

Literature Review of Water Quality Indices (WQIs)

Task 1 of 5 of Scope of Work for Development of a WQI for Watershed Assessments

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Executive Summary

Six peer reviewed papers related to WQI development and practical applications were read and summarized. In addition, staffs from the City of Greensboro's Stormwater Management Division were contacted to discuss the use of their WQI. Staff also provided several internal reports that were reviewed and summarized.

WQIs are commonly used throughout the United States and some countries as a means to describe, synthesize and summarize water quality analytical data for easy and rapid interpretation. Consumers of this information can range anywhere from knowing nothing about water quality to being closely connected to the resource.

Hallock (2002) explained that WQIs are not accepted by all professionals because they are considered too automated and provide an uncritical summarization of data. Professionals prefer to give no answer rather than an imperfect one that could lead to misunderstanding. The layman usually prefers an imperfect answer to no answer at all.

The WQIs summarized below are a version of a WQI that originated from work conducted by the National Sanitation Foundation (NSF) in the 1970s. In general, each of the papers described similar chronological steps used to derive the WQI but the aggregation techniques and final WQI expression varied based on their specific needs.

All authors followed the numbered steps below to generate a WQI except for Said et al, (2004) and Schiff and Benoit (2007), each of whom elected not to transform parameter concentrations to a sub-index score (as outlined in the numbered item three below) prior to aggregating. They developed unique equations tuned to their specific needs using parameter concentrations (see item four below).

In general, the steps others used to develop their WQI included: (1) the selection of a panel of experts or interested individuals that were to; (2) define the purpose of the index and select appropriate parameters; (3) transform data from a parametric system to a dimensionless system by producing graphs that link parameter concentrations to a sub-index scale from worst (0) to best (100) or some other arbitrary sub-index scale, i.e. to eliminate concentration units and simplify calculation of the final index; (4) derive the aggregation process or equation to combine all the sub-index values which in turn produces the final WQI; (5) test the index for sensitivity to changes in parameter concentrations; and, optionally, (6) develop a computerize spreadsheet that will facilitate

calculations and final WQI. The final WQI varied between a single number or a numerical range along with a narrative expression of quality. For example a WQI score of 90 – 100 could equate to Excellent or Healthy or a WQI of 89 – 50 could equate to Moderate or Stressed or any other combinations to express quality as recommended by the panel of experts or interested parties.

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Table 1. Description of water quality indices reviewed.*

Author	Purpose of WQI	Parameters	WQI Development
City of Greensboro, Stormwater Management Division, (2000)	Simplify WQ reporting to the public.	DO as percent saturation, fecal coliform, pH, BOD ₅ , total nitrates, total phosphates, TS, temperature, and turbidity	Standardize parameter concentration to sub-index score. Final WQI computed using an unweighted product equation of sub-indices.
Hallock, (2002)	Used as a tool to summarize and report routine stream monitoring data to the public. Indicates whether WQ is less than expected to support designated uses.	DO as concentration, fecal coliform, pH, total nitrogen, total phosphorus, TSS and turbidity.	Quadratic equation to convert results to sub-index score. Apply weightings and other rules to account for strongly correlated parameters and to avoid double weighting. Final WQI is average of three lowest sub-index scores.
Kaurish and Younos (2007)	Evaluate WQ data in a way that is scientifically valid and easily understood by professionals and the public.	Variable. Based on recorded biological response of indicator organism (eg., fish or benthos) by ecoregion. As an example, they used field measurements of DO, pH, temperature, and conductance.	Standardization of parameter concentration to biological response and narrative category. Assign numerical rank to narrative category. Final WQI is average of all worse case ranks over monitoring period.
Said et al., (2004)	Same as above but they wanted to develop a new WQI with fewer parameters that is simpler than most other WQIs.	DO, fecal coliform, turbidity, total phosphorus and specific conductance.	No standardization of variables to sub-index score. Rank and weight parameters based on significance. Conversion to logarithmic scale to keep final WQI a small number.
Schiff and Benoit (2007)	Used as an aid to describe WQ variables related to a watershed study exploring relationships between urban non-point pollution, land use (imperviousness), habitat and benthos across an urban-forest gradient in New Haven, Connecticut.	TSS, TDS, fecal coliform, nitrate, phosphate, the chloride to sulfate ratio, and the nitrate to total nitrogen ratio.	No standardization of variables to a sub-index score. Tuned a common WQI to quantify non-point source pollution levels in urbanized watersheds. Equation was described as a normalized average of seven parameters.
Smith, (1990)	Intended to develop a WQI that would not hide or “eclipse” vital information.	Varied base on designated use. DO, pH, TSS, turbidity, actual temperature, temperature above natural, BOD ₅ , ammonia, and fecal coliform.	Panel of experts selected parameters and produced graphs to standardize results to sub-index scale and aggregated sub-index scores for final WQI using the lowest sub-index score or “minimum operator” function.

