INNOVATIVE PRE-SAMPLING GEO-STATISTICAL TECHNIQUE TO IDENTIFY HISTORICAL CONTAMINANT INVENTORY IN NAVIGABLE WATERWAYS

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ABSTRACT

Many of the Nation's navigable waterways have been heavily impacted by historic industrial waste discharges, often consisting of hazardous chemicals that can become intermixed with sediments during downstream sediment migration and/or tidal and storm-related forces that persist through time. Natural and human forces occurring during the same period as the industrialization have resulted in the contaminated sediments being eroded, remixed, and re-deposited, creating historical contaminant inventories (HCIs) dispersed from their original source to fill-in low-lying, low velocity pockets that may temporarily exist along the waterway bottom at the time of deposition, which in-turn may have since been covered over and obscured by wider ranging sediment deposition by non- or lesser-contaminated sediments. Miscellaneous activities including but not limited to transient berthing of navigational ships and/or placement of utility crossings/outfalls can create short-term depressions in the waterway bottom that result in a concentration of contaminated sediments at that location (further noting that in the case of cables/utilities, grid sampling programs most often purposely avoid sampling at/near these locations, thus making a potentially major mistake and missing significant HCIs). Thus it is demonstrated that locating these inventories utilizing conventional grid sampling techniques and post-sampling statistical approaches is less effective and often results in inventory discovery (and increased construction costs) during sediment removal and treatment/disposal efforts. We have therefore developed and helped regulatory agencies to execute and prove-out a more cost-effective, targeted sediment sampling technique by utilizing data from the most viable source or combination of sources (e.g., bathymetric surveys, aerial photos/maps, USGS topographic maps, NOAA charts, Tidelands maps, etc.) and then evaluating and presenting it with state-of-the-art spatial analysis technique and 3D/4D visualization programs (e.g., ArcGIS (Geographical Information Software by *ESRI Corporation*) and MVS (Mining Visualization Software by C-Tech Inc), etc.) to refine and guide sampling and avoid blind, grid type approaches. Findings obtained using these innovative techniques can thereafter be validated with existing sediment sampling data and contaminant profiles generated using advanced 3D Indicator Kriging leading to development of targeted inventory investigation, delineation efforts and subsequently to a much more fiscally responsible and effective remediation design and construction program than is often the case when ordinary grid-type investigations are relied upon.

Improved, more focused investigative findings resulting in a more comprehensive and defensible engineering study is a direct benefit of the "Innovative Geo-statistical Technique." Furthermore, use of this technique can assist in understanding of the waterway from a historical discharge perspective leading to a more effective and tailored remedial strategy formulation, in-turn leading to more cost effective design and construction.

Keywords: Dredging, Kriging, Sampling Planning, Sediment Sampling, Historical Discharges.

INTRODUCTION

It is understood that historic discharges of industrial waste (solid waste and/or wastewater) in navigable waterways was a somewhat common occurrence, and the resulting contamination often persists in a waterway becoming intermixed with and/or adsorbed to sediments (see Figure 1). These Historical Contaminant Inventories (HCIs) are usually impacted by human and natural forces existing at the same time as the industrial activity as they were dispersed from their original source to fill-in low-lying, low velocity pockets that may temporarily exist along the

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waterway bottom at the time of deposition, which in-turn may have since been covered over and obscured by wider ranging sediment deposition by non- or lesser-contaminated sediments, possibly from a completely different source and time-frame.

Further refinement and development of contamination profiles using the 3D Kriging, can add much to findings associated with historical HCIs, thus providing stronger evidence of hot spots/hot zones which may potentially exist but are not so-clearly identified due to lack of actual sample core testing information because a grid-type approach was used and did not happen to co-locate a sample at the location of the HCIs. With the likelihood of substantial volumes of dredge material to be handled under any given remedial scenario that is explored and/or deliberated upon, it would be prudent to further characterize the contaminant inventory, both known and what might exist to validate our current understanding by allowing for the interpretation of partially conclusive evidence derived from all available information so that a more targeted, surgical, cost-effective confirmatory investigation can be pursued. Therefore, Berger has developed a conceptual sampling plan based on the rationale presented herein and further developed through a 'Contamination Sampling Flow Chart,' (which is included in "Procedure for Sampling Protocol" Section) to assimilate the available information as a useful tool geared to further delineate/define contaminants within study areas that are known to contain the highest mass of contamination. It has been shown that this step will assist in generation of a more resolute and accurate contamination identification and quantification for the purposes of remedial alternative selection and dredged material management options. A conceptual sampling plan can then be developed in a layered approach using various levels of contamination, as will be demonstrated.

