National Water Quality Monitoring Council
Working together for clean water

Water Quality Monitoring: A Guide for Informed Decision Making

Using the designs together

About

Protecting our Nation's water resources is increasingly challenging given diffuse pressures of population growth, development and changing climate. High quality water is essential to protecting human health and sustainable ecosystems. This heightened importance, is driving an increased need for data documenting the quality of water resources and how they are changing at national, regional and local levels.

What you need to know

One monitoring design will not fit all water quality management needs. This series of fact sheets details the strengths, limitations and products of common monitoring designs. This overview encourages use of a combination of designs to address multiple water quality questions. Begin with the identifying monitoring objectives, the questions needing answers, and then engage partners on design/implementation.

Integration of monitoring designs provides:

- Information on physical, chemical and biological integrity of waters
- Changes and trends in water quality integrity
- Extent of degradation and key stressors
- Location and characterization of impaired waters
- Input to plans to restore water quality (TMDLs and watershed plans)
- Effectiveness of protection and restoration actions locally and across the state and nation

Monitoring Design Summary

Monitoring Type	Strengths	Limitations	Products
Targeted Monitoring	In-depth collection of data for an area(s) of interest	Generates site specific data with limited ability to extrapolate to broader areas	Decisions about individual assessment units, local action plan like TMDL, effect of permitted discharges
Fixed-Site Monitoring	Long-term, routine water quality data supports site-specific trends like flow and flux at a basin outlet	Not designed to represent trends beyond specific monitoring locations	Historical record of water quality trends, loads of key parameters like nutrients
Statistical Surveys	Cost effective, statistically representative method for assessing condition of a broad population and tracking changes over time	Not designed for localized site assessments, except for the sites sampled	Broad, unbiased assessments of status and trends across multiple scales, analysis of patterns in stressor-response relationships
Remote Sensing	Obtaining estimates of condition over large areas in a low-cost manner	Requires a data management strategy and monitoring data to ground truth algorithms	Early indication of emerging problems to inform on-the-ground action and follow up monitoring

Table 1: The above table outlines 4 types of monitoring designs and is intended to provide an overview of each design. To get a more comprehensive overview of each survey design, please see its' corresponding fact sheet.

Integrating Monitoring Designs to Support Program Needs

Each monitoring design has strengths and limitations. When used in combination, we _advance our understanding of water quality and increase monitoring efficiency. Given resource constraints and competing priorities, leveraging across programs and coordinating among monitoring activities increases the ability of the monitoring investment to meet the needs of multiple regulatory and water quality management programs.

Figure 1 provides a conceptual illustration of leveraging or combining monitoring approaches to inform multiple water quality decisions. Most states have long-term fixed monitoring sites sampled for decades that provide historical record of trends at those sites. Statistical surveys are a newer approach that balance the constraints of funding with the need for unbiased state or regional estimates of water quality conditions. Survey data support analysis of patterns among stressors to focus priorities. Remote sensing ground-truthed with field monitoring predicts occurrence of key parameters like algal blooms. Both surveys and remote sensing inform follow up monitoring. Targeted sampling is key to confirm impairments and generate detailed data to guide local restoration actions. Together these designs track change.

Streamlined Monitoring—Using the Designs Together

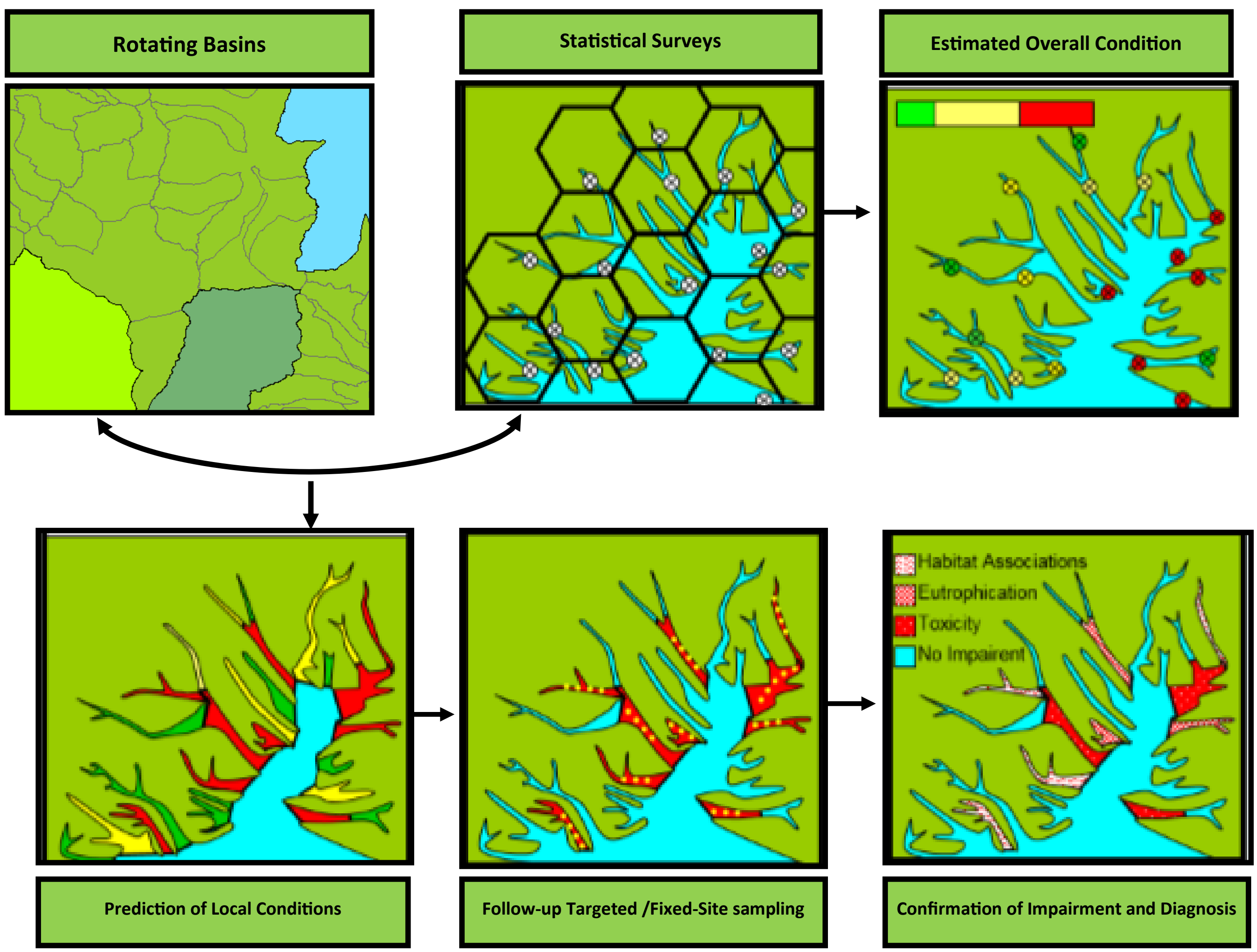

Figure 1: An example of how multiple monitoring designs can be used to inform water quality protection and restoration.

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Targeted Water Quality Monitoring

About

Targeted monitoring is the intentional selection of monitoring locations, parameters or timing for sample collection and analysis. It is typically used when there are previous data, information or risk factors available to assist in the monitoring design. Targeting the sampling location, pollutant types, timing of sampling or some combination of these factors can be an effective way to collect data that will inform a specific issue or question.

