Ecology's new Water Quality Composite Index

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Note: *An index is an effective communication tool for consistently reporting complex information while alerting experts and the public to important changes. In the environment indices help increase awareness about the specific components they present. However, indices cannot substitute for detailed scientific investigations aimed at determining the causality of changing environmental conditions. Ecology's new Water Quality Composite Index (WQCI) encourages scientists to use the index as an effective communication tool. For this reason the index has been structured around scientific principles.*

I. Motivation:

Since 2002 Ecology has been reporting water quality using two indices (Water Quality of Concern and Sensitivity to Eutrophication, Dr. Jan Newton). Both indices use combinations of up to five indicators (e.g. *Oxygen, Fecal Coliform Bacteria, Dissolved Nitrogen, Ammonia, Stratification or Duration of Low Nitrogen*). Concentration thresholds are based on expert knowledge and divide water quality into four categorical classes ranging from low to very high. Ecology is updating its index reporting system to a) better incorporate and utilize the sixteen variables routinely collected by the marine monitoring program, b) reflect advances that have been made in published mathematical index formulations and, c) move towards a statistical-based index formulation effective at including the volume of data increasingly shared across agencies.

II. Objectives:

A. Ecology's new Water Quality Composite Index (WQCI) highlights sites experiencing rapid changes in water-quality side-by-side with areas of chronically low water quality**.** As spatial and temporal patterns of water quality do not always coincide, such side-by-side presentation provides a contrasting and more comprehensive perspective.

B. **The WQCI reports on basin-wide fluctuations and trends in eutrophication**. It is designed to provide the temporal and large-scale statistical context needed to support local water quality programs, remediation and modeling efforts.

C. We seek to strengthen the effectiveness of the WQCI as a communication tool by:

1. Using a peer reviewed, published and tested statistical index formulation covering both fresh and saltwater.
2. Building a quantitative index structure to facilitate consistent reporting over time. Water quality objectives are contingent on long-term site-specific statistical data to better detect relative change in the environment.
3. Engaging index users through a transparent index structure with individual modules representing scientific concepts relevant to eutrophication.
    - Multiple levels of numerical detail and presentation provide options for water-quality tracking. A graphical synthesis reports the status, the trend and the statistical significance of water quality at the highest reporting level.
    - Individual modules (4) represent the drivers, progressive stages and impact of eutrophication in progressive order. The intent is to facilitate effective communication of the state of water quality from experts to management and encourage management to respond to environmental challenges with more informed measures.

4. **Designing a comprehensive statistical framework** to track the significance of trends in the context of large scale climate and oceanographic variability.
    - Stations are aggregated into index reporting regions using statistical methods.
    - Temporal changes of all index components are statistically evaluated.
    - The climatic and oceanographic context is provided using two regionally relevant indices: the Pacific Decadal Oscillation (PDO) and NOAA's upwelling anomaly index (PFEL). The PDO and PFEL are presented for comparison, but not otherwise incorporated into the formulation of the WQCI.

D. To facilitate better communication we promote a cohesive marine/estuarine water quality index formulation across ecosystem, state and national boundaries.

- The Canadian Water Quality Index (CCME) has been implemented in marine, brackish and freshwater environments across Canada and also in San Francisco Bay, California (see addendum).

III. **Approach:**

A. **Water quality objectives for the WQCI were developed using Ecology's 10-year monitoring record (1999-2008).** Water quality objectives for each site were selected based on summary statistics of monthly (120 months) and depth aggregated variables (16 variables). These site-specific objectives provide the fixed temporal framework needed to detect and statistically evaluate changes in eutrophication over time.

B. **The index is formulated around the variability of indicator data around a 10-year monthly mean (residuals).** Residuals reflect site-specific variability that remains after the seasonal signal has been removed. Using de-seasonalized data effectively amplifies inter-annual changes that are otherwise difficult to detect. In addition, this approach allows easier integration of datasets across agencies (e.g. King County vs. Ecology), a step critical for effective partnerships.

C. **Assumptions inherent to the index.** The WQCI is built around natural well-established indicators (n=16). Table 1. Threshold values (objectives) of the indicators are selected to reflect average conditions at each sampling location from 1999-2008. Measurements that fall above and/or below the objective affect the index score.

Table 1: Exeedances lowering the index score:

Exceeding the site-specific objectives	**Not reaching the site-specific objectives**
• *Chlorophyll a conc.*	• *Silicate : Dissolved inorg. Nitrogen*
• *Energy for vertical mixing*	• *Nitrogen : Phosphate*
• *Thermal energy content*	• *Nitrate : Dissolved inorg. Nitrogen*
• *Fecal coliform bacteria*	• *Similarity in water masses*
• *Nitrate and Phosphate conc.*	• *Oxygen content*
• *Enrichment of NO_3, PO_4 and NH_4 in relation to reference (JEMS 30-80 m)*	• *Euphotic depth*
	• *Water transparency*

D. **Stabilizing environmental variability.** Depth integration (0-50m) is performed to reduce the number of individual observations and to derive metrics that are more representative of the upper water column. Water quality variables are aggregated as follows.

1. For continuous CTD profiles, depth integration is applied
2. For discrete samples, median/average values are used.

E. **The WQCI scale.** The Canadian National WQ Index (CCME) reports water quality on a scale from 0-100. The selection of the objective based on a 10-year mean implies that the mean score naturally falls near a score of 50. The scale for the WQCI has been adjusted to vary around 0 (range -50 to +50) to better reflect the focus of the index on relative change to a temporal reference period.

F. **Reporting the status of water quality is performed separately and hinges on ranking 16 variables and 27 stations over a period from 1999-2008**. Station rank sums of all 16 variables were added and subsequently scaled between 0-100. Minima and maxima were determined using the extremes at either end of the spectrum. Ranking was performed using depth-normalized data to account for variable water depth.

G. **Index reporting regions** are clustered by statistical methods (multidimensional scaling) and are based on monthly data from 1999-2008 (192 variables). Fourteen reporting regions were statistically determined and subsequently expanded into 17 geographically-coherent reporting regions.

H. **Statistical evaluation of the index occurs in three steps - a) statistical index formulation of the WQCI, b) trend analysis, c) correlation with external indices.** As time progresses, statistics are updated in two ways. The objectives for all WQCI modules statically reference the period 1999-2008. This ensures that long term-changes are described in relation to a temporal reference (the beginning of the millennium).For b) and c) a 10-year statistical frame is progressively moved as more data become available.

I. Temporal resolution of the index. Station-specific index scores are calculated annually (12 months, 16 variables, 27 stations). This ensures a robust index formulation that is less sensitive to biases caused by seasonal phase shifts and occasional data gaps.

IV. Outlook

A. **Ecology seeks to present its index report via an improved web-based interface.** Ecology plans to emulate Chesapeake Bay Health index's graphical interface.

B. **Ecology marine monitoring program will maintain a separation of the index score from its evaluation** e.g. a reporting of the overall "Puget Sound water health". Ecology would like to explore how the Science Panel envisions the structure for this process.

V. Addendum:

- Literature:
  1. CCME Water Quality Index 1.0, Technical Report, 2001. Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment, p 13.
  2. Limited G. A., 2006. A Sensitivity Analysis of the Canadian Water Quality Index, Council of Ministers of the Environment, p 38.
- Examples: Preliminary WQCI scores for selected regions in Puget Sound (1999-2008)
- Presentation: "Ecology's new marine WQCI", Dr. Christopher Krembs