A SEDIMENT NEWSLETTER FROM INTEGRAL CONSULTING INC.

# The Benthic Zone

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# Using Accurate Sample Elevations to Characterize Sediment Conditions with 3-Dimensional Modeling

## Why Recording Vertical Location in Elevation Is Preferable to Depth

**By Brandon Tufano,** *Project Scientist*
**Kelsey Kirkland, G.I.T.,** *Scientist*
**Logan Uselman, Ph.D., P.G.,** *Senior Scientist*

## Introduction

Contaminated sediment sites are complex systems with spatially and temporally variable conditions. Sediment sampling and bathymetric surveys are two common methods used to characterize these dynamic systems and provide insight into changes in sediment conditions over time. Sediment samples provide physical, lithologic, and chemistry data, whereas bathymetric surveys produce riverbed morphology data at the time of each survey. Comparisons of surveys recorded at different times provide information about where and by what magnitude areas of the riverbed/seafloor[1] experience erosion or deposition/shoaling.

Conceptual site models (CSMs) and 3 dimensional mapping software, such as Seequent's Leapfrog® Works, are tools used to compile various data (e.g., bathymetric, lithologic, and chemistry data) and generate a multidimensional visual representation of the sediment bed. Development and use of CSMs in complex sediment sites is beneficial because they allow users to visualize the sediment bed in three dimensions and provide insight into current and historical conditions. CSMs are often used to inform risk assessments and management decisions, so it is important that they accurately reflect site conditions, particularly when key conditions are highly variable and when data have been collected over a long period of time (as is common in sediment megasites).

## Surface Sediment—Why is it important and how is it defined?

The sediment bed is characterized as either surface or subsurface, and data sets are typically divided into these subsets based on the depth from which the samples are collected, or the depth interval the sample represents. How this can be different from the depth at sample collection is addressed in this article. Surface sediment is the upper layer of the sediment bed between the mudline and the bottom of the biologically active and oxygenated zone, which can be determined using sediment profile imaging. Contaminants in surface sediment can pose risks to ecological and human health through finfish and shellfish consumption. The biologically active zone, critical in determining the depth of surface sediment, is the depth to which benthic invertebrates at the base of the food chain live, and bioavailable contamination present in surface interval can accumulate particularly in the tissues of macroinvertebrates and bottom dwelling fishes (e.g., sole).

Risk assessors evaluate contaminant hazards in surface sediment (where biota are exposed to contamination), and remedial designs target often cleanup of contaminated surface sediment to reduce risk. In dynamic water bodies, the sediment constituting the surface layer can be subject to continual change, and as a result, historical data collected from the once surface sediment layer should not be assumed to represent the surface layer or its conditions in perpetuity.[2]

## Recording Depths and Elevations

When sediment samples are collected, their vertical positions are recorded and brought into databases as an upper depth and a lower depth below the mudline (e.g., 0 to 6 in.; 1 to 2 ft). However, in dynamic water bodies subject, the recorded depth interval is only representative of conditions at the time of sample collection. For instance, in a depositional environment, a surface sediment sample collected 10 years ago could be buried multiple feet deep within the sediment bed, and thus would no longer represent surface conditions. It should not be evaluated as part of a surface sediment dataset.

Because the mudline can be a dynamic and everchanging reference point, a depth measurement relative to this point does provide enough information about a sample's location over time. Instead, a measurement basis that is not relative to a moving starting point (the mudline) is required. Evaluations of particular layers of the sediment bed will we erroneous if depth alone is to map data. Figure 1a shows how errors are introduced when depth alone is used to define sample location.

