Benefits of a Biological Monitoring Program for Assessing Remediation Performance and Long-Term Stewardship – 12272

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ABSTRACT

The Biological Monitoring and Abatement Program (BMAP) is a long-running program that was designed to evaluate biological conditions and trends in waters downstream of Department of Energy (DOE) facilities in Oak Ridge, Tennessee. BMAP monitoring has focused on aquatic pathways from sources to biota, which is consistent with the sites' clean water regulatory focus and the overall cleanup strategy which divided remediation areas into watershed administrative units. Specific programmatic goals include evaluating operational and legacy impacts to nearby streams and the effectiveness of implemented remediation strategies at the sites. The program is characterized by consistent, long-term sampling and analysis methods in a multidisciplinary and quantitative framework. Quantitative sampling has shown conclusively that at most Oak Ridge stream sites, fish and aquatic macroinvertebrate communities have improved considerably since the 1980s. Monitoring of mercury and PCBs in fish has shown that remedial and abatement actions have also improved stream conditions, although in some cases biological monitoring suggests further actions are needed. Follow-up investigations have been implemented by BMAP to identify sources or causes, consistent with an adaptive management approach. Biological monitoring results to date have not only been used to assess regulatory compliance, but have provided additional benefits in helping address other components of the DOE's mission, including facility operations, natural resource, and scientific goals. As a result the program has become a key measure of long-term trends in environmental conditions and of high value to the Oak Ridge environmental management community, regulators, and the public. Some of the BMAP lessons learned may be of value in the design, implementation, and application of other long-term monitoring and stewardship programs, and assist environmental managers in the assessment and prediction of the effectiveness of remedial actions and pollution abatement.

INTRODUCTION

Few sites in the U.S. have the complexity of environmental stressors and regulatory considerations as those at DOE facilities [1], [2]. Cleaning up the nation's nuclear weapons complex remains one of the most technologically challenging and financially costly problems facing the DOE. Beyond the challenges associated with implementing remedial actions and decontamination and decommissioning (D&D) activities at DOE sites, the required long-term monitoring and stewardship activities have their own significant challenges and costs. For many contaminated sites, it is recognized that in-place remediation options with long-term monitoring and risk management may be the preferred environmental management alternative. The need to monitor the environment over long time scales is reinforced by estimates that more than 100 DOE sites will have remaining residual contamination at the completion of remediation programs and contaminant transport and fate concerns will exist for decades [3]. Recognizing the challenges to long-term monitoring, the DOE has invested substantial technical and scientific resources into evaluating potentially more effective and less costly long-term monitoring and stewardship strategies. The DOE convened a Long-Term Monitoring Workshop in February 2009 in Atlanta, Georgia, with the goal of defining potential long-term monitoring strategies, tools, and data systems that might be useful for environmental management and long-term stewardship evaluations at DOE sites. More recently in November 2011, a DOE-sponsored technical expert workshop was held at the Interstate Technology and Regulatory Council (ITRC) meeting in Denver, Colorado. A goal of the workshop was to obtain input from ITRC participants on a draft DOE internal guidance document titled "Scientific Opportunities for Monitoring of Environmental Remediation Sites (SOMERS)", which attempts to go beyond tool development and focus on systems-based approaches to monitoring [3]. This effort was prompted by recognition that there is a critical need to move away from the cost and labor intensive point-source monitoring to more leading edge, systems-based monitoring strategies. Of course, defining good long-term monitoring approaches is a need that goes beyond just the DOE sites. With many aquatic systems in stress or in peril and increasing concerns regarding the effects of sublethal, chronic stressors (e.g., nonpoint source impacts, climate change effects), the need for long-term, scientifically sound monitoring programs has been highlighted by many recent researchers [4], [5].

Given international, national, and DOE site-wide need for more effective long-term monitoring strategies, the BMAP experience, which has been implemented on an annual basis in Oak Ridge, Tennessee for 25+ years, may offer a useful case study. Many of the environmental management implications of the BMAP's implementation in one large stream in Oak Ridge, East Fork Poplar Creek, were highlighted in a recent "special issue" volume of *Environmental Management* [6]. The program is further evaluated herein by taking a more comprehensive view of the biological monitoring results and trends across the entire Oak Ridge site, with a particular focus on how the program has been of benefit in assessing remedial and pollution abatement performance, as well as addressing other DOE goals and missions.

