APPLICATION OF THE NATIONAL SANITATION FOUNDATION WATER QUALITY INDEX IN THE CAZENOVIA CREEK, NY, PILOT WATERSHED MANAGEMENT PROJECT

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ABSTRACT: *In an effort to develop a watershed-wide water quality management plan for the Buffalo River, NY, the Erie County Department of Environment and Planning has begun a pilot watershed management project for Cazenovia Creek, one of three major tributaries. In support of the management project a water sampling effort covering four events and two non-events for 25 different analytes at 12 sites was conducted between 4/24/96 and 7/10/96. The National Sanitation Foundation (NSF) Water Quality Index (WQI) was one of the analytical tools used to summarize the data. Essentially, the WQI converts the concentration data for nine analytes into one of five water quality classes, ranging from "very bad" to "excellent". Based on the WQI values, water quality typically was in the "good" range. The sites nearest the headwaters had the highest water quality rating with significant decreases in water quality occurring downstream, particulary in urban-impacted areas. Water quality also was significantly impacted by storm events. High fecal coliform levels (>200 microorganisms/100 ml) are of particular concern at the majority of sites.*

INTRODUCTION

The Great Lakes Water Quality Board of the International Joint Commission (IJC) has identified 43 Areas of Concern (AOCs) in the Great Lakes region. The heavily industrialized lower 9.6 km of the Buffalo River, NY, are designated an AOC due to well-documented poor water and sediment quality (Versar, 1975; IJC, 1988; New York State Department of Environmental Conservation (NYSDEC), 1989; Atkinson et al., 1994). Under the U.S.-Canada Water Quality Agreement, a Remedial Action Plan (RAP) will be developed for each AOC. A RAP consists of three stages: (1) define the environmental impairments (cause and effect); (2) outline remedial objectives and designate the organizations or agencies responsible for implementing remediation within a

given time frame; and (3) confirm restoration and IJC delisting as an AOC (IJC, 1991). The IJC utilized an innovative approach to remediation by mandating citizen participation in the RAPs. In 1989, the stage 1 Buffalo River RAP was submitted to the IJC by the NYSDEC and the Buffalo River Citizens Committee (NYSDEC, 1989).

Conventional wisdom suggested that the pollution problems for the Buffalo River emanate primarily within the industrialized AOC (e.g. NYSDEC, 1989; Atkinson et al., 1994). However, recent sampling efforts have indicated that pollutants are entering the AOC from the upper watershed (Atkinson et al., 1994; Irvine and Pettibone, 1996). In recognition of this problem and toward its role in achieving the RAP goals, the Erie County government has implemented a two-year, three-phase program to develop a watershed management project for the entire 1,155 km^2

watershed. The first phase of the program is the development of a pilot watershed management project focusing on the Cazenovia Creek basin, one of the three major tributaries of the Buffalo River. Cazenovia Creek was chosen because the watershed lies entirely within the boundaries of Erie County (Erie County, 1995).

Water quality data to support the development of best management practices for the project are essential. To this end, a water sampling effort covering four events and two non-events for 25 analytes at 12 sites was conducted between 4/24/96 and 7/10/96. The objective of this paper is to summarize general water quality characteristics within Cazenovia Creek using the sample results for nine analytes as input to the National Sanitation Foundation (NSF) Water Quality Index (WQI). The WQI can serve as one tool in evaluating baseline water quality conditions as well as identifying spatial and temporal trends in general water quality. The results of this study also are compared with WQI calculations from a 1978 sampling effort (Erie County, 1978).

The National Sanitation Foundation Water Quality Index

Numerous water quality indices have been developed as a convenient means of summarizing water quality data, each using various groups of analytes (e.g. House and Ellis, 1987). One such index was developed by Brown et al. (1970) and hereafter is referred to as the NSF WQI. Brown et al (1970) assembled a panel of 142 persons throughout the U.S.A. with known expertise in water quality management. Three questionnaires were mailed to each panelist. In the first, the panelists were asked to consider 35 analytes for possible inclusion in a WQI and to add any other analytes they felt should be included. The panelists also were asked to rate the analytes that they would include on a scale from 1, (highest significance), to 5, (lowest significance).

