

Water Quality Index as Applied to Fall Creek

Beginning in 1998, the Marion County Health Department, Department of Water Quality and Hazardous Materials Management Department has routinely sampled and monitored Fall Creek. 327 IAC 2-1-6 (Minimum Surface Water Quality Standards, State of Indiana) provides the basis for the Department's surface water sampling and monitoring program. Specific standards exist for each parameter such as E. coli levels, pH, and dissolved oxygen. A fairly large amount of data is collected to determine long-term compliance or noncompliance with 327 IAC 2-1-6.

A dilemma exists however when determining overall compliance among different parameters. For example, it is possible for a parameter such as E. coli to be out of compliance over a several month time period while all other parameters measured in the same time period are within compliance. A common inquiry of the data (regardless of whether the inquiry originates from the public, lawmakers, or the media) is a short summary of whether Fall Creek is "polluted" or "clean." Largely in response to similar requests, a task group organized by the *Canadian Council of Ministers of the Environment* (CCME) developed a water quality index to "grade" rivers and lakes using data collected from fixed locations over several months. As with any tool or data analysis methodology, there are advantages and limitations, nuisances, and conditions to acknowledge and follow:

Advantages of Water Quality Index

- Conveniently summarizes complex water quality data
- Facilitates clear communication of results to a large general audience
- Provides mechanism to gauge/trend several parameters over several years
- A wide range of parameters can be used simultaneously within the index, including the use of biological indicators (bacteria levels), physical parameters (dissolved oxygen, turbidity, dissolved solids), and chemical parameters (concentration of heavy metals, petroleum products)
- Compliance values or standards (as established by a written Code or other regulatory document) for each parameter can readily be incorporated into the index

Limitations of Water Quality Index

- Calculated index values are placed in categories such as excellent...fair...poor; range of calculated index values for each descriptive category are largely based on expert judgment and general public expectations of water quality
- Repetitive samples taken at a fixed location over several years is typically required
- Factors, circumstances, and site conditions contributing to a poor or excellent rating are not specifically identified
- Index is simply one tool in the toolbox; further investigation, description, and analysis is typically required to provide a comprehensive characterization of the water quality and the processes involved

The CCME water quality index was applied to the following fixed sampling/monitoring locations along Fall Creek using specific conditions/criteria:

39th Street pedestrian bridge, providing a connection between the former Nickel Plate rail line to the Indiana State Fairgrounds. One combined sewer overflow outfall is upstream of this location, thus this site is not largely impacted by concentrated overflows of sewage as compared to downstream sampling locations.

Central Avenue Bridge, 13 combined sewer overflows are upstream of this sampling location.

Stadium Avenue Bridge, this is the last sampling point Marion County Health Department uses along Fall Creek before the confluence of White River and Fall Creek. There are 25 upstream combined sewer overflow outfalls at this sampling location.

To account for and minimize natural seasonal fluctuations affecting the monitored water quality parameters, CCME recommends using data collected over a several month time period. For each sampling location on Fall Creek, sampling data accumulated over a two-year period was used. Completing an index value for each of the three sampling locations every two years provides a basis to determine if the water quality at each site is improving, getting worse, or remaining static over time. Since the same parameters are being measured at each sampling location, within minutes of each other, and under similar weather conditions, the index value for one Fall Creek location can reasonably be compared to a different location along Fall Creek when using the same data collection period.

Three separate water quality index values were calculated for each location, spanning a total of six years. For example, at the 39th Street bridge an index value was calculated using the data collected solely in the years 2003-2004, a second index value was calculated using data solely collected in the years 2005-2006, and a third index value was calculated using the data solely collected in the years 2007-2008. The same time periods/years were used to calculate an index value using the data collected from the Central and Stadium Avenue sampling locations. A total of nine water quality index values were calculated.

CCME recommends a minimum of four parameters be used to calculate the index value for any one location. Additional parameters are recommended when the index is being used as a decision tool for more advanced studies. If less than four parameters are used, any one parameter may overly influence the outcome of the final index value. For the Fall Creek locations, the following parameters and conditions were used:

- E. coli bacteria: Per 327 IAC 2-1-6, E. coli bacteria shall not exceed 235 (colonies) per 100 milliliters in any one sample in a thirty-day period
- Dissolved oxygen: Per 327 IAC 2-1-5.8, concentrations of dissolved oxygen shall average at least 5 milligrams per liter (or 5 parts per million) per calendar day
- Specific conductance (dissolved solids): Per 327 IAC 2-1-5.8 shall not exceed 1200 microhos at 25 degrees Celsius
- PH: Per 327 IAC 2-1-6 specifies no pH values below 6 or above 9 shall be permitted except for daily fluctuations exceeding a pH of 9 correlated with photosynthetic activity