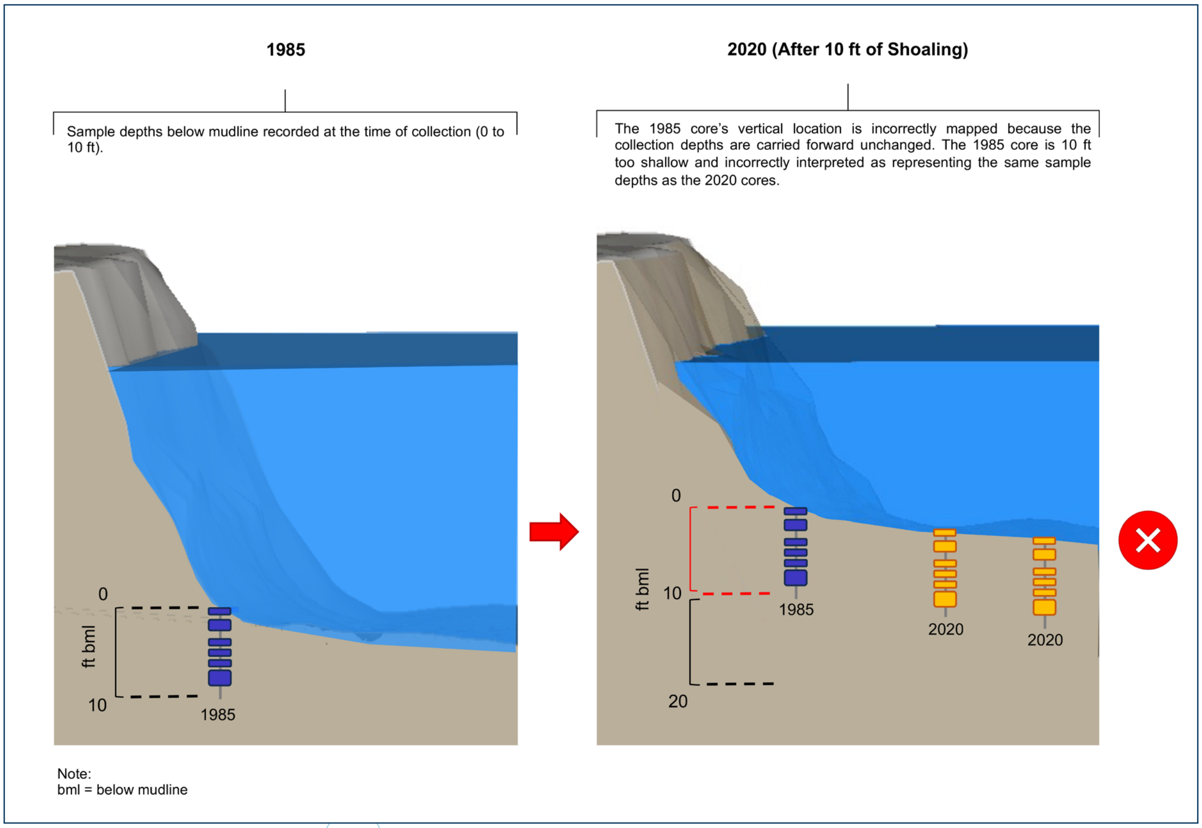


**Figure 1a.** Erroneous mapping of historical data in a depositional setting

Elevation is the static way to understand and track the vertical location of sample intervals.

The elevation of the top of the core or of a grab sample can be determined in two ways:

1. During sample collection, the water depth at the core/grab collection location is recorded using a lead line, fathometer, or equivalent sounding device. In a tidal water body, the tidal stage at the time of core/grab collection is recorded and used to convert the measured water depth to a mudline elevation (e.g., tide stage in ft NAVD88 minus depth of water in ft = mudline elevation in ft NAVD88).

2. If a comprehensive bathymetric survey is performed at or near to the time of sample collection, this information can provide the mudline elevation at each sample location. One may assign an elevation to a sample location by finding the bathymetric grid cell it overlaps and extracting the elevation from the raster file. Because the sample location is not surveyed in the same manner as an upland sample location, the precision of the core elevation is based on the precision of the bathymetry data and the Cartesian coordinates of the core. Such propagation of error should be considered in any decision-making based on the data.

For subsurface sediment samples, finding the elevations of each sample interval requires subtracting the depth below mudline of the top and bottom of the sample interval from the elevation of the mudline at the sample location. Using elevation substantially reduces error and is preferred for analysis because it offers better vertical representation and puts both current and historical data in the same vertical datum. Understanding where the sediment represented by historical data lie within a current sediment bed would require a current-day bathymetric survey and a comparison of the elevations for each sample interval to the mudline elevation at the sample location. For example, a historical sample collected at -25 to -26 ft NAVD88 from a depositional location with a current mudline elevation of -22 ft NAVD88 would represent sediment 3 to 4 ft below that current mudline. An evaluation of current conditions should consider those data to represent the 3- to 4-ft interval of subsurface sediment, regardless of the depth below mudline from which the sample was originally collected years before. Figure 1b shows a correct representation of historical data in vertical space where a riverbed has shoaled. (Figures 2a and 2b illustrate