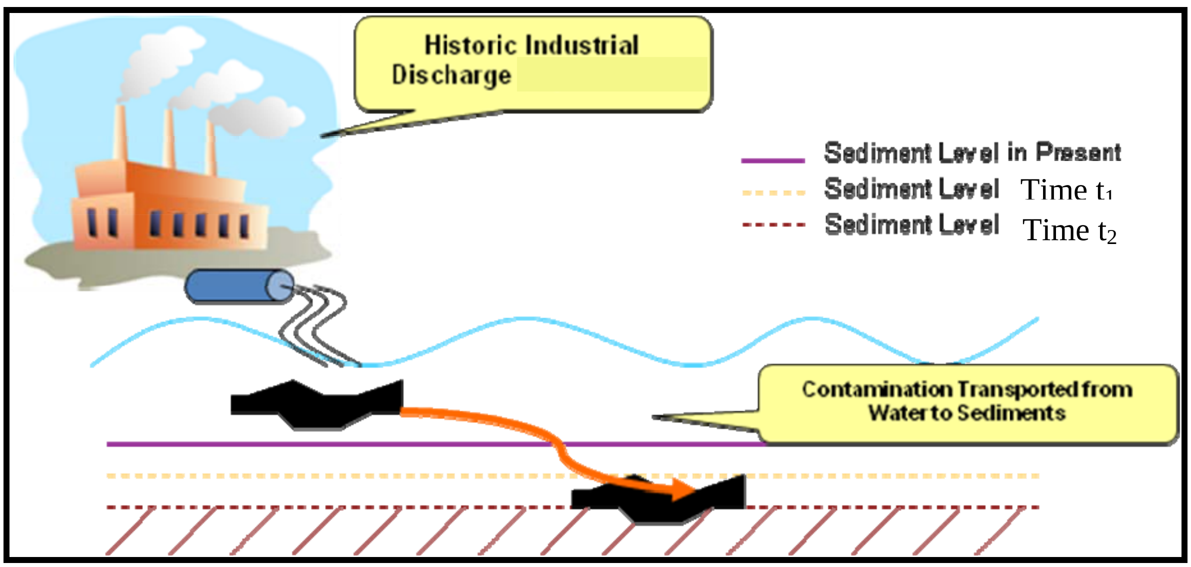

Figure 1. Schematic of historical industrial discharge

Using conventional grid investigation methods, identifying these HCI areas at-depth could be challenging at best, if not nearly impossible. Such areas would be expected to contain significantly elevated contaminant concentrations relative to generally prevailing concentrations. Despite this potential difficulty, identifying such high-concentration HCIs within each study area should be a very high priority because they often can drive the results of risk assessments, and also impact development of cost-effective remedial options and an associated remedial design that is more implementable.

The HCIs are typically formed by transient filling-in of low-lying, low velocity pockets that may temporarily exist along the waterway bottom at or immediately after the time of waste discharge. These waterway sub-bottom spaces are silted-in and -over during the course of time as the waterway shoreline and bottom invariably changes (including disappearance of several channels, tributaries and other outfalls of the waterways) during and after the time of maximum industrialization. Specific emphasis thus needs to be given to the waterway shoreline and elements located there (e.g., old outfalls, piers, slips, bulkheads) as indicated by historical maps and aerial photos.

To properly identify HCIs and/or to further characterize the potential impact of other HCIs, one must obtain (often done) and fully process (not often done) relevant historical information from several resources (e.g., topographic maps and navigational charts from multiple historic timeframes to piece together the changing picture of the waterway bottom over time). The analysis is best facilitated by the use of geographical information systems (GIS) software and associated interpretive utilities.

IDENTIFYING AND LOCATING HCIs

Identifying and locating HCIs utilizing conventional grid sampling techniques is extremely unlikely because it would not be cost-effective to have a tight enough sample grid to catch all of the HCIs, that can often be highly localized yet contain significant contaminant inventory relative to the overall sediment mass and character, especially in an active waterway with many variables and challenging investigative logistics. Thus it is more appropriate and cost-effective to use historic and geo-statistical techniques to identify the most likely locations of HCIs using an extensive "historical and contemporary information database" which contains maps and other available information from multiple representative timeframes immediately prior to, during, and since industrialization.

Several sources of information can be utilized for the historical search including but not limited to:

- Information obtained from library and online;
- Historical topographic maps and historical navigational charts;
- Historical aerial photographs;
- Historical bathymetry records;
- Tideland/riparian maps.

Reviewing all available sources of information is recommended as each of the above-referenced most likely is tied to different boundary limits and data overlapping will be warranted. These sources are further discussed below. While none of these sources are likely to be left out of even the typical grid-type investigation, the part that is often not done properly is the interpretation and mapping of the continuum of waterway bottom immediately prior to, then during, then after the industrial discharges likely occurred. The suggested approach to performing this interpretation and mapping is discussed in the next section.

