11. Monitoring Network Design and Implementation Scenarios

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This chapter emphasizes flexibility in designing and implementing approaches to monitoring that are based on well-documented science and judgment and that meet state objectives for both large-scale (e.g., statewide) and small-scale (e.g., drainage basin, waterbody) water quality characterizations. A state is likely to employ a combination of designs to meet its monitoring objectives. A state is also likely to use a variety of implementation strategies to balance the diverse demands of issuing NPDES permits, calculating total maximum daily loads (TMDLs), and assessing all state waters. The primary sections in this chapter follow:

- How does the state define its waters?
- What monitoring designs does the state use to support its decision making needs?
- How does the state implement its monitoring program to achieve its monitoring objectives?

11.1 How Does the State Define the Population of Waters Covered By Its Monitoring Design?

Defining the target population and developing the sampling frame are two key steps in designing a monitoring network. The target population is the set of waters that will be characterized by the monitoring design. In the broadest sense, the target population is all waters of the state; however, most states divide the population into subpopulations such as rivers, lakes, or wetlands. The target population is specified sufficiently well so that users of the monitoring information know what resources are included. The sample frame is a list or map that represents the target population or subpopulation.

The sample frame may be defined in various formats. For example, it may be a list of lakes within the state or a list of wellhead protection areas. It may be a map or GIS coverage of the river and stream network, wetland areas, groundwater aquifers, or coastal areas. When the sample frame is based on a map or GIS coverage, the scale of the coverage (e.g., 1:24,000 or 1:100,000) influences how well it coincides with the target population. Frequently, the sample frame does not coincide with the target population. It may include elements that are not part of the target population (overcoverage) or exclude elements that are part of the target population (undercoverage). The sample frame quality should be verified. This typically occurs during field monitoring when staff encounter a sampling location that does not meet the definition of the target population or subpopulation. Verification can also be conducted prior to identification of and visits to the sampling locations. The monitoring design, particularly probability survey designs, should address differences between the sample frame and target population.

The sample frame is used to generate the set of sampling units or sampling locations that is representative of the target population. The sampling units are the individual members of the target population that will be monitored to collect data about core and supplemental indicators. The water quality results from the sampling units are then used to describe the target population.

In water quality monitoring, as in most environmental monitoring, the target population has both spatial and temporal characteristics. Spatial characteristics are the fundamental consideration in monitoring network design, although temporal characteristics can be addressed when defining the target population. The temporal aspect can also be addressed through the selection of indicators and the definition of sampling protocols for each indicator.

11.2 What Are Monitoring Design Scenarios?

Monitoring design scenarios are part of the overall monitoring strategy that describes all aspects of monitoring activities, including defining the target population, selecting sample locations, selecting indicators to measure, defining how samples are collected and analyzed, and analyzing and presenting data and results. The state's assessment methodology should include a brief description of the monitoring designs used to generate water quality results. The methodology may refer readers to the state's monitoring strategy for additional details about the designs.

The following section focuses on options for designing the monitoring network. Three basic design options are described and may be used, typically in combination, to determine the extent of attainment or nonattainment of state waters and to describe the status of specific waters at an appropriate scale for supporting management decisions.

- Census—measurements are taken for every element in the population
- Judgmental (targeted)—measurements are taken at waterbody locations selected on the basis of experience of experts, and results are extrapolated on the basis of expert judgment
- Statistical survey (probability-based)—measurements are taken of a randomly selected sample of the target population, and statistical inferences about the distribution of values for the entire population are drawn from the sampled units.

States generally employ a combination of monitoring designs to address management questions. Judgmental designs tailored to a specific management question dominate state programs. Many states, however, are adding probability-based surveys. The U.S. Environmental Protection Agency (EPA) Environmental Mapping and Assessment Program (EMAP) program has assisted more than 30 states in designing probability surveys to meet a portion of their monitoring requirements.

