Level 1
Problem Identification

1. Establish management sphere

Who will be responsible for implementation?
What other programs are being implemented within watershed?

2. Gather/review historical data

Identify programs /studies already implemented in the watershed.
Determine problem areas and assess effectiveness of earlier efforts.

3. Identify potential receiving water impacts

Identify uses/characteristics which may be impacted by stormwater runoff.

- Hydrology and hydrodynamics (flooding, drainage, physical habitat)
- Biological integrity (fish diversity, macro. community)
- Non-contact recreation (sports fishing)
- Supply (potable water)
- Contact recreation (swimming)
- Aqua-culture (shellfish harvesting, food fishing)

4. Inventory resources and identify constraints

Determine staff and funding limitations.
Identify regulatory-mandated deadlines and programs.

- Scheduling Constraints
- Funding
- Regulatory Compliance

5. Assess baseline conditions

Use rapid (qualitative) assessment methods versus detailed quantitative techniques to assess baseline conditions.

Indicator Options by Receiving Water Use

- Hydrology and hydrodynamics
  Physical / Social / Programmatic / Site
- Biological integrity
  Biological / Water quality / Social / Programmatic / Site
- Non-contact Recreation
  Water quality / Physical / Biological / Social / Programmatic / Site
- Water Supply
  Water quality / Biological / Social / Programmatic / Site
- Contact Recreation
  Biological / Water quality / Physical / Social / Programmatic / Site
- Aquaculture
  Biological / Water quality / Physical / Social / Programmatic / Site

Level 2
Assessment of Management Program

1. State goals for program

Based on baseline conditions, resources, and constraints, articulate goals for stormwater management program in terms of measurable achievements.

2. Inventory prior and ongoing efforts

Identify prior stormwater management efforts and assess success of prior efforts.
Identify current stormwater management efforts and assess success of ongoing efforts.
Incorporate complementary programs and goals. Identify potential conflicts.

3. Develop and implement management program

Identify and implement specific program facets in order to achieve goal.

4. Develop and implement monitoring program

Based on goals, program structure, resources and constraints, select indicators to be used to assess success of stormwater management program. Level II indicators will likely be more quantitative in comparison to Level I techniques.

5. Assess indicator results

Analyze indicator monitoring results.

- What do the monitoring results indicate about the success of the stormwater management program?
- Have the indicators accurately reflected the effectiveness of the management program?
- What do indicators suggest about the ability of the stormwater indicator monitoring program to measure of overall watershed health?

6. Re-evaluate management program

Re-evaluate resources and constraints. Update (if necessary) assessment of baseline conditions. Review and revise program goals. Review and revise management program. Review and revise indicator monitoring program.

Figure 1: A Methodology for a Stormwater Indicator Monitoring Program (Claytor and Brown, 1996)

come major elements of municipal and industrial site monitoring and management assessment programs.

References

Bannerman, R.T., D.W. Owens, R. Dodds, and P. Hughes. 1992. *Sources of Pollutants in Wisconsin Stormwater*. WI Dept. of Natural Resources, Madison, WI.

Claytor, R. and W. Brown. 1996. *Environmental Indicators to Assess the Effectiveness of Municipal and Industrial Stormwater Control Programs*. Final Report. Center for Watershed Protection. US EPA Office of Wastewater Management. Silver Spring, MD. 210 pp.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yand, and I.J. Schlosser. 1986. *Assessing Biological Integrity in Running Waters: A Method and its Rationale*. Illinois Natural History Survey Special Publications 5.

Miller, D.L., P.M. Leonard, R.M. Hughes, J.R. Karr, and P.B. Moyle. 1988. *Regional Applications of an Index of Biotic Integrity for Use in Water Resource Management.* Fisheries. Volume 13, No. 5. September - October 1988. pp. 12-20.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic and Fish*. Environmental Protection Agency, Office of Water. Washington, DC. EPA/440/4-39-001.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC. pp. 275.