Library and Online Review and Research

A library and online review can be conducted to obtain historical information pertaining to the focused historical records study area (e.g., urbanization, industrialization, deterioration, etc.) leading to the identification of potential sources of contamination and associated historical search areas with potential contaminant inventory in the sediments.

Historical Topographic Maps/Navigational Charts

Historical topographic maps and historical navigational charts (see Figure 2) are used to identify trends and changes in the shoreline, waterfront structures and the general landscape along the waterway. United States Geological Survey (USGS) topographic maps (http://topomaps.usgs.gov/) for various years, as well as historical navigational charts are available from many different years, and make excellent information sources.

Historical Aerial Photographs

Historical aerial photographs (see Figure 2) can provided a visualization of the historical search study area over time. The photographs enhanced findings based on the historical topographic maps and navigational charts.

Historical Bathymetry Data Review

Historical bathymetry data (see Figure 2), including navigational channel information of the waterway, can be extracted from the publicly available bathymetric surveys information compiled by the USACE. The surveys were prepared and archived in various digital and non-digital formats. The surveys conducted prior to digital age are stored in microfiches, where individual soundings were marked by hand on manually drafted plans. Bathymetric surveys relevant to the study area need to be selected for review based on their relevance and comparisons to the navigational dredging history. The dredging records certainly play a significant role in this selection.

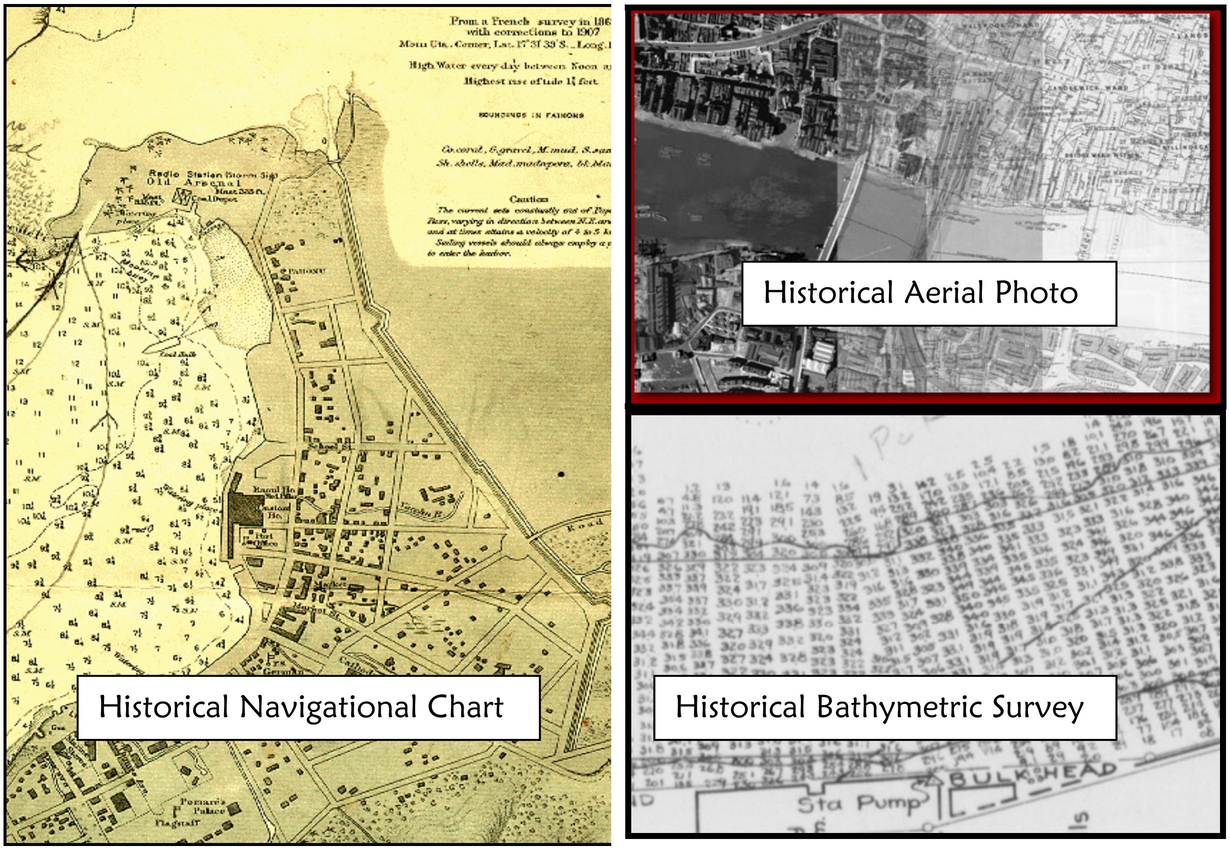

Figure 2. Examples of historical information

Tidelands/Riparian Maps

Tidelands/Riparian Maps in GIS format can be used to identify historical tributaries of the study area. Tidelands/Riparian Lands are all those lands now or those that formerly flowed by the mean high tide of a natural waterway. These maps are primarily used to issue lease/license fees and grants for the claimed lands.

