



Dredging and the Environment – Part 2
A SunCam online continuing education course

Dredging and the Environment

Continuing Education Course

Part 2: Dredging of Contaminated Sediments

Course Summary:

This is Part Two of a multi-part course on Dredging that examines dredging as it relates to various types of environmental projects. This Course covers Dredging of Contaminated Sediments, which examines basic design concepts as well as the Management/ Constructability (“how-to”) aspect of dredging as it relates to various types of environmental waterway restoration projects. If the reader is not already familiar with the fundamentals of dredging we suggest a review of our course titled “Dredging and the Environment Part One”, also available on this site, before launching into this course, as there are a number of important terms and subjects covered in Part 1 that will be applied in this course, and without an basic understanding of the material covered in Part One the reader may not get the full benefit of this course. Subjects that will be covered in this Part 2 course are:

1. Historical Overview
2. Nature and Identification of Contaminated Sediments
3. Sampling and Site Investigation
 - a. Survey
 - b. Sediment Sampling
 - c. Quality Control
4. Design Procedures and Precautions in Waterway Remediation
 - a. Design Overview



Dredging and the Environment – Part 2
A SunCam online continuing education course

- b. Bottom Graded Finish – what to expect
- c. Dredging Accuracy
- d. Side Slopes

This course is recommended as an introduction for the individual that is interested in the overall aspects of how the Dredging process can be used as an environmental restoration tool. The course material is suggested for the designer, permitting specialist or regulator; it is intended to help broaden the understanding of this technology. It is also intended to be very practical in nature, and focused on how the dredging process can work best in the restoration of waterways. It will also cover many of the dos and don'ts of dredging and project management – as well as what can and cannot be expected and accomplished using today's available technology.

This document does not cover the regulatory aspect of the process, which would include the permitting and the analytical testing components associated therewith; although it does cover many of the field components thereof, such as practical ways to obtain the most accurate and complete test samples. Rather, it assumes that the reader already has familiarity with the regulatory/ scientific components of the subject and wishes to understand more about the design and physical aspect of dredging process itself.

Use of this course material for design purposes is strictly subject to the limitations and disclaimers set forth which are as follows:

This course is intended only as a study guide of design considerations and is limited to the specific types of projects discussed within this specific course. It is not intended nor is it possible within the confines of such a course to cover all aspects of dredging design or permitting. It is not intended that the materials included herein be used for design of facilities that exceed the size or exposure limitations as demonstrated by the examples. Nor is it intended that an engineer



Dredging and the Environment – Part 2
A SunCam online continuing education course

that is inexperienced in maritime design should study this course and immediately undertake design or permitting of a dredging project without some oversight or guidance from someone more experienced in this field. This is especially important for design of projects that could adversely affect the environment. It is important to know that there are an abundance of regulations regarding the undertaking of a dredging project and how it must be conducted such as to minimize its impact on the environment. Failure to properly follow regulatory procedures can result in severe penalties or other liabilities. This course is intended to build the engineer's understanding of maritime design so that he or she can work with other engineers who are more experienced in this area and to allow them to contribute meaningfully to a project. The author has no control or review authority over the subsequent use of this course material, and thus the author accepts no liability for secondary damages that may result from its inappropriate use. In addition this document does not discuss environmental or regulatory permitting, which is a key component of maritime projects – these matters are best taken up with professionals who routinely perform these functions as regulatory issues can dramatically affect design.

Portions of this document refer to the US Army Corps of Engineers Shore Protection Manual and Coastal Engineering Manual; and the US Army Corps of Engineers Engineering Manual on Hydrographic Surveying – EM-1110-2-1003 we wish to formally thank the COE and acknowledge the contributions and research done by the US Army Corps of Engineers as well as the US Army Waterways Experimental Station, & Coastal Engineering Research Center, Vicksburg, Mississippi for there work in producing these manuals. We also wish to thank the Western Dredging Association (WEDA) for there efforts in bringing the subject of Dredging and the Environment to the attention of the world at large, and producers of Hypack Software for their pioneering efforts and contributions to the advancement of Dredging and Hydrographic Software solutions, as well as the following equipment manufacturers and contractors for their contributions: Ellicott Dredge. LLC; Liquid Waste Technology LLC; Cable Arm.com and Mobile Dredging & Pumping Company.



Dredging and the Environment – Part 2
A SunCam online continuing education course

Section 1: Historical Overview:

It has been speculated that almost every waterway in the Continental United States has some level of contamination within its underlying sediments and that very few waterways remain virtually free of contaminated sediments. The contamination level in an average waterway may range from trace levels (Part per Billion - PPB) to very high (parts per thousand - PPT). The environmental impact of these concentrations - with respect to acute toxicity to the environment and human/animal exposure varies considerably depending on the nature of the contaminant and its toxic reaction on the recipient. Common contaminants found in waterways are Heavy Metals, Volatile Organics, Pesticides, PCBs, Oil & Grease and a host of other chemicals which find their way to the waterway from industrial or mining processes, and can also come from developed urban/suburban upland run-off as well as from concentrated agricultural practices.

Contamination levels found in sediment do not always mirror the contaminants suspended in the water column itself – rather the concentrations found are more a function of the sediment particle size – wherein contaminants tend to bind to the finer fraction soils, such as silt and sedimentary clay. Thus a rule of thumb would be that if the waterway's bottom material under consideration is primarily silt (mud) versus sand, then the respective highest contaminant levels are usually found in those finer (muddy) soils. Depths to which contaminated sediments can be found also vary considerably, depending on the geological history of the site. It was not until the Kennedy/ Johnson era (1960s) that America began to wake up to the issues of waterway pollution and it was not until the early 1980s that serious efforts were undertaken to actually begin clean-up of contaminated waterways. In those early days methods for clean-up and containment/disposal



Dredging and the Environment – Part 2
A SunCam online continuing education course

of contaminated spills were quite crude by today's standards. This was because when it came to the average maritime site - little existed in the way of sediment sample collection, field testing, and measurement devices and containment/entombment technology and areas were virtually non-existent. Fortunately, in the 30 years that have passed – many improvements have been made in equipment and technology that have greatly enhanced the effectiveness of waterway restoration; but with that said there is still a long way to go – and there is still much room for improvement at all levels. In today's market it is not uncommon for dredging and disposal of lightly contaminated sediments to cost between \$30 and \$100 per cubic yard, and if those sediments are located in large urban areas where haul distances and traffic come into play, dredging and disposal costs can reach \$300 per cubic yard. Once contamination levels breach the “hazardous” level the costs can skyrocket, typically ranging from \$500 to over \$1000 per cubic yard. Because of the relative scale of these costs – coupled with the volumes involved in even a small restoration project, the single most inhibitive factor of all is the cost of the restoration itself – which most levels of Government are not readily able to absorb. With this in mind, one can easily see where the importances of the subjects that will be discussed herein will come into play, and that any remedial project be designed be as cost efficient and effective as possible. To this end - the most critical factors of remedial dredging design are: practical design, sufficient and accurate survey, sampling and testing techniques, selection of the most appropriate dredging equipment, accuracy of dredging, and consistent and persistent quality control.

Section 2: Nature and identification of Contaminated Sediments:

The level and makeup of the contaminants found in sediment are what drive the cost of disposal, which is usually the lion's share of the dredging expense. There



Dredging and the Environment – Part 2
A SunCam online continuing education course

are several levels of contamination which form “break points” regarding how the disposal of contaminated sediments must be dealt with. These levels are set at the Federal Regulatory level (US Army Corps of Engineers & EPA), and also at state level where additional permits – including the Water Quality Certification must be obtained. Typically the regulations at the State Water Quality level are more stringent than the COE/EPA level – but not always. Generally speaking the general classifications of sediment contamination from lowest to highest are:

1. **Below Detection Levels (BDL) to Low Level Contamination:** Under present regulation these soils are not usually considered to be a serious problem to the environment – and can be disposed of appropriately in the marine environment or near-shore areas. These soils are usually sandy in nature (which naturally retain less contamination), but they can also contain significant levels of non-contaminated silt. Offshore disposal sites may be available for this soil classification – depending on the project location, however most agencies also require some level of beneficial re-use where feasible. Possible beneficial re-use in the marine habitat would be beach nourishment for sandy soils or wetland restoration/ reclamation projects for finer soils (both of which will be covered in Part 3 of this course).
2. **Low to Moderate Levels of Contamination:** These soils are more of a concern to regulators but they are not at a level of concern that they require special handling. This is the most common level on contamination found in developed areas, and the contamination is typically caused by Urban or Suburban run-off. Typically, soils with this level of contamination require containment at some upland location



Dredging and the Environment – Part 2
A SunCam online continuing education course

such as landfill cover where the contaminants will not likely leach back to the waterway, or contaminate ground water.

