Building Teams And Finding Solutions:
Monitoring Program Design and Performance Measures
July 7-10, 1998 (Reno, NV)

INTRODUCTION

The Freshwater Initiative (FWI) is a five-year program of The Nature Conservancy designed to significantly advance the Conservancy's ability to contribute to freshwater conservation. Three strategies drive the FWI:

- **Strategy One** - Develop biological information on freshwater targets needed to design ecoregional portfolios that meet the standards set by the Nature Conservancy (see *Conservation by Design* and *Designing a Geography of Hope).*
- **Strategy Two** - Make significant breakthroughs in threat reduction at selected freshwater sites.
- **Strategy Three** - Exponentially increase the quality and frequency of interactions among staff, partners, and outside scientists and experts by providing new tools and approaches for training, information and data sharing, and collaboration.

Strategy Two of the Freshwater Initiative focuses on developing, testing, and refining various strategies to reduce hydrologic alteration and water quality[1] threats at freshwater sites. More than thirty sites, organized into two networks dealing with each of these threat types, are engaged in this Initiative. Please see Appendix A for a list of these sites. Site-based work pursued through this strategy will be highly collaborative among site teams, supported with increased access to internal and external expertise in threat abatement and freshwater biodiversity. [2] This effort will utilize adaptive management to develop and refine strategies for freshwater biodiversity conservation.

Adaptive management requires measuring the ecological and hydrologic response to strategy implementation, then using this information to adapt strategies, making them more effective in abating threats. Accordingly, adaptive management requires monitoring. On July 7-10, 1998, 29 staff and partners representing 18 of the sites met with Freshwater Initiative support staff in Reno, Nevada for a workshop on monitoring and adaptive management. Please see Appendix B for the list of workshop attendees and facilitators. This workshop focused on how to design a monitoring program that (a) provides adequate information to judge the effect of strategy implementation, and (b) produces scientifically defensible results. This workshop also provided workshop participants with opportunities to learn practices and address common issues

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[1] The emphasis on these two threats derives from a recent survey of freshwater sites where TNC is currently active, which revealed that 80% of these sites are afflicted by one or both of these types of threats.

[2] For more information please see the Strategy Two Document which describes these Threat Networks, or Building Teams And Finding Solutions: Developing Strategies to Abate Water Quality Degradation (April 8 - 10, 1998) or Building Teams and Finding Solutions: Developing Strategies to Abate Water Quality Degradation (May 13 -15, 1998) which summarize emerging strategies for abating key threats.

at a variety of sites.

This document distills the workshop content into a written record for workshop participants and other interested parties. This document describes relevant concepts pertaining to: threat networks, site conservation planning, and monitoring; scientific method and experimental design; applying sound science in our work; and completing the feedback loop (adaptive management). Not included within this summary are the examples of monitoring program design presented at the workshop by staff and partners from La Encrucijada (Mexico), Mackinaw River (IL), Upper San Pedro River (AZ), and Truckee/Provo Rivers (NV/UT); nor descriptions of sessions (attended by workshop participants) at the National Water Quality Monitoring Council's National Monitoring Conference, which took place in Reno at the same time as this workshop. Please see Appendix C for the actual workshop agenda.

FOUNDATIONS FOR SUCCESS

A. Threat Networks, Site Conservation Planning, and Monitoring

The idea behind the threat network approach articulated in Strategy Two of the Freshwater Initiative is to unite sites addressing similar threats in an effort to develop and test strategies to abate those threats. By testing the effectiveness of our strategies, we hope to: document what we have accomplished for internal audiences; produce results that are replicable; provide adequate scientific rigor to convince skeptics and engage partners; and provide guidance for freshwater biodiversity conservation beyond the places engaged in this Initiative.

Developing a monitoring program begins with attaining adequate knowledge of a site. Thus, before embarking on developing a monitoring plan, all site teams should first develop a site conservation plan. Site conservation planning is the process of asking and answering the following questions:

1. What are the conservation targets and long-term conservation goals for the targets?
2. What ecological attributes define the functional ecological system?
3. What economic activities and land uses, laws and policies, cultural attitudes, and constituencies are relevant to conservation at the site?
4. What disorders affect or threaten the ecological system and what human activities or policies cause or promote (or likely might cause or promote) these disorders?
5. Which individuals, groups, or institutions are likely to affect or be affected by efforts to conserve the ecological system?
6. What can be done to prevent or abate threatening activities, maintain the ecological system, or address stakeholders?
7. Where are the areas on the ground to which specific conservation objectives and strategies apply?
8. What actions are necessary to implement the conservation strategies?
9. Who will do them, when will they be done, how long will they take, and how much will it cost?
10. Can the conservation strategies be implemented and goals met, given the situation for

conservation, program capacity to accomplish actions, and other programmatic commitments?

11. Are the actions having the intended effect, and is progress being made toward meeting the site-based conservation goals?

The process of site conservation planning is as important, if not more important, than the product. This process is not static but iterative, and new information can be added to existing plans and planning as it becomes available. Information may be incomplete to adequately answer all of these questions (e.g., site-based team members may not fully understand the interactions among biotic aspects of the ecological system at the site, or adequately understand the human context pertaining to resource use at the site). However, this information should not stop site-based representatives from developing a plan and moving forward with strategy implementation.

