EPA United States Environmental Protection Agency

Technology Innovation Program

Measurement and Monitoring Technologies for the 21st Century (21M²)

Sampling for Contaminants in Sediments and Sediment Pore Water

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Introduction

This report is a survey of the equipment that can be used to collect sediment and pore water samples. The report is not meant to be a "how to" on sampler use or sediment site characterization planning, but rather a basic reference for screening methods for further investigation. The sediment collection information is mainly taken from *Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses* (USEPA, 2001) and *Assessing Aquatic Ecosystems Using Pore Waters and Sediment Chemistry* (Burton, 1998).

The physical location of the sediment, its particle size distribution and compaction, and the final use of the data often dictate the type of sampler chosen. Physical location considerations include the depth of the water body overlying the sediment and the strength of the current present. Unless the sampling event is to occur in a very shallow environment, a bathymetric survey, conducted prior to choosing the sampling equipment is recommended, and a general understanding of the current to be encountered needs be obtained. Particle size distribution and compaction generally dictate whether a given sampling device is capable of obtaining a sample of the target sediment. Coring devices are usually not effective in gravelly bottoms, and grab samplers may have problems in areas where there is extensive vegetative debris or compacted sediment.

The data quality objectives established for the project determine the depth horizon needed for the sediment sample, the volume required, and the acceptable degree of disturbance. For investigations concerned with recent contamination events or the affects of contaminated sediments on the benthic community, the sampling horizon is generally in the 10 to 15 cm range (EPA, 2001). On the other hand, if historical deposition patterns are the focus or the actual thickness of contaminated sediment is needed for remedial evaluations, then the required depth may extend to several meters or more.

The type of chemical or toxicological testing that needs to be performed influences both the required volume of sediments and the amount of disturbance that can be tolerated. A full chemical suite of analytical testing for the presence of contamination requires a large volume of sediments which will result in some degree of disturbance. When the concern is bioavailability, a large quantity of sediments may be required for testing while preserving the in situ redox conditions to the extent possible (EPA, 2001). Preserving redox conditions

requires maintaining the sample's integrity by minimizing disturbances in the sediment's structure and exposures to conditions (atmospheric oxygen) that might change the chemical balance (EPA, 2001). Also the materials the sampler is constructed of needs to be evaluated to determine if they will have any impact on the chemical integrity of the sample. Table 1 presents typical volume requirements for various tests. Tables 2 and 3 provide sample volumes for corers and grab samplers respectively and identifies the advantages and disadvantages of the more commonly used samplers.

The bioavailability of chemicals in sediments is often estimated using sediment pore water (Burton, 1998). Pore water can be obtained by ex situ (centrifuge, suction, or pressure) methods or in situ (probe pumping or diffusion) methods. While in situ methods generally are better than ex situ at preserving the samples integrity, logistical constraints such as the depth of the water or the volume of sample required sometimes leave ex situ methods as the only viable choice. If ex situ methods are needed, centrifugation is the preferred method (USEPA, 2001). This report does not address ex-situ pore water extraction techniques.

Sampler Types

In addition to the physical conditions at a site (water depth, sediment type, current strength), the choice of sampler from among the wide variety available depends on what the data objectives are (e.g., undisturbed core to determine sedimentation history, maintenance of sample redox conditions, sample analysis volume requirements). Sampler descriptions may be divided into two large groups: those capable of providing sediment solids and pore water and those capable of collecting pore water alone.

Sediments and Pore Water

Dredge and Grab Samplers

Although similar in mechanical design to grab samplers, dredges are generally designed to efficiently remove bottom sediments with little regard for maintaining the integrity of the sediment. The bucket and dipper designs are examples of these. In the bucket design (e.g. clamshell and orange peel), the device is dropped into the sediment with its jaws open. After penetrating the sediment, the jaws are closed and the bucket of sediment is raised to the surface. Newer designs make the closed bucket water proof so potentially contaminated water does not drain out the bottom. However, these designs can cause considerable disturbance of the sediment stratigraphy, and washout of surficial materials is common. The dipper design resembles the surface operating steam shovel where a rigid bucket is driven into the sediment in a scooping motion before bringing the sediment to the surface. This design also is subject to severe washout problems. Dredge samplers are generally not recommended for environmental sampling, but may be useful in benthic collection (USEPA, 2001).

Grab samplers are designed to minimize the bow wave caused by the sampler's descent. They typically do this by incorporating flaps on the top of the sampler that open as the sampler moves down to allow water to pass through rather than being pushed ahead. Also, unlike the dredge equipment, grab samplers are designed to minimize disturbance of the sediment when the sample is taken and brought to the surface. The flaps mentioned above are closed during ascent to protect the surface of the sample and prevent washout.

Birge-Ekman style grabs (Figure 1) vary in size with larger models requiring a winch for operation. The spring-tensioned jaws are mounted on pivot points and are set with a trigger assembly that is activated from the surface by weighted messenger. Flaps on the top of the sampler open during descent to allow water to flow freely through and close during ascent to reduce the loss of sample. The sediment can be subsampled through the flaps. Birge-Ekman samplers are suitable for collecting, soft, fine-grained sediments. Larger matrices (gravel, shells) and vegetative matter tend to prevent the jaws from fully closing, which results in sample loss and the need to resample (Resources Inventory Committee, 1998). Birge-Ekman samplers may be restricted to low current situations and have been known to lose fine surface sediments during retrieval.

Figure 1. Birge-Ekman grab sampler.

Source: USEPA, 2001.

Figure 2. Petersen grab sampler.

Source: USEPA, 2001.

Petersen grab samplers (Figure 2) consist of a pair of weighted, semi-cylindrical jaws that are held open by a catch bar. The impact with the sediment loosens the tension on the catch bar allowing the jaws to close. Additional weights can be added to the jaws to provide better penetration into harder compacted sediment. As there is no access through the top of the sampler, only bulk samples can be taken. Petersen samplers are suitable for collection of hard bottom material such as sand, marl, gravel, and firm clay (Resources Inventory Committee, 1998). These samplers are restricted to low current conditions and may produce a bow/shock wave that disturbs fine grained sediments. In the presence of cobbles or vegatative debris the jaws may not completely close.

Ponar grab samplers (Figure 3) come in two sizes (standard and petite) and have a pair of weighted, tapered jaws that are held open by a catch bar. The sampler is triggered by impact with the sediment bottom. The upper portion of the sediment jaws is covered with a mesh screen that allows water to freely flow during descent thereby reducing the bow wave that precedes the sampler and reduces disturbance of the sediment surface. Upon recovery, the wire mesh can be removed to allow subsampling. Ponar grabs can sample fine-grained to coarse materials (Resources Inventory Committee 1998). The standard sampler is heavy and requires a winch for deployment while the 1 liter petite may not penetrate the sediment to the desired depth and may require multiple deployments to obtain sufficient sediment sample. Both samplers are subject to incomplete closure and loss of sample in large grained sediments or those with vegetative matter.

