Chapter 5

# Common Hydrologic Census Methods

*"Water is the driving force of all nature."* - Leonardo Da Vinci

Within the aquatic sciences, it is nearly impossible (in practice or in concept) to separate natural waters from the myriad of dissolved and suspended constituents therein. Therefore, the aquatic sciences are as much about the study of water as everything else. So it should come as no surprise that our consideration of the fluid medium—the study of water itself—should be the foundation on which we must build our field research program.

But there is far more to this task than simply following a prescribed analytical methodology. The very best methods, like the very best equipment, can be rendered impotent if our sampling procedures were inherently flawed, or if our samples were inexpertly collected. In truth, the careful planning and execution of our sampling plan is perhaps the most critical aspect of our analyses—more so than the latest gizmos or the most advanced laboratory techniques.

So when it comes to hydrologic census techniques, deciding when, where, and how to collect the most pertinent hydrologic data from the field will go a long way to guaranteeing solid experimental results. After all, little can be wrought from a poor sampling plan, except poor-quality data.

## Key Concepts

- Hydrology is different from hydrography in that it focuses exclusively on the intrinsic qualities of natural waters.
- The periodicity of hydrologic data collection will determine what analyses are possible and which time-sensitive dynamics are captured in the dataset.
- The number, location, and orientation of the chosen sampling sites will define the horizontal and vertical gradients of all hydrologic parameters.
- The methods chosen for measuring the dissolved and suspended constituents of natural waters will require a combination of colorimetric, titrimetric, and electronic analyses.

## The Difference Between Hydrology and Hydrography

As an integrative discipline, the marine sciences require that we know a little something about both the hydrology and hydrography of the ocean. **Hydrology** is quite literally the "study of water" that focuses on the movement and distribution of water, as well as the composition of the aquatic medium and all its constituents. In natural waters, hydrology includes much more than just the water molecules themselves—it also includes the quantitative and qualitative measurement of all the other materials suspended or dissolved in that same water (more generally regarded as **water quality**). For this reason, hydrologic parameters (especially those that affect water quality) are considered to be **intrinsic** to the water; in other words, they are qualities that "belong" to the water. For example, the salinity of seawater is an excellent example of a quantitative hydrologic measurement, because it defines the total dissolved salt concentration within the water.

This is different from **hydrography**, which focuses instead on the geophysical parameters that define a particular body of water, usually from the perspective of global positioning, navigability, and shipping safety (such as coastline geometry, bathymetry, tides, and currents). These sorts of parameters are not a natural part of the water; they are actually defined by factors external to the water. For example, if we wished to define the depth of the water column in a particular location, we could not accomplish this without also defining our position and perhaps the tides and currents affecting the height of the water column at the instant we wished to make that measurement. All of these features provide an external influence on our measurements; thus, hydrographic parameters such as these are considered to be **extrinsic** to the water.

As you can well imagine, hydrography and hydrology are both critical to the study of marine science, but they are not necessarily equal in their importance. Typically, hydrographic parameters are measured in order to define the dynamic range and context of the pertinent external influences on our efforts in the field. However, the hydrologic parameters are most often viewed as the most powerful and most informative analyses that can be conducted in marine science. This is because the hydrologic properties of water are inherent to the water, so they come with the water and will not change, even if we remove the water from its original place. Hydrographic properties are just the opposite. Since they are dependent on external forces, they will change (or be impossible to measure) when the water is removed from its natural place of origin.

## When to Measure Hydrologic Data

Deciding just how often you must collect samples is much more difficult than you would think. From a theoretical perspective, the more often you collect a water sample (and perform a measurement), the better your chances of capturing rare events and time-sensitive dynamics. Of course, the more often you collect a water sample, the quicker you exhaust your supplies, storage space, handling time, and crew morale! No matter what, **periodicity** of sampling swiftly becomes an issue with which you must deal.

In some cases, you might be able to get away with storing your samples for months on end, but if you must perform your analyses immediately (or with a 24- to 48-hour turnaround, which is much more typical), you will absolutely need to determine the best strategy to not only collect but also analyze all of your samples. If you have access to automated and/or electronic equipment that can make rapid measurements and store the results in a digital format, **continuous sampling** is certainly the way to go. However, if your measurement and analysis methods are decidedly more low tech, you will be forced to adopt a **periodic sampling** strategy.

### Continuous Sampling Methods Are Best When Measuring Rapidly Changing Hydrologic Variables

Owing to critical technological advancements in the past two decades of ocean research, many of the most commonly measured hydrologic parameters (salinity, temperature, pH, dissolved oxygen, and chlorophyll *a* (chl *a*), for example) can now be measured using differential optical and/or electrical resistivity. Since these electrical responses occur, and can be accurately measured, in mere microseconds, what used to take minutes to measure can now be measured several times each and every second! This has led to the development of near-continuous oceanographic sensors that are able to take hundreds of nearly instantaneous measurements and transmit those data to a laptop or flash memory device for easy data storage.

Because of the tremendously swift response time of these sensors, the data they collect are only useful if they are exposed to different water masses over the duration of their deployment. After all, why take thousands upon thousands of measurements of an unchanging water mass when just a few, redundant measurements would suffice? Thus, hydrologic sensors are best used on a platform that is guaranteed to be exposed to different water masses, like on a moving vessel or on a buoy affected by changing currents and the tides. Although expensive, these systems are the backbone of modern oceanographic research and are typically employed either in an **underway system** or a **moored system** for continuous sampling.