For each index period and sampling/monitoring location, approximately 100 entries or data values are available for each of the four parameters, thus approximately 400 total data values are used per two-year period. When calculating the index, three major factors are being evaluated to determine the overall index value:

- Whether the parameter being used within the index (i.e. pH, E. coli) is out of compliance at least one time within the data set for the parameter, if so the scope (or percentage) of how many parameters are out of compliance (F1 or factor one, see example calculation below)
- Whether each data value is in compliance or out of compliance (yes or no) for the particular parameter, or in other words the frequency of non-compliance for each parameter data value calculated (F2, see example calculation below)
- If the data value parameter is out of compliance, a calculation is completed to determine how far out of compliance it is (amplitude of noncompliance) (F3, see example calculation below)

Each parameter is not assigned a weight in terms of its importance or relevance in influencing water quality, however if a particular parameter is consistently measured to be out of compliance (and to a large degree), the values of this parameter may result in a lower index value for the site.

The calculated index values for each site and time period are then compared to a 100-point grading scale:

95-100	Indicates excellent water quality
80-94	Indicates good water quality
65-79	Indicates fair water quality
45-64	Indicates marginal water quality
0-44	Indicates poor water quality

The actual formulas and an example of an abbreviated set of data values used to determine an overall index value are provided below. Non-compliant parameters and individual data values are displayed in red.

Fall Creek at 39th Street					
Date	Time	pH	SpCond	DO	E. Coli
	HMMSS	units	mS/cm	mg/l	
28Apr03	92116	8.1	0.05846	9.95	122
21May03	100602	7.98	0.0512	9.89	171
29May03	93507	7.86	0.0555	8.33	583
03Jun03	95119	7.86	0.0554	8.74	213
12Jun03	93947	7.94	0.0545	8.2	4611
16Jun03	102233	7.81	0.05295	9.92	481
19Jun03	92456	7.76	0.0568	7.71	169
26Jun03	94836	7.78	0.06011	7.45	121
02Jul03	90314	7.63	0.0609	7.16	24192
16Jul03	91113	7.68	0.03561	8.48	1043
22Jul03	92932	7.96	0.044	8.01	173

$$F1 = \left(\frac{\text{Number of failed parameters}}{\text{Total number of parameters}} \right) \times 100$$

$$F1 = \left(\frac{1}{4} \right) \times 100 = 25$$

$$F2 = \left(\frac{\text{Number of failed/noncompliant data values}}{\text{Total number of data values}} \right) \times 100$$

$$F2 = \left(\frac{5}{44} \right) \times 100 = 11.36$$

$$F3 = \left(\frac{NSE}{.01 * NSE + .01} \right) \times 100$$

NSE= normalized sum of excursions. NSE is calculated through the formula of: $\left(\frac{\text{Sum of excursions}}{\text{Number of data values}} \right)$

Individual **excursions** (for above data set only) are calculated through the formula:

$$\left(\frac{\text{Failed/Non-compliant data value}}{\text{Objective or maximum compliant value}} \right) - 1$$

For the above data set, the excursions (five total) were calculated as follows:

$$\left(\frac{583}{235 \text{ (Per State of Indiana WQ standards)}} \right)^{-1} = 1.48 \quad \left(\frac{4611}{235} \right)^{-1} = 18.62$$

$$\left(\frac{481}{235} \right)^{-1} = 1.04 \quad \left(\frac{24192}{235} \right)^{-1} = 101.94 \quad \left(\frac{1043}{235} \right)^{-1} = 3.43$$

To calculate the NSE, the five excursions are summed and then divided by 44, the number of data values. The NSE equals 2.87. The NSE value of 2.87 is then plugged into the F3 equation=

$$\left(\frac{2.87}{0.038} \right) = 75.52$$

The last part of the index calculation has five parts to it:

- F1, F2, and F3 values are squared...F1=625, F2=129, F3= 5703.2
- Squared F1, F2, and F3 values are then summed... 6457.2
- Square root of value obtained from previous step (6457.2) is then obtained...80.35
- Square root obtained from previous step (80.35) is then divided by 1.732...46.4
- Result from previous step is then subtracted from 100...**53.6**

Using the water quality index with the above values resulted in an overall value of 53.6 or marginal water quality per the grading scale.

