MEASURES OF FLOW VARIABILITY
FOR
GREAT LAKES TRIBUTARIES

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Abstract. Design of monitoring programs for load estimation is often hampered by the lack of existing chemical data from which to determine patterns of flux variance, which determine the sampling program requirements when loads are to be calculated using flux-dependent models like the Beale Ratio Estimator. In contrast, detailed flow data are generally available for the important tributaries. For pollutants from non-point sources there is often a correlation between flow and pollutant flux. Thus, measures of flow variability might be calibrated to flux variability for well-known watersheds, after which flow variability could be used as a proxy for flux variability to estimate sampling needs for tributaries for which adequate chemical observations are lacking.

Three types of measures of flow variability were explored: ratio measures, which are of the form \( q_x / q_y \), where \( q_x \) is the flow corresponding to the percentile \( x \), and \( y = 100-x \); spread measures, of the form \( (q_x - q_y) / q_m \), where \( q_m \) is the median flow; and the coefficient of variation of the logs of flows. In the latter, flows are log transformed because flow distributions are often approximately log-normal. Three ratio measures were evaluated, based on the percentiles \( (10,90) \), \( (20,80) \), and \( (25,75) \). The analogous spread measures were also evaluated; the spread measure based on percentiles \( (25,75) \) is derived from the commonly used fourth spread of non-parametric statistics. The ratio measures and the spread measures are scale independent, and thus are measures only of the shape of the distribution. The coefficient of variation is also scale independent, but in log space.

Values of these measures of flow variability for 120 Great Lakes tributaries are highly intercorrelated, although the relationship is often non-linear. The coefficient of variation of the log of the flows is also well correlated with the coefficient of variation of fluxes of suspended solids, total phosphorus, and chloride, for a smaller set of rivers where the existence of abundant chemical data allows comparison.

Tributaries with abnormal distributions often show up as outliers when one measure of flow variability is plotted against another. Several examples are discussed.

Introduction

In tributary systems which are dominated by non-point sources of pollution, concentrations of many pollutants increase with increasing flow, remain approximately constant, or decrease less markedly than the flow increases. Flux rates, which are the product of concentration and flow, therefore tend to increase with increasing flow in these systems, in contrast to flux rates primarily from point source inputs, which may be approximately independent of flow. In these non-point dominated systems, the linkage between flow and flux carries information which can be used to estimate fluxes from flows, when fluxes are not measured directly (usually, when chemical data are lacking). This linkage also means that, if a river has highly variable flows, it is likely to have highly variable fluxes, and will require a relatively detailed, probably flow-stratified sampling program if precise and accurate pollutant load...
estimates are sought. It further provides the opportunity, in principal at least, to obtain an initial estimate of sampling needs for load calculations from the flow data alone.

Because of this linkage, the concept of 'event responsiveness' has developed, and been used in Great Lakes research for a number of years. Rivers thought of as event-responsive show large increases in flow during runoff events following storms, whereas stable response rivers have much smaller increases in flow following storms. Soil type is a major factor determining event responsiveness, with event-response behavior typically associated with fine-grained, heavy soils and stable response behavior connected with looser, coarser soils with better infiltration capacity. Land use also has an effect, with agricultural and urban basins typically being more event-responsive than forested ones.

Monteith and Sonzogni (1981) classified the major U.S. tributaries to the Great Lakes into three groups: Event Response, Variable Response, and Stable Response (this classification is referred to herein as EVS). The classification was intended to reflect the relative difficulty of characterizing loadings, particularly of suspended solids and total phosphorus, from each tributary. Their classification was based initially on the slope of the regression of suspended solids concentration on flux (Sonzogni et al., 1978). Unfortunately, the analysis was of necessity based on limited data for many tributaries. Furthermore, the strength of the relationship ($r^2$) was not very good in many cases. The 1981 report provides a much more complete list of classified tributaries, but gives no data on the regression analyses used to make the classification. Sonzogni (private communication, 1987) indicated that the 1981 classification was based in part on judgement, using flow data, soil type and land use as criteria, when concentration data were inadequate or unavailable.

Subsequent work has shown the utility of the concept of event-responsiveness for planning monitoring programs, but the lack of a continuous scale which can be widely and uniformly applied has hampered detailed use of the concept. The development of flow-responsiveness measures is one step in the attempt to provide such a quantitative tool. Since flow variability is generally closely linked to flux variability, an adequate index of flow variability should prove a useful predictor for flux variability and thus for sampling requirements for load estimation. Detailed flow data over a long period of record are available for most larger Great Lakes tributaries, in sharp contrast to chemical data. Furthermore, they are available in a form which lends itself to ready quantification, in contrast to land use and soil type information.

This paper describes and evaluates several alternative measures of flow responsiveness, and explores their potential use in deriving initial estimates of sampling frequency for load estimation. In a related work, Richards (1989) used the flow measures to re-classify the Great Lakes tributaries into event-response groups, updating the work of Sonzogni and Monteith and extending it to the Canadian Tributaries.