### Underway Systems Provide Continuous Sampling During Transit Between Multiple Locations

These are typically integrated into a seagoing vessel, often as a self-contained plumbing system, external to the ships systems (to avoid sample contamination). An intake port is usually oriented at the bow of the vessel, whereby ocean water is forced into the intake port by the vessel's forward progress. As the water is forced through the plumbing system (**Figure 5.1**), its hydrologic parameters are continuously measured by an oceanographic sensor

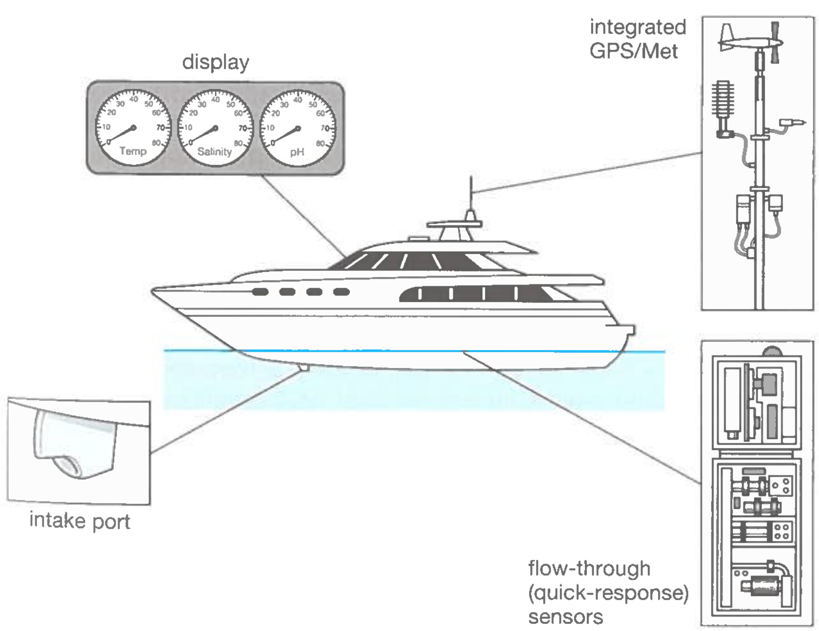


**Figure 5.1** An underway system, which allows rapid measurement of important hydrologic parameters on a near-continuous basis. As water is forced into the intake vent at the ship's bow, it travels downpipe to integrated oceanographic sensors that make rapid measurements and store the data prior to the water exiting through the excurrent vent at the ship's stern. Underway data are easily displayed to the ship's captain or research team for real-time visualization of critical oceanographic variables.

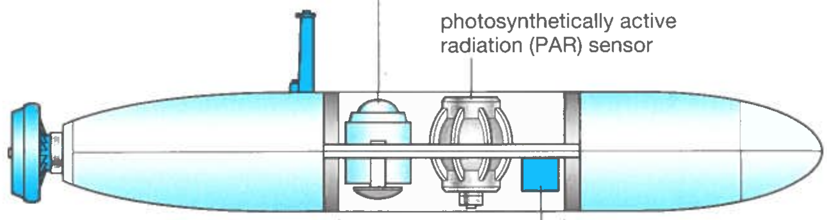


**Figure 5.2** Autonomous underwater vehicles (AUVs) can be deployed virtually anywhere in the ocean to conduct oceanographic measurements, which are recorded on board and then uploaded to either a satellite or a nearby ship using microwave transmission technology. Several different combinations of hydrologic sensors can be fitted into the payload bay of an AUV for continuous measurements, each of which can be easily swapped out with new sensors if the AUV is retrieved and batteries recharged for subsequent deployments.

package, which is integrated with instantaneous hydrographic data (for example, for GPS positioning, water depth) and meteorological data, and the data are automatically stored in digital format for analysis at a later time.

Because large seafaring vessels can easily contaminate the hydrologic parameters we seek to measure, underway systems are usually designed to be self-contained plumbing systems that are mounted to the ship's hull, externally if possible. For example, seawater passing close to the ship's engines might provide enough heat to "contaminate" water temperature measurements. Likewise, we may not trust our trace metal analyses if our measurements were taken from waters in close proximity to the ship's hull.

Autonomous underwater vehicles (AUVs) are designed specifically as underway systems, but the entire sensor package is instead stored in the body of the AUV and is in constant, direct contact with the surrounding water. These are among the cleanest seafaring vessels and thus require no external plumbing (**Figure 5.2**). Of course, these are also among the most expensive hydrologic sensor platforms available for use.

## Moored Systems Provide Continuous Sampling at Fixed Locations Only

Instead of placing oceanographic sensors aboard a moving vehicle, in some instances it may be more advantageous to place the sensors in a fixed position, either on a moored buoy or attached to a permanent, submerged structure. In this way, the natural currents flowing past the moored sensors provide the necessary movement of water for continuous sampling.

For buoys deployed in the deep ocean, any number of sensors can be attached in different positions along the mooring cables, which can be thousands of meters long (**Figure 5.3**). In this fashion, the entire vertical profile of the deep ocean can be monitored continuously, at virtually any depth. In the coastal ocean, it is much more cost effective to incorporate continuous sampling devices on semipermanent structures, such as wharf pilings or offshore oil rigs.

Despite the many benefits of underway systems, their use does come with some significant downsides. As mentioned, electronic oceanographic sensors are quite expensive, and the volume of data collected from a single mission can quickly exceed a terabyte or more. But perhaps the most significant drawback is that it is usually not possible to collect a physical sample of water from an underway system. Since most underway systems only measure the most basic hydrologic parameters, your options to explore the other dissolved or suspended constituents (or contaminants) in the water will be significantly limited. For those analyses, you will have to collect your hydrologic data the old-fashioned way: using periodic, discrete sampling.