The formulas and calculations necessary to derive the final index value are largely based on statistical analysis. Ironically, the statistical analysis concepts used in the water quality index were largely first applied to the industrial quality control programs of a non-natural product: telephones.

It should be noted the calculations necessary to ultimately produce an index value between 0 and 100 are "built into" the final formulas. For example, a negative index value (or a value above 100) is not possible unless the end user committed a mathematical error.

The calculated water quality index values for each location along Fall Creek are as follows:

39th Street		
<u>2003-2004</u>	<u>2005-2006</u>	<u>2007-2008</u>
72, fair	76, fair	64, marginal
Central Avenue		
<u>2003-2004</u>	<u>2005-2006</u>	<u>2007-2008</u>
49, marginal	52, marginal	49, marginal
Stadium Avenue		
<u>2003-2004</u>	<u>2005-2006</u>	<u>2007-2008</u>
47, marginal	57, marginal	47, marginal

Conclusions and future actions using the 10 Essential public health services as a template

Developed in 1994 by the Core Public Health Steering Committee (consisting of representatives from US public health service agencies and related public health entities), the ten essential public health services is a framework to define and guide public health services and actions. Through the 10 essential public health services framework, a nationally recognized action plan is accessible and can be readily applied to any state and local public health agency. The 10 services are as follows:

- 1) **Monitor** health status to identify and solve community health problems
- 2) **Diagnose** and investigate health problems and health hazards in the community
- 3) **Inform, educate, and empower** people about public health issues
- 4) **Mobilize** community partnerships and action to identify and solve health problems
- 5) **Develop policies and plans** that support individual and community health efforts
- 6) **Enforce** laws and regulations that protect health and ensure safety
- 7) **Link** people to needed personal health services and assure the provision of health services when otherwise unavailable
- 8) **Assure** competent public and personal health care workforce
- 9) **Evaluate** effectiveness, accessibility, and quality of personal and population-based health services
- 10) **Research** for new insights and innovative solutions to health problems

Through the index, a water quality baseline for a significant stretch of Fall Creek was identified and quantified. While the index values provide a valuable tool to characterize the environmental health of a natural resource subject to several potentially degrading inputs, a comprehensive review requires the use of several monitoring methodologies. It should be noted the monitoring and indexing/grading of water quality fulfills the first essential public health service, *monitor health*.

Once the baseline is established, the second essential public health service, *diagnose and investigate* the factors inhibiting and/or preventing excellent water quality. For Fall Creek, the largest factor (or low-hanging fruit in terms of eliminating) has consistently been the impact of combined sewer overflows. A precipitation event as little as two tenths of an inch may result in raw sewage discharging into Fall Creek from the combined sewer overflows. Raw sewage contributes to elevated bacteria levels, facilitates low dissolved oxygen, and increases turbidity, factors that typically degrade water quality fairly quickly.

In reality, the third, fourth, and fifth essential public health services may not necessarily play out neatly in order (as with the other seven essential public health services). Regardless, they are still important steps in preventing and eliminating obstacles:

- Third essential health service of *inform, educate, and empower* involves educating the general public on their role in improving water quality
- Fourth essential health service of *mobilize* community partnerships to identify and solve problems
- Fifth essential health service of *develop policies and plans* to support public health objectives and goals

Local not-for-profit volunteer watershed organizations, through their unique design and execution of their mission are pivotal in accomplishing public health essential services three through five. While many volunteer watershed organizations seek financial grants through State and Federal agencies to better accomplish their objectives/goals, this process is not required. In addition, the formation of the watershed groups is not mandated or required by law.

Informing, educating, and engaging the public on the impacts presented by residential, commercial, public and industrial properties on water quality is continually completed by local watershed groups. Educational workshops, creating opportunities for panel discussions, and websites are just a few examples of how watershed groups actively accomplish the third essential public health service. Membership within local watershed organizations (including administrative positions) is typically diverse and representative of a wide range of expertise, backgrounds, and interests. Watershed

groups rely on the diverse backgrounds and expertise of their members to better reach and connect with the general population as a whole.

Local watershed groups provide a mechanism, avenue, and audience for the formation of community partnerships, ultimately facilitating the identification and solving of problems. In many instances, the watershed group must seek out and work with outside entities (examples include private business, government agencies, community development corporations) to provide and encourage the use of best management practices within the community. Examples of best management practices commonly promoted by watershed groups include the distribution of rain barrels, construction of rain gardens, and the organization of clean-up days along a particular river or stream.

