Webcast Sponsored by EPA's Watershed Academy

Monitoring Watershed Program Effectiveness

April 10, 2008 Webcast at 2-4pm EST

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Assumptions

- Project has correctly identified water quality problems and critical areas
- Project has developed a good plan to solve the water quality problems
- The 9 Key Elements* provide the basis for the plan
- Audience is familiar with monitoring variables, basic sampling equipment, and sample analysis methods

* See EPA's 319 guidance for list of "9 Key Elements" of a watershed plan at: www.epa.gov/fedrgstr/EPA-WATER/2003/October/Day-23/w26755.htm

Today's Discussion

- Emphasis is on watershed project effectiveness
  - Not assessment
  - Not individual BMP effectiveness
  - Not program delivery effectiveness
- We will be presenting OPTIONS for your consideration
  - Not intended to be prescriptive
  - Project needs vary
  - Other options exist
- We will not discuss volunteer monitoring
  - Can have an important role in projects
  - Role varies from project to project

Basic Monitoring Concepts

Purposes and Design

Design Steps (USDA, 1996)

1. Identify problem
2. Form objectives
3. Monitoring design
4. Select scale (watershed)
5. Select variables
6. Choose sample type
7. Locate stations
8. Determine frequency
9. Design stations
10. Define collection/analysis methods
11. Define land use monitoring
12. Design data management

1. Identify Problem

- Use impairment (e.g., fishery damaged)
- Waterbody (e.g., stream)
- Symptoms (e.g., depressed population)
- Causes (e.g., sediment)
- Sources (e.g., streambank erosion)

2. Form Objectives

Complementary Management & Monitoring Objectives

- Management: Reduce annual P loading to lake by at least 15% in 5 years with nutrient management

- Monitoring: Measure changes in annual P loading to lake and link to management actions

3. Monitoring Design

- Depends on study objective
- Select before project begins

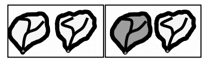
Designs NOT Recommended

- Single Watershed Before/After
  - Vulnerable to climate variability
  - Difficult to attribute causes → BMPs or climate?
- Side-by-Side Watersheds
  - Cannot attribute causes → BMPs or watershed differences?

Recommended Designs

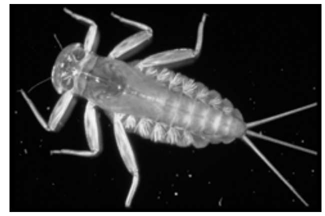
Design	Advantages	Disadvantages	Cost
Paired	•Controls for hydrological variation •Can attribute water quality ∆s to BMPs	•Difficult to find pairs •Difficult to control land use/treatment in control •Takes 5+ years	Highest
Up/Down	•Fairly EZ 2 Do •Isolate critical areas •Can attribute water quality ∆s to BMPs if do pre/post	•Takes 5+ years if pre/post •Upstream impacts can overwhelm •Climate variability somewhat problematic if not pre/post	Higher
Trend	•EZ 2 Do •May account for lag time	•Long term •Data gaps problematic •Must avoid major LU ∆s •Methods cannot ∆ •Must track precipitation, land use/treatment, flow over long term to relate water quality ∆s to BMPs	Lower

Recommended Designs

- Paired-Watershed 
  - 2 watersheds and 2 treatment periods
  - Calibrate before implementing BMPs
  - Compare regression relationships between 2 watersheds from pre- and post-treatment periods
- Upstream-Downstream 
  - Paired t-test (above and below),
  - Non-parametric t-tests
- Trend 
  - Time plot, Regression, Nonparametric Seasonal Kendall test
  - Adjust trend data set for hydrologic influences

Step 7: Watershed project effectiveness monitoring designs determine basic station locations.

5. Select Variables



- Study objectives
- Waterbody use/problem
- Pollutant sources
- Difficulty and cost of analysis
- Sample covariates for full story
  - Flow for suspended sediment concentration and particulate P
  - Eutrophication
    - Algae + D.O. + temperature + nutrients + chlorophyll a
  - Fish
    - D.O., temperature, substrate, shade

Which Form of N?

Variable	Details	Possible Application
Total N	All forms of N, organic and inorganic. All forms converted to nitrate and measured.	Areas impacted by organic and inorganic N with varying travel times to waterbody.
TKN	Organic N plus ammonia N. Does not include nitrite and nitrate.	Manure-impacted areas with rapid delivery to waterbody.
Organic N	TKN minus ammonia N.	Research?
NO_3	Inorganic nitrate.	Ground water studies, drinking water issues, riparian zone
NO_2+NO_3	Inorganic nitrite plus nitrate.	

Which Form of P?

Variable	Details	Possible Application
Total P	All P forms converted to dissolved ortho-PO_4 and measured.	Situations where ortho-PO_4 isn't major P form.
Ortho-PO_4	Most stable PO_4. Filterable and particulate.	Most situations.
SRP	Orthophosphate; filterable (soluble, inorganic) fraction.	Most situations.
Acid-hydrolyzable P	Condensed PO_4 forms. Filterable & particulate.	Research?
Organic P	Phosphate fractions converted to orthophosphate by oxidation.	Manure-impacted areas with rapid delivery to waterbody.

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Most P in natural waters is a form of phosphate (orthophosphate, polyphosphate, pyrophosphate, etc.)

SRP = Soluble Reactive P. Directly taken up by plants; respond to colorimetric tests without preliminary hydrolysis or oxidative digestion.

Acid-hydrolyzable P - Falls between ortho-PO_4 & organic P.

Which Form of N and P?

- Total N and Total P for automated samplers
  - Preservation/holding time (H_2SO_4,<4 ^oC/28 days)
  - Keep it simple

TSS or SSC?

