5. THE NPS POLLUTION INDEX

5.1 Introduction

Computer models are powerful tools for targeting NPS pollution and for watershed management. However, models were not always designed with the end user in mind, since most originated as research tools. Model output can be voluminous and confusing. If models are to be utilized by planners and decision-makers, the information generated by them must be presented in an easily understandable way. Historically, one way of simplifying complex information, has been to synthesize data into indexes (Steinhart et al., 1982). Indexes are commonly used in our everyday life from the Dow Jones index and the Index of Leading Economic Indicators to the weatherman's daily heat index; from the Consumer Price Index to the air quality index and the erosion index for determining highly erodible land. The nonpoint source pollution (NPSP) index was developed as a means of synthesizing model output for evaluation of land use impacts in the urban fringe.

NPS pollution is generally reported as annual loads in units of *kg/ha* or its equivalent, and NPS indexes are consistently based on these units. Two basic changes are incorporated in this NPS pollution index: a change in the unit of measurement, and a change in the time period of assessment. Although the annual *kg/ha* unit is useful in comparing effects of differing land uses, it does not lend itself for use in establishing a fixed-scale index, because it does not differentiate seasonal or annual variations in runoff, the primary factor behind NPS pollution. Furthermore, without standards or criteria as a basis for a quantitative relationship between index values and parameter loads, acceptability or meaning of index values is difficult to establish, except in a relative sense. A different unit of measure, *kg/ha-cm*, is proposed to overcome some of these obstacles. While not a new unit, *kg/ha-cm* is less frequently used in assessing NPS pollution and has not been used to date in published NPS indexes. The *kg/ha-cm* unit has some attributes which make it desirable for use with an index. For one thing, it normalizes load with respect to watershed area and runoff depth, making it equivalent to long-term concentration, with *1 kg/ha-cm = 10 mg/L*. Although there are no established standards or criteria related to watershed loadings of nutrients and sediment, ground water and lakes represent two related waterbody categories whose measurements more closely resemble long-term concentrations, and for which some standards and criteria are available. These can serve, in the interim, as a basis for the development of rating curves that relate sub-index values (SI) to individual NPS pollution parameters. The base time period chosen for this unit was the *month* in order to assess intra-year variation, and to be comparable with generally available monitored data.

A procedure was developed for creating a NPS pollutant index based on the *kg/ha-cm* unit, which incorporated monthly loads of three NPS pollutant parameters: total nitrogen, total phosphorus, and suspended sediment. Initially, COD was to be included as a fourth parameter. However, repeated model runs produced minimal COD loading at scattered points throughout the watershed, but never any loads at the outlet. Therefore, this parameter had no impact on the index, except to dilute the impact of the other three parameters. Since no COD output was ever generated at the watershed outlet, and since the intent of this study was to use the AGNPS model in an uncalibrated mode, this parameter was dropped rather than attempting to calibrate COD for a meaningful output.

These parameters were chosen to represent the major expected NPS pollutants in agricultural and rural residential watersheds, and their form was chosen with the monthly basis in mind. The NPS indexing procedure followed the general form for water quality indexes outlined previously in the Literature Review section. Rating curves were developed based on criteria or standards to translate parameter concentrations into sub-index values. Weighting of individual pollutants was considered, and weighted sub-indexes were then aggregated into an index. The criteria in Table 5-1 were chosen subjectively from various sources of long-term concentrations to illustrate possible values and sources for use in defining low (1) and high (9) sub-index values as the basis for rating curves for each of the three chosen parameters.