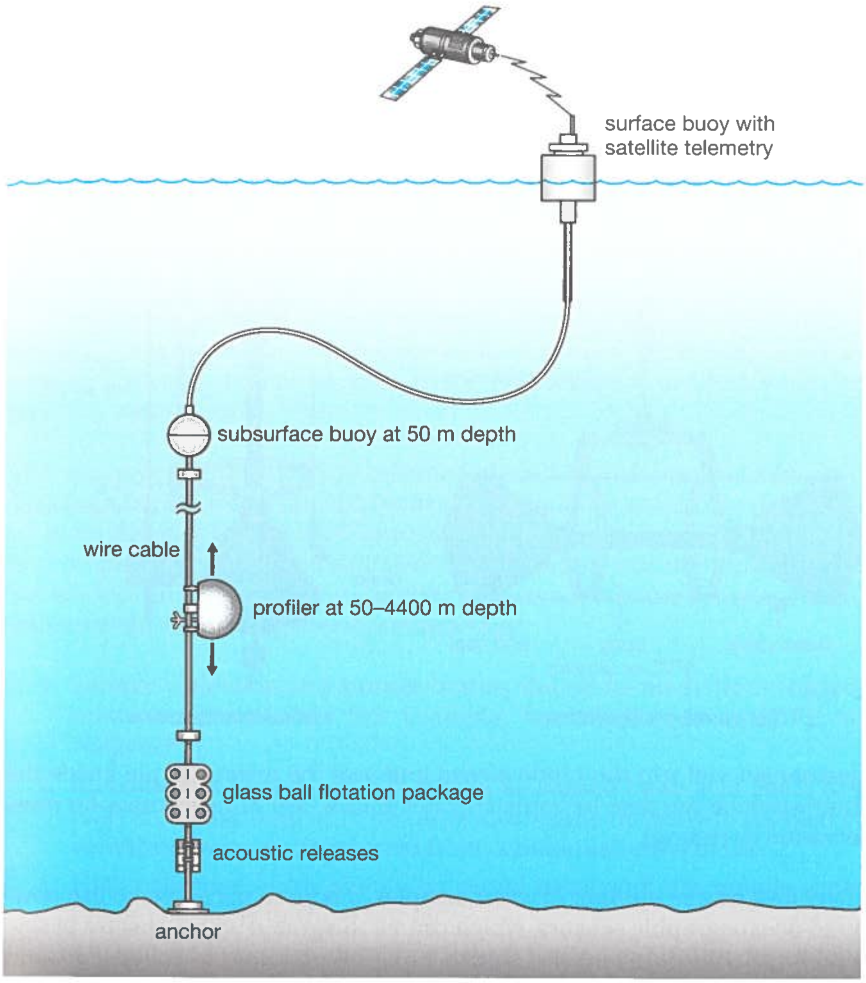


**Figure 5.3** A typical oceanographic buoy, with any number of electronic sensors positioned along the mooring line and on the surface buoy. Sensors can also be mounted to a collar that is programmed to control its own buoyancy to float (ascend) or sink (descend) along the wire cable in order to take continuous "profile" measurements of the entire water column. If the sensor package ever needs to be retrieved for maintenance, the acoustic releases are triggered, and the entire mooring line will separate from the anchor and float to the surface with the aid of the glass ball flotation package.

## Discrete Sampling Methods Are Best When Measuring Slowly Changing Hydrologic Variables

In most circumstances, it is always preferable to collect a physical sample of the water using discrete sampling. This is because the water sample you collect will contain within it the hydrologic parameters you might wish to quantify (beyond the typical measurements of salinity, temperature, and density). And as long as the sample being collected is relatively small (<20 L), we can assume that all of the dissolved and suspended constituents in that sample are evenly distributed throughout. That means we can divide the water into much smaller volumes, or **aliquots**, and perform entirely different analyses on each of the aliquots without fear of compromising the integrity of the original collected sample.

The equipment used to collect samples from the surface can be as mundane as a clean bucket thrown over the side of the ship. If it is necessary to collect water samples from discrete depths, the easiest solution is to employ a **Van Dorn** bottle (**Figure 5.4**). Van Down bottles consist of a horizontal or vertical tube with tension-mounted rubber flanges at each opened end of the bottle. The central frame of the Van Dorn bottle will also have two protruding pins that, when depressed, will trigger each of the tension-mounted flanges to snap shut. If the Van Down bottle is attached to a rope with depth markings, it can be lowered to the desired depth, whereby a heavy brass weight (sometimes called a "messenger") can be threaded onto the line and dropped. When it reaches the submerged Van Dorn bottle, the impact of the

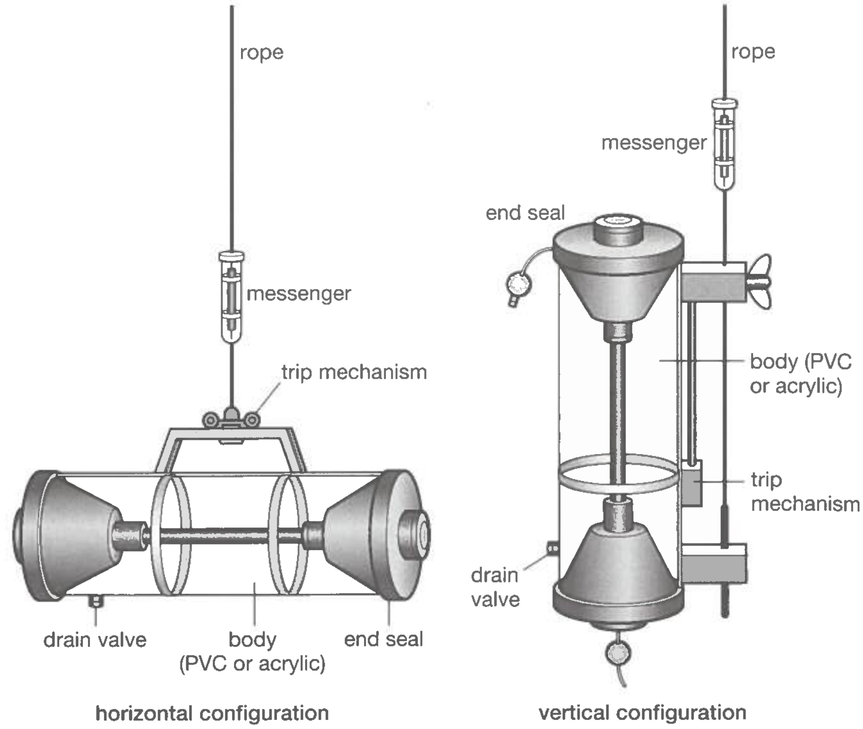


**Figure 5.4** A Van Dorn bottle, often used to collect water samples from discrete depths when only a few samples are needed (or when field conditions will not allow the use of powered oceanographic sensors). The Van Dorn bottle is first loaded with the end seals held open with a tension rod, and then lowered to the desired depth. A heavy brass weight (called a "messenger") is sent down the line to trip the release mechanism, which causes the end seals to snap shut and form a watertight seal, capturing a fixed volume of water within the Van Dorn bottle. When it is hauled back aboard the ship, the drain valve is opened to decant the water sample collected at depth.

