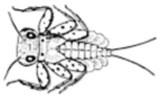
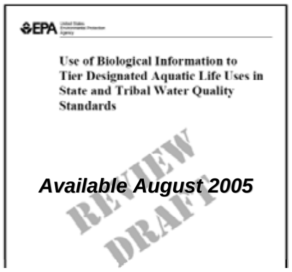
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

EVALUATING OPTIONS FOR DOCUMENTING INCREMENTAL IMPROVEMENT OF IMPAIRED WATERS UNDER THE TMDL PROGRAM

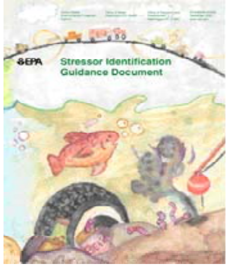


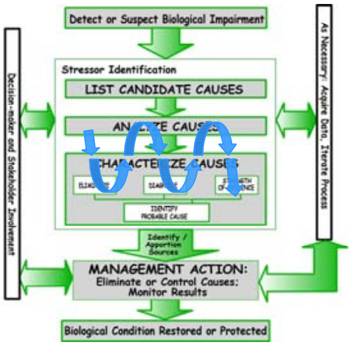

EPA

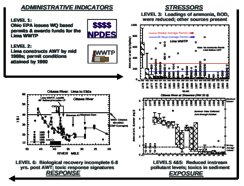
Use of Biological Information to Tier Designated Aquatic Life Uses in State and Tribal Water Quality Standards

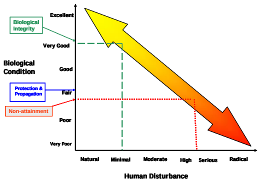
Available August 2005

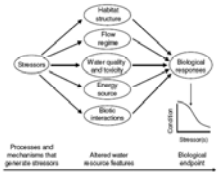
REVIEW DRAFT


EPA Stressor Identification Guidance Document









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EVALUATING OPTIONS FOR DOCUMENTING INCREMENTAL IMPROVEMENT OF IMPAIRED WATERS UNDER THE TMDL PROGRAM

November 30, 2008

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INTRODUCTION

The Midwest Biodiversity Institute was tasked by EPA to develop and evaluate options for identifying incremental improvement in impaired waters based on biological, chemical and physical monitoring methods, and data interpretation methods currently in use among (or available to) state and regional water programs. This report is the principal product of a detailed work plan that was approved as work assignment 4-68 (WA 4-68) under HECD contract 68-C-04-006 in December 2007. The primary goal of this report is to document working examples of detecting and quantifying incremental improvement and to summarize the key concepts and methods into a consistent framework.

What is Incremental Improvement?

Incremental improvement is defined here to represent a measurable and technically defensible, positive change in the condition of an impaired water body within which an improvement has been measured, but which does not yet fully meet all applicable water quality standards (WQS). The general principles of this investigation are defined as follows:

- ***measurement of incremental improvement*** can be accomplished in different ways, provided the measurement method is scientifically sound, appropriately used, and sufficiently sensitive enough to generate data from which signal can be discerned from noise;

- ***measurable parameters and indicators*** of incremental improvement may include biological, chemical, and physical properties or attributes of an aquatic ecosystem that can be used to reliably indicate a change in condition; and,

- ***a positive change in condition*** means a measurable improvement that is related to a reduction in a specific pollutant load, a reduction in total number of impairment causes, a reduction in an accepted non-pollutant measure of degradation, or an increase in an accepted measure of waterbody condition relevant to designated use support.

EPA Program Issues

A protocol for the documentation of incremental improvements in impaired waters is a major need of the TMDL program and other surface water protection programs. The evaluation of program success has almost exclusively focused on the full restoration of listed impairments. While this seems a straightforward process based on the removal of all impairment causes and meeting all WQS, it is presently difficult to account for improvements that have occurred as a result of TMDL based restoration actions, but do not yet meet all WQS. This can result in the perception that the program seems staked to an "all or nothing" end result with no recognition of any positive movement towards full attainment of WQS. Furthermore, failing to recognize that waters are improving and are on a positive trajectory can lead to erroneous conclusions about the attainability of Clean Water Act (CWA) goals and the viability of certain management practices. Hence, developing ways to measure and display incremental improvement would be beneficial to all CWA programs in a number of different ways. While the TMDL program is the primary water program that is dedicated to the delineation and tracking of the status of impaired surface waters and the progress of their restoration to meet CWA goals, other EPA water programs can also benefit from the measurement of incremental change.

Evaluating incremental improvement short of fully meeting WQS (i.e., no causes of impairment are removed, but evidence of improvement exists) can be variable and subject to interpretation - there are presently no widely accepted "benchmarks" for recognizing *partial* improvement, as compared to the clear target represented by fully meeting specific WQS. Although a number of TMDLs have produced such full restoration, many more if not most of the TMDL program's currently undocumented successes are assumed to be incremental improvements and thus, their reliable documentation poses a challenge. Because full recovery may take several years to become manifest and most TMDLs are comparatively recent, consistent protocols to recognize partial recoveries are essential to demonstrate interim program success. In addition to the TMDL program, other CWA clientele will also have an interest in the accurate identification of incremental improvements (Table 1).

EPA Program Needs

Although some EPA water program actions acknowledge the concept of incremental improvement, performance measures and guidance for determining incremental improvements to date have been limited. EPA and the states need program evaluation protocols that recognize and give credit to the documentation of partial progress toward the full attainment of restoration goals. EPA's 2006-2011 Strategic Plan (U.S. EPA 2008a) contains several targets based on full restoration to the point of meeting all WQS, but this Plan was EPA's first to begin addressing incremental improvements. Specifically, Goal 2 "Clean and Safe Water" includes demonstrating such improvements on a watershed basis by 2012. Two programmatic targets directly linked to this goal include watershed improvement measure SP-12 (U.S. EPA 2008b) and partial restoration measure SP-11 (U.S. EPA 2008c). To meet measure SP-12, one or more impairment causes for water bodies in the watershed must either be removed, or alternatively show watershed-wide improvement based on "credible scientific data". The Agency is seeking to achieve these improvements in 250 HUC-12 scale watersheds by 2012 nationwide. To meet measure SP-11 nationally, a minimum of 5,600 water body specific impairment causes must be removed by 2012. This measure recognizes incremental improvement in cases where restoring waters impaired by multiple causes may eliminate some of those causes yet fall short of attaining all WQS by removing all causes.

Both of these targets include incremental improvements that do not represent full restoration, and thus, will require the demonstration of numerous partial successes while full recovery progresses along more extended time frames. These will require sound, defensible reporting and accounting protocols and decision rules, and each requires sound and consistent guidance to ensure credible and consistent reporting and counting. Whereas these measures are a start toward recognizing partial progress in restoration, additional targets concerning incremental improvement may be considered in upcoming EPA strategic planning. Even beyond strategic planning and EPA programs, formal and informal evaluations of the variety of state and federal programs that are oriented toward restoration should be capable of weighing partial as well as full restoration success.

Table 1. Clientele for a framework document on incremental improvement measurement concepts and methods.

Clientele	Reason for Interest
TMDL program managers (primary clientele)	Demonstrate partial recoveries as program results in outcomes potentially earlier and in larger numbers than full recovery (i.e., a recognition that all stressors cannot be remediated in the same time frames).
NPS program managers	Related to qualifying for NPS success stories recognition; also demonstrate more 319 progress and results.
Monitoring program managers	Once documented as partially recovered, help orient limited monitoring funds to measuring waters more likely to have completely recovered. Also documenting incremental improvement is a primary component of post- project effectiveness monitoring.
4b projects (controls other than TMDL are in place)	Demonstrate progress being made within a reasonable time period so as not to revert from 4b to 5/4a process.
EPA Surface Water Strategic Planners and Watershed Managers Forum	Clarify and help defensibility of counting rules on partial restoration measures (W, Y). Also, aid the consideration of possible new measures concerning incremental improvement.
States	Additional consideration in performance partnership agreements & reporting to EPA.
WQS program	Related to determination of highest attainable use for the purpose of designating aquatic life uses; essential in use attainability analysis (UAA) considerations.

Current Challenges and Issues

The significant challenges in addressing the need for a framework and protocol for measuring incremental change center on the inherently competing concepts of EPA desiring a readily available and tractable process for reporting and the fundamental need to have it based on sound data and information (i.e., "credible scientific data"). We are clearly taking the position here that the integrity and strength of the underlying data and information upon which the incremental change indicators are founded is the starting point for devising and demonstrating a framework within which EPA can have such reliable measures of progress. One problem with the current situation is that a wide range of different approaches are essentially homogenized by existing measures of designated use attainment. This is commonplace within CWA program reporting and prior examples include state variability in 305[b] reporting from the previous 25-30 years and the litany of "lists" that have been produced from the same baseline data for a variety of purposes.

A fundamental problem with these past approaches has been the homogenization of technically different baseline inputs in designated use status reporting. Many states base their assessments of status either wholly or partially on chemical/physical parameters and indicators while others employ bioassessment results, yet each is distilled to a common terminology and "currency" expressed as the proportion of a waterbody that partially or fully achieves designated aquatic life use support. As has been shown in prior comparability studies (Rankin and Yoder 1990; Rankin 2003; Karr and Yoder 2004) such assessments based on chemical/physical indicators can be substantially different than biologically based assessments, the differences being up to 50% in some cases. In such cases, biological assessment contributed to the avoidance of the type II assessment errors that are inherently propagated in chemical/physical assessments, which results in the significant under-reporting of aquatic life use impairments. Current practice would in effect obliterate these important differences by effectively homogenizing the fundamentally different assessment protocols. There are additional differences in state programs that also contribute to the uncertainty about the reliability of status assessments and these include differences in spatial sampling design and the level of rigor of state monitoring and assessment (M&A) programs. These almost certainly contribute an as yet undocumented degree of variability and uncertainty in consolidated measures of program effectiveness. A major focus of this report is about how to relate baseline chemical, physical, and biological measures and indicators in an integrated assessment process that results in improved accuracy and consistency in the type of reporting that are to be accomplished by measures SP-11 and SP-12 (aka measures W and Y). This is an important prerequisite to assuring that "credible scientific data" are effectively used in the measurement of incremental change within these measurement frameworks.

TECHNICAL APPROACH

The technical approach followed by this report is intended to address the following questions:

1) What constitutes a bona fide incremental improvement in an impaired water body that is not yet meeting water quality standards?

2) What scientifically valid methods are appropriate for detecting incremental improvement in a water body, and what types of data are required to use these methods?

3) How are states presently documenting incremental improvement in their waters?

4) What capacity do state programs need to document incremental improvements, and how does this generally match the current range of state capabilities?

To demonstrate the process and framework we reviewed a set of case examples from the state of Ohio that encompass a range of spatial context from statewide to watershed level reporting and for different types of water quality management program issues. Five of these case studies are reported in full detail in Appendix A and follow the principles and concepts of adequate watershed monitoring and assessment (Yoder 1998; Yoder and Rankin 1998; Appendix B) that is envisioned here as a framework to assure the use of "credible scientific data". To answer the question about how states presently accomplish incremental assessment and if they have the technical and logistical capacity to do so, we accessed the results of the recent evaluation of state WQS and monitoring and assessment programs that have taken place in multiple states since 2002 (MBI 2004; Yoder and Barbour 2009).

CASE STUDY: OPTIONS FOR DEMONSTRATING INCREMENTAL IMPROVEMENT

To illustrate *what constitutes a bona fide incremental improvement in an impaired water body that is not yet meeting water quality standards* we chose a case study involving the assessment of designated aquatic life use support from an eastern Ohio watershed. This is one of a collection of watershed case studies from Ohio that deal with small watersheds of the size envisioned in SP-11 and SP-12 that have been the subject of acid mine drainage abatement and treatment projects that are detailed in Appendix A. This will demonstrate the utility of using chemical, physical, and biological indicators both singly and collectively in a multiple lines of evidence approach and within a framework of adequate monitoring and assessment (Appendix B) to demonstrate reasonably available options for incremental assessment. We focused on the sequence of stressor, exposure, and response indicators (Figure 1) using each singly and in combination as multiple lines of evidence to not only demonstrate incremental improvement, but to facilitate a complete assessment of the degree of program success to date and what can be expected in the future.

Case Study: Mine Drainage Abatement in Small Watersheds

We utilized the results of watershed assessments performed by the Ohio University Voinovich School for Leadership and Public Affairs, the Midwest Biodiversity Institute, and selected watershed groups in support of Acid Mine Drainage Abatement and Treatment (AMDAT) projects sponsored by the Ohio Department of Natural Resources Division of Mineral Resources Management and 319 implementation projects sponsored by Ohio EPA. AMDAT projects in Ohio can also qualify as TMDLs under a cooperative arrangement with Ohio EPA whereby these studies utilize the same methods and indicators and address WQS issues as part of the watershed assessment. Pollutant loading reductions needed to meet WQS are then developed and are evaluated by an adequate monitoring and assessment approach (Yoder 1998; Yoder and Rankin 1998) to determine overall abatement project effectiveness. As such the data and information are well suited to determining incremental changes in chemical/physical and biological indicators through space and time.

The five case studies are drawn from three watersheds in the coal bearing region of Ohio: Huff Run, Monday Creek, and Raccoon Creek – these are fully detailed in Appendix A. These watersheds have varying amounts of data to support the demonstration of incremental change, but each has the essential indicators to demonstrate the sequence of actions from TMDL development to pollution abatement to incremental recovery towards attainment of WQS. There are varying amounts of incremental change across these five restoration project examples each showing varying degrees of biological and chemical/physical change. Three of the five examples are active lime dosing treatment BMP projects (Jobs Hollow, Essex Doser, and Hewett Fork). The other two are examples of sub-watersheds containing numerous passive systems and varying amounts of change in the receiving streams (Huff Run and Little Raccoon Creek) through time.

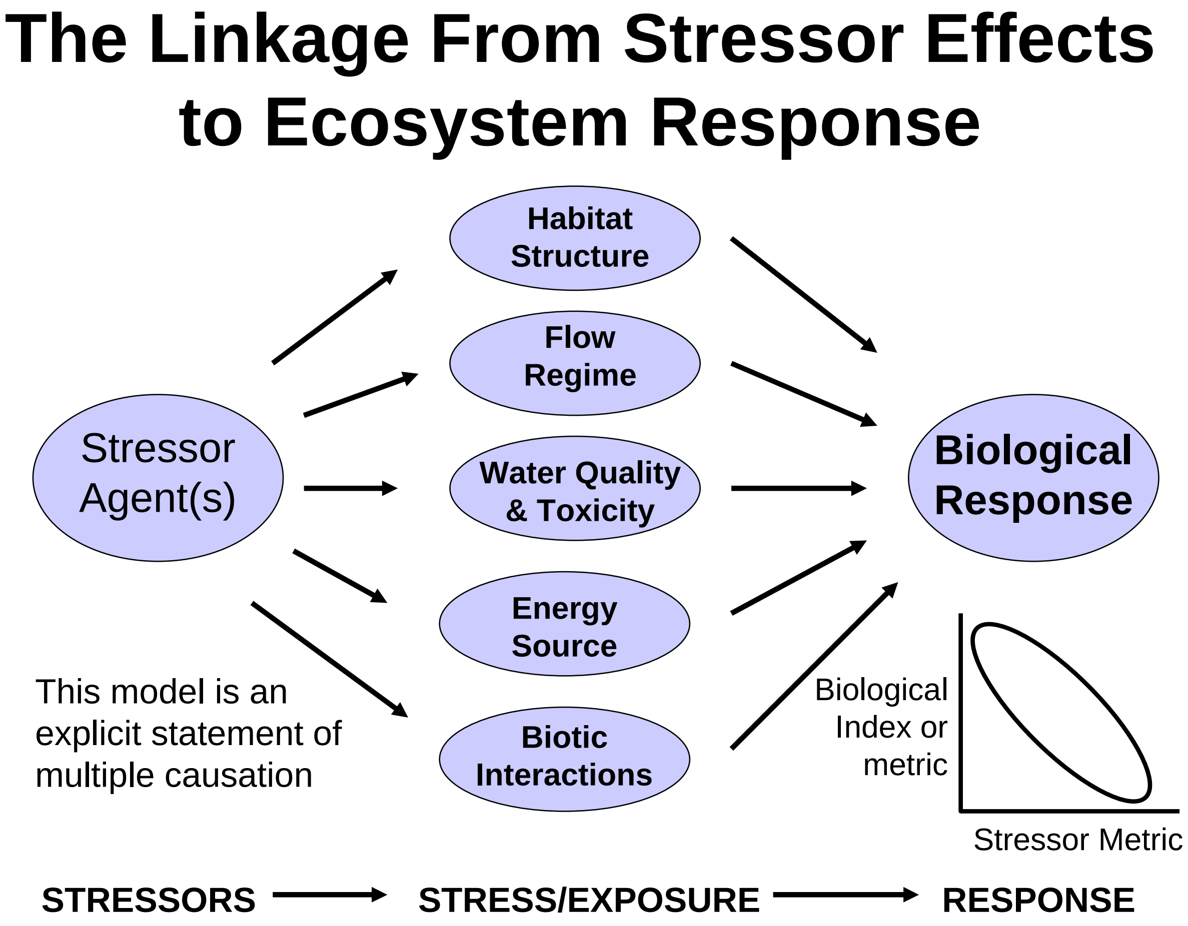


Figure 1. The linkage of the effect of stressors through Karr's five factors to the resultant biological response. The indicator roles represented by each category (stressor, exposure, response) are identified in accordance with Yoder and Rankin (1998); after Karr and Yoder (2004).

Huff Run

The Huff Run subbasin is located in eastern Ohio within the Muskingum River basin. Huff Run is 9.9 miles long with a 13.9 square mile watershed. A substantial portion of the watershed has been surface mined for coal, limestone, and clay. Because most of the mined lands were not originally reclaimed (referred to as abandoned mined lands), the watershed has been impacted by legacy acid mine drainage (AMD) and it is the principal stressor.

The Huff Run Watershed Restoration Partnership Inc. (HRWRP) has partnered with the Ohio DNR, Division of Mineral Resources Management (MRM), Rural Action, Ohio EPA, Division of Surface Water (319 program), Crossroads RC&D, and the U.S. Office of Surface Mining (OSM) "to restore the Huff Run watershed by improving water quality and enhancing wildlife habitat, through community support and involvement." As a result, seven reclamation projects have been completed in the Huff Run Watershed since 1998 with the intent of meeting specific water quality based targets and the Ohio WQS. Each project is directly adjacent to Huff Run (Figure 2).

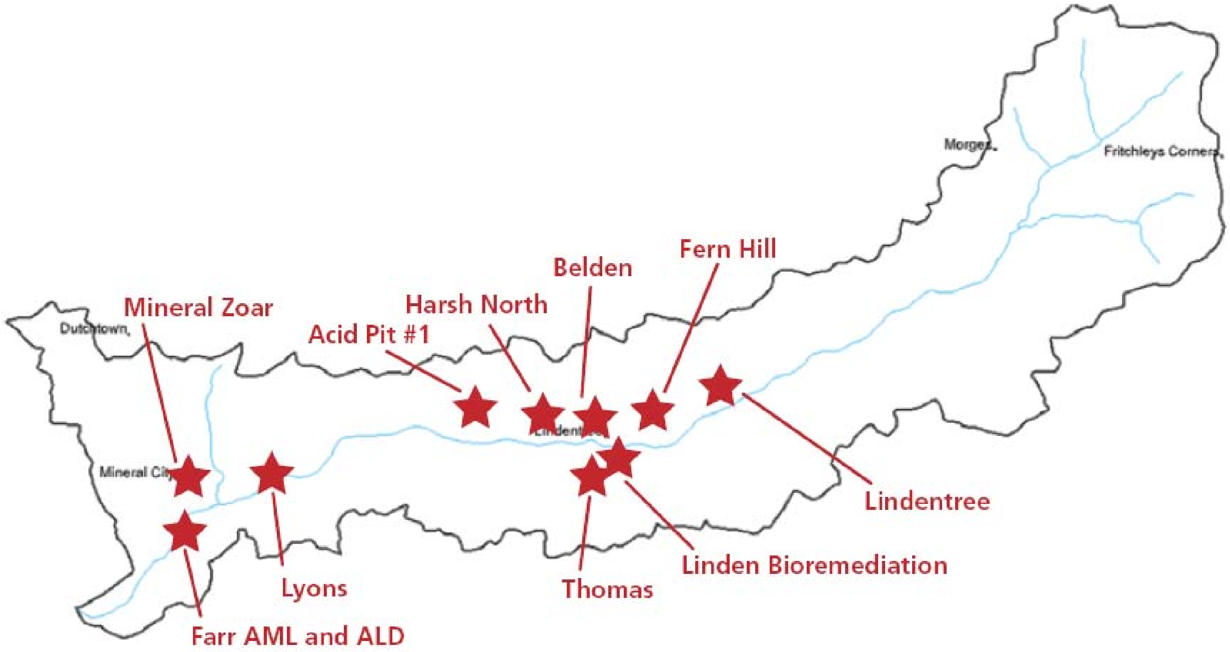
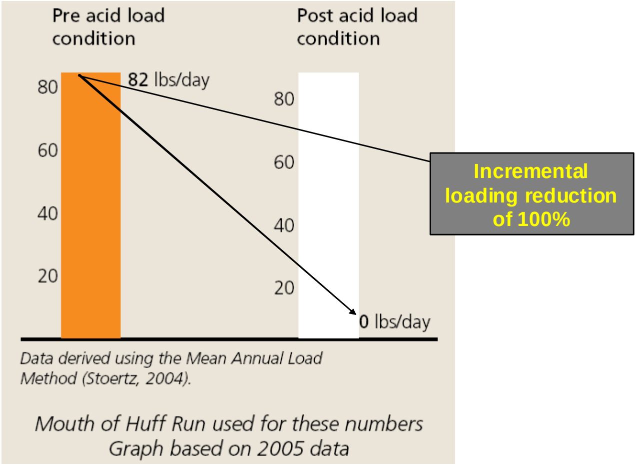


Figure 2. Funded and proposed mine drainage abatement projects in the Huff Run subbasin.



Data derived using the Mean Annual Load Method (Stoertz, 2004).

Mouth of Huff Run used for these numbers
Graph based on 2005 data

(lbs./day) estimated at the mouth of Huff Run.

Stressor Indicators: Pollutant Loadings

Using data derived from project monitoring and the mean annual load method (Stoertz and Green 2004) the total acid loading reduction at the mouth of Huff Run is estimated at 82 lbs/day (Figure 2). The pre-reclamation acid load condition was based on two samples (1985 and 1996). Since 1999 the mouth of Huff Run has continued to be net alkaline (i.e. all net acidity has been reduced). Heavy metal loading reductions were also derived using the same method. There were no metal load reductions up to 2005, with minimal loading reductions indicated after 2007. In this case study acidity is a targeted and management relevant parameter. The TMDL target for this watershed is -67 mg/l hence the net reduction to <0 mg/l represents an incremental improvement in at least one of the targeted parameters.

Exposure Indicators: Chemical Constituents

Eight locations along the mainstem of Huff Run have been monitored since 1985. The values for pH were average during the pre-construction time period prior to 1997. From 1998 through the present, seven remedial projects were completed (Appendix A) and this is considered the "post-construction" time period in the data analysis. However, water quality is technically in a transitional construction phase until all remediation projects are complete. Water quality data collected at the mouth of Huff Run (RM 0.4) demonstrate an increase in both pH and net acidity through time (Figure 4). Total iron concentrations were elevated at the mouth of Huff Run with post construction values being similar to pre-construction values and exceeding the Ohio WQS of 1.0 mg/l (Figure 5) with a negligible decrease in the post-remediation period. Total aluminum concentrations declined more during the post construction time period, but remained in excess of the U.S. EPA chronic maximum (CMC) and continuous aquatic criterion (CAC) of 0.087mg/l (Figure 5; Ohio has no WQS for aluminum). Taken at face value all of these results indicate incremental improvement that falls short of fully meeting WQS. Both pH and acidity show virtual attainment for those parameters, but the two heavy metal parameters indicate continuing exceedences that remain to be resolved.

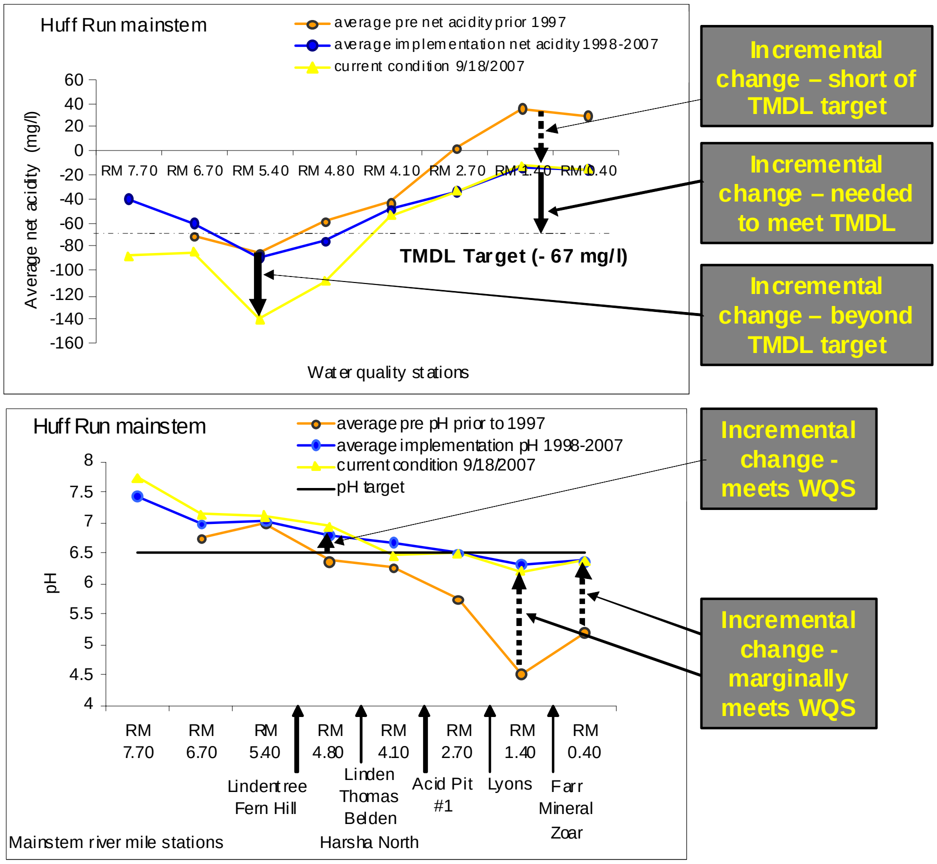
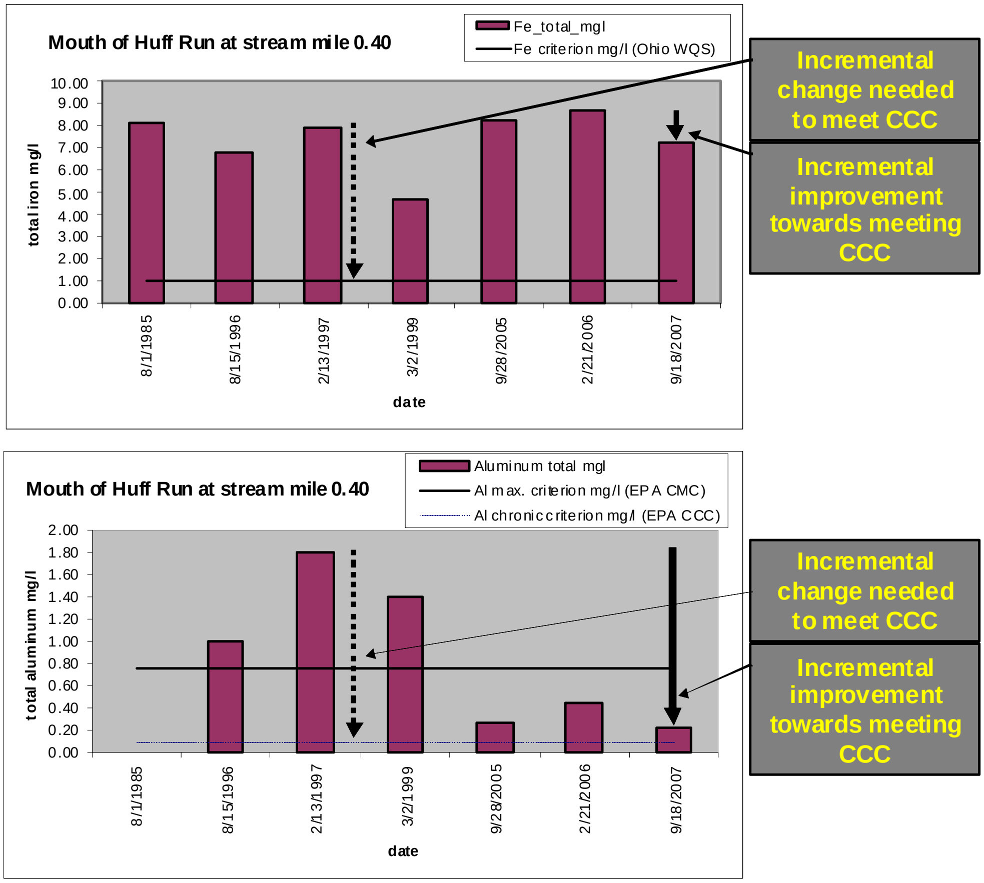


Figure 4. Spatial and temporal patterns in pH and net acidity (mg/l) at eight monitoring locations in Huff Run showing average pre-, during, and post-implementation results.

Exposure Indicators: Physical Indicators

An essential component of adequate monitoring and assessment for designated aquatic life use support is habitat assessment that is included here in the form of the Qualitative Habitat Evaluation Index (QHEI; Ohio EPA 1989; Rankin 1989). The results obtained since 1997



Incremental change needed to meet CCC

Incremental improvement towards meeting CCC

Incremental change needed to meet CCC

Incremental improvement towards meeting CCC

Figure 5. Temporal pattern in total iron (mg/l) and total aluminum (mg/l) at the mouth of Huff Run between 1985 and 2007.

indicate that while habitat in Huff Run is sufficient to support aquatic assemblages that meet the Ohio EPA biological criteria (Table 2), problems remain. The most significant mine drainage related impact is the moderate to heavy siltation and moderate to high degree of embeddedness of the substrates, which alone can impede full biological recovery. In terms of this indicator there is no evidence of incremental improvement, but the lack of data prior to 1997 may preclude a firm showing. What we do know from the results of this indicator is that further remediation is needed to resolve specific habitat deficiencies.

Response Indicator: Macroinvertebrate Assemblage

Biological assessment in Huff Run included both macroinvertebrates and fish in keeping with methods applicable as level 3 bioassessment under the Ohio Credible Data Law[1] and the Ohio WQS. This means that these data can be used to directly determine designated aquatic life use

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[1] The Ohio Credible Data Law specifies three levels of data; level 3 is the highest level of rigor and is required for all regulatory purposes, i.e., WQS and TMDL listing and de-listing.

attainment status under the Ohio WQS for purposes such as TMDL listing and development and evaluating the appropriateness of the existing designated uses. The demonstration of incremental improvement in the biological indicators was of particular importance to the latter process for mine drainage impacted streams in Ohio.

Table 2. QHEI scores and metric values for sites in Huff Run.

Key
QHEI
Components

			WWH Attributes											MWH Attributes																				
														High Influence						Moderate Influence														
River Mile	QHEI	Gradient (ft/mile)	No Channelization or Recovered	Boulder/Cobble/Gravel Substrates	Silt Free Substrates	Good/Excellent Substrates	Moderate/High Sinuosity	Extensive/Moderate Cover	Fast Current/Eddies	Low-Normal Overall Embeddedness	Max Depth > 40 cm	Low-Normal Riffle Embeddedness	Total WWH Attributes	Channelized or No Recovery	Silt/Muck Substrates	No Sinuosity	Sparse/No Cover	Max Depth < 40 cm (WD, HW)	Total H.I. MWH Attributes	Recovering Channel	Heavy/Moderate Silt Cover	Sand Substrates (Boat)	Hardpan Substrate Origin	Fair/Poor Development	Low Sinuosity	Only 1-2 Cover Types	Intermittent and Poor Pools	No Fast Current	High/Mod. Overall Embeddedness	High/Mod. Riffle Embeddedness	No Riffle	Total M.I. MWH Attributes	(MWH H.I.+1)/(WWH+1) Ratio	(MWH M.I.+1)/(WWH+1) Ratio
(17101) Huff Run																																		
Year: 1997																																		
7.4	72.50	24.39	■	■		■	■	■	■		■		7						0		■			■					■	■		4	0.13	0.63
5.2	60.00	26.58	■	■				■	■		■		5		◆	◆			2		■			■	■				■	■		5	0.50	1.33
0.3	60.50	16.48	■				■	■	■		■		5			◆			1		■			■	■				■	■	■	6	0.33	1.33
Year: 2005																																		
7.7	59.50	24.39		■				■	■		■	■	5						0		■								■			2	0.17	0.50
6.7	63.50	15.00	■	■		■	■	■	■				7		◆				1		■								■	■		3	0.25	0.63
5.4	77.00	26.58	■	■		■	■	■	■	■	■	■	9						0													0	0.10	0.10
4.8	77.00	15.00	■			■	■	■	■		■	■	7						0		■								■			2	0.13	0.38
3.0	64.50	16.48	■				■	■	■		■	■	6			◆			1		■		■	■	■				■			5	0.29	1.00
2.7	68.00	15.00	■			■	■	■	■		■		6						0		■		■						■	■		4	0.14	0.71
1.4	67.00	15.00	■			■		■	■		■		5			◆			1		■			■	■				■	■		5	0.33	1.17
0.4	68.50	16.48	■	■		■	■	■	■		■		7						0		■								■	■	■	4	0.13	0.63
Year: 2006																																		
5.4	76.00	26.58	■	■		■	■	■	■	■	■		9						0		■								■	■		3	0.10	0.40
4.1	34.50	15.00									■		1	◆	◆	◆	◆		4		■			■	■			■	■	■		6	2.50	5.50
0.4	66.50	16.48	■	■		■	■	■		■	■		7				◆		1		■			■				■	■	■		5	0.25	0.88

Macroinvertebrate and fish assemblages were monitored in Huff Run in 1997 (fish only), 2005, and 2006, most of which occurred during the post-remediation period. Both assemblages demonstrated incremental improvement, each to a differing degree. The Invertebrate Community Index (ICI; Ohio EPA 1987; DeShon 1995) shows a spatial pattern in Huff Run that closely follows pH and is the opposite of acidity, a tacit confirmation that biological assemblages have responded positively to reduced loadings of acidity and allied constituents (i.e., heavy metals). However, the ICI remained well below the warmwater habitat (WWH) use designation biocriterion at the two downstream most sites that are in the segment of greatest impact from mine drainage (Figure 6). The incremental improvement in the ICI (and other biological indices) can

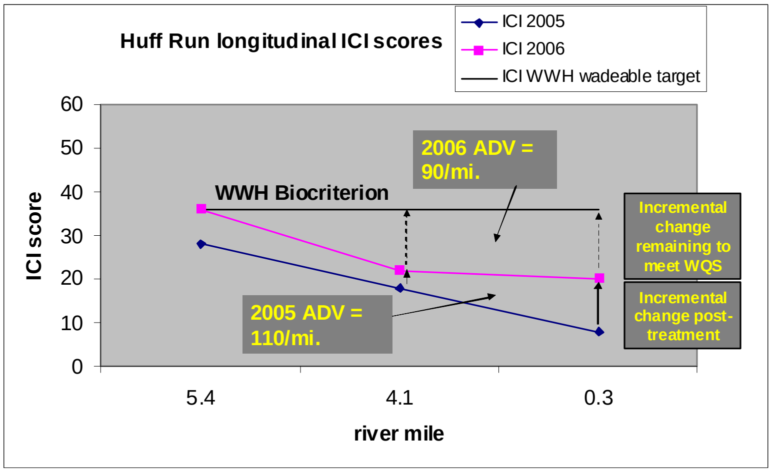


Figure 6. Invertebrate Community Index (ICI) results at three locations in Huff Run during 2005 and 2006.

also be portrayed by the Area of Degradation Value (ADV; Yoder and Rankin 1995) which combines the severity and extent of the departure from a biocriterion and the length of stream over which it occurs. In this case the ADV decreased from 110mi. in 2005 to 90/mi. in 2006, a positive change of 18%. The fish assemblage data showed lesser improvements in the Index of Biotic Integrity (IBI) ranging from 16 in 1997 and 2005 to 18 in 2006, a non-significant improvement; the ADV/mile for the IBI declined by 10% between 1997 and 2006. However, species richness improved from 1 and 2 species in 1997 and 2005 to 7 in 2006. Fish frequently lag macroinvertebrates in their recovery taking longer to respond especially where the spatial scale of the impacts inhibits reinvasion and reproduction. One issue with these results is that the biological data were collected mostly during the post-implementation phase of the Huff Run abatement projects. However, knowing how the biota are impacted in general by severe acid mine drainage in Ohio, these results represent a bonafide incremental improvement in response to the aggregate of the abatement projects. In this case the biota improved from very poor quality to poor and even fair quality at some sites.