11.2.1 When Does the State Census All Target Populations?

A census monitors each element of a population. This type of census design eliminates the error associated with not monitoring every member of the population. Census designs offer site-specific information about whether a given waterbody is attaining water quality standards (WQS) for all members of the population.

Because the total population of waters of a state is large, a census generally is impractical for comprehensive assessment. A census for all State waters would be expensive, time consuming, and resource intensive. Such censuses may be more appropriate for smaller populations or subpopulations such as designated bathing beaches or a specific drainage basin or waterbody segment. Even in these situations, a combination of designs is useful. For example, if all bathing beaches are monitored (census of bathing beaches), samples may be collected at random or judgmental locations from any given beach to characterize water quality at that beach.

Examples of a census used in water quality monitoring

No state currently employs a census for assessing all its waters, such as all lakes/ponds, all river/stream reaches, or all estuarine areas. Some states, however, apply a census to a subset of waters that share a particular designated use or feature (e.g., designated bathing beaches, drinking water reservoirs). The states may monitor all designated bathing beaches periodically during the swimming season, or all drinking water reservoirs.

11.2.2 When Does the State Use Judgmental (targeted) Designs?

Targeted designs rely on expert knowledge or best professional judgment based on experience to select sampling sites to meet specific objectives. These designs also use professional judgment to determine the spatial and temporal representation of each sample. By specifying the spatial extent of each sample location, analysts can piece together the total amount of waters assessed under a targeted design. Unless complete coverage can be pieced together, EPA recommends that judgmental designs cannot be used to draw conclusions about the extent to which the entire target population is attaining WQS. When judgmental designs are used, no quantitative statements can be made about the level of confidence in the sampling results (U.S. EPA 2000a).

Under a judgmental design, monitoring sites are selected in a nonrandomized way. Targeted site selection is generally used to answer specific questions regarding the condition of that particular site (U.S. EPA 1997a). Each site is selected on the basis of specific requirements that meet project or program objectives. The requirements may be environmental features (e.g., flow, wadeable riffled area), human population densities, and/or easy accessibility. A judgmental or targeted network is composed of sampling sites that are selected with a variety of criteria such as:

- Downstream discharge of a waterbody or watershed unit
- Known or suspected water quality problems
- Sources of potential water quality problems
- Upcoming events in the watershed, such as development or deforestation, that may adversely affect water quality.

Sites may also be selected to monitor best management practice (BMP) effectiveness or habitat restoration that is intended to improve waterbody quality. A judgmental network provides assessments of individual sites or reaches the sites are determined to represent (U.S. EPA 1997b). The extent or size of a waterbody that is represented by a given monitoring station will depend on the waterbody type. Given the complexity of lakes and estuaries, no specific guidelines are available. For streams, a monitoring station can be considered representative of a stream waterbody for a distance upstream and downstream that has no significant influences that might tend to change water quality or habitat quality (U.S. EPA 1997a). More specific information on monitoring designs for wetlands has recently been released via www.epa.gov/owow/wetlands/monitor/#meth and is cited in U.S. EPA (2002).

Initially, the number of sites selected usually depends on the resources available. Often sites are prioritized, so high-priority sites are sure to be monitored if staff and funding resources are limited. In the long term, many sites may be added to the network over a number of years, so that the state is peppered with a dense sampling network. Each site may still be selected based on “core criteria.” It is possible, however, that the network may be composed of sites that meet a variety of different criteria.

Judgmental sampling may be used in conjunction with other sampling designs to produce better documented results. In fact, judgment is an integral part of any monitoring network design. Existing information almost always helps develop a more efficient probability-based design.

Examples of judgmental designs

The water quality monitoring programs of most, if not all, states are based on a judgmental monitoring design. Several states have extensive fixed-station networks for chemical monitoring, macroinvertebrate sampling, and analysis of certain stream orders that were developed from targeted site selection. Depending on the sampling methods, some states monitor riffled areas only, whereas other states have both riffle and run sites.