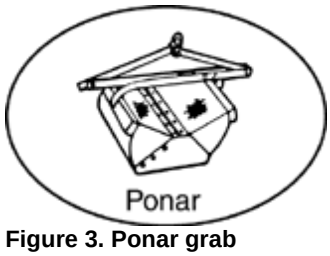

Figure 3. Ponar grab sampler.

Source: USEPA, 2001.

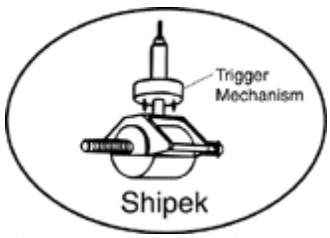

Figure 4. Shipek grab sampler.

Source: USEPA, 2001.

Shipek grab samplers (Figure 4) have a top cast half cylinder barrel attached to a lowering wire with stabilizing bars to keep the sampler vertical. Within this barrel is a second sampling cylinder that is activated by a high torque spring. When activated, the second cylinder rotates 180 degrees through the sediment and forms a seal with the upper cylinder. The sample is removed from the sampler by disconnecting it from the upper assembly. The sampler is designed for unconsolidated sediments in deep lakes and near offshore locations to a depth of approximately 10 cm. Hard, compacted sediments can present sampling problems and washout of fines can occur during the ascent of the sampler from the bottom have been reported with some designs. Large objects such as pieces of wood or shells can be trapped as the sampler closes causing washout when it is drawn to the surface.

Smith-McIntyre grab samplers (Figure 5) are mounted on steel frames that can be weighted and ensure the sampler remains vertical. The two spring-loaded jaws are released when the frame comes to rest on the bottom. The jaw tops are covered with brass screens and rubber flaps to minimize the bow wave on the descent and prevent sample washout on the ascent. The sediment sample can be subsampled from the top of the sampler. The typical sampled area is about 31 cm by 31 cm square. Smith-McIntyre samplers can sample soft, fine-grained to sandy sediments and are designed primarily for deployment in marine environments. The sampler requires a power winch to deploy.

Figure 5. Smith-McIntyre grab sampler.

Source: USEPA, 2001.

Van Veen grab samplers (Figure 6) are manufactured in several sizes. A stainless steel screen with rubber flaps covers the top of the jaws. This design allows the sampler to be lowered to the bottom with a minimum bow wave, thus preserving the integrity of the sediment surface. Upon reaching the bottom the tension in the lowering wire slackens, releasing the small chains holding the jaws open.

Figure 6. Van Veen grab sampler.

Source: USEPA, 2001.

Pulling up on the lowering chain engages the chains attached to the jaw arms, causing them to bite into the sediments and close. Latches on the jaws ensure they stay closed. The sediment sample may be subsampled through the removal of the screens on the jaws. Lead weights are available to improve the sampler's penetration into the sediment. This sampler is effective in fine-grained to sandy sediments that are in deep water and strong currents. The sampler may not close completely resulting in loss of sediments and requires a winch to deploy.

Core

Hand Corers (Figure 7) are generally suitable for collecting sediment samples in marshes, streams, and shallow rivers, or at some depth by diver. Depending upon the sediment composition, the samples typically are less than 1 meter in depth. Samplers need to be equipped with a top valve that allows water to pass through when set in the sediment and closes during withdrawal to prevent washout. An alternative design is a piston type device that forms a seal with the corer walls and is drawn or pushed up as the sample is collected. The piston maintains a vacuum against the top of the sediment which aids in its retention and prevents water from entering the sampler during withdrawal.

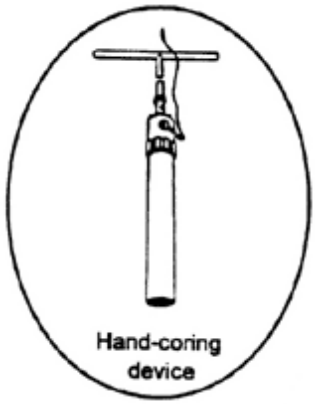

Figure 7. Hand corer.

Source: USEPA, 2001.

[click to enlarge]

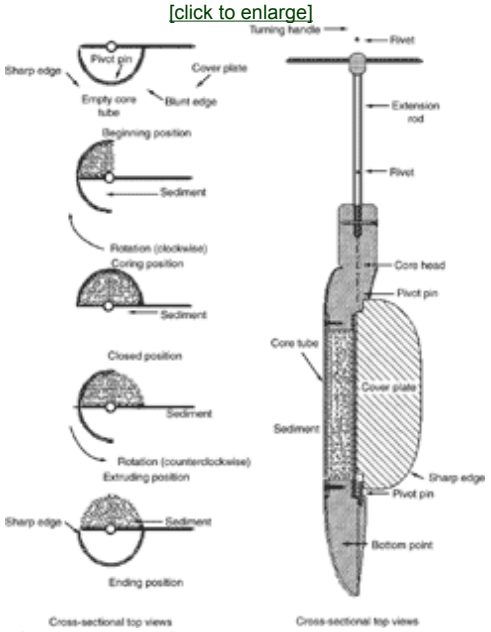

Figure 8. Russian Peat Borer.

Source: USEPA, 1999.

Russian Peat Borers (Figure 8) are another form of hand corer that are side filling and are designed to collect relatively uncompressed sediment samples. The components of the borer include a stainless steel, chambered core tube; extension rods, a stainless steel turning handle; and a core head and bottom point that support a stainless steel cover plate. The cover plate is curved and sharpened to minimize disturbance when the sampler is driven into the sediment. Once driven to the target depth, the core tube is rotated clockwise to fill the tube by cutting out a segment of sediment. The borer is capable of obtaining samples at depths of 10 feet or more with little sample loss (USEPA, 1999).

Ogeechee™ Sand Corers are another form of hand corer that have been designed to specifically sample sandy sediments. The corer consists of a core head that contains a check valve that can be manually closed by the operator, a stainless steel core body with plastic liner and core catcher, and driving tip (Figure 9). The sampler can be twisted or hammered into the sediment. Extension handles allow for sampling in deeper water (15 feet) and it can be used in fast moving water that can adversely affect the performance of gravity type corers.

Alpine gravity corers (Figure 10) are finless with a heavy (45 kg, 100 lb) lead weight attached at the top. The core tube ID is 4.1 cm and can be up to 1.8 m (6 ft) long. A valve at the top of the sampling tube is maintained by a light spring that allows the valve to open during descent and close after the sampler penetrates the sediment. The closed valve protects the sample from washout during ascent. Mudroch and MacKnight, 1994, report that this sampler may have problems entering the sediments vertically. Also, examination of the cores showed sheared laminae and disturbed surfaces of the sediment samples.