But what do we monitor to enable us to evaluate the effect of our strategies and actions? The last step in our site conservation planning method pertains to measuring progress. As indicated by the diagram below, measuring progress relates to various parts of the plan, including conservation targets, threats, strategies, and even stakeholders:

Site Conservation Planning Diagram

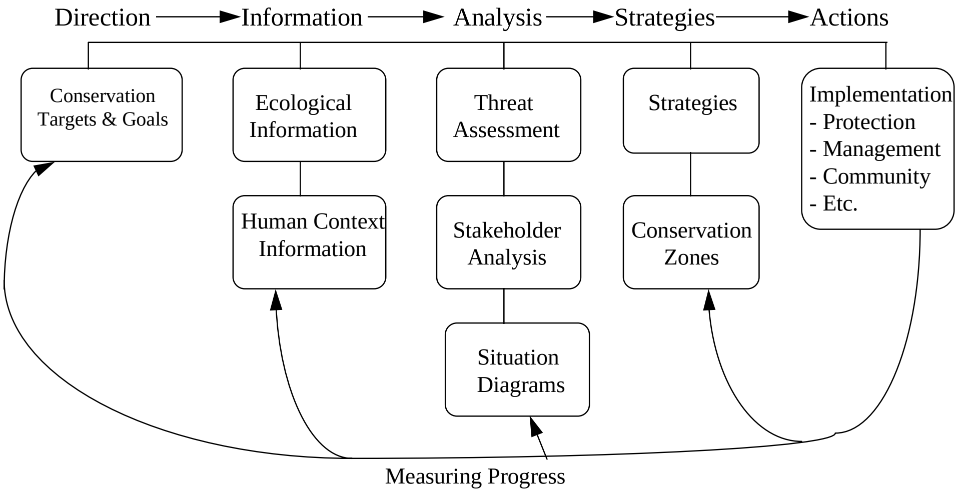

Figure 1

At previous workshops we used “situation diagrams” to help you develop objectives and then strategies to abate threats. We also used these diagrams to develop measures of progress and grouped these measures into three categories: activity (are we implementing the strategies and actions indicated by our site conservation plan), capacity (do we have the staff and partners to implement the articulated strategies and actions), and impact (do we observe a response in the conservation target, threat, or other indicator from strategy and action implementation). This workshop focuses on the most difficult category: impact measures.

What are impact measures? Our ultimate concern is the biodiversity that brought us to a site to begin with. Therefore, the responses of individual targets of biodiversity to the implementation of our strategies and actions would be of obvious interest. However, depending on the target, the response may be very slow or masked by natural variation in the system. Or, the biological target may be very difficult to monitor. And even if we choose to measure the response of a specific conservation target, what method of monitoring do we use, in what locations and at what frequency, and who would do this monitoring? We could also measure the response or reduction in a particular threat targeted by our strategies and actions. But can you determine which of your strategies is most effective in reducing a particular threat? If we implement all of our strategies, yet see no improvement in the system, can we be certain our strategies have failed, or tell if other factors have intervened to thwart or mask their effects? Will the results of the monitoring efforts adequately demonstrate the effectiveness of select strategies to skeptics? The answers to these and other related questions lie within the rubric of applying the scientific method, adequate experimental design, and statistical rigor.

B. Scientific Method and Experimental Design

Most of us learned the scientific method in high school and college science classes. The scientific method is the process of developing a hypothesis based on previous observations, then testing this hypothesis through experimentation to determine its veracity.[3] The long and mature history of science has shown that a reliable experiment requires the comparison of experimental conditions with controlled conditions. When properly designed, the experimental conditions should differ from controlled conditions only by the imposition of a "treatment."

The scientific method cannot prove anything is correct, but can prove something is incorrect. An example may help describe this process better. In the 17th century, people commonly believed that living things arose from lifeless matter. In 1650 Francesco Redi designed and tested a hypothesis to prove this belief incorrect. His hypothesis was that maggots or flies do not come from decayed meat, but from the fertilized eggs laid by the female fly in the meat. His experimental design was to place the same kind and quantity of meat in three jars. The first jar was left uncovered. The second jar was covered with a porous cloth. The third jar was covered with material thick enough to prevent the escape of odor from the jar. Flies laid their eggs on the meat in the open jar and on the porous cloth of the second jar. Eggs were not laid on the thick cloth covering the third jar. The eggs then hatched into larvae (maggots), and flies then developed from the larvae. Although the first jar had larvae then flies in the decaying meat, and the second jar had the same in the porous cloth, the third jar had no larvae or flies in either the decayed meat or the thick cloth covering the jar. Mr. Redi proved that flies and larvae did not arise from the decayed meat.

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[3] Some suggest that articulation of hypotheses may vary depending on whether the objective is to detect change or to understand causality. A hypothesis for detecting change should be stated in terms of an expected response over a certain amount of time (e.g., if your goal is to expand habitat for aquatic communities, your hypothesis may be that you can expand this habitat by 1 stream mile over the next five years between Jamestown Junction and the Rincon Bridge). A hypothesis for understanding causality should be stated in the negative, or as a null hypothesis (e.g., if you believe that restoring a more natural hydrologic regime will lead to a more diverse age class and diversity among a stream's riparian communities, then your null hypothesis might be that the hydrologic regime has no effect in riparian biota). Documenting change or establishing causality also affects monitoring design. See Figure Two for a decision tree to help address this distinction.

Unfortunately, the scientific method often works slowly, particularly when you are testing only one hypothesis at a time. Even if you can prove that one hypothesis for your observations is incorrect, that does not mean that you have proved any particular alternative hypothesis is correct. Instead, you are faced with the task of considering still other possible hypotheses, and trying to prove them incorrect as well. If you go about this process testing only one possible hypothesis at a time, you will be at your job a long time indeed. The scientific method can also require substantial resources, which add up quickly if you go about the business one hypothesis at a time.