- SSC better for loads
  - TSS may underestimate suspended sediment by 25-34%
  - Problem is sub-sampling not laboratory analysis
  - USGS policy
- TSS-SSC correlation improbable
- TSS good for other purposes
  - Use appropriately
  - Document clearly

Gray, J.R., et al. 2000.
http://water.usgs.gov/osw/pubs/WRIR00-4191.pdf

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USGS policy (Office of Water Quality Technical Memorandum No. 2001.03, 11/27/2000):

1. The use of Total Suspended Solids data (TSS, parameter code 00530) resulting from the analysis of water samples to determine the concentration of suspended material in water samples collected from open channel flow and calculations of fluxes based on these data is not appropriate. Collection of samples to determine TSS requires concurrent collection of samples for suspended sediment concentration (SSC) analysis. Concurrent SSC analysis can only be discontinued after it is conclusively documented in a published report that the TSS data, on a site-by-site basis, can adequately represent SSC data over the whole range of flows that can be expected.

It is recommended that SSC be used for load estimation instead of TSS unless it can be shown that the sand portion of suspended sediment is less than 25 percent of the mass and will remain less than 25 percent of the mass throughout the study. It would make sense to collect samples for both SSC and TSS during the assessment and planning stages of a project to test this relationship and develop a better understanding of sediment issues in the watershed. The wet-sieving filtration method (Method C) for SSC is recommended to provide sand-size and silt/clay-size particle concentrations at the beginning of a project.

TSS can be used for all purposes other than sediment load estimation, but it is important to be clear about what is and isn’t measured using the TSS method. Agitation of the whole sample should be performed rigorously and consistently over the course of a study to maximize the potential for capturing an aliquot representative of the whole sample. Sampling in triplicate, etc. may prove useful in estimating variability of TSS measurements.

6. Choose Sample Type

- Selection Factors
  - Study objectives
  - Variable sampled
    - Bacteria → grab
    - Suspended sediment → integrated
  - Concentration or mass
    - Grab generally unsatisfactory for load
    - Load estimation

Sample Type	Advantages	Disadvantages
Grab	•Equipment cost savings •Simple	•Not good for load •More labor per sample
Composite – Time Weighted	•Simple to program •Lab and field cost savings (vs. not compositing same number of samples)	•Expensive equipment •Fixed time intervals inappropriate for load estimation •Equipment maintenance/failure
Composite – Flow Weighted	•Good for load estimation •Lab and field cost savings (vs. not compositing same number of samples)	•Expensive equipment •Must know stage-discharge relationship •Equipment maintenance/failure
Integrated Grab Sample (over depth and/or width)	•More representative than simple grab •Equipment cost savings •Simple	•Not good for load •Much more labor per sample
Continuous	•Lab and field cost savings •Can track threshold exceedence	•Possible probe failure/fouling •Too much data

8. Determine Frequency and Duration of Sampling

Appropriate sample frequency/size varies with the objectives of the monitoring project:

- Estimation of the mean
- Detection of change

Mean Estimation

Determine the sampling frequency necessary to obtain an estimate of the mean for a water quality variable with a certain amount of confidence

$$n = \frac{t^2 s^2}{d^2}$$

where:

n = the calculated sample size

t = Student's t at (n-1) degrees of freedom and a specified confidence level

s = estimate of the population standard deviation

d = acceptable difference of the estimate from the true mean (%)

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Mean estimation - example

Based on historical monitoring data from Ramirez Brook, how many samples are needed to be within 10 and 20 percent of the true annual mean TP concentration?

- Mean = 0.89 mg/L
  Std Dev.= 0.77 mg/L
  n = 165
- The difference (d) for 10% and 20% would be:
  d = 0.10 x 0.9 = 0.09 mg/L
  d = 0.20 x 0.9 = 0.18 mg/L
- The t value for >120 d.f. at *p* = 0.05 is 1.96

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Mean estimation - example

73 samples/yr → mean TP concentration ± 20% of the true mean,

281 samples/yr → mean TP concentration ± 10%

Mean estimation

Can work backwards to evaluate proposed frequency – knowing n, solve for d:

- For monthly sampling:

$$12 = \frac{(2.201)^2 (0.77)^2}{(d)^2} \quad d = 0.49 \rightarrow \pm 54\% \text{ of true mean}$$

- For quarterly sampling:

$$4 = \frac{(3.182)^2 (0.77)^2}{(d)^2} \quad d = 1.225 \rightarrow \pm 136\% \text{ of true mean}$$

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Minimum Detectable Change

If the monitoring objective is to detect and document a change in water quality due to implementation, selected sampling frequency should be able to detect the magnitude of the anticipated change within the natural variability of the system being monitored.

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Minimum Detectable Change

$$MDC = t_{(n_{pre} + n_{post} - 2)} \sqrt{\frac{MSE_{pre}}{n_{pre}} + \frac{MSE_{post}}{n_{post}}}$$

Where:

t = the student's t value with (n_{pre}+n_{post}-2) degrees of freedom (in this case selected at *p*=.05),

n = the number of samples taken in the pre- and post- groups, and

MSE = the mean square error in each period
MSE = s^2/n

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Minimum Detectable Change

Example:

Based on historical monitoring data from the Arod River, annual mean TSS concentration is 36.9 mg/L, with a standard deviation of 2.65 mg/L.

Evaluate the minimum detectable change for weekly, monthly, and quarterly sampling 1 year before and 1 year after implementation of erosion control measures

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Minimum Detectable Change

Weekly sampling (n = 52), MSE = 0.135
t for 102 d.f. at $p = 0.05$ is 1.982

MDC = 14%

Monthly sampling (n = 12), MSE = 0.587
t for 22 d.f. at $p = 0.05$ is 2.074

MDC = 65%

Quarterly sampling (n = 4), MSE = 1.325
t for 6 d.f. at $p = 0.05$ is 2.447

MDC = 199%

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Minimum Detectable Change

- If a reduction of 25% in mean annual TSS concentration is a goal of an implementation project, a weekly sampling schedule could document such a change with statistical confidence, but monthly sampling could not.

- A reduction of 65% or more in TSS concentration would need to occur to be detected by monthly sampling.