messenger will trip the bottle closed and seal the water sample inside the bottle (which can then be hauled up and placed into storage bottles for preservation or testing).

To collect a large number of water samples, it is often necessary to use powered oceanographic sensors, which can be integrated with a **rosette** of several large collection vessels (Figure 5.5). The principle of collecting water samples from discrete depths is the same; however, for most rosette systems,

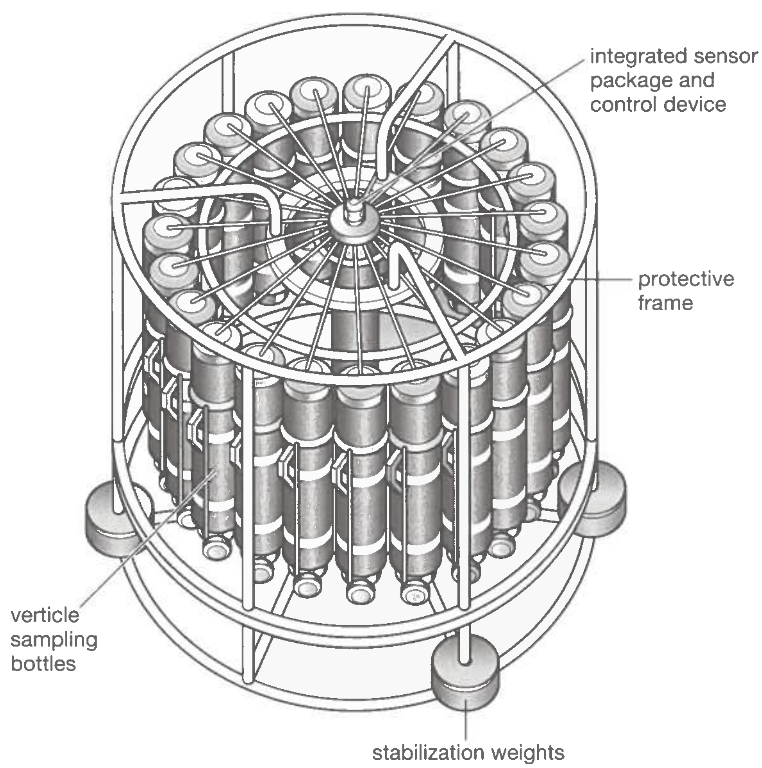


**Figure 5.5** A rosette of several large sample bottles, integrated with a CTD sensor package, and housed within a protective metal cage to prevent damage to the sensor package. Each vertical bottle within the rosette can be triggered separately via an electrical current that is delivered through a conducting cable, allowing the collection of several different water samples (from several different depths) in a single deployment.

the bottles are triggered remotely by radio transmission or by electrical signal, sent through a conducting cable. Such systems are typically deployed with a depth sensor that can relay the actual depth of the rosette back to a shipboard observer who lowers the rosette to the desired depth. When the rosette is in position, a simple press of a button will send an electrical signal to the rosette, causing a specific bottle to "fire."

Because the collection of water samples takes a significant amount of time, it is impossible to sample continuously in this fashion. Instead, the physical collection of samples must be conducted periodically. Even if oceanographic sensors are continuously recording measurements while the sampling apparatus is being lowered, only those measurements that were recorded at the moment the bottle was "tripped" can be associated with the water sample.

Whether water samples are first collected with a bucket, from a hand-lowered Van Dorn bottle, or from an electronically controlled rosette, it is critical that all water samples are handled correctly, stored in an appropriate container, and properly preserved to minimize contamination and to protect against sample loss. In most cases, the handling and storage of water samples should adhere to the following general methodology:

1. Sample collection and storage bottles should be made from rugged, nonreactant materials (for example, borosilicate glass, HDPE, or Nalgene™).
2. All collection bottles and lids should be soaked in an acid bath (10% HCl) for a minimum of 15 minutes, thoroughly rinsed with distilled or deionized water, and protected from contamination until use.
3. Each collection bottle should be rinsed twice with the sample water before collecting the final sample.
4. All collected samples should be stored at 4°C and out of direct sunlight. Light-sensitive samples should be stored in opaque bottles in complete darkness.
5. It is best to perform analyses within 12–24 hours post-collection.

Of course, the nature of the research project will dictate the specific method of collection, storage, and analysis for your water samples. But regardless of whether you have chosen to collect sensor-derived measurements on a continuous basis, or instead to collect periodic discrete samples, it is not enough to simply consider the timing of your collections and be done with it—you must also determine where you wish to collect your samples.

## Where to Collect Hydrologic Data

Depending on the focus of your field research, you should already have a basic idea of the local or regional areas where you shall focus your attention. Thus, in a very general sense, deciding on your general area of interest should be relatively straightforward. However, when it comes down to pinpointing a number of very specific locations within that general area of study, you will be required to invest a considerable amount of forethought into the process.