The results from the first survey were included with the second questionnaire and the panelists were asked to review their original response. The purpose of the second questionnaire was to obtain a closer consensus on the significance of each analyte. Also included was a list of nine

new analytes that had been added by some respondents in the first questionnaire. For the second questionnaire, the panelists were asked to list no more than 15 most important analytes for inclusion from the new total of 44.

From these first two responses, Brown et al. (1970) derived nine analytes for inclusion in the WQI. In the third questionnaire, the panelists were asked to draw a rating curve for each of the nine analytes on blank graphs provided. Levels of water quality (WQ) from 0 to 100 were indicated on the y-axis of each graph whilst increasing levels of the particular analyte were indicated on the x-axis. Each panelist drew a curve which they felt best represented the variation in WQ produced by the various levels of each analyte. Brown et al. (1970) then averaged all the curves to produce a single line for each analyte (see Mitchell and Stapp, 1995 for rating curves). Statistical analysis of the ratings enabled Brown et al. (1970) to assign weights to each analyte, where the sum of the weights is equal to 1. The nine parameters and their corresponding weights are listed in Table 1. The WQ value for each analyte then was calculated as the product of the rating curve value (also known as the Q-value) and the WQI weight.

Brown et al. (1973), as presented by Ott (1978), further assessed the validity of the WQI. A new panel of experts was assembled and polled using the same procedure as used in 1970. No significant differences were found between the quality rating curves from the original investigation and the new set of curves. According to Ott (1978), the NSF felt that the index developed by Brown et al (1970; 1973) would help alleviate the limitations of previous efforts to develop a WQI and the index subsequently was ratified by the NSF in 1974. This index also was adopted for use by the NYSDEC in 1977 (Ott, 1978). Mitchell and Stapp (1995) summarized a word descriptor scheme that corresponded to specific ranges of the WQI values and the scheme is presented in Table 2.

Brown et al. (1970) concluded that a single numerical expression indicating the composite influence of significant analytes affecting water quality was feasible. House (1990) has noted several advantages to using a WQI, including: 1) volumes of water quality data are summarized in a single index value in an objective, rapid, and reproducible

Table 1 NSF WQI Analytes and Weights

Analyte	WQI Weight
Dissolved Oxygen	0.17
Fecal Coliform Density	0.15
pH	0.12
BOD$_5$	0.10
Nitrates	0.10
Total Phosphates	0.10
Δt °C from Equilibrium	0.10
Turbidity	0.08
Total Solids	0.08

Table 2 Descriptor Words and WQI Value Ranges (from Mitchell and Stapp, 1995)

Descriptor Word	Numerical Range
Very Bad	0-25
Bad	26-50
Medium	51-70
Good	71-90
Excellent	91-100

manner; 2) the numerical scale of an index facilitates evaluation of "within class" variations, thereby allowing identification of changes in water quality at a site that would not precipitate a change of class within the classification system; 3) the index values may be related to a "potential water use" classification scheme to help determine the ecological potential of the waterbody; 4) the index and associated waterbody classification scheme may be used in operational management to identify surface waters requiring priority action; and 5) the index facilitates communication with the layperson, while maintaining the initial precision of measurement. Despite the apparent usefulness, non-specific WQI's such as the NSF WQI appear to be little applied today (Smith, 1989). More recent work by Stoner (1978) and Smith (1989) suggests that

specific water use indices may be more informative. According to Smith (1989), the main reason for the limited application of non-specific WQI's is that during the data handling process, information can be "lost". For example, if eight of the analytes under the NSF WQI indicate pristine scores, but pH scores 0, a water body might have an index value of 85. This rates as a "good" score, but clearly, a water body with extreme high or low pH would not be capable of supporting certain aquatic life and may be unsuitable for recreation, drinking, or irrigation.

Despite the limitations of the NSF WQI, it was decided to employ this analytical tool for the general reasons cited by House (1990) and in the specific case of Cazenovia Creek because: 1) a previous study of Cazenovia Creek carried out by Erie County in 1978 utilized the NSF WQI, which provides useful insights into temporal water quality trends; and 2) the IJC and Erie County consider public participation and community involvement to be key issues in achieving the goals of the RAP. As noted by House (1990) and Chapman (1992) a WQI may facilitate communication of technical information to the public.