Table 5-1. Rating Curve Parameters and Sub-Index Values

	Source	Conc. (mg/L)	SI Value
Total Nitrogen			
Lake Tahoe standard	Briggs & Ficke, 1977	0.24	1
Potomac Embayment POTW monthly effluent standard	VWCB, 1990	1	5
severe eutrophication problem threshold	Mills et al., 1982	9.2	9
Total Phosphorus			
proposed oligotrophic classification threshold	Reckhow, et al., 1980	0.01	1
Chickahominy watershed monthly standard	VWCB, 1990	0.1	5
Nutrient Enriched Waters monthly standard	DEQ, 1994	2.0	9
Sediment			
beginning sedimentation problem threshold (SS)	Mills et al., 1982	10	1
probable sedimentation problem threshold (SS)	“	100	9

The rating curve was given a log-normal shape to approximate the relationship between SI values of 1, 5 and 9 and their corresponding concentrations. A rating curve for total nitrogen is illustrated in Figure 5-1. The rating curves are defined within the sub-index range of 0 to 9, but sub-index values were allowed to range from 0 to 20 to give additional emphasis to extreme concentrations. The three pollutant parameters were given equal rating in this index. The index (I) was then calculated as:

$$I = \frac{\sum_{i=1}^{3} SI_i * w_i}{\sum_{i=1}^{3} w_i} \qquad (3.30)$$

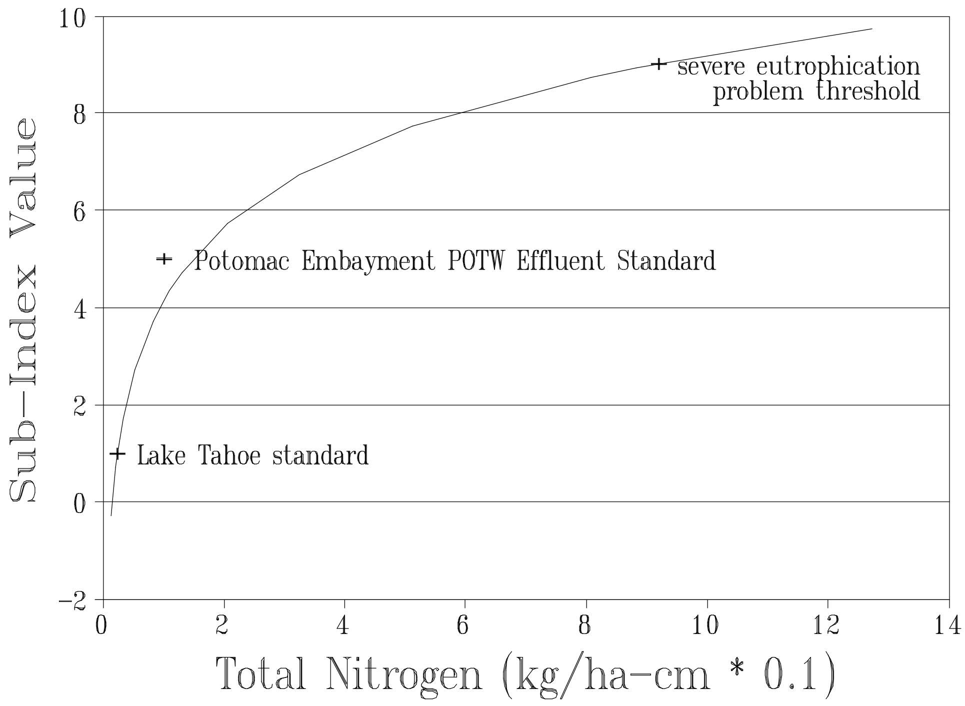

Figure 5-1. Total Nitrogen Log-Normal Rating Curve

5.2 Initial Index Calculations

The nonpoint source pollution (NPSP) index was calculated from observed and modeled monthly data sets. Note that the NPSP index is not modeled directly, but is calculated from modeled or monitored parameters. These values are included in Appendix C and are displayed in a bi-variate plot in Figure 5-2 and as sequential differences between the two alternative monthly modeling procedure-based indexes in Figure 5-3.

A large variability in model-based monthly NPSP indexes was exhibited in Figure 5-2. The largest model-based indexes, as well as the largest range of model-based indexes corresponded with smaller values of observation-based indexes. This plot also clearly shows that the AG2mn procedures produce indexes substantially closer to observation-based indexes, than do the AG1mn procedures, in all but one or two months. Figure 5-3 illustrates a tendency for smaller differences between indexes from observed and modeled data with increasing values of the observation-based indexes. Both sets of modeling procedures produce indexes which are much larger than indexes based on observed data. The variability exhibited in Figure 5-2 was much greater than expected, as it was hoped that the index would de-emphasize minor NPS pollutant differences by integrating a number of pollutants and runoff. In order to further explore these differences between observation and model-based indexes, the data sets were explored using mean concentrations.

