as increased neighborhood investment. Kiel (1995) finds that housing prices do not recover enough to overcome initial stigma of site discovery and listing. Delaying cleanup worsens property value losses (Messer et al 2006). Greenstone and Gallagher (2008) argue that local property value increases are small relative to the high costs of Superfund cleanup. In contrast, Ilhanefldt and Taylor (2004) argue that even high cleanup costs can be offset by increases in property values and, in turn, property taxes.

A few of the articles also discuss how cleanups may spur neighborhood gentrification (Noonan et al 2007, Gamper-Rabindran and Timmins 2011, 2013). With gentrification, housing prices increase but residents are priced out of the housing market. Neighborhood demographics can shift along the lines of race, class, and ethnicity. Gentrification is an environmental justice concern and can be an unintended social outcome of environmental cleanup.

4. Discussion

4.1. Trends in the literature

This literature review provides extensive evidence that social variables affect cleanup processes and outcomes in several ways. Cleanup activities affect worker health. Technical decisions are shaped by social and political dimensions. Completed cleanups have local socioeconomic consequences.

The review uncovers several trends in the literature. First, there is limited geographic coverage in social science analysis of environmental cleanups. The dearth of articles about many parts of the world shown in figure 4 may be due in part to the limitations highlighted in the methods section 2.3. It may also reflect national differences in environmental policies, remediation activities, and terminology. A third possible explanation is the reliance that the social science literature has on case studies, particularly of highly visible incidents such as the Deepwater Horizon oil spill and Fukushima nuclear accident. These incidents mobilize extensive cleanup efforts, media attention, research interest, and funding. They involve complex social dynamics that can be studied over time. One repercussion of the reliance on high-profile incidents is that analysis of other types of contaminants and cleanup situations is limited. For example, site reports indicate that stakeholder engagement and public participation positively influence brownfields redevelopment in Europe (Payá Pérez and Peláez Sánchez 2017). Brownfields sites, however, comprised the smallest portion of articles (2%) found by this search. Moreover, there is limited comparison of case studies in the literature, which would be generative of social science theory of decontamination.

A second trend is that the articles operate largely in disciplinary silos. Anthropological studies of decontamination discourse are not in conversation with economic works on hedonic pricing. Epidemiological articles on cleanup worker health do not engage with the broader social science literature on labor practices, worker identity, and embodied stigma. Thus, the social context of cleanup work is missing: how do people come to be in this work, what are their work experiences, and how does it affect households and communities as well as individual health? The silo-ization of the literature is also apparent in that while the case studies uncover diverse social aspects of cleanups, they often lack a theoretical grounding. Observed trends in methodologies provide further evidence of silo-ization. The limited use of mixed methods, such as combining health surveys with ethnography, indicates a lack of interdisciplinary engagement. Another methodological gap is the relatively low number of ethnographic accounts of cleanup experiences. One exception is Little’s (2012) study of people living with vapor mitigation systems installed in their houses as part of remediation of the IBM Endicott Superfund site in New York state. Ethnographic studies of cleanup workers, community activists, and agency staff would shed light on social relationships, cultural worldviews, decision-making, and health.

4.2. Future research needs

The review identifies research gaps in the four thematic areas. Na et al (2012) and D’Andrea and Reddy (2013) mention differences between male and female cleanup workers’ risk exposure and health impacts. A deeper discussion of the gendered nature of cleanup work is absent. Zvolensky et al (2015) report how adverse mental health impacts to cleanup workers correlate with financial problems. It points to the need to investigate how cleanup work affects families and households as well as worker populations. The Chernobyl case studies primarily analyze possible health effects of low-dose radiation exposure over a long period of time (Barnes 2001, Bay and Oughton 2005,
There is a need for longitudinal studies of other types of cleanup work.

In terms of public engagement, the articles do not address how trust is lost and how mistrust affects cleanups (e.g., Eisenman et al. 2004, Allen 2007, Ritchie et al. 2013). However, there is limited coverage of research on how to build trust and maintain it over time. Future research could examine best practices in building consensus, sharing power, and establishing trust among stakeholders. It could field test strategies for effective public engagement in different cleanup situations.

The reliance found in this literature on hedonic pricing affords a relatively limited basis for measuring societal benefits of environmental cleanups. The studies primarily use this technique at Superfund sites, so its application to other cleanup situations and non-US sites remains untested. Hedonic pricing does not capture social consequences such as neighborhood gentrification. Cleanups may well benefit society in ways other than property values. New methods for evaluating societal benefits—and costs—should be developed and tested for their applicability to different cleanup situations. Methodological challenges remain for how to measure benefits that are not easily quantifiable, such as changes to risk perception and improved stakeholder relationships.