- Quarterly sampling for TSS would be ineffective for this project

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Lag Time Issues in Watershed Projects

Some watershed land treatment projects have reported little or no improvement in water quality after extensive implementation of best management practices (BMPs) in the watershed

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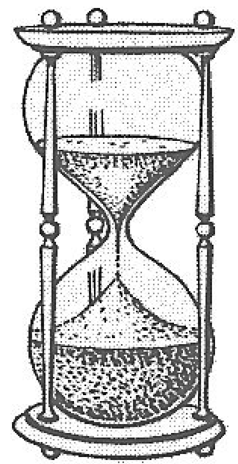
Lag time

Lag time is the time elapsed between installation or adoption of land treatment and measurable improvement of water quality.

Lag time varies by pollutant, problem being addressed, and waterbody type



If lag time > monitoring period…..

May not show definitive water quality results

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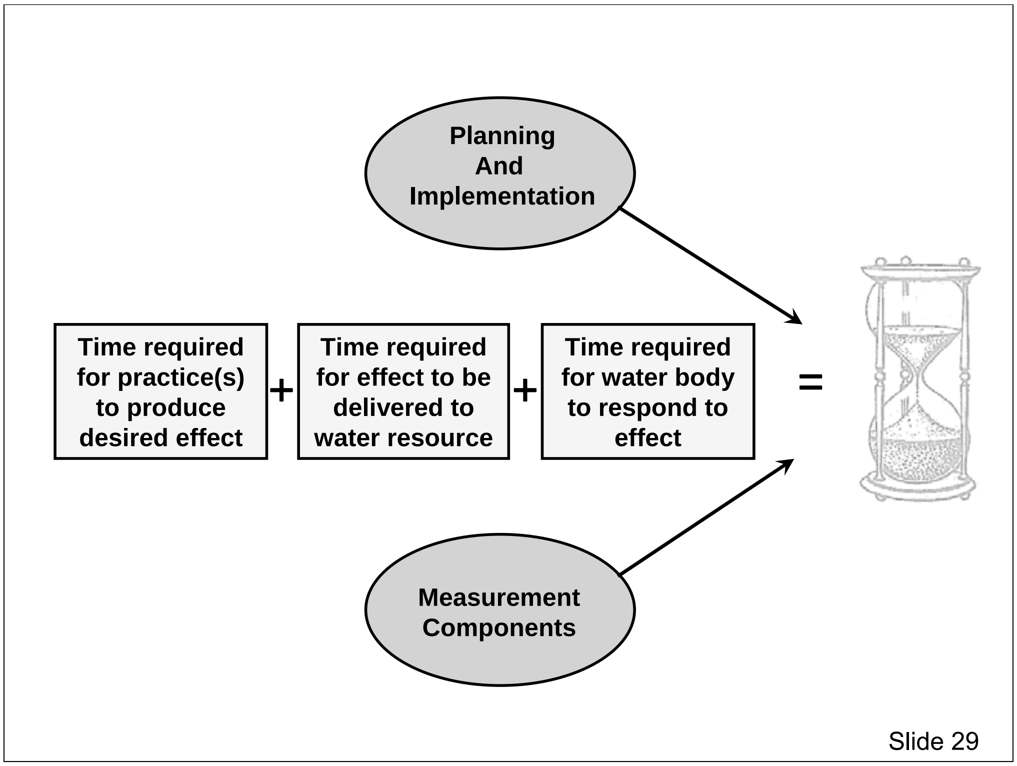
Planning
And
Implementation
Time required for practice(s) to produce desired effect
+
Time required for effect to be delivered to water resource
+
Time required for water body to respond to effect
=
Measurement Components
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Time Required for Practice to Produce Effect

BMP Development

Source Behavior

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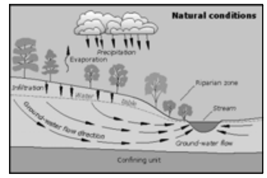
Time Required for Effect to be Delivered

Delivery Path



Nature of Pollutant

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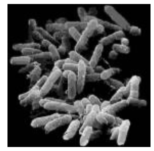
Time Required for Waterbody to Respond

Nature of Impairment




Receiving water response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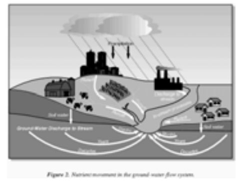
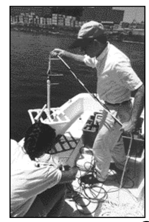
Dealing with lag time



Characterize the watershed

Consider lag time in selection of BMPs



Monitor small watersheds close to sources

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Dealing with lag time

Use social indicators as intermediate check on progress
→

Are things moving in the right direction?

Water quality can decline during implementation phase of projects, particularly with in-stream BMPs. Consider applying reduced sampling frequency of chemical/physical variables during implementation phase of project, accompanied by more frequent biological monitoring (up to 3x/year to explore seasonal impacts), reverting back to pre-implementation monitoring frequency after implementation is completed and functional. Not recommended for trend design.

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Questions?

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Next Month's Webcast

Help Celebrate Wetlands Month
by joining us for a Webcast on

Wetlands

on May 13, 2008,
2 - 4 pm EST

See www.epa.gov/watershedwebcasts
for more details

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9. Design Stations

- Determined by objectives and design
- Redundancy, Simplicity, Quality
- Stream discharge
  - Weirs → Flumes → Natural Channels
  - Avoid culverts
  - Stage-discharge relationship
- Precipitation monitoring (covariate)
  - Event sampling
  - Document rainfall vs. normal year
  - Recording and non-recording rain gages
  - Location

Measure Chemical Concentrations

- Grab samples
- Passive samplers (e.g., tipping buckets, Coshocton wheels)
- Automated samplers (e.g., ISCO, Sigma)
- Actuated sampling
  - Triggered to sample based on flow, stage, or precipitation

Sample Biota

- Plankton (vary with depth)
- Periphyton
- Macrophytes (large aquatic plants)
- Macroinvertebrates
  - Most common for NPS
- Fish