3. Moderate but “Below Hazardous” levels of Contamination: These soils are more of a concern to regulators, but they have not reached the level requiring extreme caution. They are usually found in Urban, Industrial or Metropolitan waterways, and they are usually the product of upland run-off from Industrial/ Mining runoff, Storm Drains or Combined Sewer Outfalls (CSOs). The later (CSOs) tend to be problematic, as during heavy rains they mix untreated waste water from public sewers with street runoff – and discharge it into the waterways, along with trash, dirt and grit from the streets. Depending on the level and nature of the contaminants in this soil classification - Health and Safety programs must be in place for dredge, survey, testing and monitoring personnel – but protective equipment such a breathing apparatus is generally not a requirement. Dredged sediments from these waterways tend to need some form of stabilization (usually dewatering and/or the addition of cement, lime or fly-ash), before they can be transported or stored. Depending on the nature of the contaminants some landfills can take these soils, and sometimes use them as cover, otherwise they must be transported to more secure and licensed upland disposal sites. In some cases underwater entombment of these soils in underwater excavations called “CAD” cells is allowed, but these come under a high level of scrutiny and are time consuming and costly to permit because of the potential for groundwater contamination.
4. Hazardous Level Contamination: These soils are a serious Public Health and Environmental concern to regulators and as such demand the highest level of scrutiny. However, with that said – there can also



Dredging and the Environment – Part 2
A SunCam online continuing education course

be sub-levels of concern within the Hazardous Levels. As an example there are some states where common pollutants such as petroleum products and some heavy metals are of less concern than some of the more complex pollutants such as volatile organics, chlorinated hydrocarbons and the like. Sediments contaminated to this level are usually found in waterways near mining sites, or in heavily industrial areas, but sediment can also turn up at hazardous levels in Urban and Suburban areas where leaking underground fuel tanks may have seeped into the waterway. These projects always require Health & Safety Oversight, and depending on the nature of the contaminants project personnel may be required to wear protective disposable clothing and breathing apparatus. These sediments almost always require some form of stabilization (cement, lime and/or fly-ash), and require secure transport to licensed disposal facilities. On rare occasions entombment in underwater CAD cells is allowed, but the permitting of such sites rightfully brings a very high level of scrutiny.

5. **Extremely Hazardous Contamination:** The extreme end of the contamination scale would be sites where sediments contain very dangerous substances. These might include radioactive wastes, unexploded ordinance, tactical military gases or other such substances that are immediately hazardous or deadly to the personnel involved. Such conditions might arise from acts of war or terrorism, or industrial accidents, such as leakage from a nuclear power plant. These conditions are thankfully somewhat rare within US borders and are extremely complex and specialized, and would require volumes to properly discuss; as such this course will not go into them in detail.

The categorizations listed above are very general in nature, and all fall under very complex and detailed rules of classification, which is based on detailed



Dredging and the Environment – Part 2
A SunCam online continuing education course

chemical analysis of the sediments. The contamination classification breakdowns given herein are for purposes of this course only - as they apply to this lesson plan. When working outside of this context of this course, such as in preparing dredging permit applications - the designer must refer directly to the regulations applicable to the specific jurisdiction where their project is located. Contamination classifications may also vary in name and nomenclature depending on the regulatory level (i.e. COE, EPA or State), thus one should not try to equate the general descriptions given herein to any particular regulation without the assistance of a professional experienced in this area of work.

Section 3: Sampling and Site Investigation

Since the subject of this lesson plan is remediation of contaminated waterways, this Part Two Course will focus on Sites that have sediments that lie in the category of type 3 and 4 contaminated materials as discussed above. In either case because of the costs and potential for exposure – any physical site investigation should be undertaken with considerable care, and only under the direct supervision of someone who has considerable experience in this field. First a word of caution: *If the work area involved is a waterway in an urban or industrial setting - there is always a potential for personnel exposure to seriously contaminated sediment. The personnel doing the site investigation could well come in contact with the sediments or to breathe vapors that become released from the sediment during the sampling process. If the project is one that has not been previously investigated or if the site history is not well documented – erring on the side of caution is advised; that is - assume that there may be sediments contaminated to the Hazardous level involved.* In any circumstance implementation of a well established Health and Safety Plan is advised, which would include provision of protective clothing and breathing apparatus. The cost of such precautionary measures is minimal compared to the ramifications



Dredging and the Environment – Part 2
A SunCam online continuing education course

involved if one of the work party members becomes exposed to sediment that testing later finds to be at toxic levels.

Survey:

Before any sampling is done it is always best to start the site investigation with a very accurate survey, which emanates from the need to accurately estimate dredging volumes as well as obtaining precise reference locations and elevations for obtaining sediment samples. This portion of the course assumes that the reader has first completed the course titled Dredging and the Environment Part 1 (Course 1), and as such will not go into Hydrographic Survey fundamentals in great detail.

Because of the potential of high dredging costs on project with contaminated sediments, where practical – it is recommend that the survey method used provide 100% bottom coverage. Selection of the survey system depends on the water depth over the actual dredging area. If the minimum water depths are in excess of eight feet, a multibeam survey is normally the recommended method. However since Multibeam will only plot the top surface of the softest mud layer, it is also recommended that a Dual Frequency, Single Beam survey be conducted concurrently with the multibeam. The multibeam survey will give 100% bottom coverage and a high definition picture of the bottom (Figure 1), which will limit the surprises, at least at the bottom surface level. The Dual Frequency single beam survey cannot produce 100% bottom coverage (at best 20% to 50%, depending in the density of the survey lines), but it can “look through” the very soft (fluid-like) sediment layer and identify the underlying strata of firmer material (Figure 2). In post-processing the results of each survey should be overlaid on one other in both plan and section view to be sure that they agree – and so that sub-strata issues can be identified and analyzed. It is at this level that fluid mud layers,



Dredging and the Environment – Part 2
A SunCam online continuing education course

dense layers and debris are initially identified for subsequent field confirmation during the next phase of the project, which is usually sediment sample collection. In combination - these two survey technologies are about the best available at the present time for obtaining site topography. If the water depths at the work site are predominantly shallower than eight feet and the waterway is non-tidal, multibeam is probably not the best solution for survey, as these systems do not work nearly as well in shallow water. Under these conditions they tend to produce multiple bottoms and false echoes that look like spikes (that cannot be differentiated from obstructions). In addition since the beam output is in the shape of an inverted “V” or “fan” shape, the shallow water requires that the line offset spacing be very close in order to obtain the proper “swath” overlap. In these cases the use of “Multi-transducer” survey systems are suggested over “multibeam” systems. Further details on these systems can be found in Course 1.

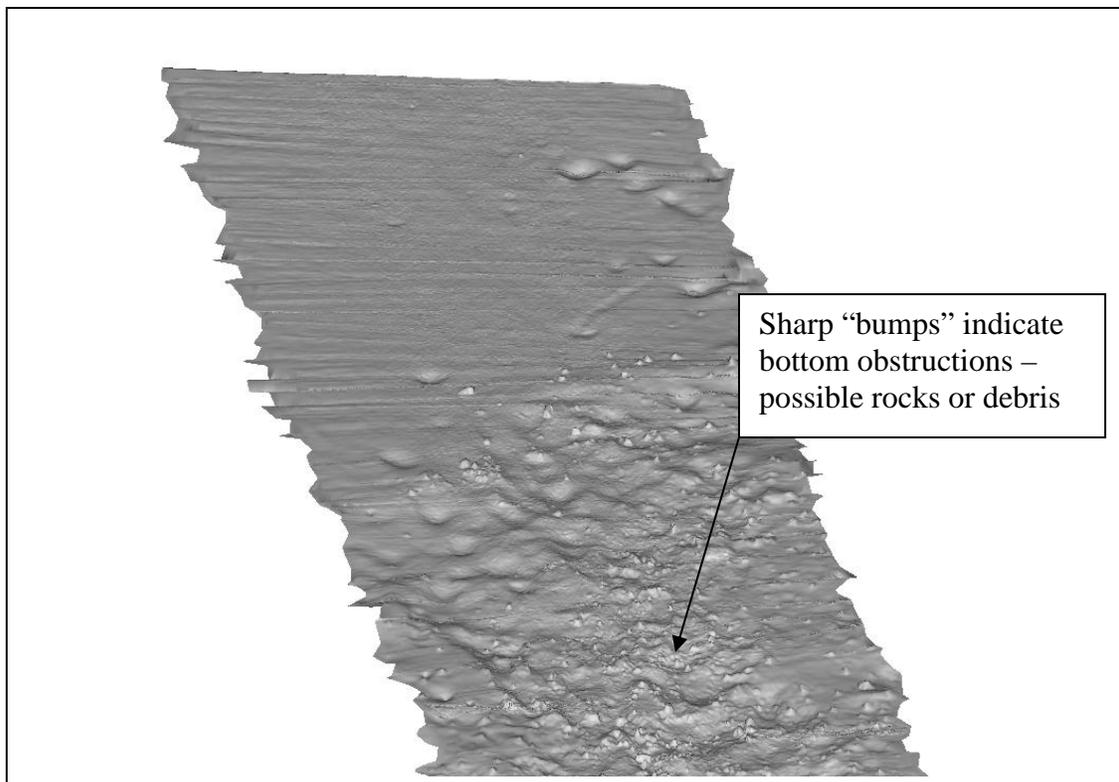
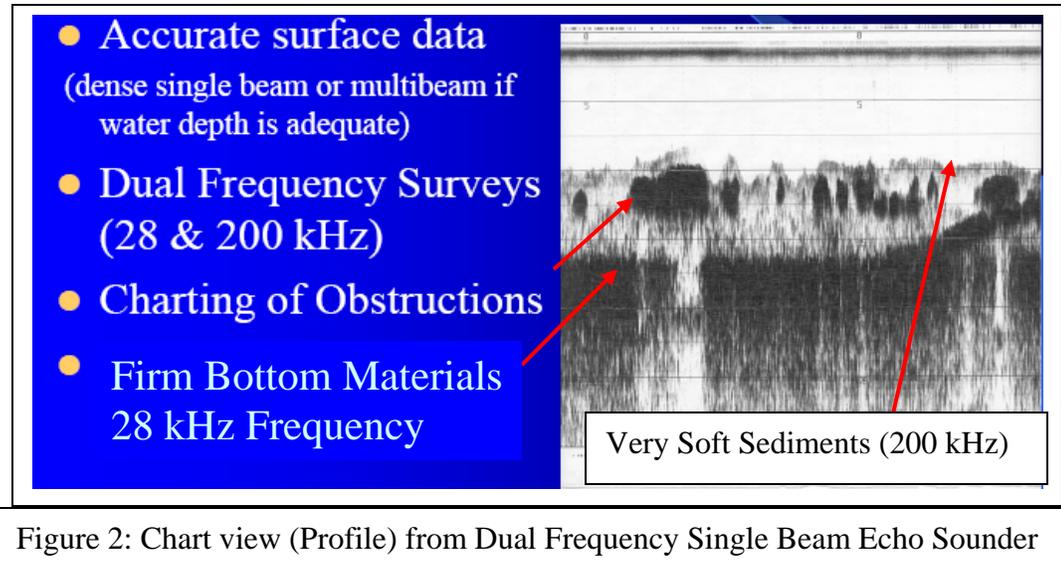


