CHAPTER 1

SELECTION OF THE STATION SETTINGS

1.1 INTRODUCTION

This chapter is intended to provide a general overview of the monitoring site selection process, focusing mainly on the site-specific characteristics. It is beyond the scope of this chapter to evaluate all components of the site selection process. Detailed information on this topic can be found in the reference section.

In a water quality monitoring project, the decision of where to locate the monitoring stations is a critical success factor. Given that it is not possible to sample the whole target area or watershed, it is essential that the stations be placed where representative samples can be obtained, and where the data measured represents accurately and precisely the water body. After defining the study objectives, monitoring site selection is one of the most critical design factors in a monitoring program.

The site selection starts by viewing the big picture to ensure achieving the monitoring objectives, and then, translating those objectives into a detailed plan to assure quality data. This process is not a simple task. Primarily because in most water quality monitoring projects a monitoring network must be defined (utilization of several monitoring stations in the water body to monitor current, short and long-term water quality conditions) and secondly, due to the fact that not only scientific considerations must be understood and addressed, but also other factors must be considered and evaluated. Among these factors; natural, temporal and spatial variability, hydrological water body characteristics (*e.g*. cross section variability, stratification), climate influence (*e.g*. icing), biological factors (*e.g*. diel patterns of biological activity such as primary productivity, animals), and human induced variability (*e.g*. sediment inputs due to farming activity, communities development) need to be considered. Thus, during the planning process certain environmental, logistic and management factors, which are site-specific and can influence the site selection decision, must be addressed.

To ensure a successful site selection process, it is recommended to apply the Shewhart or Deming's PDCA cycle (Plan-Do-Check-Act) during the selection process. This is a highly effective technique to ensure the monitoring objectives and data quality requirements are considered during the different stages of the selection process.

The PDCA cycle is the basis for continual improvement. The cycle states that to continuously improve any process, system or product, four activities must be executed iteratively: PLAN, DO, CHECK and ACT. In its simple form, the cycle can be seen as a wheel with four mayor spokes: plan, do, check and act. Once an activity, or a process, is placed inside the wheel, it is very hard for it to get out. The only thing the activity or process can do is to move by the rim from one spoke to the next one: from planning to execution, from execution to verification, from verification to analysis, from analysis to planning again, and so on.

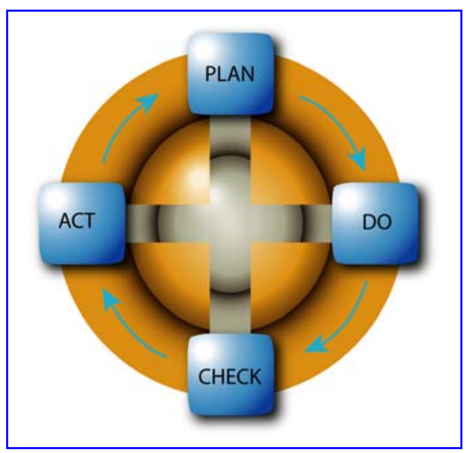


Figure 1.1 PDCA cycle

Thus, it becomes an on-going effort to improve the effectiveness, efficiency and quality of the core processes, systems, services or products. During the PLAN phase, the "what to be accomplished" is determined (*e.g*. undertake an action, solve a problem, improve a method) and all necessary planning activities are performed. After the activities of planning are completed, the execution or implementation of the plan takes place in the DO phase. Once the execution is finished, the outcomes are compared with the desired results in the CHECK phase. The final phase of the cycle is to ACT upon the results obtained during the CHECK phase (*e.g*. make changes and adjustments, run through the cycle again, implement and standardize). (Society of Manufacturing Engineers, 1993; Wealleans, 2001).

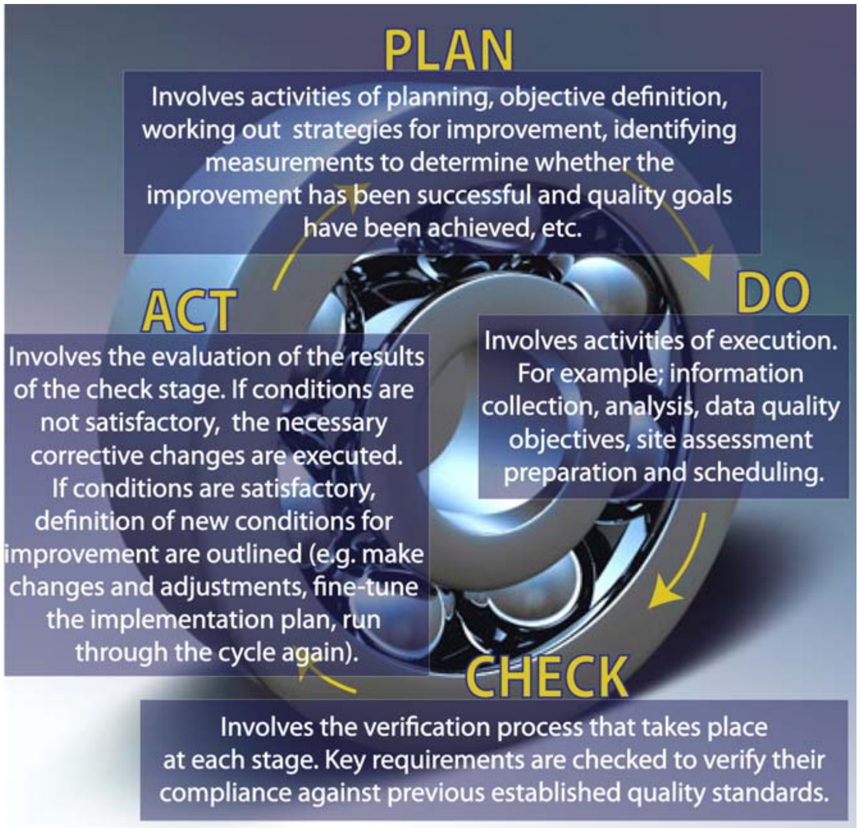


Figure 1.2 PDCA cycle activities

1.2 SITE SELECTION GUIDELINES

The degree of complexity of the site selection process is influenced by the extent of the geographic area to be monitored. The size of the monitoring area and the degree of complexity are directly related. To characterize a large geographic area, some kind of method must be employed to subdivide the area into smaller regions that maximize the representativeness between the sampling units and the target sample area. A common method that is utilized for this purpose is land classification systems. These systems can be subdivided into geographically dependent (*i.e*., Omernik 1987, Maxwell *et al*. 1995) or geographically independent (Anderson *et al*. 1976, Richards 1990, Poff and Ward 1990, Rosgen 1996, Detenbeck *et al*. 2000) as stated by the EPA (2002) and Olsen & Robertson (2003):

> *"Geographically dependent classification schemes have categories that describe specific places or regions. These classification frameworks are usually based on the premise that areas of similar climate, landform, and geology exhibit similar ecosystem potential and vulnerability to stressors. Geographically dependent frameworks tend to cover broad geographic regions at a pre-determined scale or nested scales, such as eco-regions".*

> “*Geographically independent schemes have categories that describe similar features occurring at many locations, and are not limited to a specific scale, place or region. Geographically independent frameworks are usually determined by watershed attributes that can be defined independently of a geographic region, e.g., surface-water storage or runoff characteristics, or valley or stream-channel morphology*”.

Olsen & Robertson (2003) emphasis the importance of basing the regionalization method on “*the distribution of the most strongly related environmental factors*”, and the importance of knowing the degree of representativeness between the data collected in the different regions and the target population.