STATE-OF-THE-ART 3D INTERPRETATION AND MAPPING OF THE HISTORICAL DATA

Figure 3 presents an illustration of how state-of-the-art spatial analysis software (e.g., GIS and 3D visualization software) can be used to analyze the HCI-related data using un-dredged volumes during successive historical dredge events. Initially, a 2D interpretation is accomplished and HCIs with higher confidence level are then further analyzed to depict the most likely instances of greater relative contaminant inventory. As illustrated in Figure 3, it is quite probable that dredging footprints in successive dredge events are not synonymous, and combined with a scenario of ongoing historical discharges may create predictable pockets of HCIs. As the dynamics of the waterbody evolve through various influences such as tidal and storm flows, land based flow changes, prevailing erosional and depositional forces, etc., it is important to understand the affects that each of these influences would have on the location and potential migration of the HCIs.

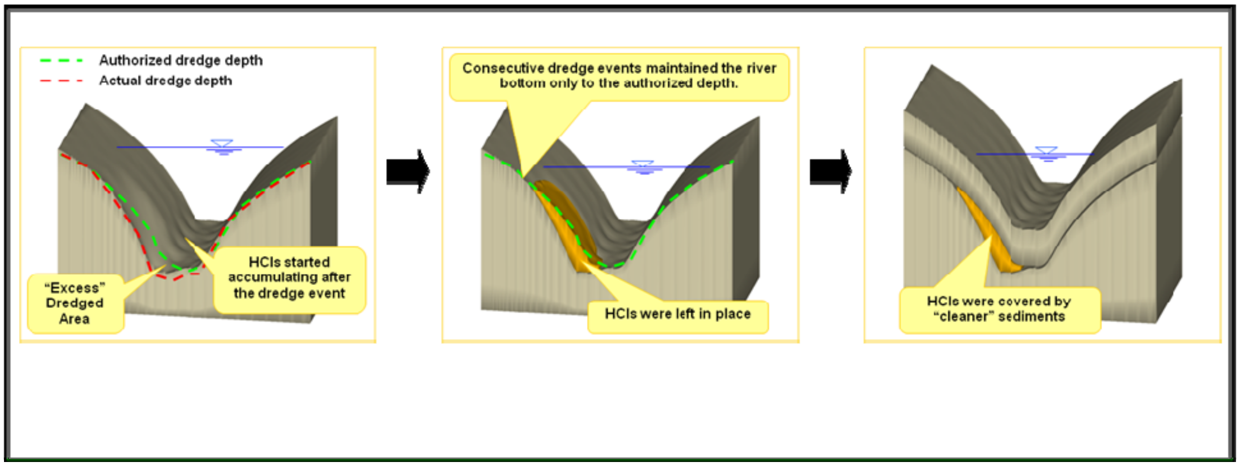

Figure 3. Undredged volumes during successive historical dredging events

Technical Approach to Investigation and Review of HCIs

Investigation and review of the HCIs were performed sequentially, beginning with procurement of historical data, preparation of a GIS database, identification of HCIs, development of cross-sectional profile for the HCIs, and finally the review and interpretation of data specific to each HCI. This process is further described below.

1- Development of Historical Search Study Area GIS Database

Non-digital historical topographic maps/navigational charts are obtained independently from library resources and USACE microfiche format that are initially scanned into usable digital images. These digital images, along with other maps, charts, and historical aerial photographs obtained and/or procured directly in digital format were geo-referenced in the form of a database consisting on overlays using the GIS software. This GIS database is prepared to assist in simultaneous review of historical information to identify a specific HCI or multiple HCIs and to identify the historical changes (e.g., change of features, tributaries, shoreline, industrialization, and change of shoreline) of the waterway stretch within the respective HCI(s). This database can be further updated appropriately at any time as more information becomes available for the area covered or a partial study area.

2- Development of Cross-Sectional Profiles and Historic Changes

Cross-sectional profiles of the identified HCIs is developed to document the time-dependent change of subsurface conditions specific to the HCIs and the navigational channel within the contaminant search area during different historical periods (see Figure 4). These profiles are also used to identify potential accumulation of contaminated sediments in waterway sub-bottom over the documented history of the period reviewed. Historical maps, historical bathymetries, and the recent bathymetry are generally used to generate the profiles.

