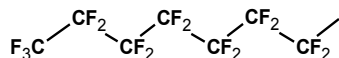


NEBRA Research Proposal

March 2018, January 2019



Measuring PFAS at Biosolids Field Sites

Evaluating PFAS Leaching & Runoff Impacts From Historic Biosolids and Paper Mill Residuals Land Application Sites

DRAFT

Phase I: Evaluations of Historic Biosolids and Residuals Land Application Sites in the Northeast Region, Including Establishing a Standard Protocol for Site Investigation of Per- and Polyfluoroalkyl Substances (PFAS), including Perfluorooctanoic acid (PFOA) and Perfluorooctane sulfonic acid (PFOS)

Update DRAFT – Jan. 14, 2019

Preliminary Research: The research effort described below will be initiated by an advisory committee assembled by NEBRA. The goal is to then expand the effort to other states and involve university researchers and regulatory agencies (including funding) in those states as well. Interest has been expressed by agency staff in Maine, Michigan, New York, and Vermont.

This research is intended to gather data to advance understanding among stakeholders – including regulators – in New England, New York, and other states regarding residuals that contain poly- and perfluorinated alkyl substances (PFAS), including perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). This initial, northeast United States research project is intended to help inform a future, larger national effort. It will ensure consistent and efficient evaluation of the core issue of potential PFAS/PFOA/PFOS leaching and surface runoff from sites with a history of land application of biosolids and/or papermill residuals.

I. Background

During the last several years, the U.S. Environmental Protection Agency (U.S. EPA) and state environmental agencies have become aware of contamination of groundwater by perfluoroalkyl and polyfluoroalkyl substances (PFAS), in particular perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS). Most frequently, the PFAS contamination in groundwater, and releases to the environment in general, are associated with direct release from local industrial

sources (use or manufacturing sites) (Zareitalabad et al., 2013). This discovery of PFAS contamination has prompted the adoption of a life-time drinking water public health advisory by U.S.EPA (70 ng/L or ppt) and enforceable drinking water and groundwater standards by several northeast states.¹

As regulatory agencies begin to discover the ubiquitous nature of PFAS contamination, there has been speculation about indirect sources. Since municipal wastewater treatment facilities (WWTF) receive domestic and industrial wastes that may potentially contain PFAS, biosolids and effluent are now being scrutinized as indirect sources of PFAS (ITRC, 2018).

A few published research studies have demonstrated that land application of biosolids in various parts of the country has resulted in PFAS contamination of groundwater at measurable levels – but generally below the public health advisory screening level (Lindstrom et al., 2011; Sepulvado et al., 2011; Gottschall et al., 2017). In most cases, this groundwater contamination was associated with biosolids from wastewater facilities impacted by PFAS industrial dischargers (Lindstrom et al., 2011) or was found at sites with high cumulative levels of biosolids applications (Sepulvado et al., 2011). Given that there are agreements between domestic industries and U.S. EPA to reduce or eliminate the use and production of PFOA and PFOS (Buck et al., 2011); for PFOS, limited uses are still allowed (see ITRC 2018), it is not clear if ongoing land application programs constitute a risk to public health from contamination of groundwater through leaching of these compounds. Meanwhile, public and regulatory scrutiny has begun to include others of the thousands of PFAS compounds, some of which are more complex and may be precursors that transform to persistent PFOA and PFOS and some of which are shorter-chain and apparently less-persistent but possibly more mobile compounds (e.g. Perfluorobutanesulfonic acid - PFBS and Perfluorohexane Sulfonate/ Perfluorohexanoic acid - PFHxS/A).

The direction of future regulatory trends at the state and federal level is uncertain, especially without a sound technical basis. Since establishing its public health advisory screening level for PFOA and PFOS in 2016, U. S. EPA has continued to

- evaluate the possible need for a maximum contaminant level (MCL) for drinking water,
- develop analytical methods for PFAS in media other than drinking water (the only EPA-approved method for PFAS is Method 537, rev. 1.1, which applies to drinking water only), and
- support state efforts to evaluate and address sites with high levels of PFOA and PFOS (and other PFAS) due to industrial activities or discharges or waste disposal (e.g. at Hoosick Falls, NY; Bennington, VT; Merrimack, NH; Coakley Landfill, NH; and Pease Tradeport, NH).