MONITORING APPROACH

The BMAP was started in the mid-1980s in Oak Ridge when the extent of pollution problems associated with DOE facilities was first coming to light [7]. As a consequence of public and regulatory scrutiny and the need to provide scientifically defensible data, the program was designed from the beginning to be highly quantitative and multidisciplinary, with a primary goal of evaluating long-term ecological change. This scientifically-sound, temporal focus is in contrast to most aquatic monitoring programs that are less rigorous scientifically (e.g., little or no replication), relatively narrow in focus (e.g., one or two metrics or biological assemblages), or designed with a screening focus that emphasizes infrequent qualitative sampling at widespread locations. The BMAP approach emphasizes use of spatially integrated sampling points that couple groundwater, surface water, and biological measures where possible (Figure 1). Annual to twice annual sampling provides a consistent and defensible measure of ecological change over time without oversampling. The program is implemented within an adaptive management framework such that current results continually provide feedback to the sampling design and future monitoring approach.

The present day BMAP is primarily an Oak Ridge based monitoring program that encompasses a number of separately funded projects that may differ slightly in name and methods, but largely still use a biological monitoring strategy first developed in the mid-1980s. For the DOE facilities in Oak Ridge, the biological monitoring program is a requirement of the State of Tennessee's National Pollutant Discharge Elimination System (NPDES) permits to the facilities (to comply with the Clean Water Act), and similar biological monitoring requirements are imposed within Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) managed areas that need to comply with Applicable or Relevant and Appropriate Requirements (ARARs). Currently, Ambient Water Quality Criteria (AWQC) in Tennessee are designed to protect

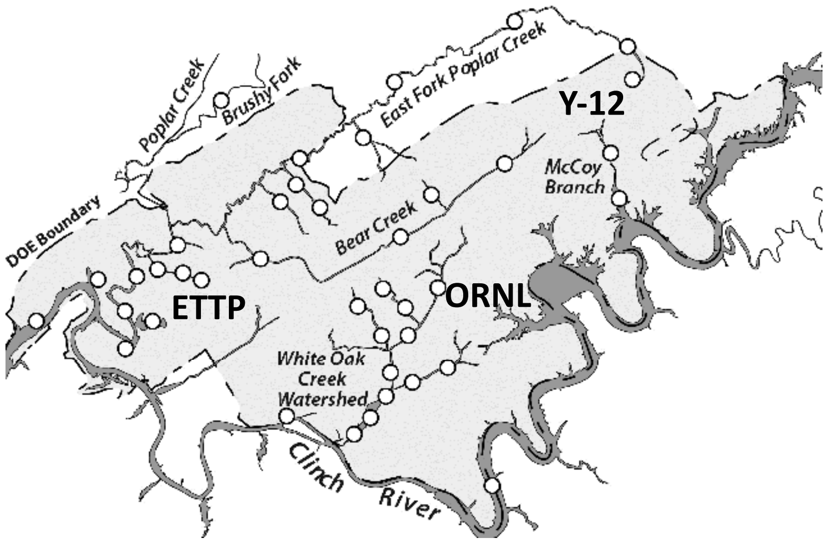

Fig 1. Biological monitoring locations on major streams and rivers near DOE facilities in Oak Ridge, Tennessee.

classified stream uses including protection of fish and aquatic life and recreational use (e.g., ensuring fish are safe to eat).

The DOE facilities monitored by BMAP have generally been large, extensively developed industrial complexes with a wide range of operations. There are three major DOE facilities in Oak Ridge: 1) the Y-12 Complex, at the headwaters of East Fork Poplar Creek, Bear Creek, and McCoy Branch, 2) Oak Ridge National Laboratory (ORNL), encompassing much of the White Oak Creek watershed, and 3) the East Tennessee Technology Park (ETTP), adjacent to Poplar Creek (Figure 1). At all three facilities, historical operations resulted in substantial contamination of surrounding soils, sediments, groundwater, and surface waters [7]. Until the 1990s, potable water release to some streams resulted in high chlorine concentrations. The most common contaminants associated with these facilities have been select heavy metals (especially mercury), PCBs and other organics, and low-level radionuclides. In addition to contaminant related stressors, the facilities and infrastructure have substantially changed the surrounding landscape, contributing to poor riparian habitat and at times large runoff volumes into streams. Four primary categories of stressors from the Oak Ridge facilities have been identified as the major influences on stream water quality: toxic substances, nutrient regime alteration, episodic events, and habitat impairment [6].