USGS

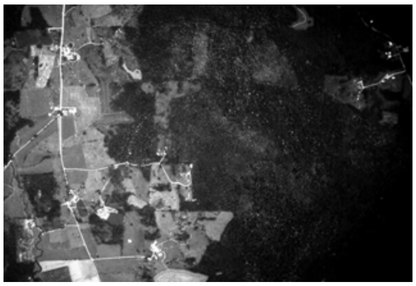
USGS

10. Define Collection/Analysis Methods

- QAPP (Quality Assurance Project Plan)
- Painful but highly beneficial
  - Project objectives
  - Hypotheses, experiments, and tests
  - Guidelines for data collection effort to achieve objectives
  - Covers each monitoring or measurement activity associated with a project
- Get the right data to meet project objectives

Open, Connected, and Social, 2008

11. Define Land Use Monitoring



- Purposes
  - To measure progress of treatment
  - To assess pollutant generation
  - To help explain changes in water quality
- Choose variables relevant to WQ problem and WQ variables
- Sampling frequency depends on monitoring objectives and land management activity
- Look for the unexpected

12. Design Data Management

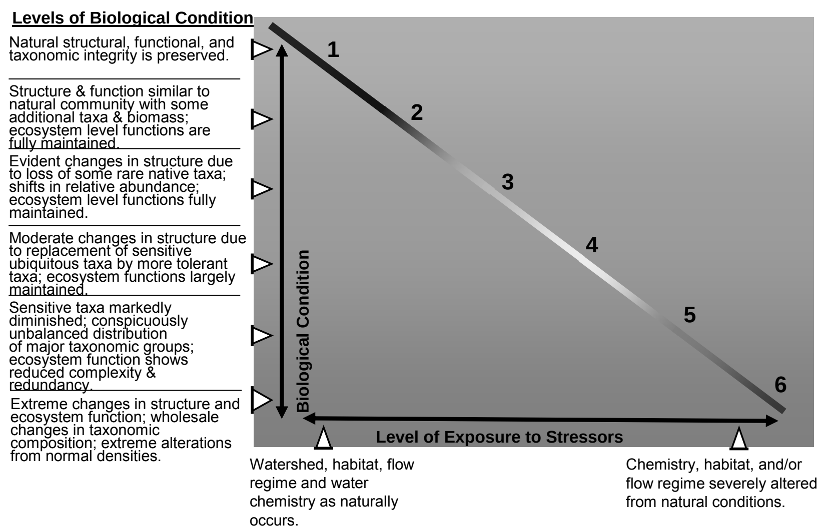
- Data acquisition
  - Develop a plan for obtaining data from different sources
    - Written agreements with cooperators
- Data storage
  - GIS not always needed
  - Select software that works for all on team
  - EPA encourages states and other monitoring groups to put their data into STORET – EPA's national repository for WQ data at: www.epa.gov/storet

Reporting

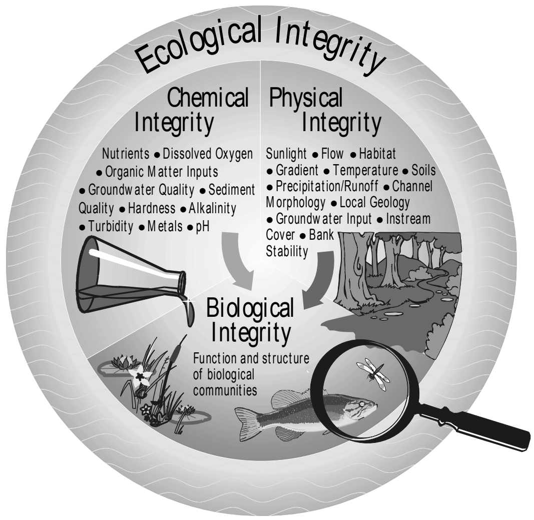
- Examine data frequently to spot problems before they grow
- Report quarterly
- Constantly inform all involved in project

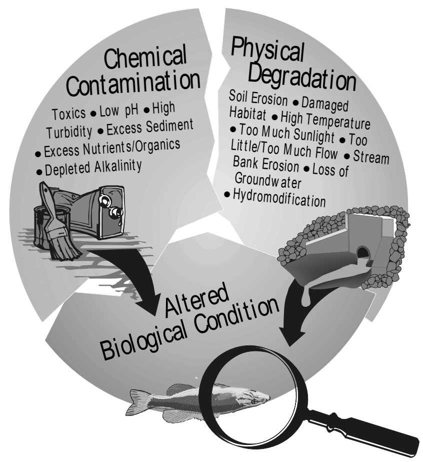
Monitoring Ecological Condition

The Biological Condition Gradient: Biological Response to Increasing Levels of Stress

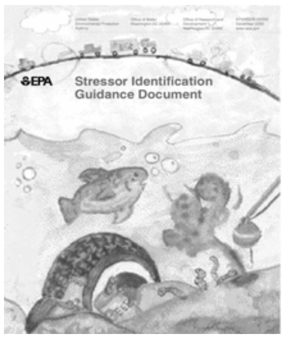


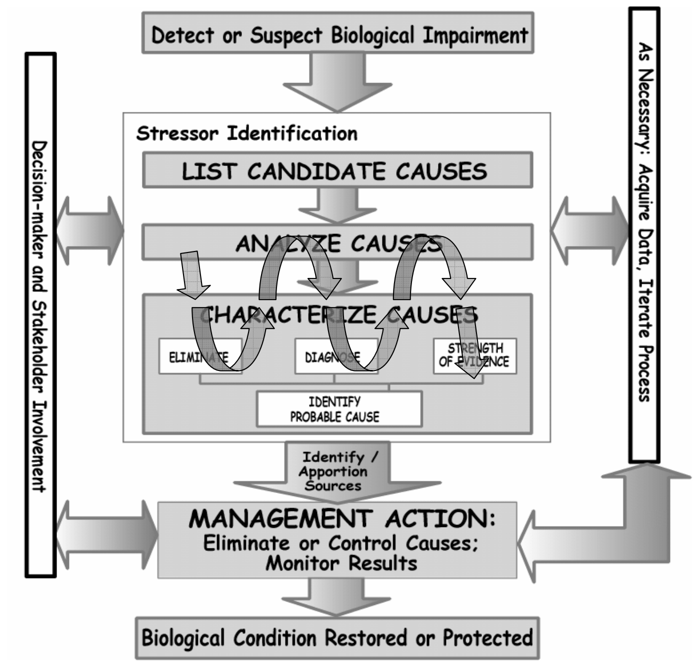
Chemical, Physical, and Biological Integrity