METHODS AND MATERIALS

Sample Area

Cazenovia Creek can be divided into three distinct sections, the Lower Cazenovia Creek and two upper sections known as the East and West branches (Figure 1). The East and West branches rise on the northern slopes of the Allegheny Plateau. The drainage of the two branches flows northwesterly to a confluence west of the town of East Aurora, forming the Lower Cazenovia Creek. The Lower Cazenovia Creek enters the Buffalo River at a point 9.2 km above its mouth at Lake Erie.

The two upper branches are different in character from the lower creek. The stream gradients are steeper (0.31 to 2.9%), resulting in high energy water movement. The elevation at the confluence of the two branches is 274 m, rising to 543 m at the headwaters (Erie and Niagara Counties Regional Planning Board, 1978). The

lower creek has a bed slope of 0.25%, with elevations of 177 m at its confluence with the Buffalo River, to 274 m at the junction of the East and West branches (Erie and Niagara Counties Regional Planning Board, 1978).

In the upper reaches, the creeks cut through bedrock composed of Silurian and Devonian dolostones, limestones, and shales (U.S. Department of Agriculture, 1986). Further downstream, the creek crosses glacial lake beach deposits, glacial tills, and lacustrine silty clay soils (Owens et al., 1977). The variety of land uses within the watershed include a high concentration of agriculture and woodland in most of the upper watershed, residential and commercial activities in several small communities through which the creek passes, and industrial activities which become more concentrated in the urban area close to the Buffalo River (Monahan et al., 1995). This range of land uses provides a number of point and non-point sources of pollution (e.g. Irvine and Pettibone, 1996).

Field and Analytical Methods

Sampling was done at 12 sites, including one U.S. Geological Survey (USGS) gauge station (site 2)(Figure 1). The sites were selected for ease of access, spatial representation of each municipality through which the creek passes, and sample locations from previous research (e.g. Irvine and Pettibone, 1996). The water sampling effort for 25 different analytes covered four events and two non-events between 4/24/96 and 7/10/96. Mean daily discharge for the event sampling ranged between 145 and 2,000 cfs (4.1 and 56.6 m^3s^{-1}) while mean daily discharge for the non-event sampling was 167 cfs (4.7 m^3s^{-1}) and 56 cfs (1.6 m^3s^{-1}) for the 6/24/96 and 7/10/96 dates, respectively. Manual grab samples were used for collection of all water samples for laboratory analysis (e.g. fecal coliforms, nitrates, total phosphates, suspended solids, BOD_5). Laboratory samples were analyzed at two contracted laboratories using Standard Methods (APHA, 1989; 1992), following a USEPA-approved quality assurance plan (Irvine et al., 1996). Other parameters (e.g. pH, conductivity, dissolved oxygen, temperature) were measured in the field using standard field meters. Only nine of the 25 analytes

measured are of interest for the WQI.

CALCULATIONS

Estimating Total Solids

It was decided to use the WQI after sampling had begun and some of the data collected were not entirely consistent with the requirements of the WQI. For example, total solids (TS) is a required parameter for the NSF WQI, but in this study only data for suspended solids (SS) were collected. Stoner (1978) recommended estimating missing WQI data from available data. Since TS has the lowest weighting in the calculation of the WQI it was decided that a best estimate of TS could be made by referring to data from a previous survey carried out by Buffalo State College in 1992-93 (cf. Irvine and Pettibone, 1996) and using the following method.

The parameters of dissolved solids (DS) and conductivity (CoN) often are correlated (Canadian Council of Resource and Environment Ministers, 1993). The 1992-93 data for these analytes for a variety of flow levels from two sample sites on the Lower Branch of the creek were plotted and a simple linear regression analysis was done (Table 3). Likewise, data for one sample site each from the lower reaches of the East and West branches were entered into separate regression analyses (Table 3). The r^2 values for the regressions indicate good fit to the data.