Once the regionalization is completed, two basic methods exist for site selection (USGS, 2004; USEPA, 2002; Olsen & Robertson, 2003):

- Professional judgment or deterministic method
- Statistical method or probability survey design

Site selection by professional judgment or deterministic method is based on expert knowledge, experience of experts, or best professional judgment. There are no specific guidelines for site selection using expert knowledge given the complexity of the different types of water bodies. Nevertheless, this approach may use a variety of criteria, for example: waterbody and land use characteristics; source of contaminants; influence of agriculture and urban development on a certain parameter; or known water quality problems.

Two points that must be taken into account when this method is employed are (USEPA, 2000):

a) Site selection is based on a nonrandomized method and the waterbody that represents a given station will depend on the particular waterbody.

b) No quantitative statements can be made about the level of confidence in the sampling results.

If statistical method or probability survey design are employed to select the monitoring sites, a variety of methods may be applied to randomly select them; for example, simple random sampling design, cluster or multistage sampling. The method to be employed will depend on the monitoring objectives, funding resources, type of waterbody, and the existing information of the target population. In general, these methods are used when rigorous analyses are required for environmental assessment with respect to mass-transport, remediation, and temporal or spatial variations. Even though the different design methods vary in complexity, and offer different advantages, there are certain common features among them (USEPA, 2002):

- *"Reduce bias in the sample results by ensuring that sample units represent the target population*.
- *Provide statistically unbiased estimates of the population mean, population proportions that pass or fail a standard, and other population characteristics.*
- *Allow documentation of the confidence and precision of the population estimates".*

For example, the Oregon Plan for Salmon and Watersheds (1999) considers three geographic scales in the site selection process: sample point, reach approach, and basin scale.

- Sample point is the most specific geographic scale where representative data is obtained from the specific location.
- Reach scale approach is used where multiple monitoring sites are selected; *i.e.* to reflect conditions and trends for a segment, *e.g.* stream.
- Basin scale is employed when landscape and stream patterns become the focus point.

Many of the different site selection methodologies employ a two-step procedure. The Australian and New Zealand Environmental and Conservation Council (2000) describes the two-step procedure as follows:

1. Select the location/locations within the watershed to satisfy the monitoring objectives (identification of the macro-location);

2. Identify the specific sample sites (micro-locations), which are independent of the monitoring objectives and are selected based on environmental conditions and representativeness of the sample.

Information on survey designs can be found in "Guidance for Choosing a Sampling Design for Environmental Data Collection USEPA QA/G-5S" and technical assistance on designing statistical water quality monitoring networks can be requested in http://www.epa.gov/wed/pages/EMAPDesign/index.htm.

Several references on how to address the monitoring network design and site selection criteria for individual monitoring station, and design by statistical and/or programming techniques can be found in Su-Young Park *et al.* (2006).

A good overview of network design procedures can be found in Harmanciogammalu *et. al.* (1999) "Water Quality Monitoring Network Design".

1.3 SITE-SPECIFIC CHARACTERISTICS (SSC)

The site-specific characteristics are all the environmental, logistic, and management factors that are particular to the monitoring site, that could influence the fulfillment of the monitoring or data quality objectives. For example, site selection can be affected by access (*i.e.* there is no access to the right sampling site), or certain laws and local regulations may control or prohibit the use of certain type of monitoring station platform.

Site selection can be seen as an interactive process between site-specific characteristics, and monitoring and data quality objectives. Site-specific characteristics can compromise the ideal scientific results if they are not properly addressed during the monitoring site selection process. To systematically address this problem, a project management support tool "the Site-Specific Characteristics Cycle (SSC cycle)" was developed (Figure 1.3) (Miles, 2008).

You can't control what you don't measure

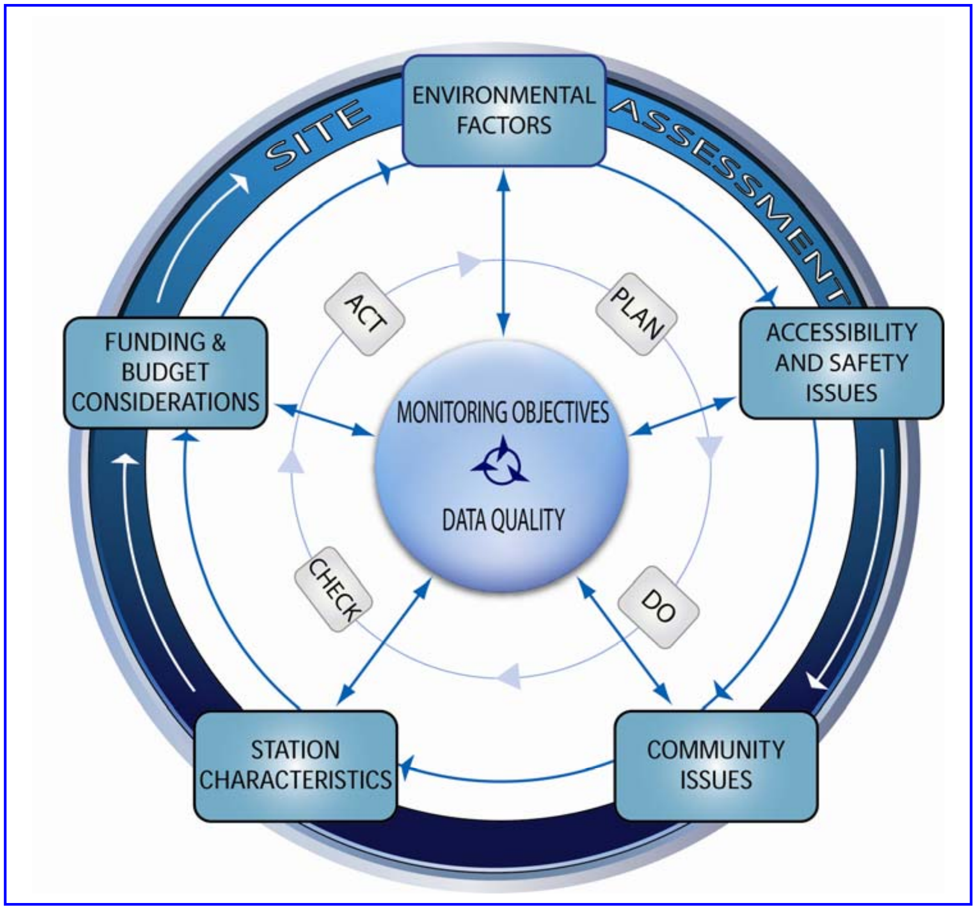


Figure 1.3 The SSC cycle

The SSC cycle is a management decision support tool designed to address the different site-specific characteristics that can influence water quality monitoring program objectives and data quality.

To assure the systematic and proper assessment of the site-specific characteristics, the cycle works under the continuous improvement philosophy. Continuous improvement can be defined as the "*recurring activity to increase the ability to fulfill requirements*" (American Society for Quality, 2000). It is the constant and never ending effort to improve the effectiveness, efficiency and quality of the core processes, systems, services or products. Thus, the activity or process enters a continuous feedback loop that ensures a methodical approach to its efficient implementation.

The site-specific characteristics are organized into five major subject areas: environmental factors, accessibility and safety, community issues, station characteristics, funding and budget considerations. All of these areas interact with each other and could trigger the inability to achieve ideal scientific results. By employing the SSC cycle, the site-specific characteristics are systematically and properly assessed to obtain the site locations that best address the monitoring objectives, and maximize data quality objectives.