EPA Stressor Identification





Using Biological Monitoring to Measure Project Effectiveness

- Problem assessment with biological monitoring
  - Get the whole picture
  - Assess stressors as well as biological communities
    - Water chemistry (is Total N high? Total P?)
    - Land use (is soil erosion impacting bio communities?)
  - Set up potential for tracking small changes (e.g., move up biological condition gradient), not just step changes (e.g., nonsupport to support of uses)
- Effectiveness monitoring
  - Monitor the biological communities
  - Monitor the stressors
    - At appropriate frequencies

Questions?

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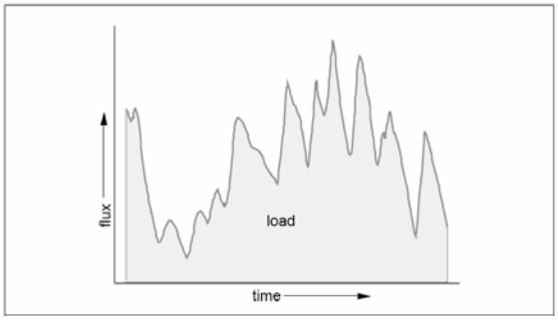
Monitoring and Pollutant Load Estimation



$$\text{Load} = \int_t \text{flux}(t)dt$$

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However, cannot measure flux directly, so calculate load as product of concentration and flow:

$$\text{Load} = k\int_t c(t)q(t)dt$$

Because we must almost always measure concentration in a series of discrete samples, estimation of load becomes sum of a set of products of flow and concentration:

$$\text{Load} = k\sum_{i=1}^{n} c_i q_i Dt$$

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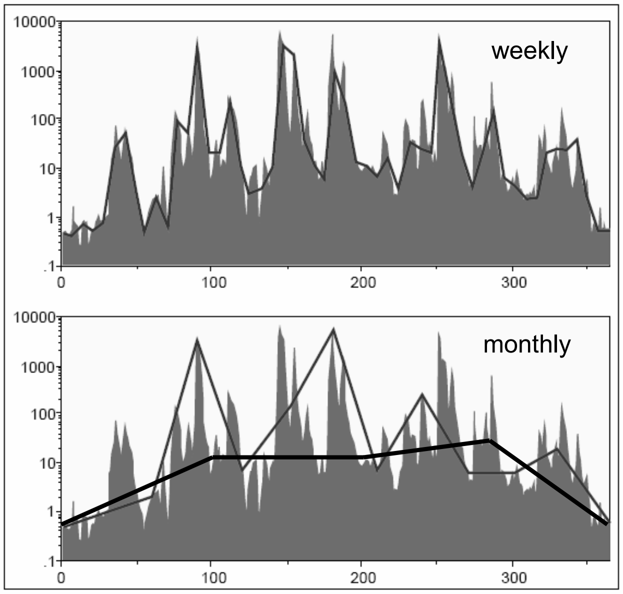

Because in NPS, most flux occurs during periods of high discharge (~80 – 90% of annual load in ~10 – 20% of time), when to sample is especially important.

Quarterly X

Monthly X

Weekly ?

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Practical load estimation

Sample types

Grab vs. Fixed-interval vs. Flow-proportional

Sample frequency

In general, the accuracy and precision of a load estimate increases as sampling frequency increases

Sample timing

Timing of samples more complex than frequency

Consider sources of variability, e.g., season, flow, source activities

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Approaches to load estimation

Choose sampling regime to give best picture of the concentration component

- **Sample type**
  - Fixed-interval → biased toward low flows
  - Stratified → focus on when the action is
  - Flow-proportional → ideal, but hard to do
- **Frequency** – 20 to 100 samples/year, consider MDC
- **Timing** – stratify to most important season, flow condition, source activity

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Approaches to load estimation

- Numeric integration

$$\text{Load} = \sum_{i=1}^{n} c_i q_i t_i$$

- Regression – use Q – concentration relationship to estimate concentration when not measured directly

- Ratio estimator – adjust estimated daily load by ratio of observed Q to mean Q

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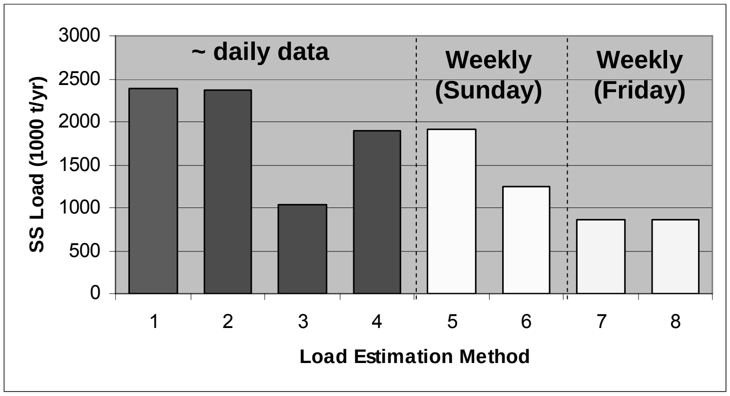
Approaches to load estimation



1 – True load (numeric integration
2 – Beale
3 – Regression
4 – Seasonal regression

5 – Beale
6 – Regression
7 – Beale
8 – Regression

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Practical load estimation

- Is load estimation necessary or can project goals be met using concentration data?
- Determine precision needed in load estimates – don't try to document a 25% load reduction from a BMP program with a monitoring program that may give load estimates $\pm$50% of the true load.
- Decide what approach will be used to calculate the loads, based on known or expected attributes of the data.
- Use the precision goals to calculate the sampling frequency and timing requirements for the monitoring program.
- Compare ongoing load estimates with program goals and adjust the sampling program if necessary.