It was not possible to produce representative regressions for each of the 12 1996 sample sites since the 1992-93 data were available for only four common sites. Hence, the best estimate TS calculations for 1996 utilized the regression equations from either the common 1992-93 site or the nearest downstream 1992-93 site. Using the 1996 CoN data with the regressions in Table 3 gave a best estimate of DS levels for each site. These estimated DS values were added to the 1996 SS data to produce best estimate TS values. Where the regressions gave negative DS values (< 5% of the cases), the data for SS only was used in the WQI calculations.

Table 3 Regression Equations to Estimate Dissolved Solids Concentrations

Site Comments	Regression Equation	r^2
Lower main branch, 1992-93 site 11, representing sites 1, 2, and 3 in this study	DS = 0.70728(CoN) - 40.2888	0.57
Upper main branch, 1992-93 site 7, representing site 4 in this study	DS = 0.62491(CoN) - 8.67254	0.64
West branch, 1992-93 site 1, representing sites 5, 6, 7, and 8 in this study	DS = 0.91766(CoN) - 111.786	0.71
East branch, 1992-93, site 2, representing sites 9, 10, 11, and 12	DS = 0.90082(CoN) - 94.8932	0.67

Conversion of Dissolved Oxygen Concentration to % Saturation

In the field, measurement of dissolved oxygen (DO) was recorded as units of concentration (mg l^{-1}). The WQI requires dissolved oxygen be reported as % saturation. The DO data were converted to % saturation using standard conversion tables provided with the meter, given the measured temperature and assuming chloride concentrations near 0. Later field measurements (total of 15) were taken in both % saturation and concentration units as a check on the accuracy of conversion. The mean difference between field measured % saturation and % saturation from the conversion tables was 3.9%.

Turbidity

Turbidity was not one of the 25 analytes measured in this study and an estimate for turbidity values therefore was taken from the data presented by Erie County (1978). It is expected that these turbidity values would represent a "worst case" scenario as it has been shown that suspended solids levels (closely related to turbidity) have declined over the past thirty years (Irvine et al., submitted). Furthermore, turbidity has the lowest weighting factor (together with TS) in the WQI, so errors should have a minimal effect.

Turbidity data for the spring and fall of 1978 (Table 4) were combined and the means calculated for each sample site. Where the sample sites were common with the 1996 survey, these mean values were used in the calculation of the WQI. Where there were no common data, the

nearest site mean was substituted.

Calculating the WQI

A Q-value was determined for each analyte based on the measured level of the analyte and using the individual Q-value charts from Mitchell and Stapp (1995) (e.g. see Table 4). Each of these Q-values was then multiplied by the appropriate weighting factor given in Table 1. These individual analyte-weighted indices were summed to establish the overall WQI for each site. Where multiple or duplicate samples were taken, the arithmetic mean of the data was used to calculate the WQI, except for fecal coliforms where the geometric mean was used (cf. Heathcote, 1991).