The U.S. Geological Survey (USGS) gaging station network that is cost-shared with many states is a judgmental network. One of the best documented examples of a targeted design is the USGS National Water Quality Assessment (NAWQA) program. More detailed information on network design is documented in Design of the National Water Quality Assessment Program: Occurrence and Distribution of Water Quality Conditions.

Arkansas’ basic monitoring program for rivers/streams consists of approximately 140 fixed monitoring sites that have been selected to assess the effects of point-source dischargers, assess the impact of nonpoint sources, monitor major rivers, and provide long-term chemical data for high-quality (least-impaired) streams by physiographic region for use in future WQS revisions. Sample sites have been selected to best represent monitoring objectives. An additional 40 monitoring stations are sampled yearly to address specific water quality interests, including unassessed major waters of the state. Through analysis of data collected at these sample locations, Arkansas was able to report on the condition of 10% of its rivers and streams in 1998.

Pennsylvania is implementing an extensive monitoring program for unassessed waters. Its design resembles a hybrid of judgmental and systematic random designs. State staff start at the mouth of a wadeable stream and move upstream, monitoring water quality at regular intervals approximately 8 to 10 miles apart. The monitoring location is selected based on the judgment of the field crew. Factors influencing this selection include waterbody and land-use characteristics. This monitoring program focuses on aquatic life and uses a macroinvertebrate rapid bioassessment approach to indicate aquatic life use support. Other monitoring designs are being developed to monitor unasssessed nonwadeable rivers and lakes.

South Carolina has a fixed network of 314 integrator sites. These sites target the most downstream access of each of the Natural Resource Conservation Service (NRCS) 11-digit watershed units in the state, as well as the major waterbody types that occur within these units. For example, if a watershed unit ends in estuarine areas at the coast, integrator sites are located in both the free-flowing freshwater portion and the saltwater area. The results are used to establish trends and identify waters that may be quality limited. Intensive monitoring or other actions may be taken on the basis of the data from the integrator network. It is important to note that South Carolina also uses a probability-based design to provide a statewide overview of the extent that its waters attain WQS.

11.2.3 When Does the State Use Statistically Based (probabilistic) Designs?

States are increasingly incorporating statistical or probability-based monitoring into ambient water quality monitoring. Some of the numerous design options are summarized in this section. Details of each design, including conditions under which the design is appropriate, benefits and limitations of the design, and information on how to use the design, are included in USEPA QA/G-5S, Guidance for Choosing a Sampling Design for Environmental Data Collection (U.S. EPA 2000a). The document guidance, although general, does address many survey design issues that arise in aquatic monitoring. States, territories, and authorized tribes may also contact the EPA monitoring design team at http://www.epa.gov/wed/pages/EMAPDesign/index.htm to request technical assistance on designing statistical water quality monitoring networks.

The designs vary in complexity and offer a number of advantages for characterizing water resources with more precision and at different spatial and temporal scales. The simplest designs require the fewest sample locations to provide broad-scale descriptions of the extent that a population or subpopulation of waters is attaining WQS. These broad-scale characterizations satisfy the section 305(b) monitoring objectives to assess all waters and can provide an indication of the amount of waters that may be expected to be section 303(d) listed waters. More complex designs, requiring more sample locations, may also satisfy both the broader scale objectives and smaller scale monitoring objectives appropriate for developing management actions, including TMDLs.

All probability survey designs have these features:

- 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.

Simple random sampling designs

Simple random sampling is the most basic probability-based design. It involves defining the target population and then using a technique to randomly select sample sites. For example, a simple random sample of a population of waterbodies can be taken by numbering all the waterbodies and then randomly selecting numbers from that list. Under this design, each element in the target population has an equal probability of being selected as a sample site. This method is the easiest way to generate an unbiased measure of the target population. The advantages of simple random sampling are that (1) sample size calculations are straightforward, (2) subsequent data analyses can use common statistical algorithms, and (3) the designs are easy to understand.