U.S. Environmental Protection Agency (EPA). 1983. *Results of the Nationwide Urban Runoff Program. Vol. I. Final Report.* Water Planning Division.

Table 5: Representative Unit Cost Data for Selected Stormwater Indicators

Indicator No.	Indicator/Basis for Cost	Implementation Cost	Notes
(1)	**Water quality constituent pollutant monitoring** • Per site, one person at each site • Sampling site accessible from land • Conventional pollutants and physical parameters (Those typically identified as pollutants of "concern" in urban runoff) • Four hour sampling event • Single composited sample provided for lab. analysis • Weir/Flume used for stage-discharge relationship • Grab samples collected manually • Composite aliquots collected with automated sampler • Compositing based on constant time-volume proportional to flow increment relationship	$675 - $825 per station, per event	Cost to set-up station (installation and calibration of weir or flume; development of stage discharge relationship; acquisition of automated samplers and DO, temperature, conductivity, and pH equipment; acquisition of reagents, sampling jars, etc.) not included. Set up costs (based on the above assumptions) will average between $4,000 - $10,000 per station. Cost may be reduced by using same sampler at different stations during different storm events and/or by using alternative methods to determine flow.
(7)	**Stream widening/downcutting** • Per reach cost • Reach defined as approximately 2,000', 10 measurements per reach • Two staff members required per site • Stream cross-sections measured with taped surveys • Field cross-sections established and recorded with flagged steel reinforcing bar • Includes overhead expenses (supplies, vehicles, travel, utilities, maintenance, rent, printing, etc.) • Includes data analysis and preparation of summary report	$575 - $700 per 2,000' reach	Cost is based on surveying first and second order headwater streams in semi-humid to humid climates. For start-up costs, add: Steel reinforcing bars, flagging, hip chain, 50' tape, wading rod, notebooks, clinometer, and computer(s).
(13)	**Macro-invertebrate assemblage** • Per sample, per site cost • Two staff members required per site • Includes overhead expenses (supplies, vehicles, travel, utilities, maintenance, rent, printing, etc.) • Includes data analysis and preparation of summary report	$500 - $625 per sample, per site	Cost is based on RBP protocol III (Plafkin, et al. 1989)m and sampling to genus level. For start-up costs, add: Microscope, kick-screen sampler(s), glassware, preservative, and computer(s)
(17)	**Public Attitude Surveys** • Per survey cost per 1,0000 households contacted • Interviews conducted over telephone • Includes survey implementation, data analysis, and preparation of summary report	$14,500 - $17,750 per 1,000 households	Generally, 50% of those households contacted respond to survey.
(21)	**No. of Illicit Connections Identified/Corrected** • Per illicit connection identification survey • Assumes survey will be conducted visually (i.e., smoke, dye, or other methods will not be used) • Illicitness of dry-weather flows will be determined by tracing source upstream in system and through use of field test kits	$1,250 - $1,750 per square mile	Cost estimate does not include cost associated with correction of illicit connections.
(26)	**Industrial Site Compliance Monitoring** • Per industrial site (based on 5 acre site) • Light-industrial land use • Visual inspections of compliance with pollution prevention plans • One technical inspector per site • Includes overhead expenses (supplies, vehicles, travel, utilities, maintenance, rent, printing, etc.) • Includes data analysis and prep. of summary report	$290 - $350 per 5 acre site	Cost estimate based on visual inspections only. For start-up costs add: Notepads, computer(s), camera.

extensive documentation of existing conditions as well as during the period of evaluation.

Photographs provide a revealing record of conditions at a given time. They are easy to do, require little special training, are inexpensive, and are easily understood by a wide audience. This tool is particularly useful for documenting changing physical conditions over time.