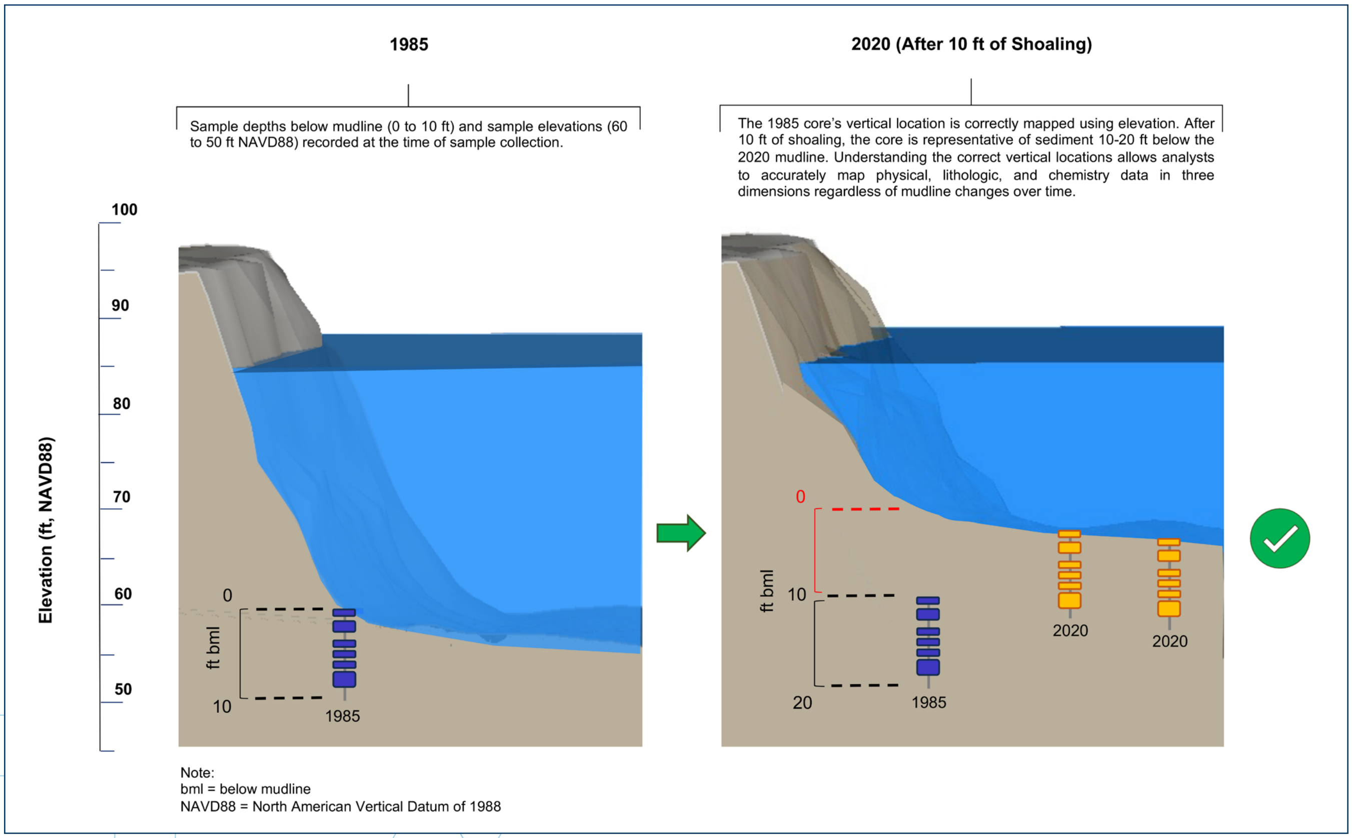


**Figure 1b.** Correct mapping of historical data in a depositional setting

erroneous and correct mapping of sample intervals, respectively, in an erosional location. This is also relevant in a dredged area, where the elevation of the sediment bed is lowered. Using sample elevations help one understand which data represent sediment that has been removed by dredging.)