1. Management actions

2. Response to management

Administrative indicators
[permits, enforcement, plans, grants]
[technologies used, BMPs installed]

3. Stressor abatement

Stressor indicators
[changes in land-use practices, effluent reduction]

4. Ambient conditions

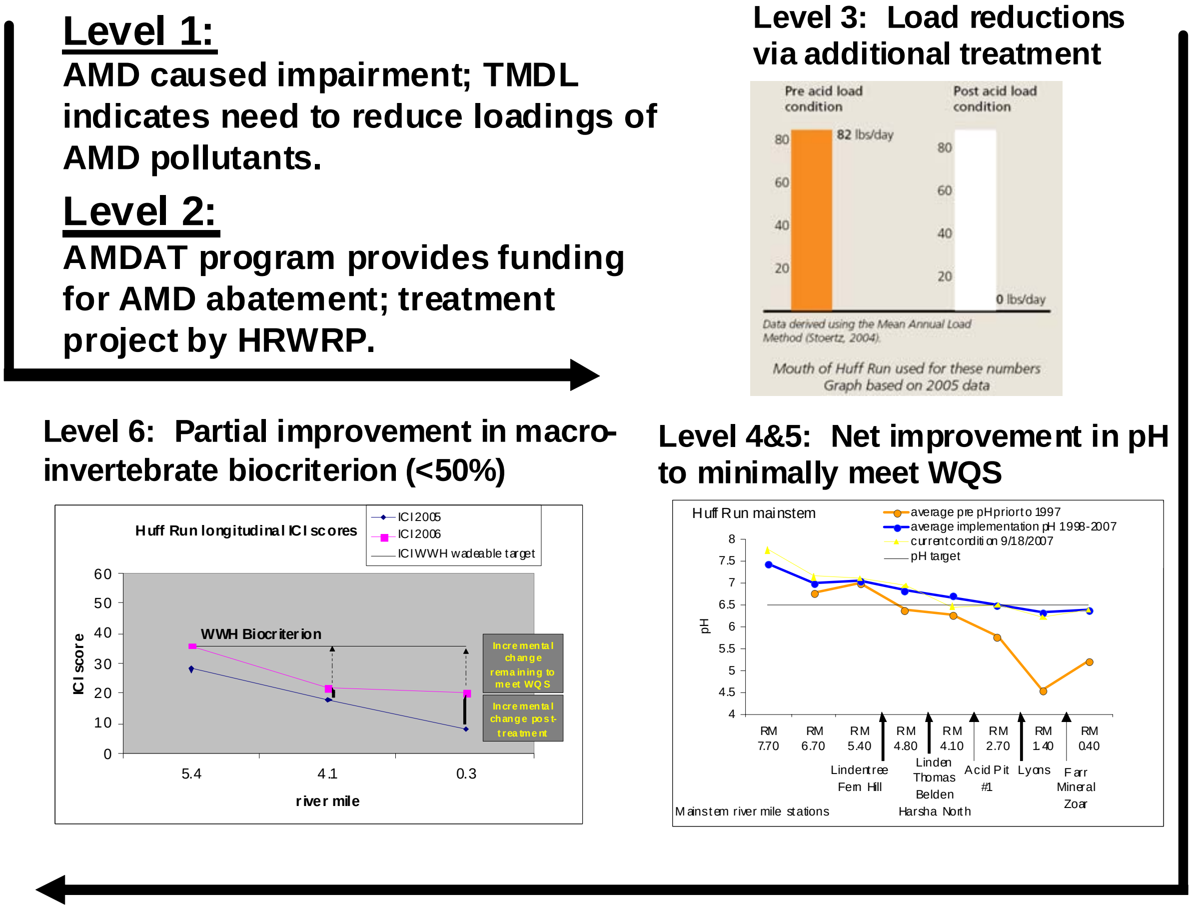
5. Direct exposure to effects of pollution

Exposure indicators
[pollutant conc., physical habitat or flow alteration]
[assimilation and uptake of pollutants, reduced spawning success, nutrient dynamics changed, sedimentation effects]

6. Biological response

Response indicators
[biological metrics, target species, multimetric indexes, other biological measures]

Endpoint: "Ecological Health" or Biological Condition



Level 1:
AMD caused impairment; TMDL indicates need to reduce loadings of AMD pollutants.

Level 2:
AMDAT program provides funding for AMD abatement; treatment project by HRWRP.

Level 3: Load reductions via additional treatment

Data derived using the Mean Annual Load Method (Stoertz, 2004).

Mouth of Huff Run used for these numbers
Graph based on 2005 data

Level 4&5: Net improvement in pH to minimally meet WQS

Level 6: Partial improvement in macro-invertebrate biocriterion (<50%)

evaluated by the environmental outcomes that are produced and within the conceptual framework of adequate monitoring and assessment. This is portrayed specifically for Huff Run (Figure 8) in which the response of the principal stressors (i.e., acidic loadings) to management are evaluated by the changes in exposure (i.e., as indicated by pH, acidity, metals, habitat) and ultimately by the biological response (i.e., as indicated by biological assemblage performance). In this case the documented improvements are incremental because they fall short of fully meeting WQS, but the expectation remains that WQS will eventually be met provided the sequence of indicators is properly analyzed and interpreted in accordance with the causal sequences portrayed in the indicators hierarchy (Figure 7). The degree to which the applied management efforts fall short of meeting restoration targets depends on which indicator is used as a basis for making that judgment. Individually, the different chemical, physical, and biological indicators each portray differing degrees of improvement, some of which indicate the virtual attainment of the WQS or TMDL goals for each (e.g., acid loadings, pH, aluminum) while others indicate comparatively less improvement (e.g., iron, habitat, biological assemblages). The easy way to deal with what would otherwise be viewed as discrepancies among the indicators would be to follow an independent applicability approach by which success is contingent on the most impacted of the indicators, in this case iron, habitat, and the biota. An alternative is to employ a multiple lines of evidence approach and in keeping with the most appropriate role of each indicator where the response indicators bear the most weight for what constitutes bonafide success. In the case of Huff Run, the Ohio WQS are explicit in defining how the attainment of the designated is determined, i.e., it

Figure 8. Hierarchy of indicators as applied to the abatement of mine drainage impacts in the Huff Run watershed and the causal linkages between stressor, exposure, and response indicators.

is based on attainment of the numerical biological criteria. Hence the principal measures for incremental improvement in this case are the biological assemblage data and indices. The role of the other indicators is to serve as the explanatory data for how the biota responds through space and time. In this case the complex mosaic of mine drainage and its array of chemical and physical impacts and parameters comprise the principal causative stressors and serve as the appropriate targets for TMDL development and resulting abatement actions. However, the stressor and exposure indicators can also serve as important signals of incremental improvement that provide more immediate feedback about the efficacy of the abatement practices. Following this approach, an indicators hierarchy for Huff Run was developed and serves as a watershed specific template for relating and evaluating incremental changes in the various indicators through time (Figure 8).

M&A Program Design Implications

The accuracy and comprehensiveness of incremental assessment is entirely dependent on adequate M&A that is designed and conducted to support the assessment of water quality management outcomes *at the same scale at which the management is being applied.* This provides the spatial connections that are essential to diagnosing causal associations and relating the extent and severity of their effects as expressed by stressor and exposure indicators. This was evident in the Huff Run example in the spatial differences in the chemical and physical indicators along the mainstem. Simply relying on the results at the mouth (i.e., the watershed "pour point") would have been much less informative about the severity and magnitude of the impact of mine drainage constituents along the mainstem. While incremental improvement was evident in some of the indicators measured at the mouth sampling site (RM 0.4), these data alone could not capture the extent of impairments along the stream and in the spatial context of individual sources and abatement projects.

The data collected at multiple sites along Huff Run documented the spatial "pollution profile" that is inherent to the action of pollutants and stressors in any flowing waterbody. A spatial sampling design that adequately captures this spatial context is essential to gaining the additional dimensions of incremental change within a watershed. In Huff Run, the change in pH and acidity demonstrate the documentation of the longitudinal pollution profile for these two parameters (see Figure 4). The importance of knowing this information is in relating the impact of remediation at each specific AMDAT project of which there are at least 7 along the stream. While these collectively contribute to the overall TMDL targets, they are in some cases funded and operated independently. This type of detail in the spatial M&A design not only allows for more detailed tracking of incremental improvements within the watershed, but it provides the opportunity to apply the most successful management approaches to other watersheds with similar sets of stressors.

The casting of chemical, physical, and biological indicators in their most appropriate role as indicators of stress, exposure, or response is a pivotal concept within the adequate M&A framework and that affects how to evaluate incremental improvements. Given that the Huff Run case example is focused on designated aquatic life use status, the principal arbiter of success are the biological assemblage indices in their role as response indicators. While this is defined by the Ohio WQS in this case, adequate M&A would cast biological indicators in that role in the absence of a formal biocriterion. However, a strict adherence to this disciplinary framework is not always practiced. Depending on which indicator is used as the arbiter of "success" a different assessment could be reached. For example, if loadings alone were used the outcome would be viewed as having achieved full recovery (see Figure 3) where acid loads at the mouth were reduced to 0. It also represents conditions only at the pour point of the watershed and the necessary assumption that it represents conditions throughout the entire watershed. The same is true for the two heavy metals aluminum and iron (see Figure 5). Acidity and pH were available at multiple locations

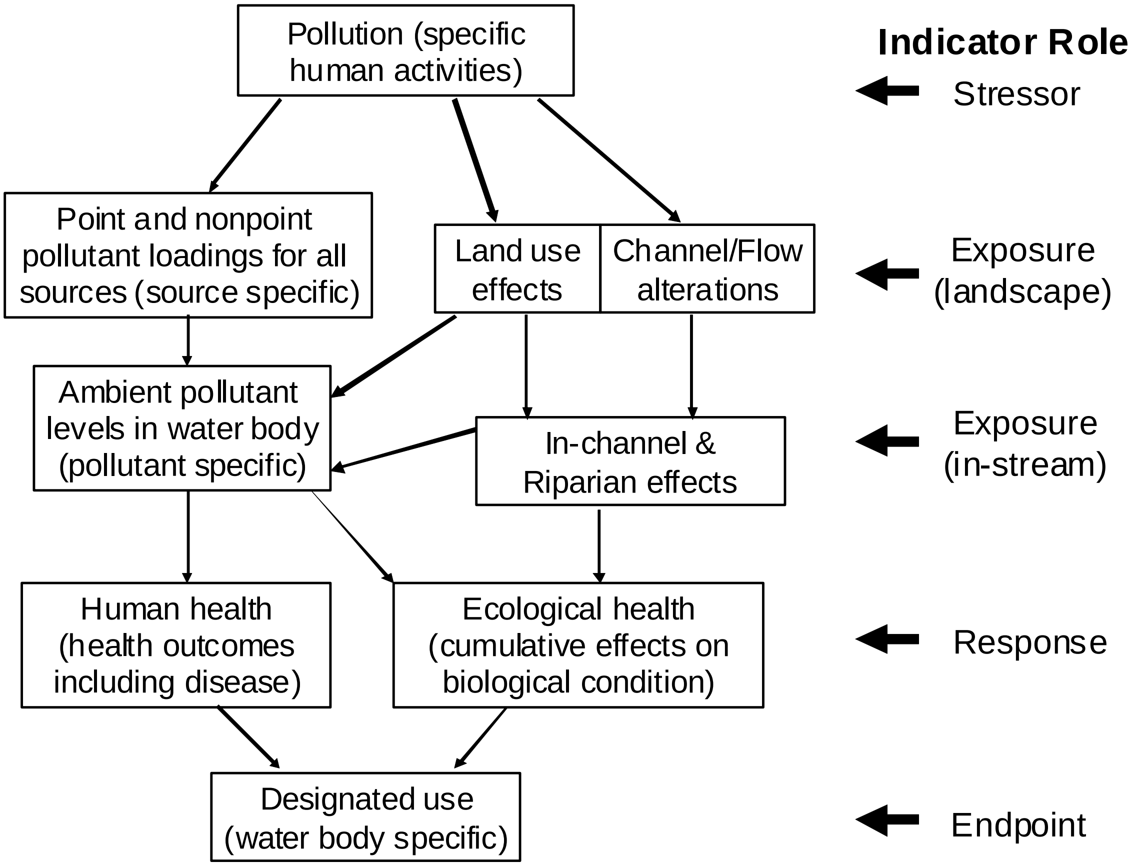


Figure 9. Position of the criterion (stressor, exposure, or response) illustrating the relationships between human activities, specific types of criteria, and designated uses that define the endpoint of interest to society (modified from NRC 2001). Their parallel roles as environmental indicators for each category is listed on the right. Arrows indicate directions and interrelationships along the causal sequence of stress, exposure, and response (after Karr and Yoder 2004).

Taken together, the closer that an indicator is to the summation of a designated use, the more it indicates that the incremental improvement observed thus far in Huff Run is just that, partial success. This illustrates the *"Position of the Standard"* concept that was articulated by the National Academy of Sciences Committee on Science in the TMDL Process (Figure 9; NRC 2001; Karr and Yoder 2004). This concept relates the "position" of a parameter or indicator as a "standard" to the designated use in the same sequence as the stressor/exposure/response roles of surface water indicators (Figure 9). The closer a parameter or indicator is to representing the direct attributes of the designated use the more accurate it will be as an arbiter of that use. In this case, the designated use is aquatic life which is specifically described in the Ohio WQS for the appropriate tier (i.e., WWH) as follows:

> "Warmwater" - these are waters capable of supporting and maintaining a balanced, integrated, adaptive community of warmwater aquatic organisms having a species composition, diversity, and functional organization comparable to the twenty-fifth percentile of the identified reference sites within each of the following ecoregions: the interior plateau ecoregion, the Erie/Ontario lake plains ecoregion, the western Allegheny plateau ecoregion and the eastern corn belt plains ecoregion. For the Huron/Erie lake plains ecoregion, the comparable species composition, diversity and functional organization are based upon the ninetieth percentile of all sites within the ecoregion. For all ecoregions, the attributes of species composition, diversity and functional organization will be measured using the index of biotic integrity, the modified index of well-being and the invertebrate community index as defined in "Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters," as cited in paragraph (B) of rule 3745-1-03 of the Administrative Code. In addition to those water body segments designated in rules 3745-1-08 to 3745-1-32 of the Administrative Code, all upground storage reservoirs are designated warmwater habitats. Attainment of this use designation (except for upground storage reservoirs) is based on the criteria in table 7-15 of this rule. A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code.

This follows the NRC (2001) *Position of the Standard* concept by defining attainment as being directly measured by the biological indices, which in the case of Huff Run are the WWH biocriteria for the ICI (see Figure 6) and IBI. In other states where designated aquatic life uses are not as specific and are instead characteristic of "general" uses, stressor and exposure indicators and parameters are either employed as surrogates for response or elevated to the same "position" in applications of the WQS. However, surrogate indicators can induce an unquantifiable level of uncertainty and error into the assessment process. Comparability studies have shown that using chemical sampling data on a parameter-by-parameter basis in a surrogate role can miss impairments that are otherwise detected and/or otherwise quantified by bioassessment (Rankin and Yoder 1990; Rankin 2003; Karr and Yoder 2004).

The implications to the TMDL program can be profound, especially when chemical-based M&A

misses impairments altogether thus improperly obviating the need for a TMDL and/or missing the opportunity for the right kind of remediation. In contrast, over-emphasizing chemical exceedences that are not proportionate to observed biological impairments can result in misdirected remediation efforts. Even when biological assessment is included as part of the assessment process, its sophistication and level of rigor can affect its ability to detect and characterize impairments and its utility as a diagnostic tool to further understand impairments (Barbour and Yoder 2008). Hence the rigor of all aspects of M&A is critical to the reliability and relevancy of reporting incremental changes.

The Huff Run case example illustrates some of the important issues involved with substituting stressor and exposure indicators as surrogates for determining designated use support. In this case loadings data used alone would have indicated more success than what had been realized biologically. The selective use of chemical parameters, while complemented by a more robust spatial M&A design, would have generated a similar finding. It was the performance of the biota that revealed the influence of multiple stressors and where a significant degree of restoration is yet to be accomplished. Hence, knowing what role an indicator best fulfills is important to applying the results of incremental assessment as a management tool. In terms of tracking overall management program success the reliability of an observed incremental improvement is enhanced with a primary reliance on using and interpreting a stress/exposure/response indicator sequence. Within this framework stressor and exposure indicators serve the vital role of providing the basis for explaining observed changes in the response indicators. In short, incremental improvement and M&A and general are best accomplished following the principles of adequate monitoring and assessment (Appendix B).

The importance of these observations to measures SP-11 and SP-12 lie in the reliability and relevancy of the parameters and indicators that are being reported. In terms of SP-11 (partial improvement) the incremental improvement based on a stressor or exposure indicator is fundamentally different than the same based on a response indicator, yet under the current guidelines these are not necessarily distinguished. While it could be argued that any showing of an incremental improvement has value, we are concerned that the inherent error tendencies of each will ultimately pose a problem for how the ultimate remediation practices are selected, developed, and judged as to their effectiveness. Again, the more gaps that remain in the baseline M&A framework in terms of parameters and indicators and spatial sampling design the greater the eventual uncertainty about the final outcomes. We believe that an adherence to the adequate M&A framework from the initial documentation of the extent and severity impairments through the remediation process will assure that these uncertainties are reduced to manageable levels.

Important Policy Implications

The ability to accurately depict and quantify incremental improvements has some equally important implications for the WQS program, specifically the assignment of attainable designated uses to individual streams and rivers. This process has been of interest to EPA via the TALU framework (U.S. EPA 2005) of which the Ohio WQS for Huff Run are a working example. The demonstration of incremental improvement like that shown for Huff Run across a number of watersheds that are impacted by mine drainage has profoundly influenced how tiered aquatic life use decisions are now made for acid mine drainage impacted streams and rivers in Ohio. Prior to having an awareness of what mine drainage remediation could accomplish, many acid mine drainage impacted streams and watersheds were assigned to the Limited Resource Waters (LRW) use designation based on persistent and severe acidity and low pH values *and* the lack of any impending remediation actions. The latter simply supported the belief that these were intractable and irretrievable impacts that resulted from pre-reclamation law mining practices that produce a high acreage of abandoned mine lands throughout eastern and southeastern Ohio. When subjected to the well structured use attainability analysis (UAA) process that has been used in Ohio since the early to mid 1980s, the result was the designation to LRW which protected against nuisance conditions well below the expectations for baseline CWA goals. This was generally the result of UAAs conducted in these types of streams in the late 1970s and early 1980s prior to the current day AMDAT and 319 remediation programs. Watershed-based remediation efforts emerged in the late 1990s with the advent of active watershed groups, the professional facilitation by the Appalachian Watershed Research Group (within the Voinovich School at Ohio University), abatement funding provided through AMDAT, 319, and U.S. Army Corps of Engineer sources, *and* evidence that there was at least a positive directional (i.e., incremental improvement) change that could be expected as a result of these interventions. While the observed incremental improvements all fell well short of fully meeting WQS, as is the case with the Huff Run and other case studies in Appendix A, it raised the issue of revisiting and ultimately changing the WQS goals for similar mine drainage impacted streams in Ohio. Clearly, the observed improvements went beyond the very minimal expectations for the LRW use designation, thus redesignation to the CWA goal compatible WWH use designation was made. This not only raised the expectations for the ultimate success of these restoration actions, but provided an impetus for continuing these restoration programs in a phased approach. The realistic expectation is that while some if not all of these waters will take many years or even decades to fully meet WQS, the trajectory of change is positive with the expectation that redeemable attributes and benefits will be accrued along the way. While the generation of public support and funding for these projects was critical, the role that a showing of incremental improvement played in these changes was equally important and provided the essential evidence of plausibility.

ASSESSMENT OF CAPACITY TO MEASURE INCREMENTAL IMPROVEMENT

Background

In addition to documenting how incremental improvement can be performed and which indicators are best suited to providing meaningful assessments, detailing the fundamental capacity that is needed to accomplish such is an important objective of this project. We have referenced what is termed “adequate monitoring and assessment” as the framework within which this is best accomplished. This framework was introduced in the late 1990s (Yoder 1998; Yoder and Rankin 1998) has been advocated for the TMDL program (NRC 2001; Karr and Yoder 2004) and for the development and implementation of tiered aquatic life uses (TALU; U.S. EPA 2005; Barbour and Yoder 2008; Yoder and Barbour 2009). States, interstate compacts, and tribes are the fundamental custodians of all aspects of monitoring and assessment (M&A) under the CWA. While the type of M&A needed to perform incremental assessment can be performed outside of state programs, we feel that states are uniquely positioned to foster a more rigorous and consistent process that not only benefits the measurement of incremental improvement, but other water quality management objectives programs as well. States can accomplish this by detailing methods and protocols in their WQS and monitoring strategy documentation. In turn, this provides outside "users" with a consistent and scientifically defensible framework for the design and conduct of data collection, data analysis, and management program targets and benchmarks. Having knowledge about the various state and tribal approaches is then a good way to determine if they are indeed up to the task of documenting incremental improvement such that it is "scientifically sound, appropriately used, and sufficiently sensitive enough to generate data from which signal can be discerned from noise".

Evaluating the Rigor of State Programs

The knowledge and generation of data and results about incremental improvement are fundamentally linked to the better use of M&A to support all relevant water quality management programs. As such, assessing the present capacity of states and others to both carry out and foster the use of incremental assessment tools and indicators is critical to the successful application of this concept in CWA programs. State program adequacy in M&A also makes standardized and robust environmental indicators, methods, QA/QC standards and best practices, assessment methodologies, and assessment criteria *readily available to external users.* By providing a supporting infrastructure of indicators and WQS, state programs can fulfill their custodial role for M&A and WQS and in a more integrated fashion. This not only makes the data and information produced by each state of sufficient quality and reliability[2], but makes it comparable and of a known quality. External users consisting primarily of other government agencies, watershed groups, academic institutions, the regulated community, and non-governmental organizations will have a consistent and standardized framework to follow in conducting their own assessments. These latter efforts can constitute an important and to date largely untapped supplement to the baseline M&A provided by states and it would help better fulfill many other baseline M&A needs in general. Presently, the lack of such a systematic framework in most states results in the production of external data that is of highly variable quality, quantity, comparability, and reliability. This can make the use of such data in incremental assessment highly suspect.

Region V States Evaluation Process

While all U.S. states more or less operate an M&A program, the quality and make-up of each varies widely in terms of organization, design, indicator development and use, and the extent to which they are used to directly support their water quality management programs. The assessment of status for 305b reporting and 303d listing purposes is a significant, and in some cases the *de facto* driver of state M&A programs (MBI 2004). The need for data that can support the TMDL program has only amplified this dependence. There is growing evidence that an over-emphasis on the statewide status assessment function of M&A can supplant and even deter the ability of states to address emerging issues such as refined uses, use attainability analyses, and improved integration between and within water quality management programs in general. All of these are dependent on the capacity of an adequate M&A program to incrementally measure environmental quality over

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[2] **It meets the goal of "scientifically sound, appropriately used, and sufficiently sensitive enough to generate data from which signal can be discerned from noise".**

space and through time and *at the same scale at which management is being applied.* Building and maintaining state capacity to conduct integrated assessments that serve multiple water quality management program needs was a major focus of this evaluation process.

Between 2002 and 2006 MBI conducted reviews of each of the six Region V state monitoring and assessment and WQS programs, specifically as each relates to the assessment of designated aquatic life uses. A report was produced and it documented the methods, indicators, and infrastructure of each state's M&A programs. One key finding was that some states designed and executed their M&A programs with the single purpose goal of producing the biennial 305b report. The net result is that these states were left ill equipped to use M&A to support multiple water quality management programs, of which the measurement of incremental change as envisioned by this report is one consistent need. The states that were found to execute M&A programs that served multiple water quality management program needs are the types of programs that are most likely to fulfill the use of incremental change as a routine management tool.

Critical Technical Elements Process

In 2003 EPA initiated the development of an evaluation framework for state bioassessment programs termed the Critical Technical Elements process. As an outcome of the Region V states pilot evaluation process, this was done primarily to determine the comparative rigor of a state program for supporting the development and implementation of tiered aquatic life uses (TALU; U.S. EPA 2005). The TALU based approach includes tiered aquatic life uses (TALU) based on numeric biological criteria and implementation via an adequate monitoring and assessment program that includes biological, chemical, and physical measures, parameters, indicators and a process for stressor identification (Yoder and Barbour 2009). In short, TALU relies on adequate M&A and its integration with WQS for the full benefits of each to be realized. The capacity to detect and articulate increments of biological change and relate that along a disturbance gradient (which includes measuring incremental changes in stressor and exposure agents) is a fundamental need and requirement to operate such a program. Hence, the baseline capacity to execute TALU is the same as that needed to determine and utilize incremental change.

The guiding principles of the critical elements approach are intended to help state and tribal monitoring and assessment programs achieve levels of standardization, rigor, reliability, and reproducibility that are *reasonably attainable* under current technology and reasonable levels of funding. In turn, this will produce an accurate, comparable, comprehensive, and cost-effective monitoring and assessment program that is capable of meeting the broad goal of supporting all relevant water quality management programs. An important goal of this process is an adherence to the following principles:

Accuracy – biological assessments should produce sufficiently accurate delineations of condition so that type I and II assessment errors are minimized;

Comparability – bioassessment programs that utilize different technical approaches should produce comparable assessments in terms of biological condition ratings, detection of impairments, and diagnostic properties;

Comprehensiveness – biological assessments should be integrated with chemical, physical, and other stressor and exposure indicators, each used in their respective indicator roles (Yoder and Rankin 1998) to demonstrate the relationship between human caused impacts and biological response; and,

Cost-effectiveness – the term as used here means that the benefits of having a rigorous and reliable biological assessment program to support making better management decisions outweighs the intrinsic costs of program development and implementation.

In this process, the key technical elements of bioassessment programs are described and ranked into one of four general levels of rigor supported by a sliding scale of resolution and development. Level 4 is the most rigorous and most appropriate to address the myriad of management issues regarding aquatic resources. The remaining three levels of bioassessment rigor may be appropriate to support some, but not all, water quality management program support needs. For the purposes of this report, determining impairment and diagnosing categorical and parameter-specific stressors provides the fundamental basis for supporting the measurement of incremental change.

Table 3 depicts how the different levels of rigor for bioassessment support the key technical questions that are the foundation for different aspects of water quality programs ranging from the determination of condition to causal analysis. The number of asterisks denotes increasing confidence in addressing the underpinnings of the baseline technical questions. The capacity of each bioassessment level to provide programmatic support is described as:

- *Level 1* produces pass/fail assessments and is not amenable to supporting other functions such as expressions of severity and magnitude of effect or causal associations.

- *Level 2* ranges from dichotomous (pass/fail) to multiple (3-4 categories) condition assessments; it is capable of only general cause and effect determinations.

- *Level 3* is capable of providing programmatic support for incremental condition assessments along the BCG and for most causal associations, but is limited to a single assemblage.

- *Level 4* achieves comprehensive fulfillment of program support by providing the most robust and complete assessments including scientific certainty, accuracy, relevancy of condition assessment, and causal associations; it includes two assemblages at a minimum.

Discussion

Since the methodology was developed in late 2003, a total of 18 states and one tribe have been formally evaluated and the level of rigor determined. Two (2) states achieved level 4, five (5) states achieved level 3, ten (10) states and one tribe achieved level 2, and one state achieved level 1. While this does not represent a random sample of the states, it is inclusive enough of different areas and regions of the U.S. to be considered a fair representation of state capacities. Detailed analyses of these results (Yoder and Barbour 2009) indicate that the level 3 and 4 states have the essential technical capacity to accurately apply incremental assessment in keeping with the principles of adequate M&A. Ohio is one of the two level 4 states and this is exemplified by the case examples in Appendix A. It also represents the value of the custodial role that is fulfilled by Ohio EPA in that these assessments were performed by external entities following their methods, protocols, and criteria. This capacity greatly diminishes at level 2 to the point where incremental assessment is rudimentary at best. While such states may be able to demonstrate incremental improvement in limited instances the inherent pass/fail attributes of their assessment frameworks technically limits incremental assessment. The recent set of state evaluations shows that each state has developmental activities either planned or underway that will result in elevating the level of rigor with the next 5+ years. Hence we should expect that the technical capacity to conduct incremental assessment should become more widespread provided that these efforts continue.

Table 3. Relative degrees to which the four different levels of rigor for bioassessment defined by the Consolidated Assessment and Listing Method (CALM) process support the key technical questions that serve as a basis for water quality management programs.

	Condition Assessment		Causal Associations		
Level	Impair/non-impaired	Multiple Condition	General	Categorical	Parameter Specific
1	*	—	—	—	—
2	**	*	*	—	—
3	**	**	**	**	*
4	***	***	***	***	**

***	Comprehensively fulfills program support role by providing robust and complete assessment including Best Available scientific certainty in accuracy (i.e., minimizing Type 1 and 2 errors) of condition assessment, and categorical causal associations.
**	Condition assessments minimizes Type 1 error but doe not adequately address Type 2; general causal associations.
*	Condition assessments only address Type 1 error at extremes of condition and do not address Type 2 error; no causal association ability.

The development of the technical capacity to accomplish incremental assessment is alone insufficient to make its practice a routine output of state programs. The overarching impetus and incentive for conducting this type of reporting is also needed and it needs to become incrementally based in its own right. Presently, the states are only required to report in a bivariate pass/fail framework with little recognition given to more detailed reporting of condition. This needs to change if the states are to make the type of broad progress that is needed to make the desired measures such as SP-11 and SP-12 have wider application and acceptance. It would seem clear that the pursuit of TALU based programs in the states is presently a good way to make this outcome a reality while satisfying many other water program needs.

REFERNCES

Barbour, M.T., and C. O. Yoder. 2008. Critical Technical Elements of a Bioassessment Program. U.S. EPA, Office of Water, Washington, DC. (September 2008). 75 pp.

Karr, J. R., K. D. Fausch, P. L. Angermier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5: 28 pp.

Midwest Biodiversity Institute (MBI). 2004. Region V state bioassessment and ambient monitoring programs: initial evaluation and review. Midwest Biodiversity Institute Tech. Rept. MBI/01-03-1. 36 pp. + appendices. (http://www.epa.gov/region5/water/wqb/wqb_r5mon.htm)

National Research Council (NRC). 2001. Assessing the TMDL Approach to Water Quality Management. National Academy Press, Washington, DC., 109 pp.

Ohio Environmental Protection Agency (EPA). 1989. Biological criteria for the protection of aquatic life. volume III: standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Rankin, E.T. 2003. Comparison of Biological-based and Water Chemistry-based Aquatic Life Attainment/Impairment Measures under a Tiered Aquatic Life Use System. Center for Applied Bioassessment and Biocriteria Fact Sheet 3-CABB-03, Center for Applied Bioassessment and Biocriteria, Midwest Biodiversity Institute, Columbus, OH. 28 pp.

Rankin, E. T. 1989. The qualitative habitat evaluation index (QHEI), rationale, methods, and application, Ohio EPA, Division of Water Quality Planning and Assessment, Ecological Assessment Section, Columbus, Ohio.

Rankin, E. T. and Yoder, C. O. 1990. A comparison of aquatic life use impairment detection and its causes between an integrated, biosurvey-based environmental assessment and its water column chemistry subcomponent. Appendix I, Ohio Water Resource Inventory (Volume 1), Ohio EPA, Div. Water Qual. Plan. Assess., Columbus, Ohio.

Stoertz, M.W. and D.H. Green. 2004. Mean Annual Acidity Load: A Performance Measure to Evaluate Acid Mine Drainage Remediation. Ohio DMRM Applied Research Conference 2004. Mineral Resource Extraction and Restoration Innovations. Ohio University, Russ College of Engineering and Technology, Athens, OH.

U.S. Environmental Protection Agency (EPA) 2008a. National Water Program: Strategic Plan and Guidance. URL: http://www.epa.gov/water/waterplan/index.html#final Accessed 11/24/08.

U.S. Environmental Protection Agency (EPA). 2008b. Guidance on Reporting Watershed Improvement under Measure SP-12. URL: http://www.epa.gov/water/waterplan/documents/SP-12_Guidance_1-31-08.pdf Accessed 11/24/08.

U.S. Environmental Protection Agency (EPA). 2008c. Strategic Target SP-11. URL: http://www.epa.gov/water/waterplan/pamsfy08/def_wq08.html#sp11 Accessed 11/24/08.

U.S. EPA. 2005. Use of biological information to better define designated aquatic life uses in state and tribal water quality standards. Office of Water, Washington, DC. EPA 822-R-05-001. 188 pp.

U.S. Environmental Protection Agency. 1995a. Environmental indicators of water quality in the United States. EPA 841-R-96-002. Office of Water, Washington, DC 20460. 25 pp.

U.S. Environmental Protection Agency. 1995b. A conceptual framework to support development and use of environmental information in decision-making. EPA 239-R-95-012. Office of Policy, Planning, and Evaluation, Washington, DC 20460. 43 pp.

Yoder, C.O. and M.T. Barbour. 2009. Critical technical elements of state bioassessment programs: a process to evaluate program rigor and comparability. Environ. Mon. Assess. DOI10.1007/s10661-008-0671-1 (accepted for publication).

Yoder, C.O. and E.T. Rankin. 1998. The role of biological indicators in a state water quality management process. J. Env. Mon. Assess. 51(1-2): 61-88.

Yoder, C.O. 1998. Important Concepts and elements of an adequate state watershed monitoring and assessment program, pp. 615-628. *in* Proceedings of the NWQMC National Conference Monitoring: Critical Foundations to Protecting Our Waters. U.S. EPA, Washington, DC, 663 pp. + app.

Yoder, C. O., and Rankin, E. T. 1995. Biological criteria program development and implementation in Ohio, pp. 109-144. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Appendix A

Demonstrating Incremental Improvement: Case Studies in Biological and Water Quality Assessment of Acid Mine Drainage Abatement and Treatment (AMDAT) Projects

Project Report to:

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U.S. EPA, HECD Contract 68-C-04-006
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Appendix A

Demonstrating Incremental Improvement: Case Studies in Biological and Water Quality Assessment of Acid Mine Drainage Abatement and Treatment (AMDAT) Projects

Background

We utilized the results of watershed assessments performed by the Ohio University Voinovich School for Leadership and Public Affairs[1], the Midwest Biodiversity Institute, and selected watershed groups in support of Acid Mine Drainage Abatement and Treatment (AMDAT) projects sponsored by the Ohio Department of Natural Resources Division of Mineral Resources Management and 319 implementation projects sponsored by Ohio EPA. AMDAT projects in Ohio can also qualify as TMDLs under a cooperative arrangement with Ohio EPA whereby these studies utilize the same methods and indicators and address WQS issues as part of the watershed assessment. Pollutant loading reductions needed to meet WQS are then developed and are evaluated by an adequate monitoring and assessment approach (Yoder 1998; Yoder and Rankin 1998) to determine overall abatement project effectiveness. As such the data and information are well suited to documenting incremental changes in chemical/physical and biological indicators through space and time.

The five case studies are drawn from three watersheds in the coal bearing region of Ohio: Huff Run, Monday Creek, and Raccoon Creek. These watersheds have varying amounts of data to support the demonstration of incremental change, but each has the essential indicators to demonstrate the sequence of actions from TMDL development to pollution abatement to incremental recovery towards attainment of WQS. There are varying amounts of incremental change across these five restoration project examples each showing varying degrees of biological and chemical/physical change. Three of the five examples are active lime dosing treatment BMP projects (Jobs Hollow, Essex Doser, and Hewett Fork). The other two are examples of sub-watersheds containing numerous passive systems and varying amounts of change in the receiving streams (Huff Run and Little Raccoon Creek) through time.