What you need to know

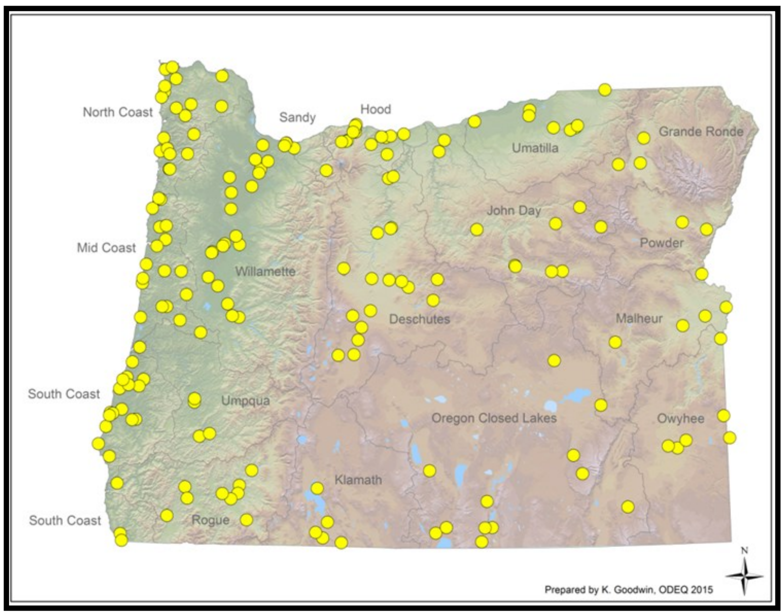

Figure 1 Targeted toxics monitoring sites in Oregon. Sites were selected using potential sources and land use factors that may influence the presence of toxic contaminants in surface water.

Where water quality problems have been previously identified, are suspected, or require an investigation, targeted monitoring can help to narrow down or identify potential pollution sources. This approach can be used to understand compliance with permits and regulations, assess environmental damages, or investigate specific pollution sources and responsibilities. Targeted monitoring can be conducted at routine sites on an ongoing basis ("fixed station" monitoring); at selected sites on an as needed basis to answer specific questions (compliance monitoring or intensive surveys); on a temporary or seasonal basis (e.g. summer sampling at bathing beaches); or on an emergency basis (such as after a spill or fish kill).

Targeted Water Quality Monitoring Summary

Strengths	Limitations	Questions Addressed
Easily developed, implemented and communicated monitoring design.	Not appropriate for describing the water quality conditions at a landscape scale.	Determining compliance with regulations
Planning, logistics and implementation are simplified because information objectives are well defined.	Information acquired cannot be used to describe conditions outside the study area.	Mixing zone studies
Data analysis and reporting are typically less complex than other monitoring approaches.	Monitoring design is difficult to integrate with other monitoring projects and programs.	Investigating pollution sources
Appropriate choice for compliance determinations, environmental damages, legal cases and investigations.	Often involves a special study which may use resources from other monitoring program areas.	Assessing resource damages
		Determining pollutant loads
		Understanding site status and trends

Table 1: The above table outlines the strengths, limitations, and products of targeted water quality monitoring.

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Fixed-Site, Trend Monitoring Network

About

A fixed-site, trend monitoring network is a water monitoring approach that uses a set of monitoring sites that remain in place and are monitored over the course of many years. Such a network is important for describing long-term water quality conditions. Depending on the frequency of water chemistry monitoring and environmental conditions, statistical trends in water quality can begin to be seen after about a decade of monitoring. Even before statistical trends can be determined, fixed station monitoring yields useful information on on-going water quality conditions.

Biological monitoring can also be performed repeatedly at fixed sites to compare changes in biological health over time.

What you need to know

Seeing changes in water quality over time through fixed site monitoring can give an indication of positive or negative changes in water quality resulting from land use changes, best management practices implementation, regulations, extreme weather events, or other influences. Quantifying success of implementation efforts can be a major benefit of this type of monitoring. Data from fixed station monitoring, while specific to the site(s) where the data are collected, can be used to create and improve water quality models that can predict water quality conditions in other non-monitored locations.

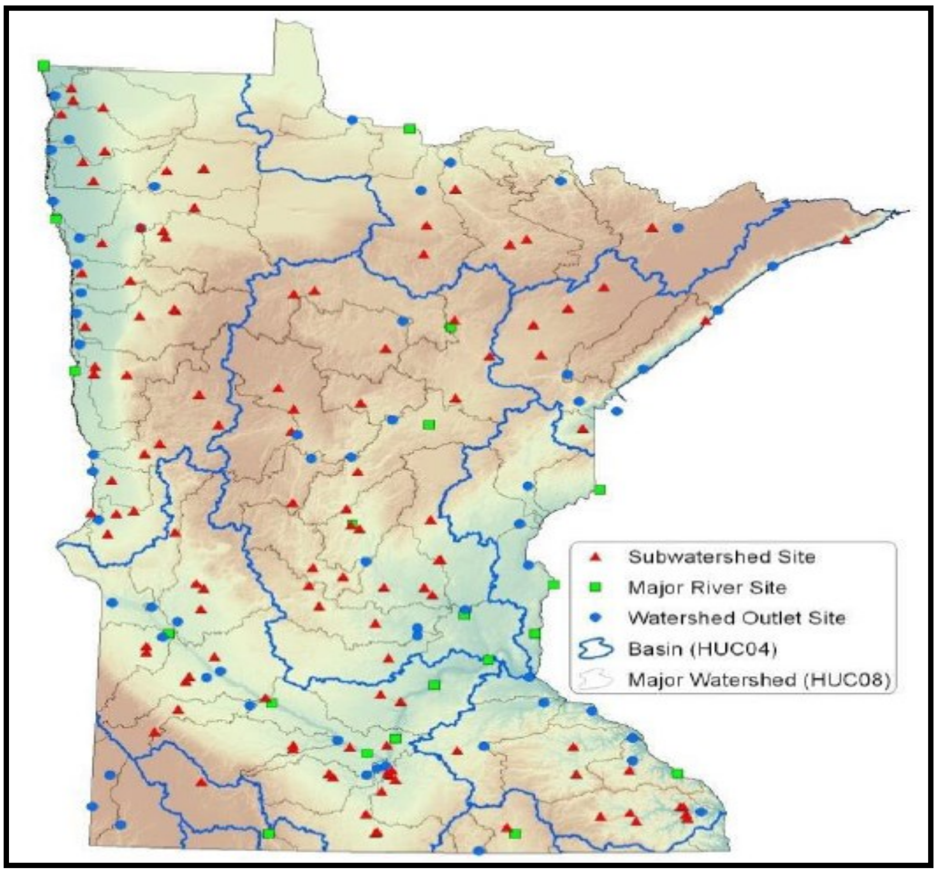

Figure 1: Minnesota's Watershed Pollutant Load Monitoring Network - each site is permanent, has water samples taken regularly, and includes a flow gage to record water quantity measurements:

Fixed-Site, Trend Monitoring Summary

Strengths	Limitations	Questions Addressed
Provides long-term, emergency, or seasonal in-depth water quality information	Usually biased sites that provide waterbody specific information	Status and trends of water quality that can be used to make assessment decisions Status of water quality at the waterbody scale Trends in water quality site-specifically Provides information that can be used to make assessment decisions.

Table 1: The above table outlines the strengths, limitation, and products produced by fixed-site, trend monitoring networks.