¹ Examples: NH has set an enforceable Ambient Groundwater Quality Standard of 70 ppt for PFOA and PFOS either alone and/or combined and as recently (12/31/18) proposed updated standards for PFOA/PFOS and other PFAS compounds, and Vermont has set an enforceable groundwater standard of 20 ppt for PFOA and PFOS either alone and/or combined. NJ is implementing a drinking water standard of 14 ppt for PFOA .

- EPA announced a multi-bureau effort to address PFAS and hosted a major summit on the issue in Washington in May, 2018.

This planned, phased research focusing on biosolids and residuals management in the context of PFAS addresses this fundamental, primary question:

Do either historic and/or current land application of wastewater residuals (paper mill residuals, municipal biosolids, etc.) represent a risk to public health from PFAS contamination of a) groundwater via leaching and/or b) surface water via runoff?

II. Two phases of research

There are two parts to the primary research question, and it is important to separate these two areas of concern:

- Regarding potential risks to drinking water resources from PFAS, the foremost need is to determine the extent of impacts to groundwater and surface water from historic (past) applications of biosolids and papermill residuals. This is addressed in Phase 1.
- Second is the need to determine the potential risk of impacts, if any, to groundwater and surface water from current biosolids and residuals land application and beneficial use programs, including determining if current biosolids products need to be screened for PFOA, PFOS, and/or any other PFAS compounds and/or best management practices need to be adjusted. This second concern is addressed in Phase 2 of proposed research.

1. Phase 1

PFOA and PFOS are and have been the focus of greatest scrutiny over the past two decades. Since these two chemicals were produced in large quantities and received widespread use, there is far more published research and federal and state regulatory review of PFOA/PFOS than other PFAS. In addition, PFOA/PFOS also exhibit the following characteristics:

- Bioaccumulative and highly persistent,
- End products of more complex precursor carbon-fluorine (C-F) compounds,
- Highly mobile,
- Found in environmental compartments worldwide,
- Apparently correlated with several negative health outcomes (PFOA C8 study), and
- The focus of Department of Defense (DoD), media, and public scrutiny due to extensive releases at military sites, fire-fighting training areas, and industrial sites around the world.

Federal and state regulatory actions have focused predominately on establishing drinking water advisory levels or, in a few states, drinking water enforcement standards for PFOA and PFOS. (A few advisory levels have included PFBS, PFHxS/A, and/or PFNA and New Hampshire has recently proposed drinking water standards for PFHxS and PFNA) Although A few additional regulatory actions have addressed source water (groundwater, surface water) protection.

Meanwhile, production and industrial use of PFOA and PFOS have been phased out substantially, and recent data corroborate this phase-out:

- Average PFOA and PFOS concentrations in current biosolids are nearly an order of magnitude less than average concentrations reported in a 2001 national survey (Venkatesen and Halden, 2011).
- Blood serum levels from the American public has been reduced 60% between 1999 and 2015 (CDC, 2018)

Therefore, PFOA and PFOS are best approached as historic, legacy contamination concerns. This is the focus of the first phase of this research effort: *Evaluations of Historic Biosolids and Residuals Land Application Sites in the Northeast Region, Including Establishing a Site Evaluation Standard Protocol*.

As a facilitator in this research on PFAS related to biosolids and residuals management, NEBRA has discussed the research question and approaches with numerous stakeholders in the Northeast and around the country, including many state and federal regulatory agency staff. Those discussions have confirmed that our proposed approach is appropriate. For example, Ronald Herrmann, a researcher in U. S. EPA's research arm in Cincinnati, independently developed a research focus that is essentially the same as this proposed Phase 1 effort (pers. communication, 3/21/18). He and his colleagues at U. S. EPA look to past efforts on ubiquitous, persistent contaminants, such as PCBs, and how those were previously addressed. They confirm that PFOA and PFOS are becoming legacy contaminants and research should be designed with that in mind.

The proposed Phase 1 effort will include establishing a standard set of peer-reviewed protocols that are then tested at three (3) sites in New Hampshire, reviewed and refined, and then finalized for application elsewhere.

NEBRA (and partner organizations) hopes to facilitate parallel Phase 1 research efforts in other states, funded by those states and other stakeholders, perhaps utilizing in-state university researchers, and following the same site evaluation protocols.

Part of Phase 1 will entail decisions about which variables to measure during field studies of historical sites. A relatively large data set from sites around the Northeast (and beyond), will allow for statistical validity in teasing out particular variables, such as soil organic matter (SOM) content, that influence leaching of PFAS from historic land applied biosolids and residuals. This information will help refine Phase 2 modeling, column, and field leaching studies. Phase 1 should also include development of a central database and associated data compilation and reporting systems to manage and analyze the potentially large data load from across the country.