Huff Run

Huff Run flows from the Morges Community in Carroll County, into Tuscarawas County and has its confluence in the Conotton Creek just South of Mineral City, Ohio. Huff Run is 9.9 miles long with a 13.9 square mile watershed. Almost all land east of State Route 542 (about 2/3 of the watershed) has been mined for coal, limestone, and clay. Because much of the mined lands were not reclaimed, the watershed is impacted by acid mine drainage (AMD). Other pollution issues in the watershed include illegal dumping, riparian encroachment, raw sewage discharges, oil and gas drilling impacts, and agricultural (row cropping) impacts.

The Huff Run Watershed Restoration Partnership Inc. (HRWRP) was founded in 1996 by a group of concerned citizens. The HRWRP has partnered with ODNR/MRM, Rural Action, Ohio EPA,

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[1] see http://www.watersheddata.com/ for watershed projects data and reports.

Crossroads RC&D, OSM and others to fulfill their mission statement "to restore the Huff Run watershed by improving water quality and enhancing wildlife habitat, through community support and involvement."

There have been seven reclamation projects completed in the Huff Run Watershed since 1998. All projects are located adjacent to the mainstem of Huff Run. Table 1 shows the name of each project, a brief description, and the year completed. Data derived using the Mean Annual Load Method (Stoertz and Green, 2004) total acid loading reduction at the mouth of Huff Run is 82 lbs/day (Figure 1). The pre-reclamation acid load condition was based on two samples 1985 and 1996; since 1999 the mouth of Huff Run has continued to be net alkaline (i.e. all acidity has been reduced). Metal load reductions were derived using this same method. There were no metal load reductions up to 2005, however with the 2007 data, minimal metal load reductions were indicated, 103 lbs/day, Figure 2.

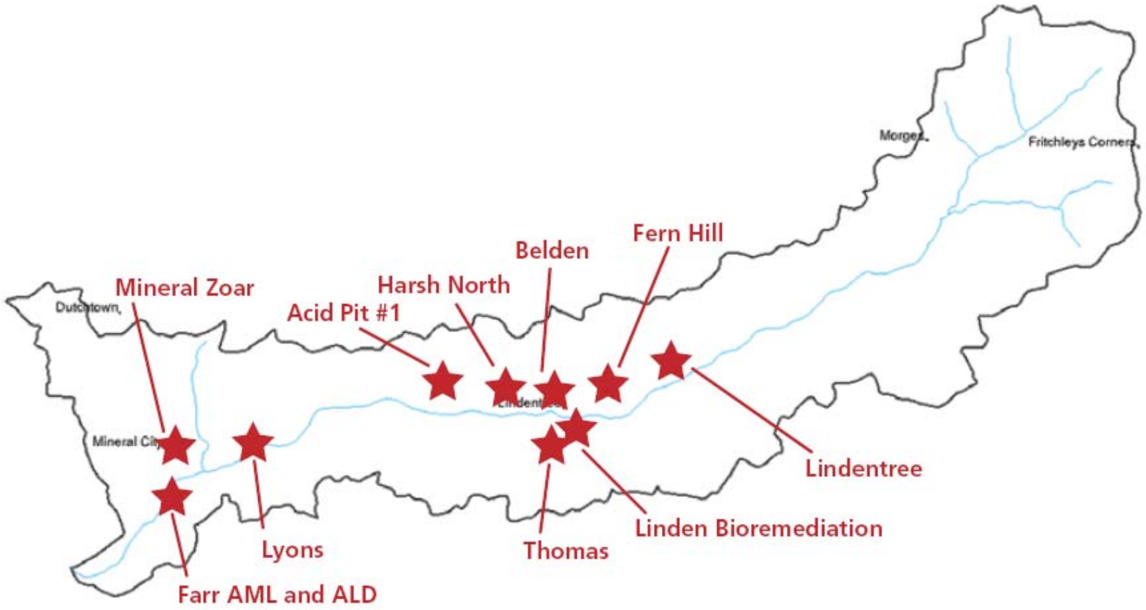
Table 1. Acid mine drainage treatment projects completed in the huff Run Watershed

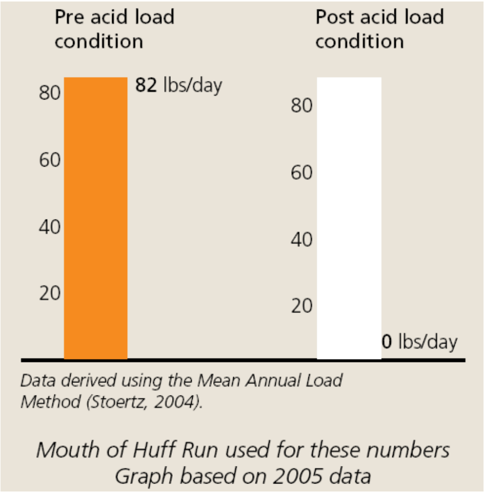
AMD project name	Brief description of treatment	Year Completed	Total Cost
Huff Run AML reclamation (Mineral City)	Surface reclamation	1998	
Farr AML and ALD	Anoxic limestone drain, limestone channels, and a wetland	2003	$180,976
Linden Bioremediation	Microbial inoculated pyrolusite limestone treatment bed	2003	$321,619
Acid Pit #1	Reclaim 15 acre gob pile and limestone drains	2004	$150,000
Lindentree	Surface reclamation, limestone and slag channels	2005	$270,240
Lyons	Gob pile reclamation (15 acres), surface reclamation (5 acres), limestone and steel slag channels	2005	$847,365
Harsh North	Surface reclamation	2006	$793,095

Longitudinal stream quality for pH and net acidity

Eight stations along the mainstem of Huff Run have been monitored through time. The values for pH were average during the pre-construction time period prior to 1997. The first project was completed in 1998. From 1998 through the present seven projects were completed at various times, see table 1. This time period from 1998 – 2008 is considered the "post-construction" time period in the graphs below figures 3 and 4. However, technically this section of stream is in a transitional construction phase until all projects are complete. There are two funded proposed projects: Belden and Thomas and two proposed projects: Fern Hill and Mineral Zoar, see map.

Funded/proposed projects: Belden, Fern Hill, Mineral Zoar, and Thomas





Data derived using the Mean Annual Load Method (Stoertz, 2004).

Mouth of Huff Run used for these numbers
Graph based on 2005 data

Figure 1. Acid load reductions at the mouth of Huff Run under pre- and post-treatment.

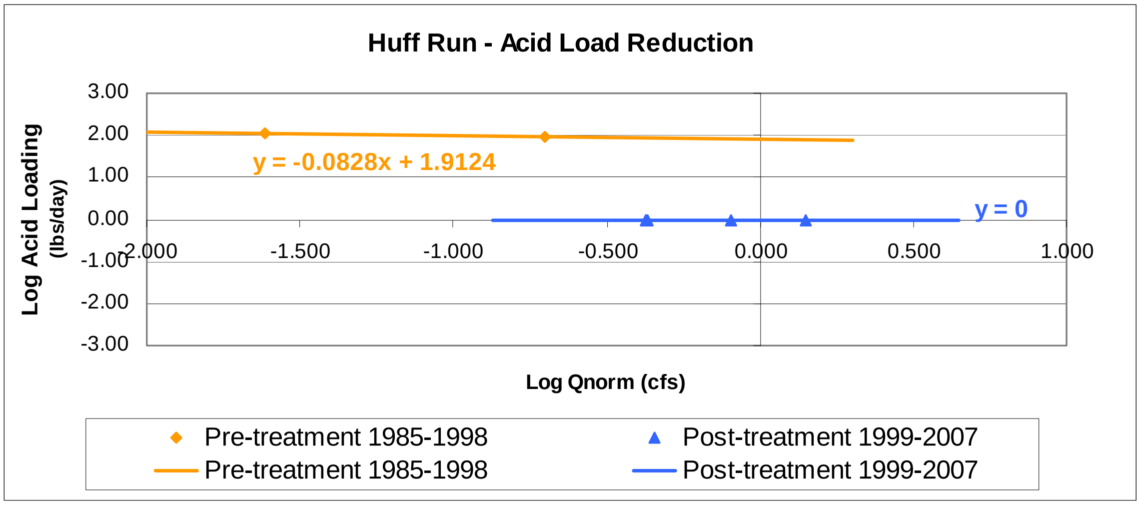
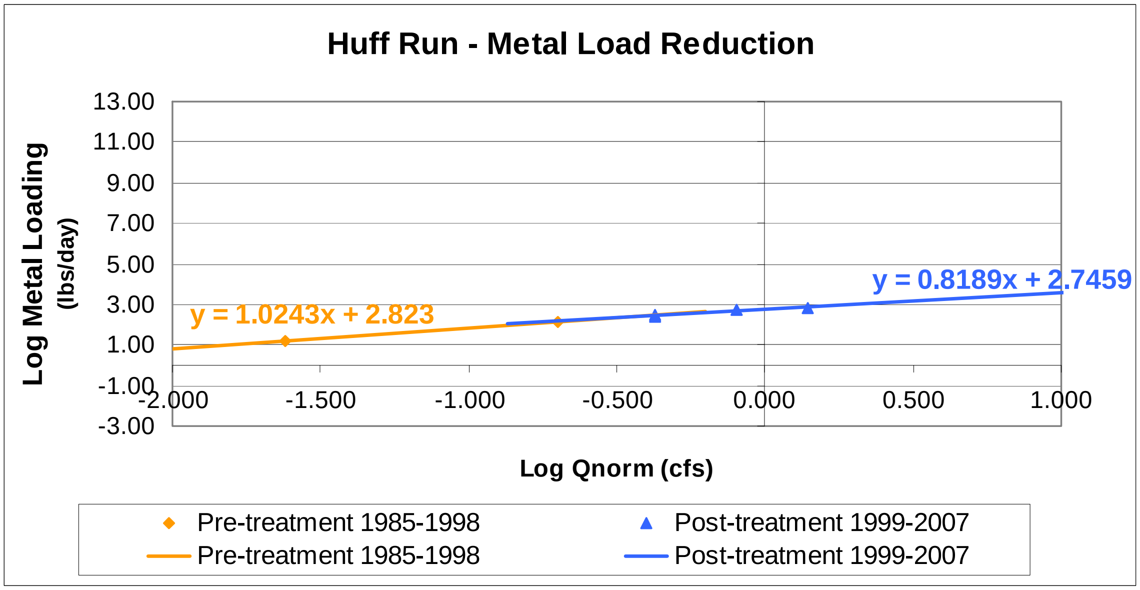


Figure 2. Metal load reductions



Water quality data collected at the mouth of Huff Run (RM 0.40) show an increase in both the pH and net acidity through time, Figure 5 and 6. Total iron concentrations continue to be elevated at the mouth of Huff Run. Post construction values are similar to pre-construction values. Iron exceeds the Ohio WQS of 1.0 mg/l, Figure 7. Total aluminum concentrations decreased during the post construction time period. However the levels of aluminum that remains at the mouth of Huff exceeded the EPA chronic aquatic criterion of 0.087mg/l, Figure 8.

How do these documented water quality improvements translate into biological recovery?
ICI data for 2005 and 2006 indicate a small increase at three stations with the largest increase noted at the mouth (two new taxa from 2005 to 2006), Figure 6. IBI scores between 1997 and 2006 indicate no significant changes at the mouth, but the number of fish species increased from 1 to 7, Table 2. Habitat is sufficient to support meeting the WWH biocriteria, but sedimentation and substrate embeddedness remains a problem and are linked to the high instream iron concentrations and general sediment in runoff, Table 3.

Figure 3. Longitudinal pH values

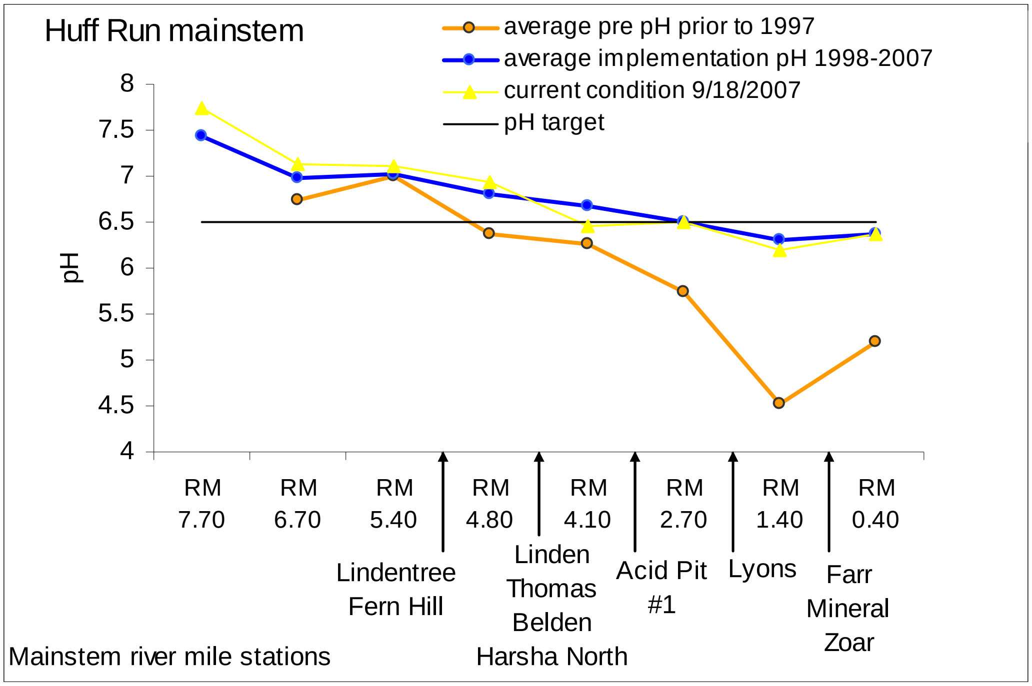


Figure 4. Longitudinal net acidity values

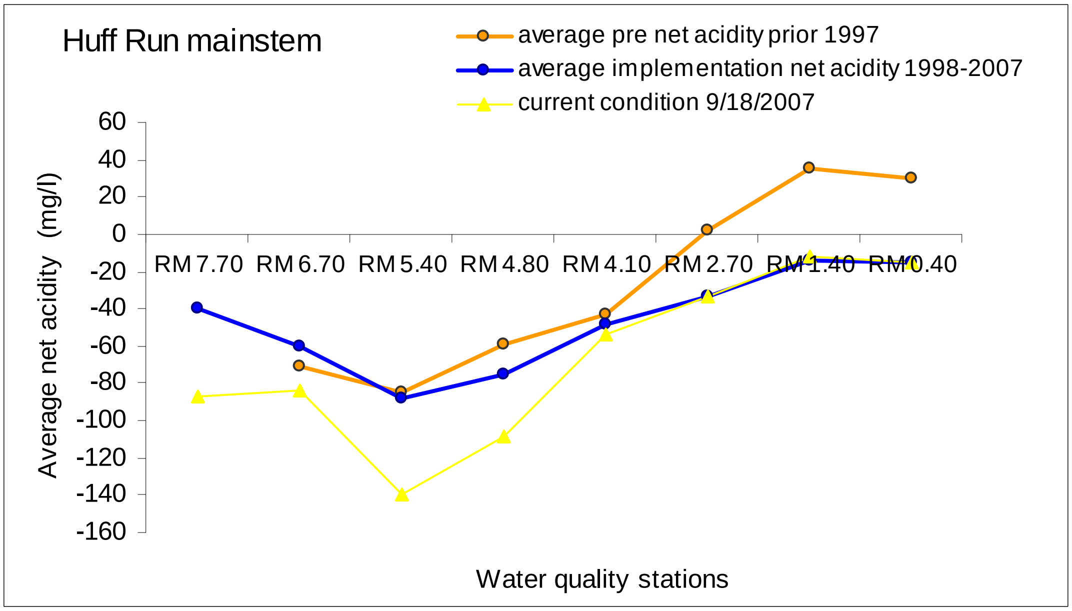


Figure 5. Water quality values at the mouth of Huff Run through time

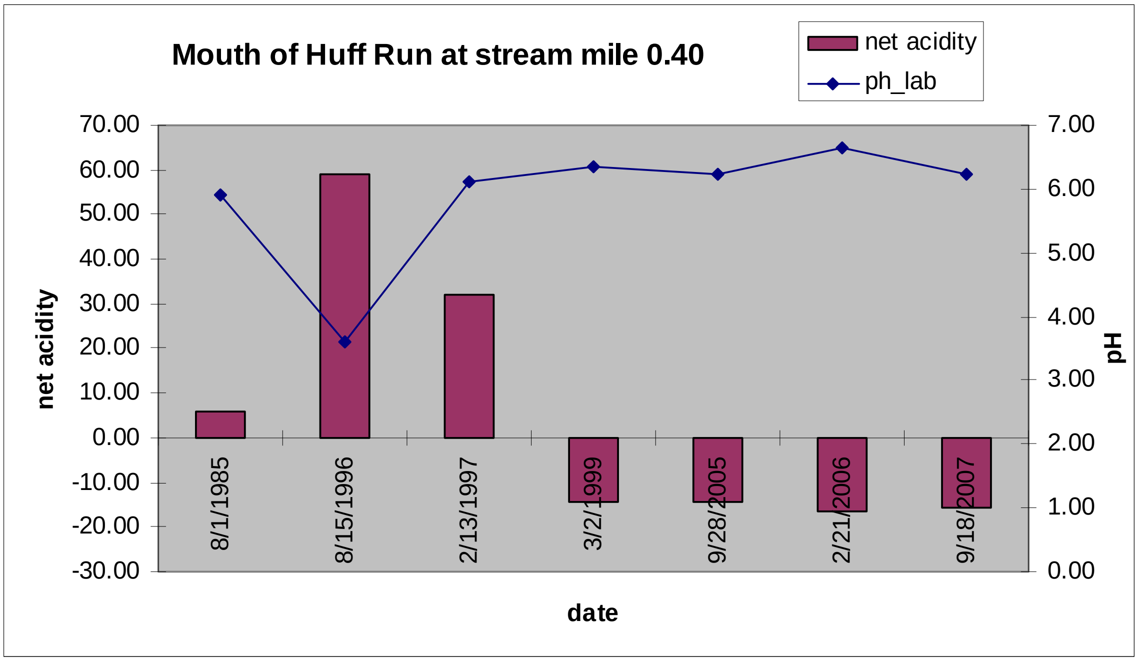


Figure 6. pH values at the mouth of Huff Run through time

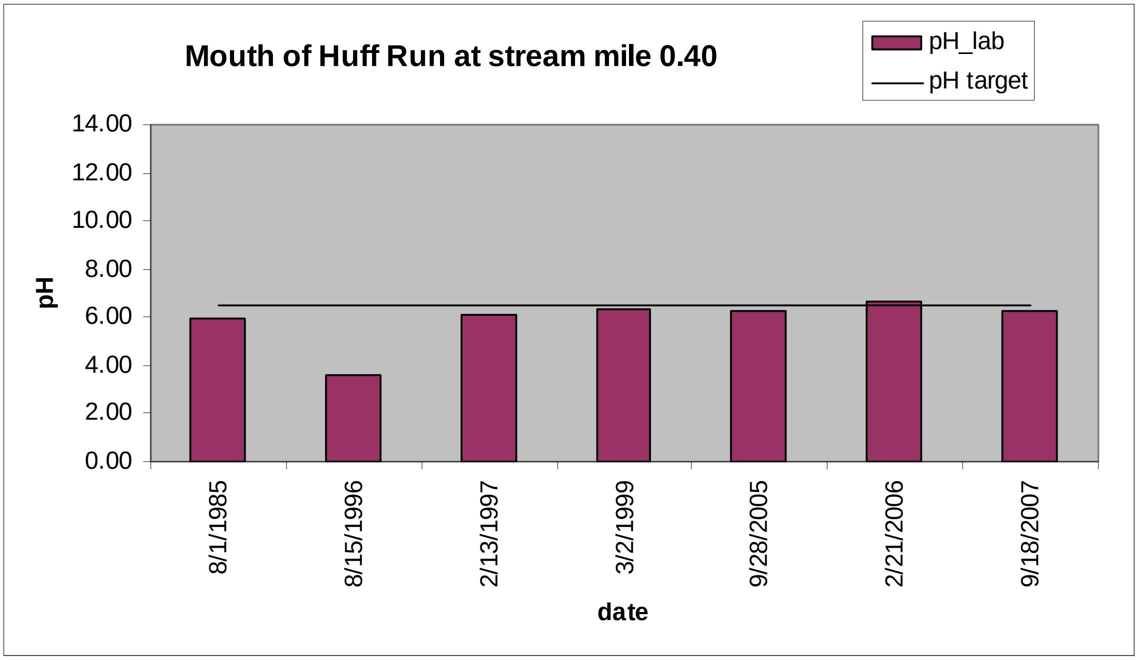


Figure 7. Mouth of Huff Run total iron concentrations

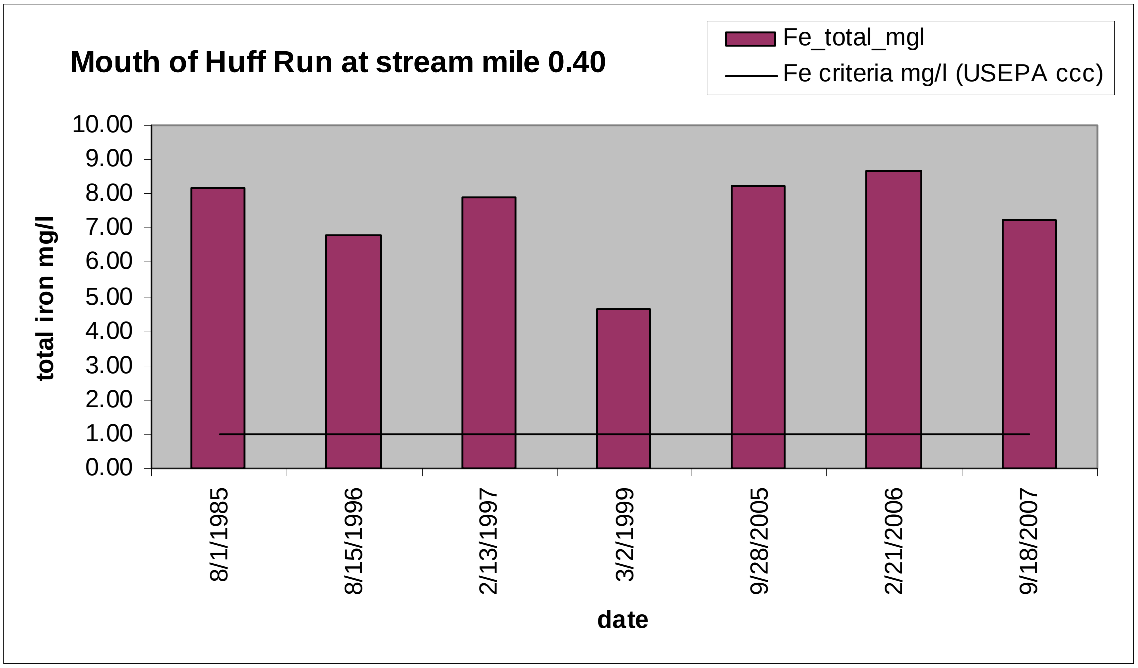


Figure 8. Mouth of Huff Run aluminum concentrations

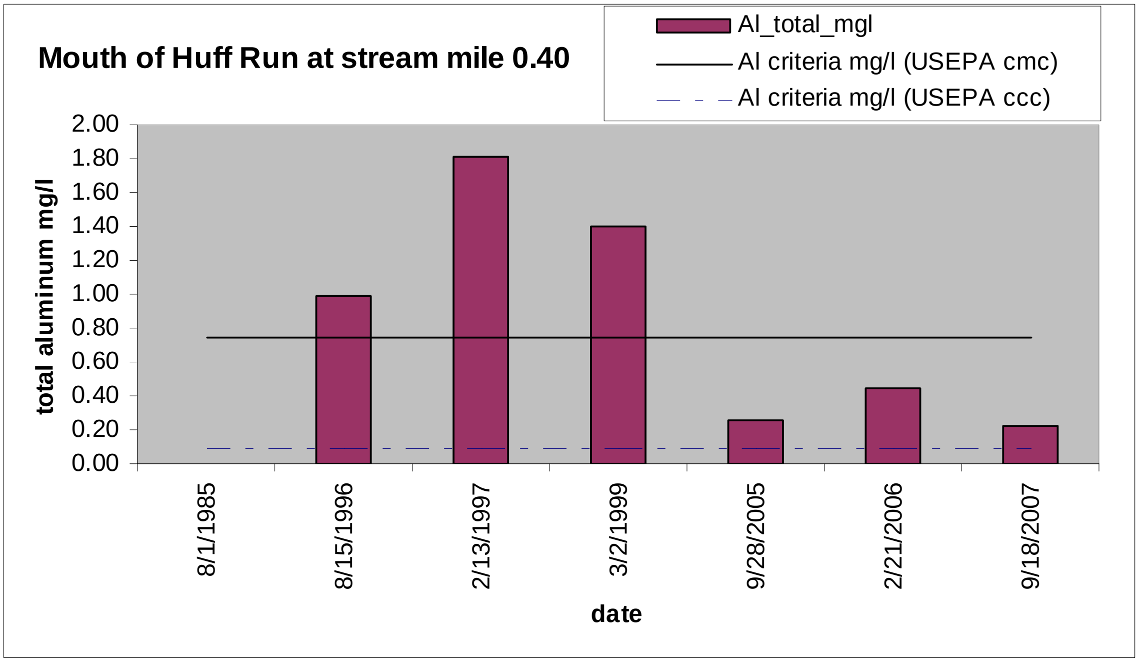


Table 2. Fish assemblage changes at the mouth of Huff Run

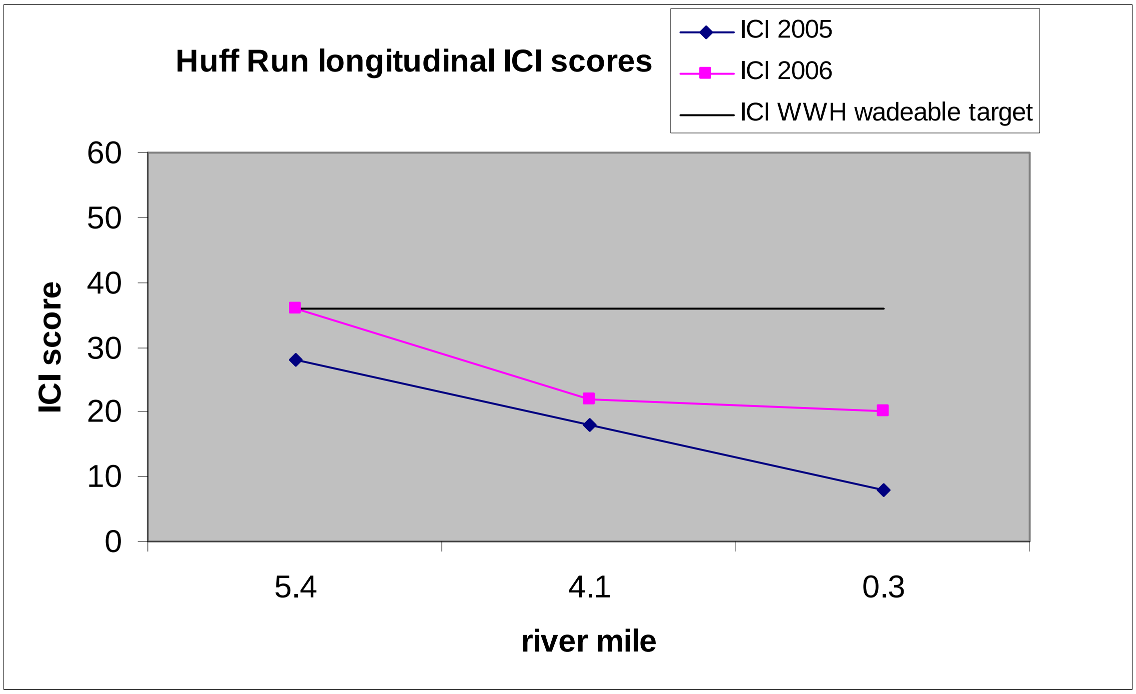
RM 0.40	IBI	Fish Species
1997	16	1
2005	16	2
2006	18	7

Table 3. QHEI scores and metric values for sites in Huff Run.

Key
QHEI
Components

River Mile	QHEI	Gradient (ft/mile)	WWH Attributes											MWH Attributes: High Influence						MWH Attributes: Moderate Influence														
			No Channelization or Recovered	Boulder/Cobble/Gravel Substrates	Silt Free Substrates	Good/Excellent Substrates	Moderate/High Sinuosity	Extensive/Moderate Cover	Fast Current/Eddies	Low-Normal Overall Embeddedness	Max Depth > 40 cm	Low-Normal Riffle Embeddedness	Total WWH Attributes	Channelized or No Recovery	Silt/Muck Substrates	No Sinuosity	Sparse/No Cover	Max Depth < 40 cm (WD, HW)	Total H.I. MWH Attributes	Recovering Channel	Heavy/Moderate Silt Cover	Sand Substrates (Boat)	Hardpan Substrate Origin	Fair/Poor Development	Low Sinuosity	Only 1-2 Cover Types	Intermittent and Poor Pools	No Fast Current	High/Mod. Overall Embeddedness	High/Mod. Riffle Embeddedness	No Riffle	Total M.I. MWH Attributes	(MWH H.I.+1)/(WWH+1) Ratio	(MWH M.I.+1)/(WWH+1) Ratio
(17101) Huff Run																																		
Year: 1997																																		
7.4	72.50	24.39	■	■		■	■	■	■		■		7						0		■			■					■	■		4	0.13	0.63
5.2	60.00	26.58	■	■				■	■		■		5		◆	◆			2		■			■	■				■	■		5	0.50	1.33
0.3	60.50	16.48	■				■	■	■		■		5			◆			1		■			■	■				■	■	■	6	0.33	1.33
Year: 2005																																		
7.7	59.50	24.39		■				■	■		■	■	5						0		■								■			2	0.17	0.50
6.7	63.50	15.00	■	■		■	■	■	■				7	◆					1		■								■	■		3	0.25	0.63
5.4	77.00	26.58	■	■		■	■	■	■	■	■	■	9						0													0	0.10	0.10
4.8	77.00	15.00	■			■	■	■	■		■	■	7						0		■								■			2	0.13	0.38
3.0	64.50	16.48	■				■	■	■		■	■	6			◆			1		■		■	■	■				■			5	0.29	1.00
2.7	68.00	15.00	■			■	■	■	■		■		6						0		■		■						■	■		4	0.14	0.71
1.4	67.00	15.00	■			■		■	■		■		5			◆			1		■			■	■				■	■		5	0.33	1.17
0.4	68.50	16.48	■	■		■	■	■	■		■		7						0		■								■	■	■	4	0.13	0.63
Year: 2006																																		
5.4	76.00	26.58	■	■		■	■	■	■	■	■		9						0		■								■	■		3	0.10	0.40
4.1	34.50	15.00									■		1	◆	◆	◆	◆		4		■			■	■			■	■	■		6	2.50	5.50
0.4	66.50	16.48	■	■		■	■	■		■	■		7				◆		1		■			■				■	■	■		5	0.25	0.88

Figure 6. ICI values along the mainstem of Huff Run



As levels of the metal concentration decrease as more projects are completed, it is expected the biological communities will continue to respond positively. However, while metal concentrations remain higher than the chronic criteria only small incremental changes can be expected.

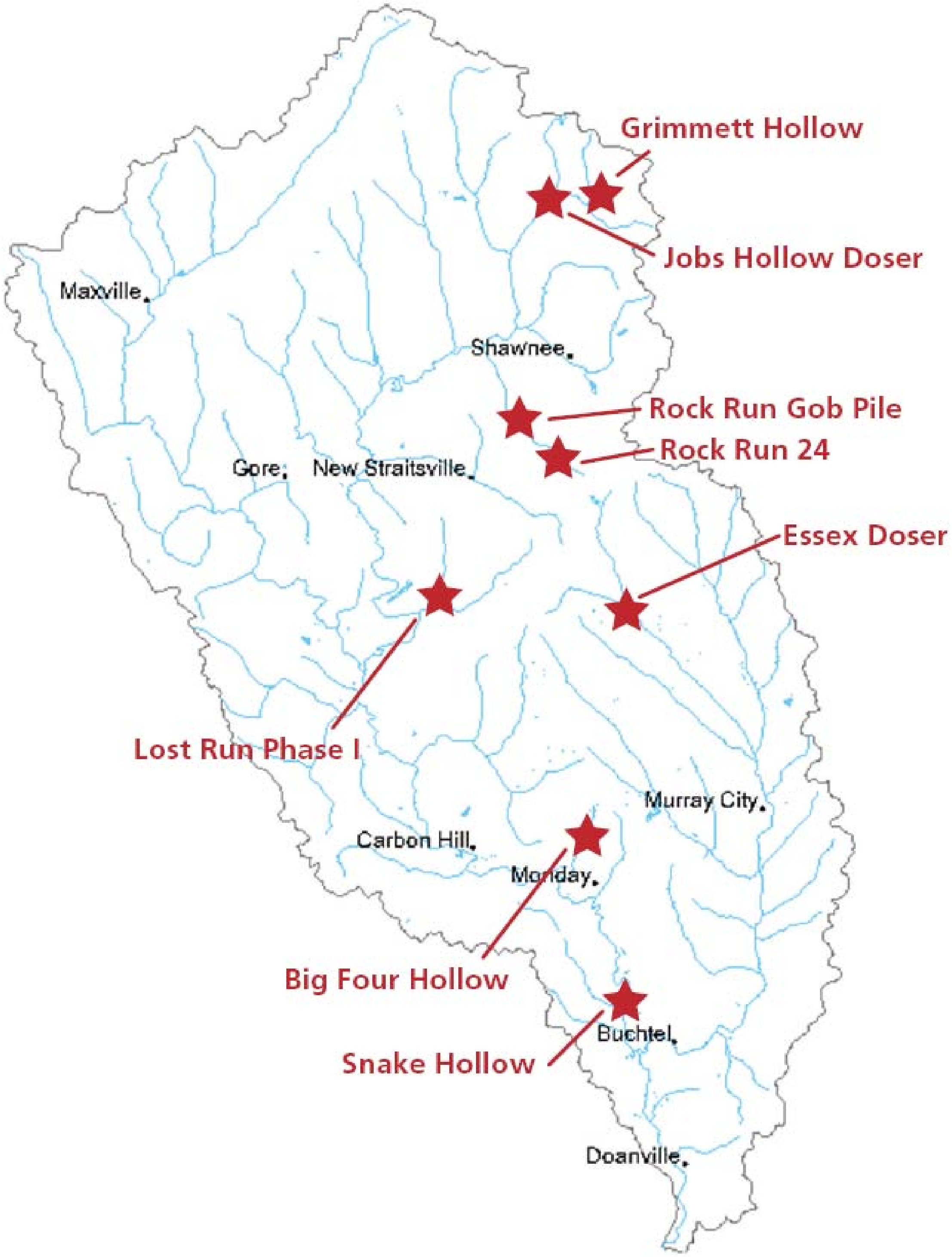
Monday Creek

Monday Creek, located in the Appalachian Region of southeastern Ohio, is a 27-mile long tributary of the Hocking River, the latter which flows directly into the Ohio River. The Monday Creek watershed drains a 116 square-mile area, with streams winding through portions of Athens, Hocking, and Perry Counties.

The Monday Creek Restoration Project is a collaborative partnership of official and residents of the Monday Creek watershed, along with more than 20 other organizations and state and federal agencies. The goal of the project is to restore the watershed for the benefit of local communities. Extensive portions of Monday Creek and its tributaries are dead due to acid mine drainage (AMD) left behind from a century of coal mining.

For purposes of the collection of case studies, two reclamation projects have been selected for review in Monday Creek: Jobs Doser and Essex Doser. Both of these BMPs are active remediation projects and require on-going maintenance for operation.