Monitoring teams generally do not use a standard procedure that ensures a systematically and comprehensive evaluation of the site-specific characteristics (*i.e.* expert knowledge is one of the most commonly used approach that project managers employ). This accounts for the fact that site-specific characteristics are overlooked, misinterpreted, or even the best practice to address them are not known or even, not properly addressed, causing several problems in the capability to optimally fulfill the monitoring and data quality objectives.

It is a good practice to have a standard operation procedure (SOP) to evaluate the site-specific characteristics. A SOP will assure the quality and consistency of the site-specific characteristics assessment, and the implementation of good monitoring practices to address them. The SSC cycle was designed with this purpose in mind, to provide a management support methodology to systematically address the site-specific characteristics, and to minimize their negative impact on the monitoring and data quality objectives. In addition, in order to take into account the natural and anthropogenic environmental variability, a common concern over the life cycle of a water quality-monitoring project, the cycle works under a PDCA methodology. This approach helps to ensure that the negative impacts of the site-specific characteristics on the project objectives are permanently monitored, it enhanced the trouble-shooting capabilities, and assures the dynamicity of the cycle to achieve continuous improvement.

The goal of the SSC cycle is to create a user generated expert system based on rules, conventions, standards, subject-specific and expert knowledge, and information acquired through field experience, to support the decision making during the site selection phase of a continuous shallow water quality project.

An example of the cycle protocol follows:

1. The project manager and design team reviews the information of the SSC cycle and considers possible impacts of each site-specific characteristic on the monitoring objectives and data quality at each monitoring site (PLAN phase).

    - Site-specific characteristics are analyzed and matched with the monitoring and data quality objectives.

    - Pre-site selection is preformed.

A good question to have in mind when selecting the site is:

"What types of problems can arise when installing, operating and maintaining the station in this site?"

2. Relevant information is gathered under each subject area of the cycle (environmental, community, budget and funding, station characteristics, and accessibility and safety) to be used during the initial site assessment (PLAN phase).

3. The initial site assessment is performed. The planning decisions are evaluated against the real settings (DO phase).

   A site or field assessment is mandatory to identify the precise monitoring station site. Site assessment is an essential step in any monitoring project. Observation, expert knowledge, measurements and analysis will help to determine if the decisions made during the planning phase are viable, or if certain points must be modified due to unpredicted factors (CHECK and ACT phases).

   If possible, the initial site assessment must be conducted during the time period considered to have the greatest negative impacts on data quality. For example, if the site is in near proximity to a marina, the initial site assessment must be conducted during summer, where the greatest boating traffic is expected. However, not always this is possible. Therefore, during the initial site assessment, the assessment team must be alert to identify any variables of concern that could have a future effect on data quality.

4. The information gathered during the site assessment is used to evaluate the design specifications outlined during the planning phase (CHECK phase). This action triggers the necessary corrective changes, or delineates conditions and criteria for improvement (ACT phase).

5. Relevant information that surfaced during this process is added to the SSC cycle.

6. Site assessments are continuously performed as an audit and improvement tool to ensure that monitoring objectives and data quality are being met, and to provide steady information for the continuous improvement of the SSC cycle.

   Most commonly, site assessment is viewed as a one-time activity. This is not the case in the SSC cycle. Site assessment is an integral part of the SSC cycle, playing a major role in linking all the different site-specific characteristics. As part of the PDCA cycle, site assessment is seen as a continuous information collection process. Data is collected continuously during the project to fine-tune and improve the monitoring endeavor, to get a better understanding of the different site-specific characteristics that affect the project, and to enhance the information in the SSC cycle.

The SSC cycle provides a protocol or a management decision process to follow. How the information is organized and presented in the cycle will depend on user needs and preferences. It can be organized from general to specific; checklists with references can be used to perform a quick selection of the site-specific characteristics, and a manual, with detailed information, can be used to obtain the best practices on how to deal with the specific characteristics. It can be presented, as tables where all the information is included, or it can be written into a computer program as an expert system. It also can be personalized for the particular watershed having one cycle with specific information for lakes, another for rivers and another for estuaries. The PDCA methodology ensures the dynamicity and improvement of the cycle as new information is continuously added.

The quality of the information included in the SSC cycle will determine the quality of the guidelines that can be derived. The approach selected to display the information in the cycle will determine the effectiveness and efficiency to obtain the right guidelines. The quality of implementation of the cycle methodology will determine the level of assurance that the SSC were systematically and comprehensively evaluated.

To better understand the information to be included in the SSC cycle, examples of general guidelines, rules and standards for each of the five subject areas are provided in the following text.

1.3.1 Environmental Factors

Environmental factors are all the physical, biological, and chemical factors (characteristic of the intended site location) that could influence data quality.

The Australian and New Zealand Environment and Conservation Council (2000) stress the fact that:

> "*measurement parameters can vary from place to place within a site, randomly or in strata. When measurement parameters are being sampled in the water column, it is sometimes assumed that the water is well mixed and that a mid-water or mid-stream sample will be sufficiently representative. This may not be the case. Even if the monitoring goal is just to measure the average concentration of a chemical in the water at a site, the sampling process must be planned so that the within-site variation is included in the estimate*".

It may prove useful to create a log with the conditions of the study site over the entire year. This information is useful when siting, as well as, designing the monitoring station. For example, the information may reveal that the best place to set the station is in the middle of a channel or near the shoreline.

Environmental Factors: Physical	
Tides & water level	Annual tide data is needed for station siting purposes. The height of the station, placement of the sensor (low mean water) and other setting considerations are affected by tidal range. When sites are not influenced by tides, average maximum and minimum water levels must be obtained (*i.e*. influence of rain over water level and flow, stream and river banks conditions during periods of high water).
Waves	Waves can affect data quality in coastlines zones. The station design must take into account wave action. Also, the size of the waves may influence the maintenance activities of the monitoring stations.
Substrate conditions	Bottom substrate characteristic impacts the type of station configuration to be used. The degree of effort needed to set the station (*e.g.* hard clay, soft mud), or the strength needed to hold it in most weather conditions (*e.g*. anchoring a surface buoy), are affected by the bottom characteristic. The type of bottom can also influence data quality. For example, muddy bottom near the shore could create turbidity in the lower part of the water column. A sonde placed very close to a muddy bottom could suffer from sediment deposition and can foster biofouling, *e.g.* by chironomid worms.
Sediments	Some sections of a river, an estuary, or a lake have a higher propensity to have redistribution, accumulation, or resuspension of sediment particles (*e.g.* deposition zones, turbidity maximum zones). This phenomenon is produced by different factors such as bottom currents or runoff. This can result in a change of the floor topography. It is a good practice to place the station platform in a location where the accumulation or resuspension of sediments is minimum.
Erosion	High erosion areas can affect long term monitoring station. The station design must take this factor into account. Localized turbidity can be present in areas with high erosion; data quality may be affected.
Water physical properties	It is good practice to have an idea of the range of values of the water physical properties to understand under which conditions the sensors, and the monitoring stations, are going to operate (*e.g*. hypoxic or anoxic conditions).
Hazards	Even though it is hard to predict hazards from upstream activity, or channel units, such as debris torrents, extreme flow magnitude, bedload transport, failure of in-channel debris structures, streamside treethrow; some sites have a higher tendency to suffer from these hazards than other, or some sites are more protected than others in case debris flow in the water [4].
Extreme weather	Some geographical areas are more likely to suffer from extreme weather events than others. If extreme weather events are common in the sampling area, it is a good practice to have an idea of the type of events that can occur. This information is helpful in siting the monitoring location, or in defining certain configuration/design characteristics of the station.
Degree of ice formation	It is important to know the degree, or history, of ice formation at the monitoring site; or what areas near the monitoring site have a higher potential to freeze. This information is helpful for station design purposes, siting, and for planning the maintenance monitoring activities.