Decisions will need to be made during Phase 1 research regarding how to address issues particularly as they affect research costs. For example:

- Precursors: published research indicates that PFOA and PFOS concentrations in soil, subsoil, and groundwater may be caused not only by applications of PFOA and PFOS, but also by precursor compounds that have degraded to the more stable PFOA and PFOS. This Phase 1 research may have to assess and estimate the level of influence of precursors based on the literature and data collected to date. However, it may be safe to assume that, at historic sites, most of the precursor degradation to PFOA and PFOS will have happened.
- What other PFAS are common enough and similarly persistent and bioaccumulative to be a focus of this Phase 1 evaluation? Likely Perfluorononanoic acid (PFNA) and similar longer-chain PFAS (anything C8 or greater) should be included in all testing and analysis.
- Other PFAS to include as well (e.g. high-performance polymers - GenX, PFHxS, etc.)

To supplement the Phase 1 effort, and in response to comments received from NH DES and other stakeholders, NEBRA has developed a risk modeling project that could help define interim best management practices and, possibly, PFOA and PFOS concentration screening levels for biosolids and residuals. To date, risk modeling for leaching of PFOA and PFOS from soils has been performed by several state agencies and individuals, with significantly different results. There appears to be inadequate data to accurately model leaching risk at this time (e.g. highly varied K_{oc} values for PFOA and PFOS). NEBRA has obtained a proposal from independent expert risk modelers at Stone Environmental who will review current modeling efforts and develop a more robust model and have it peer reviewed by states and others. This effort would be informed by the literature, as well as by data developed in the Phase 1 site evaluation field research. Ultimately this might lead to *interim screening levels* for PFOA and PFOS concentrations in biosolids and other residuals. This modeling effort is outside of the purview of this research proposal, but it is hoped it will proceed concurrently, depending on if and when funding is secured.

2. Phase 2

Phase 2 research will focus on column and field leaching of PFOS/PFOA. This phase will evaluate the potential for ongoing land application of biosolids and residuals to provide significant benefits while avoiding negative impacts on public health and the environment related to these chemicals.

Initially, this phase will only focus on PFOA and PFOS.

The basic elements and attendant costs for a column leaching study proposed by UNH in 2018 are shown below:

- 16 columns will represent 3 NH soil types and C33 sand.
- Each soil type and sand can have a different biosolids applied (short paper fiber, lime stabilized, anaerobic) and one control with no biosolids.

- There could be spiking of PFAS via a stock solution of DI water and PFAS. Alternatively, the study could rely only on any PFAS equilibrated naturally in the residuals being evaluated.
- Three years of precipitation will be run through the columns (of the stock solution) at a dripping rate to preserve unsaturated flow through the columns, or a batch of water will be periodically placed on top of each column and allowed to drip through.
- Soil chemistry will be measured. Stock solution (if used) and wet chemistry will be measured, and PFAS wet chemistry will be measured.
- Water samples will be the very first 500 ml, and then after every 5 inches of precipitation.
- Wet chemistry will occur on the first 4 samples, and after that every third sample.
- Samples not analyzed will be preserved in case they are needed in the future.
- Total cost is \$225,000. Of this total, \$140,000 is just for wet chemistry.

In order for this kind of leaching study to be useful, it needs to be validated/calibrated by a full-scale field study. Otherwise, leaching data are unlikely to be helpful in establishing defensible screening levels for soils, biosolids, and residuals.

Modeling effort aside, the proposed Phase 2 involves column leaching research validated by full-scale field evaluation of leaching at one or two well-documented field test sites with associated control sites, using today's biosolids and residuals products. Such an effort will be expensive and should be coordinated regionally or nationally for cost efficiency. Initial evaluations of leaching potential will focus on PFOA and PFOS but might expand to include other PFAS depending on funding resources.

Looking beyond PFOA and PFOS and the basic experiments outlined above, Phase 2 could quickly become more complicated and involves more uncertainties. Decisions would need to be made about how to address:

- Precursors: Do current and future biosolids and residuals contain precursors that will add significant levels of PFOA and PFOS (and similarly persistent PFAS) that threaten source water and drinking water quality?
- Variety of PFAS compounds: Research is lacking regarding the risks presented by other PFAS compounds in common use, such as GenX and PFHxS. Initial research suggests that shorter-chain PFAS are less toxic, less persistent, but more mobile in soils and within the biota. Additional research on the health risks, exposures, fate, and transport will be helpful in informing the Phase 2 research effort.
- Which PFAS are going to continue to be in commerce and which are not?
- What are the most likely human exposure routes for these other PFAS compounds?
- Analytical needs: Chemists and labs are currently further advancing methods for analyzing the >3000 varieties of PFAS related compounds, including PFAS Total Oxidizable Precursor (TOP) assays and total fluorine tests.