Figure 1: 3-D view of Multibeam Survey – showing rough bottom (possible obstructions)



Dredging and the Environment – Part 2
A SunCam online continuing education course



Employing the two types of survey discussed above on a project (Multibeam or Multi-Transducer & Dual Frequency) will provide the designer with an excellent picture of what the bottom surface of the waterway looks like. It will also provide accurate sub-surface elevation data for both the top of soft (fluid) mud, as well as the elevations of the firmer underlying soils (if they exist). An additional benefit is that these systems when used together will also alert the designer to the presence and extent of debris (see notes in Figures 1 & 2, as well as Figure 3), which can be a common problem in Urban Waterways. This is a serious consideration in the design, as debris in any significant quantity can double the cost of Hydraulic Dredging, and can create turbidity issues when employing Mechanical Dredges (debris prevents full bucket closure - see Course 1). Common problematic debris found in urban waterways can be automobile tires, shopping carts, bicycles, rocks, abandoned pilings, cables, ropes, and even automobiles.



Dredging and the Environment – Part 2
A SunCam online continuing education course



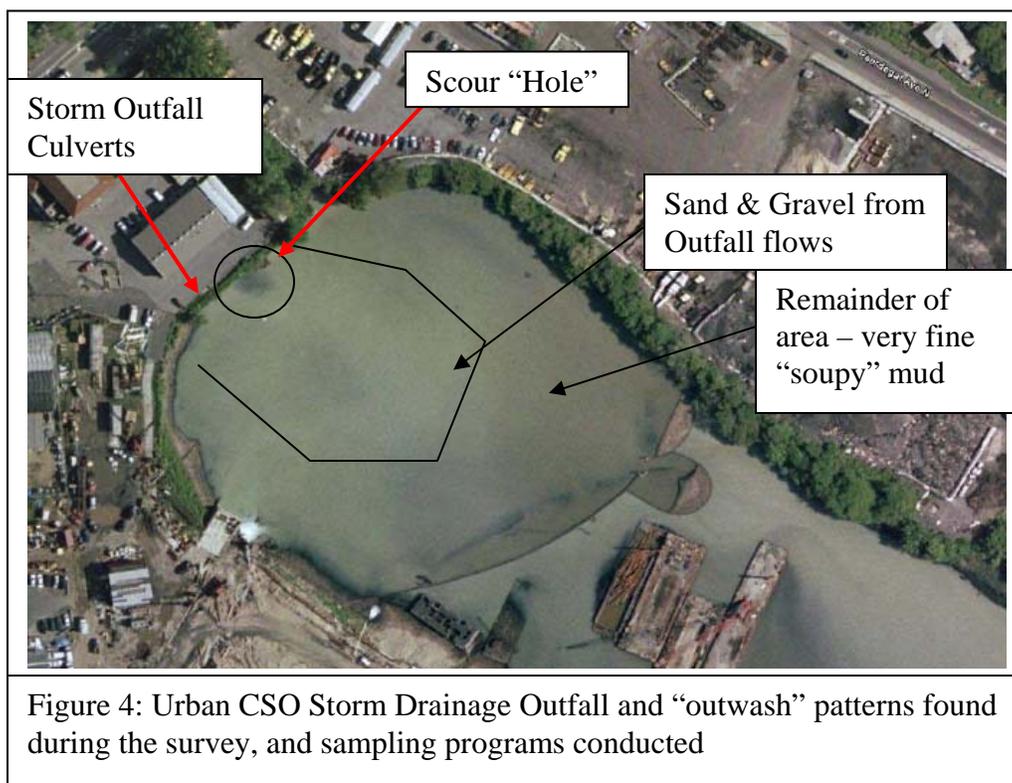
Figure 3: Common Debris in Industrial Urban Waterway (Brooklyn, NY)

Another important feature of the dual frequency component is the potential for differentiation of soil types, for instance – large storm drains tend to leave significant deposits of sand and gravel in the proximity of the outfall (Figure 4). Depending on the age, size and volume of discharge water, these sand deposits can be quite sizable – and the combination of dual frequency survey, probes and core samplings can help quantify the potential extent of the coarser soils. This becomes an important factor both from the viewpoint of disposal and planning post dredging material processing, a component that the dredging contractor will need to know to properly price the project. It should be emphasized here again, that the both the digital output and 3-D images of the Multibeam Survey, as well as the analog chart data (profiles) from the Dual Frequency Survey require follow-on investigation and analysis to determine what the “bumps” and “black spots” shown on the charts really mean. In reality they could be anything – thus the next critical step after identifying the suspect areas is to do investigative



Dredging and the Environment – Part 2
A SunCam online continuing education course

follow-up. If the site is tidal and drains at low tide, this follow-up can be something as simple as re-visiting the site at low tide (Figure 3); however if the water is deep, other approaches must be considered. One consideration is to probe the suspect areas with a steel pipe and attempt locate and “feel” what the obstructions might be. While this might sound archaic it is actually quite effective – for instance probing rubber automobile tires – with steel rims would feel different than trash bags or shopping carts, (these are among the most common forms of urban debris).



Probing requires a certain degree of skill and should be done while employing hydrographic tracking software to keep track of the probe locations, it is usually much faster than attempting to use a coring device. It is generally advisable to obtain at least some preliminary or informal sediment samples during the survey, such as coring to identify soil properties, nature and hardness (i.e. mud, sand,



Dredging and the Environment – Part 2
A SunCam online continuing education course

soft, hard), these properties will generally dictate the type of sampling equipment needed for the return visit.

Sediment Sampling:

Once the survey work is completed, the next logical step is to determine the best locations for obtaining sediment samples for analytical/ chemical testing.

Typically this is driven by a “sampling plan” which must be submitted to the regulating agencies for approval before any formal sampling is actually done.

There are usually established guidelines for how many samples are required, the preferred locations as well as the required depth of the cores. Some projects require samples be recovered at several depths within each core, as well as sampling below the finished dredge depth to ascertain the level of contamination at the final dredge elevation. This can be a complicated process in some locales - as the Federal Guidelines may differ from the State Guidelines, and it is usually best to meet with or at least consult with the person(s) doing the regulatory review during this process to make sure that everyone is clear on procedures.

Once the sampling and testing plan has been approved, the next step is to mobilize a survey vessel to perform the actual sampling. The appropriate size and capability of the survey vessel will vary depending on the water depth, as well as the anticipated depth and consistency of the contaminated sediment.

Normally sediment samples must be taken to the full depth of the planned dredging, including any anticipated “overdepth” dredging, as well as some additional depth beyond the maximum anticipated dredging excavation depth (at least two additional feet is recommended).

If the primary soils are coarse sand and gravel, or dense mud – the sampling will require some form of mechanical coring device. The most common and the most versatile device is known as a “Vibracore” sampler. This device consists of a



Dredging and the Environment – Part 2
A SunCam online continuing education course

metal sample tube (3" to 4" in diameter), which is clamped to a driving head equipped with a hydraulically driven vibrator. The head sits on top of the sample tube (Figure 5 – Left), and is supported by a cable in such a way that the tube hangs straight down with the vibrating head on top. The driver/tube is lowered to the bottom and allowed to penetrate into the soft surface mud under its own weight – then the vibrator is started and the vibrating action combined with the weight of the drive head push the sample tube into the bottom soils. When the tube has reached the desired sample depth it is then extracted using the hoisting cable. When medium to soft mud is the most common material at a site - good samples can be obtained with either a Vibracore sampler or alternatively with hand “pushed” core sample tubes. Very soft, fluid-like mud, of the variety found in confined waterways near storm drains and CSO outfalls usually requires a gentler approach. Where water depths permit - very soft to fluid sediments are best sampled by hand coring methods, at least for the first four to eight feet of depth. Cores deeper than eight feet generally require reverting back to a Vibracore Sampler.

Because of the weight of the Vibracore Driver, and the metal sample tube jacket, the driver is usually supported and manipulated from a “boom” or tripod, which can be in the form of a “wishbone” (Figure 5 – Left); samples can be taken up to 16 feet below bottom, beyond that depth the handling of the tube can become difficult. A Vibracore sampler capable of making a 16 foot core normally requires a support vessel at least 25 feet in length, with an open rear deck area where the tube can be laid down for the removal of the sample. The advantage of Vibracoring is that it can easily work in deep water, as the entire tube and vibrating head are independent and are limited only by the length of hydraulic hose required to reach the bottom, use in 50 feet of water is common. With that said – if there are currents in the waterway then anchoring of the vessel may be



Dredging and the Environment – Part 2
A SunCam online continuing education course

required, which can prove to be difficult and time consuming. This is where a very experienced boat operator is essential – in that they can many times hold the boat on station using a combination of skill, visual land references, GPS and the vessel’s power (this is generally easier with dual motors or engines).