*Abbreviations (units are all mg/L except where noted as follows): WQ – Water Quality; DO – Dissolved Oxygen; BOD₅ – 5-day Biochemical oxygen demand; TS – Total solids; TSS – Total suspended solids; TDS – Total dissolved solids; Benthos – Benthic macroinvertebrates; Conductance (uS/cm); water temperature (°C); Turbidity (NTU); fecal coliform (cols/100 mL).

Table 1 above summarizes and highlights important components related to WQI development as presented in the literature reviewed and discussed below in detail. It may be useful as a reference because it provides short descriptions of how various groups went about developing their own WQI, which parameters were selected and the aggregation methods employed to derive the final WQI.

The City of Greensboro (2000) WQI for streams is based on the NSF's method as described below in Kaurish and Younos (2007). The stream WQI incorporates nine parameters including: dissolved oxygen (DO) as a percent, fecal coliform, pH, biochemical oxygen demand (BOD), total nitrates and phosphates, total solids, temperature, and turbidity. Concentrations were assigned an individual rating based on existing standards or best professional judgment on a scale of 0 – 100. Each rating was then multiplied and the root of the product computed to obtain the final rating (Equation 1 below).

$$WQI = (P_1 * P_{i2} * P_{i3} * \dots * P_{i+n})^{1/n} \quad (\text{Equation 1})$$

- The final index value is assigned as either Good, Above Average, Average, Below Average or Poor in 20 point increments. For example 0-20 is Poor, 20-40 is Below Average and so on.
- Currently, the City of Greensboro portrays water quality monitoring data derived from the index on their website for public review. According to City staff, the City is planning to introduce a new GIS-based interactive version of the website for the general public to review water quality data as expressed by the WQI.

The City of Greensboro, Mecklenburg County Department of Environmental Protection, Duke Energy, and others developed a WQI for lakes based on work by Dr. Wallace Fusilier, a limnologist in Michigan. The concept behind its development is similar to that of the stream index in that "opinion derived" ratings that range from 0 - 100 are used to determine a value for each of the parameters, followed by a calculation of a final rating by taking the root of the product of the quality ratings (as in Equation 1 above).

Hallock (2002) provided details relative to the development of a WQI for the Washington State Department of Ecology's Freshwater Monitoring Unit based in part on the index developed by the NSF. He provided a brief background, history and purpose of their WQI and WQIs in general, and then went into detail on index calculation and comparisons between older and newer versions of their WQI based on a combination of multiple parameters over a 10-year period (1990-2000). For temperature, pH, fecal coliform bacteria and dissolved oxygen, the index expressed results relative to levels required to maintain beneficial uses based on Washington's Water Quality Standards. For nutrient and sediment measures, where standards were not specific, results were expressed relative to expected conditions in a given Ecoregion.

- The general public and other non-technical decision makers and managers have neither the time nor the training to study and understand a traditional, technical review of water quality data. WQIs are not accepted by all professionals because they are considered too automated and provide an uncritical summarization of the data. Professionals prefer to give no answer rather than an imperfect one that could lead to misunderstanding. Laymen usually prefer an imperfect answer instead of no answer at all. This WQI is an attempt at an imperfect answer to non-technical questions about water quality. It was developed as a tool to summarize and report their routine monitoring data to the public.
- A WQI is most useful for comparative purposes and for general questions vs. site-specific questions that should be addressed by an analysis of the original data. It is limited in that while a certain site may receive a good score, it may still be impaired or degraded based on a parameter not included in the index calculation. Also, aggregation of data may either mask or over-emphasize short-term (acute) water quality problems.
- Their WQI is built around the strategy that does not rank by relative water quality; it indicates whether water quality is less than expected or necessary to support designated uses. There are disadvantages to this type of WQI in that it requires subjective determinations of beneficial uses that a stream segment should support, the level of water quality required to support those uses and how critical a variation from the level of quality is. Also, comparing scores for different stations will not indicate which has the best absolute water quality unless expectations for both stations were the same.
- WQI parameters included: temperature, dissolved oxygen, pH, fecal coliform bacteria, the ratio of total nitrogen to total phosphorus, total suspended sediment (TSS), and turbidity. Because turbidity and TSS are highly correlated, they are aggregated using a harmonic mean (Equation 2 below) prior to using the index. This weights the lower score more heavily and prevents double weighting