A potential limitation of simple random sampling is that it does not incorporate other auxiliary information. This may cause the monitoring design to be inefficient, in the sense that designs that do incorporate this information can have better precision. Auxiliary information can be nothing more than geographic location. Typically, survey designs that use geographic information are more efficient than those that do not.

Systematic and grid sampling designs with random start

In systematic and grid sampling, sample sites are selected at regularly spaced intervals over space or time. An initial location or time is chosen at random, and the remaining sampling locations are defined according to a regular pattern so that all locations are in defined, regular intervals along a linear feature, across an area (grid), throughout a volume, or over time (systematic). Systematic and grid sampling designs typically are used to search for hot spots and may be concentrated in a general location. They can be used to infer means, percentiles, or other parameters and also are useful for estimating spatial patterns or trends over time. These designs provide a practical and easy method for designating sample locations and ensuring uniform coverage of a site, population, or process. A limitation of most systematic or grid sampling designs is that exact precision estimates are not available without additional assumptions. An advantage is that all potential systematic samples are balanced across space or time.

Random tessellation stratified designs

Random tessellation stratified (RTS) designs incorporate features of simple random sampling and systematic sampling designs (Stevens 1997, Stevens and Olsen 1999). RTS designs use a two-step randomization process, with the first step being the random placement of a systematic grid over the region of interest and the second step being the random selection of units associated with grid cells. The RTS design guarantees a spatially balanced sample and enables precision to be estimated. If any spatial pattern in an indicator is present, the precision of the RTS design will be better than that of simple random sampling.

Designs incorporating additional information

Simple random sampling is most useful when the population of interest is relatively homogeneous. When the target population is not homogeneous, other techniques may be used to improve the precision of the sample. One of these techniques is stratified random sampling; another is called unequal weighting. Each improves the efficiency of the sampling design by incorporating additional information about the population. To achieve improved efficiency requires that the information be related to the indicator responses. Increasing the complexity of the sampling design also increases the complexity of the subsequent statistical analysis.

Stratified random sample designs. For stratified random sample designs, the target population first is separated into homogeneous subpopulations (strata). Sampling sites then are selected randomly from each stratum or subpopulation. The results of monitoring at each sample location within each stratum allow one to characterize both the target population as a whole and each stratum or subpopulation.

This design is particularly useful when the target population is heterogeneous (e.g., waters of the state) and can be organized into more homogeneous groups (e.g., low-order streams, high-order rivers, lakes, wetlands). By organizing the population into homogeneous strata, this design reduces the variability among the sample sites within each stratum and improves the precision of the results. Examples of different ways to stratify waters include:

- Waters stratified by waterbody type (e.g., streams/rivers, lakes, wetlands, estuaries)
- Waters stratified by other hydrographic discriminators (e.g., stream order, wadeable/nonwadeable, perennial/intermittent)
- Waters stratified by designated use (e.g., aquatic life, recreation)
- Waters stratified by ecoregion, physiographic province, elevation, land cover, or other geographic discriminator.

Within each stratum, simple random sampling, systematic random sampling, or RTS sampling may be used to select the sample. Stratified random sampling is also used to simplify operations or allow different sampling designs among the strata. For example, stratifying waters by waterbody type allows different designs to be used for streams, lakes, and wetlands. If a state uses a rotating basin approach to sample its streams, then the field work is operationally simplified by having the basins sampled in one year independent of those sampled in other years.

Unequal probability sampling. Unequal probability sampling can be viewed as a generalization of stratified random sampling and as a method for selecting a sample within a stratum. In unequal probability sampling, each unit in the population can have a different probability of being selected. In simple random sampling, each unit has the same probability of being selected. To implement unequal probability sampling requires auxiliary information for each unit in the population (technically each unit in the sampling frame). For example, if the target population is streams, it is likely to include many more first-Strahler-order streams than fourth-Strahler-order streams. Unequal selection may be used to ensure that the randomly selected sample results in approximately the same number of sample units in each Strahler order. By not treating the subpopulations as formal strata, the unequal weighting technique allows researchers to characterize subpopulations that are not based on Strahler order. Unequal probability sampling can increase the precision if the auxiliary information is strongly correlated to an indicator.