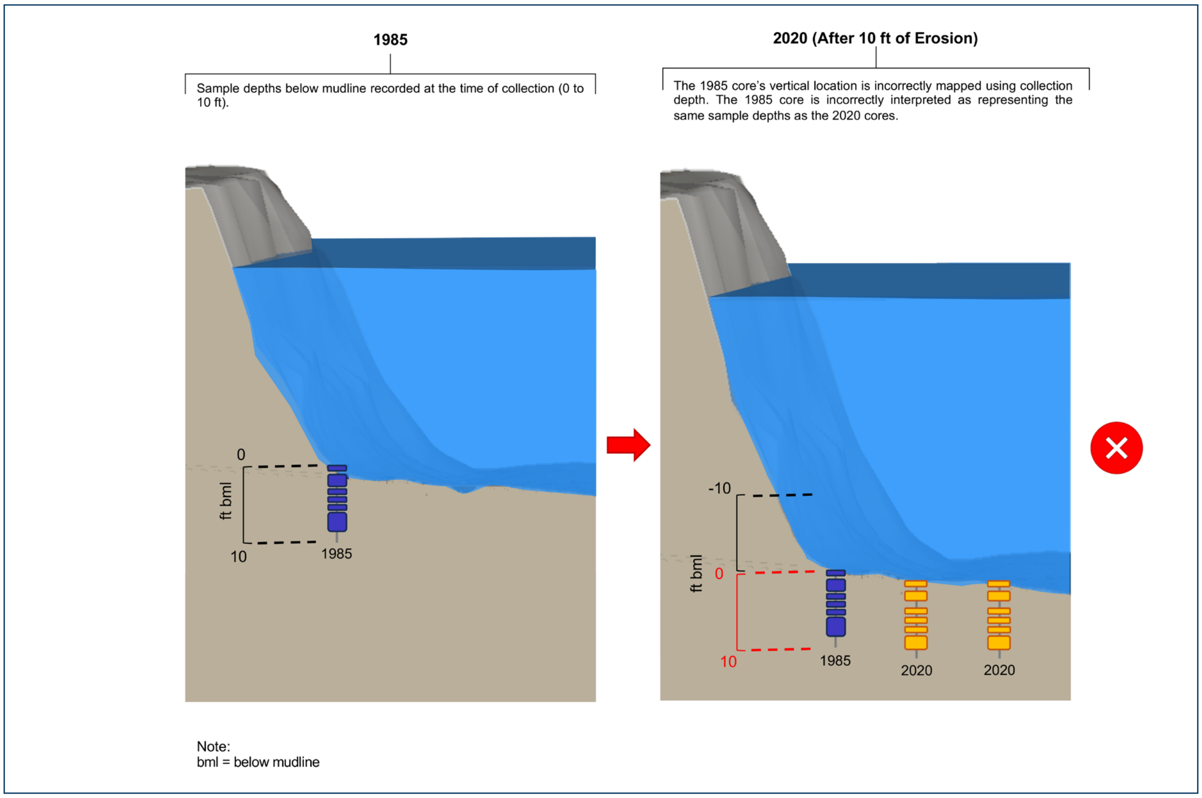


**Figure 2a.** Erroneous mapping of historical data in an erosional setting

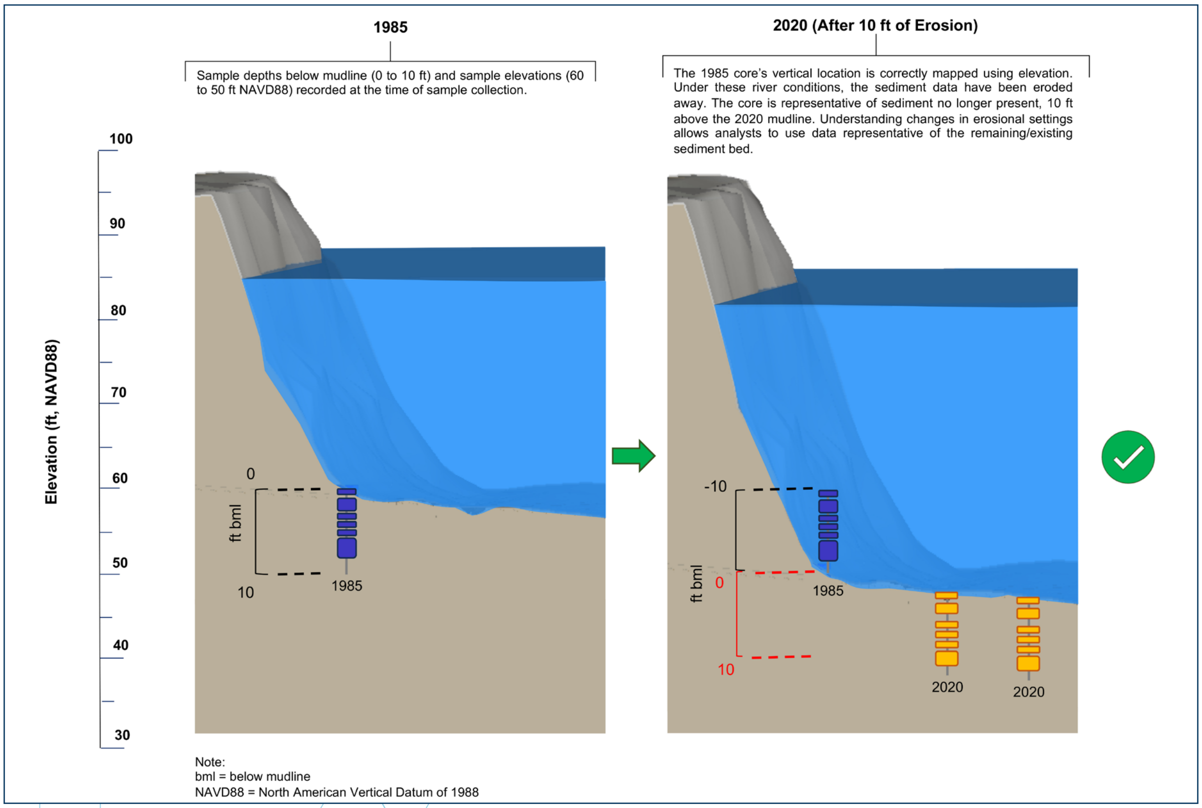


**Figure 2b.** Correct mapping of historical data in an erosional setting

## Conclusion

Rivers, waterways, canals, lakes, and bays can be complex and dynamic systems, often with long histories of modifications to their shorelines and to the seafloor, and it can be challenging to understand spatial and temporal changes. Fortunately, in instances where a sediment system has been studied extensively, various historical bathymetry, chemistry, and lithology data are available to build a robust elevation-based CSM. Three-dimensional modeling software is one of the most powerful tools for combining and viewing these data in a CSM. Seequent's Leapfrog® Works is 3 dimensional modeling software that has many data analysis capabilities, including a suite of interpolation features that allows for the numeric modeling/interpolation of 2 dimensional surfaces (e.g., depth of contamination) and 3 dimensional volumes (e.g., dredge prisms, contaminant footprints).[3] The modeling software also allows users to "hang" historical data using the elevation data on the current mudline so that the data lie accurately in vertical space relative to more contemporary data. Determination and use of sample elevations accurately accounts for changes in riverbed/seafloor morphology, precisely places chemical and lithologic data in vertical space, and produces a more accurate CSM for risk management, remedial design, and other decision-making. As a project progresses, an elevation-based dataset allows analysts and engineers to continually evolve relevant evaluations and designs to reflect current conditions as they change. This is particularly important in sediment megasites where decades of data collected over several phases, leading up to and following a Record of Decision, may be used to design a remedy and to evaluate effectiveness.