RESULTS

Table 5 provides a summary of the 1996 WQI results. Several of the sample sites from the 1978 Erie County stream survey are common to those of the present survey and the results for the 1978 survey are summarized in Table 6. Student's t-tests were applied to the 1996 WQI data and it was found that there was a significant difference ($\alpha = 0.05$) between the event mean WQI (all sites averaged) and the non-event mean WQI (all sites averaged). There also was a significant difference ($\alpha = 0.05$) in mean WQI (event and non-event data averaged) between the headwater sites and the mouth of Cazenovia Creek (i.e. site 8 vs. site 1; site 12 vs. site 1). The West Branch exhibited no significant difference ($\alpha = 0.05$) in mean WQI (event
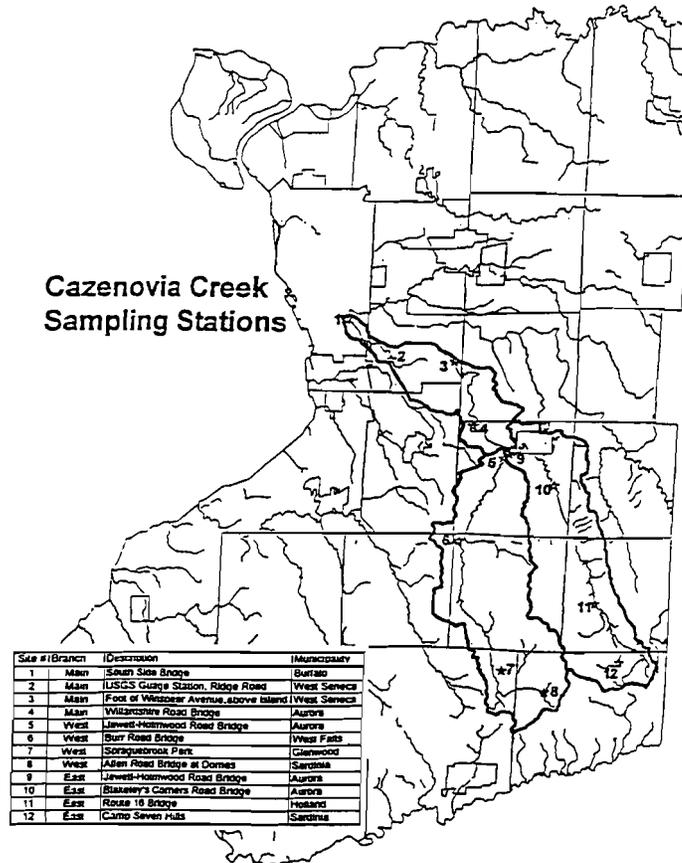
Figure 1 Cazenovia Creek watershed and sample sites.

Table 4 Substitute Turbidity Data (after Erie County, 1978)

1996 Site Number	Substitute 1978 Site Number	Spring/Fall Mean (JTU)	Q-value
1	1	11.42	72
2	(2)	9.60	77.5
3	3	17.18	66.5
4	(4)	9.60	77.5
5	(6)	40.75	45
6	(7)	31.63	51
7	8	19.96	62
8	8	19.96	62
9	(9)	49.51	39.5
10	10	44.82	42
11	(11)	27.44	55
12	12	30.54	53

(Note: site numbers in brackets are common to 1978 and 1996 sample programs)

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Table 5 Summary of 1996 WQI Results

1996 Site No.	WQI Event 1 4/24/96	WQI Event 2 4/30/96	WQI Event 3 6/4/96	WQI Event 4 6/12/96	WQI Non-event 1 6/24/96	WQI Non-event 2 7/10/96	Overall WQI Mean	Event WQI Mean	Non-event WQI Mean
1	70.34	74.67	72.79	70.82	76.74	76.01	73.56	72.16	76.38
2	75.45	76.08	73.91	76.50	73.01	75.93	75.15	75.49	74.47
3	67.20	75.87	75.24	75.53	76.03	76.62	74.42	73.46	76.33
4	67.42	74.88	75.02	77.76	80.24	78.27	75.60	73.77	79.26
5	76.55	76.92	73.16	77.66	73.61	77.82	75.95	76.07	75.72
6	71.44	76.50	76.92	77.91	74.83	79.94	76.26	75.70	77.39
7	82.50	78.69	78.29	78.88	83.46	83.70	80.92	79.59	83.58
8	83.17	78.92	76.27	79.75	82.87	80.54	80.25	79.53	81.72
9	67.79	73.99	71.26	75.14	75.59	75.83	73.27	72.05	75.71
10	78.82	73.15	75.51	76.56	76.81	76.93	76.30	76.01	76.87
11	76.73	75.71	71.86	78.25	74.95	75.17	75.45	75.64	75.06
12	82.02	76.54	76.11	77.62	77.57	78.92	78.13	78.07	78.25

Table 6 Results from 1978 Survey (Sites Common to 1996 Survey Only)

1978 Site No.	1996 Site No.	Spring WQI (1978)	Fall WQI (1978)
2	2	80.3	71.3
4	4	83.1	72.8
6	5	69.9	71.0
7	6	71.5	69.6
9	9	69.0	66.6
11	11	70.8	72.9

and non-event data averaged) between sites 7 and 8, but there was a difference between sites 6 and 7. Furthermore, there was no significant difference ($\alpha = 0.05$) in mean WQI between sites 6 and 5 or sites 6 and 1. The East Branch exhibited no signficant difference ($\alpha = 0.05$) in mean WQI (event and non-event data averaged) between sites 12 and 11, or 12 and 10, but there was a significant difference ($\alpha = 0.05$) between sites 12 and 9.