### Proper Site Selection is the Key to Success for Any Sampling Strategy

For all aquatic field studies, there are a few general considerations to keep in mind whenever you engage in the process of selecting your study sites. Although the goals of your specific research project should drive the decision-making process, you should always keep the following at the forefront of your mind when deciding where your study sites should be located:

- Greatest likelihood to meet research objectives
- Indicative of control versus experimental conditions
- Easily accessed for repeat sampling
- Broadly representative of the water body

Whatever the goals of your field study, the sites you select should offer the greatest likelihood that you will be able to collect the data you require to meet your research objectives. To that end, it is important to select a variety of sites that can serve as internal comparisons: some of which can be deemed "experimental" sites, while others can serve as baseline or "control" sites. It is also critical that you are able to easily access each of your study sites whenever your research plan requires a field measurement.

Your sites should also be located where the measurements being conducted will yield data that are representative of the water body where those sites are located. For example, if you wished to establish a coastal study site to represent a "typical" undeveloped coastal area, it would be unwise to locate your site near the outfall of a storm sewer.

With these points in mind, you must now take the time to consider the specific aquatic environment you wish to study, and how the unique features of that water body will inform your decisions. The proper placement of your study site(s) is critical to the success of your field research, so don't just wing it—take the time to get it right.

## Fluvial Study Sites Are Those Located Along Streams and Rivers

The site selection process for **fluvial** (riverine) studies is among the simplest of aquatic field studies because of the very obvious connectivity and flow pattern among streams and rivers within the **watershed**. Despite the winding paths of the many tributaries within your general study area, it is relatively easy to map out the **stream order** in an effort to explicitly define how all of the streams and rivers are connected to each other in a hierarchical pattern (**Figure 5.6**).

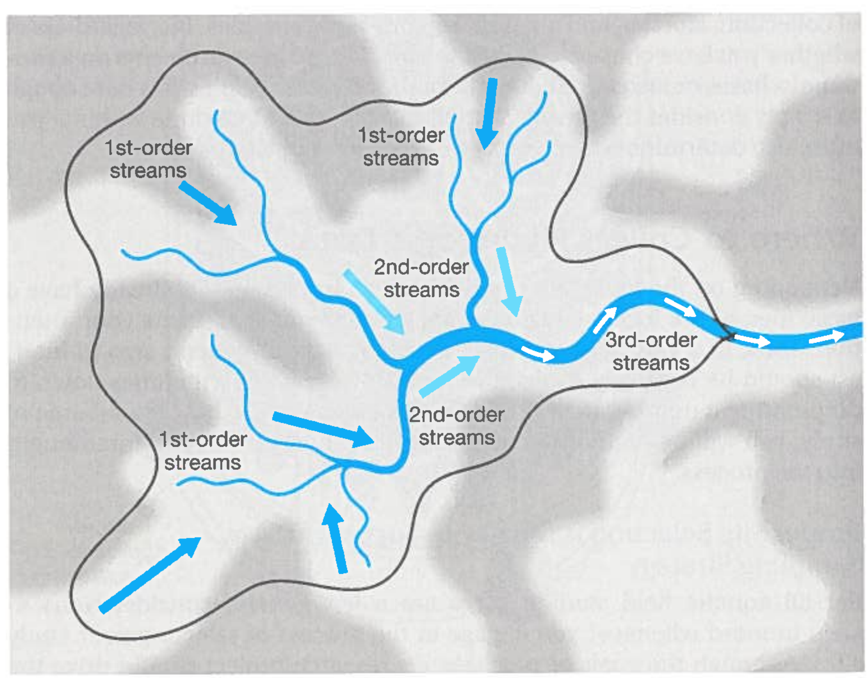


**Figure 5.6** An idealized watershed, indicating the connectivity of all associated streams and rivers, as well as the streamflow. This connectivity can be further defined by using a "ranking" process, or stream order, to elucidate exactly how the all the tributaries are connected to each other.

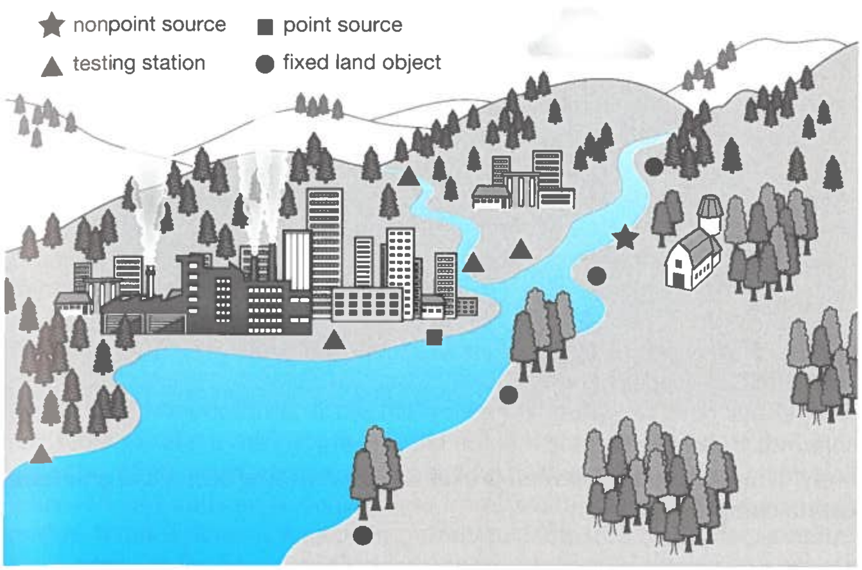


**Figure 5.7** An example of a fluvial study region, appropriately stream-ordered and with testing stations located up- and downstream in each tributary to capture the potential effects of various point and nonpoint sources of pollution. Although it is always preferable to use GPS coordinates to pinpoint the location of each study site, the low-tech method of using fixed land objects for positioning is a viable backup (Adapted from Campbell G & Wildberger S [2001] The Monitor's Handbook, 2nd ed. LaMotte Company.)