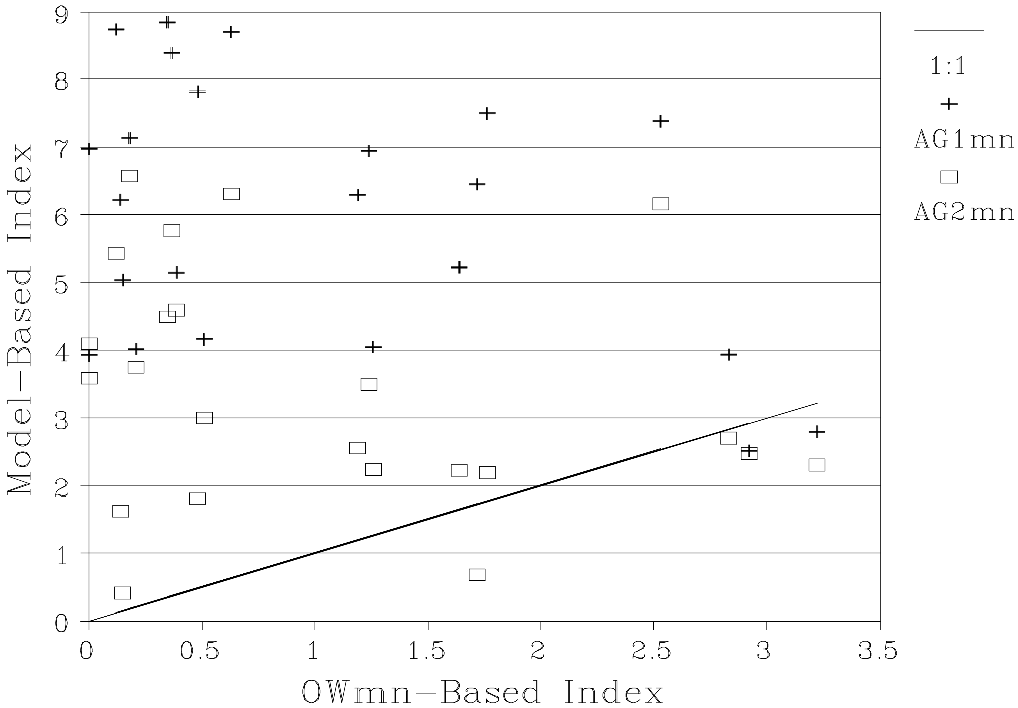

Figure 5-2. Monthly NPSP Indexes

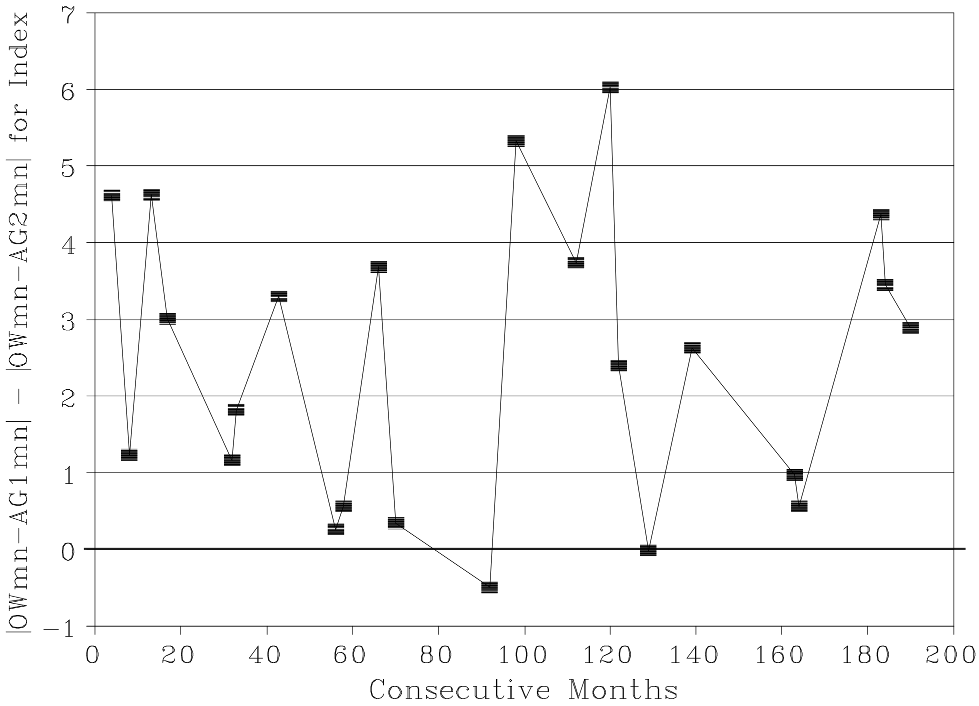

Figure 5-3. Index Differences Between Alternative Monthly Modeling Procedures

5.3 Mean Concentrations

Mean monthly concentrations serve as the basis for the NPSP index developed in this study, using units of *kg/ha-cm*0.1*, a long-term equivalent of mg/L. Although the NPSP index is based on mean monthly concentrations, the pollutants were generated as loads from the model and were compared on that basis with observed data. Calculations of mean monthly concentration and transformation via the rating curves were handled internally within the indexing program, and so were considered interim data. Furthermore, as concentrations were calculated as a composite measure, rather than modeled explicitly, no need was seen for including concentrations in the model evaluation process. During analysis, many ways of looking at the data sets were explored, with some views providing little, if any, insights. One such data set was the mean monthly concentration data set. Although nothing striking came from that view of the data, it led to looking at mean concentrations for composite period data. Although the NPSP index was not calculated for individual storms, event mean concentrations (EMC), the composite period equivalent of mean monthly concentrations, were calculated to contrast some of the characteristics of this measure relative to those of unit area loads in kg/ha in Figure 5-4. This figure shows that, while load increases in a linear fashion with increasing runoff, EMC acts in an asymptotic fashion. Higher concentrations are related to very low runoff volumes, while an almost constant concentration is associated with higher runoff.