The remedial and pollution abatement actions that have been implemented in Oak Ridge over the last 25 years have been multiple and extensive. Early actions focused on collection and elimination of direct discharges of wastewaters to the streams, by changing or eliminating some operations or rerouting discharges to new wastewater treatment facilities. Pollution prevention programs and activities were implemented that minimized inadvertent release of pollutants. Cooling water discharges to streams were dechlorinated in the early 1990s, and mercury contaminated pipes were cleaned or relined. Waste areas were progressively capped and pump and treat facilities constructed to prevent movement of contaminated groundwater. In recent years, all three DOE facilities in Oak Ridge have undergone extensive D&D activities and building removals have substantially changed the facilities' landscape. Site specific CERCLA remedial actions are too many to list here, but include such major and diverse actions as removing large amounts of mercury contaminated soil in the lower East Fork Poplar Creek floodplain, capping and groundwater radionuclide stabilization within the Melton Valley waste areas, construction and use of multiple mercury treatment facilities (three at the Y-12 Complex and one at Oak Ridge National Laboratory), and the use of an ecological management strategy to reduce PCB uptake in fish.

The spatial and temporal monitoring strategy for BMAP was well in place prior to many of the abatement and remedial actions implemented in Oak Ridge. This has been advantageous, in that the program's watershed or systems-based approach was well suited to evaluating multiple actions, including spatially within the same watershed and temporally as new remedial actions went online. In contrast, a monitoring approach that focused on site specific and shorter term strategies is less integrated across watersheds, more difficult to interpret over time, and includes programmatic redundancies that increase cost. Key components of the BMAP that have continued on an annual to twice annual basis for 25+ years include monitoring of invertebrate and fish toxicity, fish contaminant accumulation, and in-stream community monitoring (including, benthic macroinvertebrates and fish). Historical site specific measures include bioindicators of fish health (including fish reproduction), and evaluation of periphyton communities. Important parallel components of the BMAP monitoring include water chemistry sampling, data management, and the use of short-term investigative studies. More detailed descriptions of the program's tasks and methods are provided in a series of recent *Environmental Management* papers [8], [9], [10], [11], [12], [13], [14]. For each specific monitoring component, there may be multiple metrics evaluated. For example, fish community monitoring includes such metrics as species richness, density, biomass, sensitive species richness and density, and calculation of the index of biological integrity (IBI) [12].

RESULTS AND DISCUSSION

The efficacy of the biological monitoring program in Oak Ridge is demonstrated first and foremost by its focus on meeting regulatory requirements and goals. The core BMAP components that address water quality or stream health requirements include toxicity testing (using the test organism *Ceriodaphnia dubia*), benthic macroinvertebrate communities, and fish communities. The in-stream community measures emphasize measurements of the number of taxa at a site as well as the number of sensitive taxa. The goal of toxicity testing is to have no measured toxicity, and the goal of community measures is to attain a number of taxa similar to uncontaminated reference streams. To provide an overall summary of changing stream health conditions over time across the DOE Oak Ridge complex, a weight of evidence approach was used to categorize 16 monitored BMAP sites (locations varied by task) as to whether they were not improving, improving, or recovered since the early years of the program (mid to late 1980s; Figure 2). A similar approach was used to summarize the mercury and PCB bioaccumulation trends in Oak Ridge (Figure 3). The bioaccumulation goals are for fish fillets to reach levels that are no longer a human health concern if eaten.