Figure 9. Ogeechee™ sand corer.

Adapted from Wildlife Supply Company webpage.

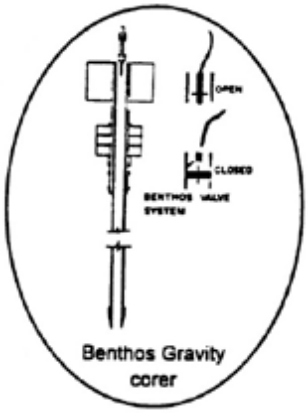

Figure 11. Benthos gravity corer.

Source: USEPA, 2001.

Benthos gravity corers (Figure 11) weigh approximately 25 kg (55 lbs) and with extra lead weights require a winch or crane to deploy. The core tube ID is 6.6 cm and the upper section has been equipped with fins to aid in vertical descent. The core tube can recover up to 3 m of sediment. A removable valve system, located at the top of the core liner, allows water to pass through during descent. The valve closes against a machined seat when the retrieval process is begun to prevent wash out. May compact the sediment sample.

Boomerang corers (Figure 12) are free falling samplers that weigh approximately 85 kg and are deployed directly from the side of a boat. They utilize a disposable ballast section (nose cone, pilot weight, core barrel, weights, float release mechanism) and a retrievable float section (two glass spheres tethered to a core assembly). The core assembly consists of a 1.2 m by 6.7 cm ID clear plastic liner with a stainless steel catcher and top cover valve. After the corer strikes the sediment surface,

the glass spheres are released, and they pull the liner from the core tube and float to the surface. Sampling depths of up to 9,000 m are possible (Mudroch and MacKnight, 1994).

Figure 12. Boomerang corer.

Adapted from Mudroch and MacKnight. (Eds), 1994.

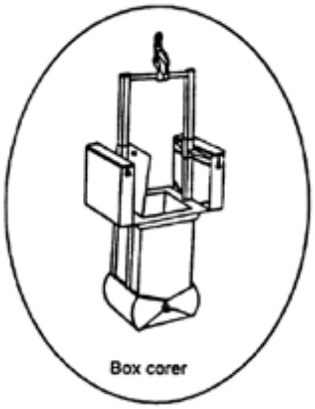

Figure 13. Box corer.

Source: USEPA, 2001.

Box corers (Figure 13) are rectangular gravity corers that come in a variety of sizes. They can take large relatively undisturbed samples in soft sediment and are excellent for sediment water interface studies. There are two basic designs: an Ekman type where two bottom flaps can be triggered and the jars close much like the Ekman grab sampler and the Reinecke design where a shovel like device slides across the base of the corer. In general, these corers are large and can only be operated from a boat with a large lifting capacity (2-3,000 kg) and sufficient deck space to accommodate it (Mudroch and MacKnight, 1994).

[click to enlarge]

Piston corers (Figure 14) are capable of taking cores up to 20 m long. They generally consist of stabilizer fins, weighted head, core barrel, piston, core retainer, cutting head, and trigger mechanism, and they are deployed by a boat equipped with a crane. The corer is not allowed to free fall from the surface. A pilot weight or corer is attached to the release mechanism by wire. The length of the wire determines when the corer is released and the distance it falls. Piston corers are generally employed for sediment studies in oceans and large lakes. Various authors (Mudroch and MacKnight, 1994) report problems with shortened samples and disturbed/missing surficial (up to 1 m) sediments when using piston corers.

Phleger corers (Figure 15) weigh about 8 kg (17 lbs) without additional lead weights and have a core tube ID of 3.5 cm (1.2 inches). The top part of the corer has fins for stabilization and an area for adding weights to increase penetration. A valve assembly at the top of the coring tube consists of a tapered bung that can slide in two directions—up during descent to allow water to flow through thereby decreasing the bow wave and down during ascent to form a seal on the tapered tube seating and thus prevent washout and aid in sample retention. This sampler is generally deployed from a boat to sample soft to sandy sediments and semicompacted material in shallow lakes or marshes. The small sample size can be an issue when chemical or biological analyses require larger volumes.

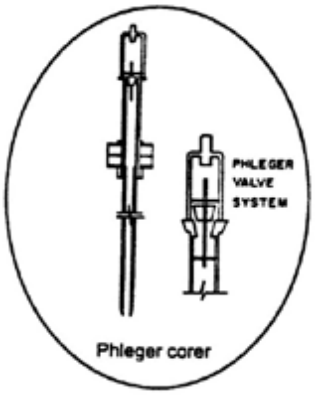

Figure 15. Phleger corer.

Source: USEPA, 2001.

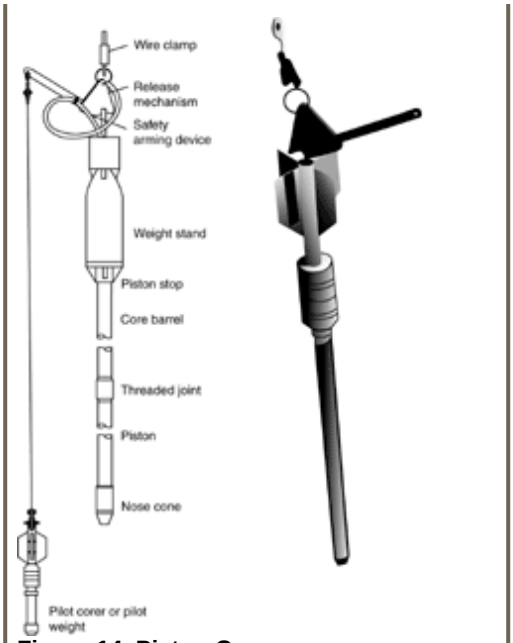

Figure 14. Piston Corer.

Standard ***Kajak-Brinkhurst corers*** (Figure 16) weigh about 9 kg (19.8 lb) without additional lead weights and have a core tube ID of 5 cm (2 in). Unrestricted water flow through the sampler during descent minimizes bow wave affects. A valve located at the top of the sampling tube closes during ascent to prevent washout. The sampler is suitable for taking soft, fine-grained sediment samples to a maximum depth of about 70 cm. While the standard Kajak-Brinkhurst corer is hand deployable from a boat, heavier versions may require a winch.

Figure 17. Vibracorer.

Source: USEPA, 2001, courtesy Allen Burton.