We can speed up the process of scientific investigation, however, and also reduce its costs, by applying an approach called “strong inference”.[4] Strong inference first involves thinking about the observations or conditions you are trying to describe or explain, and posing as many plausible, alternative hypotheses as you can for them. This step has the added advantage of forcing you to become less attached to any single hypothesis; this is crucial because the purpose of scientific research is not to make you feel better about your view of the world, but rather to help you convince others – especially the skeptics – that your views have a greater measure of truth. Strong inference then involves thinking of a single experiment or set of experiments that you could carry out at the same time, that will allow you to test as many as possible of your alternative hypotheses at once, hopefully proving some incorrect while leaving others for further investigation. By following this approach, you can wade through a number of hypotheses at once while making the most efficient possible use of your resources, narrowing the field of hypotheses at the lowest possible cost and the greatest possible speed.

In our case, we are carrying out experiments in the adaptive management of freshwater biodiversity. In particular, once you have completed your site conservation plan, you will find that you have posed several hypotheses. Most of these will come in one of three types: (1) hypotheses about the status or condition of biological targets and ecological processes at a site; (2) hypotheses about the effects of particular suspected threats on the biological targets at a site; or (3) hypotheses about the particular conservation benefits expected from your carrying out particular conservation strategies at a site. The first type deals with matters of description while the latter two deal with causality. When you are testing any of these types of hypotheses, you are not simply trying to see if things are or work the way you think they are or do. You are also trying to prove that things are not different from the way you think; that the effects you see in your biological targets are not caused by other factors than the ones you suspect; or that other factors do not cause, contribute to, counteract, or simply mask the conservation effects you expect.

For example, in collecting data on a particular target fish species at your site, you may need to prove that its population is not less than or greater than some particular number. Or, in studying the possible effects of different suspected threats, you may need to prove that the operation of a particular dam is the main culprit (with its attendant effects on the river’s flow, temperature, and chemistry) and not industrial pollutants or polluted agricultural runoff. Or in studying the possible effects of conservation actions, such as planting riparian buffer strips to reduce nitrogen pollution of a stream, you may need to prove not only that the expected effects

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[4] Platt J.R. (1964) Strong Inference. *Science,* **146** (3642), 347-353.

actually occurred, but that they were not caused by anything else, such as a drop in the use of nitrogen fertilizer brought about by an increase in its cost or a reduction in field runoff brought about by a shift in the weather. In each of these examples, and especially in the latter two, following the principles of strong inference will allow you to identify in advance all of the things you would need to measure at your site, in order to sort out your alternative hypotheses. In the second example, for instance, you would want to examine not just flow, temperature, and chemistry but also dam, point-source, and nonpoint-source discharges. In the third example, you would want to examine not just miles of buffer strips and in-stream nitrogen concentrations but also rainfall patterns, runoff rates, and actual nitrogen fertilizer usage.

The scientific method also requires statistical rigor. In order to describe conditions at a site, you must use methods that are both accurate and precise. Similarly, in order to measure the degree of association between suspected threats and their effects at your site, you must measure the suspected threatening conditions and their different possible effects with appropriate levels of accuracy and precision. The biggest challenge to statistical rigor we face, however, is in our investigating the effects of specific conservation actions. The central purpose of Strategy Two of the Freshwater Initiative is to demonstrate the effects and effectiveness of particular conservation strategies, on a sufficiently <u>large scale</u> to make a real biological difference, and with sufficient scientific credibility that we can tell which strategies are <u>transferable</u> to other sites. Making our results transferable to other sites demands an extra level of care in our selection of where, when, and how we monitor conditions at a site, to ensure that the results are “representative” of what we would expect to see at a larger “population” of similar sites. And we can achieve the maximum degree of representativeness and transferability in our results by following an approach known by its acronym, “BACI”, for “Before-After; Control-Impact”.

The BACI approach recognizes first that, in order to demonstrate the effects of any single conservation strategy, you have to monitor conditions not only at the place where you apply that strategy (the “impact” or “treated” place) but also at one or more places where you do not apply the strategy. These latter places, the “controls”, are selected so that they differ from the treated place in as few ways as possible that might affect the experimental results. In freshwater conservation, the places will almost always be adjacent or nearby subwatersheds, or the cumulative tributary subwatersheds upstream versus downstream of a treated portion of the basin. They must be selected so that they resemble each other closely in all factors that affect the flow, temperature, and chemistry of their waters, such as their size, topographic relief, soils and geology, drainage patterns, vegetation and land use, and weather.[5] By monitoring conditions both in one or more treated subwatersheds and in one or more (the more the better!) control subwatersheds, you can more easily show that any changes you observe in conditions in the treated places result from your actions and not from some other factors. After all, if the same changes take place in a subwatershed regardless of whether you implemented some specific strategy there or not, you can hardly claim that it was your strategy that made the difference. Conversely, if some predicted changes take place only in the treated subwatershed(s), you can more forcefully argue that is was your actions and not some other factors that caused the changes to occur.

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[5] For systems which have a large range of natural variability, substantial pre-treatment data may be necessary.

You can increase the representativeness and transferability of your results by introducing randomness in the selection of your places for strategy implementation and by increasing the number of control locations.[6] However, randomly selecting a treatment site for strategy implementation may not be possible at many sites given the opportunistic nature of our work, existing land uses, water management, and ownership patterns. Furthermore, finding appropriate control locations may prove difficult in some places.[7] Fortunately, you can reduce or minimize these difficulties with a good experimental design; they are not barriers to your success.