Additional design options. The sample designs discussed represent those that are commonly used. Many other types are available, including cluster sampling, multistage sampling, multiphase sampling, ranked set sampling, adaptive cluster sampling, and survey designs over time, to name a few. Which design to use depends on the monitoring objectives, the type of aquatic resource to be monitored, and the information available about the population (specifically, available sampling frames). As an example, it is possible for a sampling design to provide a statewide sample for perennial streams and rivers and a more intensive sample of perennial streams and rivers in a specific subregion. Another example would be a sample for the entire Puget Sound in Washington with intensified sampling in harbors or bays of specific interest.

Examples of statistical (probability-based) sampling designs

South Carolina uses a statewide probability design network in addition to the fixed station integrator network described earlier. The probability network provides data to make inferences, with known statistical confidence, about the condition of the state's water resources. The design is stratified by waterbody type: streams, lakes/reservoirs, and estuarine resources. Within each stratum the state uses unequal weighting to ensure sufficient sampling across subpopulations. Each sample location is monitored annually for indicators of biological condition, habitat, and sediment quality. The state conducts more frequent monitoring for specific physical/chemical indicators.

Maryland's biological stream survey monitoring program is designed to provide a statistically unbiased estimate of the condition of wadeable (first- through third-order) nontidal streams and rivers. Basins in the state are divided into three geographic regions for assessment purposes. From 1995 to 1997, basins in one geographic region were sampled each year, and one basin in each region was sampled twice. Random monitoring site selections were made from all sections of streams that could physically be sampled. Approximately equal numbers of first-, second-, and third-order streams were sampled. The number of sampling sites of each stream order in a basin was proportional to the number of miles of the stream order in the state. The sampling strategy was designed to allow Maryland to develop statistically valid estimates of largemouth bass densities, miles of streams with degraded physical habitat, and miles of streams with poor Index of Biological Integrity scores. Other types of monitoring programs (generally judgmental) apply to lakes, larger order streams, and wetlands and estuaries.

Historically, West Virginia has employed a targeted water quality monitoring program for streams/rivers to focus on known or suspected pollution problems. The state is divided into 32 watersheds (8-digit HUC), which are organized into 5 watershed groups. One watershed group is monitored in each year of the state's 5-year rotating assessment monitoring cycle. A list of streams for the watershed group is developed from EPA's Water Body System database, and samples are selected from as many listed streams as possible close to the mouth of the stream. In 1997, West Virginia established a random monitoring program to complement the targeted stream program. Approximately 30 to 45 stream locations within a watershed group are selected randomly from an EPA database to allow development of statistical comparisons among watersheds.

Nebraska employs a rotating basin approach for water quality assessment monitoring. The monitoring strategy targets resources in two or three river basins annually to allow for intensive efforts to increase the identification and abatement of pollution problems. Monitoring is conducted for rivers/streams, lakes, and wetlands located within the selected basins. All 13 water basins in Nebraska are monitored over 5 years. Since 1997, Nebraska's biological monitoring program has been based on a probabilistic methodology developed in association with EPA. Approximately 40 biological monitoring sites are selected randomly each year from the perennial streams within the water basin of interest for that year. Sample sites for other monitoring purposes are selected to best represent monitoring objectives and are based on professional judgment. The approach also supports coordination and integration of environmental programs through a Basin Management Approach.

Indiana employs a 5-year rotating basin (eight-digit HUCs) approach to monitoring surface waters. The strategy includes fixed stations, randomly selected stations for biological and water chemistry monitoring, pesticide monitoring, bacteriological monitoring, NPDES permit monitoring, TMDL development monitoring, and targeted fish and surficial aquatic sediment monitoring. The monitoring strategy is designed to describe the overall environmental quality of each basin and to identify impaired waters.