Table 1.1 Environmental Factors: Physical

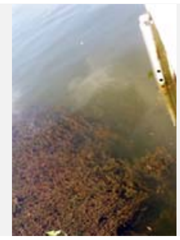
Environmental Factors: Biological	
Vegetation	The surface and subsurface vegetation densities of the monitoring sites must be examined. It is possible that under certain conditions the local vegetation will influence the representativeness of the data. If the station is placed in the littoral zone, seasonal vegetation may cover the station in certain part of the year (*e.g. hydrilla verticillata*). 
Animals	Even though it is very difficult to account for possible animal influence, in some situations animals can have negative local effects. For example, crabs or fish, could cause turbidity effects, or damage the monitoring probes. Otters, beavers, turtles, or even large animals, such as alligators or seals, can influence readings, or destroy offshore monitoring stations. Birds can build nest on top of the monitoring stations, or use them as resting place to eat fish. Bird deterrent devices may be needed.
Biofouling	Biofouling is one of the biggest factor affecting the operation, maintenance (the picture shows a datalogger left for one week in a highly fouling water) and data quality in water monitoring sensors. Most objects placed in the coastal zones waters, brackish waters or even in lakes (i.e. Lake Superior) will become covered with organisms after a period of time. Barnacles, sponges, algae, are a few of the many organisms that make up fouling communities.  Stanczak (2004), gives a very concise description of how biofouling is generated. Biofouling is not a simple process, it is a complex process which often begins with the production of a biofilm. “The growth of a biofilm can progress to a point where it provides a foundation for the growth of seaweed, barnacles, and other organisms. In other words, microorganisms such as bacteria, diatoms, and algae form the primary slime film to which the macroorganisms such as mollusks, seasquirts, sponges, sea anemones, bryozoans, tube worms, polychaetes and barnacles attach”. For this biofilm to occur certain conditions must be favorable, including proper pH, temperature, humidity and nutrient availability. Biofouling can be subdivided into two categories. Calcareous fouling or hard fouling occurs when barnacles, encrusting bryozoans, mollusks, tube worms, and zebra mussels are the organisms that settle on the substrate. Non-calcareous or soft fouling is when organisms such as algae, slimes and hydroids settle on the biofilm (Stanczak 2004). Biofouling can be very specific of the geographical site and directly related to the bioproductivity and environmental conditions that affect the site. Therefore, no unique solution exists to control biofouling and the choice of the method will have to take into account, not only the site characteristics, but also, the general design of the monitoring station. There are different ways to prevent biofouling, such as, passive ways, choosing certain construction material, painting with antifouling coatings, or active ways such as using electric fields. One important issue to address during site selection is to understand the characteristics of the site in order to identify the type of biofouling and the site conditions that can foster it. For example, enclosed areas (such as marinas) are more likely to produce more biofouling than areas where flushing occurs, or warm waters will also foster biofouling. Alliance for Coastal Technologies (2003)

Table 1.2 Environmental Factors: Biological

Environmental Factors: Anthropogenic	
Impacts of humans activities	Certain human activities can influence local water quality, thus having an effect on the representativeness of the data. It is a good practice to gather information of the different human activities near the monitoring location in order to understand possible effects and to better site the monitoring station.
Point sources	Companies can influence data quality if they discharge wastewaters directly into the water body. For example, the station can be place near a discharge pipe with very acidic conditions. It is important to survey the monitoring area to characterize wastewater discharges. Assess the degree to which these discharges impact the monitoring objectives; possible impacts on the monitoring station or sondes; and best monitoring locations to minimize, or maximize, their effect on the measurements.
Non-point sources	Some monitoring locations could be affected locally by run-off (*e.g.* close to a storm sewer carrying urban run-off). Although run-off is difficult to calculate, it is a good idea to inspect the area where the monitoring station will be located to assess if run-off can affect locally the data quality.

Table 1.3 Environmental Factors: Anthropogenic

Environmental Factors: Hydrodynamics	
1. Mixing Issues	
Water-quality monitoring site selection is determined by the data-quality objectives, and the best location for a site is often one that is best for measuring surface-water discharge. Although hydraulic factors in site location must be considered, it is more important to consider factors that affect the water-quality data (USGS, 2000).	
Edge vs. middle	Samples taken from the edge of a stream will be different from those taken near the middle. Water velocity and depth at the edges create different conditions for plant growth and animal life. Because conditions of the main stream may differ from those at the edge, sites should be located in the main current and away from the banks if possible, in areas of principal flow (Cassidy, 2003)
Upstream inputs	Check the entry points of drains. Water-quality measurements should be taken far enough downstream from drains or tributaries to allow for mixing of the waters, otherwise you will be taking a sample of the drain or tributary, not the stream. As a `rule of thumb' measure at least 100 meters downstream from any drain, pipe or tributary entering your stream (Cassidy 2003).
Lateral mixing	Lateral mixing in large rivers is not often completed for tens of miles downstream from a tributary or outfall. A location near the streambank may be more representative of local runoff, or affected by point-source discharges upstream, whereas a location in the center channel may be more representative of areas farther upstream in the drainage basin (USGS 2000)..
Lateral and vertical mixing	The lateral and vertical mixing of a wastewater effluent, or a tributary stream, can be rather slow with the main river, particularly if the flow in the river is laminar, and the waters are at different temperatures. Complete mixing of tributary and main stream waters may not take place for a considerable distance (sometimes many kilometers), downstream of the confluence (UNEP/WHO, 1996). The zone of complete mixing in streams and rivers may be estimated from the values in the following table (UNEP/WHO, 1996):

Average width (m)	Mean depth (m)	Estimated distance for complete mixing (km)	Average width (m)	Mean depth (m)	Estimated distance for complete mixing (km)
5	1 2 3	0.08-0.7 0.05-0.3 0.03-0.2	20	1 3 5 7	1.3-11.0 0.4-4.0 0.3-2.0 0.2-1.5
10	1 2 3 4 5	0.3-2.7 0.2-1.4 0.1-0.9 0.08-0.7 0.07-0.5	50	1 3 5 10 20	8.0-70.0 3.0-20.0 2.0-14.0 0.8-7.0 0.4-3.0

Table 1.4 Environmental Factors: Hydrodynamics – Mixing Issues

Environmental Factors: Hydrodynamics

1. Mixing Issues

Stream – Cross Sectional Variability	To minimize cross sectional variability on streams, the monitoring site must be located on a straight stretch of the stream. The require stretch, on either side of the station, will depend on the size of the stream, going from 10 m in small streams to 100 m in large streams. (BC Ministry of Environment, 2007).
Lakes and embayments	Where feeder streams or effluents enter lakes, or reservoirs, there may be local areas where the incoming water is concentrated, because it has not yet mixed with the main water body. Isolated bays and narrow inlets of lakes are frequently poorly mixed, and may contain water of a different quality from that of the rest of the lake. Wind action, and the shape of a lake, may lead to a lack of homogeneity; for example, wind can cause algae accumulation at one end of a narrow lake (UNEP/WHO, 1996).
Lakes horizontal mixing	If there is good horizontal mixing, a single station near the center or at the deepest part of the lake will normally be sufficient for the monitoring of long-term trends. However, if the lake is large, it has many narrow bays or contains several deep basins, more than one station will be needed. To allow for the size of a lake, it is suggested that the number of sampling stations should be the nearest whole number to the $\log_{10}$ of the area of the lake in km^2 (UNEP/WHO, 1996). Thus a lake of 10 km^2 requires one sampling station, 100 km^2 requires two stations, and so on. For lakes with irregular boundaries, it is advisable to conduct preliminary investigations to determine, whether and where, differences in water quality occur before deciding on the number of stations (UNEP/WHO, 1996).
Lakes-vertical stratification	The most important feature of water in lakes and reservoirs, especially in temperate zones, is vertical stratification, which results in differences in water quality at different depths. In stratified lakes, more than one sample point is necessary to describe water quality (UNEP/WHO, 1996).