The BACI approach recognizes second that, in order to demonstrate the effects of a particular conservation strategy, you have to monitor conditions at your treated and control places both before and after you implement your strategy(ies). The "before" monitoring establishes how similar the treatment and control subwatersheds are to each other, and allows you to measure their degree and pattern of similarity. The "after" monitoring allows you to evaluate whether, and in what ways, the treated and control subwatersheds have become more or less similar as a result of your actions. In both cases, conditions should be monitored at the same times, or as close to the same times as possible, to minimize the effects of short-term changes in conditions. The combination of before-after monitoring with the use of both treated and control locations provides a sound foundation for producing scientifically credible, transferable results.

C. Applying Sound Science in Our Work

What is the relationship between site conservation planning, developing a monitoring plan, applying the scientific method, and developing a good experimental design to evaluate the effectiveness of conservation strategies? They integrate into a 8-step approach recommended for developing an effective and scientifically credible monitoring program[8]:

1. Develop your HYPOTHESES:

> ***a. Identify your conservation strategies, their desired effects, and their associated conservation zones.*** These steps assume that you have engaged in a site conservation planning process wherein you have identified conservation targets; developed goals, ecological models, and situation diagrams; articulated objectives, strategies, and actions to reduce threats; defined zones of strategy implementation; and considered feasibility.
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> ***b. Translate strategies and expectations into specific hypotheses.*** Your expectations about the effects of each strategy constitute a hypothesis (or set of hypotheses) about that strategy.

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[6] One statistically rigorous experimental design would (1) randomly select one tributary (or sub-watershed) within a watershed from a number of similar tributaries (e.g., similar land uses, geology, soil type, drainage patterns, aquatic species, etc.) for strategy implementation (or application of a specific "treatment"); (2) use the other tributaries as controls. Other experimental designs are possible.

[7] For example, if you seek to restore a more natural flow regime on a stretch of river that is affected by an upstream dam, and comparable undammed river segments do not exist within your watershed, then you can monitor the effects of modified dam operations only below that one dam and not at any control sites. Without any adequate control sites, the effects that you would like to ascribe to the modified dam operations could arguably be ascribed to climate or other influences other than the changes in dam operations. However, there are scientifically defensible ways to overcome the limitations of such situations.

[8] This is an amalgamation of the approaches presented at the workshop.

These hypotheses have the form, “If strategy X is properly implemented, then we will see effects A, B, and C”. These effects may pertain to specific environmental conditions such as the magnitude of the one-day maximum flood event, or the mean daily concentration of nitrate in the water; or they may pertain to biological conditions such as the mean annual rate of recruitment of juvenile mussels, the density of an environmentally sensitive benthic invertebrate, or the value of the Index of Biotic Integrity (IBI).[9]

c. Formulate alternative hypotheses. As required by the method of strong inference, you also need to pose plausible alternative hypotheses that identify other factors that could produce the same effects that you expect from your strategies, or could contribute to them; and you also need to pose alternative hypotheses to identify factors that might counteract these effects, or make them difficult to detect (i.e., mask them) by adding to the variability in your results.[10]

2. Determine WHAT to monitor:

a. Identify the environmental or biological variables to monitor that will best discriminate among these hypotheses. As you examine all the alternative hypotheses from Step 1b and 1c, you should especially look for conditions or “variables” that, if you were to monitor them, will allow you to discriminate among the alternative hypotheses. That is, you should look for variables that have the potential for proving one or more hypotheses wrong, ruling some out while leaving others for further consideration. The most effective monitoring plan will focus on a small number of sensitive variables that allow you to sort out a large number of hypotheses at once.

b. Consider ancillary variables you may also need to monitor. Some additional environmental or biological variables may influence the ones you have chosen to monitor, but in ways that have nothing to do with your conservation actions. In order to take these effects properly into account, you need to identify these “ancillary” variables and add them to your

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[9] The “Index of Biological Integrity” or “IBI” is a numerical index that summarizes information on the presence or absence and density of a suite of aquatic organisms. The organisms in the suite are selected for their sensitivity or lack of sensitivity to alterations in habitat quality resulting from flow, temperature, sediment, chemical or other alteration. Index “scores” for individual samples are compared with scores obtained at regional reference sites, to provide a rapid indicator of the integrity of the aquatic ecosystem at the sample locations. The IBI is one of many “rapid bioassessment” methods developed in the past two decades to aid in the quantitative assessment of aquatic ecosystem integrity; they are powerful tools, particularly when used in conjunction with more conventional monitoring methods. We strongly encourage you to consult with your local aquatic scientists and governmental conservation agencies to see what bioassessment methods are available (i.e., have been developed and tested) in your area, or consider developing your own if no such methods yet exist. For an overview of bioassessment methods, read Chapter 3, “Biological Monitoring of Aquatic Communities” in ***Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls***, USEPA Office of Water, EPA Publication EPA 841-B-96-004, September 1997.