Vibratory corers (Figure 17) have a mechanical vibrator head located at the top end of a coring barrel. The vibrating head can be powered using several methods such as hydraulic, electric, or pneumatic. Different heads use different combinations of amplitudes and frequencies that can drive the core tube into the sediment using primarily a vertical vibration or a combination of vertical and horizontal vibrations. The type of drive motion needs to be matched to the expected sediment type. Vibratory corers come in a variety of sizes ranging from hand held types to those requiring hoists. The larger devices can typically drive a 141 mm (5.56 in) diameter core up to 6 m or more into the sediment and are generally equipped with a submersible frame for stability. Operational depths range from sampling tidal flats to depths of over 1,000 m (3,281 ft). If deployment is by boat, an on-board hoist with sufficient lift capacity to pull the core out of the sediment and enough height to lift the entire core line out of the water for core retrieval is recommended.

Samplers for Collecting Pore Water or Pore Water—Surface Water Flux

As with sampling the sediment solids, the objective of the investigation determines the best tool for collecting the sample. The following are potential objectives for sampling water in the sediments or at their surface to measure contaminant flux.

- Estimate contaminant flux from the sediments into the overlying surface water.
- Establish the presence of contaminated pore water in the sediments (does not require preservation of in situ redox conditions).
- Determine the concentrations of contaminants that are actually in the pore water within the biologically active surficial layer of sediments (requires preservation of in situ redox conditions).
- Perform biotoxicity tests using water taken from the biologically active layer of the sediments.

- Determine if there is a concentration gradient of contaminants within the sediments.
- Determine flux and composition within the sediments when the surface water is gaining and a ground-water contaminant plume is present. This determination might also try to locate preferential pathways into the surface water from the sediment bed.
- Determine the general flux of contaminants into ground water when the surface water is losing and the sediments are contaminated.

The samplers described below generally have specific uses and care needs to be taken in choosing the appropriate one to meet sampling data objectives. For example there are several passive vapor diffusion samplers. One type employs equilibrium partitioning of chemicals between the pore water surrounding the sampler and the air in the sampler. Another type employs a chemical trap such as charcoal. The concentration levels found in the equilibrium device could be very different than that found in a similarly deployed trap device.

Diffusion

Diffusion samplers use a permeable membrane or gel that allows various chemicals to establish an equilibrium between the water immediately surrounding them and their capture device. The capture device may be enclosed air, water of an appropriate quality, the gel itself, an ion exchange surface, organic hydrophobic chemical, or an activated carbon mixture. The membrane can be chosen to include or exclude various analytes as needed by the project. Cellulose based materials are not recommended as they tend to biofoul and degrade.

Water diffusion (dialysis) bags are made from permeable dialysis materials (e.g., polyvinylidene fluoride, polycarbonate) and can be constructed in several designs. Figure 18 shows a dialysis bag over a supporting perforated frame and within a PVC outer protective shell. They are filled with water of specified quality and placed into the sediment at the depth to be sampled. This placement allows them to collect a contaminant profile of the pore water at specified depth. The type of water used will depend on the purpose of the sampling and the ambient water quality. For sampling water with a relatively high oxygen content or when a change in redox conditions will not subvert the sampling objective, deionized organic free water may be used. If the sediment body is anoxic and it is important to preserve this condition in the sampled water, then preparation of the bag water will have to remove oxygen (e.g., nitrogen purging) from it prior to deployment and keep it from re-entering during transport, handling, placement, and collection. For redox preservation the bag and protective cover material should not contribute oxygen to the water or surrounding sediments. Some plastics have been shown to diffuse oxygen (USEPA, 2001). Finally, using water with a similar salinity or hardness might be important to obtaining the sampling measurement objectives.

Figure 18. Dialysis bag on perforated tube.

Courtesy: USGS.

[click to enlarge]

Peepers (Figure 19) are samplers that employ a rigid body with an opening or openings that are covered with a permeable membrane or mesh. Acrylic cylindrical chambers are a common type that contain holes in their sides that are fitted with the membrane or mesh material. Before deployment they are filled with an appropriate grade of water as discussed in the diffusion bag section. The cylinders can be deployed in several fashions. For example, they can be stacked in a specially designed corer so that they sample discrete depths or they can be placed in a shallow rectangular array for near surface areal distribution determinations. Another peeper design resembles a box corer with individual cells inside that can obtain a small transect with depth. The equilibration time for peepers can range from hours to a month depending upon the contaminant of interest, sediment type, peeper volume, and membrane pore size (EPA, 2001). Their principal drawback is that they provide small sample volumes.

Diffusion Equilibration in Thin Films(DET) are comparable with peeper systems except that the diffusive equilibrium is attained between solutes in the pore water and a thin film of gel. The thinness of the gel (≤ 1 mm) results in faster diffusive equilibration

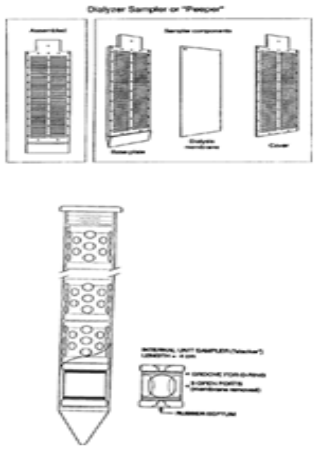

Figure 19. Plate and stacked peepers

Source: USEPA, 2001.

than with traditional peepers. It has been used to measure Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, $Fe^{+2/3}$, Mn^{+2}, Cl^{-}, SO_4^{-}, NO_3^{-}, alkalinity, and total CO_2 in pore waters at a resolution of 1-2 mm (Fones et al., 2001) and can be used to measure trace metals.

Vapor diffusion samplers (Figure 20) are used to sample volatile organic contaminants by taking advantage of the concentration gradient that exists between the contaminants in the sediment pore water and the air in the diffusion bag. In one deployment method, an uncapped 40 ml vial is placed inside a thin polyethylene bag which in turn is placed in another polyethylene bag. The bagged bottle is placed at the prespecified sample depth and buried. At retrieval, the outside bag is removed and a septum cap is screwed on without removing the original bag.

Figure 20. Passive vapor diffusion sampler.

Source: Church, et al., 2002.

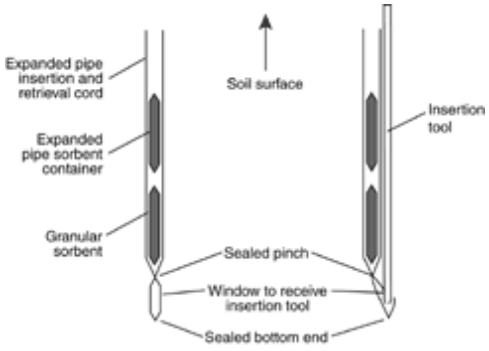

Figure 21. GORE-SORBER® passive diffusion sampler.

Source: USEPA, 1998.