If the streams are relatively shallow, or if the rivers are well mixed, it should make no difference whether we collect our data from the surface or the bottom of the stream; nor should it make a difference whether we collect our data from either shore, or even from the middle of the tributary. If this is the case, you can treat each tributary as a one-dimensional waterway, locating your study sites according to stream order and relative to each other as being some distance up- or downstream from a neighboring site (**Figure 5.7**).

For most fluvial studies, it is always a good idea to locate a site at the "mouth" of each tributary, with at least one additional site some distance upstream. If there are other points of interest along the route of the tributary (for example, sites of **point** and **nonpoint sources** of pollution outfall), you should sandwich it between a pair of up- and downstream sites as well.

## Lacustrine and Estuarine Study Sites Are Those Located in Bays and Inland Coastal Areas

Performing field studies within a large body of water, such as a lake or coastal embayment, can be much more complicated than an idealized fluvial study. Freshwater lake (or **lacustrine**) studies are similar to those involving coastal bays in that they both exhibit complex, three-dimensional variability and are more of a logistical challenge simply due to their size. Choosing study sites within bay (or **estuarine**) studies can be even more complicated than lacustrine studies because bays are fed not only by freshwater tributaries, but also by marine water encroachment due to tidal influences.

Because of these factors, it can be quite difficult to affirmatively establish which locations within a lake or bay will yield measurements that are most representative of the entire system. This will make it necessary to establish several different study sites within each lake or bay, taking great care to provide ample geographic coverage (**Figure 5.8**).

As a general rule, a study site should be located at each major inlet and outlet. If the inlets and outlets are themselves quite large, it may be necessary to establish both a nearshore and mid-water station at each inlet and outlet. Likewise, a mixture of nearshore and mid-water stations should be located throughout the larger body of the lake or bay. If possible, stations should be oriented according to some kind of geometric pattern that can be used to establish regular transects along or across the major dimension of the water

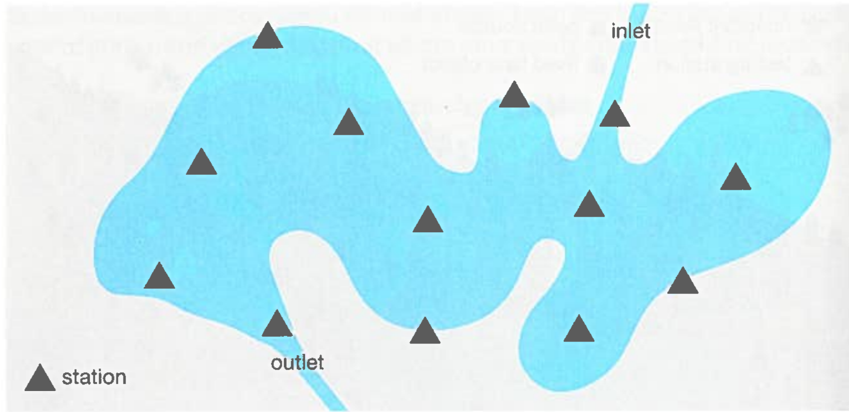


**Figure 5.8** An example of a lacustrine or estuarine study region, showing a variety of sampling stations that would provide excellent geographic coverage of an irregularly shaped lake or bay. Note that the spatial coverage is augmented by including a number of nearshore and mid-water stations throughout the entire system.

body. Transects can be extremely useful in establishing ecological **gradients** within complex systems.

## Marine Study Sites Are Those Located Along the Coast or Out to Sea

In some ways, deciding the location of marine study sites is an easier task because marine waters are less constrained by land features. In fact, the only geographic feature to consider in nearshore studies is the coastline; for open ocean studies, there are no land masses to contend with. Although this may grant you the ultimate flexibility in positioning your study sites, it also presents a unique problem: How do you choose a location that will maintain its "representativeness" if the water at each station is free to flow in or out, in any direction, at any time?

If you are attempting a Lagrangian study, it is not necessary to define a fixed study site. By definition, all of the measurements in a Lagrangian study are taken from within the same water mass, no matter where that water mass happens to travel—the ultimate in "representativeness." But for Eulerian studies, it is necessary to choose fixed positions for repeat sampling (typically done using high-precision GPS coordinates). In such studies, the sites are not meant to be representative of the ocean per se; they are meant to be representative of the dynamics experienced at those locations over time.

In most marine studies, study sites are located along specific transect lines according to some fixed geographic pattern (for example, along the same latitudinal or longitudinal lines, separated from each other by some equal distance). The number and orientation of those transect lines depend largely on the objectives of the research. For those studies that anticipate strong coastal or shelf influences, the transect lines are usually oriented perpendicular to the coast in order to determine **cross-shelf** gradients. If multiple transects are used, data from stations located along the same **isobath** can be used to determine **along-shelf** gradients as well (**Figure 5.9**). For those studies that anticipate a dilution or "spreading" effect (like the simultaneous propagation of some event, extending in multiple directions from the location of the event), transect lines are oriented in a radial pattern instead.

## Don't Forget the Vertical Dimension When Planning Your Study Sites

With the exception of most fluvial studies, it will be important to define the vertical dimension of your sampling strategy at each study site. Although each study site is chosen largely on the basis of geographic information, the three-dimensional structure of the aquatic medium often requires that we take samples from multiple depths at each study site—only then can we hope to describe the three-dimensional variability that makes aquatic field research such a challenging endeavor.

Although the primary objectives of your field research will dictate your vertical sampling regime, standard practice within the aquatic sciences is to collect measurements from both the surface and bottom (or within 0.5 m of the bottom—the closer, the better). Surface and bottom water sampling should be regarded as the bare minimum; very rarely is it justified to collect measurements from a single depth (unless you are certain the water column is well mixed).