$$x = 2 \div [1/TSS + 1/Turb.] \quad \text{(Equation 2)}$$

- Three steps were described to calculate the WQI. The first step converted each result to an index score ranging from 1 to 100 using the quadratic equation (Equation 3 below) derived from regression curve data. The specific formula used at each station varied by stream class or ecoregion for that station. The second step involved aggregating WQIs by month and calculating a simple average and applying penalty factors if necessary to reduce the likelihood of one low-scoring parameter being masked by the averaging process. The overall WQI per station is the average of the three lowest-scoring months. A similar procedure was followed to determine a WQI for each parameter. Step three involved the moderation of low scores that could be attributed to natural variance.

$$WQI = a + b_1 (\text{Parameter}) + b_2 (\text{Parameter})^2 \quad (\text{Equation 3})$$

- The paper concluded with a discussion and examples of hypothetical scenarios on the sensitivity of the WQI. That is, an index should not be too sensitive to a single aberrant result. After all, more than a single excursion beyond water quality standards is required for a station to be listed on their 303d list. He also describes a second run at the data in which he computed the annual flow-adjusted WQI scores. This was conducted to account for the variability in parameter concentrations due to flow rather than a change in watershed conditions. It was noted that trends in flow were apparently masking improving trends in water quality at most stations.

Kaurish and Younos (2007) suggested that there was a need for a water quality indexing system that accurately evaluated water quality data in a way that was scientifically valid, useful to water resource managers and easily understood by the public i.e., “how good or how bad” stream conditions are. To that end, they proposed a standardized WQI that uses the biological response approach as the common scale for evaluating stream water quality and described the concept and process for its development.

- The National Sanitation Foundation (NSF) first developed a WQI in 1970s to demonstrate the tendency for occurrence of eutrophication in streams and lakes. They chose nine parameters (temperature, DO, 5-day BOD, pH, nitrate-nitrogen, total phosphorus, total solids, fecal coliform and turbidity) to develop curves that related concentrations to index scores and then aggregated scores to a single number. The curves were a synthesis of national criteria, state standards, technical literature and best professional judgment.
- Since then, Oregon, Washington, Maryland, Canada and some European countries have developed WQIs using similar parameters and methods and for a various purposes. For example, in Oregon they were used to help with the assessment of water quality for recreational uses. In Washington, they expressed water quality relative to levels required to maintain designated uses per promulgated standards. Maryland developed a WQI for their coastal bay areas based on the status of four indicators (chlorophyll a, total nitrogen and phosphorus and DO) synthesized into a single indicator.
- Major critiques of the approaches above were that the resultant WQI is too subjective based on arbitrary and unit-less scales from 1 to 100 or 1 to 10 that produce a composite score without uniformity of scale. The rating curves between parameter concentrations and evaluations are based on statistics and best professional judgment. Rarely are they based on biological responses to stream chemistry.

- The WQI proposed by the authors needs to be ecoregion specific and requires that scientifically documented relationships between probable biological response of aquatic organisms and parameter concentrations for that ecoregion are available.
- If there were insufficient records of baseline parameter concentrations and biological response data available, the WQI could still be developed using statistics and best professional judgment. However, this approach would be considered subjective and should be phased out as complete and valid data become available.
- Specific steps for development of this WQI included: (1) the selection of an ecoregion specific organism common throughout that area along with credible data on biological responses of those organisms to specific-chemical parameter concentrations and, ideally, during different development stages of the indicator organism; (2) the selection of water quality parameters to be evaluated based on aquatic organism sensitivity, existence or absence of water quality standards or criteria and cost of data collection and analysis; (3) compile a database of parameter concentrations and matching indicator biological responses. These could range from death to prolific life, growth and reproduction each of which need to be standardized to a narrative water quality evaluation category and given a numerical rank.
- The next step (4) for this type of WQI would be to plot a parameter response curve (or graph) based on parameter concentration, probable biological responses and concomitant numeric scores and narrative evaluations. Step (5) involves the construction of parameter evaluation tables to portray normalized parameter concentration data to identical (standardized) biological response categories and identical (standardized) parameter evaluation/rank score categories.
- Step (6) involves developing a data spreadsheet to facilitate WQI calculation and printout based on the five steps above.
- Other sub-index components could be developed and incorporated into the WQI spreadsheet format. For example, a nutrient sub-index could include total nitrogen and phosphorus, nitrate-nitrite nitrogen, chlorophyll-a, dissolved metals, physical habitat and substrate components could be developed to help determine cause and possible sources of water quality degradation.
- The WQI should not stand alone as the sole interpretation of water quality and represents average conditions over the monitoring period. Therefore, the WQI and associated narrative evaluations should be scrutinized regularly to determine the greatest stressor to a particular monitoring location.