When generating the cross-sectional profiles, the bathymetric information of a specific dredging event is selected which potentially created a HCI. This potential HCI is then compared with a subsequent dredge to determine if a portion of this contaminant inventory was left behind due to dredging depth differences. This information is then profiled as the updated HCI to be used for continued mapping and profiling.

3- Identification of Historical Search Areas

As mentioned above, HCIs are defined as the section of the sub-bottom of the waterway which, based on review of historical information, may potentially contain industry-related contaminated sediments deposited due to various reasons and related to more active release of contaminant materials, associated deposition/erosion or dredging during the history of the waterway.

4- Creation of a Sub-Bottom Space by a Former Tributary/Channel

As part of the historical records search, the strong likelihood that an HCI could exist as a sub-bottom space created by a former tributary draining into the waterway, thus developing a “bottom depression” or as called hereinafter “scouring area” in the waterway bottom. This former scouring area could then serve as a potential depository for contaminated sediments migrating from upstream, downstream or directly discharged from on-shore sources. Once the tributary’s flow ceased (e.g., filled up due to land development and general industrialization of the area), the scouring area may have gradually disappeared or over a period of time formed the new waterway bottom. If the area was never subject to a dredge event, contaminated sediments would have been buried under layers of recent deposits, creating a potential HCI requiring further evaluation and assessment for inclusion in a comprehensive contaminant inventory.

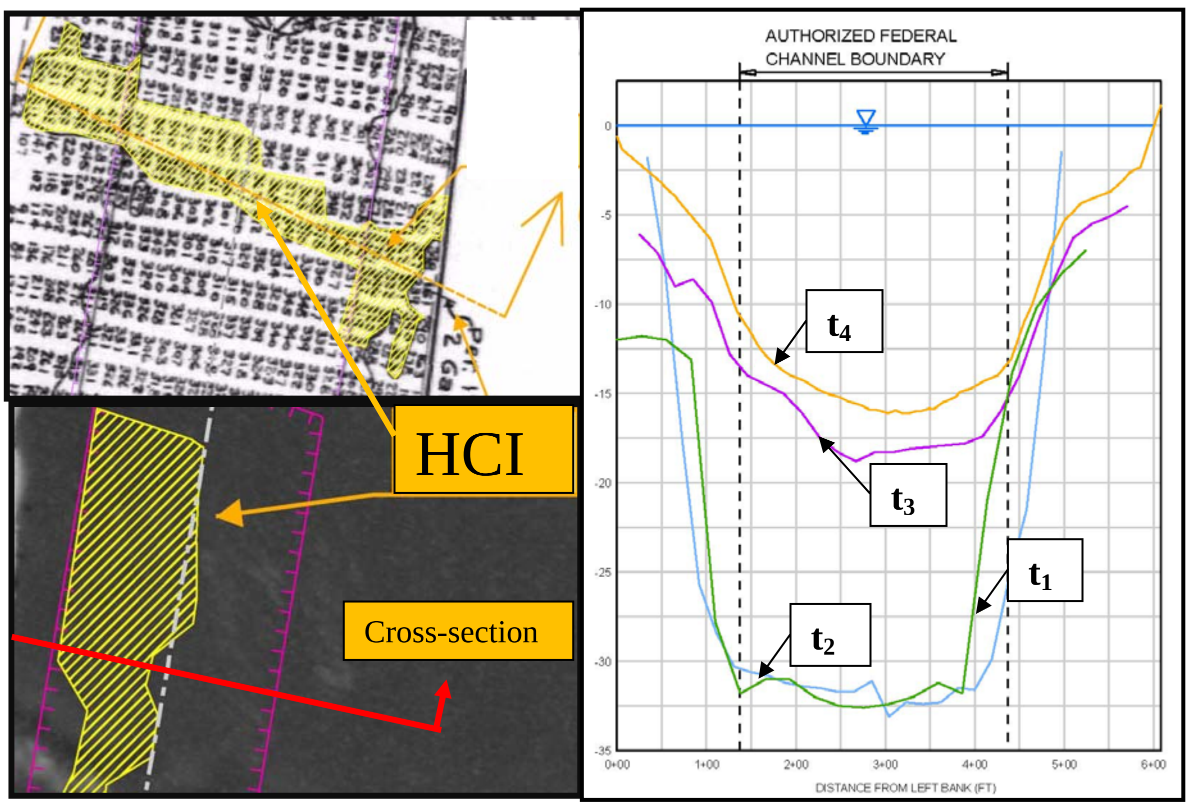

Figure 4. Example plan view and cross-sectional profile for various time intervals

5- Consecutive Dredge Events with Varying Horizontal and Vertical Extents

This criterion is used to identify HCIs on the basis of comparing successive historical dredging records by noting historical dredging depth and the horizontal dredge extent meticulously, as documented by USACE and publicly available in various digital and non-digital formats.