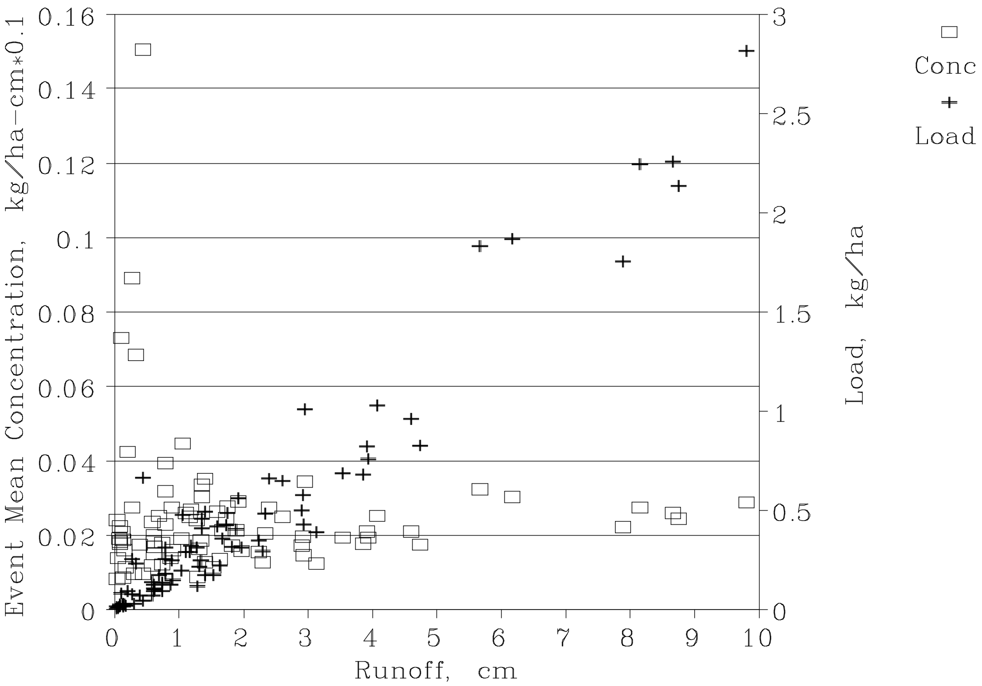

Figure 5-4. Composite Period TN Loads and EMCs

While exploring the results for analysis, plots were generated to compare monitored and modeled EMCs for each parameter by increasing observed runoff, as illustrated for total nitrogen in Figure 5-5. An identical pattern emerged for all three NPS parameters. For runoff volumes less than about 4.5 cm, the event mean concentrations (EMCs) calculated from modeled data showed extremely high variability with a range from 3 to 11 times greater than that of the observed data. For runoff greater than 4.5 cm, however, the EMCs from modeled and observed data were comparable with a mere fraction of the variability exhibited at lower runoff volumes. The reasons for the high variability were not initially apparent.