[10] For example, monitoring sediment loading alone will not allow you to distinguish whether implementation of conservation tillage practices is having the desired effect, or if other factors such as a change in rainfall intensity, a change in crop selection, a change in the rate of new housing construction, or increasing farm bankruptcy and field abandonment are affecting sediment loading in similar or counteracting ways. To distinguish among these possible causes, you need to select your treated and control locations so that these factors do not affect your results, monitor the other factors themselves, or find some other indicator that could discriminate among their effects.

list of things to monitor. The hypotheses developed should direct you in identifying these ancillary variables.[11] Stream flow is the most common ancillary variable to monitor; making sense of water quality data almost always requires flow data, even if you are not also concerned with hypotheses about the flow regime at your site(s).[12]

3. Determine WHERE AND WHEN to monitor:

a. Identify the sampling locations ideally needed to test the hypotheses. As explained in the last section, first consider what degree of statistical rigor you need at your site, both to guide your own adaptive management and to produce defensible, transferable results that will satisfy even a skeptic about their meaning. Consider BACI in your selection of sampling locations. Your selection of sampling locations will of course depend on both your scientific needs and on the opportunities provided by your landscape, its patterns of land ownership, and the physical accessibility of different sampling locations.

b. Identify the ideal times for monitoring at these locations to test the hypotheses. Once you have identified the places where you will carry out monitoring, you must determine (a) when and how often to conduct the monitoring[13], and (b) over what period of time.[14] Your

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[11] For example, fertilizer-derived nitrate concentrations in a stream may be lower during a monitoring period simply because rainfall has been higher and the farm runoff is more diluted by the abundant rainfall, not because you have reduced total nitrate runoff. In order to tell if total nitrate runoff (also called the total nitrate "load") has fallen, you therefore need to monitor stream flow as well as nitrate concentrations in the stream water. Stream flow in this example would be called an "ancillary" variable or "co-variate", because it is not the crucial indicator of your conservation actions' effects, but nevertheless must be monitored to allow the interpretation of some other, more crucial variable(s).

[12] Our discussion here focuses on the variables you should monitor in order to test hypotheses as part of a program of adaptive management. However, you may also want to consider carrying out some "routine" monitoring of variables that, if collected over the long run at a few locations, will provide very general information on your watershed for comparing it with others in your region. These variables are ones that governmental agencies often use for general comparative purposes, and may already be monitored in your watershed. While not tied to the testing of any single hypothesis, these "routine" variables often show up in hypothesis-specific experimental designs, so you may find you need to monitor them anyway: (a) biological community information on fishes, macroinvertebrates, or periphyton, such as one of the rapid bioassessment indicators mentioned earlier; (b) physical habitat indicators including channel morphology, flow, substrate quality, and riparian corridor conditions; and (c) chemical quality indicators including pH, temperature, conductivity, dissolved oxygen, nutrients, and sediment [Yoder, Chris O. 1997. *Important Concepts And Elements of an Adequate State Watershed Monitoring and Assessment Program*. Report prepared for the US EPA Office of Water and the ASIWPCA Standards and Monitoring Task Force.]

[13] Consider the following example: Assume one of your strategies is to reduce the magnitude of the one-day maximum flood level. This of course means you need to detect and measure this maximum flow. However, you can't predict at what exact moment the highest flow will occur each year, in order to be sure to be there to measure it, and you probably are interested in other flow statistics as well. As a result, your best bet is to measure stream flow nearly continuously – once every 24 hours or even once every hour or half-hour – throughout the year; this will give you the flood event data you need and allow you to examine all other flow regime parameters as well. This is the kind of reasoning you will need to carry out, to decide when and how often to collect measurements.

[14] Given the great potential for year-to-year variation in freshwater conditions in any watershed, you should always plan to continue monitoring for several years in order to be able to separate out the inter-annual "noise" from any trends truly resulting from your actions. Some references recommend a minimum of two to three years of "before-treatment" monitoring, and three to five years of "during/after-treatment" monitoring, to ensure that you can separate out the useful information from the year-to-year noise. If you have monitoring data at your site(s) going back several years already, you can carry out some simple statistical analyses to see how variable your system is. Without existing data, even for nearby, similar sites, you will just have to start collecting your data and plan on keeping it up

decisions on all of these questions should follow directly from your hypotheses.

4. Identify the QUALITY OF DATA you need.

a. Keep errors down to an acceptable level. Since errors and simple natural variation in your data are inevitable, the problem facing you is not how to prevent all error, but how to keep it down to an acceptable level. Errors can affect your data by reducing their precision – by making them "noisier" – or by reducing their accuracy by biasing the results. As part of your work at developing your monitoring program, therefore, you will need to determine just how accurate and precise your results must be.[15]

b. Develop quality assurance/quality control procedures. A good monitoring program will have built into it a set of protocols or procedures which, if followed, will do two things. First, the procedures will minimize the chances of making mistakes that will bias or cloud the results you obtain. Second, the procedures will allow you to test whether any errors were made that affected the results. The first are called "quality assurance" procedures; the second are called "quality control" procedures; together, they are commonly identified as QA/QC (Quality Assurance/Quality Control) procedures. Examples of QA procedures include training for field personnel, carrying out routine maintenance and calibration of all equipment, and the use of manuals that explicitly identify each and every step that must be followed every time a particular kind of monitoring task is carried out. Examples of QC procedures include: collecting and analyzing multiple replicate samples; submitting samples of known condition to your analyst(s), including "blanks" consisting of distilled-deionized (DI) water for water quality investigations; submitting "split" samples to different analysts; and having a laboratory analyze samples for the same parameters you have measured with your own equipment. Rigorous water quality monitoring programs, for example, often submit QC samples at a ratio of about one such sample for every ten regular samples.