- A few ways of applying the WQI were presented, one of which involved detecting problems and rating water quality conditions within sub-watersheds and ecoregions. Comparing and ranking WQI scores by sub-watersheds would provide valuable information that water resource managers could use to make informed decisions relative to prioritizing stream restoration projects. It could also be used to track incremental improvements or various parameters as well as overall progress of stream restoration projects.
- Once fully developed, it simplifies the complexity of water quality conditions into a very comprehensive holistic presentation to facilitate communications between decision makers and the public.

Said et. al, (2004) proposed a simple WQI to describe water quality. They compared the proposed index with the NSF WQI, briefly described above in Kaurish and Younos (2007), to test its sensitivity to changing water quality parameters. The index consisted of five parameters including DO, fecal coliform (FC), total phosphorus (TP), specific conductance (SC) and turbidity (Turb). The WQI requires no standardization of parameters and no sub-indices. It was designed to provide a range of 0 to 3 with 3 being ideal conditions. The proposed index is presented in Equation 4 below.

$$WQI = \log \left[DO^{1.5} \div (3.8)^{TP} (Turb)^{0.15} (15)^{FC/10000} + 0.14(SC)^{0.5} \right] \quad (\text{Equation 4})$$

In ideal waters that have 100% DO, no TP, no FC, Turb less than 1 NTU, and SC less than 5 uS/cm, the value of the index would be 3. From 3 to 2, the water is acceptable, and less than 2 is marginal and remediation (listed on the 303(d), TMDLs or management practices for example) may be needed.

- In the final form of the index DO, FC and TP were given the highest weight; turbidity and specific conductance the least. The logarithm was used to give small numbers for ease of use by non-technical persons and the general public. Other parameters were not selected (pH, temperature, nitrogen) because the authors felt the effects of these variables were reflected to a certain degree by the basic variables.
- Stream habitat is not reflected in the index. The index cannot be used to indicate trace metals, organic contaminants or other toxic substances. Nor can it be used to make regulatory decisions. Best results can be obtained in natural conditions upstream of outfalls.
- In a comparison of hypothetical data, the WQI was found to be more sensitive to total phosphorus concentrations than the NSF index. At 1.5 mg/L total phosphorus, the NSF index gave a rating of 84% or very good, whereas the WQI proposed in this paper gave a value of 1.83 which indicated that water quality was marginal or that remedial action would be required.

Schiff and Benoit (2007) describe the practical use of a WQI tuned to indicate the level of urban-derived non-point source (NPS) pollution in a study watershed near New Haven, Connecticut. The primary objectives of their study were to: (1) explore the relationship between instream variables of water quality (via their WQI), macroinvertebrate assemblages and physical habitat to impervious cover across an urban-forest gradient; and (2) to use GIS to study the relationship between instream conditions and the spatial perspective of impervious cover. This summary will focus on the WQI and how it was used in their study.

- They provided a brief history of WQIs describing them as a simple, objective way of judging and ranking water quality that is more robust than any individual parameter.
- The WQI used by the research team is presented below in Equation 5. They suggested it could also be used to evaluate the effectiveness of best management practices and stream restoration efforts to mitigate urban water quality impacts to streams.
- Equation 5 below was described as a normalized average of seven parameters (total dissolved solids, suspended particulate matter, fecal coliform, nitrate, phosphate, the chloride to sulfate ratio and the nitrate to total nitrogen ratio) where P_i is the average of parameter i for all samples collected during the study period (in this case $n = 14$) at each site, $P_{i \max}$ is the highest mean value of parameter i at any site, and n represents the number of parameters used in the index. The WQI was scaled from zero to ten, with higher values indicating higher water quality.

$$WQI = 10 - [(10/7) \times \sum_{i=1}^n (P_i \div P_{i \max})] \quad (\text{Equation 5})$$

- Justifications for including selected parameters in their WQI centered on the use of most of these parameters in early indices used to investigate sanitary pollution that illustrated the similarities between sanitary sewage and urban NPS pollution. For example, anion data revealed larger chloride to sulfate ratios at sites where higher concentrations of other urban NPS pollutants were found. The nitrate to total nitrogen ratio was included because streams effected by logging, agriculture, and urbanization were shown to export more nitrate than organic nitrogen. Dissolved oxygen concentration was not included because oxygen depletion did not parallel other common indicators of degraded water quality. This was likely a function of physical factors such as re-aeration rates associated with riffles.
- They elected to use the arithmetic mean because it has been shown by Stambuk-Gilijanovic (2003) to effectively discriminate between high and low water quality. The source was not reviewed for this summary.