Cost of Indicators

Perhaps the most frequent question asked by program managers in implementing a monitoring effort is: how much will it cost? As part of our research, we compiled comparative cost information on different stormwater indicators. Representative indicator cost data is presented in Table 5, and the full dataset is available in Claytor and Brown (1996)

The unit cost data is presented on a per station, per sampling event basis wherever possible. It should be noted that the monitoring protocol for a given indicator may require a unique combination of stations and/or samples to provide reliable data. Where possible, the cost data represents the most prevalent monitoring methodology being utilized around the country. Managers should recognize that the range of indicators often require sampling at different frequencies, densities, and for different parameters and therefore a direct comparison of unit costs can be misleading. As with all cost data, these numbers should be verified with different sources, before planning and implementing program monitoring strategies.

A Methodology for Utilizing Stormwater Indicators

Many watershed managers still prefer a simple “cookbook” methodology to assist in implementing their monitoring program. A methodology can also help bring consistency and common sense to successful programs. Historically, many stormwater monitoring programs were often regulatory-driven and focused almost exclusively on water chemistry monitoring. While this data often helped establish baseline conditions, monitoring results were generally not well suited for assessing overall stormwater management program success.

What appears to be clear is that individual indicators have distinct roles in assessing different aspects of programs and practices. Some are more appropriate for identification of problems, while others are more aptly suited to assess program effectiveness. Even the individual indicators have different level-of-effort methodologies to answer different questions. For example, macro-invertebrate monitoring may be conducted qualitatively to answer the question of whether a stream is impacted from human activity. To assess the causes and possible sources of those impacts, however, a much more quantitative analysis is often needed including chemical and physical monitoring (Plafkin *et al.*, 1989).

Table 4: Tools for Indicator Use

Tool	Application Example
Watershed Simulation Modeling	Estimate pollutant load export
Geographic Information Systems	Estimate impervious area changes
Paired Subwatershed Monitoring	Compare flow volume and and pollutant loads between two watersheds
Comparison to Reference Conditions	Compare macroinvertebrate diversity between an urban stream and a rural stream
Photographic Record	Qualitatively measure physical erosion for a stream over time

A simple, two-phase methodology for utilizing indicators is presented in Figure 1. Level 1 is targeted at municipalities and industrial sites with limited or no data available to characterize baseline conditions, and is intended to help locate and identify problems caused by urban stormwater runoff. Level 2 is geared more towards those locations which already understand their water quality problems and are interested in assessing how well their management programs are addressing those problems. The methodology is intended to be a flexible, dynamic tool for stormwater managers. There are no mandates to begin at a given step or level. Instead, managers are encouraged to utilize whatever component most accurately represents their respective monitoring needs.

Summary

Past urban stormwater runoff monitoring has tended to be more oriented towards the end-of-pipe, water chemistry mindset. In order to fully assess the impacts of urbanization and industrial site runoff, a shift is necessary that focuses more attention on monitoring the receiving water quality and the uses of those receiving waters. Stormwater indicators provide a suite of opportunities to assess different aspects of a stormwater management program, measure the stressors associated with human activity on the land surface, and establish the conditions of aquatic communities in the receiving waters. The various costs, framework, and methodology for using indicators give managers the ability to implement a monitoring program appropriate for their individual water resource protection and/or restoration goals. Given the proper regulatory environment, which incorporates flexibility and emphasizes education and voluntary actions as key components of monitoring efforts, stormwater indicators should be-and describing tools common to many different indicators.

Reference conditions are used to establish a benchmark for assessing existing conditions or to measure trends in conditions. Reference sites should be selected to represent least or minimally-impacted conditions within the same physiographic region as the water body being evaluated. Eco-regions, representing regions of similar land form, soils, climate, natural vegetation, and general land use, should also be utilized in the establishment of reference sites.

Regional geography also provides a framework for the selection of indicators. Several stormwater indicators require regional adaptation to be utilized in different regions of the county. For example, Miller and others reported that the Index of Biotic Integrity (the protocol for evaluating fish communities developed by Karr and others) can be modified in various regions to reflect local native species, thus providing an indicator of greater utility and applicability (Miller *et al.*, 1988).

Several "tools" can be utilized over a broad range of physical, chemical, and biological conditions to measure environmental indicators (Table 4). Geographic Information Systems (GIS) and watershed simulation modeling tools are used to estimate watershed variables, such as land use/land cover; analyze different development scenarios; calculate the potential pollutant load wash-off and/or assess stormwater runoff quantities; and identify locations and conditions of biological and physical parameters.