Table 1.4 (Cont.) Environmental Factors: Hydrodynamics – Mixing Issues

2. Turbulence – Bubbles
Attempts should be made to locate the sensors, particularly optical turbidity sensors, away from sources of bubbles (e.g., rocks, boulders, riffles, abutments, piles, spillways, piers, or large woody debris) (White, 1999).
Turbulent streamflow may aid in mixing, but can create problems for some monitored parameters such as dissolved oxygen or turbidity. For a medium to small stream, with alternating pools and riffles, the best flow and mixing occur in the riffle portion of the stream; however, flooding may change the locations of shallows upstream from the monitoring site, and the measurement point may no longer represent the overall water-quality characteristics of the water body (USGS, 2000).
Areas protected from turbulent flows by bedrock outcroppings, or boulders, may protect equipment from bubbles. However, it must be assured that higher flows do not lead to water cascading onto the sensors (White, 1999).
In streams a good practice is to place the sonde in a pool of water removed from riffle areas. Pools are areas of fewer bubbles, have lower velocities and therefore are more secured areas for the sensors, and ensure the sensors will be underwater during low flow conditions (BC Ministry of Environment, 2007).

Table 1.5 Environmental Factors: Hydrodynamics – Turbulence - Bubbles

3. Variable Flow

Water velocity	Excessive water velocity can introduce error. Attempts should be made to locate instruments in waters moving less than 1 m/s. (White, 1999).
Structures	Monitoring stations must be free from human regulation that cause large differences in water flow, such as release from dams upstream; variable flows caused by dams, weirs and similar structures (Cassidy, 2003).
Flow conditions	Low precipitations may cause very low water levels or even dry conditions.
Laminar flow	Although it is not always feasible, areas of laminar flow are preferred for more accurate instrument readings.

Table 1.6 Environmental Factors: Hydrodynamics – Variable Flow

1.3.2 Funding – Budget Considerations

Cost is a key factor in designing a water quality-monitoring program. As Cavanagh *et al.* (1998) emphasize,

> "*If the budget is insufficient to meet the program objective definitively (answer the required question with statistical confidence) then, either the objective has to be revised and simplified or the funds redirected to other programs. There is no point in conducting a program if it cannot provide valid information with the funds available. It is crucial that every effort is made to fit the objectives to the available budget. It is good practice to consult a statistician once the objective hypotheses have been formulated. This person will not only advise the program designers of the statistical tools and design necessary to answer the required question, but this input will clarify where monitoring effort should be better concentrated (hence defining the allocation of funds). This input will assist the program designer to determine if the budget will be sufficient to meet the minimum statistical requirements*"

Careful planning must be done during site selection in order to understand what are the ramifications that each sampling station has on the fulfillment of the project objectives. A very important point to keep in mind is that each sampling station is a cost and task driver.

Three major cost factors must be considered:

Set-up	The monitoring location will trigger the types of station configurations that are feasible, or best suited, to fulfill the monitoring objectives. For example, an offshore station will have a higher set-up cost than a station located at a pier.
Maintenance	The scheduled maintenance activities for the monitoring system will likely involve cleaning and calibration of the water quality monitoring sensors. Maintenance frequency is generally governed by: the fouling rate of the sensors and its rate varies by sensor type, hydrologic environment, season, type of energy used to power the sensors (*e.g.* battery or solar), and data storage capacity.
Access	The monitoring location will trigger an access cost that will include: type of vehicle needed to access the site (*e.g.* boat, truck, *etc*.), personnel needed (*e.g.* one, two or more depending on job and safety requirements), distance to site location, and other costs (*e.g.* lodging, meals, parking, *etc*.).

Table 1.7 Funding – Budget Considerations

1.3.3 Accessibility and Safety Issues

Accessibility and safety issues are two site-specific characteristics that play an important role in site selection. Monitoring stations should be accessible during the entire monitoring effort. Accessibility is influenced by laws, topography, landowner consent, among other things. Safety of the personnel and the equipment is a top priority; therefore, careful attention must be given to select monitoring sites that comply with the minimum safety requirements. It is possible that after reviewing the safety and accessibility information, several possible locations are selected, and the final location is chosen after the site assessment is performed.

Accessibility Issues	
Laws	Local, State or Federal regulations must be checked to see if any consideration must be taken when siting the stations.
Permission to access the site and authorization to sample	Check land ownership and determine if permission is needed to visit the site. Check if leases or agreements of water, or subaqueous bottom usage exist in the sampling area, which may require special permission to place a sampling station. White (1999) emphasis that "*a well thought out protocol for how to contact landowners, what information to provide them, and how to follow-up with landowners can significantly increase the likelihood of a landowner granting access*".
Topography-roads-navigable waters	The monitoring site must be accessible by boat, foot, truck or car.
Weather conditions (all year round)	The site must be accessible at all relevant times. Thus, it is important to know possible effects of the weather and flow conditions with respect to site accessibility. Special weather conditions must be considered, such as ice formation (for accessibility and safety issues). If winter conditions are very rough, it may require the removal of the equipment, or even the station platform.
Surveying	Sites must be accessible for surveying, if needed.
Data transfer	If data transfer is required, availability of cellular phone service, radio or landline (if possible connection) service must be checked. High-tension power lines, or radio towers, close to the site could interfere with data transfer.

Table 1.8 Accessibility Issues

Safety Issues	
Accessibility and maintenance	The site should be easily accessed and safe for the personnel conducting regular maintenance visits.
Equipment	The equipment can be damaged by natural, animal, or human activity. Natural: weather and flow conditions must be considered to determine if they can create a hazardous situation. Animals: proper precautions must be taken to minimize the risks of equipment damage by animals. Human: humans can damage the equipment either intentionally, or by accident. Intentional damage will include any act of vandalism or tamper. If possible the site must be selected where vandalism is kept at minimum. If this is not possible, the station must be designed to minimize potential vandalism. Accidental damage will include any damage cause without intention, *e.g.* with a boat. Therefore, the water site activities must be analyzed to understand what activities take place (*e.g.* crabbing, oystering, heavy boating traffic) in order to take proper precautions and minimize possible damage.

Table 1.9 Safety Issues

1.3.4 Community Issues

The role that the community plays, directly or indirectly, must be assessed when selecting a monitoring site. Many communities are very involved with the activities that take place in their localities. In these cases, it is essential to obtain community support in order to have a successful collaboration. It is important to understand what concerns the community has in the study area, and what activities take place in the monitoring locations (*i.e.* is the area used for swimming?). Possible impacts of the monitoring activities must be analyzed so they can be minimized, or discussed with the affected party. In general, it is easy to inform the community members adjacent to the monitoring site, but difficult to approach the whole community. Contact with local community leaders, local churches, community newsletter, town meetings, are possible channels to communicate the monitoring endeavor and obtain a successful collaboration. Points to consider:

Potential dangers from the stations	An area with heavy boating, swimming, or personal watercraft traffic could cause problems. Consequently, adequate assessment of these potential dangers, and how they can be eliminated, must be conducted (*i.e.* could they be eliminated by simple signaling, construction, *etc*?).
Community activities	An understanding of the activities that are performed in the area over the entire year must be acquired in order to assess possible data quality problems, or possible community complains.
Aesthetic	The installation of monitoring sites in front of private houses, or public areas, could create aesthetic problems.
Security	Community collaboration and involvement is a good approach to minimize station vandalism.