In a different arrangement, an open ended container with a chemical trap is placed in a polyethylene bag and buried. The trap (e.g., an activated charcoal formulation) is retrieved and the volatiles are desorbed and measured at a laboratory. The GORE-SORBER® sampler (Figure 21) is an example of this design.

Semipermeable membrane devices are plastic bags that contain a hydrophobic organic chemical that is used to collect trace hydrophobic chemicals in sediment and water (Figure 22). The protected bag is deployed in the sediment for a specified period of time. Hydrophobic chemicals such as dioxins, PCBs, and polynuclear aromatic hydrocarbons migrate across the bag and become attached to the organic fluid contained within it (The USGS typically uses lipids like triolein or other oil as the organic fluid). The bag is subsequently retrieved and the fluid is processed and tested for these trace contaminants. Femto and nano gram/L detection levels are routinely achieved. Since the device captures chemicals rather than

establishing an equilibrium between the oil and water concentrations, the results are an average encountered over the period of time deployed.

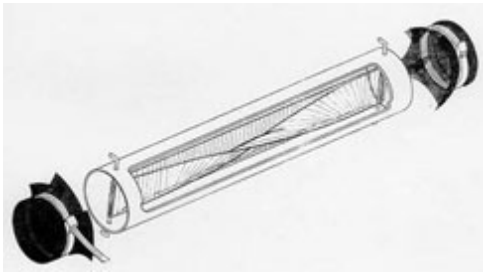

Figure 22. Semipermeable membrane device.

Source: Chapman, undated.

http://wwwaux.cerc.cr.usgs.gov/SPMD/index.htm

Direct Pore Water Sampling

Small diameter ***piezometers*** can be placed in sediments where the water is shallow and the current is relatively weak. When clustered, they can measure hydraulic head differences and provide pore water samples from different depths for contaminant concentration profiling. The pumping can be done using suction lift (peristaltic) or, if the inside diameter of the piezometer is sufficiently wide, a centrifugal or bladder pump. Note that suction lift always applies a pressure differential across a sample and could affect the analytical results (e.g., negative bias on dissolved gases and volatile organics). The pumping needs to be done at a very low rate to avoid mixing of the zones of interest. Piezometers offer advantages over diffusion samplers in that they can be sampled repeatedly, and they generally do not have volume limitations. On the other hand, preservation of in situ redox conditions is generally not possible; however, in-line measurements of parameters such as dissolved oxygen and redox can be made to determine their approximate in situ values when suction lift is not used.

Syringes can be used to take samples of pore water at different depths in the sediment profile. They can be purchased with various barrel volumes with a range of needle lengths and bore inner diameters. Pore water samples are obtained by pushing the needle to the desired depth and retracting the plunger. Syringes may not be effective in compacted sediments or gravels and can become plugged in very fine sediments.

The ***BAT™*** system (Figure)is generally associated with ground-water point sampling activities. However it can be deployed in sediments and provides profiling abilities to depths generally not achievable by other methods. The probe consists of a tip and housing, the top of which is sealed with a disc containing a flexible septum. The tip can be constructed of porous high-density polyethylene (HDPE) that allows pore water to enter the body when put under vacuum. The tip also can be constructed of stainless steel. The stainless steel tip is driven to the desired sampling depth and the body of the sampler is retracted to expose a stainless steel screen that allows pore water to enter the sample housing. A tool containing an evacuated sample vial (35 to 500 ml or 1.2 to 16.9 fluid ounces) with a septum cap and a double-ended hypodermic needle is lowered down the push rod. When the tool encounters the sample housing, the needle penetrates the housing septum at the same time it penetrates the vial septum allowing pore water to enter the vial. When the vial is full, the tool is retrieved, and the vial is stored for subsequent analysis. The advantage of the porous HDPE filter tip is that it yields a sample with low turbidity.

The ***push point sampler*** has a small diameter core barrel with lance tip and a "T" type handle. The small diameter barrel has holes drilled in the side at the bottom to allow water to enter. A solid plastic rod is placed in the barrel to prevent water and sediment from entering the sampler during pushing. When the sampling section of the barrel has been driven/pushed to the target depth, the rod is withdrawn allowing pore water to enter. The water is sampled using a peristaltic pump or in some cases a syringe. This system is useful primarily in shallow water although it can be deployed by a diver.

The Navy's ***Trident probe*** (Figure 24) is a direct push system that provides depth specific temperature and conductivity data that can be used to determine what depth water should be obtained from the water sampling probe. It can be deployed by hand or diver. The on-board air hammer can drive the samplers into more compacted or stiff sediments that would be difficult to achieve manually. One use of the tool is better estimate where the groundwater/surface water interface is by looking at the differences in temperature and conductivity of the surface

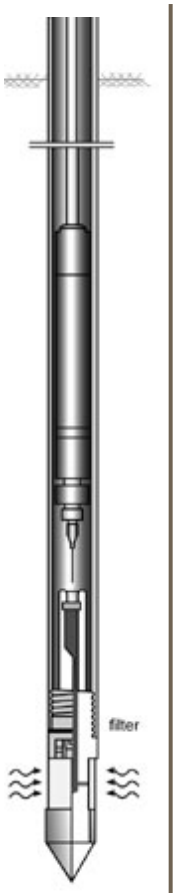

Figure 23. BAT™ sampler.

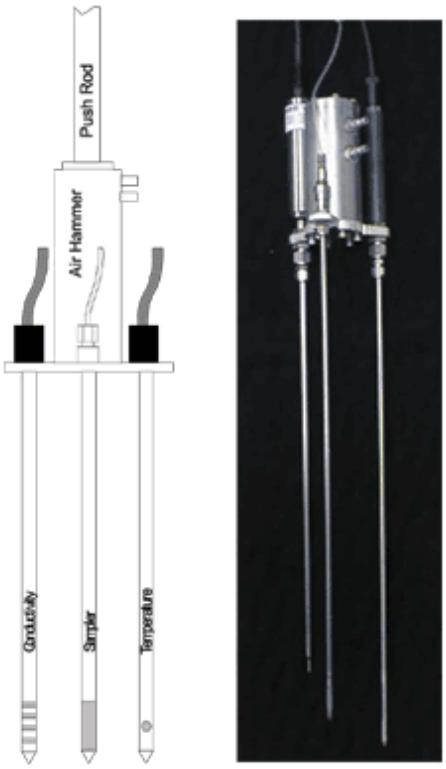

Figure 24. Trident pore water sampling probe.

Source: Chadwick et al., 2003.

water versus water at depth.