AMD project name	Brief description of treatment	Year completed	Capital Costs
Jobs Hollow Doser	Install lime doser, decrease acid load from headwaters by 54%	2004	$ 385,983
Essex Doser	Install lime doser	2006	$ 319,720



Essex Doser

Essex Doser is located in Section 18 of Ward Township in Hocking County and lies within the 14 digit HUC unit #05030204060040. The site is located along Sycamore Hollow, State Route 216. Sycamore Hollow is a tributary to Snow Fork. The design was completed by ATC Associates for a cost of $32,320. The treatment was to install a lime doser. The goal of the design was to neutralize acidity discharging from Essex Mine. The project goal, as indicated from initial post-construction sampling, has been met 100 percent. Further evaluation of this site will be completed next year after more data has been collected. A major consideration encountered during the design was the close proximity of the doser to State Route 216. Construction was complete March 31, 2006, by AWT Services Inc. for a cost of $287,400. The major responsibility of the construction company was to install the doser. The funding sources for this project were ODNR-DMRM and EPA-319 for both the design and construction.

In the short amount of time since the Essex Doser was implemented, an increase in both the chemical and biological water quality has been documented. Longitudinal chemical water quality improvements were documented from the mine discharge/doser site at river mile 9.77downstream into Snow Fork for 7 miles. There were increases in pH initially that remained above 6.5 until Sycamore Hollow flows into the headwaters of Snow Fork at river miler 6.2. At this point the pH remains higher than pre-doser conditions but is steadily dropping due to additional acidic-mine drainage discharges flowing into Snow Fork, Figure 1. This trend is mimicked in the longitudinal net-acidity values recorded along the mainstem of Sycamore Hollow and its receiving stream Snow Fork, figure 2.

Figure 1. Longitudinal pH values pre and post implementation of BMP

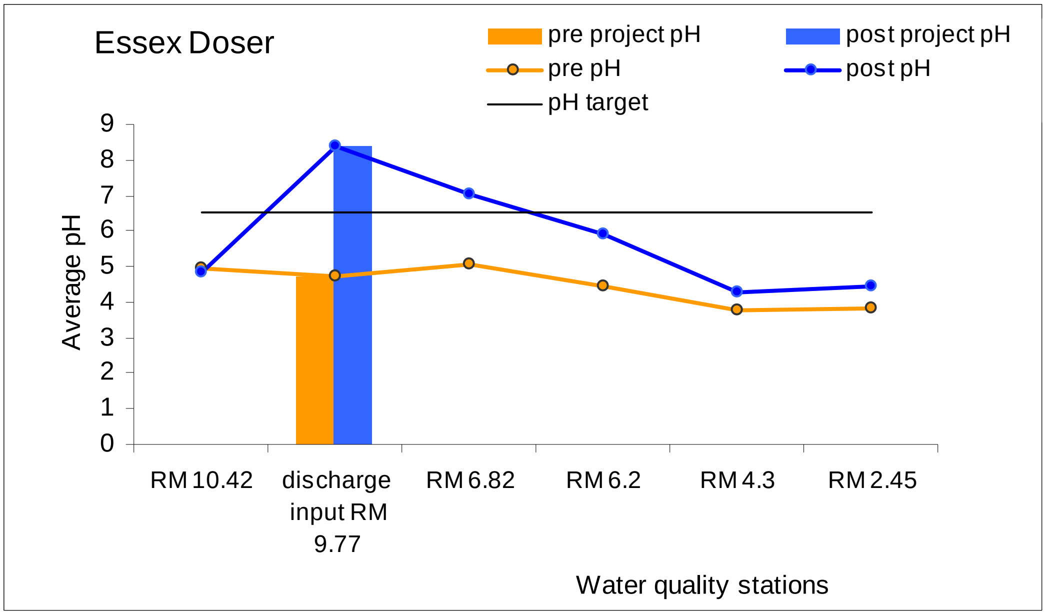
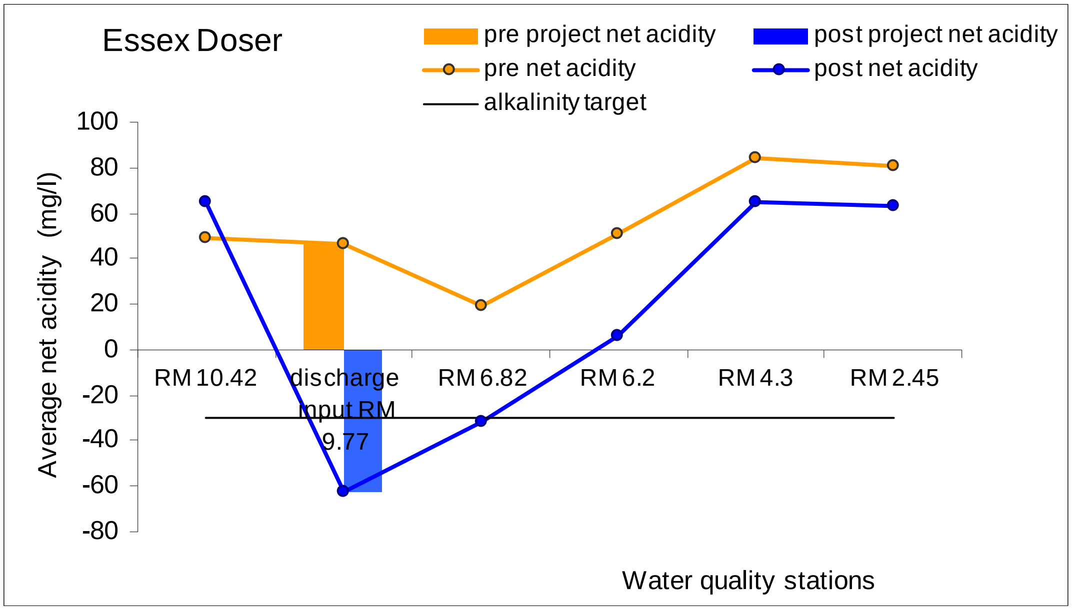
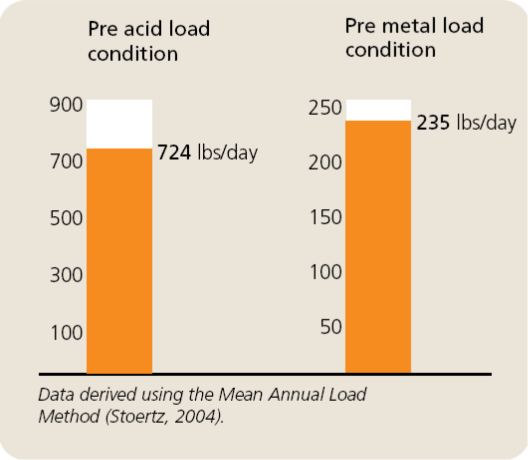


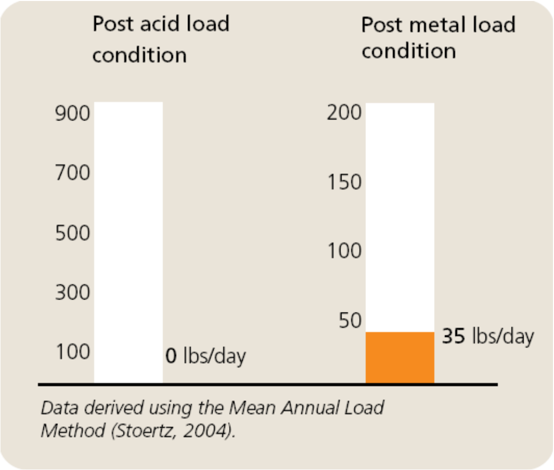
Figure 2. Longitudinal net-acidity concentrations pre and post implementation of BMP



From the Mean Annual Load Method (Stoertz and Green, 2004), the calculated acid and metal load reductions were 724 lbs/day and 200 lbs/day respectively, figure 3 and 4. Essentially all the acidity has been neutralized and the load to the stream is net alkaline at the mine site. The metals are precipitating and becoming part of the stream substrate at the site and downstream of the site.



Data derived using the Mean Annual Load Method (Stoertz, 2004).



Data derived using the Mean Annual Load Method (Stoertz, 2004).

The biological response to the chemical changes is small but do demonstrate positive change at this time, further monitoring continues. Three miles downstream of the Essex Doser before Sycamore Hollow enters into Snow Fork, IBI, ICI, and MAIS were calculated. Both IBI and ICI exhibit positive incremental change from 12 to 20 for IBI and 4 to 20 for ICI. Fish count changed from 0 in 2001 and 2005 to 222 in 2006. The overall narrative changed from VP to F during this same time period. The MAIS index didn't indicate a

Figure 3. Acid load reductions at the Essex Doser site.

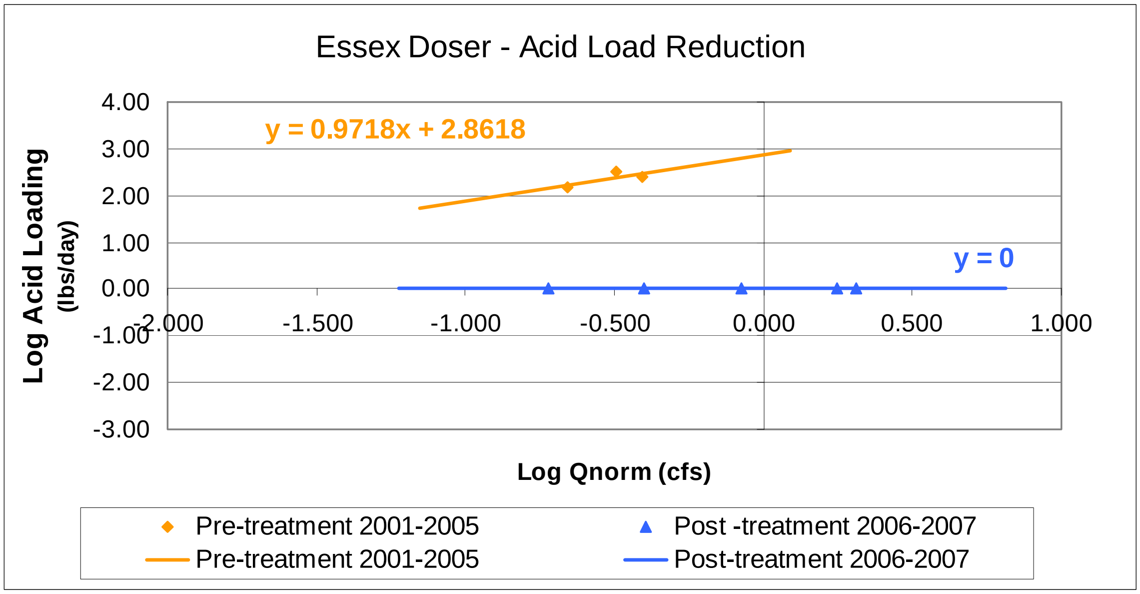
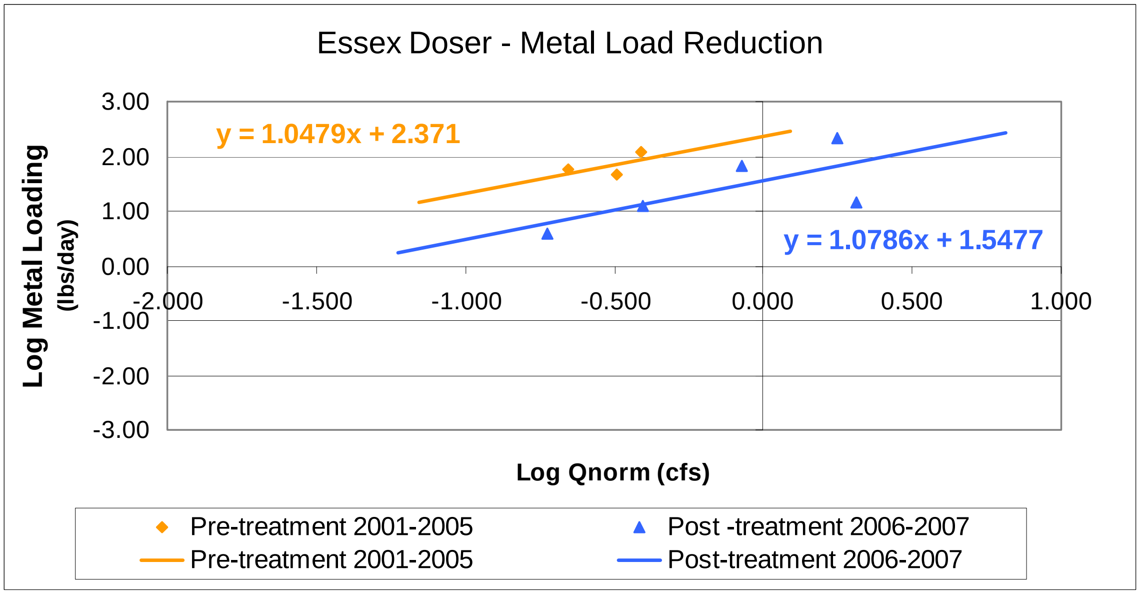


Figure 4. Metal load reductions at the Essex Doser site.



positive change at this station but did directly downstream of the doser, Figure 5. Macroinvertebrate family level index, MAIS, indicates in 2007 a MAIS score of 13 (a MAIS score greater than 11 is equivalent to good quality) at the station directly downstream of the Essex Doser, Figure 6.

Jobs Hollow Doser

Jobs Hollow Doser is located in Section 5 of Salt Lick Township in Perry County and lies within the 14-digit HUC unit #05030204060010. The site is located in the headwaters of Monday Creek Watershed downstream of Jobs Hollow at the bridge on Portie Flamingo

Figure 5. Biological response three miles downstream of the doser.

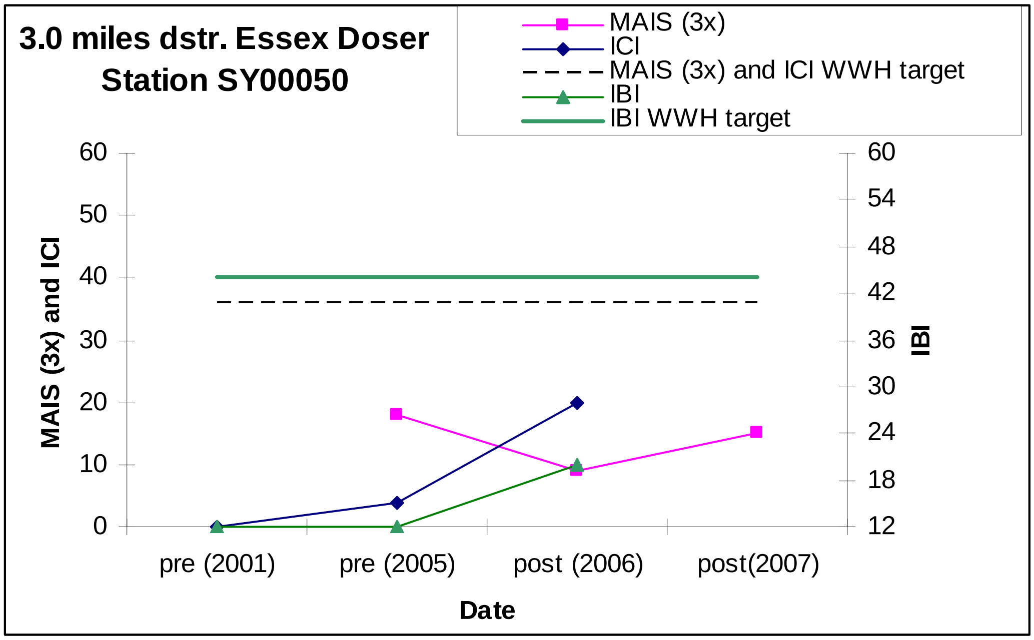
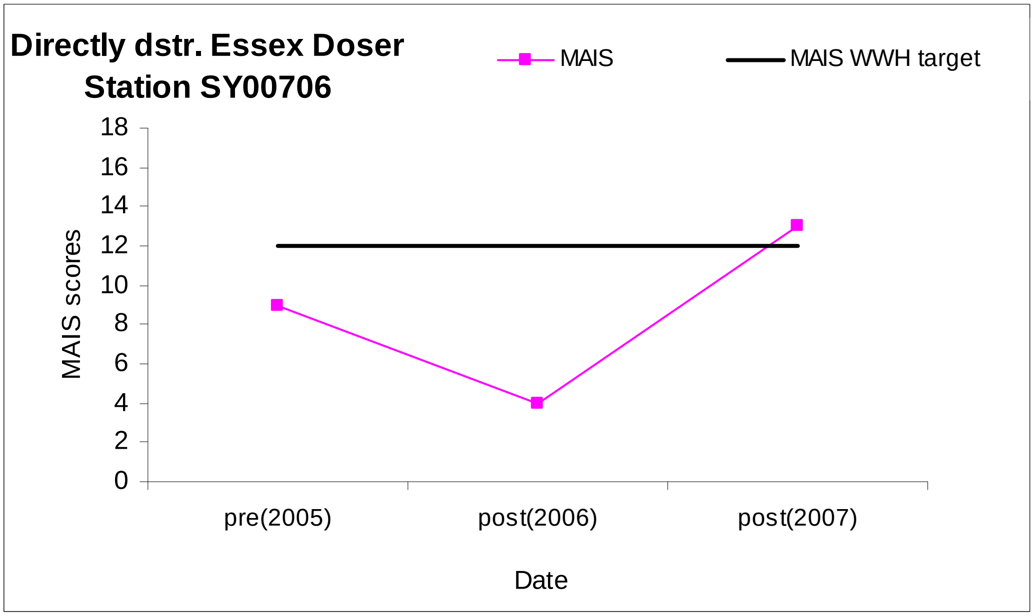


Figure 6. Biological response directly downstream of the Essex Doser



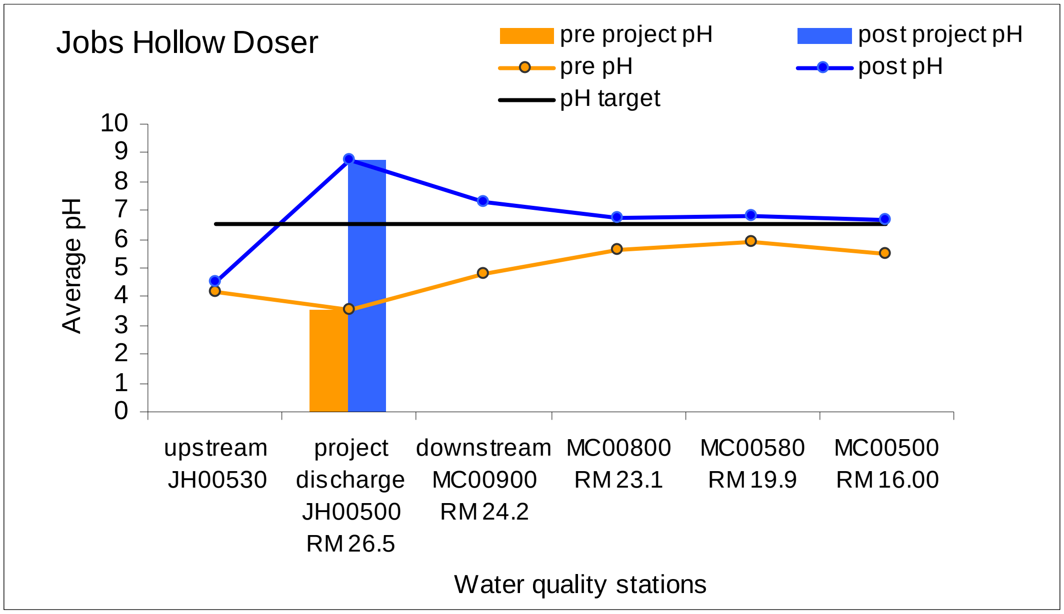
Road (CR 12). The design was completed by ATC Associates for $66,916.50. The treatment approach for this site was to install a lime doser. The goal of the design was to decrease acid load from the headwaters of Monday Creek by 54 percent. The project goal was met 100 percent. Construction was complete July, 20, 2004 by Tuson Inc. for a cost of 319,066.50. Funding sources for this project were ODNR-MRM, OSM-ACSI and OEPA-319 for design and ODNR-DMRM and OSM-ACSI for construction. Figure 3 and 4 (shown on page 3), approximately 692 lbs/day of acid was reduced from entering into

Monday Creek as a result of this AMD reclamation project. In addition to the acid loading reduction measured at this site, there are approximately 338 lbs/day of alkaline addition to the headwaters of Monday Creek. Dissolved metal load reduction occurring at this site was approximately 97lbs/ day. The metals precipitate as a result of the high pH water and become part of the substrate.

An increase in both the chemical and biological water quality has been documented downstream of the Jobs Hollow Doser site in the headwaters of the Monday Creek Watershed and downstream to river mile 16.0. In addition to the doser, along this flow path two other projects have been completed and contribute to the overall changes occurring. The Rock Run gob pile was reclaimed in 2000 and enters Monday Creek near river mile 23.5. The Lost Run subwatershed was completed in November 2006 for Phase I and January 2008 for Phase II. Lost Run subwatershed discharges into the mainstem of Monday Creek at river mile 16.1.

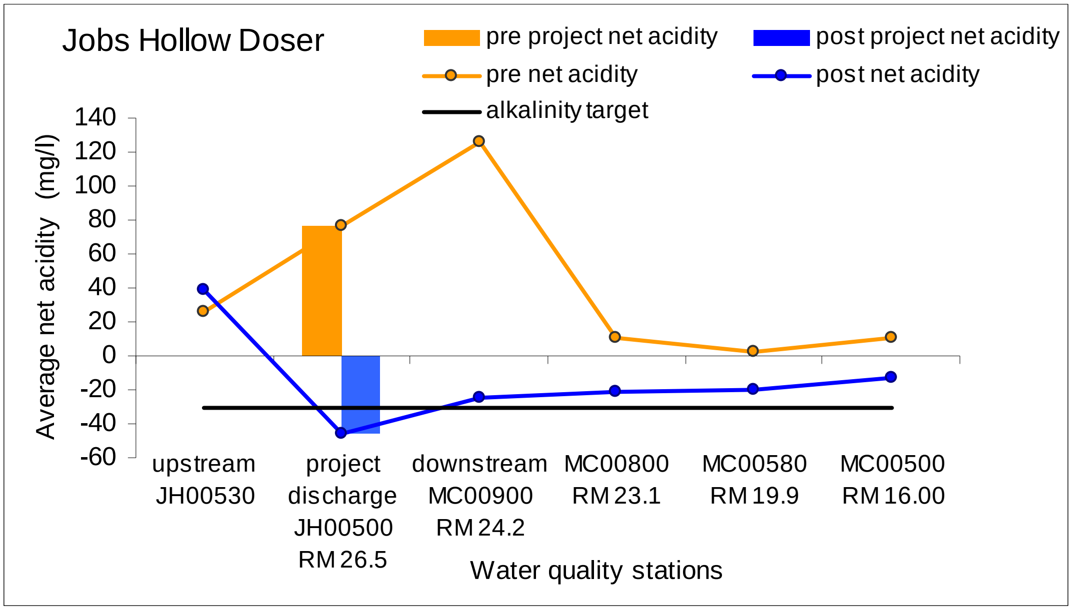
Chemical water quality improvements were documented for 10.5 miles downstream of the doser (RM 26.5) to station MC00500 (RM 16.0). The pH increases to greater than 6.5 and remains above 6.5 along the flowpath, Figure 1. During pre-construction time period all sites were on average net acidic, after implementation average concentrations of acidity remain net-alkaline for 10.5 miles, Figure 2.

Figure 1. Longitudinal pH values pre and post implementation of BMP

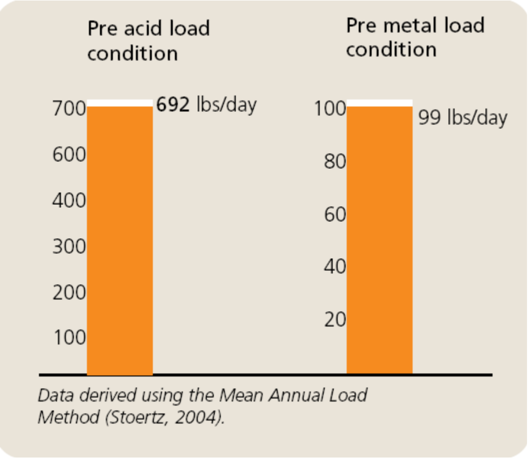


From the Mean Annual Load Method (Stoertz and Green, 2004), the calculated acid and metal load reductions were 692 lbs/day and 97 lbs/day respectively, figure 3 and 4. Essentially all the acidity has been neutralized and the load to the stream is net alkaline at the mine site. The

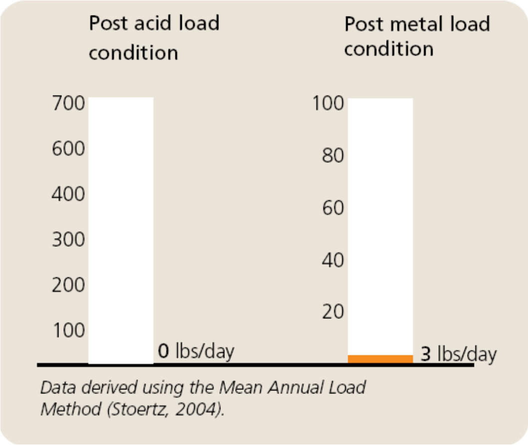
Figure 2. Longitudinal net-acidity concentrations pre and post implementation of BMP



metals are precipitating and becoming part of the stream substrate at the site and downstream of the site.



Data derived using the Mean Annual Load Method (Stoertz, 2004).



Data derived using the Mean Annual Load Method (Stoertz, 2004).

The biological response to the chemical changes is very small. The IBI results show positive incremental change during 2006 at the two downstream stations, Figure 5. The ICI results show a positive increase during the post implementation time period of 2005 and 2006, Figure 6. Macroinvertebrate family level index, MAIS, display some mixed results with a definite positive increase in 2006 and 2007 at most sites, Figure 7. In 2007 two sites scored greater than 11 for the MAIS index, the WWH equivalent score (Johnson, 2008), Figure 7. At station RM 19.9, 6.6 miles downstream of the doser both the MAIS and ICI are in agreement of showing a positive biological response reaching target levels, however the biological response for the fish community is lagging, Figures 5, 6, and 7.

Figure 3. Acid load reductions at the Essex Doser site.

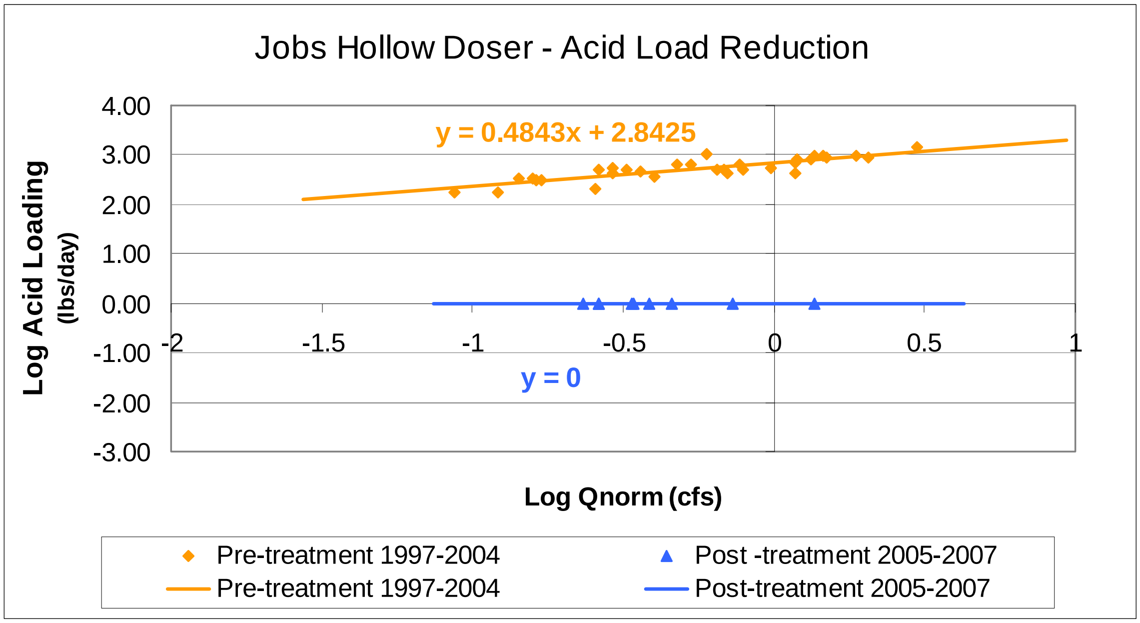


Figure 4. Metal load reductions at the Essex Doser site.

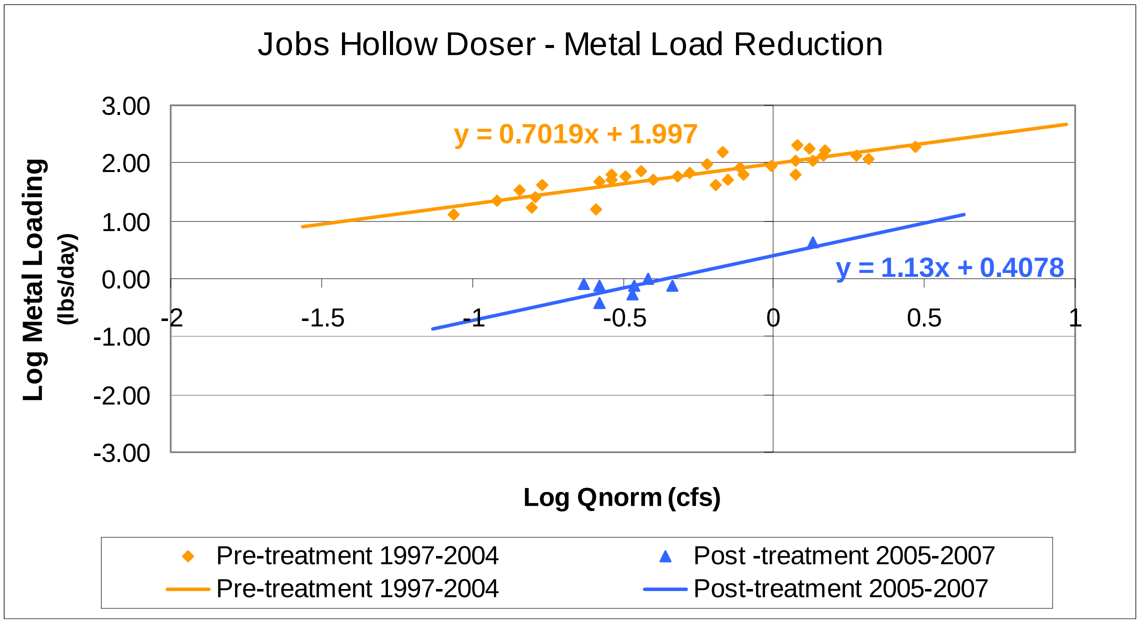


Figure 5. Biological response three miles downstream of the doser

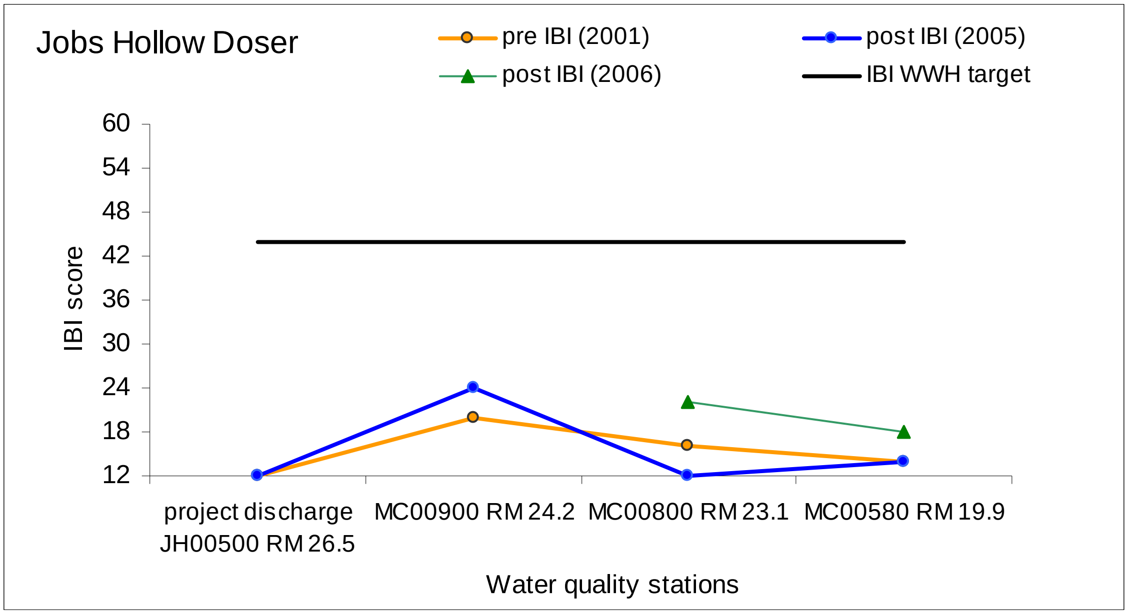


Figure 6. Biological response directly downstream of the Essex Doser

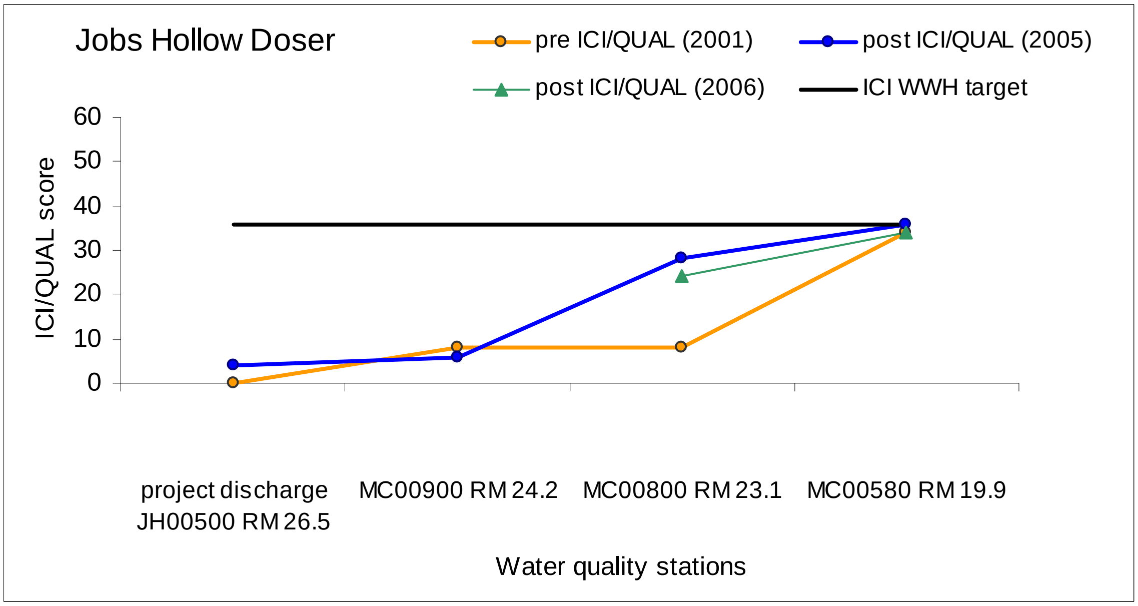
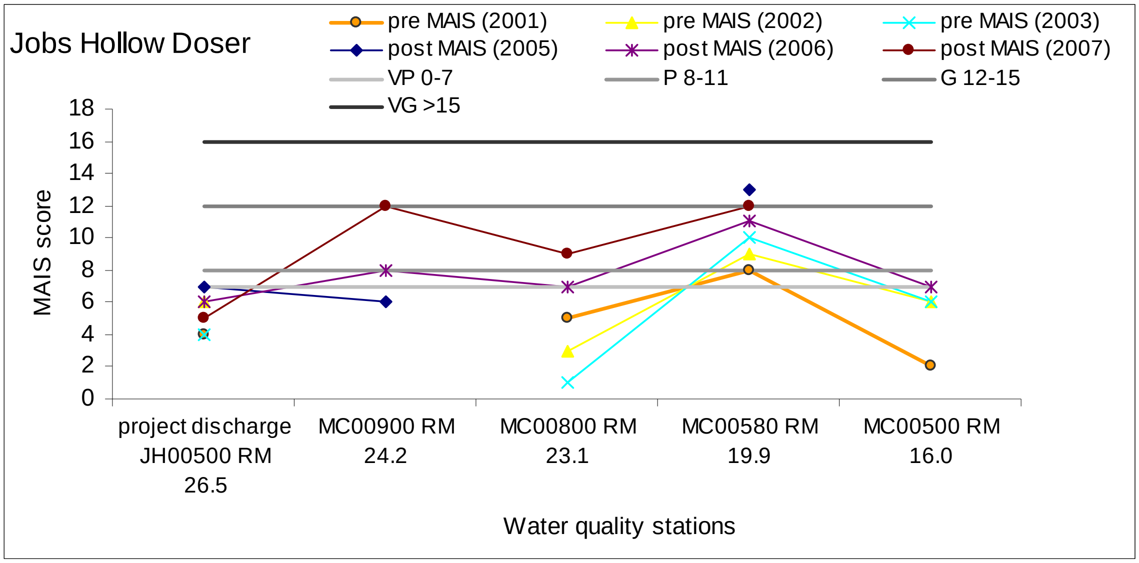


Figure 7. MAIS scores along mainstem Monday Creek



Little Raccoon Creek

Description

Little Raccoon Creek is a 38.5 mile long tributary to Raccoon Creek in Southeastern Ohio. Raccoon Creek flows to the Ohio River near the city of Gallipolis in Gallia County Ohio (Map 1). The headwaters are in south central Vinton County and water flows southeast through eastern Jackson County and enters Raccoon Creek in northwestern Gallia County. Little Raccoon Creek, draining 155 square miles, is a major tributary of Raccoon Creek and accounts for 22% of the drainage area of Raccoon Creek (683 mi^2). Little Raccoon Creek is located within the unglaciated Western Allegheny Plateau Ecoregion and although the landscape topography is steep, the gradient of Little Raccoon Creek is about 4.2 feet per mile. Little Raccoon Creek discharges approximately 400 cubic feet per second (cfs) into Raccoon Creek during high flow and less than 10 cfs during low flow.