Hand core sampling can be performed with a straight section of clear “Lexan” tubing (the type used to line “Shelby” type sample tubes), however their use is limited to soft or fluid like sediments; otherwise they become difficult to extract. In soft mud the tube is slowly and easily pushed into the sediment to the desired depth, and then gently extracted. The skin friction of the sediment generally holds the sample in place. Once the sample is extracted, it can be capped and stored until the samples can be transported to shore for post-processing.

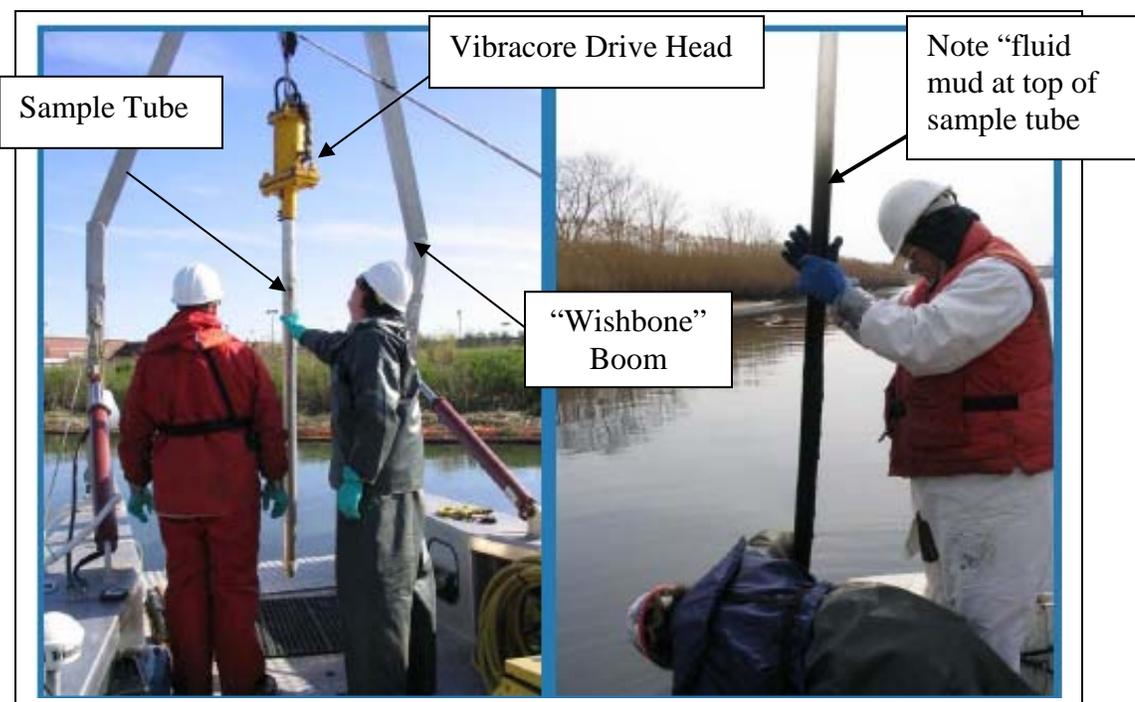


Figure 5: Vibracore Sampler (Left) in lined metal casing, vs Hand “push” cores (Right) with clear sample tubes



Dredging and the Environment – Part 2
A SunCam online continuing education course

If the sediment is very soft or “fluid” for a significant depth sampling becomes a bit more difficult and requires some experience, as the samples will tend to slide back out of the tube as it is extracted. Adding a sample “retainer ring” is of no help in these cases, because they usually clog or provide just enough of a restriction that they prevent the sediment from entering the tube. When this happens the restriction essentially seals the end of the tube just enough so that it simply pushes the fluid mud aside as the tube is advanced downward – resulting in an empty tube when the sample is extracted. The vibracore is of no help here either, as the vibrating actions breaks down the delicate cohesive soil matrix – again allowing the sample to slide out when the tube is extracted (with or without the sample retainer ring). As a fall back method – use of vacuum-plunger type samplers sometimes work in these cases – but are very limited with respect to the length of sample they can take – usually 2 to 3 feet maximum at a time. Thus in this writer’s experience when it comes to layered very soft and fluid mud conditions - the hand coring method and an adaptive learning curve seems to work best. In some cases the samples must be taken in stages, that is to say - obtaining the soft to fluid like mud samples by hand core sampling, then opening a larger entry hole and taking the deeper sediment samples with a vibracore. In both cases extreme care and constant QC are required to be sure that the extracted samples replicate the actual subsurface sediment profiles. Failure to follow very careful and appropriate sample collection techniques in soft mud conditions will produce completely erroneous results which can completely corrupt the project design. Figures 6 and 7 are typical of the sediments found in Industrial and Urban waterways – these particular samples were found to be contaminated but not to “hazardous” levels.



Dredging and the Environment – Part 2
A SunCam online continuing education course



Figure 6: Vibracore Tube liner (Left) opened for sample removal. (Right) sample of typical “soft mud” CSO Outfall sediment.

Once extracted from the “in-situ” environment sediment samples have a limited shelf life with respect to analytical/ chemical testing. It is very important to keep these time constraints in mind while performing the sample gathering – especially on hot summer days. Depending on the type of testing being performed, samples such as these need to be post-processed in a timely manner and stored in ice filled coolers until they are delivered to the laboratory for testing. If the site is to be dredged using a Hydraulic Dredge it is also advisable to obtain samples of the sediments that will be dredged (Figure 7) so that they can be used for “bench testing” by either the geotextile “tube dewatering” process and/or the “Mechanical Dewatering” process.

“Bench tests” are scale model tests done to determine the dewatering characteristics and properties of the in-situ sediment and are valuable for several aspects of the design:

1. They determine the best and most efficient type of dewatering polymer for the dredging operations. This is especially important – as not all polymers are non-toxic to marine life.



Dredging and the Environment – Part 2
A SunCam online continuing education course

2. They determine the rate and time required to obtain the optimum dewatered state (important for planning the size of the staging area required for dewatering).
3. They determine the levels of contamination and suspended solids that can be expected from to remain in the dewatering process effluent. (Important with respect to obtaining the Water Quality Certificate as well as handling, treatment and disposal of process water).



Figure 7: Samples of “fluid” or “soupy” upper sediment layers, Being collected for dewatering “bench tests”

If the site is to receive a final “Capping” at the conclusion of the dredging project - the anticipated final dredge depth must also be assessed to determine its ability to effectively support the capping materials. In plastic soils the test that typically determines the capping bed strength and suitability is the “Shear Vane” test. To perform this test one must first know the approximate final depth of dredging,



Dredging and the Environment – Part 2
A SunCam online continuing education course

which in some cases may not be determined until after analytical/ chemical testing is completed and the results reviewed with regulators. Assuming however, that at some point this depth is determined – the sampling crew will need to mobilize to the site equipped with a special shear vane testing device. If the final dredge depth is deep enough that it extends to dense virgin soils, shear testing is usually not necessary, however most typical marine restoration sites do not go to such depths, and generally tend to found capping on shallower, and softer sedimentary layer. Companies that routinely do this type of sampling will normally have access to a custom made shear vane tester that is specifically designed for these very low shear pressures.

It is important to perform shear vane tests at the design dredge depth as well as one or two feet above or below that depth. This is because the finished dredge footprint will often vary by at least this much off of the neat design depth; thus the use of a range of values obtained at these various depths help make the best determination as to whether the bed soils are suitable for supporting the final cap materials.

Quality Control:

For all of the survey and sampling that has been discussed thus far in this course, the one factor that cannot be emphasized the enough is quality control. System calibration and keeping accurate records of vessel positions, with electronic time tags, and tidal fluctuations are of utmost importance. Putting things into perspective, when dealing in the type of projects that are being discussed here – and with dredging costs commonly in the realm of \$100 per cubic yard, (and often far higher) in the present market place; at \$100 per cubic yard – a survey error of just one inch can create cost fluctuations of one dollar per square foot of dredge footprint. Putting factors like into the scale of a small



Dredging and the Environment – Part 2
A SunCam online continuing education course

project such as a barge slip, with a footprint of only 200' x 1000' – one vertical inch of error would cause a cost swing of \$200,000, a one foot error would create a cost swing of \$2.4 million dollars. As such, based on cost alone, the emphasis of accuracy and good quality control becomes self evident.

Another fact of life is - the dredging and marine construction industry has historically been one of the most litigious of all other construction trades combined, and with potential cost swings in the range just described it is little wonder. A prudent project engineer/ manager should always keep this thought in mind when gathering site data for a project – as these projects have a propensity for ending in litigation. He or she should also keep in mind that the entire workspace of the project is covered by water, and that the survey, sampling, and testing programs are all that there is with respect to preparing a plan that truly represents the work site. The procedures outlined in this course and Course 1 are the bare minimums one should consider when undertaking a waterway remediation project, historically - shortcutting any of the steps, especially in the area of survey, sampling and quality control has most often proved to be a shortcut to the litigation process.

Section 4 - Design Procedures and Precautions for Waterway Remediation Projects.