5. Identify WHO will monitor, MONITORING METHODS, and AVAILABLE RESOURCES.

a. Identify who will monitor. You may not be able, or intend, to carry out much of the monitoring yourself, because of its costs, scope, or other demands. You will then need to develop (if you have not already developed) partnerships with other organizations, with local groups, or with governmental agencies, to put together a team effort to monitor the system. Each partner to this effort will have a specific agenda or purpose that it seeks to pursue, and each will have limitations in its budget, staff, and other resources. Each also will be more or less reliable in carrying out its part of the team effort. You must design a monitoring program that serves your scientific needs, while also taking into account the complexities of getting the work done through a partnership.

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for at least three to five years. Eventually, you'll have enough data to measure your inter-annual variation and figure out how soon you will have enough data to separate out the good information from the noise.

[15] Your decisions about accuracy and precision will pivot on such questions as: how small a change do you think you will want to try to detect; what is the range of variation you will encounter in the conditions you want to monitor; and, for water quality parameters, what is the minimum concentration you will need to be able to detect? For very careful quantitative work, you should consult with Bob Unnasch for advice on determining exactly how precise your measurements need to be to answer particular quantitative questions.

b. Identify the best methods for collecting the needed data. Determining what methods to use is no small task and requires knowledge of the range of approaches available and their related equipment and costs. The easiest way to work through this step is to make a list of all the variables you will need to monitor; for each variable, you then list all of the measurement methods that are at least possible candidates for your program, based on your general knowledge of their costs, logistical requirements, and so forth.[16] Presumably, after completing this process, the "winners" will become clear to you.

c. Evaluate available resources. Although monitoring should be a priority for all sites, funding and capacity can often be obstacles between identifying monitoring needs and implementing a monitoring plan. Partners may bring some resources to the table, but you should also consider seeking funding from additional sources or alternative approaches to meeting capacity needs related to monitoring (e.g., hiring a student researcher). Be sure to keep in mind that there can be a trade-off between relying on others to collect your data and getting results of the quality you need; volunteers whom you cannot train and supervise closely may not produce good enough results. Thus, if you try to run a monitoring program "on the cheap", you may risk ending up with data that you can't use. You may also be tempted to try to cut costs by minimizing your investment in QA/QC procedures; all we can say about this is, "Please don't."

6. WRITE YOUR PLAN

a. Compile the results of Steps 2-6 into a preliminary plan. Compiling the findings in Steps 2-6 into a preliminary plan involves more than simply merging the findings from each step. At the very least, you need to list all of the variables you need to measure to address your hypotheses; your intended monitoring locations and the variables to be measured at each location; the preferred method(s) to be used to monitor each variable at each location, including the methods of sample collection, field measurement, preservation and transport, and laboratory measurement as appropriate; the time(s) each year when each variable will be monitored; the partners, facilities, staffing, staff transportation, and other field logistics required, as appropriate; and the QA/QC procedures to be used for each method. Some teams may find it useful to construct tables or charts to capture all of this information.

b. Check over the plan for internal consistency. Once you have compiled your preliminary plan, go back over the whole to make sure that the pieces all fit into a complete package that does the job you want, in the most efficient way.

7. Assess the FEASIBILITY of the preliminary plan.

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[16] One method for doing this is to tabulate (a) the cost of the equipment (if any), including annual maintenance and expendable supplies such as test chemicals, as needed; (b) the cost of keeping the equipment calibrated (if applicable), including the cost of calibration standards; (c) the cost of laboratory analysis, if required, including the costs of preserving and transporting the samples to a lab; (d) the fragility of the equipment, the ease of getting replacement parts for the equipment, or the ease of getting samples delivered promptly to a laboratory; (e) the number of people required to collect the sample or field measurement, and the complexity of the field procedures involved; and (f) the number of samples or field measurements that will be required each year, including QC samples. Other factors to tabulate may come to mind for your situation, as well.

a. Envision how the plan will work in actual operation. Consider, for example, what it would be like to carry out the prescribed monitoring activities under all different circumstances of weather, partner reliability, equipment reliability and options if equipment fails, and so forth. That is, you should picture yourself or your team trying to carry out the monitoring, and think of all the things that could go wrong. Accidents of course do happen everywhere, but some are avoidable with proper planning. Even if you have carried out Steps 2-7 above with the utmost care, you may still find that, when gathered into a whole, the complete program has bugs – avoidable weaknesses. It is better to find these before you start monitoring, than to have to modify your plans "mid-stream" (pardon the pun).

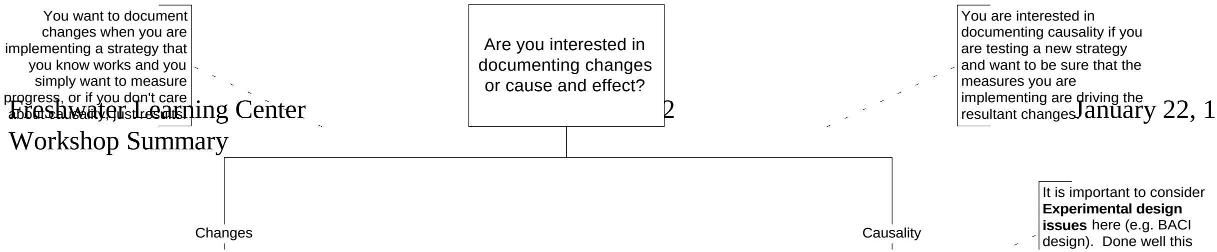
b. Consider a test run of the plan to evaluate its practicality. A monitoring plan may look great on paper, but still contain flaws. As a result, you can gain a lot of insight into your plan's feasibility by conducting an actual test run in the field under varying conditions. Methods that seem entirely feasible may still prove unworkable during an especially rainy season, or be more prone to mistakes than expected. Partners may find that they cannot meet their promises for participation, and equipment may prove less reliable than expected. Of course, time may not permit the luxury of such testing before you must begin the complete program. However, the more lead time you have to practice and to "shake down" your program and staff before starting full monitoring in earnest, the better off you will be.