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Load estimation

- Load estimation is not a trivial task that can be done as an afterthought
- Quarterly or even monthly concentration data are unlikely to be adequate for good load estimates
- Emphasize high-flow events, seasons

- If load data are necessary, design monitoring program with load estimation in mind
- Little can be done after the fact to compensate for a data set that contains too few observations collected using an inappropriate sampling design

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Project Examples

VT NMP Project 1993 - 2001

Evaluate effectiveness of livestock exclusion, streambank protection, and riparian restoration in reducing runoff of nutrients, sediment, and bacteria from agricultural land to surface waters

- Implement practical, low-technology practices to protect streams, streambanks, and riparian zones from livestock grazing;
- Document changes in concentrations and loads of P, N, sediment, and bacteria at watershed outlet in response to treatment; and
- Evaluate response of stream biota

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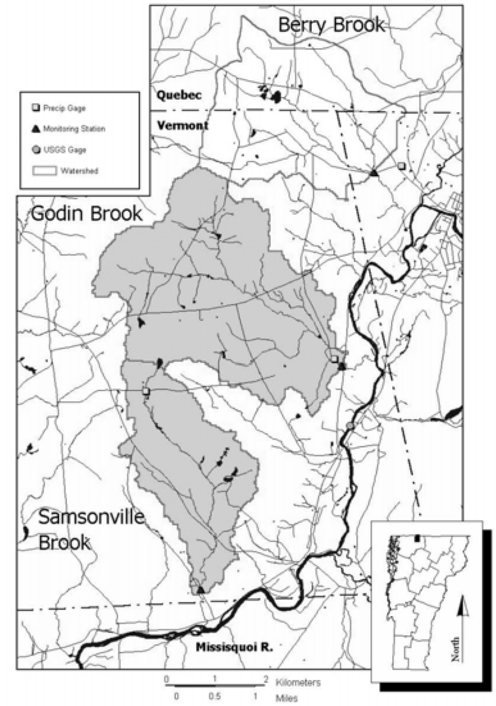
- **Paired watershed design**
- Continuous discharge
- Flow-proportional automated composite sampling (weekly)
  - Total Phosphorus (TP)
  - Total Kjeldahl Nitrogen (TKN)
  - Total Suspended Solids (TSS)
- Bi-weekly grab sampling
  - Indicator bacteria
  - Temp., conductivity, D.O.
- Annual biomonitoring
  - Macroinvertebrates
  - Habitat
  - Fish
- Annual land use/management



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RESULTS

[TP]	-15%	
[TKN]	-12%	
[TSS]	-34%	
E. coli	-29%	
Temperature	-6%	
TP load	-49%	-800 kg/yr
TKN load	-38%	-2200 kg/yr
TSS load	-28%	-115,000 kg/yr

Macroinvertebrate IBI improved to meet biocriteria
No significant change in fish community

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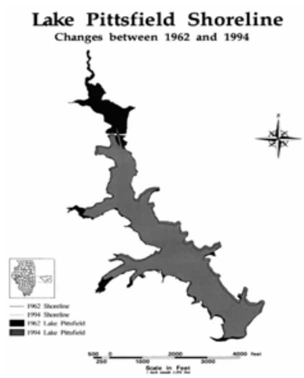
IL Lake Pittsfield NMP Project 1992 - 2004

Reduce sediment loads into water supply reservoir experiencing loss of capacity due to sedimentation

Evaluate effectiveness of sediment retention basins



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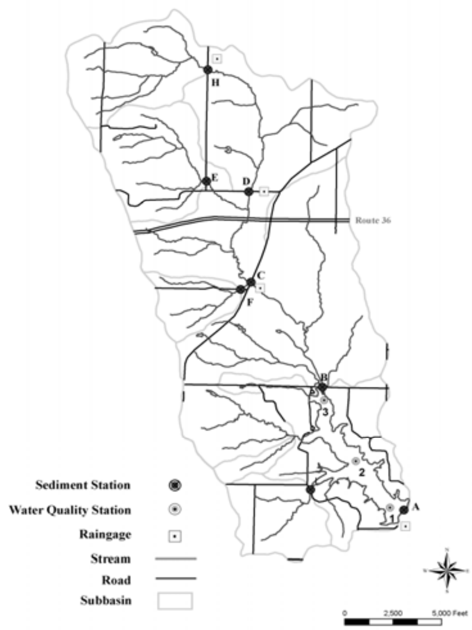

- **Before/after, trend design**
- Automated storm event monitoring at subwatershed stations (flow, TSS)
- Lake water quality and sedimentation at 3 stations
- Streambank erosion by channel cross-section survey
- Interim monitoring results used to target subwatersheds for treatment and to design additional treatments to compensate for reduced sediment concentration

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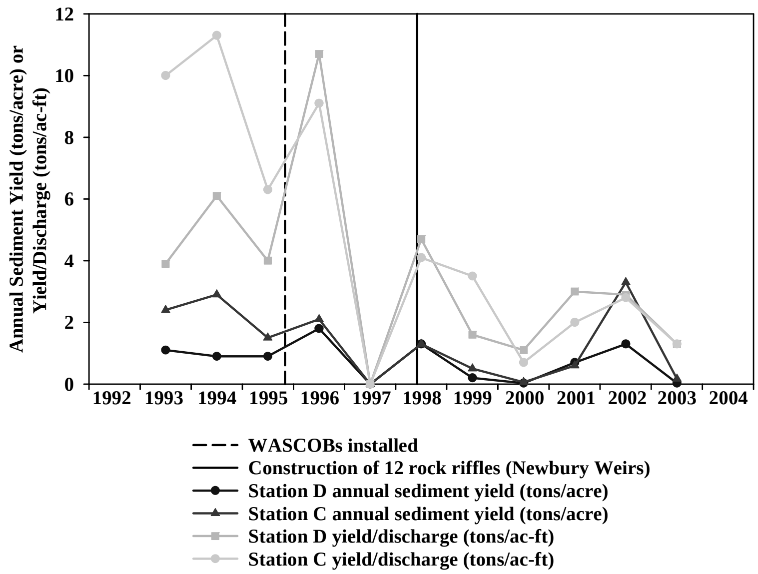
RESULTS