Designer's overview:

Once the survey, sampling and testing is completed and the project goals assessed, and the final dredge depth/ parameters and extents of dredging are determined the design can proceed. This portion of the course is designed to help the project designer become aware of the nuances of design that are specific to dredging, as well as recommend dredging methods, precautions and procedures that will help make the project successful. The most common



Dredging and the Environment – Part 2
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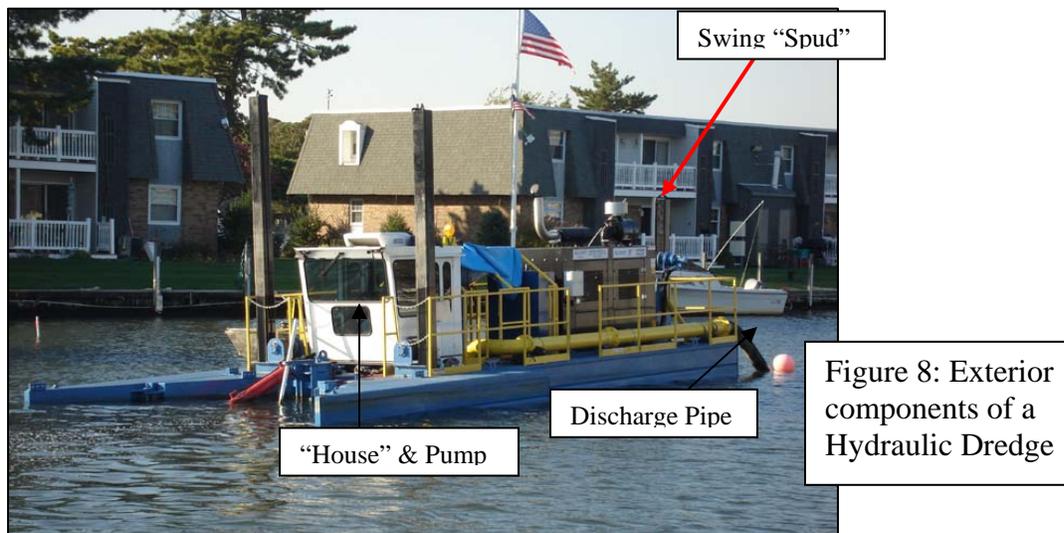
misconception that I have run into in my 40+ years around dredging is that engineers/designers who are new to the dredging trade do not understand that fundamentally a Dredge is designed to be an Underwater Earthmover and that it cannot perform the functions likened unto that of a Road Grader. 95% of all dredges are strictly designed to make shallow water deeper – that is to say – reach a common minimum project depth with a working tolerance of an additional one to three feet (depending on equipment size and type), and to move those wet soils from the waterway bed to another location as efficiently as possible. The historic development of dredging has never been geared toward “fine grading”, and until recently very little dredge equipment design effort has been geared toward anything other than higher production – while accuracy has always been an afterthought. Thus when it comes to the requirement of “fine grading” often associated with contaminant removal projects the best one can hope for is a rough bottom that varies from one to three feet off of design grade.

Modern electronic grade control devices are helping this situation somewhat – but there is still a very long way to go. In fact given even the best dredge operator equipped with the very best in electronic control, has little - if any ability to create a smooth finished grade or a complicated contoured bottom with multiple grades - or even a uniformly graded side slope condition for that matter. One large factor in this equation is that the dredge operator cannot “see” the underwater work area the way an operator can when working on dry land. Thus the whole visual aspect that operator’s are used to working with is missing – and relegated to a computer screen. In many such cases the really good dredge operator can work to some degree by “feel”, but the soft soils that are encountered in remediation dredging are usually impossible to “feel”. There is also a misconception by most lay-people is that the computer screen is acting as a form of video camera –but this is not the case, it is merely reporting what



Dredging and the Environment – Part 2
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should be happening – not what really is happening. With that said there is ongoing research in this area – integrating side-scan into the systems – but this technology is still years way from mainstream production. Until that time comes - electronic devices have no ability to measure the unseen and inadvertent soil displacement that takes place as the dredge is working. Thus for all of the electronic gadgetry that has evolved over the past 30 years, the accuracy of the final work product in most cases still comes down to the skill of the individual operating the dredge, and to this day this process still remains more of an art than a science. With that as our baseline of design understanding – the engineer should now have a mindset of how dredging differs from other design assignments; hopefully the upcoming sections will provide some further enlightenment toward that end.



Bottom Graded finish – what to expect:

Basically most dredges whether Hydraulic or Mechanical work by pivoting off of their holding “spuds” (vertical steel shafts that are set into the bottom to hold the dredge in place – see Exhibit 8). Some other dredges work off of anchored



Dredging and the Environment – Part 2
A SunCam online continuing education course

cables to hold them in place, but still dig using the arc like swing; likewise “swinging ladder dredges (pictured) hold the hull in place and move the cutter in an arc. This principle applies to 95% or more of all hydraulic or mechanical dredges, (Figures 9a & 9b). With that said - each type of dredge (hydraulic vs mechanical) leaves its own type of signature “footprint” with respect to a “finished dredged bottom”.

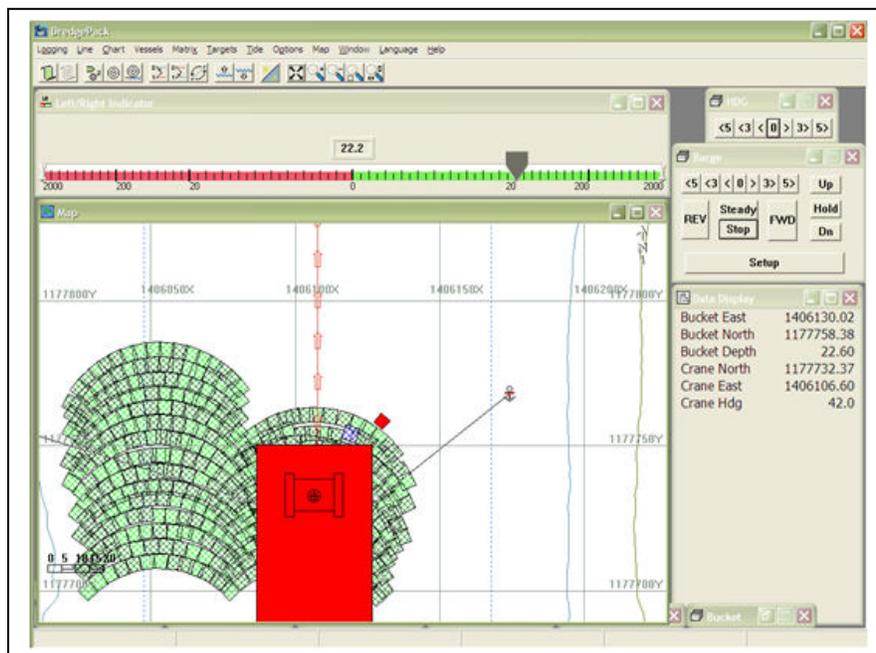


Figure 9a: Mechanical Clamshell type Dredge – digging radius arc – note bucket positions (Photo from “DredgePack software - courtesy of Hypack.com)

Mechanical dredges using conventional clamshell buckets tend to leave a marked bottom that follows the pattern of squares shown in Figure 9a. If that dredge is using a conventional clamshell bucket, (Figure 10) it will leave a pattern of excavated “pot holes” that generally resemble the rounded cutting edge of the bucket in a closed position. However, if the dredge is using an “Environmental Bucket” (Figure 11) it will tend to leave a more leveled bottom.



Dredging and the Environment – Part 2
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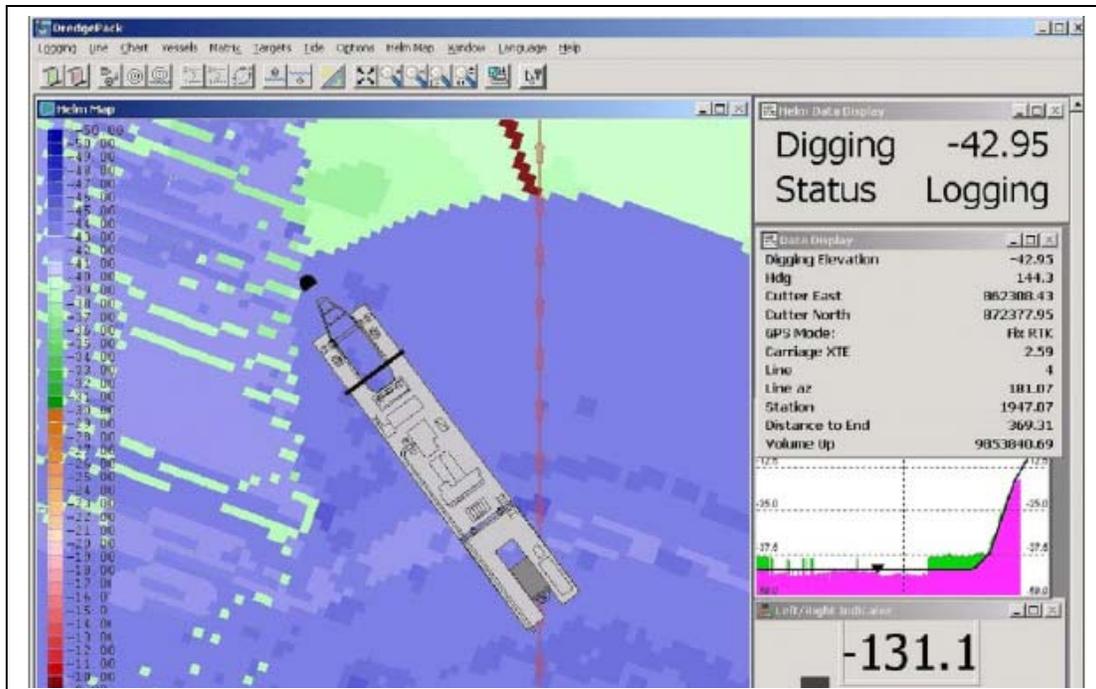


Figure 9b: Large Hydraulic Dredge – digging radius arc from stern “holding spud”
(Photo from “DredgePack software - courtesy of Hypack.com)

The problem with either of these buckets is that when they close on muddy sediments they tend to squeeze the materials – not unlike a tube of toothpaste, which allows a relatively small, but significant percentage of material to escape out to either side – as mounds or windrows (some environmental buckets have features that control this spillage to a degree – but this process takes very slow and close operator control to maximize avoidance).