8. Adequately RESPOND TO CHANGES THAT ARISE during implementation

a. Ensure continuity of data and purpose. Even with a careful evaluation of feasibility, and even with a test run, you may still find that you need to improve your monitoring program after you begin. Better equipment may become available or affordable, new partners may offer to join the effort, permission may be granted or withdrawn for you to conduct monitoring at some location(s), and so forth. The need to change a program after it starts places a special responsibility on you, to make sure that whatever changes you make result in data that are at least as accurate and precise as those you previously collected, entail methods that are at least as reliable as those you replaced, and refrain from introducing bias into your data. There is nothing wrong with improving a monitoring program as you go along, so long as you ensure continuity of data and purpose.

The Freshwater Initiative team recommends that all site teams follow this approach to develop their monitoring plan. Please also consider using the decision tree presented by Figure 2 if it helps you decide what to monitor and other related questions. Freshwater Initiative team members with expertise in developing monitoring plans (David Braun and new biohydrological staff scheduled for hire this fall and winter), as well as other Conservancy staff with expertise in monitoring (Bob Unnasch) are available to work with individual site teams to develop these plans.

Deciding what you want to know is the first, and most important step in designing a monitoring or research program.



You want to document changes when you are implementing a strategy that you know works and you simply want to measure progress, or if you don't care about causality, just results.

You are interested in documenting causality if you are testing a new strategy and want to be sure that the measures you are implementing are driving the resultant changes.

It is important to consider **Experimental design issues** here (e.g. BACI design). Done well this

Figure 2

D. Completing the Feedback Loop

The purpose of constructing a monitoring plan using the method described above is to generate scientifically defensible, transferable results. These results can then be used to demonstrate the efficacy of some strategies or justify their application at other freshwater sites. The results can also be used to further refine strategies and ecological models applicable to a site, as part of your program of adaptive management (see the adaptive management cycle presented in Figure 3). However, you usually should try to complete a full cycle of BACI (or similarly designed) monitoring before you begin changing your conservation practices based on your monitoring results. It can take years for some conservation strategies to begin to have their full impact, and so you should resist the temptation to abandon strategies that don’t immediately appear to be working. Conversely, some strategies may appear to be working so well, in just a short time, that you may be tempted to abandon your experimental design and begin applying them everywhere, including in your control subwatersheds. In this case, abandoning the experimental design will prevent you forever from knowing if your actions truly are working, or if the effects instead are only temporary or are caused by other factors you hadn’t anticipated. Sound adaptive management must rest on the best available scientific findings, including your own.

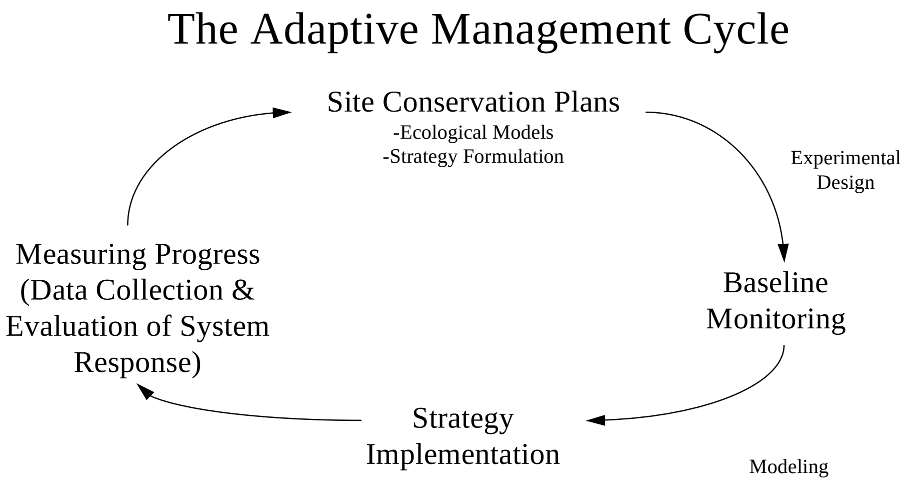


Figure 3

CONCLUSION

Site conservation planning provides an excellent foundation from which to develop a monitoring plan for your site. We expect the site-based teams engaged in the Initiative to generate scientifically defensible results which will not only guide better conservation at these sites through application of adaptive management, but help convince others, including skeptics, about the meaning of these results and their transferability. We realize that the expectation of scientifically defensible results will push many teams beyond their current practices. However, the promised fruits of this labor could prove substantial.

The Freshwater Initiative support staff hope that the information contained by the workshop held in Reno and by this document help demystify the process of monitoring plan development. The complexity of considering multiple variables and interactions is what makes developing an implementable monitoring plan difficult. This is also what makes developing clear guidelines applicable to all sites challenging. Our purpose is to present the foundations that you must consider when developing your monitoring program. We also recognize that perfect statistical rigor may not be feasible in all cases due to the kinds of hypotheses being tested and the opportunities your landscape affords. Not meeting this ideal does not mean failure; carefully designed programs, even if not ideally rigorous, can still produce very useful and transferable results. What matters is that you have a monitoring program that has adequate rigor to meet the needs of both your site and the Initiative. We will work with you to meet this goal.