~45% reduction in sediment yields



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OR Upper Grande Ronde NMP Project 1995 - 2003

Improve salmonid community through restoration of habitat and stream temperature regime

Document effectiveness of channel restoration on water temperature and salmonid community

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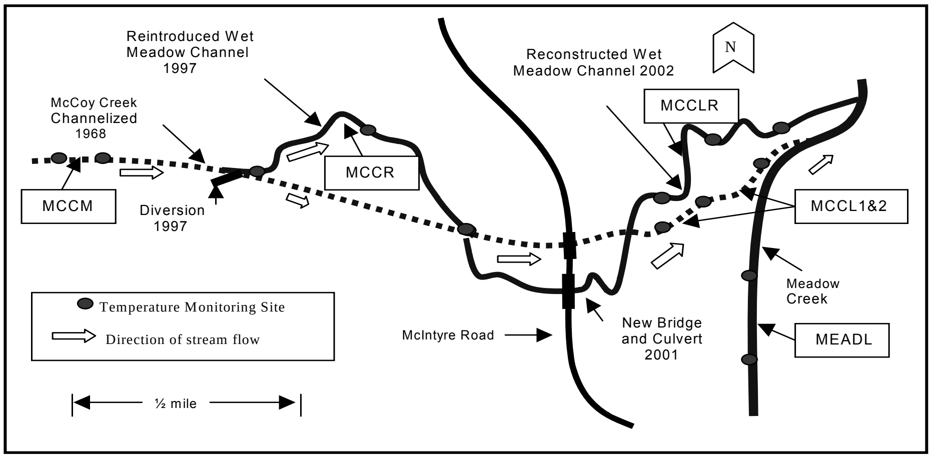

- **Before/after channel restoration, with control**
- Continuous air & water temperature, periodic habitat assessment, snorkel surveys for fish monitoring

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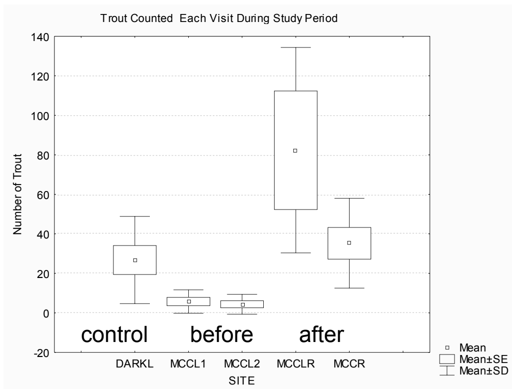
RESULTS



- Cooler water temperatures in pools and deeper runs
- Reduced width-depth ratios compared to unrestored reaches
- Rainbow trout numbers increased in restored reaches, while constant or decreasing in unrestored and control reaches

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Questions?

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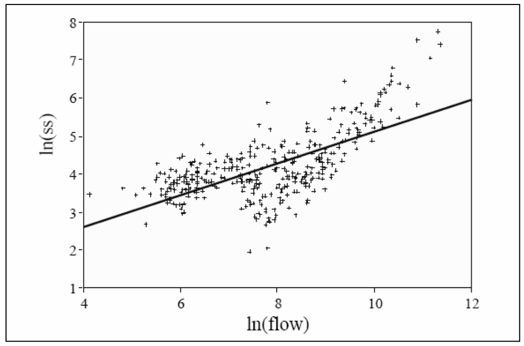
Issues and Problems

Issues and Problems: Weather

In NPS, a large part of the variance in pollutant concentrations is the result of variance in weather, i.e., precipitation, flow

Must measure in order to account for this influence!

Must document relationship between weather variable and pollutant concentration



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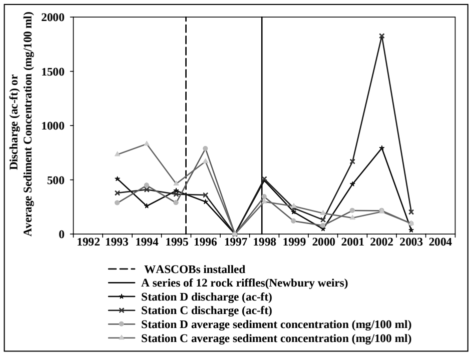
Controlling for Weather

Display



Lake Pittsfield, IL

Normalize

- Divide concentration by flow
- USGS approach:
  - adjust Q by mean or median for period
  - calculate adjusted concentration from adjusted Q in a Q vs. concentration regression model

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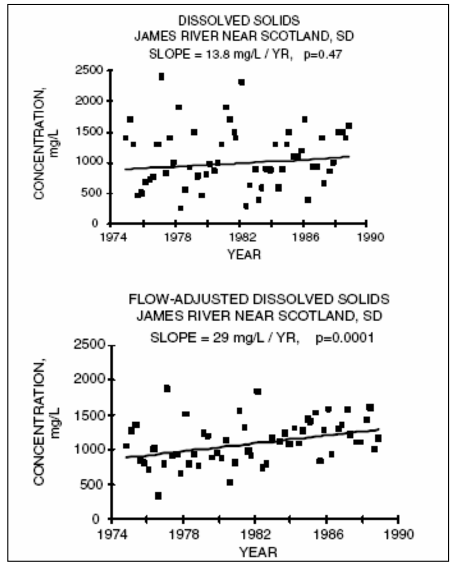
Controlling for Weather