Mining History

In the Little Raccoon Creek watershed, acid mine drainage (AMD) from abandoned underground and surface coal mine spoils and coal refuse, has degraded stream water quality and damaged fish and macroinvertebrate habitat. Coal mining occurred in approximately 22% of the Little Raccoon Creek basin. Coal has been mined underground in the watershed since the 1840's. Surface mining became the dominant type of mining starting in the 1930's and accounts for more than 90% of the coal removed to date. Surface mining continues in the watershed.

Mines are found throughout the Little Raccoon Creek watershed, but those that most affect the water quality are in Jackson County between tributaries Dickason Run (RM 12.57) and Mulga Run (RM 24.45). Acid and metals reduce the number and diversity of aquatic organisms, increase the corrosiveness of the water, limit domestic use of the water, and impair the aesthetic qualities of the water.

Watershed Restoration Efforts

The Raccoon Creek Partnership is a member based, nonprofit (501 (c) (3)) organization that was formed to improve and protect water quality in the Raccoon Creek Watershed. The RCP has partnered with ODNR-DMRM, ODNR-DOW, Soil and Water Conservation Districts, OEPA, Ohio Valley RC&D, OSM and others to fulfill their mission statement: "to work toward conservation, stewardship, and restoration of the watershed for a healthier stream and community".

The Raccoon Creek Partnership has implemented 6 AMD treatment projects in the Little Raccoon Creek Watershed since 1999. Table 1, shows the name of the project, brief treatment description and year completed. Further project details such as BMP, costs, etc. are on the NPS website at www.watersheddata.com under Reports/Raccoon Creek.

Table 1. Completed AMD Projects in the Little Raccoon Creek Watershed

AMD Project Name	Brief Description of Treatment	Year Completed	Total Cost
Buckeye Furnace (Buffer Run subwatershed)	Reclamation, Successive Alkaline Producing System (SAPS)	1999	$1,090,530
SR124 Seeps project	Reclamation, Open Limestone Channels (OLC)	2001	315,490
Mulga Run	2 Steel Slag Leach Beds (SLB), wetland enhancement	2004	440,783
Middleton Run – Salem Road	Reclamation, OLC, steel slag channel, Limestone Leach Bed (LLB)	2005	687,913
Flint Run East	Reclamation, SLB, LLB, SAPS, OLC, wetland enhancement	2006	1,456,106
Lake Milton	SAPS, SLB	2007	961,536

Acid Load Reduction at Little Raccoon Creek Treatment Sites

Data derived using the Mean Annual Load Method (Stoertz and Green, 2004) shows that acid loads were reduced following construction at all treatment sites. Figure 1 shows this reduction in pounds per day as well as percent reduction, an important comparison as acid loads vary considerably from site to site. Overall, acid loads into Little Raccoon Creek have been reduced by a total of 4,700 lbs/day since 1999. Total iron has been reduced by 291 lbs/day, aluminum 286 lbs/day, and manganese 48 lbs/day.

Water Quality Changes in Little Raccoon Creek

Water quality in Little Raccoon Creek has improved dramatically since the first survey by the Division of Wildlife in the 1950's which showed an acidic stream with little to no aquatic life. Water sampling in the 1980's in Little Raccoon Creek still showed acidic conditions with low pH for the majority of the stream, especially downstream of river mile 24.5 where abandoned mines are common. However, since the 1990's water quality in the lower section of Little Raccoon Creek has shown dramatic improvements. At river mile 1.17, near its confluence with Raccoon Creek, the pH of Little Raccoon Creek has increased from 3-4 in the 1980s to 7-8 in recent years (Figure 2). The change in pH correlates with acidity concentration decreases over time as alkalinity increased providing buffering capacity (Figure 3). Total acidity of LRC at all Little Raccoon Creek sites when compared to historical data. In fact, all Little Raccoon Creek long term monitoring stations meet the 20 mg/l net-alkalinity concentration target established by Ohio EPA in the TMDL for the Upper Basin of Raccoon Creek (adjacent watershed within Raccoon Creek) since 2005 (Figure 4). However, the impact of AMD is still noticeable on Little Raccoon Creek as alkalinity levels drop from upstream to downstream as acid from AMD sources enter the stream and buffering capacity is lost. Net-alkalinity concentrations vary greatly with flow, with alkalinity highest during low flow and lowest during high flow. This is mostly due to acidic runoff from abandoned surface mine spoil present in the watershed during precipitation events or seasonally high groundwater levels.

Biological Changes in Little Raccoon Creek

The trend of improving water quality continues as the Raccoon Creek Partnership implements AMD treatment projects, especially in the lower 18 miles of Little Raccoon Creek. IBI data for 1995/1999 was only collected at four sites but all showed considerable improvement from 1984 data, especially in the lower reaches of Little Raccoon Creek (Figure 5). Data collected in 2005/2007 indicates even more improvement from 1995/1999 data and significant improvement from 1984 near the mouth of Little Raccoon Creek. IBI scores are meeting the criteria for WWH for the WAP Ecoregion from river mile 12.71 to the mouth. Mid portions of the watershed have shown minimal improvement, as this area is the most severely impacted by AMD and where more AMD treatment is needed.

ICI data also suggests notable biological improvement in Little Raccoon Creek from 1984 to 1999 (Figure 6). Macroinvertebrates (ICI) were collected in 2005 but because of extremely low water levels and lack of flow, the data could not be used for comparative purposes. In 1990 the upper reaches of LRC showed significant improvement at both sample sites, with one attaining WWH criteria. 1995 scores decline slightly at river mile 28 but in general, show an improvement of about 10 points further downstream. Five sites were sampled in 1999 indicating significant biological improvement with the lower sections of the watershed exceeding WWH criteria. Again, the middle section of the watershed shows some incremental improvement but not complete recovery, as this area is still impacted by untreated AMD.

Macroinvertebrate Aggregated Index for Streams (MAIS) data has been collected since 2005 at all long term monitoring sites. MAIS data has shown direct correlation between upstream AMD project completion and downstream biological improvement. In reaches where AMD treatment projects have significantly reduced acid loads to Little Raccoon Creek, macroinvertebrate communities have responded quickly with steadily increasing MAIS scores from 2005-2007. For example, in Little Raccoon Creek downstream of the Mulga Run AMD treatment project MAIS scores improved steadily over the years since the project was implemented (Figure 7). At river mile 22.3 just downstream of Middleton Run where an abandoned mine land reclamation and treatment project was completed in December of 2006, MAIS score improved two points in 2007 from 2005 & 2006 scores (Figure 8). And lastly at river mile 18.7, a noticeable improvement was documented after the completion of two AMD treatment projects (Flint Run East and Lake Milton) both located in the Flint Run tributary just a ¼ mile upstream (Figure 9).

Figure 1. Little Raccoon Creek Acid Load Reductions at AMD Treatment Sites

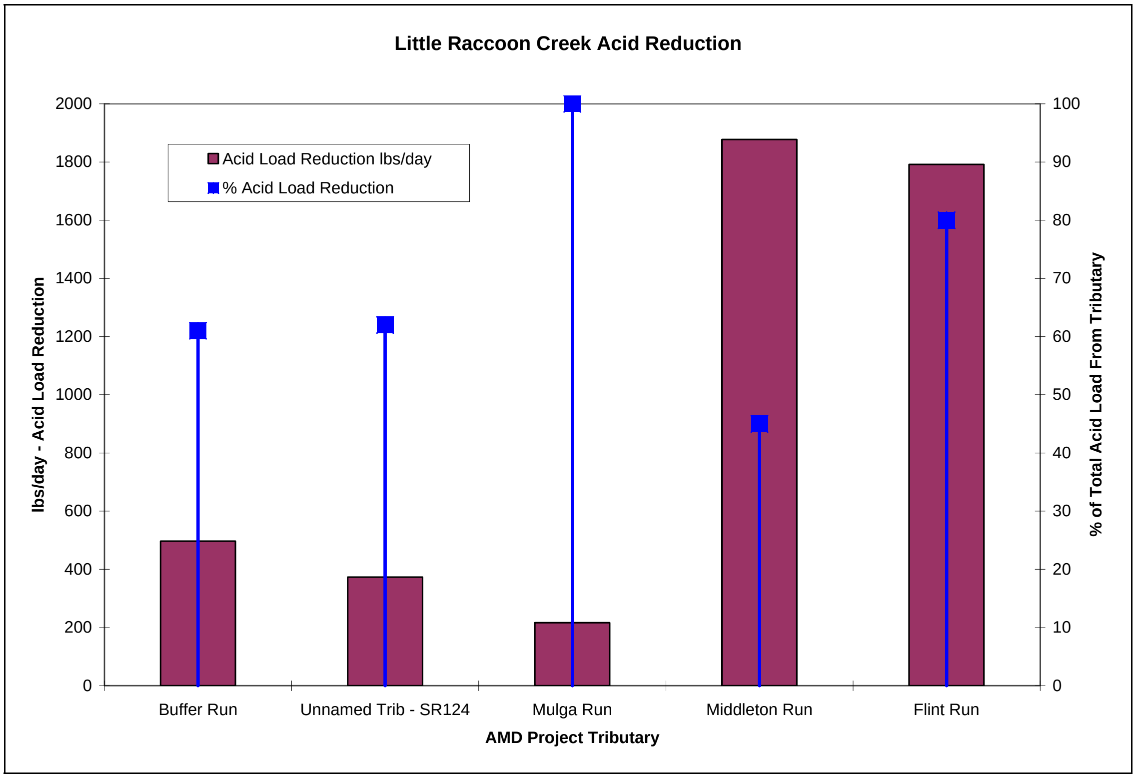


Figure 2. pH Trends in Little Raccoon Creek at RM 1.17

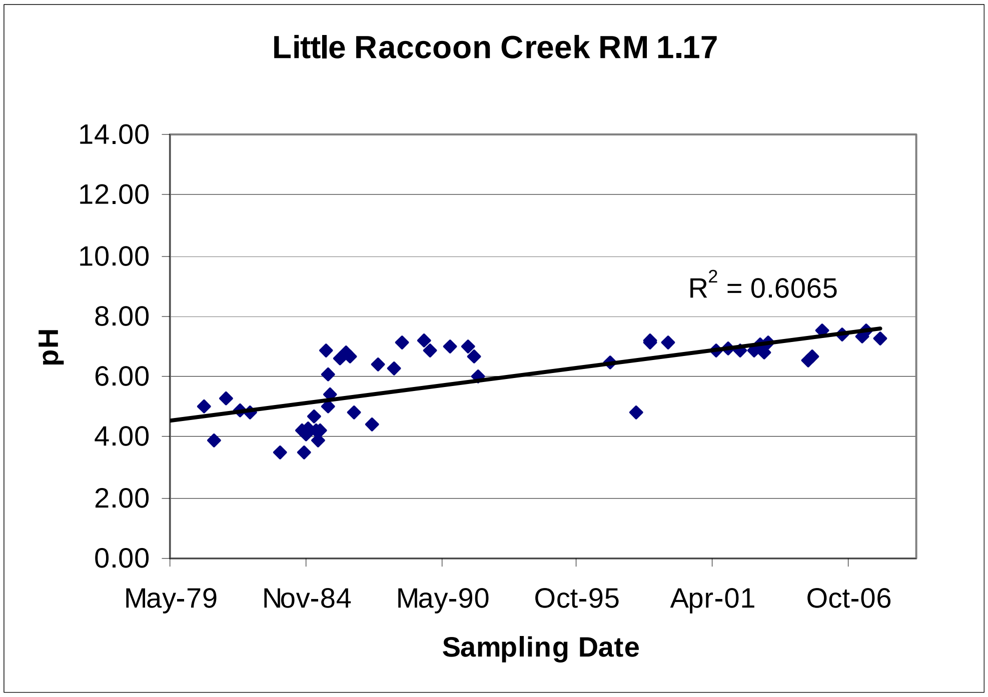


Figure 3. Acidity & Alkalinity Trends in Little Raccoon Creek at RM 1.17

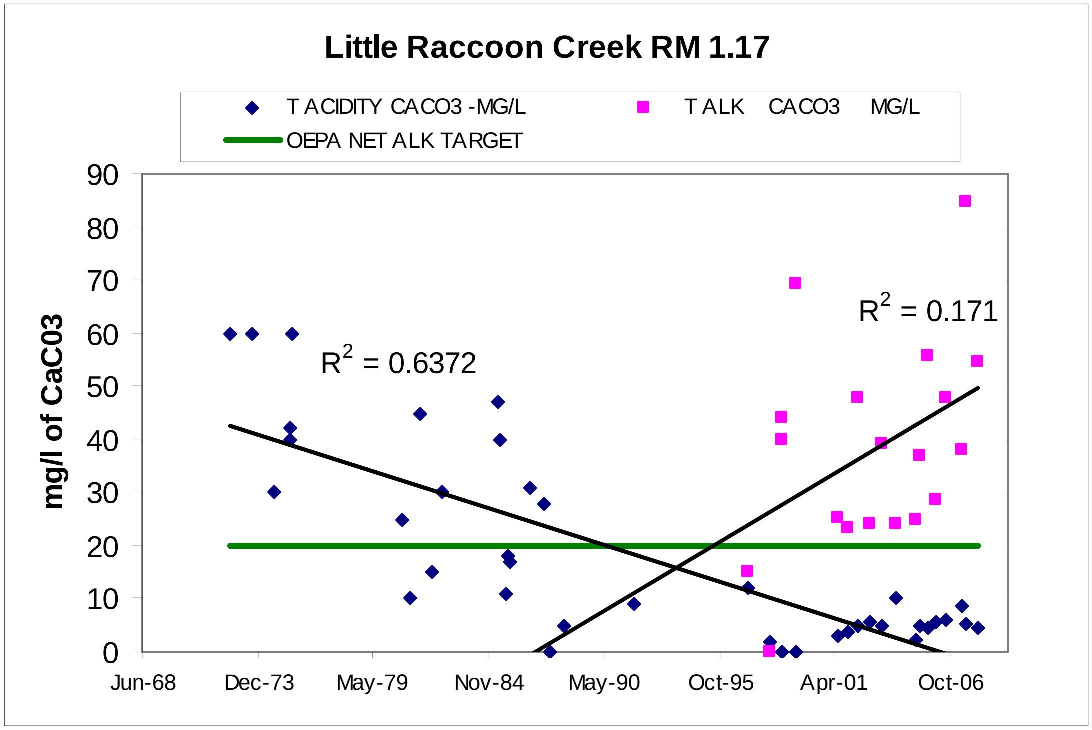


Figure 4. Little Raccoon Creek Net-Alkalinity Concentrations: 2005 – 2008

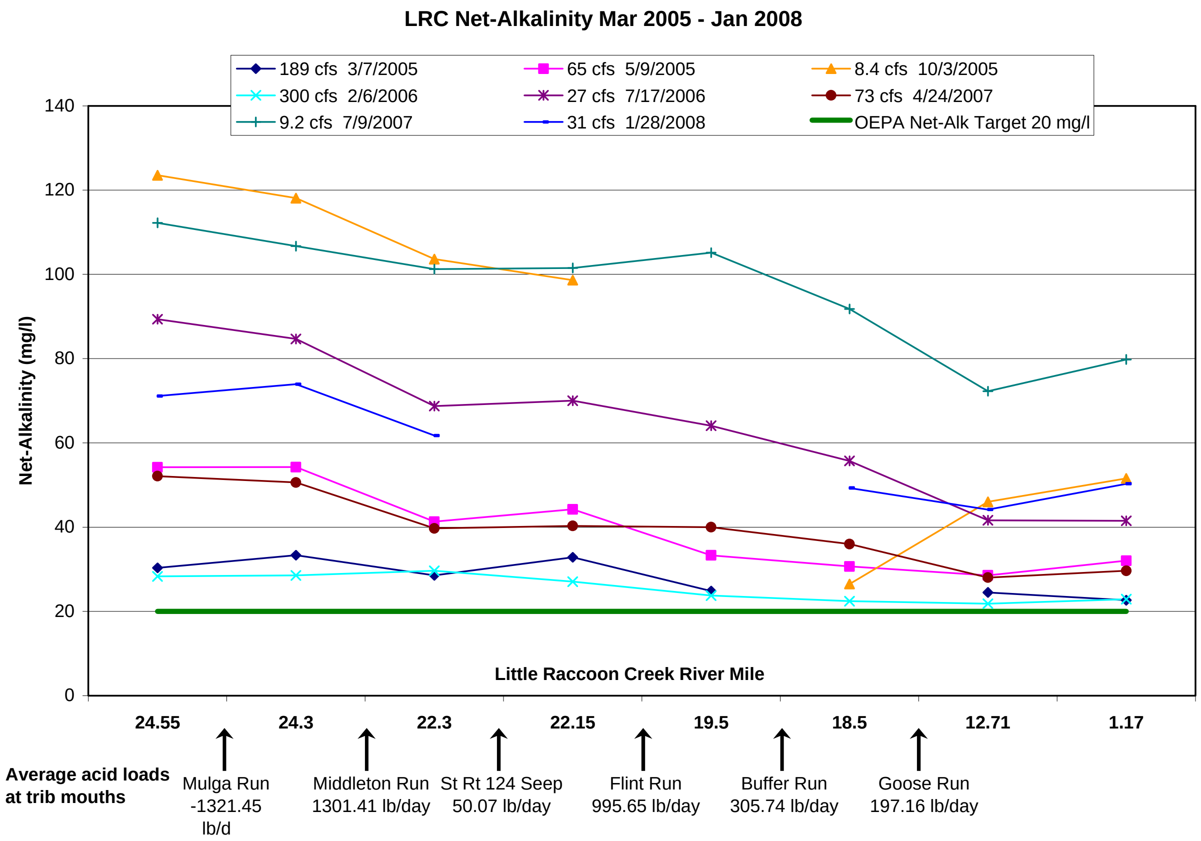


Figure 5. Index of Biologic Integrity (IBI) Scores in Little Raccoon Creek

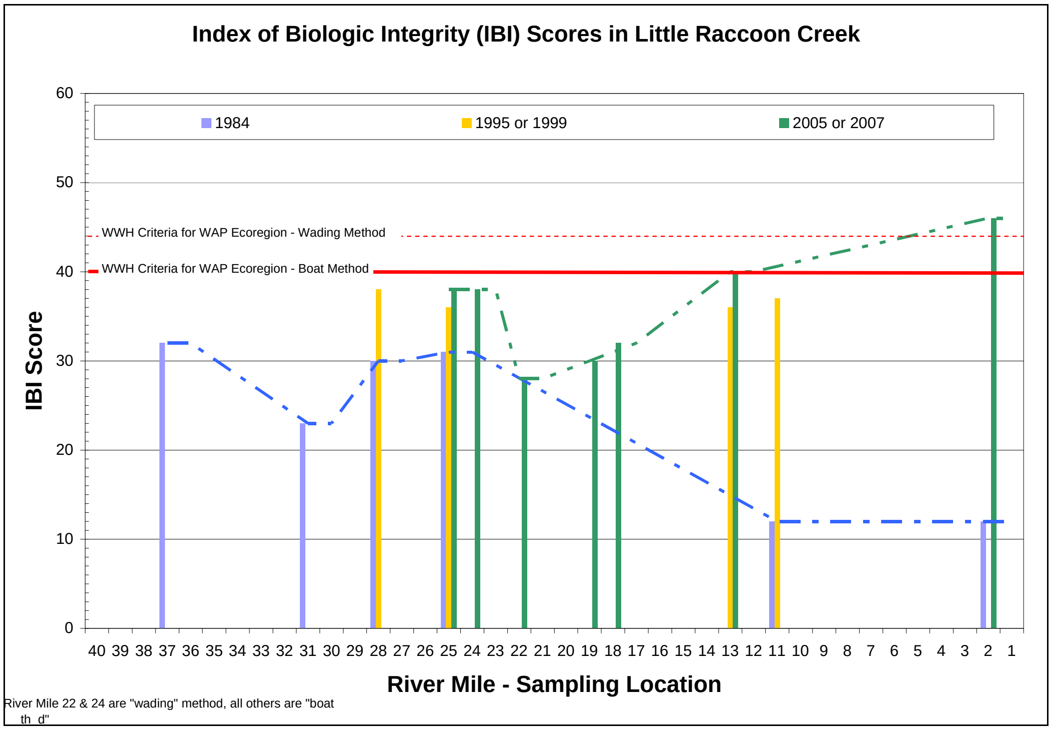
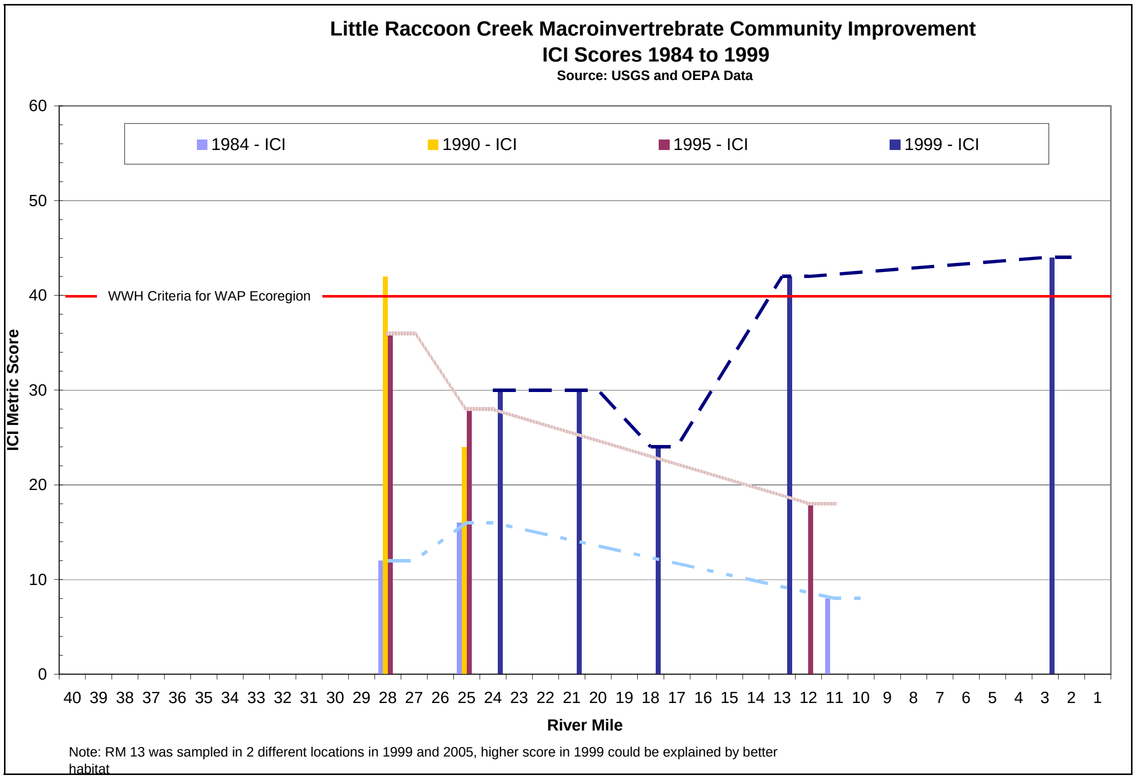


Figure 6. Macroinvertebrate Community Improvement (ICI) Scores in Little Raccoon Creek



Note: RM 13 was sampled in 2 different locations in 1999 and 2005, higher score in 1999 could be explained by better habitat

Figure7. MAIS Analysis at Little Raccoon Creek RM 24.4

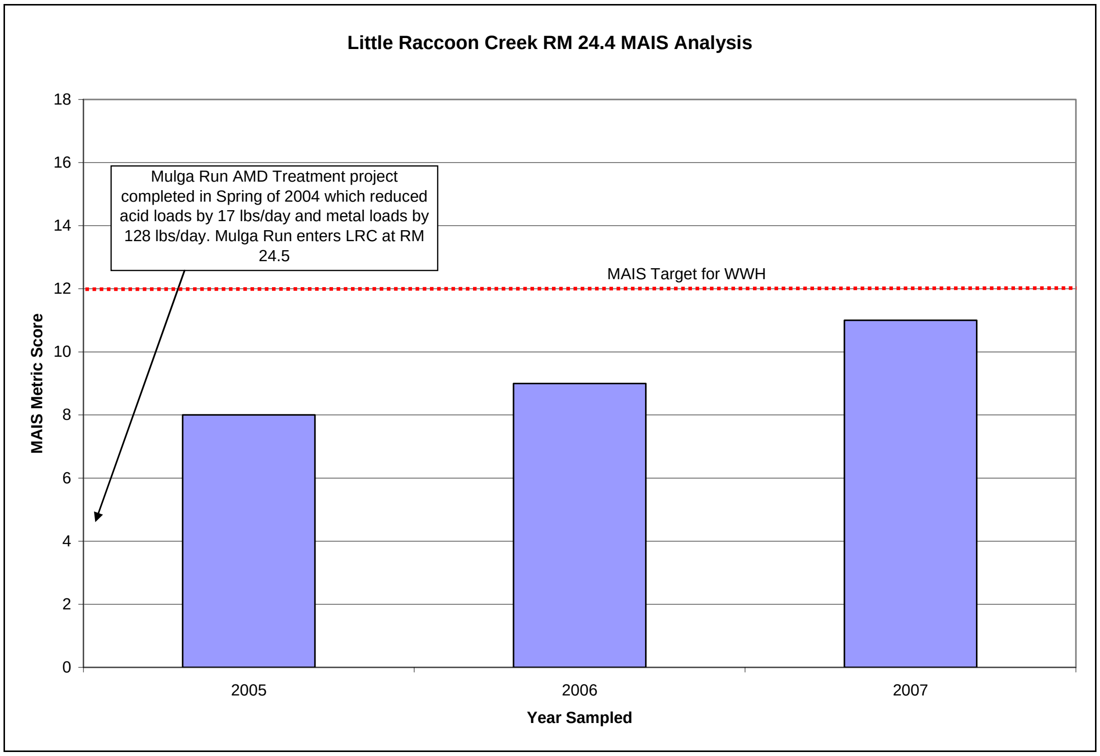


Figure 8. MAIS Analysis at Little Raccoon Creek RM 22.3

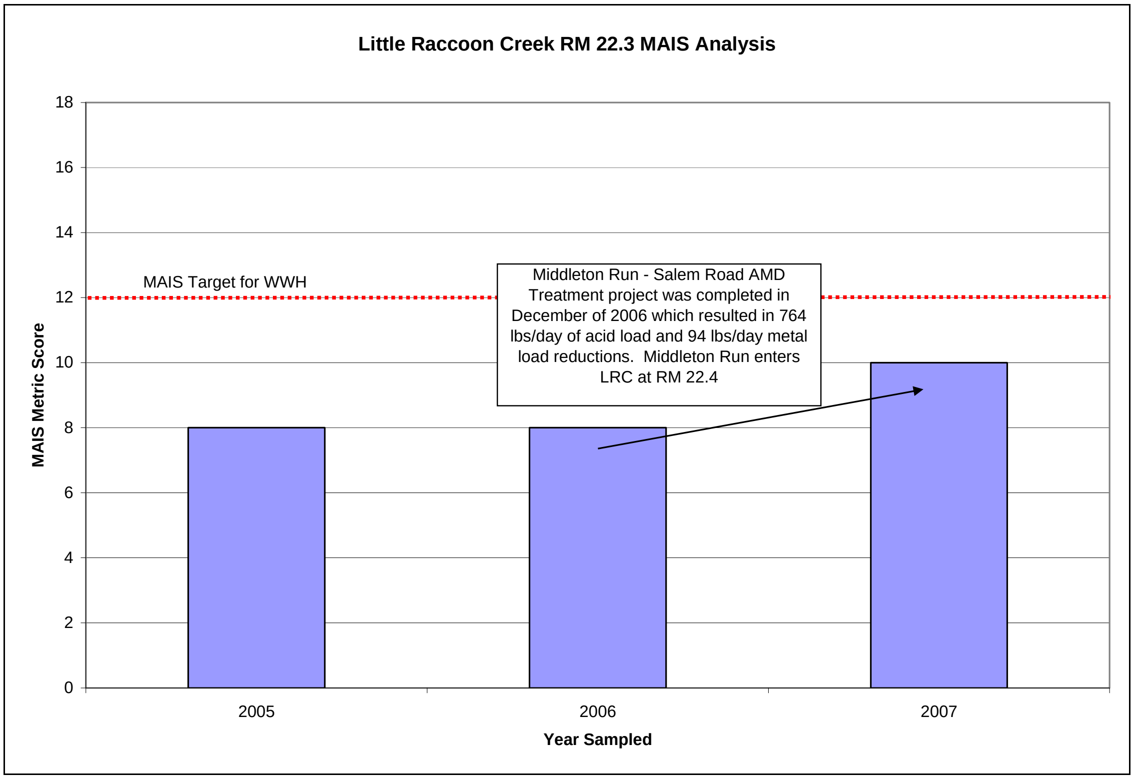
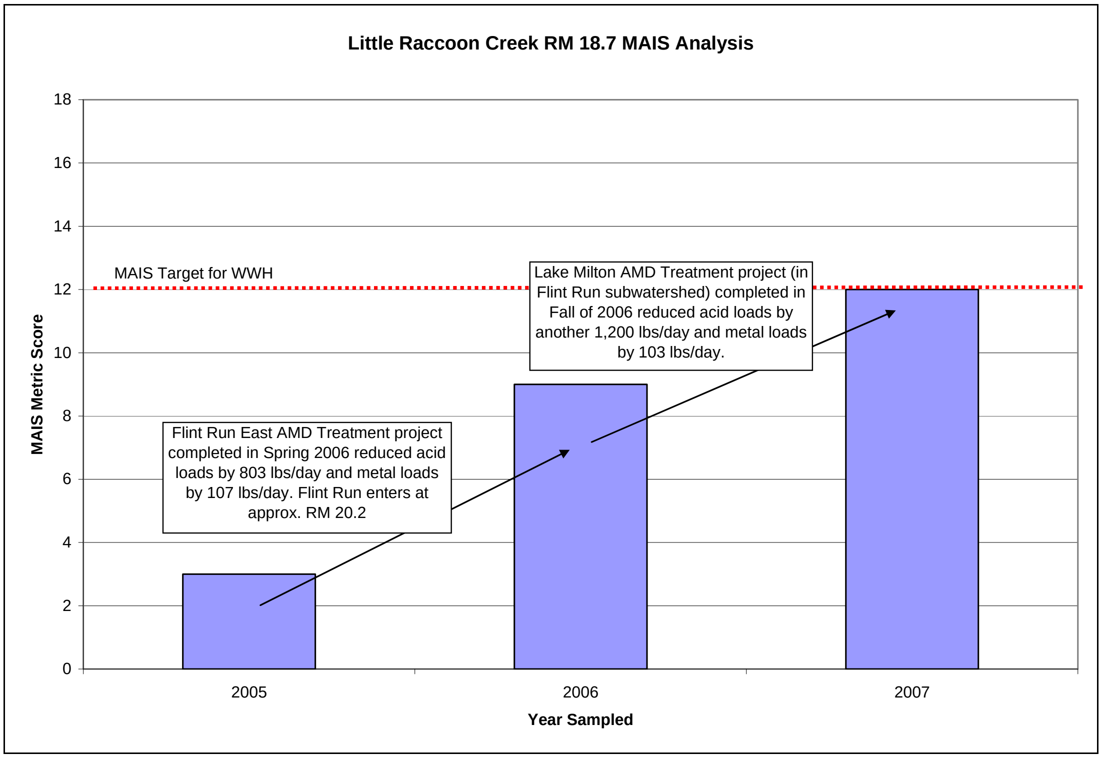


Figure 9. MAIS Analysis at Little Raccoon Creek RM 18.7



Little Raccoon Creek Changing Biological Conditions

1952 - Ohio Department of Natural Resources Wildlife Council Study:
All sites in this survey were upstream of the current SR 32, which is upstream of the major AMD loaders into LRC at present. However, it does appear that AMD was more prevalent in the section of LRC in the 1950's according to this report. Test netting at SR 75, North of the village of Hamden, caught a few fish in all four quarters (Winter, Spring, Summer, & Fall) consisting of primarily bullhead catfish and suckers. The greatest catch was 36 fish in the last quarter. Below Lake Alma fish were caught only during the second quarter and were primarily suckers and bullhead catfish with a total catch of 22 fish. East of Wellston, further downstream, fish were taken every quarter except the first when free acidity was present. 8 to 11 fish were caught consistently in the last three quarters at this site. Test netting sampling consisted of using a hoop net or a fyke net modified for stream fishing and sampling lasted for 72 hours per sampling station.

1984 – Ohio EPA Biological Survey
Fish sampling was conducted at 6 stations along the mainstem of Little Raccoon Creek. IBI scores ranged from 12 near the mouth to 32 above Lake Rupert. Above Mulga Run, IBI scores were above 30 at 3 out of the 4 sites with the exception of a 23 downstream of Lake Alma. A site downstream of Dickason Run at river mile 11.0 had an IBI of 12 and only two fish were captured (1 Green sunfish and 1 Green X Longear hybrid sunfish). Further downstream near the mouth at river mile 1.8 (Koontz Sailor Road) received the same IBI score of 12. Only two fish were caught at this site and they were both Longear Sunfish.

1989 & 1990 – USGS and Ohio EPA Biological Surveys
3 sites combined were sampled and all were upstream of Mulga Run and downstream of Sandy Run where the greatest problem with AMD is not encountered. IBI scores ranged from 26 – 34.

1995 Ohio EPA Biological Survey
Three sites were sampled: RM 11.0 at Keystone Road, dst. Sandy Run (RM 28.3), and upst. of Mulga Run (RM 24.6). Downstream of Sandy Run had an IBI of 38 and ICI of 36. SR 32 upst. Mulga Run had an IBI of 36 and an ICI of 28. The Keystone Road site showed the most dramatic change with an IBI of 18 and an ICI of ??. This is a dramatic improvement from the 1984 data with an IBI of 12 and ICI of ??. Fish diversity increased at this site from 2 fish (Green Sunfish and Green X Longear Hybrid) to 17 species and 111 fish.

1999 USGS Biological Survey
USGS surveyed a total of six sites in 1999 on the mainstem of LRC which is summarized in the LRC AMDAT plan. Macroinvertebrate data was collected at all six sites and fish were collected at two sites only (RM 12.8 & 12.5). If the RM 12.5 site (dst. of Dickason Run) is compared with the RM 11.0/11.8 OEPA site, there is a dramatic increase in ICI values. The ICI goes from a ?? in 1984, an 18 in 1995, to a 34 in 1999. The IBI goes from a 12 in 1984, a 37 in 1995, to a 40 at the same site. The 1999 data shows a stretch nearly meeting WWH criterion according to IBI and ICI.