Flux

The ***diffusion gradients in thin films (DGT)*** technique is based on a simple device that accumulates solutes on a binding agent after passage through a well defined diffusion layer. A binding agent such as a resin, selective to the target ions in solution (e.g., Chelex for trace metals), is immobilized in a thin layer of hydrogel (binding gel). It is separated from solution by an ion permeable hydrogel layer (diffusive gel). Between the diffusive gel and the bulk solution there is a diffusive boundary layer where transport of ions occurs solely by molecular diffusion. Within a few minutes of deployment, a steady state linear concentration gradient is established between the solution and the binding gel. By exploiting this simple steady state condition, the DGT technique can measure fluxes in situ (Teasdale, 1999 and Davidson, et al., 2001).

Figure 25. Benthic flux lander.

Courtesy: U. S. Navy

Benthic flux sampling devices (Figure 25) measure the flux of analytes, natural and otherwise, at the sediment surface water interface. This generally is done by lander emplacement of a container open side down in the sediment. The container is fabricated to allow surface water to flow through it until the sediment surface is penetrated where upon it seals leaving the top portion of the container filled with water. The water within the sealed box is periodically stirred and sampled. Generally the dissolved oxygen level of the trapped water is monitored and the in situ level that existed when the chamber was set is maintained. Tracers can also be released to determine if there is a net loss from the overlying water. Landers can operate unattended from a few days to months depending upon their size and design. They are fabricated to operate in shallow or deep (6,000 m) environments. In addition to a benthic flux chamber, some landers also can be equipped with coring capabilities, advective flow volume from the sediment to the surface water, and current measurement instrumentation.

Table 1. Typical Sample Volumes for Various Sediment Analyses.

Sediment Analysis	Minimum Sample Volume
Inorganic chemicals	90 ml
Non-petroleum organic chemicals	230 ml
Other chemical parameters (e.g., total organic carbon, moisture content)	300 ml

Particle size	230 ml
Petroleum hydrocarbons[1]	250-1000 ml
Acute and chronic whole sediment toxicity tests[2]	1-2 L
Bioaccumulation tests[3]	15 L
Benthic macroinvertebrate assessments	8-16 L
Pore water extraction	2 L
Elutriate preparation	1 L

[1] The maximum volume (1,000 ml) is required only for oil and grease analysis; otherwise, 250 ml is sufficient.

[2] Amount needed per whole sediment test (i.e., one species) assuming 8 replicates per sample and test volumes specified in USEPA 2000.

[3] Based on an average of 3 L of sediment per test chamber and 5 replicates (USEPA, 2000).

Table 2. Advantages and Disadvantages of Commonly Used Core Samplers.

Device/ Dimensions	Use	Depth of Sample (cm)	Volume of Sample (L)	Advantages	Disadvantages
Fluorocarbon plastic or glass tube (3.5-7.5 cm inner diameter (ID); ≤ 120 cm long	Shallow wadeable waters or deep waters if SCUBA available; soft or semi- consolidated deposits	0-10	1.1-5.3	• Preserves layering and permits historical study of sediment deposition • Minimal risk of contamination • Rapid, samples immediately ready for laboratory shipping	• Small sample size necessitates repetitive sampling
Hand corer with removable fluorocarbon plastic or glass liners (3.5-7.5 cm ID; 120 cm long)	Same as above except more consolidated sediments can be obtained	0-10	1.1-5.3	• Same advantages as fluorocarbon plastic or glass tube • Penetrates substrate with greater ease through use of handles	• Small sample size requires repetitive sampling • Requires careful handling to prevent spillage • Requires removal of liners before repetitive sampling • Barrel and core cutter metal may contaminate sample
Box corer	Same as above but depth of unconsolidated sediment must be at least 1 m	0-70	≤ 30.0	• Collects large, undisturbed sample; optimal for obtaining intact subsamples	• Difficult to handle • Relatively heavy; requiring larger vessel and power winch to deploy
Gravity corer, Phleger corer (3.5 cm ID, ≤ 50 cm long)	Deep lakes and rivers; semi-consolidated sediments	0-50	≤ 0.48	• Reduces risk of sample contamination • Maintains sediment integrity relatively well • Penetrates with sharp cutting edge	• Requires careful handling to avoid sediment spillage • Requires repetitive and time-consuming operation and removal of liners due to small sample size
Gravity corer, Kajak-Brinkhurst corer (5 cm ID, ≤ 70 cm long)	Deep lakes and rivers; soft fine grained sediments	0-70	≤ 1.37	• Collects greater volume than the Phleger corer	• Same as the Phleger corer
Benthos gravity corer (6.6, 7.1 cm ID, ≤ 3 m long)	Soft, fine-grained sediments	0-3 m	≤ 10.26	• Retains complete sample from tube because the core valve is fitted to the core liner	• Requires weights for deep penetration so the required lifting capacity is

				• Fins promote vertical penetration	750-1,000 kg • Requires vertical penetration • Compacts sediment sample
Alpine gravity corer (3.5 cm ID)	Soft, fine-grained semiconsolidated substrates	≤ 2 m	≤ 1.92	• Allows different penetration depths due to interchangeable steel barrels	• Lacks stabilizing fins for vertical penetration • Requires lifting capacity of 2,000 kg • Disturbs sediment strata and integrity • Compacts sediment sample
Large piston corers	Ocean floor and deep lakes; most substrates	3-20 m	5-40	• Typically recovers a relatively undisturbed sediment core in deep waters	• Requires lifting capacity of 2,000 kg • Piston and piston positioning at penetration may fail • Disturbs surface (0-0.5 m) layer some compaction possible
BMH-53 Piston corer	Waters ≤ 2 m deep with extension rod; soft deposits	≤ 2 m	≤ 2	• Piston provides for greater sample retention	• Metal barrels introduce risk of metal contamination
Boomerang corer (6.7 cm ID)	Ocean floor	1 m	3.52	• Requires minimal shipboard equipment so smaller vessels can be used	• Only penetrates 1.2 m • Requires calm water for recovery
Ogeechee (Stainless steel 2 inch ID 20-96 inch core lengths)	Waters up to 4.5 m with extension rod; soft to firm unconsolidated material less than 0.5 mm in diameter	0.5-2.5m	1-5	• Long core length available • Manual valve tension adjustment aids in sealing and sample retention	• Stainless Steel construction makes longer core lengths heavy.
Russian Peat Corer (3 models core length 20-40 inches; inside diameter 2 or 3 inches)	Sediments amenable to penetration by slide hammering; extension rods allow for deep sampling	>15m	0.5-1.45	• Light weight easy to use • Collects discrete relatively uncompressed/ undisturbed samples	• Cover plate is exposed to sediments to sampling depth which can result in cross contamination. • Gravels or debris can hinder closing
Vibracorer (5.0-7.5 cm ID)	Ocean and lakes; and silty sand and gravelly sand substrates of any water body	3-6 m	5.89-13.25	• For deep profiles it effectively samples most substrates with minimum disturbance • Can be used in over 20 m of water depth • Portable models can be operated from small vessels	• Labor intensive • Assembly and disassembly might require divers • Disturbs surface (0-0.5 m) • Heavier models require large boat and power winch to deploy • Core integrity slightly disturbed

Adapted from Appendix E-2 USEPA, 2001.