Table 1.10 Community Issues

1.3.5 Station Characteristics

Even though the station characteristics are not a site-specific characteristic, they are heavily influenced by them. For that reason, the station characteristics are an integral part of the SSC Cycle. The site and station characteristics must be analyzed to understand how they mutually influence each other. Given that there are many types of station configurations/designs, each one with its own strengths and weaknesses, it is important to consider the general characteristics of the station, and determine if it is the site that will define the type of station, or is the type of station that will define site location. For example, if the goal is to place the monitoring station on a fixed structure (*e.g*. bridge or pier) due to budget constraints; there must be a bridge or a pier near the intended site that complies with the representative data conditions. Each type of station triggers certain conditions that must be met in order to ensure safety, accessibility, and proper data gathering. For example, a permanent real-time reporting station will trigger different conditions in the station, and site selection, than a one-month continuous monitoring station. In addition, the evaluation of the other site-specific characteristics may trigger certain characteristics that the station must comply with (*e.g.* aesthetic).

1.4 INFORMATION SOURCES

Selecting the right monitoring site entails gathering a lot of information. There is a range of web information sources that can be easily accessed to assist in the siting process. In the following tables, some useful sources are provided.

MAPS	
NOAA	
NOS Data Explorer Data Explorer offers interactive mapping tools that allow users to locate NOS products in any area in the United States	http://oceanservice.noaa.gov/topics/welcome.html
USGS	
USGS Library	http://library.usgs.gov/
USGS water site maps	http://water.usgs.gov/maps.html
National Cooperative Geologic Mapping Program	http://ncgmp.usgs.gov/
Coastal and Marine Geology Program Internet Map Server and GIS Data	http://coastalmap.marine.usgs.gov/
Geography: Maps and Digital Data	http://geography.usgs.gov/products.html#maps
The National Map: The Nation's Topographic Map	http://nationalmap.gov/index.html
EPA	
Surf your Watershed	http://www.epa.gov/surf/
Other Sources	
National Atlas	http://www.nationalatlas.gov/
Geospatial data and information	http://www.geodata.gov/gos
Maps (Disaster or Emergencies) ReliefWeb	http://www.reliefweb.int/rw/dbc.nsf/doc100?OpenForm
Electronic Navigation Charts, NOAA	http://chartmaker.ncd.noaa.gov/MCD/enc/index.htm

Table 1.11 Information Sources: Maps

WEATHER DATA	
National Climate Data Center, NOAA	http://lwf.ncdc.noaa.gov/oa/ncdc.html
Weather Maps	http://www.hpc.ncep.noaa.gov/dailywxmap/index.html
NWISWeb Data for the Nation USGS	http://waterdata.usgs.gov/nwis/

Table 1.12 Information Sources: Weather Data

PHOTOS & Digital Satellite Data	
Terra Server USA from USGS (Excellent site to see aerial photos from any part of the US)	http://terraserver-usa.com/default.aspx
Digital Satellite Data USGS	http://www.usgs.gov/pubprod/satellitedata.html
Graphics, Photograph, and Video Collections (USGS)	http://www.usgs.gov/pubprod/multimedia.html
Visible Earth, NASA	http://visibleearth.nasa.gov/
Selected Satellite Products NOAA	http://www.osdpd.noaa.gov/OSDPD/OSDPD_high_prod.html
Links to Images and Data SEC – University of Wisconsin-Madison	http://www.ssec.wisc.edu/data/
Earth Observing System Data Service, NASA	http://eospso.gsfc.nasa.gov/eos_homepage/data_services.php
Google Earth	http://earth.google.com/

Table 1.13 Information Sources: Photos – Digital Satellite Data

TIDES & FLOW & BUOY	
Tide Tables NOAA	http://tidesonline.nos.noaa.gov/
Flow Data USGS	http://water.usgs.gov/waterwatch/
National Data Buoy Center, NOAA	http://www.ndbc.noaa.gov/dataindex.shtml
Tides from University of South Carolina	http://tbone.biol.sc.edu/tide/sitesel.html

Table 1.14 Information Sources: Tides – Flow – Buoy

MODELS	
USGS Hydrologic and Geochemical Models	http://water.usgs.gov/nrp/models.html
EPA Models	http://www.epa.gov/epahome/models.htm
The Princeton Ocean Model (POM) The model has been used for modeling of estuaries, coastal regions, basin and global oceans.	http://waterdata.usgs.gov/nwis/
Computer Library Models ODU	http://eng.odu.edu/cee/resources/model/

Table 1.15 Information Sources: Models

1.5 ANALYSIS OF PRELIMINARY INFORMATION

The data gathered during the pre-site selection must be organized to promote an accurate analysis, synthesis, understanding and communication. It is a good practice to have guidelines or standard operating procedures on how to organize the data for analysis. Employing a well-defined methodology allows the design team to systematically consider the different factors that affect the practical implementation of the project, and to evaluate the trade-offs that must be made in order to get, as close as possible, to the ideal scientific solution. Well-organized information can be managed and communicated more efficiently. In addition, organization allows for the identification of the need to collect further information or discard unnecessary data.

There are numerous ways to organize, summarize and arrange information in an orderly and comprehensive fashion. The best method to employ will depend upon the type of information being organized and the specific purpose for the information.

- Common formats employed in organizing data are: problem/solution, chronological, ranking, deductive or inductive order.

- Common graphical organizers are: mind mapping, network tree, interaction outline, series-of-events chain, among many others.

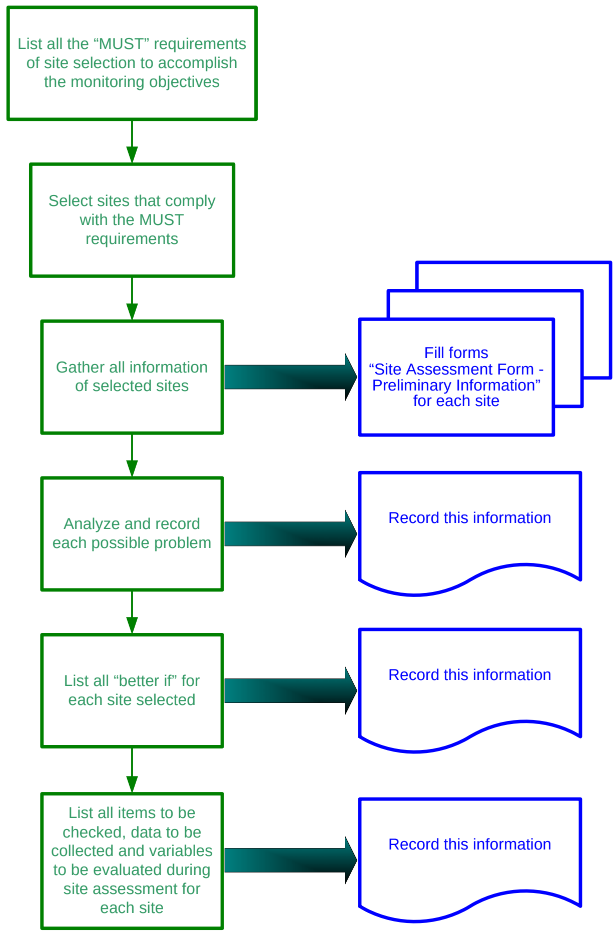
Given the reality that siting water quality monitoring stations is based mainly on experiential insights and subjective judgments, the monitoring team must employ these two steps:

1. Define a process to organize the data: the process must assure that all relevant data is collected; must facilitate orderly and efficient processing; and must provide the knowledge basis to enable professional judgment.