In any event - most clamshells leave some form of ridges of residual material between “bites” of the bucket. If a residual layer of contaminated material is not problematic to the project goals, the dredge operator can periodically fully open the bucket and “sweep” it from left to right - which “knocks down” most of the residual high spots. This process is 90% effective at leaving a somewhat “flatter”



Dredging and the Environment – Part 2
A SunCam online continuing education course

bottom surface, although the trade-off is that it will create pockets of residual contaminated mud because it “sweeps” that residual sediment into the depressions.



Figure 10: Conventional Clamshell bucket, with rounded digging “nose”, generally used for harder bottom materials

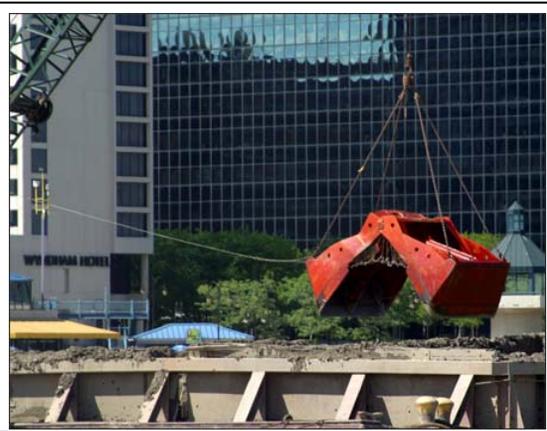


Figure 11: “Environmental Clam Bucket, with flat cutting edges (Photo courtesy of Cable Arm Inc. - Cablearm.com)

Where maximum contaminant clean-up is required as a project goal, multiple passes by the dredge over the same area (typically using an environmental bucket) followed by sampling and testing after each pass has historically been the only sure remedy to correct this spillage situation. The straight cutting edge of the Environmental Bucket and its level digging geometry has a decided advantage over the rounded conventional bucket in such a situation, and in fact, properly operated – the Environmental bucket tends to leave the “flattest” finished surface of all dredging methods. The disadvantages of the environmental bucket are its inability to dredge anything but soft sediments effectively and its susceptibility to closure problems when debris is encountered and gets lodged between the closure surfaces.



Dredging and the Environment – Part 2
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If one has ever viewed a freshly plowed field, with ridges and “furrows” – this is a very close description of the finished bottom surface that a conventional Hydraulic Dredge leaves. The obvious difference being that the “plowed furrows” are in the form of large arcs (Figure 9b), rather than the straight lines of a farmer’s field. The width and depth of the furrows are proportional to the size of the dredge and the corresponding size of the cutter head. As an example, a traditional 12” hydraulic dredge (as in Figure 8) would leave a furrow pattern about 12” to 14” deep, with the crests of the furrows about two to three feet apart from crest to crest. Several innovative contractors have designed special conical cutter heads (in lieu of the traditional rounded head), or horizontal wheel cutters that alleviate this problem to a degree; some have also experimented with hoods, flapper valves and other devices to help reduce turbidity. However, these tend to be ongoing private experimentation projects rather than commercially available dredging accessories.





Dredging and the Environment – Part 2
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One of the few exceptions to the “arc swing” rule in the class of dredges being discussed for environmental work - are a class of small dredges commonly referred to as “Mud-Cats™”, technically known as “horizontal auger” dredges (Figure 12). The MudCat™ class of dredge does not work off of “spuds” - rather it traverses the work site by pulling itself along a long taught cable, usually pulled between the opposite shores of a water body. These are basically hydraulic dredges with “ladders” but instead of a conventional cutter head, they have a large horizontal auger as shown in the exhibit. The simplest way to describe the function of this equipment is that it operates along the lines of a floating “bulldozer” combined with a snow blower running in reverse. That is to say – as the dredge pulls itself along the cable, it pushes the mud into the auger using a blade type cowling, then the auger mixes the mud with the additional water required to create a pumpable mixture; whereupon the mixture is then sucked into the pump intake located at the end of the ladder and then pumped to a disposal or processing site. This is a very efficient type of dredge for small, confined and shallow restoration projects; it also leaves a fairly smooth – well graded bottom. The problem with this type of dredge is that it tends to “bulldoze” “wind-rows” of excess material to either side of each pass. These windrows can be sizable and will become problematic if not tended to, the only known remedy is again - performing multiple passes over the work area to either clean up, or knock down the windrows. On projects where contaminated material removal is to be maximized – three or four “cleanup” passes over the same area are usually required for this type of dredge; however the advantage over other dredging methods being considered here - is that when this clean-up process is done properly – the site is usually left with a much “cleaner” bottom condition. The biggest down-side with this machine is its susceptibility to debris – abandoned chains and wire rope are particularly problematic and can cause extended shut-downs for their removal.



Dredging and the Environment – Part 2
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Dredging Accuracy:

Although this subject was covered in Part 1 of the Dredging and the Environment Course there are some aspects of this subject that bear review in more detail. Despite the discussion at the outset of this section, most remediation projects require some advanced form of accuracy over traditional methods to meet project goals – cost considerations enter into this picture as well. Where the previous sections discuss the limitations of dredging equipment with respect to what the equipment can and can not do – the emphasis in this section is to suggest guidelines for making the most of the chosen equipment with respect to achieving the best performance. There are a number of effective tools available for achieving the better dredging accuracy in the form of electronic positioning systems for both the positioning of the dredge hull, as well as the digging device (clam bucket, cutterhead, etc). Both visual images are important, as they help the operator orient him or her self to the project digging template. There should also be an electronic depth sensor available on the digging device (bucket, cutterhead) so that the operator can get an accurate fix on how deep he or she is digging. All dredges are routinely equipped some form of standard “mechanical device” that performs this function, but they are rarely accurate to within a 6” to 12” of true digging depth; whereas electronic depth measuring devices allow theoretical depth measurement to within fractions of an inch. For the best possible dredging results – these devices require careful set-up and diligent calibration, as well as several digging trials followed by confirmation surveys. In addition to the depth sensor, there must also be an electronic water level sensing device (i.e. electronic tide gauge) – with wireless communication to the dredge, preferably linked to the dredge’s onboard computer. These devices are an absolute necessity for work in tidal waterways, and are even recommended as a quality control check for non-tidal projects. All of this position, swing angle,



Dredging and the Environment – Part 2
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digging depth and tide (or water level) electronic data then needs to be fed to the on-board computer equipped with dredge guidance software such as that pictured in Figures 9a & 9b. This creates a “heads up” package for the operator to view while working; the visual screen image should also be programmed with the dredge footprint, as well as the required dredging depths and other pertinent data. As an important reality check however, the design engineer/ project manager must keep in mind that while all of this finite measurement helps the operator a great deal – it only reduces the margin of error – it does not eliminate it. With that said - proliferation of these systems throughout the industry has greatly enhanced operator acceptance and improved dredging accuracy – and a properly working system is critical to a dredging project where dredging accuracy is required.

All of this comes at cost however, that is to say – the first cost is only the beginning - these systems require constant maintenance, as well as monitoring and diligent calibration checks on a regular basis. Thus if the designer specifies the use of electronic measurement for a project where accuracy is important, he/she also needs to carefully specify guidance for the contractor with respect to maintaining and routine re-calibration on a regular basis throughout the project. There is far more to be known on this subject than the volume of this course has space for – however this writer and others have produced a number of reports and case studies on dredging accuracy that can be obtained from the Western Dredging Association's (WEDA) archives of presentations at WEDA Conferences.

Side slopes:

The next greatest misconception in dredging design is that a common dredge can produce a uniform, neatly graded sloped surface. This is not the case, in fact



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the reality is that the best one can hope for on sideslopes generated by a dredge is a jagged “stepped” slope, that collapses on itself and reaches some randomly uniform natural angle of repose (usually between 2:1 to 4:1 – depending on the soils). On some projects this is all that is required to achieve the project goals, however on many environmental restoration projects as well as remediation projects it can create problems.

