P8 Enhancements & Calibration to Wisconsin Sites

prepared for

Wisconsin Department of Natural Resources

by

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Introduction

This project initiates development of P8 Version 2.0. Enhancements to P8 developed under this contract include:

- Conversion Utility for EarthInfo, NOAA, & P8 version 1.1 Precipitation Files
- Snowfall/Snowmelt Routine

The file conversion utility (P8CONV.EXE) is documented in separate report. Appendix A describes the snowfall/snowmelt routine (derived from the GWLF model) and other model enhancements developed independently. Appendix A lists model Help screens describing new model features; these screens can be accessed from the P8 'Help' procedure.

Version 2.0 of the model will be finalized after inclusion of a new street-sweeping routine being developed under contract with the Minnesota Pollution Control Agency.

A diskette containing the revised model in draft form has been provided. This draft is for review by WDNR only and should not be distributed outside of the Agency.

P8 was originally developed as a tool for sizing urban BMP's and calibrated to generalized data collected under the USEPA's Nationwide Urban Runoff Program (NURP). This report describes initial attempts at calibrating the model to data from specific sites. This exercise has provided useful insights into model capabilities and limitations, along with particle files which may be more representative of Wisconsin conditions than the original NURP calibrations

The calibration process has required a substantial unanticipated investment in data manipulation. The resulting analytical framework could provide an excellent basis for future refinements of both calibrations if a more realistic scope & budget could be developed. Addition of calibration routines (mimicking of those demonstrated below) to the P8 model would greatly facilitate calibration of the model to other sites and/or data sets.

Snowmelt Routine

The snowfall/snowmelt routine is derived largely from GWLF (Generalized Watershed Loading Functions, Haith et al, 1992). Snowmelt is sumulated using the SCS degree-day method. Snowfall, snowpack, and snowmelt are simulated at a hourly time step and assumed to apply uniformly to each watershed. Effects of diel variations in air temperature are not considered. The sum of rainfall & snowmelt drives runoff calculations.

The simulation is controlled by the following input coefficients:

- Air Temperature Offset. modifies input temperatures to account for differences in elevation. (default = 0 deg-F)

- SnowFall Temperature. precipitation is assumed to be snow if the daily mean air temperature is below this value (default = 32 deg F).

- SnowMelt Temperature. snowpack starts melting when air temperature exceeds this value (default = 32 deg-F).

- SnowMelt Coefficient. determines rate of snowmelt at a given air temperature (default = .06 inches/deg-F-day).

- Scale Factor for Maximum Abstraction. multiplied by maximum abstraction computed from SCS curve number during snowmelt periods (range 0-1). low values of this parameter will increase runoff response of pervious areas during snowmelt periods. (default = 1).

The above default parameter values have been used in calibration runs described below. The SnowMelt coefficient is the primary calibration factor. Figure 1 shows simulations of the Monroe Street watershed during snowmelt periods for three values of the melt coefficient (.03, .06, .10 inches). Decreasing the coefficient will defer snowmelt & increase event size.

A continuous daily flow record would be strongly preferred over sporadic and incomplete event monitoring as a basis for calibrating and testing the snowmelt simulation. A continuous record would provide a basis for model testing against total seasonal flows. Because snowmelt events are less distinct than rainfall events, pairing observed and predicted events is difficult.

Calibration Procedures & Results

The remainder of this report describes calibration of particle files to two Wisconsin sites:

- Monroe Street (Madison)
- Lincoln Creek (Milwaukee).

Site characteristics are summarized in Table 1.

Project scope is limited to calibration of solids loading rates and particle contents to match observed flow-weighted-mean concentrations for suspended solids, total phosphorus, and trace metals. Calibration to individual events or peak concentrations requires a more intensive effort. Given the large number of degrees of freedom in the P8 particle/component matrix, a conservative approach to calibration is warranted. Consistency with assumptions inherent in the original particle files (NURP50%, NURP90%) has been preserved where possible. The following assumptions are unchanged in the calibration:

- 5 particle classes (1 dissolved, 4 particulate)

- 4 particulate classes (P10%, P30%, P50%, P80%) represent 20%, 20%, 20%, and 40% of total suspended solids, respectively. (P10% represents particles with a settling velocity at the 10^{th} percentile of the generalized settling velocity distribution derived from NURP data)

- Particle settling velocities are unchanged from original calibration. Particle size distribution data were provided for other Wisconsin sites, but not for the calibration sites.

- With the exception of setting velocity, parameter estimates for the P10%, P30%, and P50% particle classes are identical.

- Particulate phosphorus, copper and zinc are evenly distributed across P10%, P30%, & P50% classes. Particulate lead is evenly distributed across all classes.