   A simple methodology to organize data is to create an outline of the relevant information that must be considered. The outline is a very simple method to arrange the information into a logical order, in a hierarchical and sequential manner. The data can be grouped by similar concepts, or content, by identifying the main topics, subtopics, and details under each subject. An example of an outline is presented in the Appendix section, Appendix 1 "Monitoring Site Location – Information Collection & Summary Instructive Form".

2. Define a procedure to ensure that critical details are not overlooked in the selection process: when a lot of information must be managed; a lot of details must be remembered; in addition to the fact that trade-offs must be made; it is good practice to use a procedure that ensures that all critical factors are considered and not overlooked during the decision process.

   Information flow charts and checklists are simple tools employed to ensure that all relevant facts are not overlooked. As an example, an information flow chart is presented next.



1. The requirements that each monitoring site must fulfill are specified.

   The program objectives can trigger two different types of requirements in terms of site selection:

   The "**Musts**": Necessary and specific requirements; those key things that the site must have in order to accomplish the program objectives. Failure of any of these requirements is likely to cause problems meeting the program objectives.

   The "**Better if**": Second tier of requirements that are better if they are achieved, but if they are not met, the monitoring objectives are not affected. For example, given budget constraints, it will be better if the monitoring station is placed on a pier rather than constructing an off-shore station. This option eliminates the need of a monitoring vessel.

2. Each key requirement is analyzed in order to determine which monitoring location complies with these requirements; and those that do not comply, why they do not?

   Is possible to adapt or modify some features or attributes to change the nonconformity to conformity?

3. Select possible monitoring locations that comply with all the "MUST" requirements.

4. Analyze possible problems these locations have, or could have. List all potential problems.

5. List possible causes for each potential problem, and the risks associated with them.

   The risk reflects both the likelihood of an event and the severity of the impact if it did occur. For example, potential impacts (low, medium, high), and plausibility (low, medium, high).

6. List possible solutions. Develop preventive actions or contingency plans where possible or necessary. List pros and cons.

7. List all "better if" characteristics for each monitoring site.

8. List all information that must be checked, data to be collected, and variables to be evaluated during the site assessment.

The result of this planning phase is:

- To have the information organized for each potential monitoring site selected: location, map, pictures, relevant environmental data, permits if any to be obtained, *etc*.

- To have the necessary instructions and relevant information for the site assessment phase:

  - Information to be collected, checked, and analyzed
  - Problems to be aware of
  - Solutions or feasible alternatives

This information will be used during the site assessment planning meeting. Benefits that can be obtained from organizing the information are:

- Get the big picture and comprehend all possible factors of the monitoring sites that can affect the monitoring objectives.
- Define possible problems or concerns that can arise.
- Define preliminary preventive actions or contingency plans where necessary.
- Define monitoring sites to be evaluated during the site assessment phase.
- Define what items must be checked, data to be collected, and variables to be evaluated during the site assessment.

1.6 SITE ASSESSMENT

Site assessment is a crucial step in site selection. As Cavanagh *et al.* (1998) mention

"*Once the objectives of the program are developed (including an evaluation of the budget constraints and statistical requirements) and related information is reviewed, it is wise to conduct a preliminary field inspection prior to further development of the program. The importance of actually "ground- truthing" an area at this stage of design cannot be over emphasized*".

Site assessment is an essential step in siting the monitoring stations. It is the first time in the monitoring project where planning decisions are evaluated against the real settings. As previously mentioned, observation, expert knowledge, measurements and analysis will help to determine if the decisions made during the planning phase are viable, or if certain points must be modified or changed given unpredicted factors.

Site assessment, as part of the SSC cycle, is not only a verification process, but also an information collection process. Information is collected to fine-tune the monitoring project, to get a better understanding of the watershed or waterbody, or even to change same variables to be monitored (*i.e.* during site assessment, it is observed that a new building project is been undertaken and this can have some future influence on some water quality variables). As integral part of the PDCA methodology, site assessment is an activity that will be performed continually during the whole monitoring project lifecycle. Information that can have a significant influence on data quality is continuously collected and properly recorded for future analysis.

The site assessment process starts with a meeting to go over the assessment plan. During this meeting, the project manager lays out the assessment plan, defines objectives, presents the key critical factors of the survey, reads over the general information (so each member has the whole picture), describes problems and possible solutions, defines the activities and measurements to be executed, and assigns responsibilities.

It is a good practice to have a critical mind during the survey, looking for possible problems not considered during planning

How to conduct, and what to expect, from a site assessment will depend greatly on the monitoring objectives. For example, an impact assessment project will trigger different requirements than a trend study. Nevertheless, common guidelines are given in three areas:

- → Human Activity
- → Mixing
- → Stratification

These three areas are part of the SSC Cycle and must be addressed during the cycle process. A few points are detailed in this section to emphasize their importance during the site assessment process.

1.6.1 Human Activity

It is very important to assess all possible human impacts during the site reconnaissance. Overlooked human activity can greatly impact directly and indirectly the success of the monitoring program (*i.e.* vandalism or point sources inputs to the water body). If possible, the initial survey must be conducted during the time period in which human activity is likely to have the greatest negative impact. For example,

- If boat traffic is seasonal in a narrow river, it is important to understand high peaks of traffic to assess possible impacts, *i.e.* where is the best place to set the station?
- What are the present uses of the water body within or in near proximity to the project site? *e.g.* bathing, washing, fishing, drinking water, recreation, commercial navigation, etc.

If human activities currently exist in near proximity of the monitoring site (*i.e.* marina, construction, farming, *etc*.), the survey should document the location and magnitude of these activities, and observe any possible linkages between these activities and water quality (at the moment of the survey or in the future).

1.6.2 Mixing

Mixing problems appear in rivers, streams and certain parts of lakes and estuaries. In order to adequately categorize a water body region with one monitoring site, it must be assured that the water in the selected site is sufficiently well mixed. Therefore, adequate cross-section measurements at different points across the width and depth near the prospective site must be taken to verify mixing conditions.

- <u>Results do not vary significantly</u>: the station can be established at any convenient point.

- <u>Results vary significantly</u>: consideration must be given to select another site, or use a <u>different</u> approach to meet the data quality objectives; for example, cross-section corrections.

In sites where poorly mixed conditions exist, USGS (2000) recommends a minimum of two cross-section measurements per year, to verify if significant changes in the distribution of the constituents of concern have occurred. Within the cross-section measurement sampling regime, vertical mixing measurement at a minimum of two depths is required.

In order to determine if seasonal changes affect significantly the distribution of constituent values in the cross section, USGS (2000) recommends that a minimum of six cross-section measurements, representing different flow conditions, be taken for longer term studies.

1.6.3 Stratification

Physical properties of water change due to seasonal temperature variations and mixing of water of different origins (*i.e.* freshwater entering a bay through runoff). The two factors that define stratification are: temperature and salinity. These factors are known as conservative properties, in contrast to other factors that change even though there is no stratification (*i.e.* oxygen, nutrients).

It is a good practice to investigate if different masses of water (in terms of salinity or temperature) exist in the water body to be monitored. If stratification occurs, measurements of water quality variables may be different depending on where they are taken in the water body.