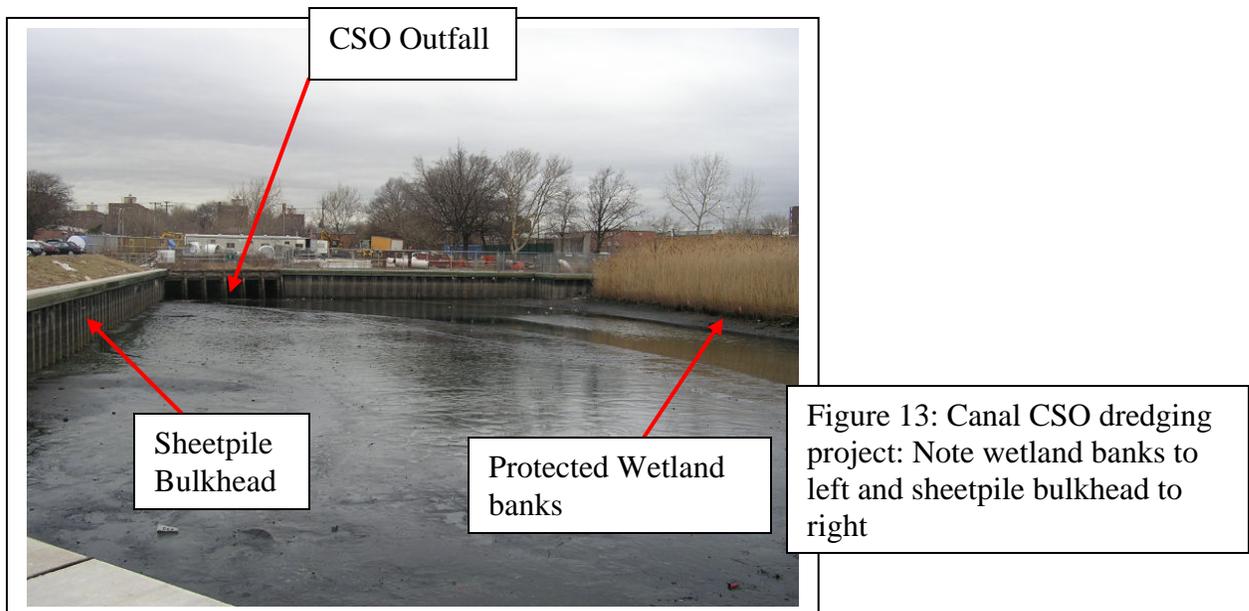


Figure 13 is an actual planned dredging site where the goals of the waterway restoration project required removal of contaminated sediment right to the edge of the wetlands (right side of photo), and up to the bulkhead to the left as well. The first design constructability issue was how to dig up the edge of the wetland marsh without undermining it – which is much more difficult than it first seems to the average viewer. To understand the problems involved one must have a basic understanding of the field conditions under which a dredge operates. Referring to Figure 14, which is a cropping of Figure 9a, the red circled areas are an example of the sideslope plan view configuration typical of almost any dredge. Note how a dredge leaves a “saw toothed” finish on either side of its work limits – which can



Dredging and the Environment – Part 2
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be quite large depending on the size of the dredge – even on small dredges five feet from the root to the tip of the “saw tooth” is common, and could be considered as the minimum to be dealt with.

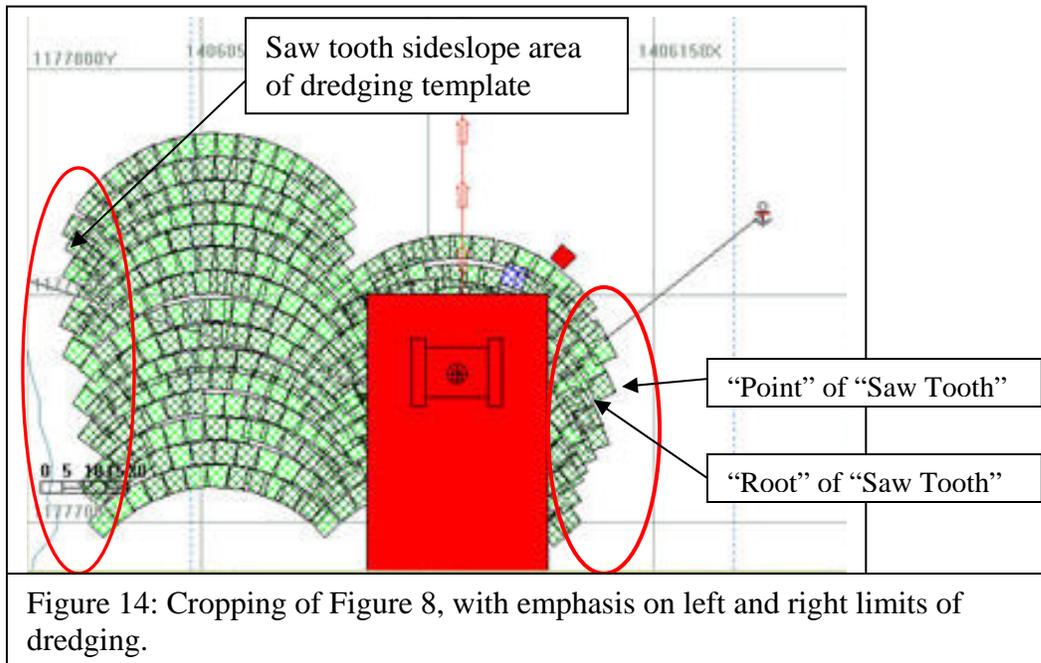


Figure 14: Cropping of Figure 8, with emphasis on left and right limits of dredging.

This brings up a very important point with respect to a little known industry standard – which applies only to dredging, and flies in the face of what most engineers who are not experienced in dredging projects would logically think. The Industry standards of practice for dredging of the “side slopes” of any project are such that when a slope is shown or called out on a plan, it is assumed by the dredging contractor that he/she has the right to perform a rough “box-cut” that will allow the slope to fall at some rough approximation of the final slope called for (see Figure 15). Further, the engineer is understood to have investigated the soils and warrants that the soils will stand to the slopes indicated – unless specifically specified otherwise. This is primarily because a conventional dredge has no real way to physically shape the slopes (such as a contractor would when



Dredging and the Environment – Part 2
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building a highway embankment) – other than by way of the natural “box cutting” process indicated in the Figure below.

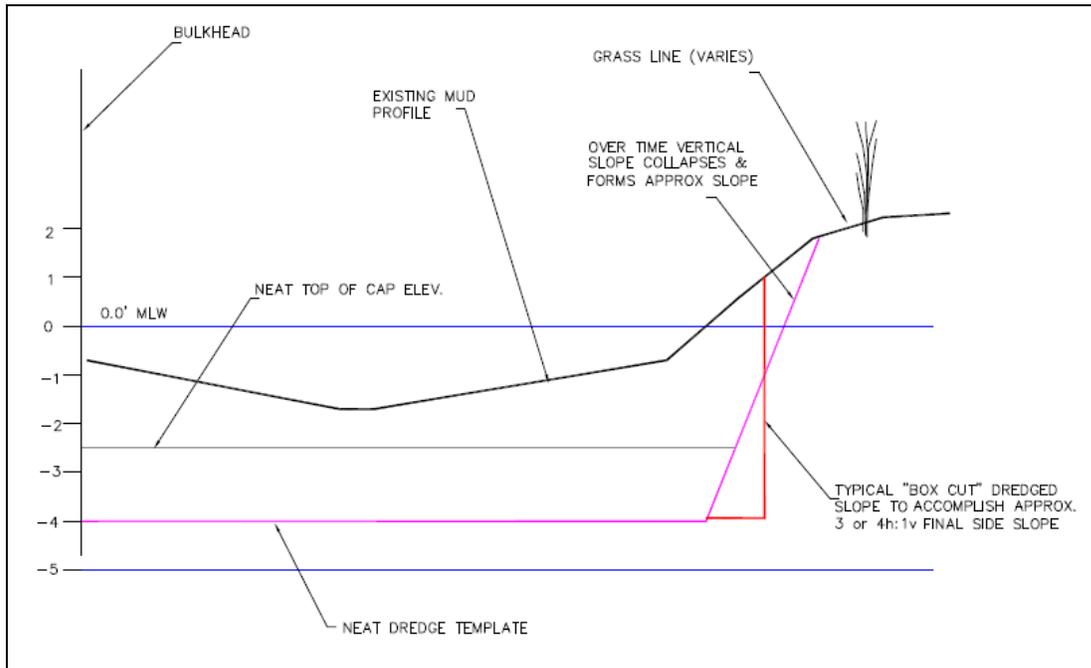


Figure 15: Diagram of how a side slope is normally “box cut” by a dredge – then allowed to naturally from its own slope over time

This is justifiable in contractual terms because the “box-cut” does produce a rough but generally stable slope that is generally acceptable on 99% of all dredging projects that are designed, including the Federal Navigation projects designed by the US Army Corps of Engineers. However, if your dredging project abuts critical habitat, nearby structures or if there are serious contamination issues that need to be managed – your plans need to be clear and concise with respect to what you as the designer are expecting as the contractor’s method of performance. If the intent of the design is such that graded sideslopes are required - the plans need to specifically state that the finished slopes are to be “graded” or “shaped”, as well as what the limits of over/under excavation are, the acceptable construction methods, and a tolerance for the finished work. This



Dredging and the Environment – Part 2
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needs to be spelled out on the plans and in the contract documents in such a way that there is no misunderstanding or misinterpretation of the design intent by the contractor. Failure to make these provisions part of a contract can cause serious contractual issues from a legal perspective, and may well compromise the design intent – potentially creating permit violations and even more extensive litigation.

With all of that said – bear in mind that detailed underwater grading of slopes is tedious and slow – and carries a significant price tag. If the side slopes are located in water over 10 feet deep, special equipment and monitoring are required in order to perform the work with any degree of accuracy. As such, if cost and time of performance are a consideration the design should attempt to work around the need for the graded side slope if at all possible.

The conceptual design shown in Figure 16 was one approach for producing a “stepped box-cut” side slope, which might have worked if the interface between the contaminated soil and the bordering root mat were not such a close interface, however there were two problems:

1. The stepped design took a series of box-cuts from the slope area, in the hope that the slope would form a natural angle of repose of 4:1. However the in-situ soils in the vicinity of the slope were a mixture of root mat, and alluvial sand, covered with contaminated mud. Each of the two soils would have their own respective natural angle of repose (not necessarily the same), and the root mat would probably stand straight up – at least for a while. Over time the underlying soils would erode or slough away, or the root mat would decay, at which point the root mat would probably break at some unpredictable location – and fall into the waterway - most likely bringing some of the wetland grass with it. This was obviously not a desirable solution.