- Baseflow water chemistry varied little at each site; however, between site variation was evident. Storm flow samples were not collected. Natural breaks in the WQI score distribution were determined and described as
- Good (i.e., $WQI \geq 7.9$), Moderate (i.e., $7.0 > WQI \geq 3.4$) and Poor ($WQI < 3.4$). They also reported that water quality declined sharply as impervious area increased from 0 – 10%, and then plateaued at a degraded state beyond 10% imperviousness.

Smith (1990) describes the development of a WQI based on the minimum operator (or parameter) that is the most limiting, in terms of use support or suitability-for-use, in New Zealand. Instead of aggregating scores, they simply take the lowest sub-index score as the final index score. This approach eliminates the “eclipsing effect” of other indices that can sometimes “hide” the identity of the most limiting parameter. They employed the Delphi Method to organize a panel of experts to help select parameters and develop sub-index/concentration curves and descriptors for the range of values. The WQI was compared with two other WQIs to test the sensitivity to changes in parameter concentrations and the extent to which eclipsing problems existed. An example was provided of demonstrate how the index score would be obtained. The goal was to produce an index based on something specific, definable and meaningful to water managers, politicians and laypeople to address the question, “how suitable is a particular water for certain uses?”

- Two equations were presented as examples of aggregation techniques used by others that suffer from eclipsing tendencies that hide the identity of the determinand or parameter that may be degrading water quality. In the weighted multiplicative function (Equation 6 below), I is the final index score, I_{sub_i} is the sub-index rating for the i th determinand, w_i is its weighting, and n is the number of determinands in the indexing system. Equation 7 below relies on a modified weighted additive aggregation function.

$$I = \prod_{i=1}^n I_{sub_i}^{w_i} \quad \text{(Equation 6)}$$

$$I = 1 \div 100 \left(\sum_{i=1}^n I_{sub_i} w_i \right)^2 \quad \text{(Equation 7)}$$

- A simpler alternative function was proposed that avoids the eclipsing effect. It was described as the “minimum operator” and uses the lowest sub-index rating to produce the final index score as in Equation 8 below.

$$I = \min(I_{sub_1}, I_{sub_2}, \dots, I_{sub_n}). \quad \text{(Equation 8)}$$

- A panel of 18 experts was selected to produce a list of parameters and graphs linking parameter concentrations to a sub-index scale (in this case suitability for

use scale) in Phase 1 and 2 of the process. In Phase 3, the sub-index aggregation process was derived which then resulted in the final index formulation.

- Toxic substances were not included because a wide range of different chemicals would have to be measured and in practice toxicity was not a widespread problem in New Zealand waters.
- They chose nine parameters similar to those selected by the NSF as described above by Kaurish and Younos (2007) based on water uses (General, Bathing, Water supply and Fish spawning); some with standards, others without.
- Curves drawn by panel members were averaged to produce final graphs. New curves were developed based on these averages along with 95% confidence limit curves and returned to panel members for comment.
- WQI narrative descriptors ranged from “Eminently suitable for all uses” $100 \geq I_{sub} \geq 80$ to “Totally unsuitable for main and/or many uses” $20 > I_{sub} \geq 0$.
- Equation 8 above was chosen as the final WQI because of eclipsing problems associated with Equations 6 and 7. To demonstrate insensitivity to water quality degradation, all parameters but one were set to produce their maximum sub-index rating and ran through each aggregation technique. The altered parameter was set to vary from its lowest to highest I_{sub} rating and weighting factor. They provided an example using fecal coliforms and dissolved oxygen using curves to show how an index score changes with different values of the altered sub-index rating.
- Advantages of the minimum operator (Equation 8) include: no restrictions on the number of parameters employed; new parameters can easily be added or dropped at a later stage without affecting index computation; and, weightings are not required further simplifying index development.
- The WQI was tested an additional time by asking an independent panel of 23 water managers to derive their own index score (0 – 100) based on their knowledge and experience using various parameters and the list of descriptors for the range of sub-index values. The responses (the mean index and 95% confidence limits) were plotted against the theoretical index score, i.e. the one obtained from the first panel’s sub-index curves. In all cases, the regression line of the mean index scores was not significantly different from the theoretical line.