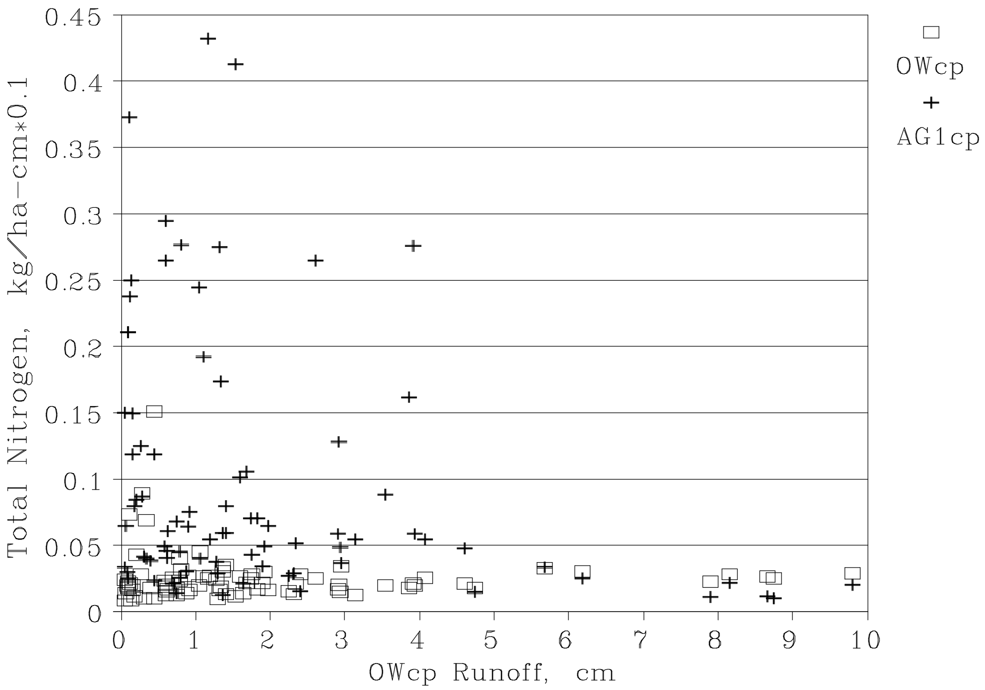

Figure 5-5. Composite Period Observed vs. Modeled TN EMCs

When model-based EMCs for total nitrogen were plotted against modeled runoff in Figure 5-6, the same shape curve was observed as for the observation-based EMCs in Figure 5-4. Only when the model-based EMCs were plotted against observed runoff did the pattern in Figure 5-5 appear. One explanation for the pattern can be found in the plot of modeled vs. observed runoff in Figure 4-1. The modeled runoff varied greatly from observed runoff, and the index was influenced more by runoff than any of the NPS parameters. The higher concentrations were due to underestimates of monthly runoff. The lower the runoff values, the more sensitive concentration became to a unit change in runoff. Modeled runoff poorly simulated monitored runoff, as we discovered in Figure 4-20, because many of the modeled rainfall events did not correspond with the events producing the observed runoff and loads. One possible explanation is as follows: with lower intensity storms, storms were not uniform across the watershed and may have varied considerably from the rain gauge to the watershed; whereas with higher intensity storms, less variability occurred both across the watershed and between the rain gauge and the watershed. If this were the case, this variability at lower intensity storms (lower storm runoff) would take the data points on the left side of