Fixed-Site, Trend Monitoring Network Results

Sampling a waterbody once gives a snapshot of the current condition at a moment in time, but sampling in the same fixed location repeatedly over the course of many years gives a picture of how water quality changes over time. The more frequently samples are taken and the longer the site is monitored, the better the shorter term effects of weather on data quality are understood and accounted for. Very high (flood) and very low water levels (drought) will result in very different water quality results, from each other, and from average flow conditions. Frequent, long term sampling in a fixed site network helps describe water quality conditions under all flow conditions.

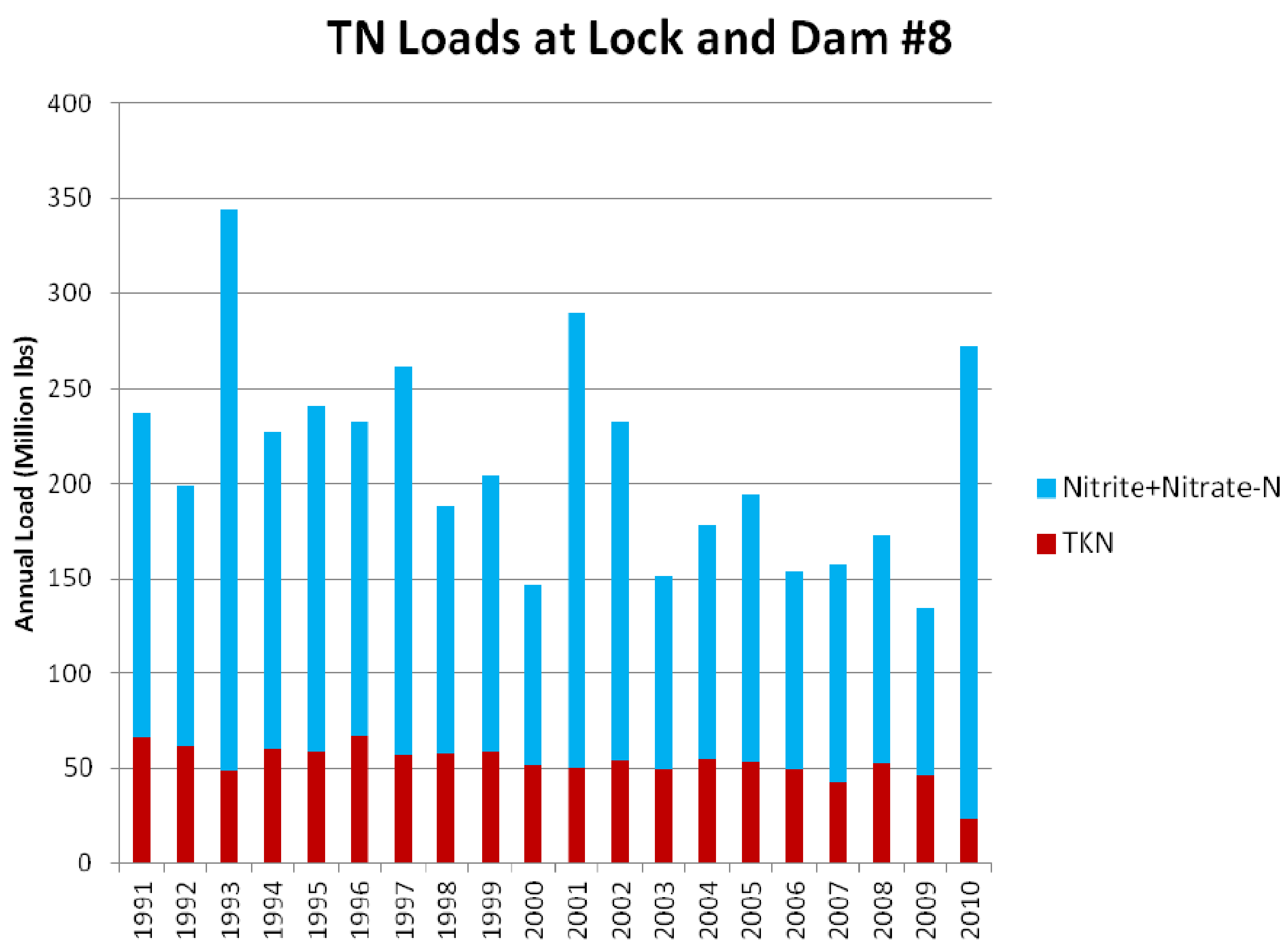

Figure 2: Annual Total Nitrogen (TN) loads in the Mississippi River at Lock and Dam #8 (near Iowa border), showing year to year variability between 1991 and 2010 and the proportion of TN which is in the nitrite plus nitrate and TKN (ammonium plus organic-N) form

Whereas water quality samples alone can be analyzed to determine pollutant concentrations in a waterbody at a given time, pairing regular water quality sampling with water quantity monitoring, or flow gaging, yields much better information. Combining concentration data with flow data can allow for calculation of average concentrations of pollutants in the water over various flow levels (flow-weighted mean concentrations), pollutant loads (the total mass of pollutants in the water over time), and pollutant yields (the mass of pollution generated per acre over time).

See the Minnesota Pollution Control Agency website for maps displaying this type of information on a watershed basis: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/streams-and-rivers/ watershed-pollutant-load-monitoring-network.html#products-data .

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Statistical Survey (Probabilistic) Design

About the Series

This is one in a series of fact sheets describing different water quality monitoring designs and the specific questions that can best be addressed by each. They are intended to point out the strengths and limitations of each design and to illustrate the role of each in a comprehensive monitoring program.

About the Design

A statistical survey design (sometimes referred to as a probabilistic design) allows one to make statements about a large population based on a smaller unbiased sample of the population. A variety of fields use statistical surveys, including public health, economics, and market research, to provide representative, scientific information when it is not cost-effective or possible to measure the characteristics of each member of the population. The Center for Disease Control uses a statistical survey design when conducting the National Health Interview Survey (NHIS) to track health status, health care access, and progress toward achieving national health objectives.

The strength of the results from statistical surveys is their ability to characterize and describe the overall population, with documented confidence.

What you need to know

Statistical surveys are an important element of a comprehensive monitoring program and do not replace other designs (see other fact sheets in this series). EPA, States and others use statistical surveys as a cost effective tool for assessing our Nation's water resources. Using an unbiased sample, statistical surveys can be designed to estimate conditions for the national, state, watershed, or other geographic scales.

A statistical survey estimates the extent of impacted water across a state and supports analysis of whether the impacted water have common attributes that could inform management priorities. While the statistical surveys describe the extent of impacted waters, it doesn't identify the specific location of each impacted. Other types of data analyses, modeling, and targeted monitoring contribute information on specific locations of impacted waters.

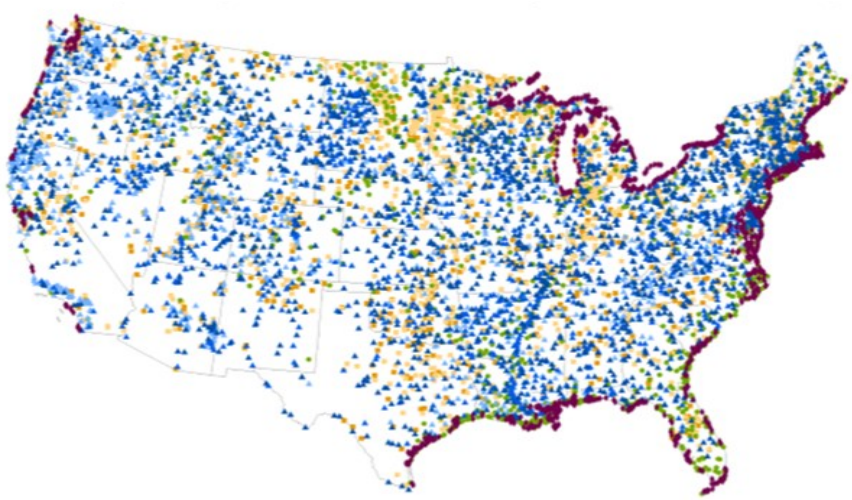

Figure 1: Probability monitoring sites sampled through the National Aquatic Resource Surveys.