When a watershed group forms, developing written policies and plans for an organized, relevant, and thorough completion of educational programs and promotion of best management practices is often among the first items completed. Prior to the awarding of grants, government agencies and private foundations providing the grants will typically require the submission of written policies and plans of the watershed group.

Enforcement of laws and regulations is the sixth essential public health service. For Fall Creek, the consent decree signed by the United States Environmental Protection Agency, Indiana Department of Environmental Management (as plaintiffs), and the City of Indianapolis (defendant) is currently the most relevant example. Finalized in October of 2006, the consent decree provides a legal basis for all parties to move forward and establish transparent written objectives and goals. To mitigate the impact of combined sewer overflows, the City of Indianapolis is currently directing a significant amount of resources to build sewer infrastructure designed to lessen the incidence of sewer overflows into creeks and rivers within Marion County.

Linking resources and services is the seventh essential public health service. Whether the resources and services are implemented by the City of Indianapolis or a not-for-profit watershed/environmental group(s), the main focus has been on stormwater management. Stormwater management involves but is not necessarily limited to:

- Reducing the amount of stormwater directed to Fall Creek
- Controlling the rate of stormwater flow
- Eliminating/preventing contaminants from being released into the general environment
- Filtering out and removing released contaminants before they reach stormwater infrastructure or at some point within the stormwater infrastructure

A rain barrel distributed to a household located within a combined sewer area provides an inexpensive source of irrigation water. 10,000 rain barrels used within combined sewer neighborhoods not only provides inexpensive irrigation water, but also removes approximately 500,000 gallons of stormwater (during one precipitation event) from stormwater infrastructure, potentially mixing with raw sewage and resulting in a combined sewer overflow into Fall Creek.

A competent public health work force is essential public health service eight. A competent public health work force is largely accomplished through voluntarily imposing high training standards and minimum skill level expectations. Workplaces encouraging employees to take advantage of (and facilitating the completion of) additional educational opportunities typically have competent work forces. Developing and maintaining a competent work force is a continual process.

Evaluating the effectiveness and accessibility of public health services is the ninth public health service. The effectiveness of the water quality index can be thought of in terms of how accurately and clearly it conveys the environmental conditions of Fall Creek. How large an audience the index reaches and the public's understanding of the factors, conditions, and circumstances impacting the index relate to its accessibility. The recipients of the service, not the providers, are in a better position to provide an evaluation of the public health service. Of course, improvements should be carefully considered and implemented throughout the essential public health service framework process.

Research, which provides new insights and innovative solutions to public health problems, is the tenth public health service. New insights and innovative solutions should apply both to how data is collected, organized, and used to characterize the water quality as well as how technology or best management practices can be used to reduce the impact of combined sewer overflows and other degrading factors. Examples of potential improvements in the collection and analysis of water quality data include:

- Providing site specific data and analysis to determine the impacts (environmental, social, monetary) an implemented best management practice (or technology) has on water quality
- Providing site specific data and analysis before, during, and after a best management practice or technology is implemented
- Identifying and quantifying additional pathogens (bacteria, viruses, and parasites) and other degrading factors (algae growth) in a cost efficient manner

Examples of how best management practices and technology have been used to improve water quality:

- Use of underground stormwater containment basins and related infrastructure to temporarily hold stormwater, essentially introducing stormwater into the combined sewer system in a gradual and controlled manner
- Identifying and correcting properties (developing a systematic program) wherein stormwater collection infrastructure is incorrectly connected to sanitary sewer infrastructure, for both combined sewer and “separate” areas
- Promoting the use of rain barrels, rain gardens, and riparian zones (if applicable) on residential, commercial, industrial, and public property
- Engaging and empowering the public so they understand the big picture and have a means to participate

The 10 essential public health services provide a template or framework of actions to implement and facilitate the continual completion of public health goals. While it has been applied in this instance to the improvement of water quality for Fall Creek, it is easily adapted to a wide range of public health services. Examples include population health (immunizations, monitoring of disease, and the prevention of disease, illness, and death due to preventable causes), food safety, environmental health threats related to housing conditions (including private water wells and sewage disposal systems), control and reduction in mosquito and rodent populations, and the safe use/storage of hazardous materials. As with any public health program, it is important to consider how it can be carried out in a more effective, thorough, and beneficial manner. A valuable benefit of using the 10 essential public health services template is to maximize the use of collected data and convert it into useful information, resources, and actions.