Conclusions

The 1952 DOW study showed low fish populations and diversity and documented AMD impacts in the upper third of the watershed (upstream of SR 32). This is interesting because there is very little evidence of AMD upstream of SR 32 currently and according to the 1999 AMDAT study none of the major AMD loaders were in this part of the watershed.

Since Ohio EPA began collecting biological data in the watershed it is evident that biological communities have improved drastically. Upstream of SR 32 and Mulga Run (the furthest upstream major AMD loader) there is contradictorily data. IBI scores are 30, 31, 23, and 32 as you move upstream from RM 25 to 37. The 23 IBI is due to point source impacts not AMD. This demonstrates relatively fair fish community performance, although not meeting WWH status. However, ICI scores show macroinvertebrates are more impacted with ICI scores at RM 25 & 28 scoring 16 and 12 respectively. This section of the creek shows dramatic improvement in ICI scores according to the 1990 and 1995 data with a high score of 28 in 1995 at RM 25 and both dates scoring over 36 (WWH) at RM 28. IBI scores show improvement also but not as drastic as ICI at RM 25 and RM 28. 1995 data has an IBI of 36 and 38 at these two sites. Both the fish and macroinvertebrate scores are relatively close to meeting WWH status in this upper section of the creek according to the most recent data.

In 1984 from RM 12 downstream to the mouth, 2 IBI scores of 12 were recorded with only 1 to 2 species present. ICI at RM 12 scored an 8, also exceptionally low. Basically, the creek was devoid of much life in 1984 in this lower section, which is downstream of all the major AMD loaders. However, more recent data show dramatic improvement. Sampling at approximately RM 11 in 1995 showed an IBI of 37 and at RM 12 an ICI of 18. Both sites showed improvement, but it's much more profound in the fish population. RM 13 was sampled in 1999 (still dst. of all major AMD loaders) and showed even more improvement in both macro's and fish with an ICI of 34 and an IBI of 40. A site further downstream at RM 3 was only sampled for macroinvertebrates, but scored an ICI of 44, which is meeting WWH habitat. Fish populations have not been sampled below RM 11 since 1984 but with macro's improving it would be likely for improving fish populations as well. According to the biological data it appears that the conditions in Little Raccoon Creek have been improving drastically over the past 20 to 50 years. If decreases in AMD are continued there is evidence to suggest LRC would recover to attain WWH status.

Little Raccoon Creek Water Quality Improvement Summary

Little Raccoon Creek (LRC) has been severely impacted by acid mine drainage from abandoned coal mines in Jackson County. The majority of mining occurred between RM 24.5 and RM 13 in LRC or subwatersheds. Historical data from the 1970's and 1980's show acidic conditions from RM 24.5 downstream and fish and macroinvertebrate populations severely impaired if existent.

Historical water quality data sets show a trend of improvement in the late 1980's or early 1990's as mining decreased, reclamation laws were enforced, and ODNR began reclaiming abandoned mine lands. The trend of improving water quality continues today as the Raccoon Creek Partnership implements AMD treatment projects, especially in the lower 18 miles of LRC. Sampling locations at RM 1.17 and 12.71 meet WWH criteria for fish and score in the "Good" range for the MAIS metric in 2007. ICI data in 2005 still showed impaired conditions at these sites with scores of 26 & 24 respectively but have not been sampled since.

The Raccoon Creek Partnership has implemented 6 AMD treatment projects in the Little Raccoon Creek Watershed since 1999. Project details such as BMP, costs, etc… are on the NPS website at www.watersheddata.com under Reports/Raccoon Creek.

1999: Buckeye Furnace (Buffer Run subwatershed)
2001: SR124 Seeps project
2004: Mulga Run
2005: Middleton Run – Salem Road
2006: Flint Run East
2007: Lake Milton

Since 2005, 8 long term monitoring events in LRC show attainment of a 20 mg/l net-alkalinity target established in the RC Headwaters TMDL by Ohio EPA (2003). Alkalinity concentrations vary greatly with flow in LRC, with alkalinity highest during low flow and lowest during high flow. This is due to acidic runoff from surface mines during precipitation and high groundwater interacting with coal refuse piles. Iron and Aluminum have yet to be graphed for these same sites and time period.

Hewett Fork Water Quality Improvement Summary

Hewett Fork is a 40.5 square mile, 15.4 mile long tributary to Raccoon Creek in Southeastern Ohio (Map 1). Hewett Fork flows from north to south/southwest in Hocking, Athens, and Vinton Counties and contains a large amount of public property including Zaleski State Forest, Waterloo Wildlife Area, and the Wayne National Forest.

Community driven watershed action has existed in Raccoon Creek since the early 1980's with an active restoration partnership taking hold in the late 1990's. Currently, the Raccoon Creek Partnership, a membership based non-profit organization coordinates water quality restoration projects along with education and outreach efforts in the watershed. Since 1999, agencies and organizations involved with the Raccoon Creek Partnership have implemented 10 acid mine drainage (AMD) treatment/abatement projects to improve water quality and restore aquatic life in Raccoon Creek and its tributaries.

One of those projects is the Carbondale Doser. The Doser project was completed in the spring of 2004 at a cost of $389,637 with EPA and ODNR funding and was the second attempt at AMD treatment at the abandoned underground coal mine near the village of Carbondale. The first attempt, an aerobic wetland installed by the Ohio Department of Natural Resources Division of Mineral Resources Management in the early 1990's did not improve biological conditions in the receiving stream, Hewett Fork. A 75 ton silo dispenses calcium oxide pellets into the AMD water via a water wheel and auger. The calcium oxide mixes with the acidic water in a concrete channel with nine, six inch drops before entering Hewett Fork at river mile 11.0.

Pre & Post Construction Pictures of the Carbondale Doser AMD Treatment System.

Pre-construction

Post-construction

The goal of the lime doser was to eliminate acid loads into Hewett Fork from the Carbondale mine and to improve water quality and biota in Hewett Fork downstream of the doser. The project was successful at neutralizing the entire acid load from the site. Based on 18 pre treatment and 10 post treatment samples, a mean of 785 pounds per day were neutralized by the doser (Figure 1). In addition, 631 pounds per day of additional alkalinity are discharged into Hewett Fork post treatment. Iron and aluminum loads increased to pre-wetland treatment system levels because the eliminated wetland was capturing and storing between 25 – 50% of the aluminum and iron load. Currently the mean iron loading from the site is 190 lbs/day and aluminum is 105 lbs/day.

Mean pH levels increased at all sampling sites downstream of the doser post treatment (Figures 2 & 3). Before dosing only the lower 3.9 river miles had a mean pH over the USEPA high level of protection of pH 6.0. Since dosing, the entire 11 miles downstream of the doser have a mean pH over 6.0 and 4 out of the 5 sites are above pH 6.5 (maximum level of protection). Alkalinity concentrations also increased from pre to post treatment (Figures 4 & 5). The entire 11 river miles downstream of Carbondale in Hewett Fork exhibited net-acidic conditions pre-treatment (with limited data at some sites. Post-treatment shows net-alkaline conditions for the entire length of Hewett Fork demonstrating water quality improvements. On average, the lower 3.9 river miles attain the 20 mg/l net-alkalinity concentration established by Ohio EPA for the Upper Basin Raccoon Creek TMDL in 2003. Limited data for iron and aluminum, the dominant metals associated with abandoned coal mines in the area, exists to compare pre & post conditions at most Hewett Fork sampling sites. Post treatment concentrations of iron and aluminum remain high close to the doser but decrease in concentration towards the mouth of Hewett Fork (Figures 6 & 7). In summary, AMD treatment improved water quality conditions such that pH and net-alkalinity have improved throughout Hewett Fork. Total concentrations of aluminum and iron

Map 1: Hewett Fork Watershed

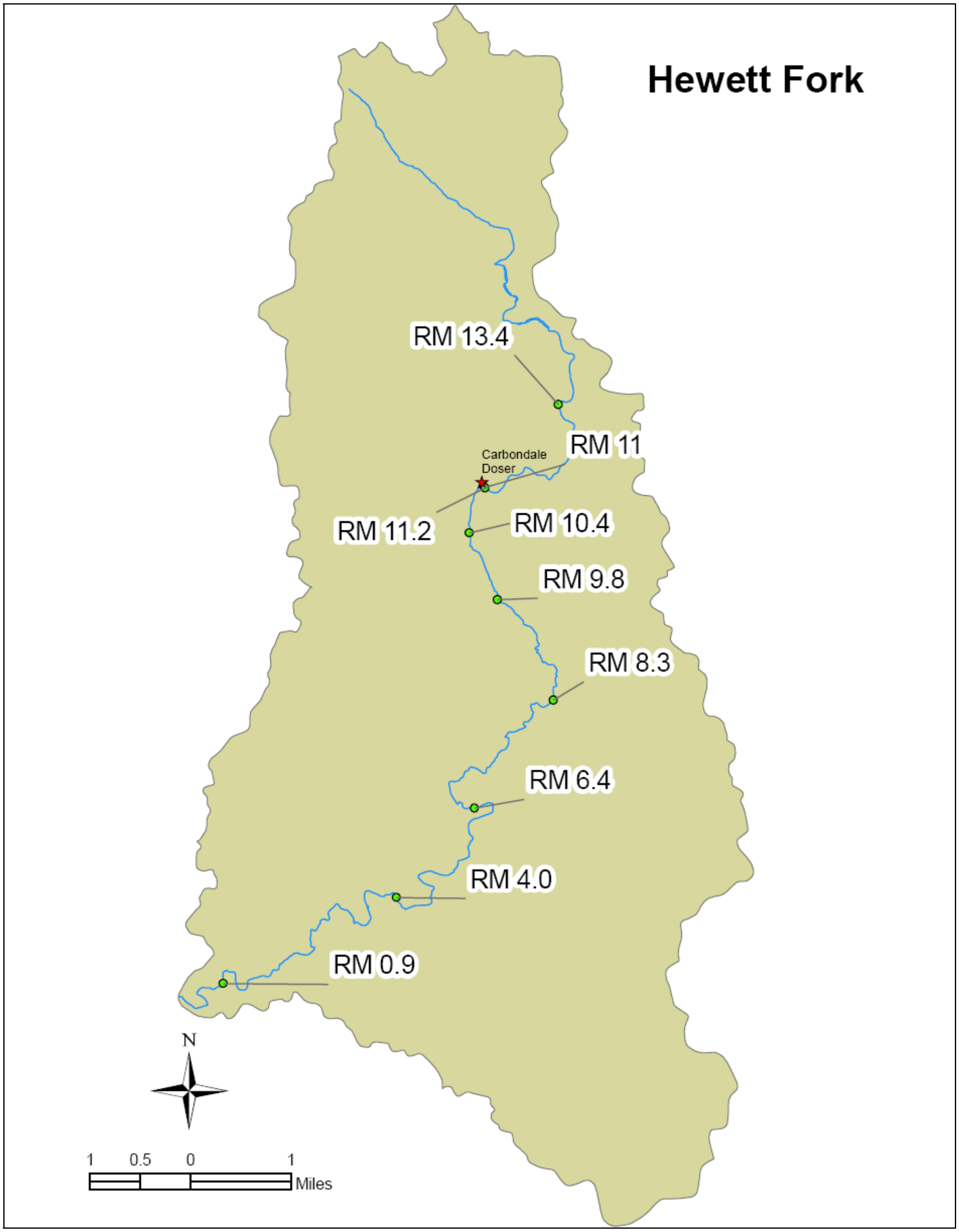
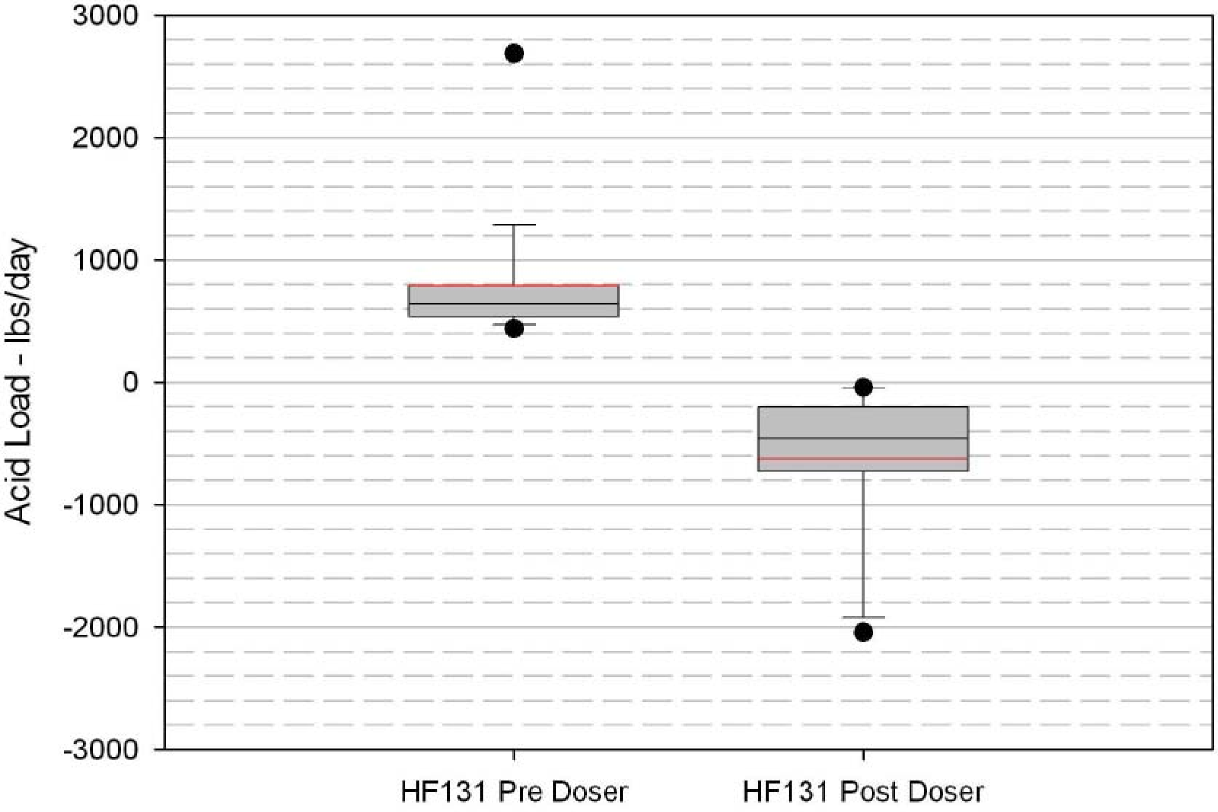


Figure 1: Acid Loading at the Carbondale AMD Discharge (HF131) Pre and Post Lime Dosing



are incremental in most of Hewett Fork but are below EPA criteria in the lower 3.9 river miles.

Incremental changes in the Fish and Macroinvertebrate communities were documented from 2004 – 2007. Only one sample site pre-treatment existed on Hewett Fork, which was at river mile 8.3 (2.7 miles downstream of the Carbondale AMD discharge). Fish responded immediately at river mile 8.3 with an increase from 0 species in 2000 pre-dosing to 8 species present in 2004, just months after treatment at Carbondale (Figure 8). The number of fish species at the site has remained between 8–10 since 2004. Macroinvertebrate communities also showed improvement from pre to post treatment at river mile 8.3 of Hewett Fork using the Macroinvertebrate Aggregated Index for Streams (MAIS) metric (Family Level) (Figure 9). Overall the fish community improved from 2004 – 2007 in the lower 8.3 river miles of Hewett Fork with the most productive fish communities in the lower 3.9 river miles (Figure 10). 2007 data showed slight decreases in IBI at most sites which is likely related to a low water levels as opposed to higher levels of AMD. Macroinvertebrate data show a similar trend as fish data along Hewett Fork with improving conditions moving downstream from the doser in 2006 and 2007 (Figure 11).

Figure 2: pH in Hewett Fork Pre AMD Treatment (Carbondale Doser)

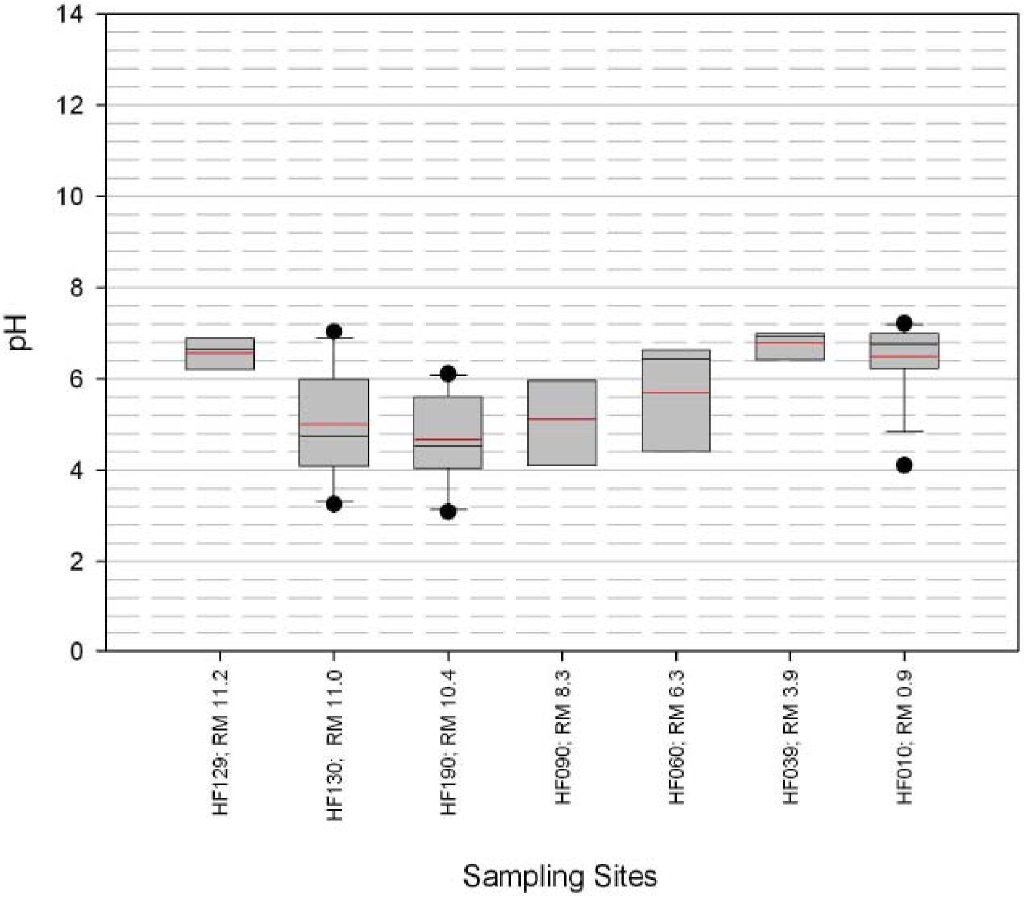


Figure 3: pH in Hewett Fork Post AMD Treatment (Carbondale Doser)

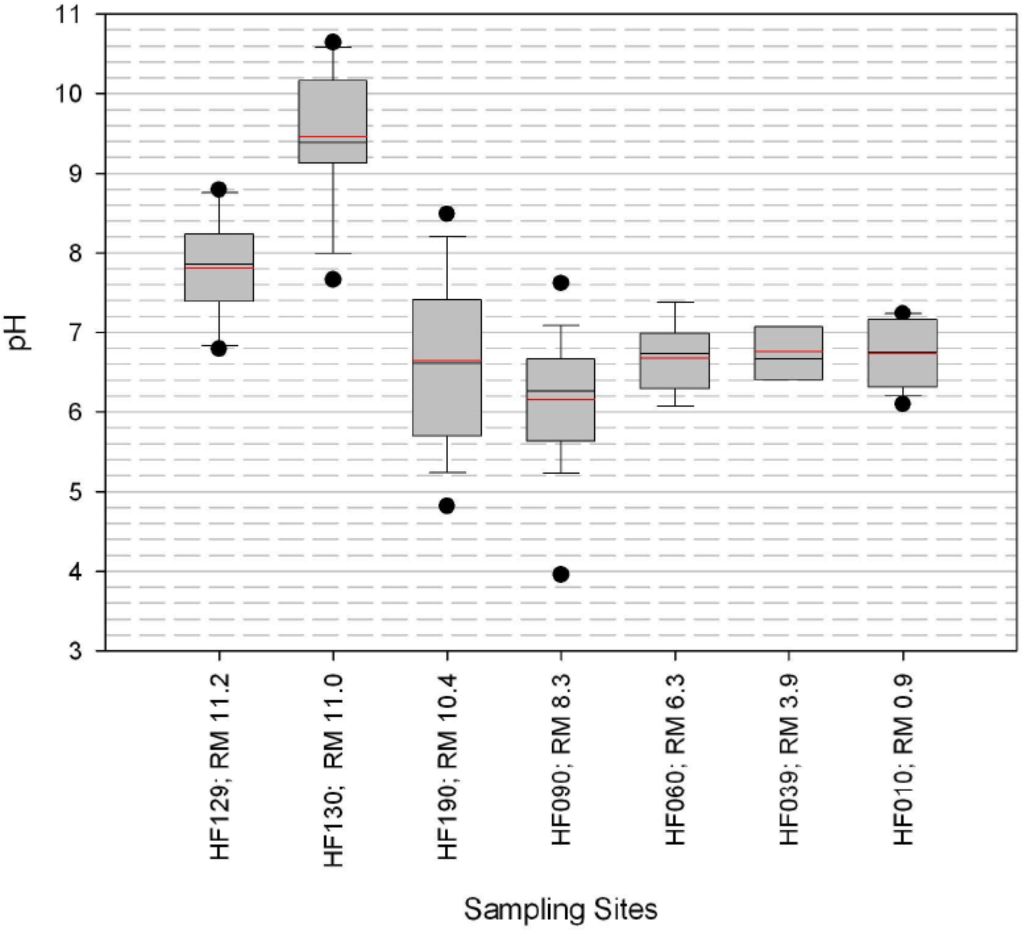


Figure 4: Net-Alkalinity Concentrations in Hewett Fork Pre AMD Treatment (Carbondale Doser)

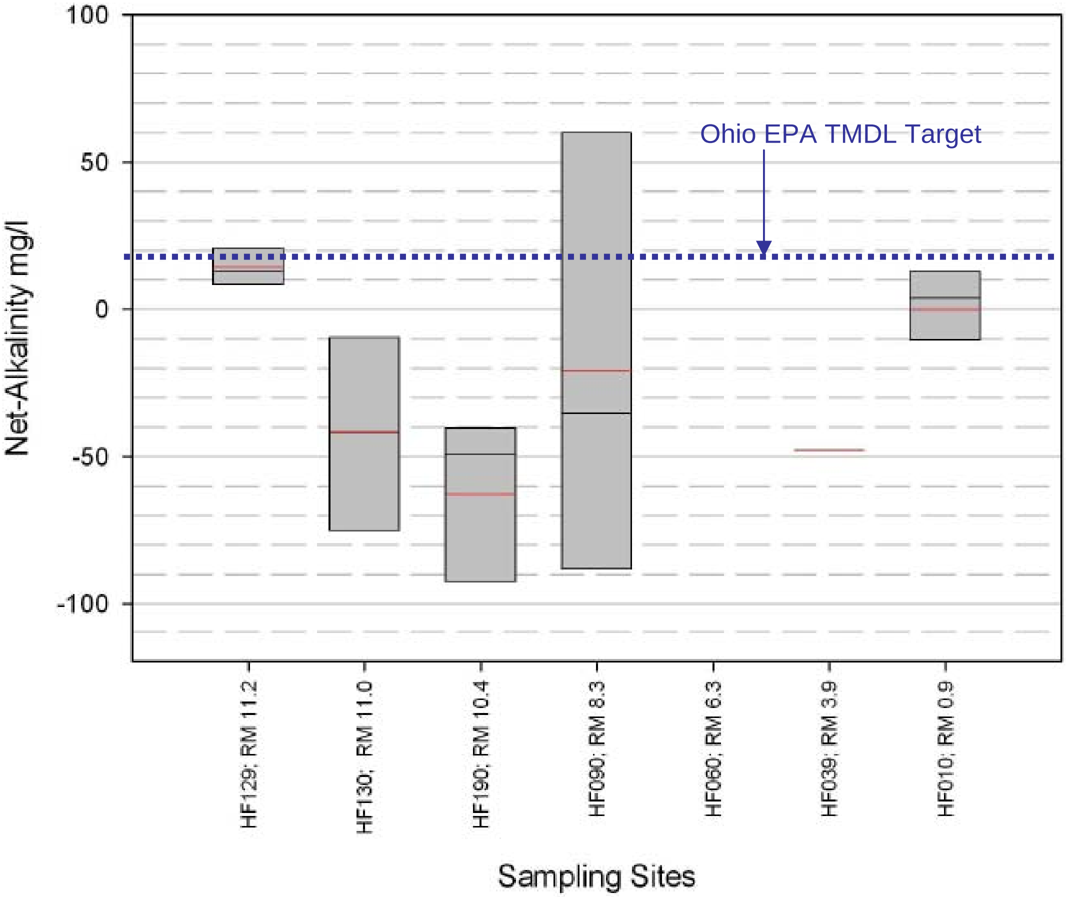


Figure 5: Net-Alkalinity Concentrations in Hewett Fork Post AMD Treatment (Carbondale Doser)

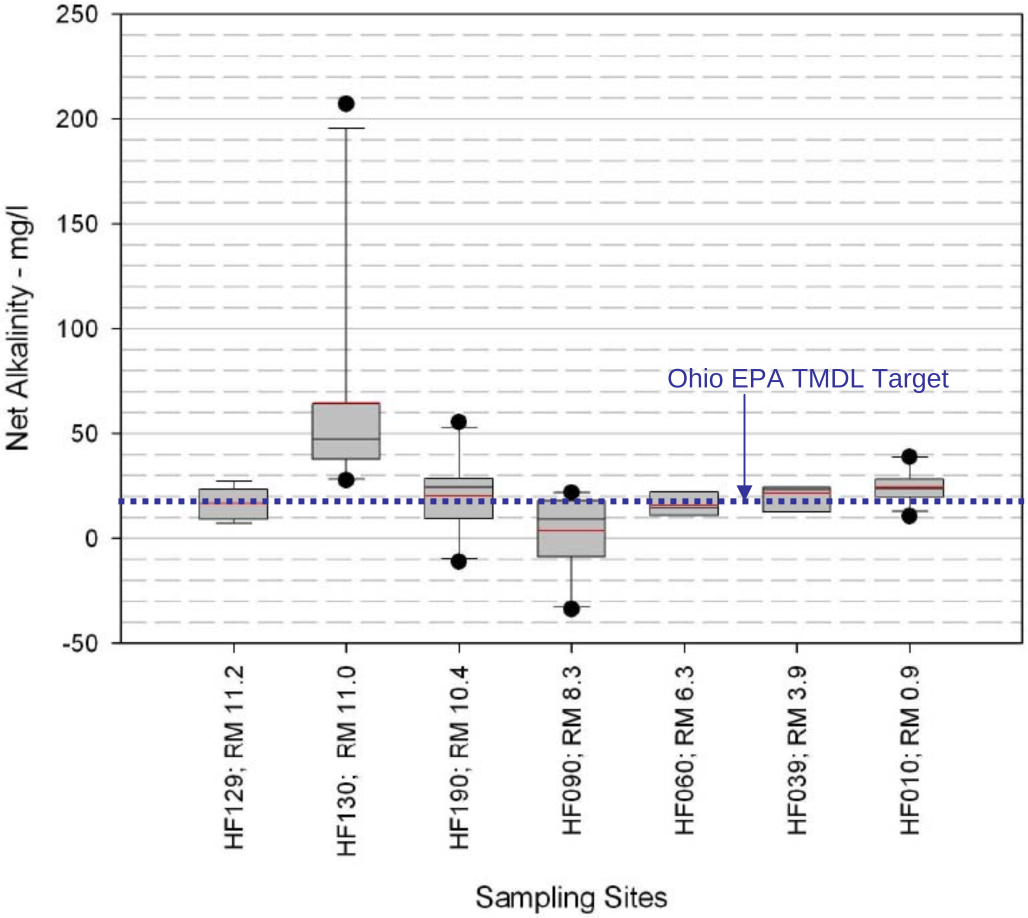


Figure 6: Total Iron Concentrations in Hewett Fork Post AMD Treatment (Carbondale Doser)

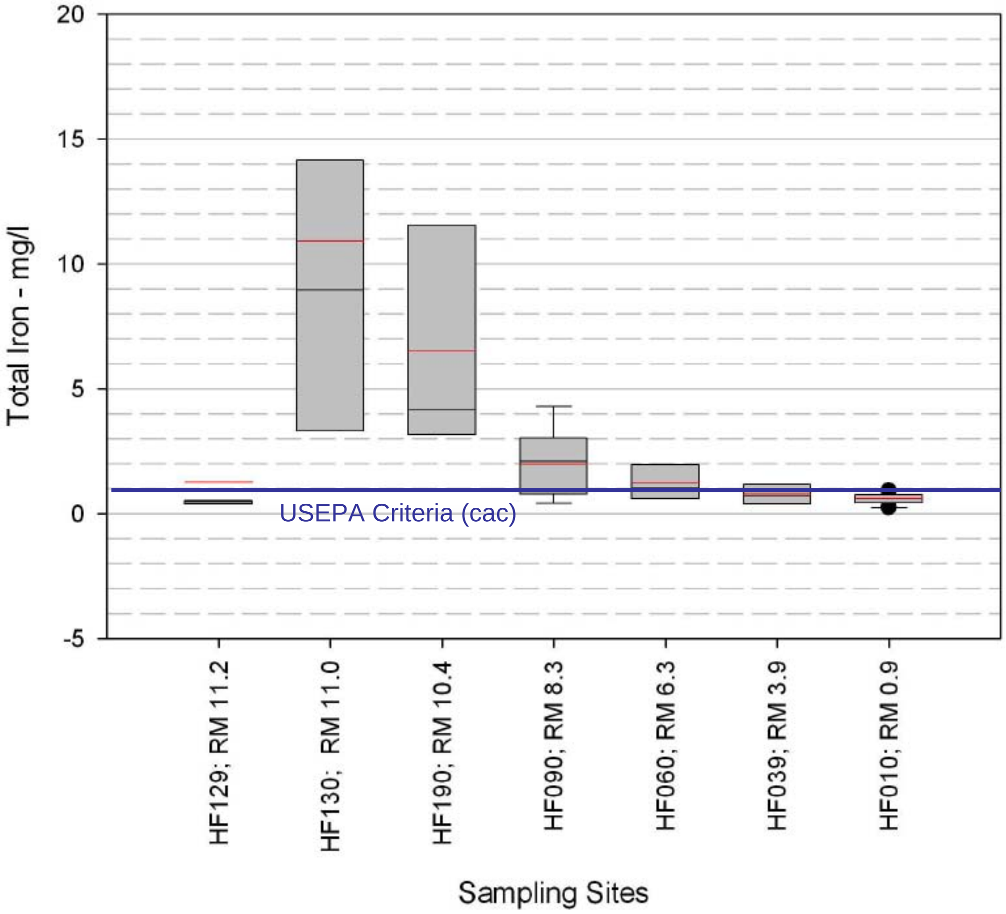


Figure 7: Total Aluminum Concentrations in Hewett Fork Post AMD Treatment (Carbondale Doser)

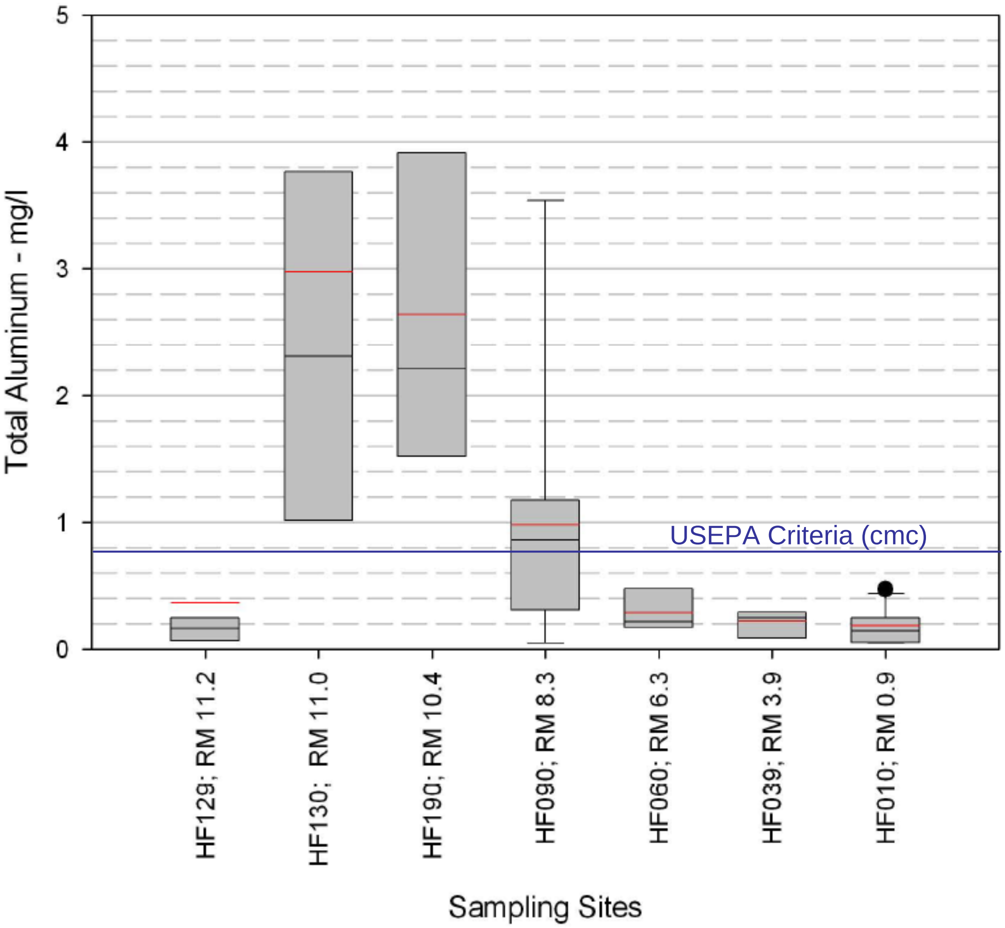


Figure 8: Fish Species Richness at Hewett Fork River Mile 8.3 Pre & Post AMD Treatment (Carbondale Doser)

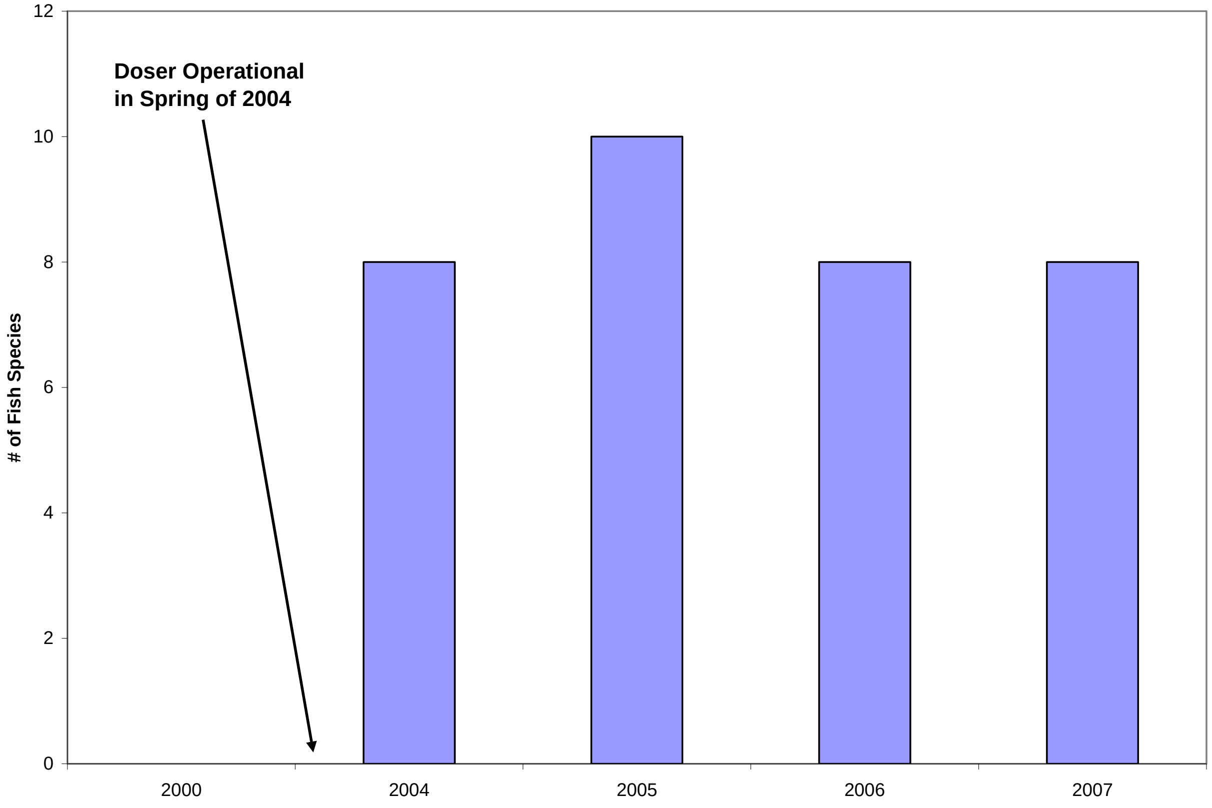


Figure 9: Macroinvertebrate Aggregated Index for Streams (MAIS) Metric Scores for Hewett Fork River Mile 8.3
Pre & Post AMD Treatment (Carbondale Doser)