The stream health trends vary by task. For toxicity testing, dramatic improvement was observed after discharge treatment and dechlorination [8]. For sites monitored in recent years, including outfalls and stream sites, approximately 90% of sites were no longer toxic. As measured by benthic macroinvertebrate and fish communities, stream conditions at the majority

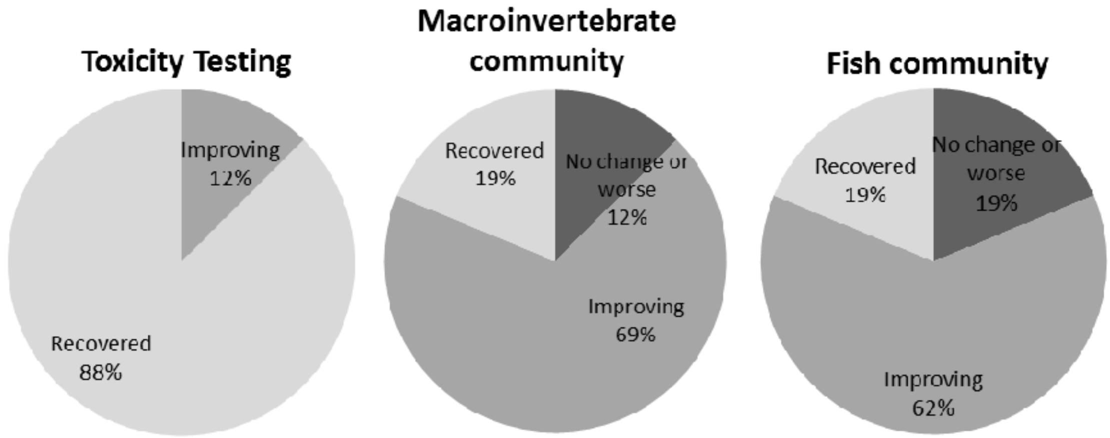

Fig 2. Based on a weight of evidence approach to evaluating the temporal trends (1985-2011) for each monitoring task (toxicity testing, macroinvertebrate community, and fish community), the percentage of total biological monitoring sites (n=16) with conditions that are: 1) not changed or worse, 2) impacted, but improving, or 3) at or near the reference condition (recovered).

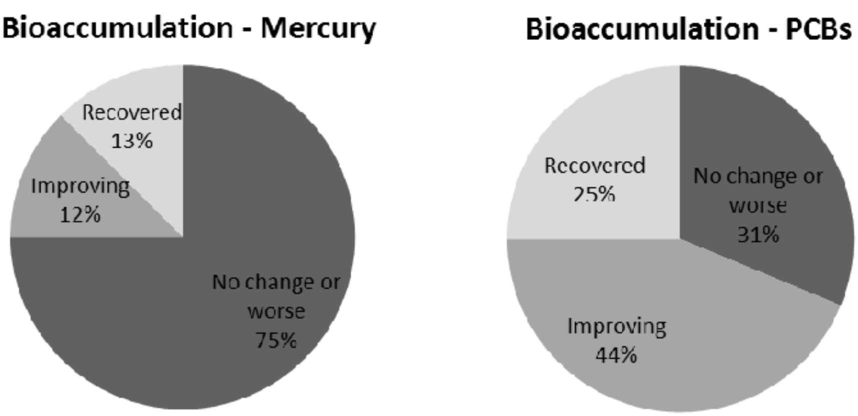

Fig 3. Based on a weight of evidence approach to evaluating the temporal trends (1985-2011) of mercury and PCB bioaccumulation in fish, the percentage of total biological monitoring sites (n=16) with conditions that are: 1) not changed or worse, 2) impacted, but improving, or 3) at or near the reference condition (recovered).

of monitored sites (60-70%) have improved, but only 20% could be considered at or near reference site conditions. At a very few number of sites (10-20%) stream health has not changed. Overall, the biological communities have improved substantially (primarily in increased species richness and number of sensitive taxa) as various abatement and remedial actions were implemented in Oak Ridge over the years.

The trends in bioaccumulative contaminants are also varied (Figure 3). For mercury, fish fillet concentrations at most sites (75%) have not changed or increased since the early years of the program. The rest of the sites are improving or have recovered. In contrast, PCB concentrations in fish at many sites have decreased substantially over the years as PCB use has been discontinued or controlled (44% of sampled sites), with some concentrations now below target levels (25% of sites). Only 31% of the monitored sites have not shown improvement (Figure 3).