Comparison of dredging records is valuable for identification of HCIs, since consecutive dredging events generally followed the same navigational channel layout with slightly varied footprints, thereby creating lateral overlaps and lateral shifts. Different dredge depths can be observed between different dredge events; which, combined with lateral overlaps/shifts, could create potential sub-bottom spaces or voids which may contain contaminant inventory, reflective of the time period between specific dredge events.

6- Miscellaneous Activities leading to the Creation of Sub-Bottom Space

Miscellaneous activities including but not limited to transient berthing of navigational ships and/or placement of utility crossings/outfalls can create short-term depressions in the waterway bottom that result in a concentration of contaminated sediments at that location (further noting that in the case of cables/utilities, grid sampling programs most often purposely avoid sampling at/near these locations, thus making a potentially major mistake and missing significant HCIs). Creation of historical berthing areas for ships and placement of the utility pipelines and cables could have resulted in either prop scouring or the removal of significant amount of sediments outside of navigational channel, which are subsequently filled-in with deposited sediments and contaminant levels reflective of that specific time period during and immediately after this transient, artificially created pocket in the waterway bottom.

PROCEDURE FOR SAMPLING PROTOCOL

The proposed sampling locations and sampling depths were developed using the approach presented in Figure 5 and further explained below:

1. In order to develop an effective contamination sampling plan, select the concentration ranges as the sequential step to best fit sample locations in a layered approach. The approach is developed using a systematic trial and error process until an optimized scenario is established. Most importantly, the sample spacing is crucial in developing any single approach and the final spacing concentration levels is deemed the most effective with a designed 20% overlap within the circle of influence of each sample location.

2. The candidate HCIs from the historical search is used as a second stage bias to further develop the conceptual sampling plan by either adjusting concentration based locations and/or proposing additional locations to best-fit the HCIs.

3. The 3D Indicator Kriging results for the contamination profile is utilized to determine the estimated vertical depths for each proposed sampling location with the sampling depth equal to and/or exceeding the threshold.

4. The proposed vertical core depths of sampling locations biased for potential HCIs is based on understanding of historical dredge bathymetry. The concentration based sampling locations is also adjusted to account for historical bathymetry information resulting in varied sampling depths to adequately assess potential contaminant inventory.

5. The proposed sampling location plan is further screened and reviewed as part of the due diligence process to ensure that the plan effectively incorporated technical and cost considerations and was developed in accordance with the listed assumptions and understanding of the sampling objectives.