Summary

Many WQIs in use today are based on work by the NSF in the 1970s. WQIs can be used to aggregate results of several types of physical, chemical and biological measurements into a single indicator of water quality conditions for streams and lakes. Water resource agencies develop and use WQIs to facilitate communication of complicated scientific information to the public in a format that is easily understood. Portraying WQI scores graphically, in color, in website format is a common method to disseminate water quality data that has been indexed.

WQIs can be used to compare and report large scale (e.g. statewide) ambient monitoring data (Hallock, 2002) or they can be tuned for a more specific purpose as Schiff and Benoit (2007) did to meet a need for a water chemistry-based management tool to help identify non-point source pollution in urbanized watersheds within a smaller study region. Said et al. (2004) developed a WQI to support an argument that a WQI was sensitive enough to use as a mechanism for regulatory reporting purposes.

WQIs are mostly based on “opinion derived” ratings that transform parameter concentrations to values ranging from 0 – 10 or 100, followed by calculating a final rating using a user derived aggregation equation that can range from very complex with weightings and miscellaneous rules (Hallock, 2002), to very simple by using the minimum or maximum operator or sub-index score as the final WQI (Smith, 1990). Daurish and Younos (2007) suggested a more scientific approach to WQI development based on known biological response of aquatic organisms to specific parameter concentrations. The final WQI score, regardless of complexity, is typically followed by a narrative expression of quality.

The use of indices is not universally accepted by the scientific community mainly because they provide an uncritical summarization of data and aggregation techniques can sometimes eclipse or hide important limiting parameters. In the end, all agree that it is important to use indices with care to avoid missing important information that could lead to the discovery of causes or sources of water quality problems.

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Metrics to Consider for a Water Quality Index (WQI) for Watershed Assessments

Task 2 of 5 of Scope of Work for Development of a WQI for Watershed Assessments

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Introduction

As previously presented in the Literature Review of WQIs under Task 1, the parameters or metrics selected for a WQI will vary based on the purpose or intended use of the WQI. It was also shown that the selection of parameters and concentrations was rarely based on biological responses to stream water chemistry. Rather, parameter selection was typically a subjective process based (1) on best professional judgment, (2) on expected water quality conditions in a given Ecoregion, or (3) on water quality criteria or standards.

For example, Hallock (2002) chose parameters based on whether or not water quality for a given ambient monitoring location was less than expected or necessary to support designated uses based on the state of Washington's water quality standards. As such, the resultant WQI could not be used to compare water quality between monitoring locations unless expectations or intended uses were the same. Kaurish and Younos (2007) provided an ideal example that selected parameters based on numerous factors including, but not limited to, the sensitivity of aquatic organisms to parameter concentrations during different life stages, existence or absence of water quality criteria for the parameter and cost of data collection and analyses. Finally, Schiff and Benoit (2007) selected parameters to tune their WQI for a specific purpose, in this case a study that helped identify non point source (NPS) pollution levels in an urbanized watershed. One common parameter (dissolved oxygen) was excluded from their WQI *a posteriori* because oxygen depletion did not parallel other common indicators of degraded water quality; dissolved oxygen levels at the monitoring sites were a function of physical factors such as re-aeration rates associated with turbulent riffles.

Therefore, the draft list of parameters and reasoning provided in Table 1 below were developed with a purpose in mind as described below. In the Appendix that follows, a flowchart is provided to remind readers of the various sequential tasks that must be completed for development of the final WQI.

WQI Purpose

As explained in the Scope of Work, the intended use of this WQI is to assist with describing water quality conditions to stakeholders and other interested groups within the context of a local watershed planning as directed by the NC Ecosystem

Enhancement Program (NCEEP). The WQI is a tool used to facilitate communication of water quality data collected from several locations, over a certain time period, within a designated watershed(s) for the purpose of water quality comparison and characterization between sub-watersheds and catchments. It may be used to identify problem areas and stressors to water quality, signal where more specific monitoring may be needed or to prioritize locations for stream and riparian restoration or enhancement projects. Use of the WQI would be used in addition to the conventional review of existing water quality data and integrated report presently provided to EEP as part of the local watershed planning process.