Table 3. Advantages and Disadvantages of Commonly Used Grab Samplers

Device	Use	Sample Depth (cm)	Sample Volume (L)	Advantages	Disadvantages
Orange Peel	Marine waters, deep lakes	0-18	10-20	• Comes in a range of sizes	• Need large boat, powered winch and

					cable line • Blocking of jaws may cause sample loss
Smith-McIntyre	Deep lakes, rivers, and estuaries	0-20	10-20	• Trigger plates provide added leverage essential to penetrating substrate	• Heavy, need boat and power winch • Inadequate for deep burrowing organisms
Birge-Ekman, small	Lakes and marine areas; soft sediments, silt and sand	0-10	≤ 3.4	• Handles easily without crane or winch • Can be adapted for shallow water use • Good for soft sediments, sand, and silt • Allows subsampling	• Restricted to low current due to light weight and messenger activation • May exceed target penetration depth • Subsampling may be restricted due to size of top flaps • Loss of fine surface sediments may occur during retrieval
Birge-Ekman, large	Lakes and marine areas; soft sediments, silt and sand	0-30	≤ 13.3	• Can be adapted for shallow water use • Good for soft sediments, sand, and silt • Allows subsampling	• Restricted to low current • May exceed target penetration depth • Heavy, requires winch • Loss of fine surface sediments may occur during retrieval
PONAR, standard	Deep lakes and estuaries; useful on sand, silt, or clay	0-10	7.25	• Most universal grab sampler • Adequate on most substrates • Large sample obtained intact, permitting subsampling • Good for coarse and firm bottom sediments	• May not close completely, resulting in sample loss • Heavy, requires winch
PONAR, petite	Deep lakes, rivers, and estuaries; useful on sand, silt, or clay	0-10	1.0	• Adequate for most substrates that are not compacted	• May not penetrate sediment to desired depth, especially in consolidated sediments • Susceptible to incomplete closure and loss of sample • Requires more casts to obtain sufficient sample if many analyses needed
Van Veen	Deep lakes, rivers, and estuaries; useful on sand silt or clay	0-30	18-75	• Adequate on most substrates that are not compacted • Large sample obtained intact, permits subsampling • Available in stainless steel • Effective in marine environments in deep water and strong currents	• May not close completely resulting in sample loss • May close prematurely in rough waters • Heavy, requires winch
Modified Van Veen (e.g., "Ted-Young grab")	Lakes and marine areas	0-15	≤ 18.0	• Fluorocarbon plastic liner can help avoid metal contamination • Screened bucket cover helps reduce bow wave effects	• Requires winch • Relatively expensive
Petersen	Deep lakes, rivers, and estuaries; useful on most substrates	0-30	9.45	• Provides a large sample • Penetrates most substrates	• Shock wave from descent may disturb fine-grained sediment • Lacks lid cover to permit subsampling • May not close completely • Restricted to low current conditions • May exceed target penetration depth
Shipek,	Marine waters	0-10	3.0	• Sample bucket	• Heavy, requires winch

standard	and large inland lakes and reservoirs			opens to permit subsampling	• In some designs, can result in the loss of the topmost 2-3 cm of very fine, unconsolidated sediment • Not useful for compacted sandy clay or till substrates
Mini Shipek	Lakes	0-3	0.5	• Handles easily without winch or crane from most platforms • Useful for most substrates that are soft	• Requires vertical penetration • Samples small volume • In some designs, may lose fine-grained sediment • May close prematurely

Adapted from Appendix E-1 USEPA 2001.

References

The citations below are provided as additional references. The documents *Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses* and *Assessing Aquatic Ecosystems Using Pore Waters and Sediment Chemistry* contain extensive bibliographies on sediment sampling and testing.

Apitz, S., et al. 2002. *Critical Issues for Contaminated Sediment Management*, MESO-02-TM-01, Marine Environmental Support Office, U.S. Navy.

Burton, G. 1998. *Assessing Aquatic Ecosystems Using Pore Waters and Sediment Chemistry*. Aquatic Effects Technology Evaluation Program, Natural Resources Canada.

California Environmental Protection Agency Department of Toxic Substances Control. 2000. Certification of U.S. Navy Benthic Flux Sampling Device. http://www.dtsc.ca.gov/TechnologyDevelopment/TechCert/company_index.cfm

Campbell, J., F. Lyford, and R. Willey. 2002. *Comparison of Vapor Concentrations of Volatile Organic Compounds with Ground-Water Concentrations of Selected Contaminants in Sediments Beneath the Sudbury River, Ashland, Massachusetts, 2000.* USGS Open-File Report 02-143.

Carr, R. and M. Nipper, (Eds). 2001. Summary of a SETAC technical workshop: Porewater toxicity testing: biological, chemical, and ecological considerations with a review of methods and applications, and recommendations for future areas of research. Summary of a SETAC Technical Workshop: Porewater Toxicity Testing: Biological, Chemical, and Ecological Considerations with a Review of Methods and Applications, and Recommendations for Future Areas of Research; 18-22 March 2000, Pensacola, FL. Society of Environmental Toxicology and Chemistry.

Chadwick, B. and A Hawkins. 2008. Monitoring of Water and Contaminant Migration at the Groundwater–Surface Water Interface, Final Cost and Performance Report, ER200422. SSC San Diego, Technical Report 1966, 75 pp. http://www.spawar.navy.mil/sti/publications/pubs/tr/1966/tr1966cond.pdf

Chadwick, D., J. Groves, B. Harre, R. Paulsen, and C. Smith. 2003. Coastal Contaminant Migration Monitoring: The Trident Probe and UltraSeep System: Hardware Description, Protocols, and Procedures. SSC San Diego Technical Report 1902. http://www.spawar.navy.mil/sti/publications/pubs/tr/1902/tr1902cond.pdf

Chandler, G. 2002. *Assessment of Genetic, Population, and Community Level Effects of Pesticides, PAHs, and Metal Mixtures on Sediment-Dwelling Meiobenthos.* http://enhs.sph.sc.edu/enhstc-res1.htm

Chapman, D. undated. *The Virtual Fish:SPMD*. USGS website: http://wwwaux.cerc.cr.usgs.gov/SPMD/

Church, P.et al. 2002. *Guidance on the Use of Passive-Vapor-Diffusion Samplers to Detect Volatile Organic Compounds in Ground-Water-Discharge Areas, and Example Applications in New England*. USGS, Water-Resources Investigations Report 02-4186.