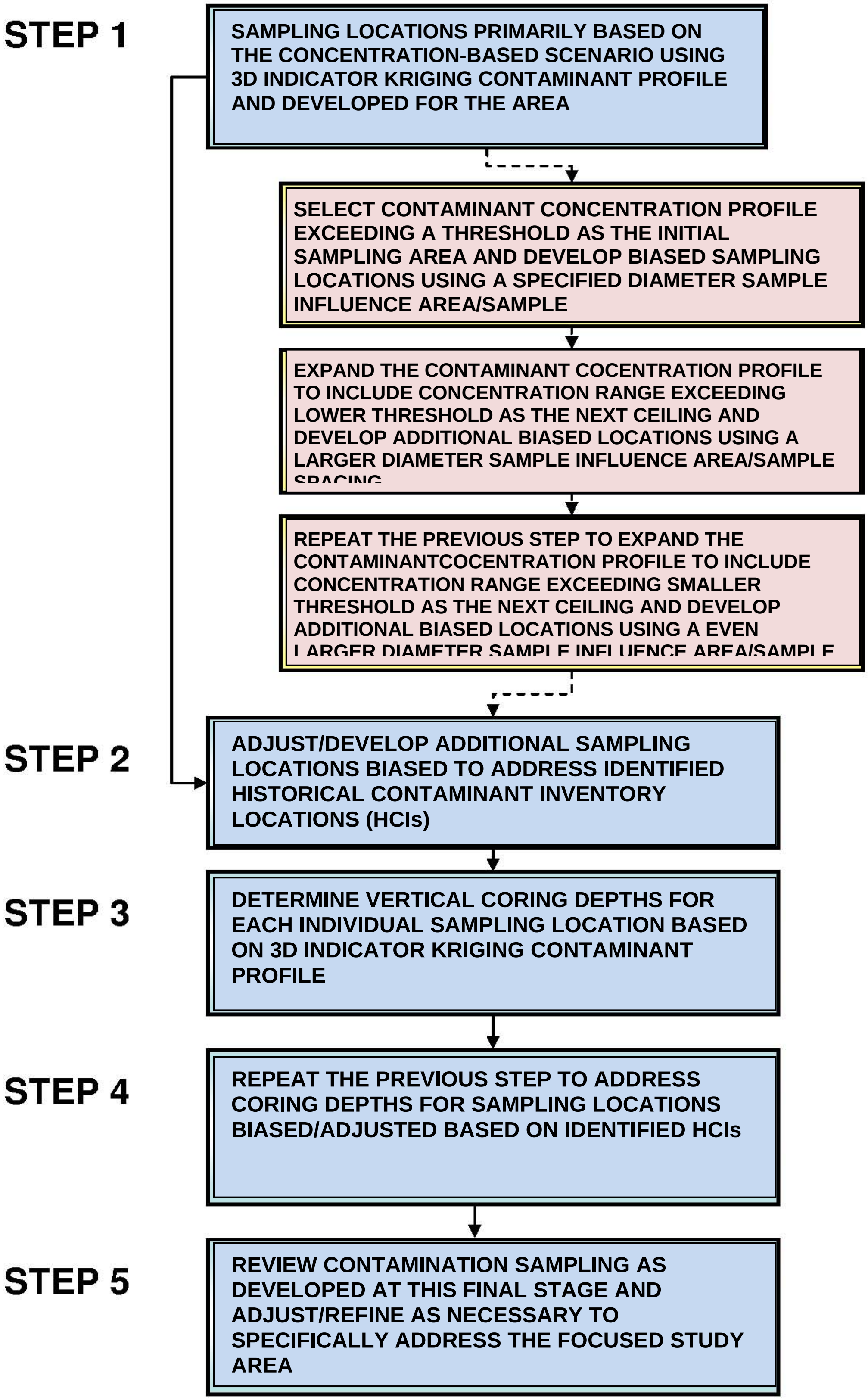

Figure 5. Conceptual sampling plan development flow chart

VALIDATING HCIs

Other technical tools such as Kriging Analyses performed to prepare a contaminant mapping profile can be utilized to cross-validate HCIs identified and located using the "Innovative Geo-statistical Technique" as illustrated in Figure 6. This figure depicts kriging analyses of existing sediment sampling data along with potential location of the HCIs obtained from the innovative geo-statistical technique. Identification and validation of the HCIs is the next step towards developing and completing a more effective investigative and feasibility effort.

As depicted in Figure 6 below, potential HCI may coexist at the same locations as the kriging analyses would produce. In areas where it is not clear (i.e., without a HCI analysis) or otherwise missed, this innovative sampling techniques would help identify those locations where historical contamination may have missed and potentially reducing the number of sampling location in the process.