The WQI is not intended to provide evidence of (1) use support, (2) that NC water quality standards were violated or (3) that a stream segment may be a candidate for the 303(d) list.

In Table 1 below, a potential list of conventional water quality parameters and indicators that have been used in previous watershed assessments are listed with brief explanations relative to the logic for selecting a parameter or metric for the WQI.

Selected metrics associated with the Biological Assessment Unit's (BAU) Mountain/Piedmont Habitat Assessment Form are proposed as part of the WQI because they evaluate indicators of water quality that are not adequately addressed in baseflow chemistry sampling but that have potential to affect water quality during storm events. For example, baseflow monitoring does not capture sediment pollution (via turbidity or total suspended residue) even though unstable stream banks and bedload may be apparent at a monitoring location and throughout the reach that contribute sediment downstream during storm events.

Table 1. List of parameters or indicators and reasons for including them in the WQI.

Parameters/Indicators of Water Quality	Include as part of WQI?	Reasoning
Specific Conductance (uS/cm)	Yes	Compared to reference conditions, it indicates dissolved pollutants and potential upstream watershed disturbances.
Dissolved Oxygen (%)	Yes	A standard water quality parameter. It indicates oxygen demand as well as supersaturation (evidence of excessive alga and nutrient enrichment).

Table 1. List of parameters or indicators and reasons for including them in the WQI.

Parameters/Indicators of Water Quality	Include as part of WQI?	Reasoning
pH (s.u.)	Yes	A standard water quality parameter. Values outside of desired range may indicate a water quality problem.
Water Temperature (°C)	Maybe	If monitoring is conducted in summer then yes; otherwise, no. Project dependent (Mtns vs Coast)
Nitrite-Nitrate Nitrogen (mg/L)	Yes	Compared to reference conditions, it provides evidence of nutrient enrichment, disturbance and pollution sources.
Total Kjeldahl Nitrogen (mg/L)	Yes	Same as above.
Ammonia Nitrogen (mg/L)	Yes	Same as above.
Total Phosphorus (mg/L)	Yes	Same as above.
Total Suspended Residue (mg/L)	No	Turbidity and bank stability metrics below will capture potential sediment pollution. During baseflow, this parameter may not adequately reflect the potential for sediment pollution.
Turbidity (NTU)	Depends	Indicates potential sediment or particulate pollution. If stream bank stability metric below is included, turbidity may not need to be included. However, it could provide evidence of sources if turbidity is present during baseflow.
Sodium (mg/L)	No	Specific conductance will capture problem levels.
Chloride (mg/L)	No	Same as above.
Metals (Cu, Zn, Pb, etc.)	No	Typically levels are very low. Uncertainty remains in interpreting total recoverable vs dissolved data. Turbidity and other sediment indicators will capture potential problem.

Table 1. List of parameters or indicators and reasons for including them in the WQI.

Parameters/Indicators of Water Quality	Include as part of WQI?	Reasoning
Fecal coliform (cols/100 mL)	Yes	Indicates potential sewer line leaks, failing septic systems and upstream livestock operations.
Organics	No	Too expensive. Other parameters could be a surrogate for organic pollutants.
Livestock Access	Yes	We know that livestock represent a stressor to both water quality and the riparian environment.
Light Penetration (Shading)	No	Riparian vegetation would capture this parameter.
Bank Stability	Yes	This metric captures a source of sediment pollution during storm flow and may be the sole metric to represent potential sediment pollution during storm flow. Others are listed below.
Bank Height Ratio (BHR)	Maybe	This estimate may a more robust measure of potential sediment pollution during storm flow than simply bank stability. However, this metric and estimates of bank stability (a sort of pseudo BEHI) would be a powerful parameter combination indicating sediment pollution.
Riparian Zone Width/Vegetation	Yes	We know that riparian conditions (width and type of vegetation) affect water quality functions. Conventional chemistry parameters alone do not adequately address this metric.
Bottom Substrate	Maybe	This would address sediment pollution in terms of bedload and may not be needed if one of the other sediment related metrics are included.

References

Hallock, D., 2002. A Water Quality Index for Ecology's Stream Monitoring Program. Washington State Department of Ecology. Publication No. 02-03-052. November.

Kaurish, F.W. and T. Younos, 2007. Developing a Standardized Water Quality Index for Evaluation Surface Water Quality. *Journal of the American Water Resources Association* 43(2):533-545.

Schiff, R. and G. Benoit, 2007. Effects of Impervious Cover at Multiple Spatial Scales on Coastal Watershed Streams. *Journal of the American Water Resources Association*. 43(3):712-730.