Figure 5-6 and spread them over a wider range of runoff, giving the pattern observed in Figure 5-5. The data in Figure 5-5 supports the position, that for higher runoff volumes, the model is doing a very good job of matching observed concentrations. This close correspondence of concentrations occurs, in spite of the fact that loads and runoff for these events were all underpredicted (see Appendix B).

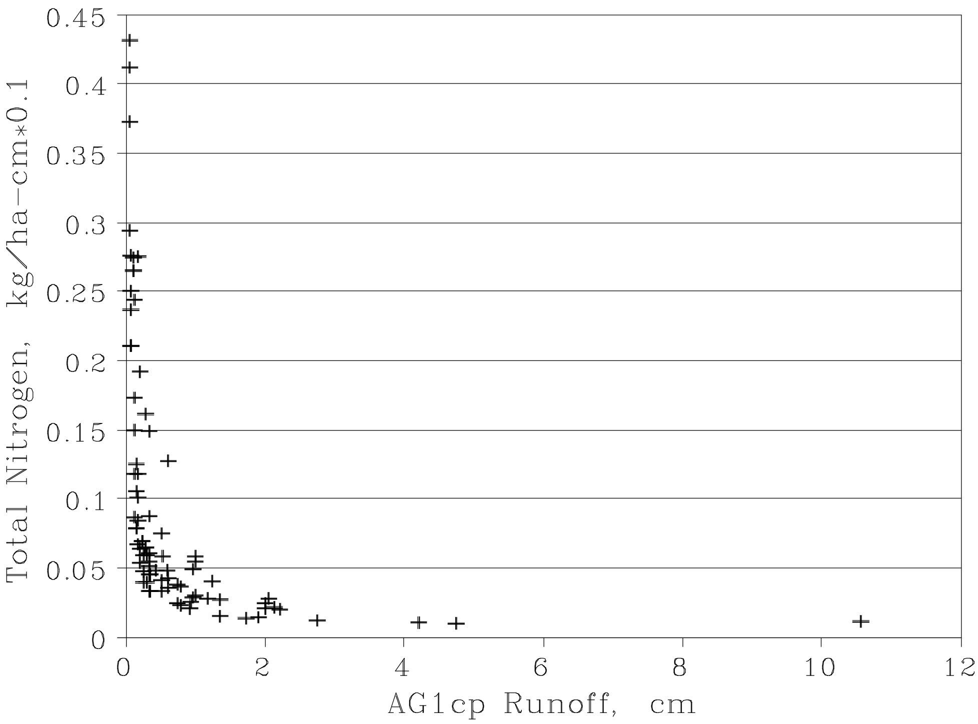

Figure 5-6. Composite Period Modeled TN EMCs

An additional issue was raised by the above discussion. The NPSP index was intended to flag NPS events of concern to a watershed. Both high concentrations at low runoff and large loading events are important to the health of a watershed from a NPS point of view. If the EMCs consistently conform to the asymptotic shape as in Figure 5-6, the NPSP index will always be lower for large runoff events, and will consistently give lower index scores to larger NPS loading events, as in Figure 5-7. Anticipated larger mean monthly concentrations associated with larger runoff events never were observed in modeled output. Therefore, the index did not perform as intended. It flagged high loads from low runoff, but never flagged larger loading events, as their concentrations were shown to be consistently lower. The index, therefore, was revised so that both high loads from low runoff <u>and</u> large loading events would produce larger index values.