The BMAP case study has provided clear evidence of improving conditions and useful and actionable information regarding the priorities for remedial actions. Improved conditions can be conclusively demonstrated to stakeholders because good biological monitoring programs have a number of key characteristics: they are watershed based, spatially and temporally explicit, consistent and repeatable, quantitative, and multidisciplinary (Table I). Historically, monitoring was more like characterization: project specific and not effectively integrated across space and time. The BMAP is a good example of an integrative, long-term approach using varied monitoring tools at key watershed integration points. Some of the many characteristics and advantages, as well as disadvantages, to using biological monitoring techniques are provided in Table I. Consideration of the advantages and disadvantages to biological monitoring techniques should be considered early in monitoring program design.

The BMAP has been used to address the DOE's regulatory, operational, resource management, and scientific goals in Oak Ridge (Table II). Many of the program's attributes support multiple and overlapping goals and missions. All goals are supported by a better understanding of the affected ecological environment and the likely changes as a result of remedial or facility abatement actions. The knowledge needs associated with environmental decision-making in complex contaminated environments is the underpinning justification for biological monitoring in the multi-purpose DOE facility environment.

A broad benefit of a comprehensive long-term monitoring program is "an increase in the efficiency of environmental management" [15], in part by avoiding reactionary, uncoordinated, or piecemeal environmental evaluations that are less cost effective. Quantifying the benefits of long-term monitoring programs can be difficult, but one measure is how a monitoring program realizes unexpected benefits or provides additional values to supporting organizations. For example, long-term monitoring studies have contributed to diverse needs, including the significance of chemical, biological, and physical disturbance, the role of pathogens and introduced species, the knowledge of natural temporal variation and its magnitude, and the efficacy of protection and remediation [16].

Examples of multiple and varied benefits of the BMAP program, beyond environmental compliance at DOE sites, include satisfying other regulatory objectives like environmental restoration and risk assessment (Table II). BMAP data have been an important component of defining long-term stewardship strategies, protection of rare species, and environmental protection and surveillance. Results have also been used for environmental damage assessment [e.g., Lower Watts Bar Natural Resources Damage Assessment (NRDA)] and environmental impacts of proposed actions (via NEPA Environmental Impact Statements). The

Table I. Characteristics and Advantages of Biological Measurements (adapted from [6], [17], [18]).

Characteristic	Biological measurements
Specificity	Can be very specific to the contaminant or stressor of concern, for example when measuring contaminant uptake in fish. Stream biological community metrics are less specific, and represent cumulative biological/ecological responses to environmental conditions over time and space.
Impairment sensitivity	Impairment most often measured against reference streams; biological regulatory criteria, typically indices like the index of biological integrity, increasingly more common.
Temporal scale	Biological monitoring data reflect longer temporal scales and can be advantageous; data are cumulative and integrative over time; organisms are continuously exposed to all substances in water or sediments and integrate the effects of this exposure.
Early warning	Some ecological assessment tools, like bioindicators, can provide ecologically relevant early warning indicators of biological stress. Community metrics and responses less specific and rarely suitable as early warning indicators.
Spatial scale	Data are well-suited for far-field effects, reflecting watershed-scale ecosystem responses. In contrast, water sampling of downstream larger water bodies may not be representative, depending on sampling regime.
Exposure/bioavailability	Fish physiological and bioaccumulation techniques can elucidate contaminant exposure, for example when liver metal concentrations are elevated. Exposure is sometimes not evident even if sediment contaminants are present.
Risk assessment	Biological data is often a key part of human and ecological risk assessments. Direct measurements of biological conditions or bioaccumulation are preferred over modeled extrapolation from chemical data.
Detection limits	In most cases meaningful analytical results can be obtained from biota tissue. Adequate tissue size can be a problem when analyzing invertebrates or small organs or tissues. For some contaminants like PCBs, biota analyses are preferred as the contaminant of concern may not be easily or routinely detectable in water.
Influence of flow and other environmental factors	Biological monitoring data are affected by flow and other natural environmental factors over time. Thus, it is important that impacted sites be compared to local reference streams so that natural variability is accounted for.
Sampling frequency	The BMAP has found that annual to twice yearly sampling is desirable for long-term assessment, depending on the stressor and operational changes at the facility.
Cost	Biological monitoring can be relatively laborious and expensive per sampling event, but requires less sampling events than water sampling to provide meaningful information.
Consistency	Sampling methods should stay consistent for spatial and temporal trending, but methods across the US often vary by organization.
Causal interpretation	BMAP has found that tools like toxicity testing, bioindicators, and periphyton measures have been useful in determining the causes of stress or bioaccumulation. Community measures like fish and benthic macroinvertebrates are integrated responses and not as useful in evaluating cause.
Sample turnaround time	Rapid bioassessment techniques can provide immediate results, but are less useful for evaluating change over time. More quantitative techniques (e.g., identification and enumeration of species) can provide a better assessment of temporal trends, but obtaining the results can be months-long.
Public understanding	Biological monitoring results are generally understandable to the public, for example when the number of fish species is reduced. However, more detailed analyses are less understood.
Endpoint or stopping point	Biological monitoring can provide an end-point, as when the biological community is equivalent to reference sites, or when a criterion or index score is achieved.