Because of the complexity and uncertainties around Phase 2, NEBRA intends to focus its Phase 2 efforts, in the short term, only on the PFOA and PFOS risk-modeling effort described above.

III. Details of Phase 1 Research: Evaluations of Historic Biosolids and Residuals Land Application Sites in the Northeast Region, Including Establishing a Standard Protocol

The initial Phase 1 research effort will include:

- A review of the literature specifically related to field research evaluating the potential for leaching of PFAS (PFOA and PFOS in particular) from sites where biosolids and other residuals have been historically land applied (sites older than 10 years), and
- A review of unpublished, screening data collected over the past few years by states and others from sites where biosolids and other residuals have been land applied.

This information will help with decisions on significant variables to be included, site selection, sampling, testing, analysis, and other details.

1. Significant Variables

The initial research effort (Phase I) is aimed at historic biosolids and residuals land application sites in New England and New York. It will build on initial state regulatory agency testing of a few biosolids and residuals land application sites, and it will develop and utilize rigorous protocols and quality controls.

The first step is to review lists of sites where biosolids and/or paper mill residuals (also known as short paper fiber) were land applied. NEBRA will facilitate a collaborative including a variety of stakeholders (state agency staff, NEBRA representatives, wastewater and residual professionals UNH) to develop a list of potential research sites. Sites will be selected and prioritized based upon their availability and input from stakeholders. The number of sites chosen for initial investigation will depend on funding, but between 3-5 sites seems most feasible. As additional funding becomes available, the prioritized, characterized list of sites will enable additional sites to be sampled in order of priority.

Site selection prioritization will consider the following variables (in no certain order), and, potentially additional variables that result from collaborative discussions and newer research outcomes of other studies:

- Site access and site control
- Onsite or nearby control area (where no land application of residuals has occurred)
- Willingness of property owner to engage in this research
- Site soil(s)
- Depth of overburden
- Depth to groundwater

- Proximity and nature of surface water
- Types of residuals land applied
- Dates of land application
- Frequency of land application
- Source(s) of residuals
- Availability of historic residuals quality data and site management data
- Availability of details about other farming practices and other potential confounding sources of PFAS
- Utilities

There are numerous variables that need to be considered, controlled, or at least characterized. However, certain variables will be determined to be particularly important and may become a focus of the research. Some of these are discussed below.

Type and Quality of Wastewater Residuals

There are a variety of wastewater residuals that could be incorporated into this research. However, biosolids and paper mill residuals are the wastewater solids that will be the focus initially. There are certainly other residuals worthy of consideration (e.g. septage, food waste composts, organic composts), but funding limitations are likely to preclude inclusion in preliminary research efforts, and the current regulatory concern is with paper mill residuals and biosolids and related to PFOA and PFOS in particular.

Within these two broad categories, there are distinctions between residuals that may cause them to react differently when applied to land. For example, alkaline stabilized biosolids behave differently in the environment than composted biosolids. Even within the alkaline stabilized category, biosolids products can be different depending upon the alkaline material used for treatment. Other considerations that can affect the properties of residuals include solids handling within the treatment facility, dewatering methods, and digestion, as well as handling of residuals products after treatment.

Chemical quality of wastewater residuals, especially relative to PFAS concentrations, is a crucial factor to be considered. Past biosolids research has established that the overall chemical composition, as well as certain physical properties, can determine the fate and transport of individual chemical constituents in the environment. For example, increases in soil sorption of PFAS have been observed in the presence of nonfluorinated aqueous film-forming foam (AFFF) surfactants (Guelfo, 2013). Consequently, it is critical that wastewater residuals evaluated in any research project be adequately characterized in terms of their chemical and physical properties, to the extent possible. Of course, historic concentrations of PFAS in particular biosolids will not be available, and it may be necessary to rely on published values (e.g. Venkatesan and Halden, 2011). The year in which the residuals were generated is an important consideration. Older residuals (from the 2000s or the 1990s or before) likely contain more PFOA and PFOS than today's residuals, because of the voluntary phase-out of these two chemicals that began in 2002. An additional confounding factor is the lack of data on the levels of precursor

compounds in historic biosolids and residuals. This is a challenge for the Phase 1 research effort. In contrast, the Phase 2 effort will rely heavily on thorough characterization of the PFAS concentrations in the materials tested.