Statistical Survey Design Summary

Questions Addressed	Limitations
Estimates the extent and proportion of the population in condition classes (i.e. meeting or not meeting standards) with known levels of precision and documented margin of error	Not designed for localized or site specific characterizations, though data at sites sampled supports detailed characterizations
Repeated surveys track changes and trends in condition across the population to evaluate effectiveness of overall protection and restoration investments	Generally not applied to characterize local , site specific effectiveness assessments (e.g. TMDL's, BMP's)
Identifies patterns as well as associations between indicators to broad analysis of stressor/response signals	As with all designs, changes detected by repeat surveys must consider hydrologic and other factors
Flexibility: can be based on a single or multiple visits, rotating basins, or ecoregions, etc	

Table 1: The above table outlines the strengths, limitation, and products produced by statistical surveys.

How are surveys conducted?

In order to pick an unbiased, random sample it is necessary to first know the location of the members of the population of interest. Typically a map of waters is used as the "sample frame" for a population. Next, a set of sites are randomly selected from that population, where every element in the population has a known probability of being selected for sampling. This key feature ensures that the results of the survey reflects the full range, in both character and variation, of the whole population. For a geographically widespread population of interest, the site selection process can also be controlled for spatial distribution to make sure sample sites are evenly distributed across the entire population of interest.

The selected sites are then sampled with a predetermined frequency for a set of indicators of interest. This can be a single visit for biological community assessment, or seasonal, bi-monthly, monthly, or weekly sampling events, depending on the parameter of interest and the frequency necessary to meet the appropriate water quality standard and/or assessment methodology.

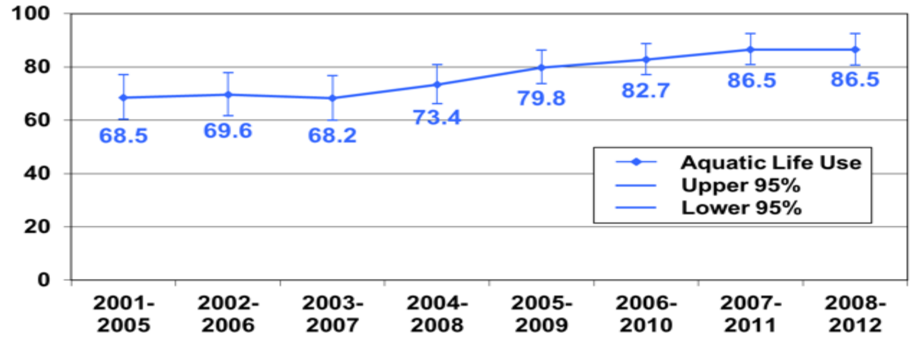

Figure 3: Percent of South Carolina streams fully supporting aquatic life use over eight sampling cycles between 2001-2012, including 95% confidence limits.

What can the surveys tell us?

Condition of the nation's waters

The National Aquatic Resource Surveys (NARS), conducted by USEPA and the states, are examples of national scale statistical surveys. Figure 2 reports the extent of stream miles in a condition category and the margin of error (i.e., confidence intervals surrounding the point estimate such as 42% ±3%).

Assessing trends over time

When statistical surveys are repeated iteratively, as shown for South Carolina in Figure 3, they are capable of discerning changes and trends in the condition of the resource over time. Statistical surveys are particularly well suited to answer the question, "Has the quality of streams in my state improved or gotten worse over time"?"

In this case, a statistically significant change appears to be occurring over time as aquatic life use improves. By using a statistical Survey design, such inferences can be made about the population of streams assessed allowing decisions makers to consider whether the collective water quality management actions across the state, region or watershed are making a difference.

Statistical survey water quality data can also be used to make inferences, with a known margin of error (confidence), about the relative impact of various stressors. The products of a statistical survey monitoring design are intended to be statistically valid statements about water quality for large populations of interest.

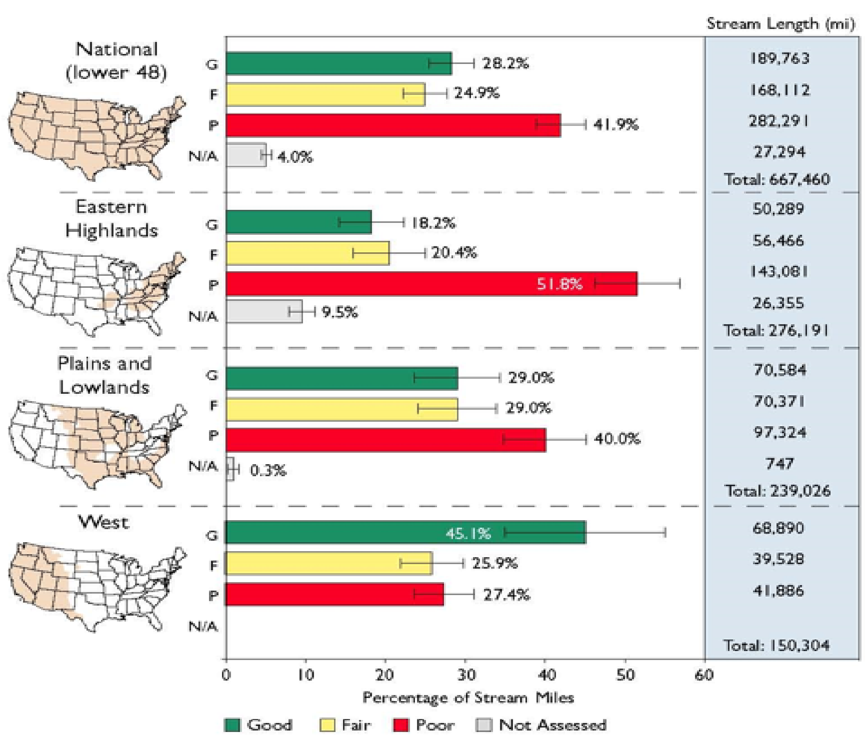

Figure 2: The Wadeable Streams Assessment (WSA), a statistical survey conducted in 2004, assessed more than 670,000 miles of streams in the conterminous U.S. and showed that 28% were in good condition, based on a macroinvertebrate MMI, while 25% were in fair condition and 42% were in poor condition. The WSA also found that conditions differ across the country, with the largest percent of stream miles in poor condition located in the east and the smallest percent in the west.

For more information on statistical survey designs:

National Environmental Methods Index (https://www.nemi.gov/home/)

General Overview of Probabilistic Surveys (http://www.epa.gov/nheerl/arm/designpages/monitdesign/survey_overview.htm)

Aquatic Resource Monitoring (http://www.epa.gov/nheerl/arm/)

Spatially balanced survey designs for natural resources, 2012. Olsen, T., Kincaid, T., Payton, Q., in *Design of Analysis of Long-term Ecological Monitoring Studies*, ed. R.A. Gitzen, J.J. Millspaugh, A.B. Cooper and D.S. Licht. Published by Cambridge University Press.