Table II. Examples of Biological Monitoring Program Activities that Address Multiple DOE Goals in Oak Ridge, Tennessee.

Broad DOE Goals	DOE requirements and objectives	Biological monitoring program examples
Regulatory	Environmental compliance	Biological monitoring required by CWA/NPDES, TN AWQC, and CERCLA ARARs
	Environmental restoration	Biological temporal assessments of effectiveness of abatement and remedial actions; CWA/CERCLA/RCRA
	Environmental protection	Collection, analysis, and reporting of environmental samples conforming to applicable DOE Orders such as 231.1A and 430.1
	Environmental damage	Biomonitoring data provide basis for valuations of environmental damage, e.g. Lower Watts Bar Natural Resource Damage Assessment
	Risk assessment	Fish contaminant data in particular extensively used for human and ecological risk assessments; CERCLA
	Protection of rare species	Management plan developed for federally threatened spotfin chub (protected under Endangered Species Act and TN Code)
	Long-term stewardship	Biological monitoring assures continued evaluation of residual contamination sites not remediated; e.g., offsite fish contaminant trends (CERCLA)
	Regulatory data access	Per Federal Facilities Agreement (FFA) between DOE, EPA, and the State, biological monitoring data is entered into a centralized database
Facility operations	Pollution prevention	Stream ecological improvements highlighted to facility pollution prevention and operations staff; education leads to “ownership”
	Spill assessment and response	Assessment of stream biological status used to establish spill boundary condition and improvement after spill
	Source identification	Spatial evaluations of bioaccumulation have identified relative role of discharges and sediment sources targeted for abatement
	Public relations	“State of the Creek Address” is provided to the public and highlights facility commitment to environmental improvement
	Eval of remedial alternatives	Abatement and remedial options are considered relative to the likely benefit to ecological resources and the potential unintended consequences of actions
	Development planning	Biological baseline information used to assess environmental impacts from proposed actions, e.g., Y-12 Complex draft EIS for NEPA
Resource manage-ment	Conservation	Oak Ridge Reservation a valuable example of ecoregion and National Environmental Research Park (NERP) conservation and educational goals
	Rare species	Biomonitoring identified and characterized status of rare fish species
	Land use planning	Biodiversity economic evaluations for development decision-making
	Restoration	Example: re-introduction of fish species upstream of barriers to fish movement
	Invasive species control	Control of nonnative problem species (e.g., grass carp) and promotion of native species through aquatic and riparian habitat enhancement, erosion control, etc.
	Watershed management	Working with towns and cities, TVA, and other stakeholders to jointly improve water quality in the watershed
	Natural resource partnerships	Stream ecology an important consideration in multi-organizational watershed water supply (e.g., flow management) and water quality issues
	Species specimen collections	Species, population, and community data entered into NERP databases
Science	Stream impairment and recovery	Research on the spatial and temporal ecological trends of contaminant exposure, fate and transport, and effects
	Natural stream dynamics	Trends in natural streams of value in long-term assessment of climate change; target conditions for ecoregion useful to regulators
	Development of new tools	Monitoring tool examples include clam bioassays and caged bioaccumulation studies
	Decision-making strategies	Biometrics a key component of habitat valuation strategies for effective cost-benefit decision-making
	Remediation technologies	Bioaccumulation responses key to defining effective new strategies or technologies
	Energy alternatives	Examples: biological assessments of oil spills and fly-ash release
	Historical data repository	Archival collections of fish and benthic macroinvertebrates, and biological tissue are available and may be of future scientific value
	Education	Hundreds of university and high school students have participated in biological monitoring research as part of national laboratory education programs