The paired watershed monitoring protocol compares the response of two watersheds, with a documented relationship, when subjected to different management strategies and/or development patterns. One watershed usually serves as the control, where no changes occur, while the other watershed receives some kind of treatment. This approach allows monitoring studies to be conducted reasonably quickly and permits the presentation of more timely results. Paired watershed studies have the advantage of accounting for climatic or hydrologic anomalies (i.e., floods or droughts), but usually require more resources in terms of money and staff, since at least two sets of measurements must be collected. These studies also require

Table 3: Full List of Stormwater Indicators

Indicator Type	Indicator Name	Number
Water Quality Indicators	Water quality pollutant constituent monitoring	1
	Toxicity testing	2
	Non-point source loadings	3
	Exceedance frequencies of water quality standards	4
	Sediment contamination	5
	Human health criteria	6
Physical and Hydrological Indicators	Stream widening/downcutting	7
	Physical habitat monitoring	8
	Impacted dry weather flows	9
	Increased flooding frequency	10
	Stream temperature monitoring	11
Biological Indicators	Fish assemblage	12
	Macro-invertebrate assemblage	13
	Single species indicator	14
	Composite indicators (e.g., IBI)	15
	Other biological indicators (e.g., mussels)	16
Social Indicators	Public attitude surveys	17
	Industrial/commercial pollution prevention	18
	Public involvement and monitoring	19
	User perception	20
Programmatic Indicators	No. of illicit connections identified/corrected	21
	No. of practices installed, inspected, and maintained	22
	Permitting and compliance	23
	Growth and development metrics	24
Site Indicators	BMP performance monitoring	25
	Industrial site compliance monitoring	26

tors have already identified a problem, or where a legal dispute necessitates the identification of a particular pollutant or group of pollutants.

Physical/hydrological indicators measure changes to the physical environment associated with changing conditions, such as changes in stream channel geometry or bottom sediment composition resulting from increased frequency of erosive stormflows. These indicators are generally less expensive to conduct, but may often need to be combined with other indicators to tell the full story.

Biological indicators are useful for gaging the cumulative effects of urban runoff, since biological communities are continually exposed to the intermittent and widely varied effects of urban runoff flows and pollution pulses. Different techniques are more aptly suited to assess long-term versus short-term impacts. This group of indicators is already reshaping many monitoring programs across the county, and promises to continue to provide meaningful results at a fraction of the cost of more traditional water chemistry monitoring methods.

Social indicators are more aptly suited to gaging responses of the public to water resource conditions. These indicators assess public opinion, political will and industry willingness to implement, maintain, or expand stormwater management programs.

Programmatic indicators are mainly utilized by municipal, state, and federal officials to gage program success through results from quantitative analyses of program initiatives, such as the number of permits issued or inspections conducted for a given program element. Programmatic indicators do not provide specific measurements of waterbody health, but can provide valuable information about potential impacts or program effectiveness.

Site indicators are specifically adapted to measuring conditions at the site level. Only two individual indicators were singled out as assessment tools at this level; stormwater practices performance monitoring; and industrial site compliance monitoring. Others are certainly adaptable to the on-site assessment level, but are described more in the context of watershed-wide investigations. Table 3 identifies 26 indicators.

Framework for Using Indicators

The Center's research observed that many practitioners are already applying stormwater indicators in monitoring local and state programs. As part of our efforts, the Center compiled an annotated bibliography of environmental indicators. The bibliography contains approximately 500 citations of studies involving environmental indicators in the last 15 years, primarily in the urban stormwater arena.