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Rotating Basin Monitoring Designs

About

Many states and other monitoring entities employ rotating basin designs for assessing the condition of their surface waters. This approach addresses Clean Water Act objectives for assessing watersheds on a statewide basis, repeated at regular intervals, while allowing resources to be focused in a smaller geographic area in any given year. In general, to implement a rotating basin design, a state or region is divided into several geographic areas or hydrologic basins and one or more of these areas is assessed each year over the rotation cycle. A rotation cycle is commonly five or more years in length.

What you need to know

The sampling design used to assess individual basins or areas varies from program to program. Some states utilize a statistical survey approach within the basin of interest, where a probabilistic design involving random site selection is employed to allow one to make general statements about the characteristics of that basin, and at the end of the rotation cycle, about the condition of the state or region as a whole. Other states use a "targeted" or "fixed" design within the basin of interest. A targeted design typically places fixed sites along the main stem, at tributary inputs to the main stem, at watershed pour points, and/or above and below important discharges or changes in land use. Targeted surveys are effective at addressing watershed and site-specific questions, such as identifying specific reaches of stream or watersheds with impairments, determining sources and loads of pollutants or assessing temporal or spatial trends. Many states, such as Oregon, Indiana and Nebraska, use a combination of probabilistic and targeted sampling within a rotating basin approach, to address a broad array of questions about the basin.

Rotating Basin Summary

Strengths	Limitations	Questions Addressed
Focused approach in a smaller geographic areas allowing for a more robust characterization and more collaboration with other water resource programs and local entities. As well as cross program integration. Travel time to sites is reduced through selection of rotational areas. Assessment reports are scaled to a smaller area, making them more manageable and allowing for more detailed analysis of potential sources. Rotating basin designs paired with long-term trend monitoring at "integrator" sites overcome the lack of ongoing data between rotations. The approach is flexible regarding within-basin study designs, and adaptable to a variety of monitoring questions.	It will take 5 years or more to monitor the entire study area Annual changes in weather, stream flow, and other variables make it challenging to compare assessments between basins. If rotational assessments are not coordinated in a basin approach with the 303(d) listing cycle, they may not provide the data to support 303(d) listing or delisting on the most desirable time frame because of the time interval between rotations. Detecting trends is challenging with data collected on five year intervals. A water quality change of concern may not be detected for a number of years, depending on its timing relative to the rotation schedule.	What is the extent of waters in the basin, and the State as a whole, supporting all uses? How do basins compare in terms of extent of waters meeting standards and benchmarks? What is the extent of the water-quality problems in the basin? What are the main pollutants or conditions responsible for the problem? What are the trends in the overall condition of the basin and State? **A targeted design within basins can be used for addressing questions like:** Where do reaches in the basin show indications of impairment and where do reaches meet water quality standards? Which tributaries are contributing pollutants to the main stem that may be resulting in impairments? How does water quality change above and below a tributary or point source input? What are trends at long-term monitoring sites revisited at each rotation?

Table 1: The above table outlines the strengths, limitations, and products of rotating basin water quality monitoring.

How are rotating basin designs conducted?

Basins are typically defined using Hydrologic Units or other standard characterization of watersheds or watershed groups. States utilize rotating basin design in a variety of ways. Utah utilizes a six year rotation and follows a probabilistic assessment with targeted monitoring two years later to follow up on problem areas. Florida selects one area to assess each year within a basin so that the entire basin is completed in five years. Connecticut and the Central Coast of California divide their respective jurisdictions into five areas (some including more than one basin or hydrologic unit) and sample one area per year over the course of five years using a targeted monitoring approach. Oregon samples three of its fifteen Hydrologic Unit Classifications each year over a five year rotation, employing a probabilistic approach for biomonitoring and targeted monitoring for toxics and groundwater. New Jersey uses a rotating basin approach for much of its biomonitoring and targeted monitoring, based on a 5- year cycle for its 5 major basins.

What types of information and products come from rotating basin designs?

The products that can be derived from a rotating basin design are as diverse as the study designs used within the basins. Some states coordinate their rotating basin approach with 303(d)/305(b) assessment and listing cycles, TMDL compliance monitoring needs, discharge permit cycles, or other programmatic needs.

For example, Indiana's five-year rotational strategy uses a combination of targeted and probabilistic monitoring to support permitting programs, CWA Section 305(b) assessments and 303(d) listings, TMDL determinations, drinking water source protection activities, agency-wide initiatives, watershed assessment reports and other products. Oregon used a risk based targeted toxics monitoring strategy in three geographic areas over a six-year period to generate the first statewide toxics assessment report. Due to the size of the state and complexity of its aquatic environment, California now focuses on three of its nine Water Quality Control Regions in each listing cycle, developing changes to 303(d) impaired waters listings for the entire state over three listing cycles. Data are used to support status and trend reports, basin or watershed specific assessments, special studies focused on specific contaminants or land use associations, integrated reports for 303(d)/305(b), and other products.

CASE STUDY:

California Central Coast Ambient Monitoring Program

The California Central Coast's Surface Water Ambient Monitoring Program (CCAMP) employs a 5-year watershed rotational strategy in a targeted assessment of its waters. The rotational design allows for more focused use of resources, and can also support special projects or TMDL data needs in the area of interest.

Conventional chemistry is collected monthly at fixed sites for trend assessment. Toxicity, bioassessment and other measures are collected less frequently at a subset of sites. CCAMP uses an analyte scoring approach similar to the Canadian Water Quality Index to score sites and watershed rotation areas for health. Site-level data are combined with modeled data from the California Healthy Watersheds project to assess "what percent of the watershed (or rotation area) is healthy?"

Sites are evaluated for statistically significant change in multiple parameters. Indications of change are used to help address the question, "in unhealthy areas are there indications of improvement?"

Figure 1: Five watershed rotation areas of the California Central Coast Region. Hydrologic Units are outlined.

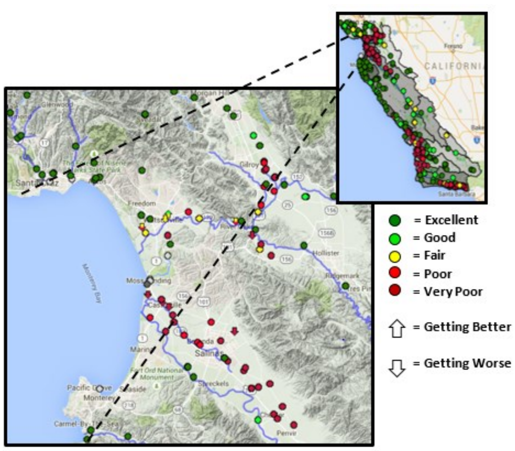

Figure 2: Nitrate (N) in the Monterey Bay Area, scored relative to the drinking water standard of 10 mg/L. Very high nitrate concentrations are found in the "lettuce bowl" of the Salinas Watershed.

CCAMP data are used extensively for 305(b)/303(d) listing, enforcement, watershed assessment, regulatory decision making, TMDL support and other management decisions. Where possible, TMDL compliance monitoring is associated with CCAMP stations, in consideration of the five-year watershed rotation schedule. Stakeholders and staff in monitoring, permitting, and enforcement programs coordinate each year prior to the start of the rotation to enhance usefulness of the data. All data, and associated documentation, is available online in map, graph, and table format at www.ccamp.org

Where can I go for more technical information on rotating basin designs?