Greater comparison among sites within a given country and internationally is needed. It would help answer research questions about: how does stigma differ when radiological, chemical, or biological contaminants are involved? Are public engagement strategies transferable among Superfund, brownfields, and emergency response? Does post-cleanup gentrification play out differently in cities, suburbs, and rural areas? What are similarities and differences in public engagement strategies, worker health protection, and post-remediation property values when comparing sites internationally? Site comparison can help identify technical, policy, and public engagement approaches that foster achievement of positive social and environmental outcomes (Coulon et al. 2016, Payá Pérez and Peláez Sánchez 2017). It can also assess how multi-criteria decision support tools (e.g., human health risk assessment (Wcislo et al. 2016), integrated assessment modeling (Schädler et al. 2012)) support cleanup decision-making (see Normann et al. 2016 for an example).

The review found that there is no overarching model or framework to explain how social dynamics affect cleanup activities, the origins of these dynamics, and what the social impacts of cleanup activities and outcomes of cleanup completion are. We suggest that a comprehensive framework should be developed. One possible theoretical foundation is a socio-environmental systems (SES) approach that addresses interactions between social and biophysical systems (Machlis et al. 1997, Musters et al. 1998). SES has largely focused on ecosystems, land use, and urban ecology, and does not always directly address human health, though, so a framework might also benefit from incorporating elements from health risk assessment (Wcislo et al. 2016). Social science theory that situates people’s relationships with chemicals, toxics, and post-industrial sites in a broader culture and political economic context (Fortun 2012, Shapiro and Kirksey 2017) may be informative, but challenging to incorporate into a model. Participatory socio-environmental modeling techniques may allow site-specific details to emerge (Gray et al. 2018). This analysis identifies several important factors to address in a framework: multiple phases of cleanup actions; positive and negative social impacts (e.g. stigma); the social as well as toxicological context of worker health; governance approaches to public engagement, trust, and stigma; scientific decision-making; institutional roles and constraints; and measures of societal outcomes of cleanup.

4.3. Application to policy and practice

The case studies present strategies to help cleanups achieve positive social and environmental outcomes. For example, steps can be taken to support the health of workers and community members. In the US, removal and remediation is often done by contractors and sub-contractors. The US Government Accountability Office (2006) reports that DOE provided incentives for contractors to meet health and safety standards at the Rocky Flats Superfund site. Moreover, it encouraged contractors to share the incentives with workers. Providing additional worker benefits such as counseling, financial management, and transition aid can aid worker health and reduce local economic shock after cleanups are complete (US Government Accountability Office 2006, Zvolensky et al. 2015). Counseling services could be provided for affected communities through coordination with health organizations. Overall, this body of literature prompts us to reevaluate cost-benefit analysis of remediation by considering the toll it takes on workers (Leigh and Hoskin 1999, Lowe et al. 2015). It also underscores the importance of providing mental health services for cleanup workers and affected communities, in addition to physical health monitoring.

The articles detail techniques that have been used for effective public engagement. Halfacre (2009) suggests using focus groups to elicit concerns of underrepresented stakeholder groups as a complement to community-wide meetings. Burger et al. (2005) describe a process of consensus building that engages citizens and scientists in development of a science plan. The National Research Council (2005) outlines steps to help achieve socially acceptable cleanup standards. Zaferatos (2006) stresses the importance doing truly meaningful consultation when working with Tribal Nations. Unfortunately, it may be difficult for agencies to adopt these best practices and adapt them...
to different cleanup situations given limited authority, budgets, and staffing.

It may be more challenging to put into practice hedonic pricing methods to evaluate cleanup outcomes. They may be of limited applicability to emergency response and the other non-Superfund cleanup situations listed in Table 1. It takes expertise, time, and funding to obtain and analyze local housing data. These economic articles do suggest changes to policy and practice. The observation that delaying cleanup worsens property value losses provides a strong impetus for getting cleanups done in a timely manner (Ketkar 1992, Sigman 2001, Ihlafeldt and Taylor 2004, Messer et al 2006). The observation that stigma can increase as additional cleanup actions are announced (Messer et al 2006) is a reason to carefully craft communications and public engagement so as not to inadvertently increase stigma.

4.4. Complicating cleanups
Agency definitions, case study descriptions, and statutory language often characterize environmental cleanups as involving discrete sites or incidents, established cleanup goals, a prescribed set of steps and actions, and measurable transition from a contaminated site to a cleaned-up one. This literature review instead reveals a fuzziness to the boundaries of what a site is, timeline for when cleanup begins and ends, and the social meaning of contamination, decontamination, and clean. For example, many hazardous waste sites have more than one contaminant. Site assessment, remediation, and community engagement may need to address uncertainties about cumulative health risks from multiple contaminants.