While reviewing and compiling the bibliography, we observed several common elements which suggest that the identification and selection of appropriate indicators for monitoring programs should be conducted within an established framework. This framework focuses on the relationship between urbanization and impacts on water resource quality by presenting the importance of reference conditions, reinforcing the concept of eco-regions and regional considerations,

Table 2: Categories of Environmental Indicators Used for Stormwater Assessment

Indicator Category	Description	Linkage element being assessed
Water Quality	Group of indicators used to measure specific water quality or chemistry parameters	Receiving water resource quality
Physical/ Hydrological	Group of indicators used to measure changes to, or impacts on the physical environment	Receiving water resource quality
Biological	Indicators which use biological communities to measure changes to, or impacts on biological parameters	Receiving water resource quality
Social	Group of indicators which use responses to surveys or questionnaires to assess various parameters	Human activity on the land surface (stressor)
Programmatic	Indicators which quantify various non-aquatic parameters for measuring program activities	Regulatory compliance
Site	Indicators adapted for assessing specific conditions at the site level	Human activity on the land surface (stressor)

Table 1: Typical Stormwater Outfall Mean Concentrations for Several Source Areas—Arithemetic Means for the Source Area (Wisconsin, 1992)

Source Area	Susp. Solids (mg/L)	Total Phos. (mg/L)	Diss. Phos. (mg/L)	Total Cd (µg/L)	Total Cr (µg/L)	Total Cu (µg/L)	Total Pb (µg/L)	Total Zinc (µg/L)
Industrial roof	54	0.13	0.02	0.3	—	7	8	1348
Arterial street	875	1.01	0.25	2.8	26	85	85	629
Feeder street	969	1.57	0.62	3.7	17	97	107	574
Parking lot	474	0.48	0.07	1.2	16	47	62	361
Residential driveway	193	1.50	0.87	0.5	2	20	20	113
Flat roof	19	0.24	0.11	0.4	—	10	10	363
Collector street	386	1.22	0.36	1.7	13	61	62	357
Arterial street	241	0.53	0.14	2.6	18	50	55	554
Parking lot	91	0.26	0.07	0.8	7	21	30	249
Residential lawn	457	3.47	2.40	—	—	13	—	60
Residential roof	36	0.19	0.08	0.2	—	5	10	153
Feeder street	1085	1.77	0.55	0.8	7	25	38	245
Outfall	374	0.86	0.34	0.6	5	20	40	254

Note: Dash indicates insufficient sample size.

Environmental Indicators–Stormwater Monitoring Tools

The Center has recently completed an investigation on the use of monitoring methods to evaluate municipal and industrial stormwater programs and practices. The research focused on the use of *environmental indicators* as tools for monitoring urban stormwater runoff. Environmental indicators are direct or indirect measures that indicate trends or responses in receiving waters. Environmental indicators can be used to characterize overall or specific conditions in receiving waters and can help provide a benchmark for assessing the success of stormwater management strategies. For instance, indicators can be broadly based, as in measurements of global changes in species extinction rates, or very specific, as in the loss of a sensitive stonefly species in a headwater stream system.

In one sense, environmental indicators can be viewed as economic indicators, such as housing starts, or growth in GNP, which are direct measures of economic activity and are used to assess the health of the overall economy. Similarly, environmental indicators may be able to provide assessments of improvements (or downturns) in the watershed and measure the effectiveness of watershed management strategies.

Environmental indicators cover a wide array of monitoring parameters applicable to a variety of environmental settings and management concerns (i.e., water supply, point sources, forests, wetlands, or groundwater). **Stormwater indicators** apply to a subset of environmental indicators that specifically address urban stormwater runoff impacts and the evaluation of stormwater programs and practices. Stormwater indicators are designed for use by municipal stormwater managers, regulatory agencies, or industrial site managers to assess the effectiveness of specific management strategies.

Research was conducted on a total of 26 stormwater indicators which were grouped into six broad categories. Each category (identified in Table 2) represents a distinct area of stormwater monitoring and/or assessment. Several of the topics will be familiar to many stormwater practitioners, while a few, such as social and programmatic indicators, may represent new approaches to evaluating stormwater program effectiveness. An important element to consider is the linkage between what is done on the land, how it is regulated or evaluated, and the corresponding effects to the receiving waters or environment.