DRAFT

Appendix

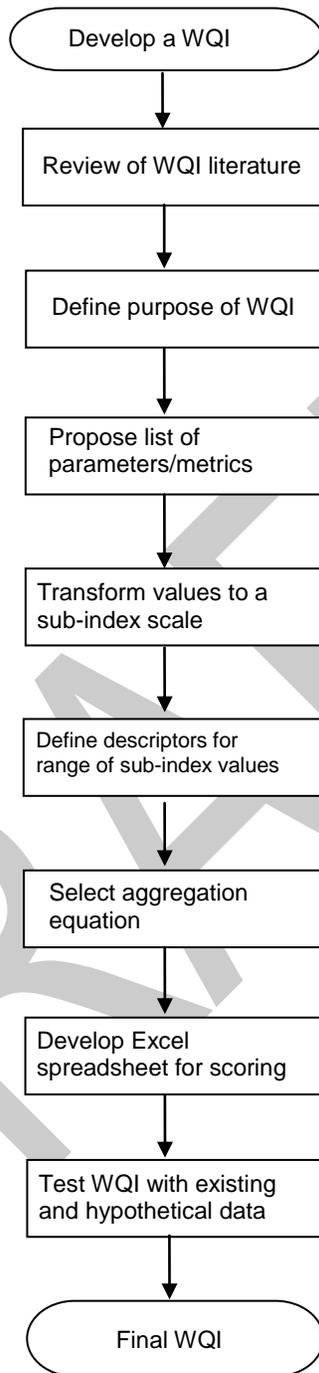


Figure 1. Flowchart of progressive tasks to be completed for development of a WQI for watershed assessments.

Water Quality Index Project-EEP Comments

In general, development of a WQI has the potential to be a very useful communication tool and Tasks 1 and 2 have provided good information to begin discussion and development of such a tool. EEP does feel that in order to be effective, a WQI will need to undergo more comprehensive data development and analysis as well as review by water quality experts beyond EEP and DWQ.

Task 1: Literature Review

- Interesting references, but the organization of the information is confusing. Page 1 begins with an Executive Summary, but there are no additional sections broken out until Summary. Suggestion, include the following breakdown for each method: Background, Objective, WQI Development and Methods, WQI Use and Limitations.
- Table 1 is a helpful summary of information. It would be helpful to organize the information by study with each paper/study a separate section that is bolded and clearly identified. Right now, it is difficult to follow when one review begins and another ends within the narrative (see above comment).
- This provides a summary of six different approaches to WQI, but in some cases, it appears that there is some critique included within study description. Is this just documenting critiques noted in papers? Need to be very clear as to whether this is a summary or critique of information.
- The NSF method from the 1970s is noted extensively throughout the document and it would be beneficial to include a complete individual summary on this method.

Task 2: Metrics to Consider for a WQI for Watershed Assessments

- Critical question in development of WQI is: who is target audience? If this is a tool for stakeholders in LWP process, there should be an understanding that stakeholders within the LWPs generally have technical background and so would not need to oversimplify information.
- Development of a WQI should not be used for purposes beyond a tool for communication---important data could be lost if this becomes only summarization of data.
- Perhaps a logical way to organize information is to breakdown WQI into sub-indices. For example, biological (benthos/fish), sediment and nutrients, chemical parameters.
- The literature review developed in Task 1 identified standard steps used in development of an index. One key step that was not incorporated here is (1) Selection of panel of experts to provide input and review. This is a very important step and would need to incorporate individuals outside of EEP and DWQ.
- Are other groups within DWQ (ex. Modeling and Regulatory groups) aware of the proposal to develop a WQI and if so, do they support it? If not, it should be communicated clearly with other divisions prior to initiating more work.
- Methods reviewed in Task 1 had very robust data analysis prior to incorporating into an index. There will need to be much more work to develop data and information provided on what is driving the rating or comparison.
 - What methodology will be used to derive Index Values
 - How will WQI address regional differences and watershed specific issues?
 - Interpretation of existing data will need to be well understood prior to plugging in information and/or developing a WQI.
- It appears the next step, Task 3, needs to be broken out into sub-tasks:
 - Compile existing data/review
 - Proposed methodology
 - Circulate for review by panel of experts.
- EEP would like to revisit proposed parameters (Table 1) once some of the general questions/comments above are addressed. In general, EEP agrees that not all datasets listed are necessary for a WQI, but would reiterate that the parameters to include are watershed-dependent.