Dredging and the Environment – Part 2
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2. Secondly, if one visualizes the stepped side slope, and then combines the view from above (Figure 14 combined with Figure 16), it can be seen that the final stepped slope would also be combined with the random “saw-tooth” configuration discussed earlier. The problem lies in the fact that the existing slope line of the marsh was generally straight, which when interfaced with the newly dredged “saw-tooth” contour line would leave pockets of contaminated soil in the “root” of the “saw tooth” intermixed with areas that encroached too closely to the wetland at the “point” of the tooth. As an added problem – the soft pockets would not provide uniform support for a follow-on capping operation. All in all, this was not a desirable design. Figure 17 shows how the final design resolved this issue with a graded slope, as well as specific instructions in the specifications on how to achieve the slope. In the end it was the only real and workable solution to this issue.

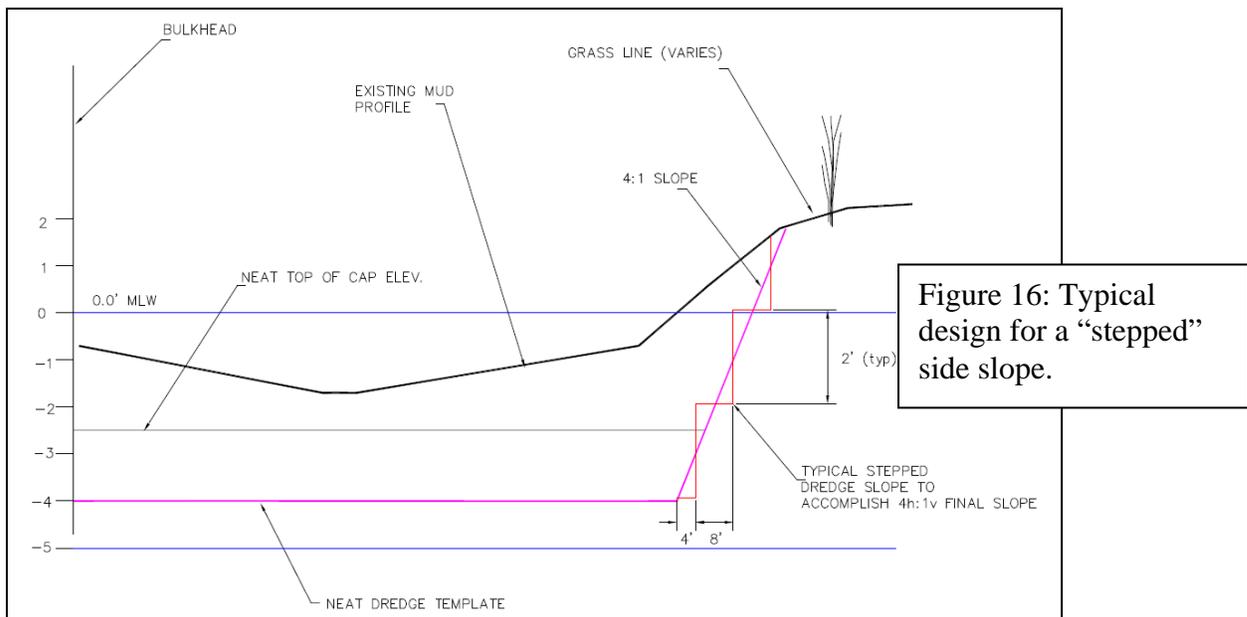


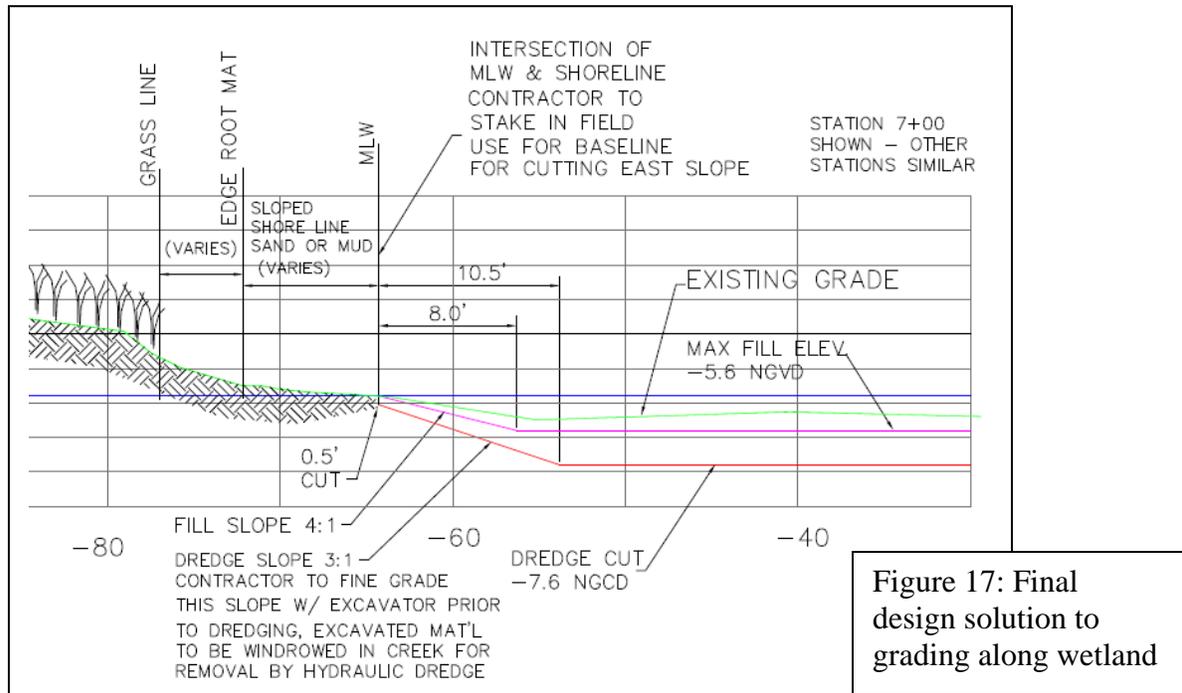
Figure 16: Typical design for a “stepped” side slope.

Thus, the answer was to abandon the idea that a dredge should attempt to perform fine grading near a critical area. The design documents for this sample



Dredging and the Environment – Part 2
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project specifically required that the contractor mobilize a separate barge mounted piece of equipment, such as a “grade-all” or backhoe, to come in ahead of the dredge and shape the finished slopes.



Fortunately the water was shallow enough on this particular project that the work area could be carefully staked and marked in advance (at low tide) using traditional upland survey methods. The excavator would then leave the material that was carefully trimmed from the slope in a wind-row – within the dredging area - placed far enough away from the slope to allow for the dredge to come in and remove it at a later time. Using similar methods, when the dredging was completed, this same excavator would be used to place and grade the sandy capping material along the restored shore line.

Bulkheads can present similar problems; the bulkhead pictured to the left in Figure 13 is reasonably straight, but it also has the typical large corrugations



Dredging and the Environment – Part 2
A SunCam online continuing education course

typical of a sheetpile wall. The dredge would need to stop its swing short of the wall in order to avoid probable damage, thus again the final product would be the same “saw toothed” configuration described in the section on wetlands (above) – with the nearest “point” of “saw toothed” limit of dredging remaining a few feet from the sheet pile wall, and the root of the “saw-tooth” being as much as five or six feet away from the wall. The solution to this issue was again the use of a barge mounted Grade-all excavator or possibly a small backhoe to remove the mud from the face of the bulkhead, and from between the corrugations of the sheet piles, while being careful not to damage the epoxy coating on the steel. The small excavator would then to place the soils far enough from the bulkhead so that a conventional dredge could remove them at some later point in time without having to be preoccupied with causation of damage.

This level of detail on a routine navigation dredging project is normally not required or necessary, and thus – even when the dredging specifications are silent on the issue – it is understood that the contractor has the right to keep the digging implement a safe distance from such a structure. As such unless the contract documents are specific and concise about the standards of material removal that are required, lacking such direction – and based again on industry performance standards - the contractor would have every right to expect that he/she need only comply with industry practices. Thus they could simply dredge as close as might be reasonable to the structure – tempered with how close their experience dictated - and then stop. This bears repeating - if the project has contaminated soils – and the performance standards of the project require its complete removal – the level of performance must be clearly and concisely spelled out for every interface of the project (just as with side slopes discussed above).



Dredging and the Environment – Part 2
A SunCam online continuing education course

Course Recap:

In Part 2 of the “Dredging and the Environment” course we have learned the basics and a few of the complexities involved in the Dredging of contaminated sediment. Upon completing this course the Engineer should have an understanding of the following:

1. The basic types of sediment contamination, and the standard procedures for site survey, and sediment sampling.
2. The basic concepts of the finished dredging design and what should and should not be expected in the finished work product
3. An understanding of the basic methods required to achieve an accurately dredged final project
4. Fundamental design practices for dredging in close proximity to sensitive bordering areas (i.e. wetlands & bulkheads)

Once the Engineer has developed an understanding of these components, he or she should be in a position to go on to study other levels of dredging design. Future Continuing Education Courses will delve into other areas of environmental restoration, which will include the basics of Beach Nourishment and Wetland/Habitat restoration, as well as Capping and more Advanced Contamination Remedial Dredging & Design.