The following coefficients have been calibrated to each site:

- <u>Runoff coefficient for Impervious Areas</u>. provides volume calibration; values = 0.54 Monroe St. & 0.76 for Lincoln Creek;

- <u>Washoff Coefficient for Particles on Impervious Surfaces;.</u> rates proportional to runoff intensity (washoff exponent = 2); The original calibration (20 in^{-1}/(in/hr)) was based upon the assumption that a 1 inch, 8-hour storm would remove 92% of the accumulated particle load. Based upon review of residuals plots (ln (Observed/Predicted) values vs. event volume & intensity, Appendices B & C), a value of 10 in^{-1}/(in/hr) provides a better fit of Wisconsin data and has been used in both calibrations.

- <u>Impervious Particle Loadings</u>. Adjusted to match observed, flow-weighted-mean TSS concentration for events with total rainfall + snowmelt less than 1 inch. Larger events are excluded from calibration to focus on impervious area responses (see below)

- Dissolved Concentrations. Assigned to P0% particle class; based upon measured flow-weighted-mean concentrations at Monroe St. Since dissolved species were not measured at Lincoln Creek, dissolved percentages are assumed to equal those measured at Monroe Street.

- Particle Concentrations. Adjusted so that observed and predicted flow-weighted-mean concentrations for each water quality component are equal for the calibration events.

Observed concentrations for TKN and hydrocarbons were not included in the calibration data sets. Particle contents for these parameters are derived from the NURP50% file. Cadmium has been added to the calibrated files.

The calibrations focus on the responses of impervious areas is each watershed. This is achieved by restricting the calibration data set to events with total rainfall+snowmelt less than 1 inch. The pervious portion of each watershed is characterized by a single runoff curve number. A more detailed description (minimally representing the distributions of curve numbers in different subwatersheds) would provide a better basis for simulating pervious area responses. Because of non-linear response characteristics, two pervious watersheds with the same average curve number (say, 65) but with different CN ranges (say, 60-70 vs. 55-75 could have very different hydrologic responses. Given this limitation, it would be difficult to obtain a reliable calibration of the pervious particle characteristics.

In the original P8 particle files, particle concentrations in pervious runoff were adjusted so that the long-term-average flow-weighted-mean concentrations in pervious and impervious runoff were approximately equal (for a simulation of Providence rainfall & curve number of 74). For consistency, the same approach has been taken here. Pervious runoff concentrations have been increased by a factor of 4 to approximately match predicted impervious runoff concentrations over all events at each site. The pervious particle concentrations should not be considered calibrated, however.

Generally, calibration to small storms results in under-prediction of suspended solids concentrations in large storms (see residuals plots in Appendices B & C). This most likely reflects erosion from pervious areas. The effect is less pronounced for phosphorus and metals.

Although calibrations are based upon <1 inch storms, comparisons between observed & predicted concentrations are made based upon the following statistics:

- Flow-Weighted-Means, Calibration Events (< 1 inch rainfall+snowmelt)
- Flow-Weighted-Means, All Events
- Flow-Weighted-Means, SnowMelt Events (Monroe) or Jan-April Events (Lincoln)
- Median, Event-Mean Concentrations, All Events
- 90^{th} Percentile Event-Mean Concentrations, All Events

The following data-reduction and calibration procedures have been followed for each site:

1. Compile observed data set (dates, volume, and loads for each event).

2. Delete records which, based upon the preciptation record, are not likely to represent complete events or where the difference between the reported event rainfall differs from that derived from the hourly precipitation file by more than 0.5 inches.

3. Combine records on adjacent dates when separation of events is not distinct.

4. Calculate flow-weighted-mean concentrations for each water quality component and event.

5. Examine scatter plots of phosphorus & trace metal concentrations vs. total suspended solids; delete suspected outliers (1 Monroe event with TSS = 1821 ppm, Cu = .005 ppm, Pb = .005 ppm)

6. Set up P8 input file with watershed characteristics summarized in Table 1. Rout the watershed to a 'Pipe' device with a time of concentration of 0 hrs.

7. Compile precipitation & air temperature data for monitoring period.

8. Run the model with the NURP50% particle file and export the results summarized by event to an ASCII file using the (new) 'List File Concentrations' procedure (see Appendix A).

9. Import the P8 Output file to a spreadsheet containing observed data.

10. Pair up each observed event with a predicted event based upon starting date.

11. Once the pairing of observed & predicted events has been established, repeated model calibration runs can be made and new results imported to the spreadsheet for statistical analysis & display.

12. Identify calibration events as those with total rainfall + snowmelt < 1 inch.

13. Calibrate the event volume prediction by adjusting the impervious runoff coefficient so that the observed and predicted mean (& total) runoff volumes are equal for the calibration events.

14. Calibrate the total suspended solids prediction by rescaling the impervious area particle loadings (P10%-P80%).

15. Calibrate the dissolved fractions of the remaining water quality components by setting the 'Particle Content' value for the dissolved fraction (P0%) equal to the observed flow-weighted-mean dissolved concentration (ppm) x 10^6.