issue of cost effectiveness of biological monitoring programs is in part mitigated by the large number of regulatory requirements that are addressed by biological monitoring data.

The three main facilities in Oak Ridge are each large industrial complexes with a variety of missions and operations. The biological monitoring program has provided benefits to facility operations, including: pollution prevention (education of facility staff regarding the stream's ecology), spill assessment and response (biological status used to establish stream boundary conditions and improvement after a spill), and source identification (e.g., caged clams have been used to evaluate the relative importance of outfall sources of PCBs) (Table II). Biological monitoring program benefits to the facilities also include: improved public relations via public meetings and information releases, evaluation of remedial action alternatives, and improved site development decisions (Table II). At the ETTP site, biological monitoring highlighted the value of a pond ecosystem where ultimately a nondestructive remediation option was chosen [19]. Other researchers have highlighted that adequate monitoring can reduce the likelihood that ecological resources will be harmed during remediation [20], [21].

The DOE has significant natural resource protection responsibilities. The three DOE facilities in Oak Ridge are within the Oak Ridge Reservation (ORR), with substantial parts of the reservation comprised of the relatively undisturbed Oak Ridge National Environmental Research Park (NERP). Many DOE sites across the US have large buffer lands that are relatively undisturbed ecosystems, in part because of security needs [21]. These areas in some cases provide good representative reference sites for comparison to the more industrially impacted streams. Future land uses on DOE reservations include continued industrial development or ownership by industry, recreational, residential, and conservation or wildlife refuges [22]. The long-term biological monitoring of streams for CWA and CERCLA compliance has provided a better understanding of the NERP's natural resources. Biological monitoring program contributions to natural resource management include: conservation, watershed management, and ecological restoration (Table II). The BMAP data has been used for various inter-organizational collaborations and partnerships, natural resource historical survey data, and most importantly, land use planning. Biological monitoring information has been used for biodiversity and habitat valuations designed to assist with future land use decision-making at remediation sites [2], [23], [24].

Lastly, long-term biological monitoring programs can provide important scientific contributions. This is an especially important component of the BMAP, which is led by national laboratory scientific staff with an organizational mission focused on science. The multidisciplinary science focus of the program, coupled with the close proximity of the national laboratory to field research sites, has helped address two key attributes of effective biological monitoring programs: that they involve experienced scientists [25], and there is low turnover of personnel [26]. The BMAP has made scientific contributions to the understanding of the environmental consequences of energy alternatives, development of new monitoring tools and sampling strategies, and understanding of the recovery process (Table II). BMAP researchers have developed new remediation technologies to address contaminant exceedances in biota [19], [27], and supported science education through ORNL student internships.

The benefits of long-term biological monitoring programs are rarely assessed because benefits are difficult to define or to quantify [15], [26]. Highlighted herein are some of the characteristics and benefits of a 25+ year biological monitoring program designed to evaluate the impact of DOE facility releases and remedial actions. The program has demonstrated ecological improvement and recovery (Figure 2 and Figure 3), provided a holistic approach with many monitoring tool and assessment strategy advantages (Table I), and has contributed to multiple additional and unexpected benefits to other DOE missions and goals (Table II). Overall, the Oak Ridge program has provided an integrated assessment of improving environmental conditions over time in response to facility abatement and remedial actions. As a key measure of environmental compliance, remediation performance, and long-term stewardship at the DOE sites, it is of significant value to site environmental managers, regulators and the public.

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