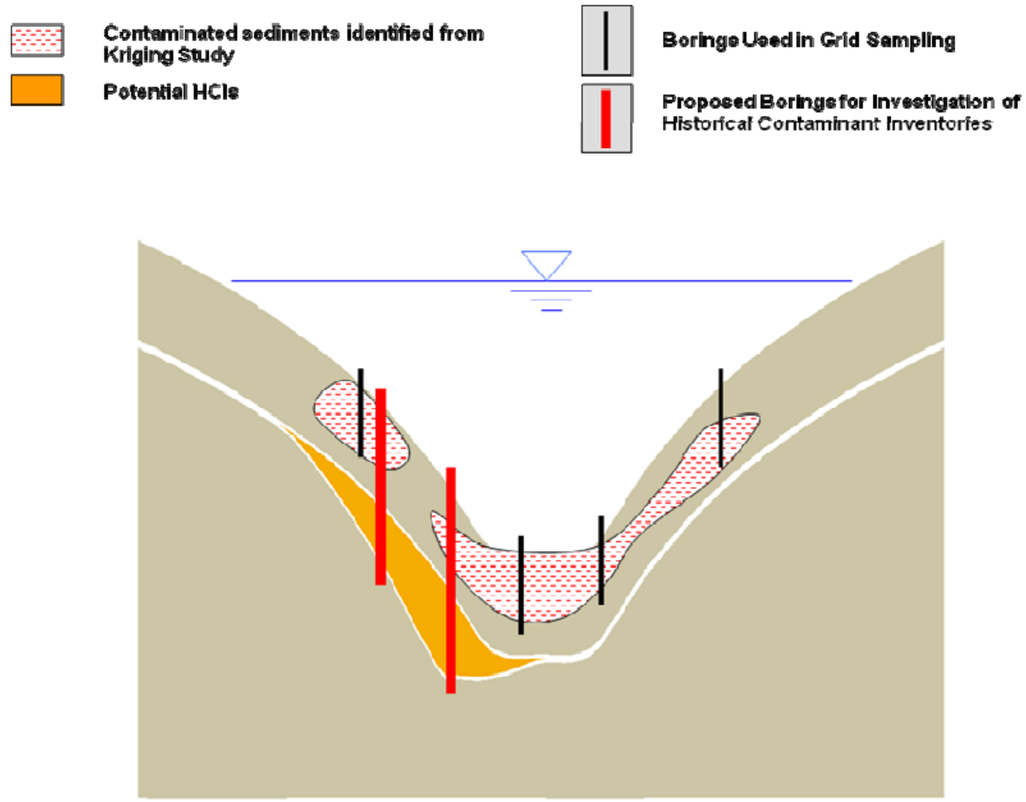

Figure 6. Schematics of kriging vs. grid sampling location in cross-section

BENEFITS AND CONCLUSIONS

Improved investigative findings resulting in a more complete engineering study are some of the benefits of the "Innovative Geo-statistical Technique" – and more importantly can avoid the inherent and potentially risky and costly mistakes that often come along with the use of an ordinary grid sampling approach (for example, purposeful avoidance of sampling near historic utility crossings/outfalls and other waterway structures where the likelihood of an HCI is actually higher depending on when it was installed versus the historic waste discharge and migration pattern). Furthermore, use of this technique can assist in better understanding the waterway system from a historical discharge perspective (Figure 7), ultimately leading to a more effective remedial strategy formulation, and thus a more cost-effective remedial design and implementation/monitoring program that better ensures there are no high-contamination pockets left behind in the sub-bottom which could later become exposed and create subsequent risks and/or re-contamination. This innovative Geo-Statistical technique should be more widely employed as it would almost certainly assist in refining the investigative and engineering efforts associated with contaminated sediment projects by creating a higher regulatory confidence level and more effectively identifying and locating the highest risk and/or cost inventories of contamination.

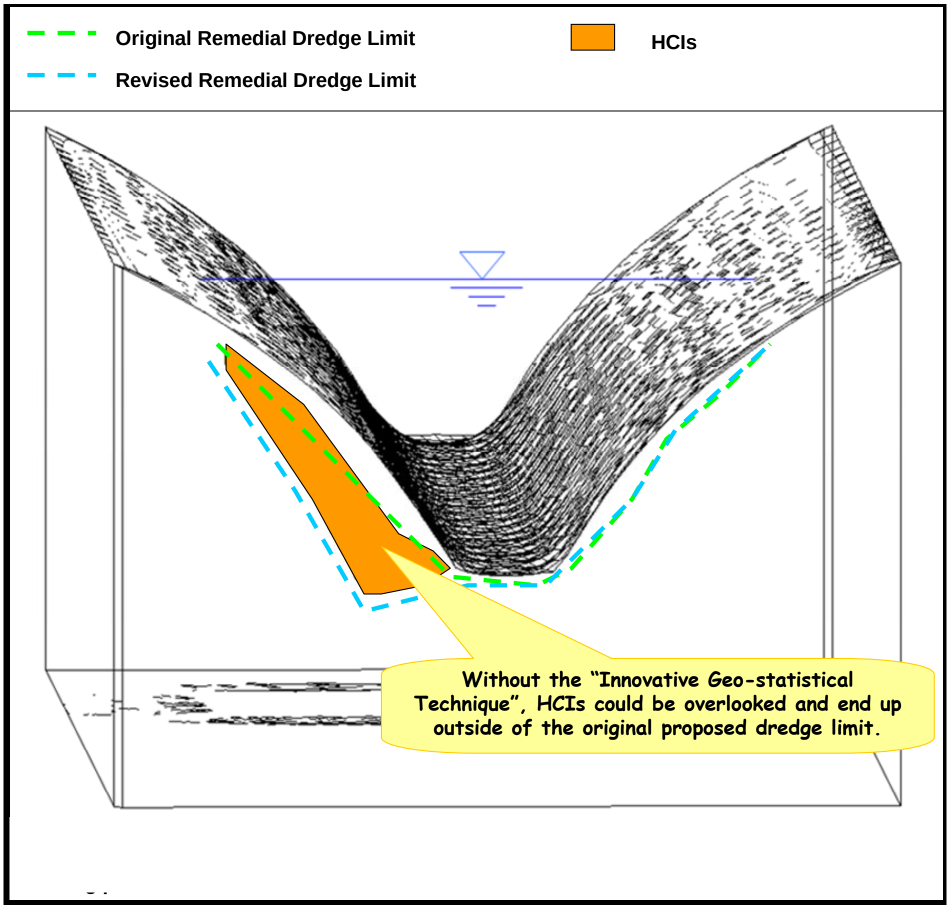

Figure 7. Original vs. revised remedial dredging limit based on the HCI sampling technique