16. For each water quality component, calibrate the particulate fractions by rescaling the particle contents (P10%-P80%) so that observed & predicted event-mean total component concentrations are equal.

17. Examine scatter plots of observed, predicted values, and residuals (ln (observed/predicted) vs. event characteristics.

Calibration results & diagnostic plots are provided in Appendices B & C. The first two pages in each appendix compare observed & predicted values for model runs using the NURP50%, NURP90%, and calibrated particle files.

The following summaries and diagnostic plots are shown for each site:

- Summary of Calibration Results
- Bar Charts of Observed & Predicted Concentrations
- Listing of Observed Data
- Plot of Observed & Predicted Runoff
- Plot of Runoff Error vs. Precipitation Error
- Runoff Residuals (ln [Observed / predicted]) vs. Event Characteristics
- Observed & Predicted Time Series, All Events
- Observed & Predicted Time Series, Paired Events
- Observed vs. Predicted Values, All Events
- Concentration Residuals vs. Date
- Load Residuals vs. Date
- Concentration Residuals vs. Julian Day
- Concentration Residuals vs. Rainfall+Snowmelt Intensity
- Concentration Residuals vs. Predicted Runoff
- Concentration Residuals vs. Event Rainfall+Snowmelt
- Load Residuals vs. Antecedent Dry Period

The following calibrated files are provided with the revised model:

- MONROE.CAS - Case File for Monroe St
- MONROE.PAR - Particle File for Monroe St
- LINCOLN.CAS - Case File for Lincoln Creek
- LINCOLN.PAR - Particle File for Lincoln Creek

Discussion

Plots of residual concentrations against Julian date suggest that the model under-predicts observed concentrations of trace metals in the first ~3 months of the year at each site. The pattern is more pronounced at Monroe Street than at Lincoln Creek. The monitoring data indicate that dissolved concentrations and particle contents (mg/kg) tend to be higher in these months than during the remainder of the year. It is possible that this pattern reflects a seasonal loading phenomenon, such as corrosion of automobiles induced by road salt or other process related to snowfall/snowmelt. The model is not currently structured to provide seasonally varying loads or particle characteristics. A separate particle file could be calibrated to represent these periods, if they are of special interest. Otherwise, the model could be recoded to permit seasonally varying loading rates with an expanded particle matrix (e.g., 'winter' particles).

Data from 1993 & 1994 have been used in calibrating the Monroe Street site. Limited data from March-July 1992 were also provided, but have not been used in calibration. Diagnostic plots in Appendix B reflect all data. Observed concentrations of TSS and other water-quality components in 1992 are significantly higher than predicted. Residual variance is also significantly higher in 1992. A portion of the apparent bias in 1992 may be related to seasonal effects discussed above, since a high proportion of the 1992 events were in winter months.

The primary limitation of the Lincoln Creek simulation is substantial under-prediction of runoff volume for the largest event (4/19/93, Observed Rainfall = 827 ac-ft, Observed Runoff = 456 ac-ft). Adjustment of snowfall/snowmelt parameters within reasonable bounds does not provide a satisfactory simulation of this event Given the relatively large size of the watershed, it is possible that the deviation is related to base flow contributions which are not represented in the simulation.

Generally, model calibrations to flow-weighted-mean concentrations provide reasonable predictions of median and 90th percentile event-mean concentrations. Intensity-dependent washoff from impervious surfaces (exponent = 2) is important for simulation distribution of event-mean concentrations. The governing equation is:

$$\text{Washoff Rate (1/inch)} = \text{Constant} \times (\text{Runoff Rate, in/yr})^{\text{Exponent}}$$

Figure 2 compares the observed frequency distribution of event-mean zinc at Monroe Stree with predicted distributions assuming washoff exponents of 1 and 2. Variance is substantially under-predicted when the model is re-calibrated with an exponent of 1 (constant washoff rate).

Copper concentrations at both sites were substantially over-predicted using the NURP50% & NURP90% particle files. For other parameters, measured concentrations are within or close to the range predicted by the uncalibrated files. Suspended solids concentrations at Monroe Street are at the upper end of the range, particularly when all events are considered.

Table 1 - Characteristics of Wisconsin Sites

Watershed	Monroe St	Lincoln Creek
Location	Madison	Milwaukee
Land Use	Residential	Urban
Drainage Area (acres)	233.3	6399
Impervious Fraction	0.34	.41
Pervious Curve Number	62	65
Calibration Period	1993-1994	1993-1994
Runoff Events Total Calibration (<1 inch)	 45 28	 44 34
P8 Case File	MONROE.CAS	LINCOLN.CAS
P8 Particle File	MONROE.PAR	LINCOLN.PAR
Air Temp File	MADISON.TMP	MILWAUK.TMP
Precipitation File	MONR9294.PCP	LINC9395.PCP

Appendix B

Calibration Results for Monroe Street Site

Appendix C

Calibration Results for Lincoln Creek, Milwaukee