PFAS Compounds to be Considered

There are a large number of chemicals included in the PFAS category. If precursor compounds found in products (including residues of precursors used to synthesize PFAS products, e.g. fluorotelomers) are included, this family of chemicals becomes even larger (Buck et al., 2011). Current research and drinking water regulations focus on PFOA and PFOS, with some efforts on other persistent, longer-chain compounds such as PFNA. However, the list of PFAS compounds included in research projects and requested for analysis by regulators is expanding. Research has also shown that PFAS precursors discharged into the environment can be converted to PFOA and PFOS (Sepulvado et al., 2011; Guelfo, 2013). These two particular transformed PFAS may be, or become, subject to regulatory limits in drinking water, groundwater, soil, or solids, whereas any precursors are not. The PFAS compounds to be included in this research are dictated by a balance between funding and regulatory needs. Determinations of public health risk are made by federal and state agencies. Target analyte lists established by state regulatory agencies will be considered for this research to ensure its value in relation to existing and future regulatory responses. However, the final list of analytes included in this study will be dictated, in part, by available funding. The likely list is included below.

Field conditions (climate, soil type, depth to groundwater, etc.)

Research regarding potential PFAS impacts in real-world field conditions is valuable and provides different results than laboratory, microcosm, or column studies. However, any field research will present a host of variables that can not be controlled. Soil type, proximity to water, topography, climate, vegetation, etc. are all field conditions that will impact outcomes. These variables generally cannot be controlled independently under field conditions. Careful selection of research sites can control for some of these variables, but will not eliminate experimental variability. For example, soil types and topography can vary significantly within an agricultural field. This variability impacts experimental results and interpretation of those results.

Given the variability of field conditions, experimental results observed in one region may not be applicable in other regions. Some researchers have attempted to solve this problem by selecting experimental sites that represent a “worse-case scenario”. For example, for field research involving the movement of contaminants to local water resources, an agricultural site with sandy soils, low organic matter, drainage tiles, and high annual rainfall could be selected to evaluate offsite movement of contaminants to groundwater and surface water. Researchers have also attempted to reduce field variability by reducing the scale of field experiments by establishing experimental plots within a larger field. This affords researchers the ability to control or minimize variability of some environmental factors.

For this evaluation of historic biosolids and residuals land application sites, data will be collected on the variables listed in the discussion of site selection, above, and any additional variables

identified in the final intensive design of the study. As the data set expands from this effort and parallel efforts in other states, the significance of particular variables should become more evident.

Other potential confounding sources of PFAS

Because PFAS – especially PFOA and PFOS – have been ubiquitous in use and are being widely found in the environment, this research effort must carefully assess the potential for cross-contamination from non-residuals sources. Limited information suggests that some agricultural and machinery chemicals may have contained PFAS in the past, and cleaning chemicals certainly did. If fires have occurred on or near a land application site, contamination via fire-fighting foams may be a concern. Other potential concerns are historic formulations of pesticides and herbicides and the potential of past or current air emissions of PFAS from industrial sources close up wind. Each land application site that is prioritized for thorough evaluation will be screened for all potential contamination sources. For each site, control locations nearby are included to understand the ambient setting unaffected by biosolids/SPF application.

In addition, the research team will need to develop written sampling and analysis protocols, based on the published literature, reliable guidance documents (HWRB QAPP, DOD, and other guidance documents), and state agency experience. These protocols should be discussed and reviewed by an outside technical advisory group potentially composed of state agency officials, NEBRA, researchers, and other interested parties. The protocols will ensure minimization of any potential cross contamination as part of the research team's sampling and analysis activities.

2. Proposed Initial Details of the Phase I Research:

The goal of the Phase I research is to evaluate distribution/movement of PFAS on a field scale at agricultural or other sites that have received multiple applications of wastewater residuals (biosolids and/or paper mill residuals) over a long term – “historic” sites. These sites will be characterized in terms of soil type, depth to groundwater, land application history, cropping history, and other parameters (see discussion above). Nearby fields that have not received residuals and are upgradient and upwind will be preferred locations for control/background comparison analyses.