DISCUSSION AND CONCLUSION

The WQI values in Table 5 typically are in the "good" category (Table 2), although three sites (3, 4, and 9) are in the "medium" category for the first sampled storm event. A comparison of the results from this study (Table 5) with the 1978 results (Table 6) suggests that the WQI values for

the upper watershed (sites 5, 6, 9, and 11) have remained similar, or shown slight improvement. The WQI values for the lower watershed (sites 2 and 4) from this study appear to be similar, or slightly lower than the 1978 results. The slight decline in water quality may be associated with increased urban development in the towns of West Seneca, Elma, and Aurora (Erie County, 1991). It is expected that development will continue through 2010, particularly in West Seneca and Elma (Erie County, 1991) which may lead to a continued decline in water quality for the lower watershed.

Results of the statistical analysis indicate that the WQI values are lower for storm events as compared to non-event periods. These results are not unexpected, as many studies have shown increases in sediment concentrations, bacteria, and total phosphorus associated with storm runoff and increased discharge (e.g. Walling, 1977; Yaksich and Rumer, 1980; Irvine and Drake, 1987; Irvine and Pettibone, 1996). However, the results indicate that non-point sources can provide an important contribution to contaminant loadings.

The statistical analysis also indicates that water quality declines significantly from the headwaters to the mouth of the creek. Again, this appears related primarily to urban development, although agricultural-based sources also may contribute to a decline in water quality (e.g. Irvine and Pettibone, 1996). Water quality (as defined by the WQI) on the West Branch of Cazenovia Creek appears to decline significantly along the reach between sites 6 and 7. Identification of potential contaminant sources and development of best management practices might focus initially on this area. Water quality on the East Branch of Cazenovia Creek is relatively consistent above the village of East Aurora (sites 10, 11, and 12), but shows a significant decrease immediately downstream of the village (site 9). This result is consistent with the findings of Irvine and Pettibone (1996) and suggests that local urban stormwater runoff and, possibly, inputs from the sewage treatment plant may be negatively impacting water quality. Similar declines in WQI values were reported by Palupi et al. (1995) for three rivers passing through Jakarta, Indonesia and by Sharifi (1990) for two rivers passing through Rusht, Iran. Sharifi (1990) noted an increase in the WQI at stations 20 km downstream of the river and

attributed this to the restoration of self-purification processes with distance from the major contaminant sources.

As noted above, a disadvantage of the non-specific WQI is that the impacts of individual analytes are "smoothed out". The analytes of greatest concern for this study appear to be fecal coliforms and phosphorus. The fecal coliform levels exceeded state guidelines for primary contact (200 microorganisms per 100 ml) in 70% of the samples. The exceedance rate was greatest for the event samples and the results of this study concur with those presented by Irvine and Pettibone (1996). Total phosphate levels tended to be higher during storm events and 42% of all samples exceeded the Ontario Ministry of Energy and Environment guidelines of 0.03 mg l^{-1} (New York State does not have a standard for total phosphates). In comparison, the Welland River, Ontario which is tributary to the adjacent Niagara River AOC, typically has higher total phosphate levels (averaging 0.15 to 0.4 mg l^{-1}, with maximums of 2 mg l^{-1}) (Attema and Forsey, 1996). Development of best management practices initially should focus on fecal coliforms and phosphorus.

Finally, the WQI calculations were based on a relatively small, but spatially diverse number of samples. Because the ultimate goal of watershed management is to implement programs that will conserve water quality, it would be prudent to begin a longer term monitoring program at a selected few sites. The longer term monitoring will provide a tool by which to evaluate the effect that best management practices have on water quality and help assure public accountability. Lack of longer-term monitoring has been suggested as one reason why success of non-point source control programs has been difficult to document (Wolf, 1995).

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