The spatial unboundedness of sites is made apparent by the extent of cleanup activities, workers, and community impacts in large-scale disasters such as the Deepwater Horizon and Exxon Valdez oil spills (Shaw 1992, Russell et al 1993, Bond 2013). It is underscored by the complexities of managing cleanup goals and actions at Superfund sites that are dozens of square miles or more with varying levels of contaminants across the site (Gray and Becker 1993, Burger et al 2004). Even smaller sites may be physically cordoned off but still retain community ties and be of local cultural or historical significance (Bluestone 2007, Kirkwood 2007). The final disposal location for waste that is removed also complicates the idea of what a site is. Waste disposal sites may be enmeshed in environmental justice struggles of their own (Wright 2011).

Articles delineate cleanup phases differently than the official steps detailed in Table 1, bringing cleanup timelines into question (e.g. Ketkar 1992, Bittner 1993, Anspaugh 1996, Page 1997, Allen 2007). The predominance of multi-phase analysis in the literature suggests it is important to analyze cleanups holistically, rather than in discrete parts. It also suggests that remediation and incident response steps are experienced as loosely bounded temporal phenomena. Site discovery, listing, and assessment may be iterative processes rather than a single act (Zaferatos 2006). Moreover, there is a temporal collapse of pre- and post-cleanup during decision-making. Cleanup levels are set based on health risk assessments, as well as on expected post-cleanup land use (Gephart 2003, Masco 2004, Gochfeld et al 2007). How clean is clean thus differs for sites intended for residential, industrial, or conservation use. Being able to assess redevelopment options early on is important (Wcislo et al 2016).

Stakeholders who bring different needs, values, and goals to the table contest the meaning of how clean is clean (Hoffman 1995, Gephart 2003, Cheong 2012). Approaches that use only technical criteria to determine when a site is cleaned-up and do not take social contexts into account are not likely to resolve these conflicts (Elcock et al 2004, Auer 2010, Frickel 2012). At Love Canal, for example, only a single guideline about dioxin was used as a standard for reoccupation habitability despite the multitude of contaminants at the site (Hoffman 1995). The nuclear era itself has led to modifications of what is considered background levels of radiation against which the health effects of contamination are measured (Masco 2004).

Cleanup complexities require further research to advance social theory about contaminated and post-contaminated lands and bodies, i.e. theories of the Anthropocene, disasters, late-industrialism, chemo-ethnography, and infrastructure-society relations (Fortun 2012, Moore 2016, Anand 2017, Barrios 2017, Malhi 2017, Shapiro and Kirksey 2017). Understanding these complexities is of more than theoretical importance, since debates over how clean is clean can contribute to cleanup delays (Page 1997). Being able to understand and navigate these complexities can resolve social conflicts that arise, allow cleanups to proceed despite scientific uncertainty, and support informed decision-making that considers potential social and economic outcomes.

5. Conclusions
This literature review highlights the complex ways that social factors affect environmental cleanup processes and outcomes. It establishes what we term the ‘social science of decontamination’ as an area of study. There are an emerging number of articles, books, and gray literature from a variety of academic disciplines that address this topic.

Several important themes emerge from the review. Public health and epidemiological studies document the impact of environmental cleanups on worker physical and mental health. Many of these focus on the case study of Chernobyl. This research lays the foundation for discussions of worker rights and the connection between social vulnerabilities and environmental cleanup work. Another theme in the literature is the focus on
improving decision-making and risk analysis processes. Many of these studies assert the importance of public engagement and the need for more public involvement in cleanup decisions to improve outcomes and avoid conflicts. They also highlight how decisions about future reuse of sites shape risk determinations and cleanup actions, demonstrating the importance of using a systems approach and analyzing cleanups as a multi-phase process. The third major theme in the literature is evaluation of societal outcomes of cleanup, primarily through hedonic price models of property values near Superfund sites in the US.

Despite the variety of literature relating to the social science of decontamination, there is still a need for further studies due to specific gaps. The studies utilize a wide array of qualitative and quantitative research methods, but there is a lack of mixed methods and interdisciplinary engagement within the social sciences. Many articles rely on case studies of large-scale disasters or Superfund sites, leaving room for comparisons of how social dynamics differ among cleanup situations. In particular, more international comparisons would aid understanding of how these dynamics play out in places with different forms of governance and social histories. Development of a comprehensive framework or model is necessary to advance the social science of decontamination. Broader questions complicating cleanups need to be explored. Further investigation into specific topics such as labor practices, gender, race, and power relationships is also necessary. Overall, this area of research has significant potential to benefit environmental cleanup policy and practice, as well as advance social theory about people and the environment.

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