## Want More?

Please join us at the Sediment Management Work Group Fall Forum on October 17 in Detroit MI, where [Nicole Ott] will be presenting on this topic.

## Glossary

**Depth**—The vertical distance from a reference point (e.g., the sediment surface, also referred to as mudline, at the time of sample collection) to another point. Depth is a relative measurement for which the reference point must be defined because in a dynamic sediment system the reference point's (the mudline's) vertical location (i.e., elevation) changes. Assuming that a reference point such as the mudline surface is fixed over time may lead to inaccurate interpolations.

**Elevation**—The height above or below a fixed reference datum. Elevation is a static measurement useful for accurately recording a sample's vertical location in a manner independent of whether the sediment bed shoals or erodes. Common datums include the North American Vertical Datum of 1988 (NAVD88) and National Geodetic Vertical Datum of 1929 (NGVD29).

**Mudline**—The surface of the sediment bed, also referred to as the riverbed or the seafloor. In dynamic water bodies, the mudline can change over time through shoaling or erosion.

**Vertical Datum**—A geodetic model with a unique and static (fixed over time) zero point. Several regional and local vertical datums are typically relevant in a particular study area, such as NAVD88 (regional current), NGVD29 (regional historical), the Columbia River Datum (local), and tidal datums (local and specific to a particular coastline, bay, or tidally influenced river). So the vertical datum used must be clearly defined when vertical locations are recorded.

[1] In this article "mudline" refers to the top of the riverbed or the seafloor; the interface between the sediment and the water column.