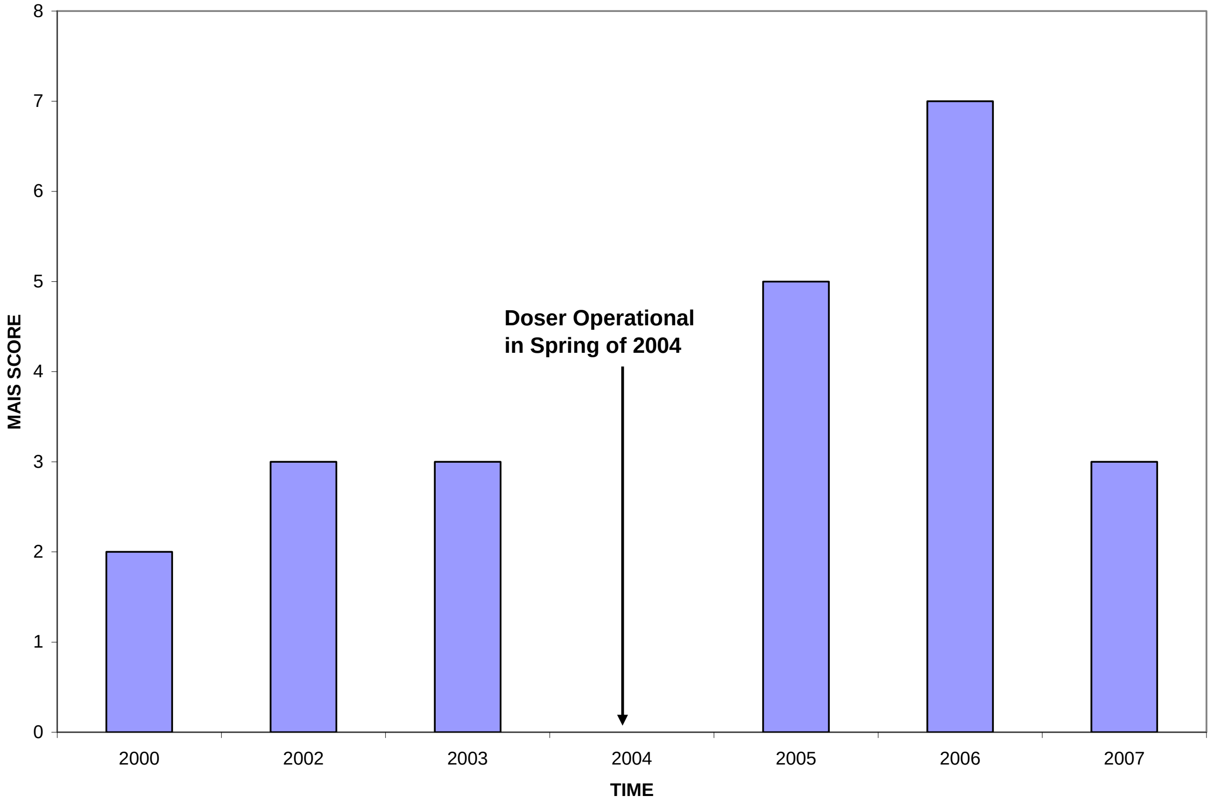


Figure 10: Index of Biological Integrity (IBI) Scores for Hewett Fork Pre & Post AMD Treatment (Carbondale Doser)

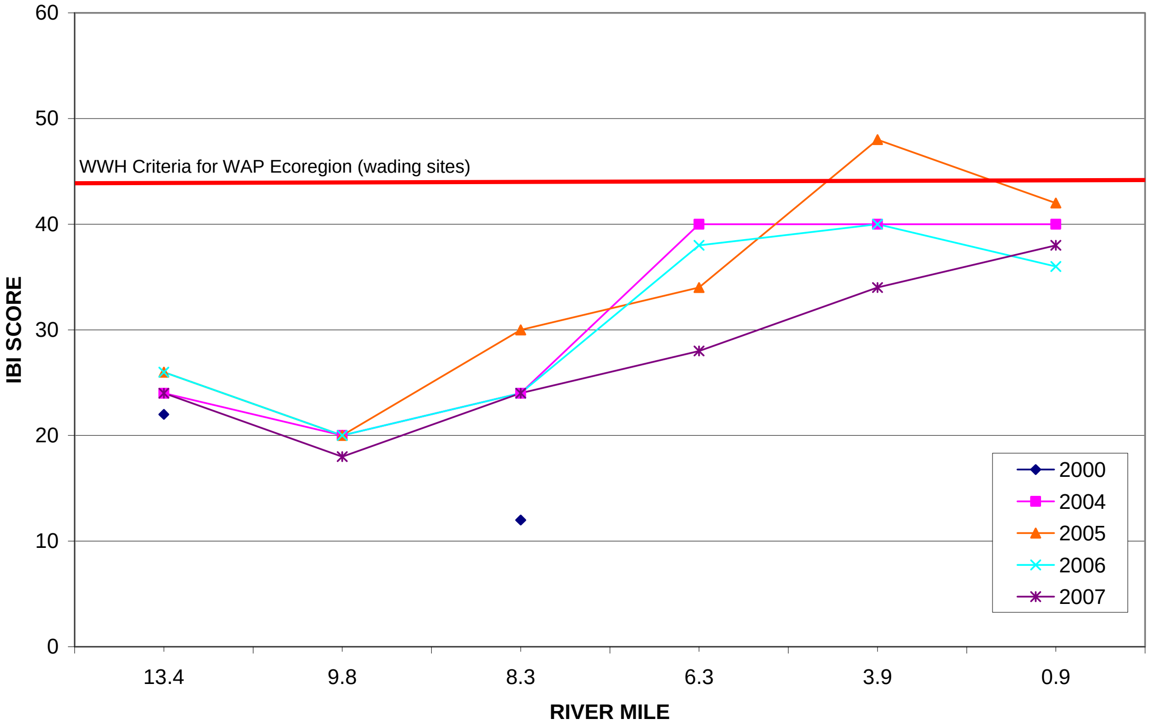
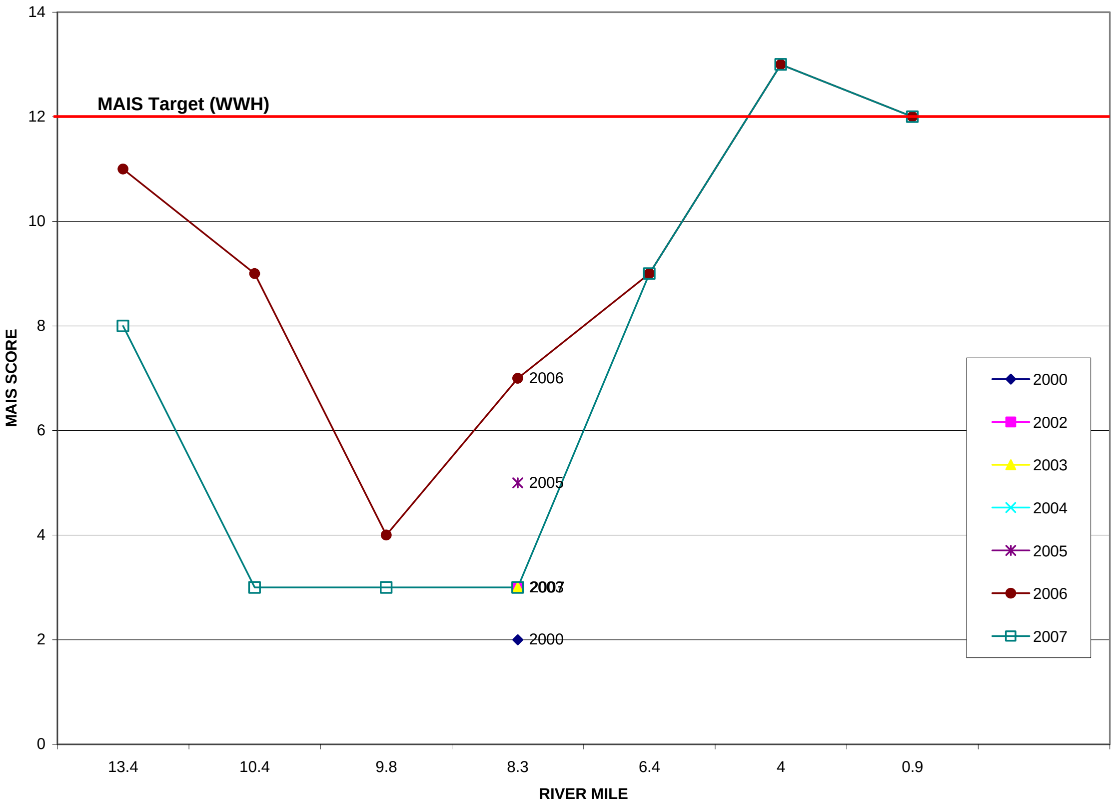


Figure 11: Macroinvertebrate Aggregated Index for Streams (MAIS) Metric Scores for Hewett Fork Pre & Post AMD Treatment (Carbondale Doser)



REFERNCES

Stoertz, M.W. and D.H. Green. 2004. Mean Annual Acidity Load: A Performance Measure to Evaluate Acid Mine Drainage Remediation. Ohio DMRM Applied Research Conference 2004. Mineral Resource Extraction and Restoration Innovations. Ohio University, Russ College of Engineering and Technology, Athens, OH.

Yoder, C.O. 1998. Important concepts and elements of an adequate state watershed monitoring and assessment program, pp. 615-628. *in* Proceedings of the NWQMC National Conference Monitoring: Critical Foundations to Protecting Our Waters. U.S. Environmental Protection Agency, Washington, DC.

Yoder, C.O. and E.T. Rankin. 1998. The role of biological indicators in a state water quality management process. J. Env. Mon. Assess. 51(1-2): 61-88.

Appendix B

Demonstrating Incremental Improvement: Adequate Indicators and Monitoring and Assessment Are Essential to Accurate Watershed Characterization

Prepared for:

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Appendix B

Demonstrating Incremental Improvement: Adequate Indicators and Monitoring and Assessment Are Essential to Accurate Watershed Characterization

Background

As the need for adequate supplies of clean water increases, concerns about public health and the environment escalate, and geographically targeted watershed-based approaches increase, the demands on the water quality monitoring "infrastructure" will likewise increase. These demands cannot be met effectively nor economically without fundamentally changing our attitudes towards ambient monitoring (ITFM 1995). An adequate ambient monitoring and assessment framework is needed to ensure not only a good science-based foundation for watershed-based approaches, but water quality management in general. This paper attempts to describe the important elements, processes, and frameworks that need to be included as part of an adequate State monitoring and assessment program and how this should be used to support the overall water quality management process. Furthermore, it is a goal of this effort to highlight the need to revitalize monitoring, assessment, and environmental indicators as an integral part of the overall water quality management process.

Monitoring and assessment information, when based on a sufficiently comprehensive and rigorous system of environmental indicators, is integral to protecting human health, preserving and restoring ecosystem integrity, and sustaining a viable economy. Such a strategy is intended to achieve a better return on public and private investments in environmental protection and natural resources management. In short, more and better monitoring and assessment information is needed to answer the fundamental questions that have been repeatedly asked about the condition of our water resources and shape the strategies needed to deal with both existing and emerging problems within the context of watershed-based management.

Watershed-based approaches are gaining widespread acceptance as a conceptual framework from within which water quality management programs should function. However, overall reductions and inequities in State ambient monitoring and assessment programs jeopardize the scientific integrity of watershed-based approaches. This also has had the undesirable effect of failing to properly equip the States and EPA to adequately meet the challenges posed by recently emerging issues such as cumulative effects, nonpoint sources, habitat degradation, and interdisciplinary issues (e.g., TMDLs) in general. In response to these concerns a framework for adequate watershed monitoring and assessment was developed in 1997.

A Framework for Adequate Monitoring and Assessment

Yoder (1998) detailed a framework for assuring that state monitoring and assessment programs are adequate in terms of parameters, indicators, design, and assessment outputs. Some of the contemporary efforts to revitalize and better define the role of monitoring and assessment in state and federal programs (ITFM 1992, 1995; U.S. EPA 1994) and the emergence of workable, biological indicator concepts (Karr and Dudley 1981; Karr et al. 1986) offer detailed frameworks that are the basis of what is termed here as "adequate" monitoring and assessment (Yoder 1998).

The term "adequate" was deliberately chosen as a theme on which to base the template for evaluating individual state programs. It is an attempt to avoid usage of the term "minimum" which is what EPA has historically accepted. The term "comprehensive" was considered, although it can imply doing more than is necessary to achieve the basic goals and objectives outlined by the above referenced processes.

The baseline components of an adequate monitoring and assessment program were originally described in *Important Concepts and Elements of an Adequate State Watershed Monitoring and Assessment Program* (Yoder 1998). This document relied principally on the products and recommendations of the ITFM process, EPA's environmental indicators initiatives of the 1990s, and the experiences of selected states in operating consistent and adequately funded programs. In turn, these efforts have given critical foundational support to EPA's CALM process and later the TALU process (U.S. EPA 2005). What is different here is the greater level of detail and specificity regarding specific roles and types of indicators and parameters and the tie-in to WQS, specifically designated uses and criteria. It is a fundamental premise of adequate monitoring and assessment that achieving a sufficient level of integration and detail is contingent on actually executing an adequate approach to monitoring and assessment. This includes the incorporation of essential, underlying concepts in addition to the *adequacy* of what is measured and monitored and over what spatial scales that it takes place. It also includes "infrastructure" issues such as staffing (including professional qualifications), facilities (e.g., laboratory, equipment, instrumentation), and support (e.g., data management, fiscal and administrative support). It is important to recognize that achieving adequacy is as much about framework and process as it is about data sufficiency. Successfully addressing the process issues are key to resolving the current deficiencies and inequities within and between state programs and still lingering questions about the reliability of state and national 305[b] reports and, by extension, 303[d] listings, nonpoint source and watershed management, and WQS. Certainly measuring incremental change is an important outcome of this process.

An important prerequisite to achieving an adequate monitoring and assessment approach is the incorporation of fundamental concepts in the development of the indicators and criteria that operationally determine the status of aquatic resources, designated uses, and the effectiveness of water quality management. These include a comprehensive approach to developing indicators and endpoints leading to the appropriately detailed and refined criteria and standards that guide management programs and measure their effectiveness. This approach addresses two of the principal issues identified by the National Research Council (NRC 2001) in their review of the role of science in the TMDL process; 1) adequate monitoring and assessment, and 2) appropriately refined and detailed water quality standards (WQS). Adequate monitoring includes the following key attributes and principles:

- Indicator development, position, and selection adhere to baseline theoretical concepts (i.e., Karr's five factors; NRC position of the standard [NRC 2001]);
- Indicators are comprehensive, yet cost-effective;
- Indicators are used within their *most appropriate* roles (stress, exposure, or response);
- Indicators are directly tied to WQS via designated uses and numerical or narrative criteria;

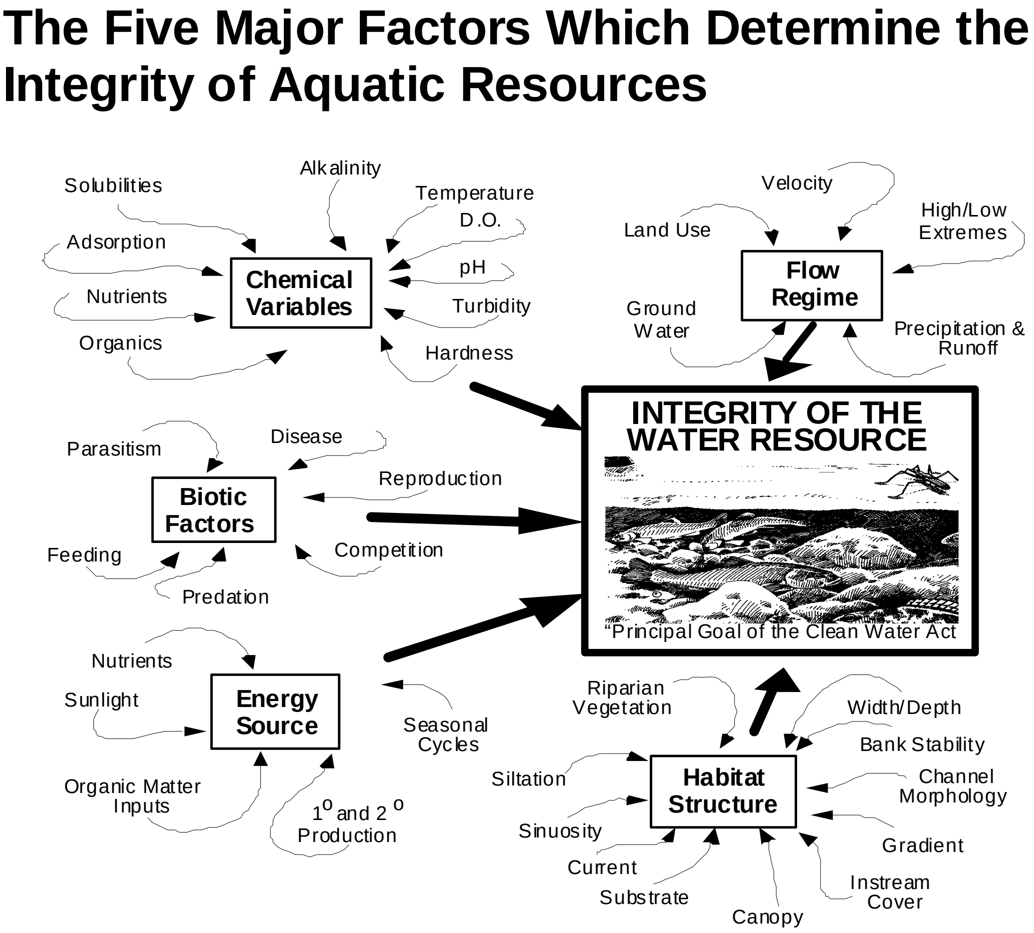


Figure 1. The five factors which determine the integrity of aquatic ecosystems with selected attributes of each (modified from Karr et al. 1986).

- Measurement and data quality objectives (MQO/DQO) are defined in the WQS and are adequate to support accurate assessments and perform diagnostic functions;
- The program can adapt quickly to improved science and technology;
- The program is supported by adequate resources, facilities, and professionalism;
- The spatial design(s) matches the scale at which management is applied; and,
- The end product is an integrated assessment, not just the data.

Theoretical Concepts – Karr's Five Factors

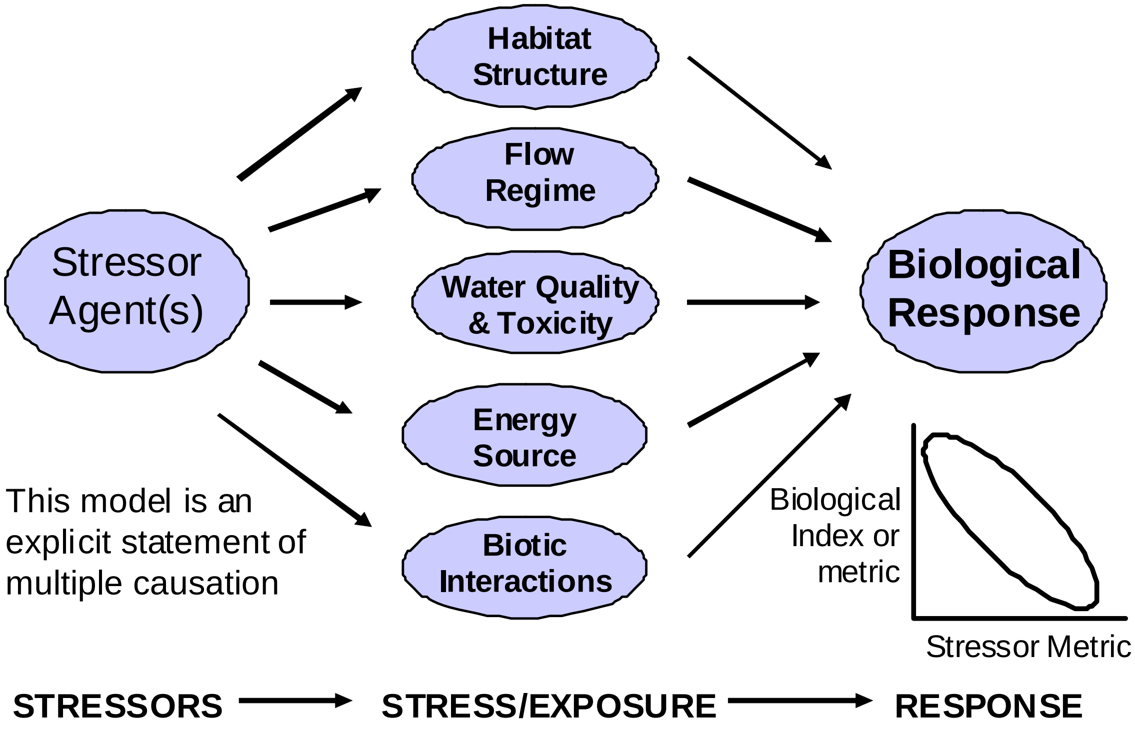
One of the most important concepts developed over the past three decades is the recognition of how diverse human activities alter water resources and the extent to which those activities interact with topographical, geological, climatological, and biological differences among watersheds (Karr and Yoder 2004). Five features (or factors) of water resources that are altered by the cumulative effects of human activities (Figure 1; Karr et al. 1986; Karr 1991) are:

Energy source: includes changes in the food web including nutrients, organic material inputs, seasonal cycles, primary and secondary production, and sunlight.

Chemical variables: includes changes in chemical water quality including D.O., pH, turbidity, hardness, alkalinity, solubilities, adsorption, nutrients, organics, toxic substances, temperature, sediment, and their interactions.
Flow Regime: includes modification of flows including precipitation, seasonal patterns, land use, runoff, velocity, ground water, daily and seasonal extremes.
Habitat structure: includes alteration of physical habitat including bank stability, current, gradient, instream cover, vegetative canopy, substrate, current, sinuosity, width, depth, pool/riffle ratios, riparian and wetland vegetation, shorelines, sedimentation, channel morphology.
Biotic factors: includes changes in biotic interactions such as introductions of alien taxa, feeding, reproduction, predation, harvest practices and rates, diseases, parasitism, competition.

First, this model essentially defines the role and relevance of various chemical, physical, and biological attributes, some of which can be measured and used as indicators. It is the interaction of the attributes of the five features that produces the state or quality of a water resource. A measurable attribute of one of the five features by itself is seldom, if ever, a reliable indicator of the whole system or its state. However, measures that approximate the condition of the system as a whole are "positioned" closer to the endpoint of concern and hence function as more reliable indicators of condition (NRC 2001). Second, it provides a conceptual basis for choosing and using various chemical, physical, and biological indicators and measures within an adequate monitoring and assessment framework. An understanding of these interactions is an important guide to the selection of indicators for monitoring programs (Karr 1991; Yoder 1998). Third, it places biological measures in the role of an integrative response indicator that represents the synthesis of the interactions of the chemical, physical, and biotic attributes of a water resource. It provides a comprehensive signal to evaluate management actions that are inherently limited to measuring and controlling only *some* of the attributes. Lastly, it provides the basis for an allied model by which the sequence of stress and exposure can be validated by the observation of ecosystem response (Figure 2). Indicators of stress and exposure are routinely used in water quality management as design criteria and as compliance thresholds. Used alone, these may not achieve the desired result (i.e., restoration of an impaired designated use) or they may have unintended consequences, unless they are evaluated through the lens of biological response (Karr and Yoder 2004). It is the accurate measurement of biological response that is key to making this process work in actual practice, much more so than our ability to precisely measure stress or exposure. Stress and exposure criteria are determined through indirect means and as such function as surrogates for true biological response. This process offers a way to ground truth the application of water quality and other criteria in relation to the totality of the interactions that result in a biological response, but which cannot be accounted for on a parameter-by-parameter basis. Sequencing the management of stress through how it affects key attributes of the five factors through to the eventual biological response provides a process by which adequate monitoring and assessment can be used to validate the effectiveness of management actions to control stressors (Figure 4). The severity and degree of the biological response to these impacts is ultimately what is important, not the mere presence of an impact.

The Linkage From Stressor Effects to Ecosystem Response



This model is an explicit statement of multiple causation

Cost-Effective Indicators

Cost-effective indicators are based on proven sampling methods and procedures that can be executed in a reasonable time frame and with reasonable effort. A commonly used description are measures that can be accomplished at a sampling site in a "few" hours, allowing several sites to be sampled each day, tens of sites per week, and hundreds of sites per year by a single field crew[1]. However, it includes indicators that are sufficiently developed, calibrated, and proven so as to ensure accuracy and precision. Accuracy includes the minimization of type I and II assessment error, i.e., the under or over estimation of status. It also includes the ability to extract meaningful diagnoses of observed responses using multiple chemical, physical, and biological parameters and measures, each used in their most appropriate roles as stressor, exposure, and response indicators. Precision includes reliable estimates of chemical, physical, and ecological properties and that produce statistical rigor. Frequently, statistical rigor implies attention to sampling frequency and reducing variance estimates. However, it is also important to understand the assessment capacity

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[1] A field crew is a 2-4 person team dedicated to the collection of data for a specific indicator category (chemical, physical, biological).

of each indicator and its position within the five factors that determine the integrity of a water resource. For aquatic life assessments, basing measures of condition on a biological indicator incurs the power of assessment inherent to the position of this indicator relative to the endpoint of concern, i.e., the health and well-being of the biota. Whereas attempting to estimate biological status using chemical or physical surrogates introduces the need to achieve statistically valid estimates for the parameter of concern, which may mean expending significant analytical and sampling resources. The use of the most direct measure of the endpoint of concern can in effect "leap frog" the statistical (i.e., sampling frequency) issues involved with surrogates and reduce the need for a higher degree statistical rigor for the surrogate indicator. In turn, the surrogates fulfill the role of stress and exposure indicators, which requires less statistical rigor and fewer samples. The trade-offs involved result in a more cost-effective monitoring and assessment program.

Another aspect of a cost-effective approach to monitoring and assessment is determining which indicators and parameters are measured in a given situation. The ITFM (1992) indicators process arranged indicators according to their role and value for first determining the state of the aquatic

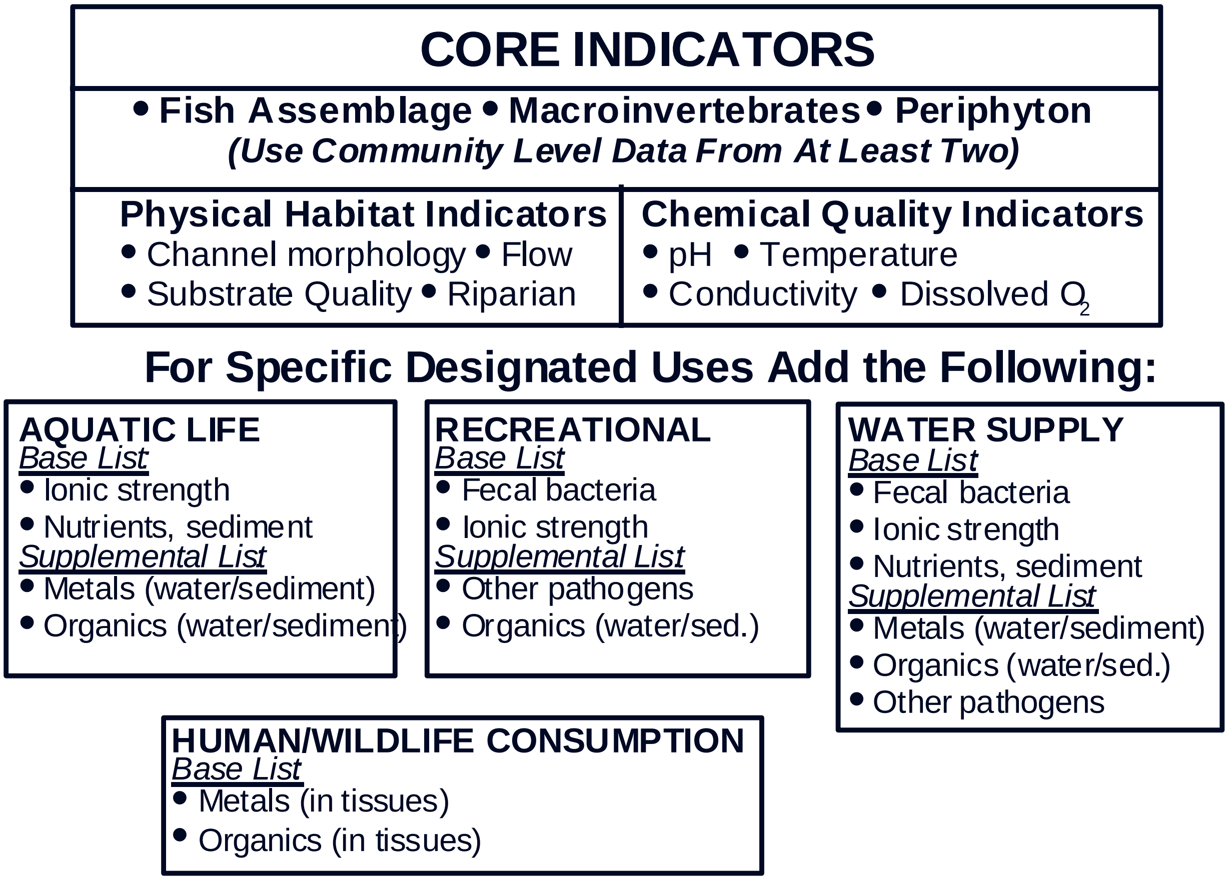


Figure 3. Core indicators and parameters by designated use to support an adequate watershed monitoring and assessment approach (after ITFM 1992 and Yoder 1998).

system and adding key parameters and indicators in accordance with specific designated uses and the complexity of the setting. The different types of measurements that comprise an adequate watershed monitoring and assessment approach consist of core and supplemental indicators and parameters (Figure 3). The **core** parameters are collected in *all* situations regardless of the assessment, regulatory, and management issues of concern. These represent the key, essential chemical, physical, and biological elements of water resource integrity (Karr et al. 1986) and reflect the most basic components of all aquatic ecosystems (living biota, habitat, and primary water quality). These fulfill the need to first characterize the condition and status of the baseline attributes. They are also measured directly in the field, thus providing rapid feedback to qualified analysts. Conventional approaches to monitoring and assessment attempt to formulate the assessment questions prior to deciding what to measure. However, adequate monitoring generates data and information about the core parameters in order to determine what the assessment questions should be, some of which cannot be sufficiently formulated without such data and information. Furthermore, they directly represent the fundamental attributes of aquatic ecosystems and, as such, comprise the baseline of adequate information needs for fundamental and recurrent assessment questions such as use attainment status, water quality standards compliance, use attainability analyses, delineation of associated causes/sources of threat and impairment, and basic reporting (305b report) and listing (303d listings). The supplemental parameters are added as the assessment needs (or questions) increase in diversity, quantity, and complexity of the setting. For example, a comparatively simple setting with one or two principal stressors may be adequately addressed by the core parameters plus the base list for aquatic life and recreation. As the complexity of a study area increases in terms of stressors and uses, the list will increase to include more of the supplemental parameters, the frequency of their collection and analysis, and the spatial intensity of the sampling design. This is a reasoned and stepwise selection of additional measurements, most of which require laboratory analysis. It can also include media in addition to the water column such as bottom sediments and organism tissues. All of this is dealt with in the initial planning of the watershed assessment and the development of a detailed plan of sampling.

Another dimension of cost-effectiveness is the capture of all relevant management objectives with the chosen suites of indicators. Table 1 relates indicator categories to classes of common water resource management program objectives. These may be addressed as part of the field sampling or accessed later in the analysis and reporting phases of the assessment process. These are critical components of the sequential analysis of the monitoring data and information, which relates designated use impairments to associated causes and sources. This approach also economizes sampling resources by scaling the intensity and complexity of the monitoring and assessment effort in accordance with the management issues to be addressed. This type of approach also allows for more flexible management responses that are attenuated by the information revealed about the environmental complexity of the setting, the quality of the aquatic resource, and the potential pollution problems encountered. Effective implementation of this process is improved through the experience and knowledge gained by conducting monitoring and assessment for many years and over a wide geographical area.

Table 1. Summary matrix of recommended environmental indicators for meeting management objectives for status and trends of surface waters (a boldface "X" indicates a recommended primary indicator after ITFM 1995; other recommended indicators are designated by a "√"). The corresponding EPA indicator hierarchy level (see Figure 6) is also listed for each suite of indicator groups.

	Categories of Management Objectives					
	Human Health			**Ecological Health**	**Economic Concerns**	
Indicator Group	Consump-tion of fish/ shellfish	Public Water Supply	Recreation (swimming, fishing, boating)	Aquatic/ Semi-aquatic Life	Energy/ Transportation	Agriculture/ Forestry/ Mining
Biological Response Indicators (Level 6)						
Macroinvertebrates		X	X	**X**		**X**
Fish	**X**	X	X	**X**		**X**
Semi-aquatic animals	X		X	**X**		X
Pathogens	X	**X**	**X**			X
Phytoplankton	X	X	X	X	X	
Periphyton				X		
Aquatic Plants		X	X	X	X	X
Zooplankton		X	X	X		X
Chemical Exposure Indicators (Levels 4&5)						
Water chemistry	**X**	**X**	**X**	**X**	**X**	**X**
Odor/Taste	X	X	X			X
Sediment Chemistry	**X**	X	X	**X**	**X**	**X**
Tissue Chemistry	**X**	**X**		X	X	
Biochemical Markers	√	√	√	√		
Physical Habitat/Hydrological Indicators (Levels 3&4)						
Hydrological Measures	X	X	X	**X**	**X**	**X**
Temperature	X	X	X	X	X	**X**
Geomorphology	X	X	**X**	**X**	**X**	**X**
Riparian/Shoreline	X	X		X	X	X
Habitat Quality			√	√	√	√
Watershed Scale Stressor Indicators (Levels 3,4,&5)						
Land Use Patterns	X	X	X	X	X	X
Human Alterations	X	X	**X**	**X**	X	
Watershed Impervious-ness (% of watershed)			√	√		√
Pollutant Loadings Indicators (Level 3)						
Point Source Loads	√	√	√	√		√
Nonpoint Loadings	√	√	√	√	√	√
Spills/Other Releases	√	√	√	√	√	√

Indicator Discipline – Adherence to Indicator Roles

An important factor in achieving the cost effective approach just described is using chemical, physical, and biological indicators in their most appropriate roles as stressor, exposure, or response indictors. The accurate portrayal of the condition of aquatic resources depends on wider development and use of response indicators and adequate spatial monitoring designs conducted at the same scale of water quality management. Part of the solution to these challenges is to use indicators within their most appropriate roles. The EPA environmental Monitoring and Assessment Program (EMAP; U.S. EPA 1991) classified indicators as stressor, exposure, and response. Yoder and Rankin (1998) further organized the concept defining the most appropriate roles of parameters and measures when used in an adequate monitoring and assessment program.