Davidson, W., et al. 2001. Dialysis, DET and DGT: In situ diffusional techniques for studying water, sediments, and soils. *In Situ Monitoring of Aquatic Systems: Chemical Analysis and Speciation*, J. Buffle and G. Horvai (Editors). John Wiley and Sons, Inc.

Euliss, N. and R. Barnes. 1992. A new device for collection of interstitial water from wetland sediments. *Wetlands Ecology and Management* 1(4): pp. 233-237. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page.
http://www.npwrc.usgs.gov/resource/wetlands/newdevic/index.htm

Fones, G., et.al. 2001. High-resolution metal gradients measured by in situ DGT/DET deployment in Black Sea sediments using an autonomous benthic lander. *Limol. Oceanogr.* 46 (4), pp 982-988.

Hampton, T. and D. Chadwick. 2000. *Quantifying In Situ Metal Contaminant Mobility in Marine Sediments*. San Diego Navy Space and Warfare Systems Center Technical Report 1826.

Holcombe, B., R. Keil, and A. Devol. 2001. Determination of pore water dissolved organic carbon fluxes from Mexican margin sediments. *Limnology and Oceanography*, Vol. 46(2), pp 298-308.

Krom, M., et al. 2002. In-situ determination of dissolved iron production in recent marine sediments. *Aquatic Sciences* 64 (2002) 282-291.

Lager, T., et al. 2002. Pore water sampling by means of dialysis technique and centrifugation—predicting the source strength of harbour sludge. GeoProc2002, March 4-7, 2002, Bremen, Germany.

Mudroch, A. and J. Azcue. 1995. Manual of Aquatic Sediment Sampling. Lewis Publishers Inc., Boca Raton, FL.

Mudroch, A. and S. MacKnight. (Eds). 1994. *Handbook of Techniques for Aquatic Sediments Sampling*, Second Edition, ISBN: 1566700272. Lewis Publishers, Boca Raton, FL.

Navy Environmental Leadership Program. 1996. Petrex passive soil gas and sediment vapor sampling system. *NELP Fact Sheet No. 7*.

New Jersey Department of Environmental Protection. 1999. *Guidance for Sediment Quality Evaluations*. http://www.state.nj.us/dep/srp/regs/sediment/

Ohio Environmental Protection Agency. 2001. *Sediment and Sampling Guide and Methodologies* (2nd Edition).

Radtke, D. 1997. Chapter A8. Bottom-material samples. *National Field Manual for the Collection of Water-Quality Data.* USGS Book 9 Handbooks for Water-Resources Investigations.
http://water.usgs.gov/owq/FieldManual/Chapter8/index.html

Resources Inventory Committee. 1998. *Lake and Stream Bottom Sediment Sampling Manual*. Province of British Columbia, Canada.

Schüürmann, B.V. 2000. Calibrating the uptake kinectics of semipermeable membrane devices in water: the impact of hydrodynamics. 6th International SPMD Workshop and Symposium, July 25-27, 2000, USGS Columbia Environmental Research Center.
http://www.cerc.cr.usgs.gov/Brnch_Webs/EChem/workshop.htm

Shoven, H. 2000. Monitoring dioxin levels in Maine rivers with semipermeable membrane devices. 6th International SPMD Workshop and Symposium, July 25-27, 2000, USGS Columbia Environmental Research Center.
http://www.cerc.cr.usgs.gov/Brnch_Webs/EChem/workshop.htm

Society of Environmental Toxicology and Chemistry. 2001. *Summary of a SETAC Technical Workshop: Porewater Toxicity Testing: Biological, Chemical, and Ecological Considerations with a Review of Methods and Applications, and Recommendations for Future Areas of Research*.
http://www.setac.org/files/porewatersummary.pdf

South Carolina Department of Health and Environmental Control. 2001. *Methods to Evaluate Contaminated Groundwater Discharges to Surface Water.*

Stüben, D. 2001. *Development of a Pore Water Sampler (PWS) for Marine and Fresh Water Use Up to 100 m Water Depth*. Institute for Mineralogy and Geochemistry, University of Karlsruhe, Karlsruhe Germany.

Teasdale, P. 1999. DGT (diffusive gradients in thin films), an in situ method of measuring porewater concentrations or fluxes from solid to solution phase in sediments—background and recent developments. Northwest Analytical Division of the Royal Chemical Society Workshop, Liverpool (July, 1999).

Tetra Tech EM, Inc. 2003. *Literature Review and Report: Surface Sediment Sampler Database*. Office of Research and Development, USEPA.

Tse, E., B. Richardson, and P. Lam. 2000. Uptake and Release of selected organochlorines and PAHs by mussels and SPMDs. 6th International SPMD Workshop and Symposium, July 25-27, 2000, USGS Columbia Environmental Research Center.
http://www.cerc.cr.usgs.gov/Brnch_Webs/EChem/workshop.htm

USEPA, 2001. *Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*, EPA/823/B-01/002. Office of Water.
http://epa.gov/waterscience/cs/library/collection.html

USEPA. 2000. *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Freshwater Invertebrates*. Second Edition. EPA/600/R-99/064, Duluth, MN.

USEPA. 1999. *Innovative Technology Verification Report: Sediment Sampling Technology, Aquatic Research Instruments Russian Peat Borer*, EPA/600/R-01/010. Office of Research and Development.

USEPA. 1998. *Environmental Technology Verification Report: Soil Gas Sampling Technology W. L. Gore & Associates, Inc. GORE-SORBER Screening Survey*, EPA/600/R-98/095. Office of Research and Development.

USEPA. 1994. *Assessment Guidance Document*, EPA/905/B-94/002. Assessment and Remediation of Contaminated Sediments Program, Great Lakes National Program Office, Chicago.

USEPA. 1987. *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound*. USEPA Region 10 Office of Puget Sound and Puget Sound Water Quality Authority.

USEPA. 1986. *Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound*. USEPA Region 10 Office of Puget Sound and Puget Sound Water Quality Authority.

Winter, T. 2002. Subaqueous capping and natural recovery: Understanding the hydrogeologic setting at contaminated sites. *DOER Technical Notes Collection* (TN-DOER-C26), U.S. Army Engineer Research and Development Center, Vickburg, MS.
http://www.wes.army.mil/el/dots/doer

Winterhalter, B. 2000. *The New Undisturbed Sandy Sediment Sampler*. Geologic Survey of Finland. http://www.kolumbus.fi/boris.winterhalter/OSCOR.pdf

Wisconsin Department of Natural Resources. 2001. 701.4 General sediment sampling equipment and procedures. *WI DNR Field Procedures Manual Internet Edition*, *Part B: Collection Procedures.*
http://www.dnr.state.wi.us/org/water/wm/wqs/sediment/sampling/701_4.htm

http://www.clu-in.org/programs/21m2/sediment/default.cfm
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