[2] The length of time it takes for surface sediment to be eroded or buried depends on many factors, including but not limited to, water body size, currents, tidal exchange, anthropogenic activities, flood events, and sediment loads from upstream and lateral inputs. However, in general, it takes years to decades for entire surface sediment intervals to change, either through burial (deposition, shoaling) or erosion.

[3] https://www.seequent.com/products-solutions/leapfrog-works/

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# PFAS at Contaminated Sediment Sites: Evolving Technical, Regulatory, and Legal Priorities

**By Miranda Henning, BCES,** *Managing Principal*
**Jarrod D. Gasper,** *Consultant*

Contaminated sediment sites are among the country's most complex and expensive sites to characterize and remediate. As per- and polyfluoroalkyl substances (PFAS) garner attention in the news, courts, Congress, and regulatory agencies, it is somewhat surprising that this group of compounds has yet to loom large at most contaminated sediment sites. However, the U.S. Environmental Protection Agency (EPA) has proposed listing PFAS as hazardous substances under the Comprehensive Environmental Response, Compensation and Liability Act, and such a listing may shift investigation, cleanup, and enforcement priorities at virtually all contaminated sites, including sediment sites. There is an increasing prevalence of fish consumption advisories and drinking water supply concerns as a result of releases of PFAS.  The proximity of those advisories to Superfund sites and industrial facilities suggests that the technical, regulatory, and legal priorities at contaminated sediment sites may shift in the near future. Many factors differentiate PFAS from legacy sediment contaminants, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), mercury, and lead.  The combination of characteristics of these compounds is noteworthy in several respects, as summarized below.

First, PFAS represent a broad array of compounds. The universe of PCB and PAH compounds is well-defined, in that regulators, scientists, and engineers rarely debate whether a substance is or is not a PCB or a PAH. In contrast, there is no consensus definition of PFAS. Most often, substances are included based on chemical structure—specifically, carbon atoms linked to each other and bonded to fluorine atoms. Structures and properties of PFAS vary widely and include solids, liquids, and gases; neutral, anionic, cationic, and zwitterionic substances; inert to highly reactive substances; insoluble to soluble substances; involatile and volatile substances; virtually immobile and highly mobile substances; and linear and branched structures. But PFAS are not limited to manufactured substances. They also include salts, degradants, impurities, metabolites, by-products, and other transformation products. Depending on the breadth of the definition applied to PFAS, the group may comprise only a few thousand to more than ten thousand individual substances.

Second, PFAS use is ubiquitous, and the sources are diverse. Industrial and commercial activities and products often associated with PFAS are wide ranging.

They include fire suppression (military, fire training, civilian airports, oil refineries, petrochemical facilities), plating/metal finishing, plastics, coatings, tanneries, leather/fabric/carpet treaters, consumer and personal care products, chemical manufacturing, automotive, paint, paper manufacturing, and semiconductor manufacturing. Wastewater treatment facilities that receive effluent from commercial and industrial users of PFAS can be of concern due to both end-of-pipe discharges and disposal of solids generated during treatment.

Third, PFAS are essentially unamenable to destruction or degradation in the environment. Compounds may transform or breakdown—but the fluorinated carbon chains are stable. Transformation processes can cause degradation product concentrations to increase over time since release and distance from release.

Fourth, conceptual site models—mapping sources, migration pathways, unintentional recycling, fate, and receptors—can be extremely complex. Proprietary formulas, complex mixtures that change over time, transformation of PFAS precursors, and other factors greatly complicate analyses. Multiple pathways are available for transport—water, sediment, and air can transport PFAS effectively. Substantial water solubilities, and a propensity for the air–water interface, allow for effective groundwater and surface water transport. Though sorption of PFAS to sediment is less strong than that of legacy contaminants, PFAS do sorb effectively and often irreversibly to sediment. Consequently, like legacy sediment contaminants, sediment can accumulate PFAS and act as a secondary source to surface water and biota.

Fifth, treatment and risk mitigation are currently focused on drinking water. Mitigating risk to humans and ecological receptors posed by PFAS in surface water systems is likely to require administrative controls (e.g., fish consumption advisories), sediment remediation, and surface water treatment. But treatment of drinking water is likely to take priority over treatment of water that is not a drinking water source. EPA and many states have promulgated or proposed PFAS regulations in drinking water at parts-per-trillion levels. (**https://www.integral-corp.com/our-services/pfas/**). Water standards in the parts-per-trillion range indicate that very low sediment concentrations can drive problematic water concentrations. Regulation of PFAS at sediment sites may occur during the remedial investigation and feasibility study process, as well as after remedies have already been selected and during 5-year reviews.