There is no formal definition of a salinity gradient to define stratification. Most commonly, salinity increases with water depth, unless the water column is well mixed. Differences in salinity of 5 ppt or more can occur per meter in water with significant density gradient.

Given the variability of stratification scenarios (*i.e.* seasonal, regional, *etc*.), the best approach during site assessment is to get an idea of the probability of stratification occurrence. Quick measurements can be taken to categorize the site, but caution must prevail given the temporal variability of stratification.

Technically speaking, a thermocline is defined as a layer of water where the temperature decline exceeds one degree Celsius (1°C) per meter (Florida Lakewatch, 2004). Temperature stratification can be detected by taking a temperature profile of the water column. If there is a significant difference (for example, more than 3 °C) between the surface and the bottom readings, there is a "thermocline".

1.6.4 Site Assessment Information Forms

Site assessment is not only a verification process, but also an information collection process. During site assessment, information is collected to fine-tune the monitoring project, to get a better understanding of the watershed, and/or to change some variables to be monitored.

It is a good practice to use forms during the site assessment to ensure the required activities are performed and the necessary information is collected and adequately recorded. At least two forms must be used:

- → A form that details all the activities or information necessary to carry out the site assessment.
- → A form to register the information collected during the site assessment.

An example of a site assessment form is presented in Appendix 1 (Appendix Section).

1.7 REFERENCE

Alliance for Coastal Technologies. 2003. **Biofouling Prevention Technologies for Coastal Sensors/Senor Platforms**. Workshop Proceedings. Solomons, Maryland. November 19-21. Indexing No. ACT-03-05.

American Society for Quality. 2000. **Quality management systems-Fundamentals and vocabulary**. ANSI/ISO/ASQ Q9000-2000.

Anderson, J.R., E.E. Hardy, J.T. Roach and R.E. Witmer. 1976. **A land use and land cover classification system for use with remote sensor data**. U.S. Geological Survey Prof. Paper 964, 28 pp. Reston, VA, USA

Australian and New Zealand Environment and Conservation Council (2000). **Australian Guidelines For Water Quality Monitoring And Reporting**. Australian Water Association.

BC Ministry of Environment. 2007. **Continuous Water-Quality Sampling Programs: Operating Procedures**. Watershed and Aquifer Science. Science and Information Branch.

California Department of Transportation. 2004. **Guidance Manual: Stormwater Monitoring Protocols**. Second Edition. CTSW-RT-00-005.

Cassidy Michael. 2003. **Waterwatch Tasmania Reference Manual: A guide for community water quality monitoring groups in Tasmania**. Waterwatch Australia.

Cavanagh, N., R.N. Nordin, L.W. Pommen and L.G. Swain. 1998. **Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia**. Ministry Of Environment, Lands And Parks. Province of British Columbia.

Detenbeck N.E., S.L. Batterman, V.J. Brady, J.C. Brazner, V.M. Snarski, D.L. Taylor and J.A. Thompson. 2000. **A test of watershed classification systems for ecological risk assessment**. Environmental Toxicology and Chemistry 19:1174-1181.

Harmanciogammalu Nilgun B., O. Fistikoglu, S.D. Ozkul, V.P. Singh, and M.N. Alpaslan. 1999. **Water Quality Monitoring Network Design**. Water Science and Technology Library. Springer.

Maxwell, J.R., C.J. Edwards, M.E. Jensen, S.J. Paustian, H. Parrott and D.M. Hill. 1995. **A hierarchical framework of aquatic ecological units in North America (neartic zone)**. NC-176:1-76. Technical Report. US Department of Agriculture, Forest Service, Washington, DC, USA.

Miles, Eduardo J. 2008. **The SSC cycle: a PDCA approach to address site-specific characteristics in a continuous shallow water quality monitoring project**. Journal of Environmental Monitoring:10, 604 – 611. DOI: 10.1039/b717406c.

Olsen, A.R. and Dale M. Robertson. 2003. **Monitoring Design**. Water Resources IMPACT. September. Volume 5, Number 5. National Water Quality Monitoring Council (NWQMC)American Water Resources Association. Virginia.

Omernik, J.M. 1987. **Ecoregions of the conterminous United States**. Annals of the Association of American Geographers 77 (1):118-125.

Oregon Plan for Salmon and Watersheds. 1999. **Water Quality Monitoring: technical guide book**. Version 2.0. Oregon Watershed Enhancement Board.

Poff, N.L. and J.V. Ward. 1990. **Physical habitat template of lotic systems: recovery in the context of historical pattern of spatiotemporal heterogeneity**. Environmental Management 14:629-645.

Richards, R.P. 1990. **Measures of flow variability and a new flow-based classification of Great Lakes tributaries**. Journal of Great Lakes Research 16:53-70.
Rosgen, D.L. 1996. **Applied River Morphology**. Wildland Hydrology, Pagosa Springs, CO, USA.

Simpson, J. H., and J. R. Hunter. 1974. **Fronts in the Irish Sea**. Nature, 250, 404–406.

Society of Manufacturing Engineers. 1993. **Tool and Manufacturing. Engineers Handbook. Volume 7. Continuous Improvement.** Ramon Bakerjian Editor. Fourth Edition. ISBN 0872634205.

Stanczak, Marianne. 2004. **Biofouling: It's Not Just Barnacles Anymore**. The Hot Topic Series. CSA Illumina. www.csa.com

Su-Young Park, Jung Hyun Choi, Sookyun Wang and Seok Soon Park. 2006. **Design of a water quality monitoring network in a large river system using the genetic algorithm**. Ecological Modeling. Volume 199, Issue 3, Pages 289-297.

UNEP and WHO. 1996. **Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes**.

U.S. Environmental Protection Agency. 2003. **Delivering Timely Water Quality Information to Your Community**. The River Index Project: Lower Great Miami River Watershed. National Risk Management Research Laboratory. EPA625/R-03/002

U.S. Environmental Protection Agency. 2002a. **Development of Watershed Classification Systems for Diagnosis of Biological Impairment in Watersheds and Their Receiving Water Bodies**. National Center For Environmental Research. Grant Sorting Code 2003-STAR-A1. Summary Of Program Requirements.

U.S. Environmental Protection Agency. 2002b. **Delivering Timely Water Quality Information to you Community**. The Chesapeake Bay and National Aquarium in Baltimore EMPACT Projects. EPA/625/R-02/00X

U.S. Environmental Protection Agency. 2002c. **Consolidated Assessment and Listing Methodology Toward a Compendium of Best Practices**. First Edition. Office of Wetlands, Oceans, and Watersheds.

U.S. Environmental Protection Agency. 2000. **Guidance for Choosing a Sampling Design for Environmental Data Collection: for use in developing a quality assurance plan**. EPA QA/G-5S. Quality System Series.

U.S. Geological Survey. 2004. **National Field Manual for the Collection of Water-Quality Data. Techniques of Water-Resources Investigations**. Book 9. Handbooks for Water-Resources Investigations. Water Resources--Office of Water Quality. http://water.usgs.gov/owq/FieldManual/index.html

Wagner, Richard J., and Robert W. Boulger, Jr., Carolyn J. Oblinger, and Brett A. Smith. 2006. **Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting.** U.S. Geological Survey. Techniques and Methods 1–D3. http://pubs.usgs.gov/tm/2006/tm1D3/pdf/TM1D3.pdf

Wealleans. D. 2001. **The Organizational Measurement Manual**. Gower Publishing.

White Ted. 1999. **Automated Water Quality Monitoring: Field Manual. Prepared for: Ministry of Environment Lands, and Parks**. Water Management Branch for the Aquatic Inventory Task Force. Resources Inventory Committee. The Province of British Columbia.