11.3 How Does the State Integrate Broad-Scale Monitoring Designs With the Need To Identify Site-Specific Impairments?

Some designs address this issue specifically; others require a supplemental or nested approach to achieve monitoring objectives at a broad-scale statewide level and at a small-scale site-specific level. The census design provides data for both broad-scale (e.g., statewide, waterbody type, designated use) and site-specific (e.g., waterbody segment) characterizations. A judgmental design may provide characterizations at both levels if complete representation of all waters is achieved, but judgmental designs have historically provided site-specific information only for a limited amount of waters. The probability designs most frequently used for water quality monitoring are designed to provide statewide or watershed-level characterizations, though they do provide site-specific data for individual sample locations.

Probability designs support site-specific descriptions of water quality in a variety of ways. Some states use the probability design to systematically sample new locations each year. Under this approach the state gets site-specific information on waters that had previously been unmonitored, in addition to broad-scale characterizations of water quality throughout the state or watershed.

Another way probability designs support identification of impaired waters is by providing information to refine future probability designs. When analyzing the results of the probability survey, staff may identify associations between impaired waters and certain land-use, source-type, or other characteristics. Future probability (or judgmental) designs can intensify sample collection around these land uses or other characteristics in an effort to identify, at a smaller scale, waters that are impaired.

Intensified monitoring to characterize smaller scale areas can also be incorporated into the probability design from the beginning. A state may have existing data or information that certain areas are likely to be impacted (or likely to be pristine). To confirm that information, the broad-scale probability design can be supplemented with intensified sampling to characterize smaller scale conditions.

If followup monitoring is required after a probability survey to obtain site-specific information, either a judgmental or probability approach may be used. In either case, professional judgment will improve the precision and reduce the cost of the followup monitoring. The type of information used to determine where to monitor and what indicators to monitor includes:

- Results from probability and judgmental monitoring
- Predictive models
- Preexisting data and information on water quality conditions
- Land-use data
- Analysis of potential sources in the watershed (see discussion on selecting supplemental indicators in Chapter 11).

11.4 How Does the State Implement Monitoring Designs To Achieve Its Monitoring Objectives?

States generally structure implementation to distribute monitoring resources among multiple monitoring objectives and associated management priorities. There will be some shifting from year to year as priorities shift among TMDL calculation, WQS revision, NPDES permit issuance, and so on. However, to ensure that resource allocations are appropriate, it is critical that states maintain sufficient funding for a base monitoring network. This network provides the foundation for other monitoring priorities by describing the extent to which waters are attaining WQS and characterizing the causes and sources of impairments. A probability design is the most effective way to maintain a base network and maximize the resources available to support other, more narrowly targeted monitoring priorities.

States, territories, and authorized tribes should describe, in a monitoring strategy and periodic monitoring plan, both the monitoring designs and implementation plans to achieve monitoring objectives. This section explores implementation options for network designs that achieve the monitoring objectives of a state, territory, or tribal water quality management program Network designs may be tailored for waterbody types, individual basins, and applicable designated uses.

11.4.1 Tailoring Monitoring Designs for Waterbody Types

States commonly organize monitoring designs according to the waterbody types present in the state. The specific design could be a basic stratified random design, a stratified design combined with unequal weighting, a stratified design with intensified sampling in areas of concern, a ranked set, or judgmental. Regardless of the design selected, tailoring it to waterbody types requires expert professional judgment to organize different waterbody types into relatively homogenous groups or strata. The text box shows an example of potential strata for surface waters.

Example Strata for Surface Waters

Rivers/Streams
- Intermittent streams
- Wadeable streams
- Nonwadeable streams/deep rivers

Lakes
- Small lakes (<50 acres)
- Medium-sized lakes (50-250 acres)
- Large lakes (>250 acres)

Wetlands
- Depressional wetlands
- Slope wetlands
- Fringe wetlands
- Flats

Estuaries
- Small estuaries (<250 km^2)
- Large estuaries ($\geq$250 km^2)
- Large tidal rivers
- Small tidal rivers

Depending on the resources available to the effort and the other monitoring objectives that need to be accommodated, this design may be implemented under a variety of schedules. Ideally, the design would be implemented statewide for all waters every year. Alternatively, the jurisdiction could implement the design for one or more strata each year to achieve comprehensive assessment over several annual monitoring cycles (see text box).