Of course, increasing the number of samples taken in the vertical dimension will enable a much more realistic description of the true vertical structure of the water column. If the bathymetry is known at each station, it is advisable to take a mid-depth sample at each station as well. If the main objective of the research is to define the vertical structure of the water column, it is not unusual to collect data from several discrete depths at each station. If this is done, it shall be important to define the "rules" for sampling at multiple depths. For example, you may choose to collect measurements at every 10-m depth increment. Another strategy often utilized is to sample at depth intervals that are proportional to the overall depth at each station. For example, if you chose to collect water samples at 0/25/50/75/100% depth intervals, a station with an overall depth of 30 m would indicate that samples be taken at 0 m, 7.5 m, 15 m, 22.5 m, and 30 m. Breaking the vertical dimension into different depth layers and collecting samples from each of those layers is a type of **stratified sampling** (Figure 5.10). In the aquatic sciences, this method is absolutely essential for describing the hydrologic features of discrete water masses in the vertical dimension.

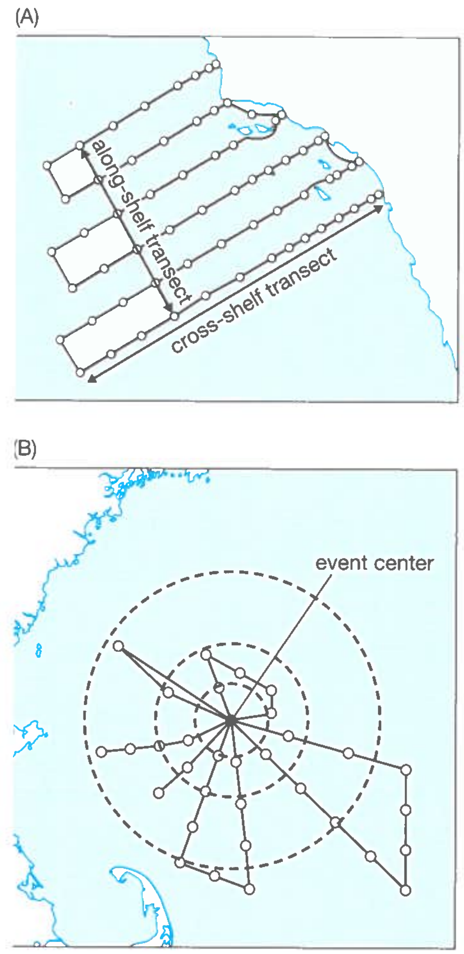


**Figure 5.9** (A) For marine studies that focus on coastal influences, it is typical to establish a number of study sites along transects that are oriented both parallel (along-shelf) and perpendicular (cross-shelf) to the coastline. (B) For marine studies that focus instead on the influence of a localized and unique event (such as an oil spill), the transects are oriented in a radial pattern, extending outward from the "epicenter" of the event.

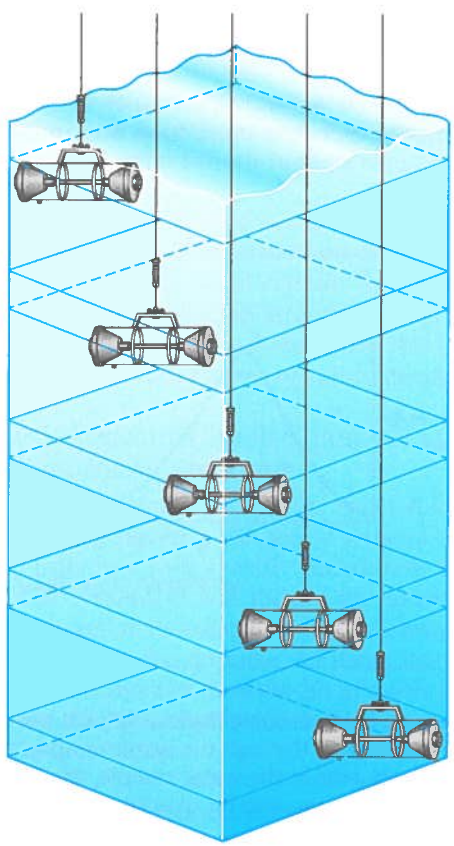

**Figure 5.10** Any water column can be subdivided into different depth layers. Water samples collected from each of these layers (using a Van Dorn sampler, or similar device) can then be analyzed separately to define the hydrologic parameters for each of the discrete water masses collected.

## How to Measure Hydrologic Data

For the most common hydrologic parameters, the equipment and methods used to collect those measurements fall into one of three main categories: colorimetric, titrimetric, and electronic analysis. If a particular hydrologic parameter can be measured by different methodologies, you should choose the method that provides the greatest precision and accuracy, whenever possible.

### Colorimetric Analysis Uses Color as a Method to Quantify Hydrologic Parameters

Occasionally, there are dissolved or suspended constituents in seawater that can be analyzed quantitatively by treating those constituents with specific chemicals that cause a unique reaction, thereby producing a colored solution. Since all colors can be defined by their unique wavelength, the development of different colors can be measured by instruments that are extremely sensitive to different wavelengths of light. Not only can these instruments (called spectrophotometers) measure the specific wavelength of each unique color, they can also determine the relative intensity of those colors. In **colorimetric** analyses, the color and intensity can be used to identify specific hydrologic parameters and determine their relative abundance (concentration) within the sample (**Figure 5.11**).

Some constituents of seawater (like chlorophyll *a*) exhibit **fluorescence**, a phenomenon that causes the spontaneous emission of light of a specific intensity and wavelength when doused with higher-energy light at a special "excitation" wavelength. If the colorimetric device being used is sensitive to fluorescence, the intensity of fluorescence can be used to determine the concentration of the fluorescing constituents in seawater. In fact, this colorimetric method is one of the most important and heavily utilized methods in the aquatic sciences. Since photosynthesis requires chl *a* it is possible to directly measure chl *a* concentrations by simply measuring the intensity of chl *a* fluorescence in a water sample.