Regression with flow

- Regression of Q vs. concentration
- Conduct analysis on residuals (influence of Q removed)



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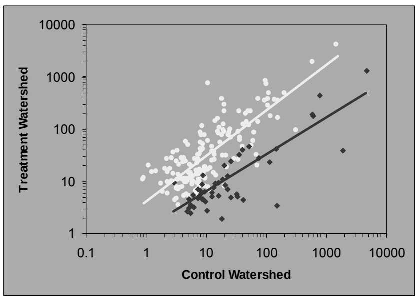
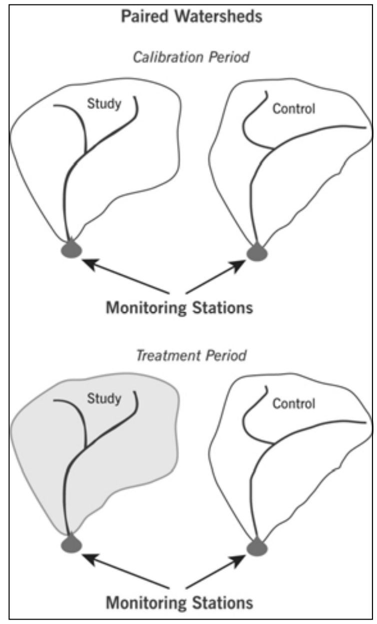
Controlling for Weather

Paired Watershed

Analysis of Covariance (ANCOVA)
Using data from control watershed as covariate controls for effects of year to year weather variation





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Issues and Problems: Land Use Change

In a large or long-term watershed project, change in land use, land cover, or management may influence water quality

Must monitor land use/land cover and land management in order to account for this influence!

Applies to both land treatment influences (i.e., BMPs) **and** other changes. Management of roads and ditches, for example, can have an effect on pollutant generation and delivery.

- Direct observation
- Aerial photography
- Landowners
- Public agencies

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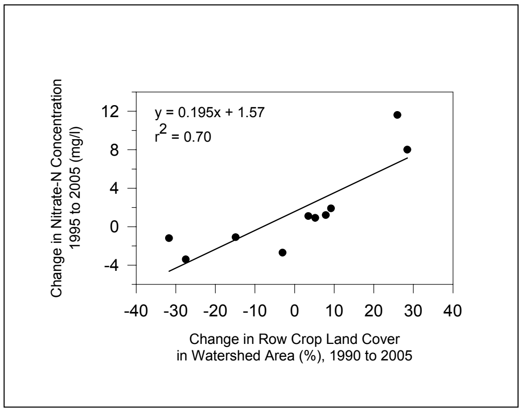
Land Use Change



Walnut Creek, IA

Incorporate land use indicator variables:

- Acres of cons. tillage
- Change in row crop land cover
- Increase in impervious cover
- Change in fertilizer applications

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Issues and Problems: The Unexpected

	Expectation	Reality
White Clay Lake, WI	Address P in runoff	Only 35% of inflow to lake from surface water
Cannonsville Reservoir, NY	Manage barnyards to reduce P loads	Winter manure spreading the main source of P
St. Albans Bay, VT	Manage dairy manure to restore water quality	P in bay sediments driving eutrophication
Oak Creek, AZ	Improve recreation management to control indicator bacteria	Main source of bacteria from elsewhere in watershed
Lake Pittsfield, IL	Intercept cropland erosion to reduce SS load to reservoir	Stream channel instability a major source of SS

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Dealing With the Unexpected

- Importance of good watershed characterization and problem definition;
- Frequent examination and evaluation of monitoring data
- Effective feedback between monitoring and project management
- Adaptive management

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Lake Pittsfield, IL

Monitoring revealed that channel instability was a larger problem than initially thought

Addition of stream restoration to implementation program yielded 90% reduction in sediment load to lake.

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Estimating Monitoring Costs

- Salaries
- Site Selection and Establishment
- Installed Structures
- Fees
- Monitoring Equipment & Supplies
- Travel and Vehicles
- Laboratory Analysis
- Office Equipment and Supplies
- Electricity and Fuel
- Site Service and Repair
- Data Analysis, Reports, and Printing
- Station demolition/site restoration

Approximate Annual Cost Per Site

Basic Monitoring Design	Volunteers Only	Experts Only	Volunteers and Experts
Bugs, Habitat, E. coli, Fish	$200-400	$1,200-$3,000	$500-$1,200
Grab chemical	$300-$450	$2,000-$5,000	$700-$2,000
Automated chemical, discharge, precipitation	n/a	$6,000-$10,000	$3,000-$7,000
Automated sampling costs can reach $20,000 per site/year depending upon equipment needs, sampling variables, and sampling frequency.			

Salary accounts for 30-80% of total costs when volunteers not used, with percentage varying with sampling variables and frequency of site visits.

Simple Rules of Thumb

- Develop your budget for the ***specific*** monitoring plan you will use
  - Details in the QAPP drive costs
  - Budget for completion of monitoring, data analysis, and reporting
- Data that don't support the purpose have no value regardless of the cost
- Purchase the right equipment
- Monitor the right variables
- Use the right methods

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Conclusions

- Follow the 12 design steps to craft a monitoring plan that addresses your needs within your budget
- Focus on objectives and adjust them – within reason – to reflect watershed and budget constraints
  - Do what you CAN do…as long as it's done well
- Use paired-watershed, upstream-downstream, or trend design as appropriate for your situation
- Be smart about selecting a tight set of variables
  - Focused on objectives, problem pollutants, ecology, stressors
  - Considering cost, redundancy, logistics, equipment
  - DO track important covariates and explanatory variables

Questions?

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Check out additional Resources at:

http://www.clu-in.org/conf/tio/owmwpe/resource.cfm

Please give us feedback on the Webcast at:

http://www.clu-in.org/conf/tio/owmwpe/feedback.cfm