Sixth, ecological risk is uncertain and stymied by information gaps. Compared to dietary exposures, gill transfer is typically the more important exposure pathway, such that lower trophic level fish may be more highly exposed than higher trophic level birds and mammals. Ecotoxicological data are limited for most substances, mixtures, and wildlife receptors. Standards and guidelines specific to human exposure are overwhelmingly focused on the drinking water pathway. In the absence of robust toxicological data, most state and federal regulatory agencies apply the precautionary principle. Consequently, it can be challenging to interpret concentrations in sediment, surface water, and biota—and to calculate risk-based cleanup levels.

For these and other reasons, PFAS can defy the customary principles of sediment investigation, such as the expectation of a decreasing gradient in chemical concentrations with distance from the source, a predictable relationship between concentrations in sediment and in surface water, increasing exposures up the food chain, and greater prevalence near industrial land uses compared to rural areas.

## Want More?

In collaboration with Robb Fox, partner at Manko, Gold, Katcher & Fox, LLP, Integral will host a 60-minute webinar on the ramifications of tighter regulation of PFAS on contaminated sediment sites, from both technical and legal perspectives. Join us on October 17, 2023, at 1:00 p.m. Eastern by registering **here.**

## Authors

BRANDON C. TUFANO

Mr. Brandon Tufano is a geologist with 5 years of experience in the environmental consulting industry. He has broad technical experience planning and conducting site investigations focused on a variety of chemicals of concern, including per- and polyfluoroalkyl substances (PFAS), petroleum hydrocarbons, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals. Mr. Tufano has successfully designed, implemented, and performed Phase II environmental site assessments, remedial investigations/pre-design investigations, light nonaqueous-phase liquid (LNAPL) recovery pilot studies, and soil, groundwater, surface water, and indoor air sampling events and evaluations.

btufano@integral-corp.com

KELSEY KIRKLAND, G.I.T.

Ms. Kelsey Kirkland is a geologist with experience in technical writing, pre-remedial design investigations, environmental sampling (sediment, soil, and groundwater, vapor intrusion), conceptual site model development, data analysis, and interpretation.

kkirkland@integral-corp.com

LOGAN USELMAN, PH.D., P.G.

Dr. Logan Uselman is a hydrogeologist and project manager with a focus on large legacy contamination sites and regulatory tracking. She has experience with data analysis, environmental quality monitoring, environmental remediation, and inorganic and organic chemistry. She has 5 years of environmental consulting experience and 6 years of experience in academia assessing mobility and source identification of trace elements in aquatic settings. Dr. Uselman is proficient in Leapfrog, ArcGIS, Surfer, and other data visualization software. She has organized and led field sampling campaigns, laboratory analysis, and data interpretation. Dr. Uselman has a passion for effective science communication and has presented her work at both national and international scientific meetings and amongst stakeholder groups.

luselman@integral-corp.com

MIRANDA HENNING, BCES

Miranda Henning helps clients in the regulated, legal, governmental, and nonprofit communities quantify and mitigate the risks and damages posed by chemicals in the environment, home, workplace, diet, and consumer products.  A certified senior ecologist and Board Certified Environmental Scientist (BCES, ecotoxicology), she provides expert testimony, conducts technical analyses, offers strategic advice, and shares findings and recommendations with diverse audiences.  Her work often takes the form of human health and ecological risk assessments, natural resource damage assessments (NRDAs), safety assessments, feasibility studies, and expert reports. Ms. Henning has contributed to nearly 100 guidance documents, scientific publications, and technical presentations.

mhenning@integral-corp.com

JARROD D. GASPER

Mr. Jarrod Gasper is a geochemist and environmental engineer with 16 years of experience.  His primary area of expertise is the analysis of the fate and transport of metals and organic chemicals in the environment, with a focus on mining and industrial sites.  Mr. Gasper's background includes aqueous geochemistry, geology, and chemical engineering.  His experience includes the forensic analysis of contaminant sources, the geochemical analysis of sediments and water, prediction and modeling of physical limnology and water quality at proposed mine pit lakes, analysis and modeling of surface water quality, and remediation of contaminated groundwater.

jgasper@integral-corp.com