New York State Rotating Integrated Basin Studies http://www.dec.ny.gov/chemical/30951.html
Connecticut Ambient Monitoring Strategy for Rivers and Streams: Rotating Basin Approach http://www.ct.gov/deep/lib/deep/water/water_quality_management/rotbasinplan.pdf
Oklahoma WQ Rotating Basin Monitoring Program http://www.ok.gov/conservation/Agency_Divisions/Water_Quality_Division/WQ_Assessment/WQ_Rotating_Basin_Monitoring_Program.html
Indiana Surface Water Quality Monitoring Strategy http://www.epa.gov/nhrlsup1/arm/documents/swqms2001finaldoc.pdf
Nebraska Basin Rotation Monitoring http://deq.ne.gov/NDEQProg.nsf/dc8559037dfefbf386257b8d007a14b3/ae3df8344c7c2c4786257cb50071f750!OpenDocument
Oregon Water Quality Monitoring Strategy http://www.deq.state.or.us/lab/techrpts/docs/WaterMonitoringStrategyFinal.pdf
Central Coast Ambient Monitoring Program (CCAMP), California Surface Water Ambient Monitoring Program: Website: www.ccamp.org; Technical Methods Report: http://www.waterboards.ca.gov/water_issues/programs/swamp/regionalreports.shtml#rb3

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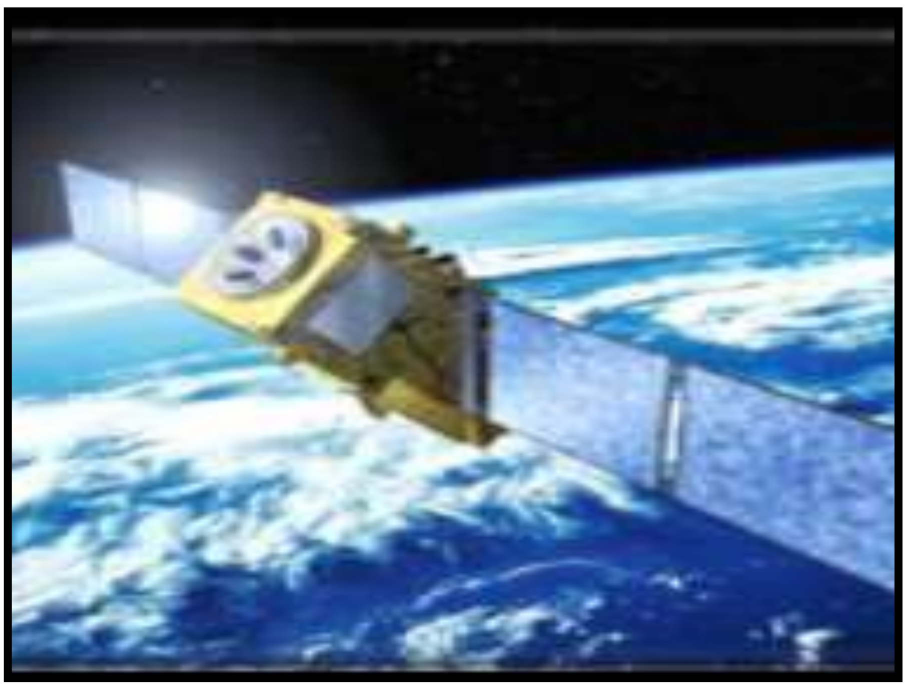
Remote Sensing

About

Remote Sensing is the use of satellites, world imagery, and light refraction off the earth to obtain information about the earth and the environment. Radiant light emitted from objects on the ground and in the water can be used to characterize land use, elevation gradients, temperature profiles, flow pathways, vegetation characteristics, chlorophyll production and much more.

What you need to know

This approach is cost efficient because there are many free data sources such as Landsat8 imagery that can be used to identify areas for potential water quality issues and can help alleviate some monitoring costs. It also can be used to determine the effectiveness of water quality best management practices. However, this approach does require staff expertise to conduct the complex analyses that remote sensing requires. A strong data management strategy is required because the datasets using remote sensing data are typically large and may require dedicated servers to house and maintain the information. This approach is limited by the data resolution and the data used to calibrate the models which are used to make the water quality decisions. This is a modeled analysis and therefore does not replace monitoring but can help an organization prioritize their monitoring or support their water quality decisions.



Remote Sensing Summary

Strengths	Limitations	Questions Addressed
Can help determine water quality issues for large areas Cost efficient by helping alleviate monitoring costs	Requires data management Requires technical staff expertise The resolution is not always adequate and thus limits the analysis	Modelled water quality to inform on-the-ground monitoring How changes in land use affect water quality Changes in stream temperature Effectiveness of BMPs, such as buffer strips and green infrastructure management practices. Algal bloom frequency

Table 1: The above table outlines the strengths, limitation, and products produced by remote sensing

Integrating Water Monitoring Data:

Water Quality Indices, Report Cards and Multi-metric Web Portals

Water monitoring programs often generate significant quantities of data for numerous chemical, physical and biological parameters and various media, such as water column, sediment and biota. Integrating these extensive and diverse data sets into information that is meaningful for use in water resource management and for dissemination to the public is often a challenge. The National Water Quality Monitoring Council, in partnership with New Jersey DEP, solicited information from water monitoring practitioners that are using different methods of communicating integrated water quality information for various types of water resources. Information on these various methods and examples of water quality indices, report cards and multi-metric portals are provided below. Each approach can provide a way to tell an effective story about water quality.

Water Quality Indices (WQI)

A water quality index is a single value (score) used to summarize water quality and resource condition for a particular location and time period. Water quality indices are typically composed of several parameters (typically 4-12) of importance to water quality and are then aggregated and calculated into an overall score. Some of the most common parameters used in water quality indices are dissolved oxygen, pH, chlorophyll a, total nitrogen and total phosphorus.

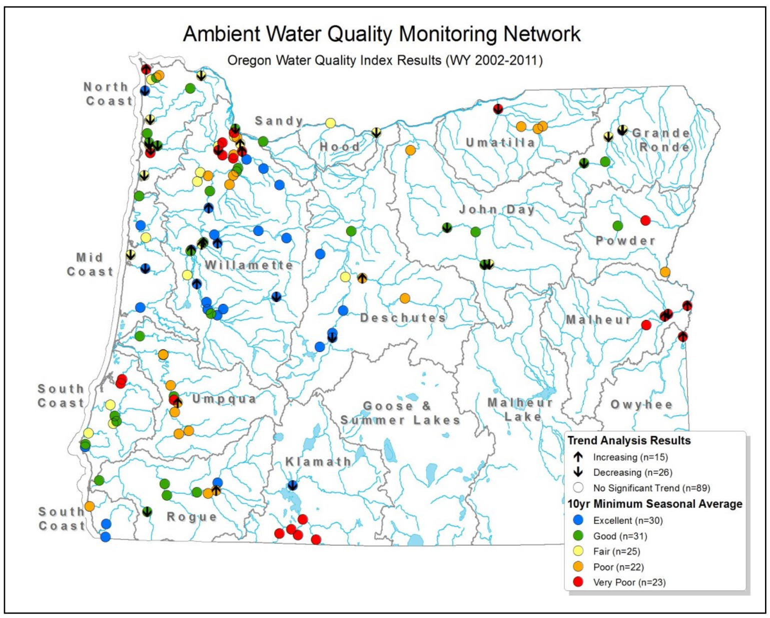


Figure 1. Example of spatial display of Oregon's WQI and trends results. Merrick, L. and S. Hubler, 2013. Oregon Water Quality Index Summary Report, Water Years 2002-2011 and 2003-2012.