At each site, five locations will be sampled for soils (one control and four in the application area). At each soil sampling site, soils will be sampled at three depths: top 2 centimeters, 15-20 centimeters, and 30-35 centimeters. The four, equal volume soil samples from the biosolids application locations at each depth will be homogenized and split into four subsamples, with one sample from each depth at each site sent for laboratory analysis of PFAS, one sample sent to a laboratory for standard wet chemistry, one sample used for particle size analysis, and one sample frozen and held for potential future additional analyses. If groundwater is deeper than 35 cm, soil samples will be collected every 30 cm until groundwater or bedrock is reached, and stored for potential future analyses.

At each site, three wells will be installed for groundwater sampling. Wells will be installed by direct push and completed with PVC casing and 10-slot screens. 10-ft long well screens will be set across the water table with not more than three feet of screen above the water table at the time of installation. Wells will be developed by overpumping with a submersible pump until no sediment is evident. Wells will be completed with a three foot stick-up above ground with locking cap, unless in an area where flush-mounted completion is preferred. During the drilling phase, equipment and field blanks will be taken and analyzed in order to assess the potential for PFAS/PFOA/PFOS contamination during the well construction process. When well completion is complete, wells will be surveyed and positioned with GPS-enabled survey equipment. Well samples will be taken no sooner than two weeks after well installation. First, depth to water will be measured. Then wells will be purged and temperature and conductivity monitored until they stabilize (stabilization criteria to be a discussion point for the technical committee). Then sample vials will be filled and additional sample volume collected for storage (storage criteria to be a discussion point for the technical committee). Sample vials will be sealed and preserved, then shipped for PFAS/PFOA/PFOS analyses according to recommended practices and lab protocols (QA/QC sampling criteria to be a discussion point for the technical committee). A parallel sample will be sent or driven directly to the wet chemistry lab for non-PFAS chemistry analysis.

At two sites, surface water samples will be collected using similar protocols.

Soil samples, groundwater samples, and surface water samples will be analyzed for the following compounds, following the research team's sampling and analysis protocols:

Perfluorocarboxylic Acids (PFCA)

1. Perfluorobutanoic Acid (PFBA)
2. Perfluoropentanoic Acid (PFPeA)
3. Perfluorohexanoic Acid (PFHxA),
4. Perfluoroheptanoic Acid (PFHpA),
5. Perfluorooctanoic Acid (PFOA),
6. Perfluorononanoic Acid (PFNA)

Perfluorosulfonic Acids (PFSA)

- 7) Perfluorobutanesulfonic Acid (PFBS),
- 8) Perfluorohexanesulfonic Acid (PFhXS),
- 9) Perfluorooctanesulfonic Acid (PFOS)

Wet chemistry other than PFAS (additional/alternative analytes will be considered)

Soils: cation exchange capacity (CEC), total organic carbon (TOC), Total Oxidation Precursors (TOPs) assay, and pH.

Groundwater: specific conductance, nitrate + nitrite, and chloride.

Surface water: specific conductance, nitrate + nitrite, phosphorus, and chloride

Lab results will include: lab credentials, analytical methods, reporting limits in the sampling and analysis plan, the branched isomers, linear isomers, and total isomers.

The results of the Phase 1 field sampling program will be summarized into tables and figures that display the spatial distribution of PFAS/PFOA/PFOS at each site. As blanks and controls are employed at each site, PFAS/PFOA/PFOS distribution attributable to the historic biosolids application may then be estimated for each site as well as how it is partitioned between soil and groundwater, and whether it has moved through the soil column at each site. This data may then lead to recommendations for present-day land application practices.

3. Estimated Costs

Costs are estimated by the UNH research team on a per-site basis incorporating researcher labor and direct costs (labs, drilling). In the following table, the costs to sample four sites are presented by cost category. These costs include UNH indirect costs and fringe benefits (for labor).

Cost category	Value
Labor	\$55,058.20
PFC analyses in water and solids	\$20,160.00
Lab analyses for wet chemistry	\$24,000.00
Field supplies	\$2,200.00
Travel	\$480.00
Well installation	\$24,000.00
Sample storage	\$6,000.00
Total	\$132,098.20

Labor was estimated for: Meetings, literature review, site review, travel, drilling supervision, soil and water sampling, sample storage, sample COC, data analysis, reports, and communications. The sample analyses represents ten water samples per site (trip blanks, field blanks, equipment blanks, groundwater samples) and six solid samples per site (3 homogenized samples per depth from 4 locations one sample from a control site, and two blanks).

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