Stressor indicators generally include activities and phenomena that impact, but which may or may not degrade or appreciably alter key environmental processes and attributes. These include point and nonpoint source pollutant loadings, land use changes, and other broad-scale influences that most commonly result from anthropogenic activities. Stressor indicators provide the most direct measure of the activities that water quality management attempts to regulate. **Exposure** indicators include chemical-specific, whole effluent toxicity, tissue residues, and biomarkers, each of which suggest or provide evidence of biological exposure to stressor agents. Fecal bacteria also serve as exposure indicators and are used as surrogates for response where direct human response indicators are either lacking or their use would pose an unacceptable risk. These indicators are based on specific measurements that are taken either in the ambient environment or in discharges and effluents, either point or nonpoint source in origin are measures and parameters that reveal the level or degree of an exposure to a potentially deleterious substance or effect that was produced by a stressor event or activity. Chemical water quality parameters and the concentrations at which they occur in the water column fulfill this role. Water quality criteria for toxic substances are developed to indicate chronic, acute, and lethal exposures. Exceedences of these thresholds, either predicted or measured, provide design targets for planning and permitting and assessment thresholds for monitoring and assessment. Fecal bacteria fulfill this role as well, indicating the level of risk posed to humans and other animals by exposure to various levels and durations of potentially harmful pathogens. **Response** indicators are measures that most directly relate to an endpoint of concern, i.e., ecological and human health. They are most commonly biological indicators, e.g., aquatic assemblage measures for aquatic life uses and human health for recreational uses and are the most direct measures of the status of designated uses. For aquatic life uses the assemblage and population response parameters that are represented by the biological indices that comprise biological criteria are examples of response indicators. For other designated uses such as recreation and drinking water, symptoms of deleterious effects exhibited by humans would serve as a response indicator, albeit these might prove more difficult to develop and manage. Response indicators represent the synthesis of stress and exposure (re: Figure 4) and are commonly used to represent overall condition or status. The key to implementing a successful indicators and watershed approach that serves as a basis for developing a synthesized report card is to ensure that indicators are used within the roles that are the most appropriate for each. The inappropriate substitution of stressor and exposure indicators in the absence of response indicators is at the root of the national problem of widely divergent 305(b) and 303(d) statistics reported between the states (NRC 2001).

Historically, states have used surrogate approaches to measuring and determining the status of designates uses. For aquatic life uses, chemical criteria have been cast in that role. For recreational uses, fecal bacteria continue to fulfill that role. Yoder and Rankin (1998) define the former practice as an inappropriate substitution of stress or exposure indicators for response. Comparisons of biological and chemical assessments show that the latter leads to listing of water bodies as impaired when they are not (type I error) or not listing when they are impaired (type II error). Rankin and Yoder (1990) using data over a 10 year period in Ohio and the Oregon Department of Environmental Quality (D. Drake, personal communication) using data from the 1990s, both showed that type II errors are the most prevalent, leaving up to 50% of the impairments detected by biological assessments undetected and undiagnosed. In the case of recreational uses, the reality of fecal bacteria exceedences and human health risks needs to be better reconciled.

A process for assembling information from cost-effective indicators comprised of biological, chemical, and physical measures used in their most appropriate roles can ensure that pollution sources are judged objectively and on the basis of quantifiable environmental results. Such an approach simultaneously assures that indicators will be representative of the elements and processes of the five factors that determine water resource integrity (Figure 1; Karr et al. 1986). An indicators hierarchy developed by U.S. EPA (1995a,b) provides a sequential process within which indicators can be linked to support assessment and management responses (Figure 6). It offers a structured approach to assure that management programs are, if necessary, adjusted based on environmental feedback (see also Figure 2). A comprehensive ambient monitoring effort that includes indicators representative of key variables within the five factors which determine the integrity of the water resource is essential to successfully implementing a true environmental indicators approach. For this approach to be successful, ambient monitoring must take place at the same scale at which management actions are being applied.

This integrated framework relies on the hierarchical continuum of administrative and true environmental indicators. This framework was initially developed by U.S. EPA (1995a). The original framework included six "levels" of indicators as follows:

Level 1 - actions taken by regulatory agencies (*e.g.*, permitting, enforcement, grants);
Level 2 - responses by the regulated community (*e.g.*, construction of treatment works, pollution prevention);
Level 3 - changes in discharged quantities (*e.g.*, pollutant loadings);
Level 4 - changes in ambient conditions (*e.g.*, water quality, habitat);
Level 5 - changes in uptake and/or assimilation (*e.g.*, tissue contamination, biomarkers, assimilative capacity); and,
Level 6 - changes in health, ecology, or other effects (*e.g.*, ecological condition, pathogenicity).

In this process the results of administrative activities (levels 1 and 2) are followed by changes in pollutant loadings and ambient water quality (levels 3, 4, and 5), all of which leads to measurable environmental "results" (level 6). The process is multi-directional with the level 6 indicators

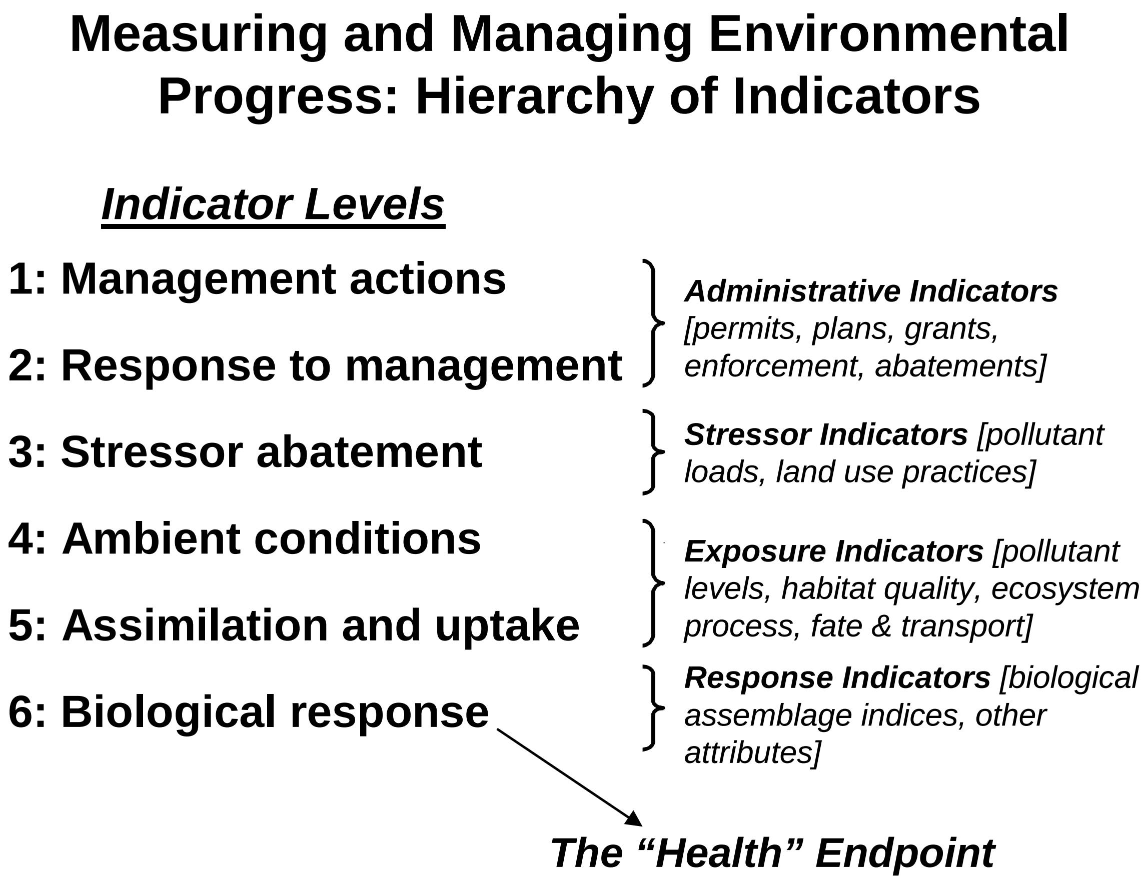


Figure 4. Hierarchy of indicators for determining the effectiveness of water quality management and maintaining appropriate relationships and feedback loops between different classes of indicators (modified from U.S. EPA 1995a).

providing overall feedback about the completeness and accuracy of the process through the preceding levels. While the U.S. EPA (1995a) hierarchy employs point source terms, it is adaptable to nonpoint sources and media other than surface waters. Superimposed on this hierarchy is the concept of stressor, exposure, and response indicators (Figure 6) similar to that developed by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP; U.S. EPA 1991). Stressor indicators include activities that have the potential to degrade the aquatic environment such as pollutant discharges, land use changes, and habitat modifications (level 3). Exposure indicators are those which measure the apparent effects of stressors and include chemical water quality criteria, whole effluent toxicity tests, tissue residues, bacterial levels, and biomarkers, each of which provides evidence of biological exposure to a stressor or bioaccumulative agent (levels 4 and 5). Response indicators include composite measures of the cumulative effects of stress and exposure and include the more direct measures of biological community and population response that are represented here by the biological indices which comprise the Ohio EPA biological criteria (level 6). Other response indicators could include target assemblages (*e.g.*, rare, threatened, endangered, special status, and declining species). All of these indicators represent the essential technical elements for watershed-based management approaches. The key is to use the different indicators within the roles that are most appropriate for each.

The processes for sequencing and synthesizing environmental data and indicators serves as a foundation for reporting on status and trends at all levels (national, regional, statewide, or local). The disciplinary process just described should minimize both type I and type II assessment errors. Such errors are a concern in the integrated 305b/303d reporting and listing process, in which both type I and II errors have been extensively propagated (Yoder and Rankin 1998; National Resource Council 2001). The results of these errors are waters that are not impaired are identified as needing corrective actions (type I error) or waters that are truly impaired are overlooked altogether (type II error). While this may be the most “visible” issue at present, the impact of such assessment errors can adversely affect other water quality management program areas. The process by which the basic data and information on which indicators are developed and used must be integrated at the outset, not as a “tack-on” at the end of the process. Bringing a more consistent and scientifically robust approach to indicators development and usage should lead to the correction of such errors and foster better policy and management outcomes as a result.

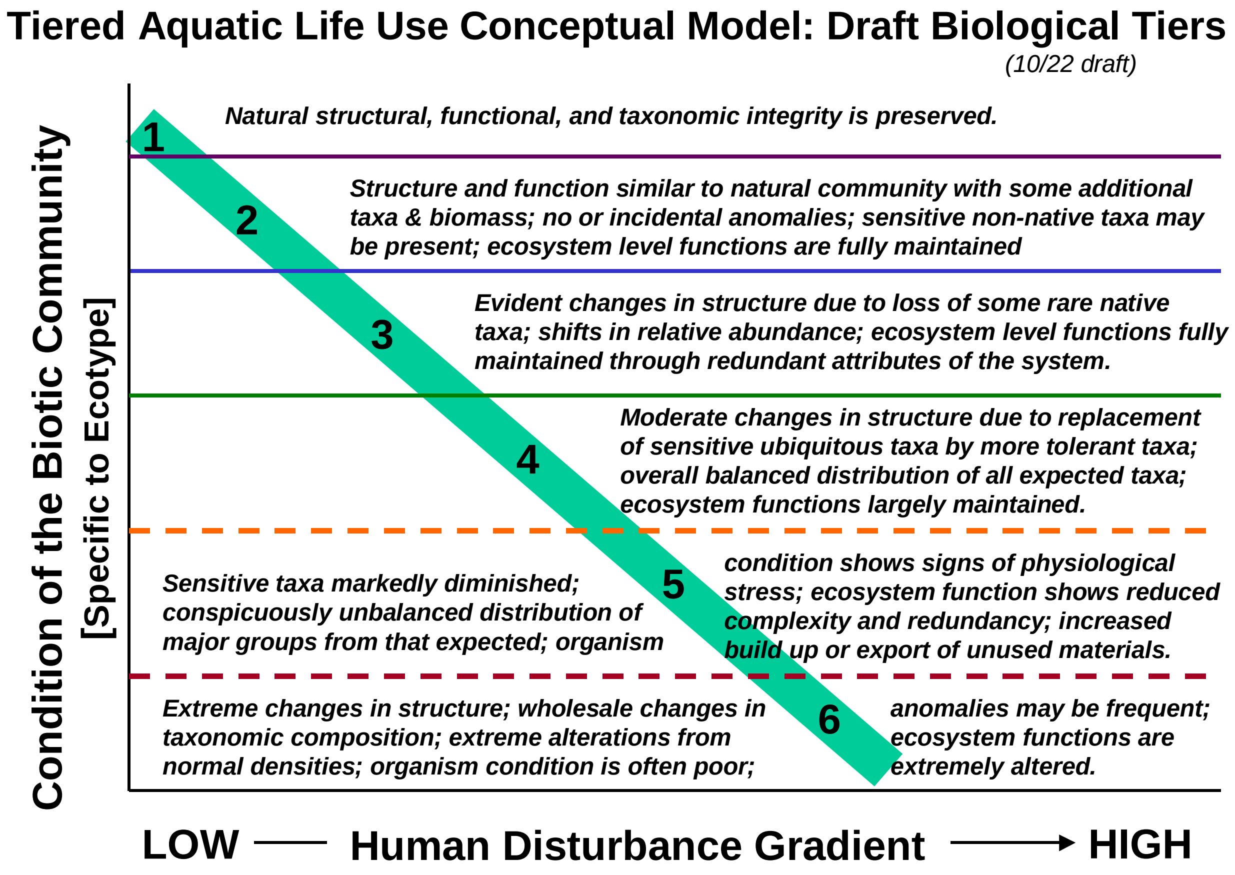
Key Indicators Are Tied to WQS - Designated Uses and Criteria

Water quality standards (WQS) establish the essential framework for developing measurable endpoints and criteria for deriving restoration and protection benchmarks. They consist of two parts – a designated use and criteria intended to protect and measure attainment of the designated use. They are used as targets for developing management strategies to achieve restoration and protection (e.g., wasteload allocations, TMDLs, BMPs, etc.) and for measuring the relative quality of water and aquatic ecosystems. Obviously, the more that WQS account for regional variability and characteristics inherent to the aquatic ecosystems of a region, the more relevant and accurate are assessments of quality and management strategies designed to achieve restoration and protection goals. WQS are an absolutely fundamental issue of adequate monitoring and assessment and the linkages between the two must be recognized (NRC 2001). States widely employ non-specific, general uses, which essentially represents a one-size-fits-all approach to designating and assessing surface waters. For example, states designate waters for the “protection and propagation of fish and aquatic life” of other general descriptions such as “cold water fishery”. Such uses are not specific enough to foster the development of the more detailed criteria and indicators that are needed to address many of the deficiencies identified by the General Accounting Office (GAO 2000, 2003b) and NRC (2001). Furthermore, the use of direct biological measures and criteria is viewed as essential to making refined uses work. A few states (e.g., Maine, Ohio, Vermont) have developed refined use designation frameworks that are supported by numeric biological criteria and these have been extensively described elsewhere (Courtemanch 1995; Yoder and Rankin 1995a; Yoder 1995). This has given rise to the biological condition gradient framework, which has been under development and testing by U.S. EPA (Figure 7) in support of the development of a national process for tiered aquatic life uses.

Water quality criteria are largely expressed as chemical pollutant concentrations and sometimes as narrative descriptors. As such, they function as indirect surrogates for the endpoint described by a designated use. The designated use is a description of a desired state or set of attributes for a waterbody and the criterion is a measurable indicator that is a surrogate of use attainment. A criterion occupies a position at any point along the sequence of stress, exposure, and response (Figure 8). The NRC (2001) described this as the "position of the standard" and concluded that a criterion that is positioned closer to the designated use is a more accurate indicator of that use. In addition, the more precisely the designated use is stated, the more accurate the criterion will be as a result. Karr and Yoder (2004) modified the original figure to show its consistency with the previously described stress, exposure, and response roles of indicators. It provides a way to relate different types of criteria (chemical, physical, biological) and how to sequence each along a causal chain of events such as that portrayed by the hierarchy of indicators. Both the appropriate roles of indicators and the hierarchy for sequencing them along a causal chain of events are embedded in Figure 8. Including adequate representatives of each indicator role and their development and calibration in a state's WQS institutionalizes their usefulness to water quality management.

Data and Measurement Quality Objectives

Data (DQO) and measurement quality objectives (MQO) determine the level of detail and analysis that is required in support of an indicator or parameter. Frequently, these are defined by the state's WQS, either directly or implicitly and these comprise an important determinant of the



Natural structural, functional, and taxonomic integrity is preserved.

Structure and function similar to natural community with some additional taxa & biomass; no or incidental anomalies; sensitive non-native taxa may be present; ecosystem level functions are fully maintained

Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained through redundant attributes of the system.

Moderate changes in structure due to replacement of sensitive ubiquitous taxa by more tolerant taxa; overall balanced distribution of all expected taxa; ecosystem functions largely maintained.

Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; ecosystem function shows reduced complexity and redundancy; increased build up or export of unused materials.

Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities; organism condition is often poor; anomalies may be frequent; ecosystem functions are extremely altered.

Figure 5. Refined aquatic life use conceptual model showing a biological condition axis and descriptive attributes of tiers along a gradient of quality and disturbance (U.S. EPA 2005).

accuracy of assessments produced by a monitoring and assessment effort. For example, if a pollutant criterion is set at a concentration of 10 μg/l, then sampling and analytical methods that ensure detection to at least that concentration will be required. As such, the 10 μg/l criterion serves as the data and measurement quality objective. Furthermore, for many parameters it will be necessary to measure below the criterion threshold as there will be management issues of interest at lower levels. An example is defining reference condition for individual pollutants, which will require knowledge of the range of occurrence from minimum detection limit up to the criterion. For biological assessments, the issue includes how samples are obtained (effort, gear selectivity), how they are processed (subsampling, handling, preservation), how they are enumerated and identified (level of taxonomy), and the attributes that are recorded (species, numbers, biomass, anomalies). This illustrates both the qualitative and quantitative aspects of this issue. In biological assessment, taxonomic resolution is a key quality objective, as this not only determines the power of the assessment tool, but the diagnostic capabilities as well (Yoder and Rankin 1995b; Yoder and DeShon 2003). DQO/MQO can be governed by methods and protocol documents, but are much less ambiguous and debatable when they are codified in the state's WQS. Data and measurement

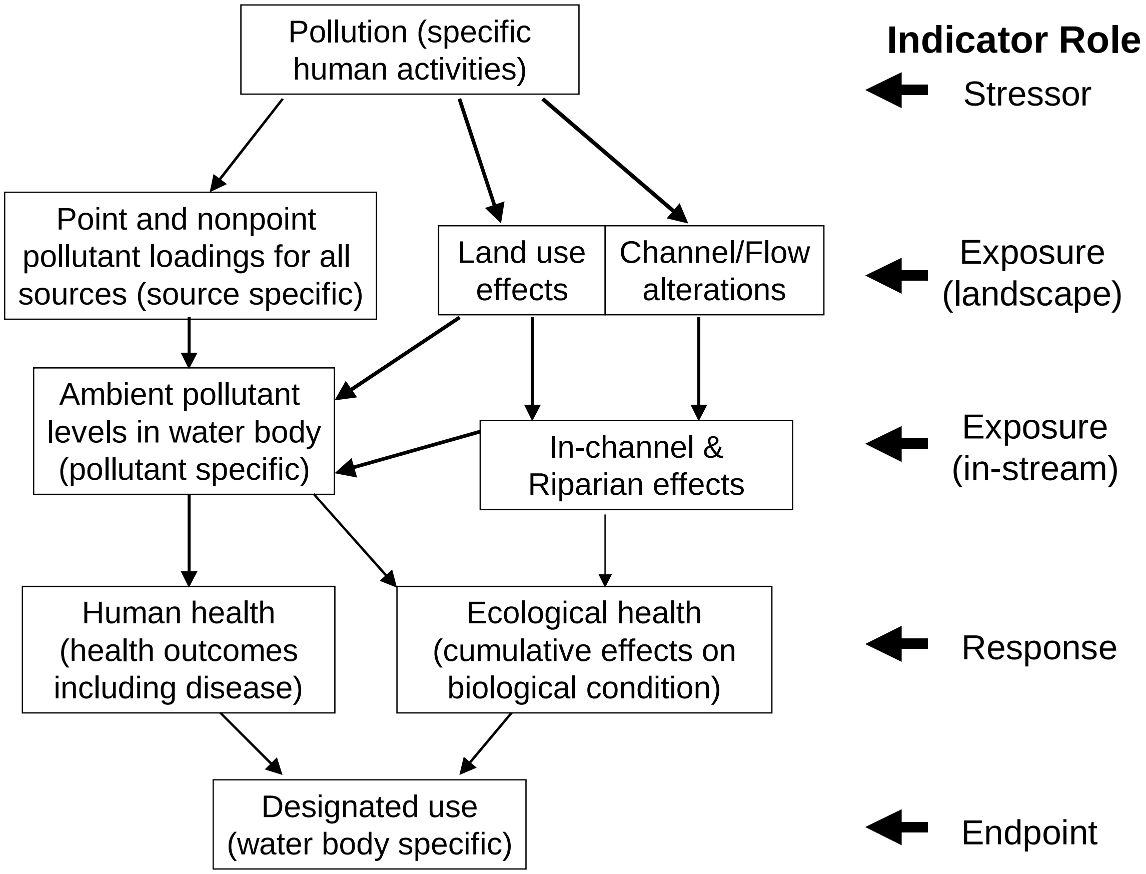


Figure 6. Position of the criterion (stressor, exposure, or response) illustrating the relationships between human activities, specific types of criteria, and designated uses that define the endpoint of interest to society (modified from NRC 2001). Their parallel roles as environmental indicators for each category is listed on the right. Arrows indicate directions and interrelationships along the causal sequence of stress, exposure, and response.

quality objectives inherently determine the overall capabilities of a monitoring and assessment program to accurately detect, quantify, and diagnose environmental status.

Strategic Issues

Adequate monitoring and assessment is an inherently strategic process. To fully realize the benefits of such requires an understanding of the multiple uses of the information in the management of water resources. A fundamental tenet of adequate monitoring and assessment is that the same set of core resources, methods, standards, data, and information should support multiple program management needs (Figure 13). It also requires a commitment to program maintenance and upkeep (i.e., maintenance of adequate resources, facilities, and professionalism) over the long term. Professionalism includes the qualifications of the monitoring and assessment personnel and their ability to carry out all tasks, including data analysis and the sequencing and interpretation of multiple indicators. Several of the indicators require specialized expertise in terms of data collection, field observations, laboratory methods, taxonomic practice, and data analysis and interpretation skills. Thus the professional qualifications of the personnel who execute and manage a statewide program is a pivotal issue.

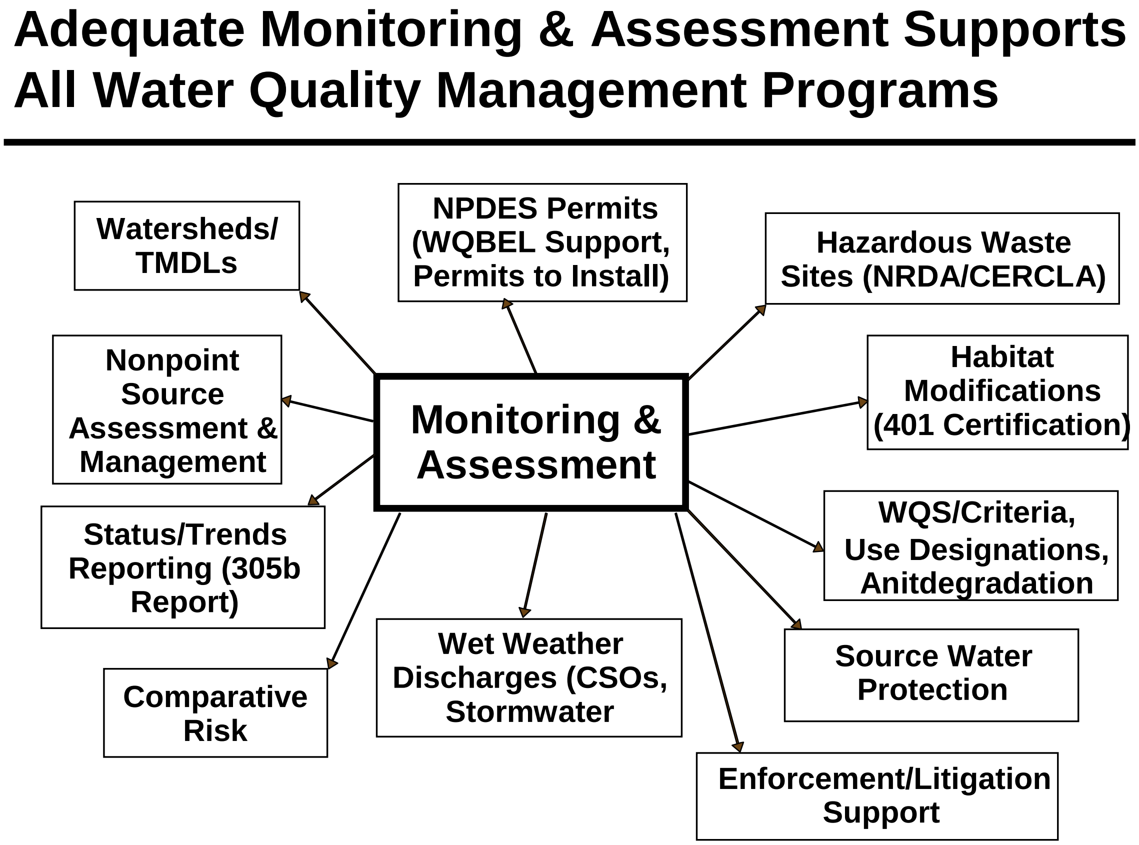


Figure 13. Adequate monitoring and assessment should be capable of supporting multiple program support needs with the same core base of indicators, parameters, and designs.

Two important functions of adequate monitoring and assessment include the functional support provided to individual management programs. The first includes tasks such as determinations of status at multiple scales, use attainability analyses, supporting the management of specific sources, and providing information to guide watershed planning and restoration processes (Figure 14; upper tier). The second is that of providing "strategic support" via the systematic accumulation of data, information, knowledge, and experience across various temporal and spatial scales (Figure 10; lower tier). This includes resources devoted to such tasks as sampling and maintenance of reference sites for determining regional reference condition and developing reference condition and benchmarks for key biological, physical, and chemical indicators and parameters. Many contemporary management needs are not well supported by conventional approaches to water quality criteria and modeling, thus new ways of developing and applying benchmarks and criteria are needed. Developing criteria for nutrients and clean and contaminated sediments are examples. Other issues such as urbanization and habitat concerns will require landscape and riparian level indicators and objectives. All require robust spatial and temporal datasets. Coupled with this is the need to conduct ongoing applied research and exploratory data analysis with the monitoring program datasets, including the aggregate experience of the program. The ongoing accumulation of data, information, and assessment across different spatial scales provides both the datasets and the assessment experiences. This comprises the strategy for delivering the criteria and benchmarks that will not be delivered by the conventional approach to developing national water quality criteria.

Finally, the recognition that the most important product of adequate monitoring and assessment is the assessment, not just the data, is critical to achieving success. Data by itself has limited usefulness to environmental decision-making unless it is converted to useful information. This means having decision criteria and benchmarks fully integrated into the monitoring and assessment program. It also means adhering to the indicator sequencing and linkage processes that were previously described and most importantly, using indicators within their most appropriate roles. An integrated assessment should serve the needs of multiple programs by the same set of assessments, without the need to generate new or different datasets for each and every management issue.

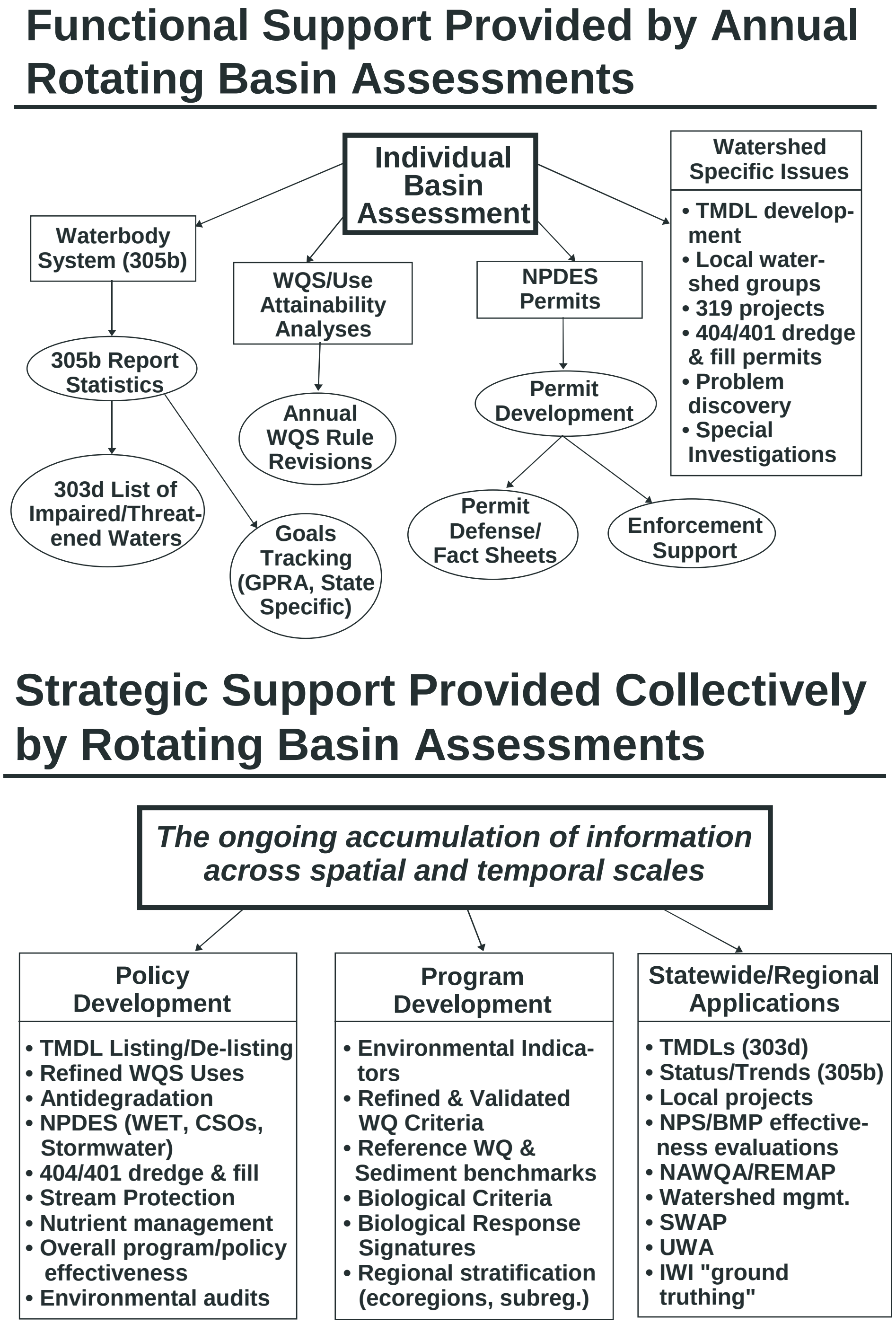


Figure 14. Examples of water quality management program support routinely provided by adequate monitoring and assessment at the watershed level (upper panel) and as a baseline support function delivered by routine monitoring over time (lower panel).

REFERNCES

General Accounting Office (GAO). 2000. Water quality – key EPA and state decisions are limited by inconsistent and incomplete data. GAO/RCED-00-54. Washington, DC: GAO.

General Accounting Office (GAO). 2003a. Major Management Challenges and Program Risks: Environmental Protection Agency. GAO-03-112. Performance and Accountability Series. US General Accounting Office, Washington, DC.

General Accounting Office (GAO). 2003b. Water quality: improved EPA guidance and support can help states develop standards that better target cleanup efforts. GAO-03-308, U.S. General Accounting Office, Washington, D.C.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1995. The strategy for improving water-quality monitoring in the United States. Final report of the Intergovernmental Task Force on Monitoring Water Quality. Interagency Advisory Committee on Water Data, Washington, D.C. + Appendices.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1993. Ambient water quality monitoring in the United States: second year review, evaluation, and recommendations. Interagency Advisory Committee on Water Data, Washington, D.C. + Appendices.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1992. Ambient water quality monitoring in the United States: first year review, evaluation, and recommendations. Interagency Advisory Committee on Water Data, Washington, D.C.

Karr, J. R., K. D. Fausch, P. L. Angermier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5: 28 pp.

Karr, J. R., and Dudley, D. R. 1981. Ecological perspective on water quality goals. Environ. Management 5: 55—68.

Midwest Biodiversity Institute (MBI). 2004. Region V state bioassessment and ambient monitoring programs: initial evaluation and review. Midwest Biodiversity Institute Tech. Rept. MBI/01-03-1. 36 pp. + appendices. (http://www.epa.gov/region5/water/wqb/wqb_r5mon.htm)

National Research Council (NRC). 2001. Assessing the TMDL Approach to Water Quality Management. National Academy Press, Washington, DC., 109 pp.

National Research Council (NRC) 2000. Ecological Indicators for the Nation. Washington, DC: National Academy Press. http://www.nap.edu/catalog/9720.html.

Rankin, E. T., and Yoder, C. O. 1990. A comparison of aquatic life use impairment detection and its causes between an integrated, biosurvey-based environmental assessment and its water column chemistry subcomponent. Appendix I, Ohio Water Resource Inventory (Volume 1), Ohio EPA, Div. Water Qual. Plan. Assess., Columbus, Ohio.

U.S. Environmental Protection Agency. 2003. Elements of a state monitoring and assessment program. EPA 841-B-03-003. Office of Water, Washington, DC. 14 pp.

U.S. Environmental Protection Agency. 1995a. Environmental indicators of water quality in the United States. EPA 841-R-96-002. Office of Water, Washington, DC 20460. 25 pp.

U.S. Environmental Protection Agency. 1995b. A conceptual framework to support development and use of environmental information in decision-making. EPA 239-R-95-012. Office of Policy, Planning, and Evaluation, Washington, DC 20460. 43 pp.

U.S. Environmental Protection Agency. 1994. Section 106 and 604[b] grant guidance - water monitoring. U.S. EPA, Office of Water, Assessment and Watershed Protection Division, Washington, DC. 9 pp. + app.

U.S. Environmental Protection Agency. 1990. Feasibility report on environmental indicators for surface water programs. U. S. EPA, Office of Water Regulations and Standards, Office of Policy, Planning, and Evaluation, Washington, D. C.

Yoder, C.O. and 9 others. 2005. Changes in fish assemblage status in Ohio's nonwadeable rivers and streams over two decades, pp. 399-429. *in* R. Hughes and J. Rinne (eds.). Historical changes in fish assemblages of large rivers in the America's. American Fisheries Society Symposium Series.

Yoder, C.O. and J.E. DeShon. 2003. Using Biological Response Signatures Within a Framework of Multiple Indicators to Assess and Diagnose Causes and Sources of Impairments to Aquatic Assemblages in Selected Ohio Rivers and Streams, pp. 23-81. *in* T.P. Simon (ed.). BIOLOGICAL RESPONSE SIGNATURES: patterns in biological integrity for assessment of freshwater aquatic assemblages. Lewis Publishers, Boca Raton, FL.

Yoder, C.O. and E.T. Rankin. 1998. The role of biological indicators in a state water quality management process. J. Env. Mon. Assess. 51(1-2): 61-88.

Yoder, C.O. 1998. Important Concepts and elements of an adequate state watershed monitoring and assessment program, pp. 615-628. *in* Proceedings of the NWQMC National Conference Monitoring: Critical Foundations to Protecting Our Waters. U.S. EPA, Washington, DC, 663 pp. + app.

Yoder, C.O. and E.T. Rankin. 1995a. Biological criteria program development and implementation in Ohio, pp. 109-144. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Yoder, C. O., and Rankin, E. T. 1995b. Biological criteria program development and implementation in Ohio, pp. 109-144. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.