Although not as sensitive as a spectrophotometer, the human eye is also capable of discriminating between color tone and intensity. Thus, simple

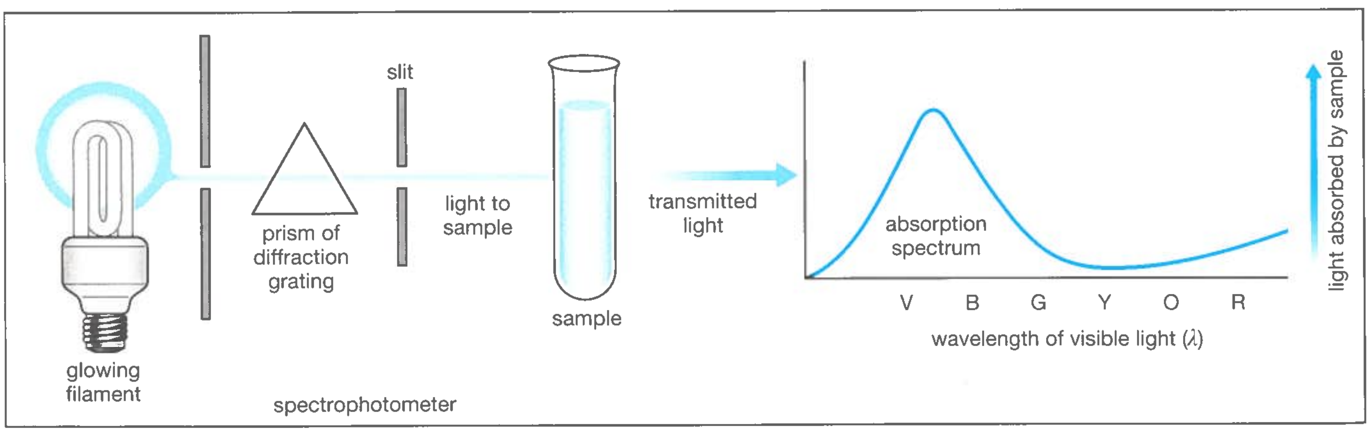


**Figure 5.11** The most common application of colorimetric analysis uses a light-sensitive device, called a spectrophotometer. Light of a specific wavelength and intensity is generated by the lamp and passed through the water sample. As different wavelengths $\lambda$ of light are transmitted through (or absorbed by) the constituents in the water sample, the unique color (and intensity of color) can be measured as an absorption spectrum, which can then be used for quantitative analysis of many different hydrologic parameters.

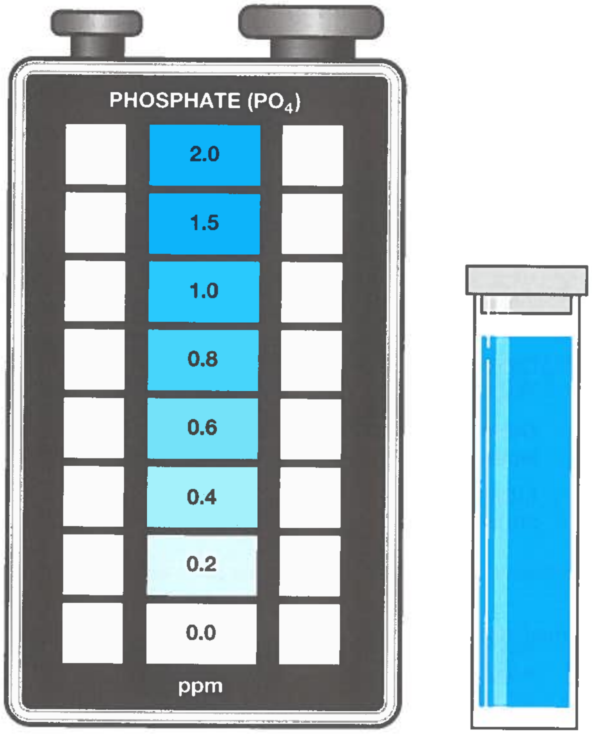


**Figure 5.12** Colorimetric test kits require either a few drops of water placed upon a test strip, or a small volume of water in a sealed test tube, combined with colorimetric reagents. When a positive reaction occurs, the intensity of color will indicate the relative concentration of the hydrologic parameter being tested. Most test kits measure chemical concentrations in parts per million (ppm), which is equivalent to mg/kg.

colorimetry test kits can be used in the field for rapid detection and quantification of seawater constituents (**Figure 5.12**).

## Titrimetric Analysis Quantifies Hydrologic Parameters by Inducing a Specific Chemical Reaction

A variation of the colorimetric method is the **titrimetric** method of analysis, which involves the addition of a chemical solution of known concentration to induce a chemical reaction with a specific constituent of seawater. If the constituent is absent, the reaction does not take place and there are no measureable results. If the constituent is present, it will react in direct proportion to its concentration in the water sample being tested.

Depending on the titrimetric method being used, a colored product may develop (in which case, a colorimetric method could be used to determine its concentration). Occasionally, solid crystals may form as a result of the reaction. If those crystals are collected and weighed (a type of **gravimetric** analysis), the data can be used to back-calculate the concentration of the constituent in seawater that caused the crystals to develop.

## Electronic Analysis Measures Small Changes in Conductance to Quantify Hydrologic Parameters

By far, the preferred analytical method for most hydrologic parameters involves the use of highly sensitive electronic sensors that have been engineered to respond only to a very specific constituent in water. If that particular constituent is present, it will induce an electrical impulse in the device that is proportional to its concentration in seawater: the stronger the concentration, the stronger the impulse. As these instruments can detect electrical changes, measured as a thousandth of a volt in just a fraction of a second, they provide the most rapid, accurate, and precise measurements obtainable by modern methods.

Of course, such instruments can be quite expensive and require both a power source and a data storage solution. Many of these systems can be powered by an onboard battery pack, or by a ship's generator and an attached electrical cable. The same electrical cable can also be used to transfer data from the sensors, uploaded to a weatherproof laptop computer or hard drive connected to the cable. To ensure against data loss, many sensors also have self-contained data storage capability, usually as a simple flash drive or memory card.

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