11.4.2 Tailoring Monitoring Designs for Individual Basins

Rotating basin monitoring designs focus monitoring and programmatic activities and resources in a few watersheds or basins (e.g., eight-digit hydrologic unit codes) each year, because

Potential Schedule for Implementing Waterbody-Type Monitoring Design

Year 1 - Wadeable streams
Year 2 - Nonwadeable rivers
Year 3 - Lakes
Year 4 -Wetlands
Year 5 - Estuaries and coastal waters
Year 6 - Intermittent streams

available resources preclude comprehensive monitoring and programmatic activities across the state. Over time, typically a 5-year cycle, all basins are monitored. Then the cycle begins anew.

The state may use any combination of the designs described in Section 11.2, or other appropriate designs, to meet its monitoring objectives within each basin.

11.4.3 Tailoring Monitoring Designs for Applicable Designated Uses

States, territories, and authorized tribes need to implement monitoring designs that describe the extent to which all applicable uses of state waters are attained. This may be achieved through the selection of indicators that are measured at each sample location. It may be achieved by developing a specific monitoring design tailored to the designated use. Or it may be achieved by a combination of options. For example, a small-scale probability or judgmental design may be used to assess designated uses that apply to a relatively small subset of waters such as high-use beaches, shellfish areas, or public water supplies. Meanwhile, other designated uses may be assessed as part of a multipurpose monitoring design that includes an appropriate suite of indicators.

Aquatic life

Most monitoring designs focus on aquatic life use. This designated use generally applies to all waters of the state, unless a use attainability analysis has demonstrated that the aquatic life use was not attainable.

States increasingly are building a probability design into their monitoring program and using it to describe the extent to which aquatic life uses are supported throughout the state or watershed. Many states are in the early stages of this design and have only developed it for a few waterbody types, typically wadeable rivers and streams. Some states have expanded this design into lakes, coastal waters and wetlands. Over time, these designs should address all waterbody types.

The results of the probability survey serve as an objective check on the results of judgmental designs. As described in Section 11.3, the results of the probability design can also be used to locate impaired waters needing restoration or pristine waters needing protection.

Recreation

A combination of monitoring designs and scales that are tailored to the level of recreational use assigned to the waterbody may be most appropriate for assessing recreational use and supporting beach advisories and closures.

For those areas identified as bathing beaches, the sampling design should provide enough information to determine whether to issue a public health-based advisory or closure. Even within beach areas, states may employ different levels of sampling intensity. This would allow the allocation of monitoring resources to target the high-use and/or high-risk beach areas.

For an assessment of whether all recreational waters (i.e., those designated for primary contact recreation) are attaining their uses, states may want to rely on probability design to evaluate the extent to which all other waters are attaining WQS.

Fish consumption

For fish consumption use attainment, the state will generally identify the waters with high use for fishing and monitor fish species that are likely to pose health threats if consumed. The simplest sampling design may be simple random or stratified random.

Shellfish consumption

EPA recommends following the National Shellfish Sanitation Program monitoring protocols to assess attainment of the shellfish consumption use. States implementing this program typically use simple random sampling at all approved shellfish harvest areas. State water quality agencies should coordinate with the responsible state agencies to maximize use of data collected under the shellfish sanitation program and minimize additional monitoring.

Public water supply

In addition to the statistical designs in Section 11.2.3, ranked set or cluster designs may also be appropriate to monitor waters designated as public water supplies (U.S. EPA 2000a). This is particularly true for supplies for which the state has already developed source water assessments. Source water assessment reports, which provide detailed information about the potential causes and sources of contamination to public water supplies, serve as valuable information in designing the ranked set or adaptive cluster designs and selecting the most appropriate indicators to measure.

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