Strengths	Limitations
Summarizes large amounts of data for a variety of audiences	May not align with state's 305 (b)/303(d) Integrated Report assessments
Can be designed to complement the 305(b)/303 (d) Integrated Report	Generally not used for specific regulatory purposes, though it may inform regulatory decisions
May include information for parameters for which there are no regulatory standards	Many do not include toxics, habitat, fish tissue or biological indices
Enables spatial display of ratings	Single parameters of importance may lose significance in composite index
Enables trends analyses of WQI scores	
Generally understood by public, however, calculation of index may be confusing	

Figure 2: Summarizes the strengths and limitations of Water Quality Indices

What you need to know

A WQI is commonly used to communicate overall water quality conditions to the public, stakeholders, local officials, and water resource managers, and also to track progress of management practices and strategic goals. Most WQI's are not used for regulatory purposes in part because many parameters often included have no water quality standards. However, a WQI may be used to provide background information to a contemplated regulatory action.

How are water quality indices calculated, and what, if any, criteria/ standards or thresholds are utilized in the index determination?

There are several approaches that have been applied to developing a WQI. Methods for aggregating subindices/parameters into an overall cumulative index calculation include weighted means, unweighted harmonic square means, and averaging ranked subindices into an overall score. The National Sanitation Foundation WQI uses a weighted mean, whereas the Oregon WQI uses an unweighted harmonic square mean formula which gives the most impaired variable more influence in the final WQI score. The Canadian Water Quality Index uses the measures of three factors (scope, frequency and amplitude) and their deviations from standard criteria. When standards exist they are generally applied; however, when no standards exist, published findings or thresholds derived from non-regulatory guidelines or percentiles of historical data are commonly used to set breakpoints among rating categories (e.g. good, fair, poor). The South Carolina Estuarine and Coastal Assessment Program uses water quality standards, published literature, and thresholds derived from percentiles of historical data (Bergquist et al., 2009). Many WQI's are developed by agency scientists or academics with input from a panel of experts, and peer reviewed internally or published in a peer reviewed journal.

Biological indices can be incorporated into the composite WQI, as many states have regionally developed multi-metric indices for fish, benthic macroinvertebrates or periphyton. The South Carolina Estuarine and Coastal Assessment Program uses their benthic index combined with their sediment quality index, and water quality index to provide a composite overall habitat quality index.

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Integrating Water Monitoring Data:

Water Quality Report Cards

About

The Water Quality Report Card concept described here was originally developed by Warren Kimball, formerly of the Massachusetts Department of Environmental Protection, and is becoming a popular model used by water resource agencies. The WQRC uses ten indicators pertaining to aquatic life, recreation, and fish edibility that are color coded to provide an assessment of a waterbody based on the standardized 305(b)/303(d) reporting procedures. The ten indicators used by Kimball are biology, chemistry, nutrients, toxics, sediments, flow, habitat, bacteria, aesthetics, and fish tissue.

What are the primary uses of the WQRC and who are the primary audiences?

The WQRC is used to communicate overall water quality conditions to the public, stakeholders, local officials and water resource managers. The WQRC condenses multiple assessment endpoints into a one page summary of a water resource. It can be used to express Clean Water Act assessment outcomes, evaluate the effectiveness of management practices, guide decision makers, identify monitoring needs and coordinate monitoring programs. Many WQRC are used by citizen scientist and watershed organizations to describe the conditions of their watershed.

Millers River — WATER QUALITY REPORT CARD — *2000 Assessment*

COLOR KEY: GOOD, CONCERN, FAIR, POOR, N/A

	AQUATIC LIFE							RECREATION		FISH EDIBILITY
SEGMENT	BIOLOGY	CHEMISTRY	NUTRIENTS	TOXICS	SEDIMENTS	FLOW	HABITAT	BACTERIA	AESTHETICS	FISH TISSUE
MILLERS RIVER										
to Whitney pond	F					Q				Hg
to Winchendon WWTF		pH		U		Q		B	C	Hg,PCB
to Otter River		pH	P	U		Q				Hg, PCB
to South Royalston			P		PCB					Hg,PCB
to Orange Center	A,F	pH	P		PCB	Q				Hg, PCB
to Erving WWTF	A,F	pH	P		PCB	Q				Hg, PCB
to Connecticut River		pH	P	U	PCB	Q			C	Hg, PCB
OTTER RIVER										
to Gardner WWTF	I,F	DO,pH,T	P						C	Hg, PCB
to Seaman Paper Co.	I,F	DO,pH, T	P	U	Me	Q	S		C,D	Hg, PCB
to Millers River	I,F	pH	P		PCB	Q			O,C,D	Hg, PCB
TULLY RIVER										
East Branch	F	pH					S		G	Hg, PCB
Boyce Brook		pH								Hg, PCB
West Branch										Hg, PCB
Lawrence Brook		pH								Hg,PCB
Main Stem	F									Hg, PCB

Figure 3. Example of Massachusetts Department of Environmental Protection's Water Quality Report Card for a watershed illustrating use of colors to assess water quality for each indicator and letters to indicate specific parameters. Source: Warren Kimball. (PowerPoint from webinar available at http://acwi.gov/monitoring/webinars/index.html, "10/10/2012: "SMART" Monitoring: Strategic Monitoring and Assessment for River Basin Teams")

Strengths	Limitations
Summarizes large amounts of water quality data	No overall rating category (e.g. good, fair, poor) of waterbody or segment
Can be designed to complement the 305(b)/303(d) Integrated Report	Lack of spatial display of rating
Can be developed using agency or organization-specific criteria or assessment methods (e.g. watershed association report cards)	Limited trends analyses
Identifies monitoring gaps (gray areas in Figure 3)	
May include nutrients, toxics, habitat, fish tissue and biological assessments	
May identify reasons for impairment (e.g. Hg, PCB for fish tissue in Figure 3)	
Generally understood by public	

How are the indicators for each column assessed, and what, if any, criteria/standards or thresholds are utilized in the determination?

The indicators may be assessed using the 305(b)/303(d) reporting rules and methodologies as described by the state or agency. For example, the "Biology" indicator may use the state's or locally valid benthic index of biotic integrity score to rate (good, fair, poor, etc.) each stream segment in the report card. For parameters which may not have numerical criteria, best professional judgement or percentile ranges based on historical data can be used to assign a category (good, fair, poor, etc.) to an indicator.