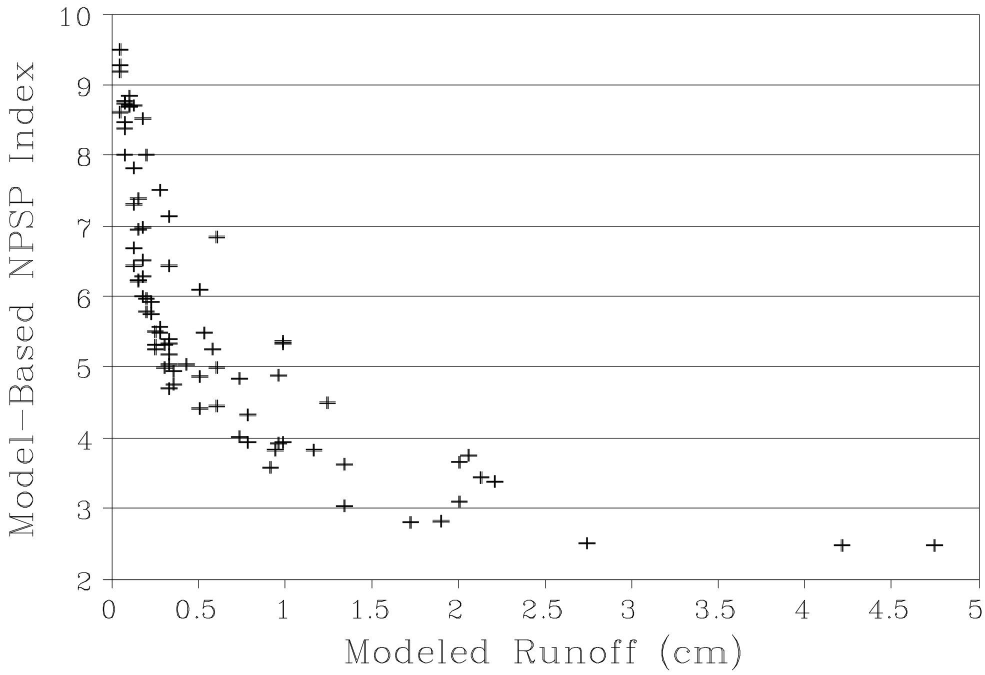

Figure 5-7. AG2mn-Based NPSP Index Distribution

5.4 The Revised Index

Analysis of calculated NPSP indexes for both monitored and modeled data in this study produced high index values for months with high concentrations, as intended. The months with high concentrations, however, always corresponded to months with low runoff. Although some dilution was expected with increasing runoff, rising concentrations were anticipated with extremely large runoff events, which was not observed in either the monitored or modeled data in this study. As was seen in Figures 5-5 and 5-6, large loading events consistently corresponded with large runoff events. Since both high mean concentrations and large loading events are important considerations in evaluating NPS pollution, the NPSP index was revised as follows to take both of these critical NPS conditions into account.

- Dual rating curves were used for rating each parameter: one based on concentration, and one based on load.
- The sub-index was calculated for each parameter based both on concentration and on load.
- The maximum of the two sub-index values was used for each parameter for incorporation into the overall index.

This revised index resulted in higher index scores for both large loading events, and for those which produce elevated concentrations at lower flow.

The following breakpoints in Table 5-2 were assigned for load rating curves based on approximate monthly mean and maximum values of each parameter within the monthly data for Bull Run.

Table 5-2. Rating Curve Breakpoints for Loads

	---- ---- Loads (kg/ha) ---- ----		
SI	**TN**	**TP**	**SS**
1	0	0	0
5	1.0	0.15	100
9	4.0	0.60	400

The load rating curves were created as segmented linear curves as illustrated in Figure 5-8. The results of re-calculating the index are shown in Figure 5-9 for the AG2mn data. This figure shows the index calculated based solely on load, solely on concentration, and then based on the maximum of the two. The maximum form of the NPSP index produced higher index values both for high mean concentrations and for large loads as intended. It will be important with this revised index formulation to obtain a balance between the two sets of rating curves for local conditions, so that both of the important NPS scenarios are taken into account.