Appendix A:
Networks of Sites

Hydrologic Alteration:
Altamaha River (GA)*
Neversink River (NY)*
Apalachicola River (FL)*
Illinois River (IL)*
Upper Klamath Basin (OR)*
Roanoke River (NC)
Silver Creek (ID)
Truckee River (NV)
Condor Bioreserve (Ecuador)
Cuatro Cienegas (Mexico)
Upper San Pedro River (AZ)
Sandia Springs (TX)
Mattaponi/Pamunkey Rivers (VA)
Mt. Bethel Fens (PA)
Main Streams, Upper Colorado River (CO/UT)
San Luis Valley (CO)
Sacramento/San Joaquin Bay Delta (CA)
Santa Margarita River (CA)

Water Quality Degradation:
Big Darby Creek (OH)*
French Creek (NY)*
Mackinaw River (IL)*
Maya Mountain (Belize)*
Green River (KY)*
Poultney River (VT)
Paint Rock River (AL)
Cache/Bayou deView (AR)
Conasauga River (GA)
Clinch River (TN and VA)
Fish Creek (IN)
Blue River (IN)
Platte River (NE)
Gila River (NM)
Upper Mimbres River (NM)
Pantanal (Brazil)
Madre de las Aguas (Dom. Rep.)
Acopian Ecosystem (PA)
La Encrucijada (Mexico)
Bocas del Polochic (Guatemala)

Appendix B:
List of Participants

Site Representatives and Additional Staff:

Susan McAlpine - French Creek (NY)
Robert Wigington - Main Streams, Upper Colorado River (UT/CO)
Omar Gordillo* and Cristina Lasch* - La Encrucijada (MEXICO)
Jeff Horton and Nils Johnson (intern) - Roanoke River (NC)
George Ivey - Conasuaga River (GA)
Dan Kelly - Upper Klamath Basin (OR)
Scott Wilber and Anne Dix - Bocas del Polochic (GUATEMALA)
Ruth Mathews - Apalachicola River (FL)
Cadie MacDonald* - Sacramento River/San Joaquin Bay Delta (CA)
Tim Tear* and Vern LaGesse - Mackinaw and IL Rivers (IL)
Douglas Zollner - Cache/Bayou deView (AR)
Judy Dunscomb - Mattaponi/Pamunkey Rivers (VA)
Paul Todd - Silver Creek (ID)
Steve Sutherland - Big Darby (OH)
Holly Richter* - Upper San Pedro River (AZ)
Patrick McCarthy - Gila and Mimbres Rivers (NM)
Francisco Nunez - Madre de las Aguas (DOMINICAN REPUBLIC)
Chad Gourley* - Truckee River (NV)
Allen Culp
Larry Serpa*

Facilitators and Logistical Support:

David Braun*
Bob Unnasch*
Brian Richter*
Nicole Silk*
Christine Carson

Guests:

Tom Davenport, USEPA*
Chris Yoder, Ohio EPA*
Janet Spooner, North Carolina State University*
Karen Worcester, Central California Water Quality District*

* Denotes presentation responsibility

Appendix C:
Workshop Agenda

Day One: (PM)

3:00 - 3:30	Introductions; Overview	Nicole, David
3:30 - 4:15	Context for Developing a Monitoring Plan	Nicole
4:15 - 6:00	Designing Monitoring Programs that Work: Research Design	David, Bob
6:00 - 7:30	Dinner	
7:30 - 8:15	Example Planning Case: La Encrucijada, Mexico	Cristina, Omar
8:15 - 8:30	Setting-up Day Two	David, Nicole

Day Two:

7:30 - 7:45	Logistics, team coordination and departures for Conference	Nicole, David
8:00 - 11:45	EPA Conference morning sessions	
12:00 - 12:45	Lunch back at Atlantis (pick up box lunches at breakfast-time)	
1:00 - 4:45	EPA Conference afternoon sessions	
5:00 - 6:30	Team presentations (at Atlantis) on Conference sessions	Nicole, David
6:30 - 8:00	Dinner (participants on their own)	
8:00 - 8:45	Example Planning Case: San Pedro River, Arizona	Holly
8:45 - 9:30	Example Planning Case: Truckee River, Nevada	Chad

Day Three:

8:30 - 10:15	Designing a Monitoring, Part I (Mackinaw River as example)	David, Bob &
10:15 - 10:30	Break	EPA guests
10:30 -12:15	Designing a Monitoring, Part II (Mackinaw River as example)	David, Brian &
12:15 -12:30	Break, pick up box lunches	EPA guests
12:30 - 1:30	Large-scale monitoring projects: EPA perspectives	EPA Guests
1:30 - 2:00	Travel to Truckee River	
2:00 - 4:00	Field Logistics and Practices	Brian, David
4:00 - 5:45	Aquatic Biomonitoring Demonstration	Larry
5:45 - 6:15	Return to Hotel	
6:30 --	Dinner & evening “free-time”	

Day Four:

8:30 - 9:30	Bioindicators and Their Application	Chris Yoder
9:30 - 10:30	Lessons from EPA Long-Term Monitoring Projects	Tom Davenport
10:30 - 10:45	Break	
10:45 - 11:30	Implementing Monitoring: Who Does It, At What Cost?	Brian, David
11:30 - 12:30	Using Monitoring Data: Completing the Adaptive Mgt. Cycle	Brian, David
12:30 - 1:00	Wrap-up	