Table 2 identifies the principal area of utility for the six indicator categories.

Water quality indicators are more traditional monitoring methods, familiar to most stormwater management officials. While these monitoring techniques may not be new by themselves, they are still very useful for specific applications, particularly where pollutant source and identification are sought. Water quality indicators are perhaps best utilized when other, less costly indica-

Article 141

Feature article from Watershed Protection Techniques. 2(2): 587-594

An Introduction to Stormwater Indicators

Municipal officials are increasingly asked to protectthreatened water resources in the face of urban growth pressures. While municipalities, industries, and governments have all developed technologies to treat human sewage and industrial wastes (i.e., point source discharges), and have developed scientifically accepted methods to monitor the success of these treatment strategies, the ability to successfully treat urban stormwater and measure the effectiveness of these treatments is still several levels below the "point source control" field.

The reasons appear to be relatively simple to explain, yet hard to quantify. Sewage treatment plant outfalls and industrial site discharges generally come from one location or source and therefore the chemical makeup of the outfall is reasonably easy to identify. Numerical limits for pollutant concentrations are relatively easy to establish (at least for dry weather conditions) and, in theory, are reasonably easy to enforce. On the other hand, pollutants in stormwater runoff are likely to come from many very small source areas that are often hard to pinpoint. Furthermore, stormwater runoff varies widely as a function of rainfall intensity and duration. Therefore, pollutant concentrations are likely to differ spatially along a given waterbody due to varying dilutions as mixing occurs from other drainage areas. Finally, stormwater runoff events are often very short-lived, particularly in urban streams. These episodes are often highly variable with large inputs of runoff and pollutants occurring and dissipating in a few hours.

Until recently, most stormwater monitoring was conducted at pipe outfalls along the urban drainage system. The data gleaned from these investigations have helped us to characterize the concentrations of untreated urban runoff. For example, the National Urban Runoff Program (NURP) studies, conducted by EPA and others in the early 1980s, helped establish a database that has proved useful in computing stormwater loadings of pollutants from various land uses. More recently, NPDES monitoring data from municipal and industrial stormwater permits have helped confirm the earlier NURP data, as well as confirm particular pollutant source increases or decreases over time (e.g., reductions in lead due to discontinuation of leaded gasoline in automobiles). An example of typical stormwater runoff concentrations is shown in Table 1.

Stormwater pollutant concentration data have been used frequently to assess compliance with water data quality standards and criteria. Examples of specific criteria include limits on maximum concentrations for either human ingestion or aquatic life exposure. These criteria were developed by EPA (1983) in an attempt to define the effects of short term and intermittent exposures typically associated with urban runoff. Problems with relying on water quality criteria include:

- An exceedance of a numerical limit in a receiving waters may occur for only a short period of time during or immediately after a storm
- An exceedance at an outfall does not necessarily mean that water quality criteria have been exceeded in a stream because of dilution
- There is a considerable scientific uncertainty about exact species effects and lethality for a given pollutant concentration
- Human ingestion limits may not appropriately reflect the aquatic life uses of the receiving waters

Consequently, it has been difficult for municipal officials and regulators to relate stormwater pollutant concentration data to evaluate the effectiveness of stormwater management practices. Furthermore, pollutant concentrations are generally similar from location to location. In fact, with the exception of a few isolated urban "hotspots," there is surprisingly little difference among recent stormwater chemistry monitoring studies.

More recently, biological monitoring methods have been used to help evaluate the cumulative effects of stormwater runoff on receiving waters. In at least one aspect, biological monitoring is perhaps a more reliable indicator than chemical monitoring, since biological communities can accumulate the effects associated with continual exposure to both stormwater and low flow events. Dr. Robert Karr, one of the preeminent scientists in the field of bioassessment, found that the health of fish communities in mid-western U.S. streams was directly related to the degree of human influence on watersheds (Karr, 1986).

While the use of biological monitoring methods is not new, it is only within the last few years that they have been applied to directly assess the impacts of urban stormwater runoff.