Integrating Water Monitoring Data:

Multi-Metric Web Portals

About

There are additional ways to bring information from multiple perspectives together to tell a story about water quality. For example, the California Water Quality Monitoring Council has formed a number of theme-specific workgroups, each charged with developing a web portal devoted to a particular theme, based on uses of water that are to be protected. Each portal addresses a key management question with data and assessment information from relevant state, federal, and local agency monitoring efforts. All are accessible through a single My Water Quality website, www.MyWaterQuality.ca.gov

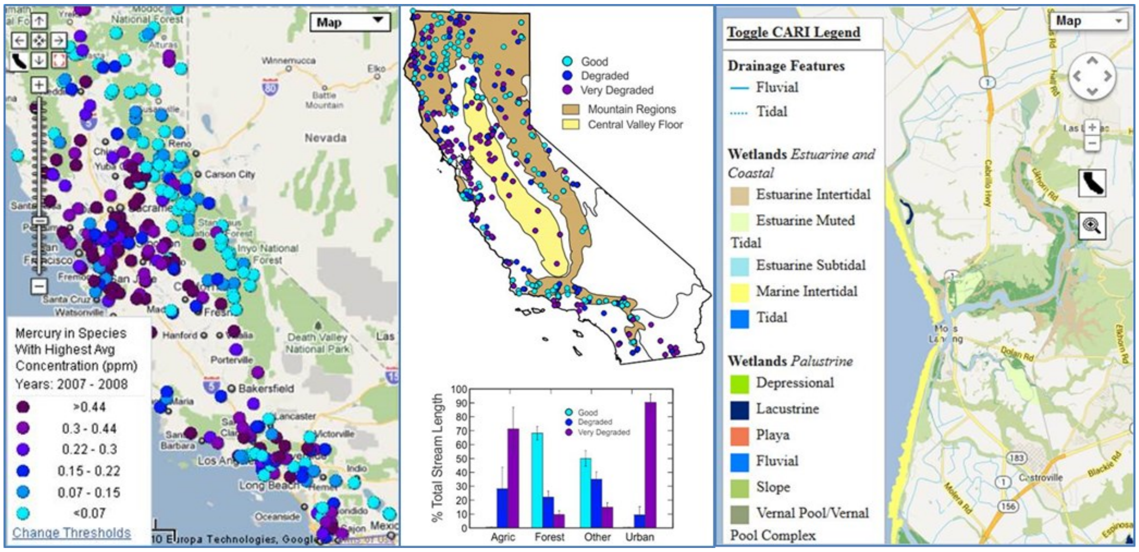

Figure 4. Examples of the various information, spatial display and data available from California Water Quality Monitoring Council web portal.

Another multi-metric web portal is the Vermont Integrated Watershed Information System (IWIS), a new online data portal that allows flexible and comprehensive access to many types of water quality information on lakes and streams in Vermont. These include chemical, physical and biological data available in several formats from site summaries to detailed individual measurements. The system allows multiple avenues from which to access data including a mapping interface on the Vermont Agency of Natural Resources Atlas as well as a form-based query tool. All retrieved data can then be downloaded in any number of formats such as Excel or PDF.

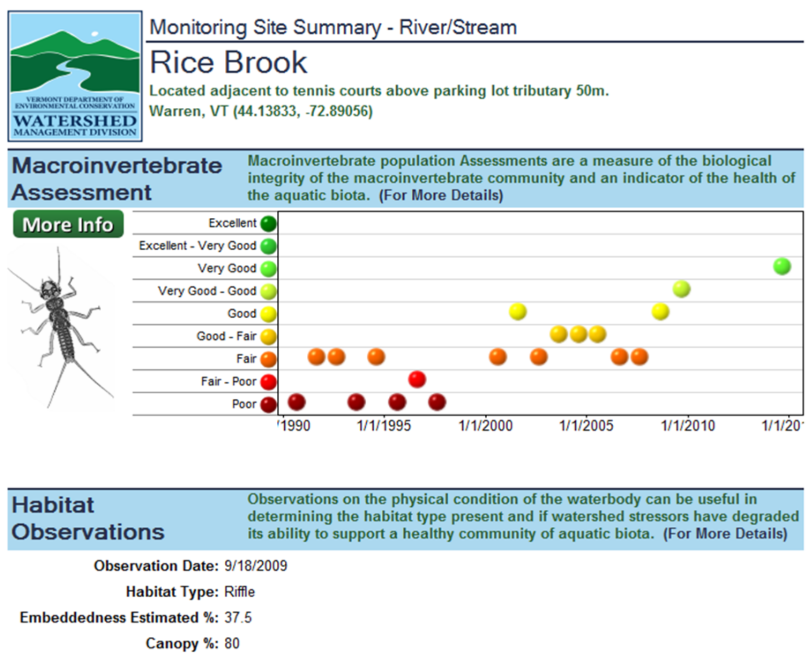

Figure 5. Example of a monitoring site summary available from the Vermont Integrated Watershed Information System (IWIS).

What are the primary audiences for multi-metric web portals?

Portals can be designed to address multiple audiences, including agency decision-makers, legislators, permit writers, researchers, and the public. Higher level pages normally target less-sophisticated users, but allow others to drill down to more detailed information or to download relevant data.

Strengths	Limitations
Deliver information to decision-makers, public and researchers that directly addresses their questions	Information is not always readily accessible in an electronic format that can be easily published on the web
Data and assessment information can be drawn from multiple agency monitoring programs, allowing broader assessments to be made through information sharing	Multi-metric indices that present overall water quality picture may not be included
Building a portal can bring together subject matter experts from various programs or state, federal, and local agencies, developing long-term relationships that can improve monitoring efficiency	For multiple program/organization portals, various perspectives presented need to be carefully explained to avoid confusing audiences
Underscore important work of various programs and organizations involved, increasing transparency and building credibility	Require agreement by the organizations involved as to how the data and information are presented; an overall management structure, such as a state monitoring council, can help address consensus

Examples of Water Quality Indices, Report Cards and Multi-Metric Web Portals

Organization	Water Resource	Media	Website
Water Quality Indices			
Canadian Council of Ministers for the Environment	Rivers and streams	Water column	http://ceqg-rcqe.ccme.ca/download/en/137
Iowa Department of Natural Resources	Rivers and streams	Water column	http://www.iowadnr.gov/Environment/WaterQuality/WaterMonitoring/WQI.aspx
Kentucky Department of Environmental Protection	Rivers and streams	Water column, sediment	http://water.ky.gov/waterquality/Pages/TMDLHealthReports.aspx
McMaster University	Great Lakes coastal marshes	Water column	http://greatlakeswetlands.ca/wp-content/uploads/2011/07/Chow-Fraser-2006.pdf
Oregon Department of Environmental Quality	Rivers (4th and 5th order)	Water column	http://www.deq.state.or.us/lab/wqm/wqimain.htm
South Carolina Estuarine and Coastal Assessment Program (SCECAP)	Coastal tidal rivers and bays	Water column, sediment, biology	http://www.dnr.sc.gov/marine/scecap/
United States Environmental Protection Agency (National Coastal Condition Assessment)	Estuaries	Water column, sediment, biology, habitat	http://water.epa.gov/type/oceb/assessmonitor/ncca.cfm
University of Maryland Center for Environmental Sciences-Integration and Application Network	Estuaries, coastal bays	Water column, biology	http://ian.umces.edu/
Vermont Department of Environmental Conservation	Lakes	Water column, biology, habitat	http://www.watershedmanagement.vt.gov/lakes/htm/lp_lakescorecard.htm
Water Quality Report Cards			
State of California, San Diego Regional Water Quality Control Board	Rivers and streams	Water column, sediment, biology, habitat	http://www.waterboards.ca.gov/sandiego/water_issues/programs/swamp/index.shtml
Massachusetts Department of Environmental Protection	Rivers and streams	Water column, sediment, biology, habitat	http://acwi.gov/monitoring/webinars/index.html
Multi-Metric Web Portals			
State of California, Central Coast Regional Water Quality Control Board	Rivers and streams	Water column, sediment, biology, habitat	http://www.mywaterquality.ca.gov/monitoring_council/healthy_streams/docs/healthywatersheds_krw.pdf
State of California, Water Quality Monitoring Council	Rivers, streams, lakes, estuaries, wetlands, coastal ocean	Water column, sediment, biology, fish tissue	http://www.mywaterquality.ca.gov
Vermont Integrated Watershed Information System (IWIS)	Rivers, streams, lakes	Water column and biology	https://anrweb.vt.gov/DEC/IWIS/

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