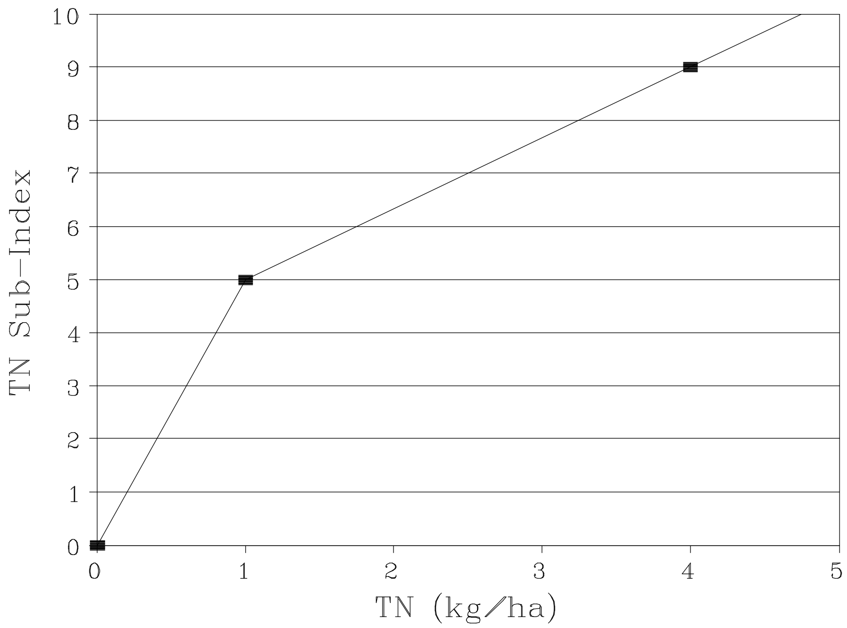

Figure 5-8. Linear Segmented TN Rating Curve

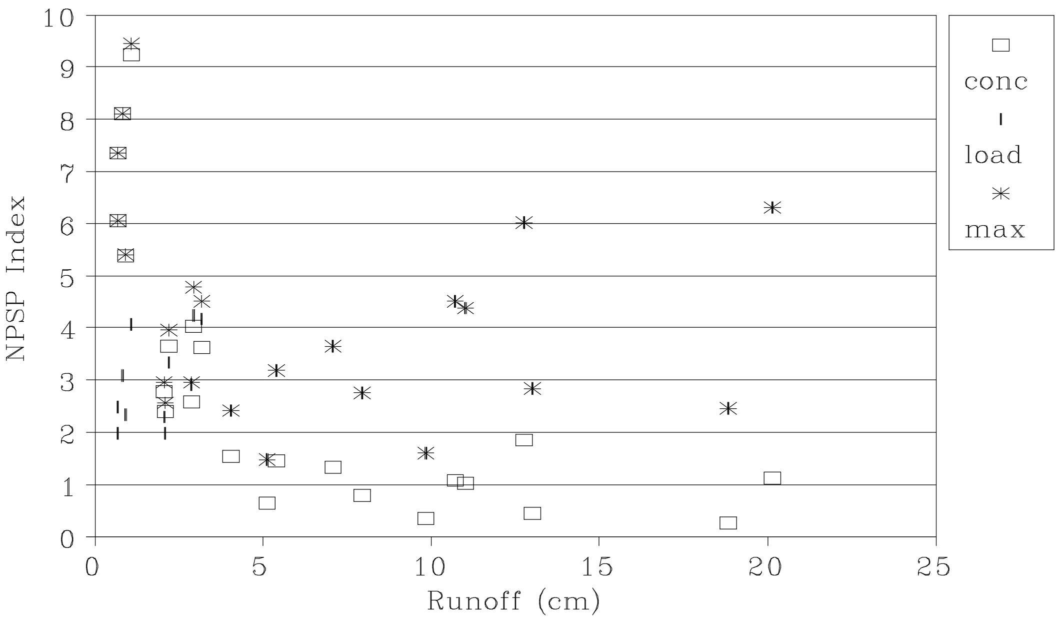

Figure 5-9. Revised NPSP Index Based on AG2mn Data