Adjustment of Regional Regression Models of Urban-Runoff Quality Using Data for Chattanooga, Knoxville, and Nashville, Tennessee

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95-4140

Prepared in cooperation with the

City of Chattanooga, Tennessee,
the City of Knoxville, Tennessee, and the
Metropolitan Government of Nashville and Davidson County

Adjustment of Regional Regression Models of Urban-Runoff Quality Using Data for Chattanooga, Knoxville, and Nashville, Tennessee

By ANNE B. HOOS and ANANT R. PATEL

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95–4140

Prepared in cooperation with the

City of Chattanooga, Tennessee,
the City of Knoxville, Tennessee, and the
Metropolitan Government of Nashville and Davidson County

Nashville, Tennessee
1996

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For addtional information write to:

District Chief
U.S. Geological Survey
810 Broadway, Suite 500
Nashville, TN 37203

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Report Section
Box 25286, Mail Stop 417
Denver Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot (ft^3)	28.317	liter
cubic foot (ft^3)	28,317	cubic centimeter
pound (lb)	0.4536	kilogram

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8 \times (°C + 32)$$

ABBREVIATIONS

ADD	Number of antecedent dry days
BCF	Bias correction factor
CD	Total-recoverable cadmium
COD	Chemical oxygen demand
Cp	Mallow's coefficient
CU	Total-recoverable copper
DA	Total contributing drainage area
DP	Dissolved phosphorus
DS	Dissolved solids
IA	Impervious area, as a percent of total contributing drainage area
INT	Maximum 24-hour precipitation intensity that has a 2-year recurrence interval
LUC	Commercial land use, as a percent of total contributing drainage area
LUI	Industrial land use, as a percent of total contributing drainage area
LUN	Nonurban land use, as a percent of total contributing drainage area
LUR	Residential land use, as a percent of total contributing drainage area
MAP	Model-adjustment procedures
MAP-1F-P	Single-factor regression against regional prediction
MAP-R-P	Model-adjustment procedures based on regression against prediction value alone
MAP-R-P+nV	Regression against regional prediction and additional local variables
MAP-W	Weighted combination of regional prediction and local-regression prediction
MAR	Mean annual rainfall
MJT	Mean minimum January temperature
MNL	Mean annual nitrogen load in precipitation
NURP	Nationwide Urban Runoff Program
O	Observed values of storm-runoff load or mean concentrations
P_{ai}	Adjusted-model predicted value of response variable for unmonitored site and storm i
P_u	Predicted values of storm-runoff load or mean concentration from the unadjusted regional model
P_{ui}	Predicted value of response variable from the unadjusted regional model for unmonitored site and storm i
PB	Total-recoverable lead
r	Correlation coefficient
r_S	Spearman's rho
RMSE	Root mean square error
SE	Standard error of estimate
SEP	Standard error of prediction
SS	Suspended solids
TKN	Total ammonia plus nitrogen as nitrogen
TN	Total nitrogen
TP	Total phosphorus
TRN	Total storm rainfall
ZN	Total-recoverable zinc

Adjustment of Regional Regression Models of Urban-Runoff Quality Using Data for Chattanooga, Knoxville, and Nashville, Tennessee

By Anne B. Hoos *and* Anant R. Patel

ABSTRACT

Model-adjustment procedures (MAP's) were applied to the combined data bases of storm-runoff quality for Chattanooga, Knoxville, and Nashville, Tennessee, to improve predictive accuracy of storm-runoff quality from urban watersheds in these three cities and throughout Middle and East Tennessee. Data for 45 storms at 15 different sites (5 sites in each city) constitute the data base.

Comparison of observed values (O) of storm-runoff load and event-mean concentration to the predicted values from the regional regression models (P_u) for 10 constituents shows prediction errors ranging from 59 to 806,063 percent. MAP's, which combine the regional model predictions with local data, are applied to improve predictive accuracy.

For 8 of the 10 load models, the variation in P_u explains much of the variation in O, and the direction of bias of P_u relative to O is consistent and positive; that is, P_u consistently overestimates O. The MAP based on regression against P_u alone, MAP-R-P, is therefore favored for most of the load models.

For 7 of the 10 concentration models, however, the variation in P_u does not sufficiently explain the variation in O, and furthermore, correlation between O and each of the additional explanatory variables is not significant. None of the MAP's is, therefore, appropriate for the concentration models for these constituents. For three of the seven constituents, the prediction error is small enough that the analyst may use the regression model without adjustment. For the other four, a simple estimator such as the mean of the observed concentration values may be used, or additional data could be collected to calibrate a local model.

Standard error of estimate for the selected MAP's ranges from 0.263 log units (67 percent) to 0.677 log units (322 percent). Calibration results may be biased due to sampling error in the Tennessee data base. The relatively large values of standard error of estimate for some of the constituent models, although representing significant reduction (by at least 50 percent) in prediction error compared to estimation with P_u, may be unacceptable for some applications. The user may wish to collect additional local data for these constituents and repeat the MAP analysis, or calibrate an independent local regression model.

INTRODUCTION

Urbanized areas are a major source of nonpoint-source pollution. The design of effective remedial programs requires information on pollutant loads from individual watersheds. The 1987 amendments to the Clean Water Act require cities with populations of more than 100,000:

- to characterize storm-runoff quality and quantity from representative storm-sewer outfalls during several storms; and
- to estimate annual and seasonal pollutant loading from each major storm-sewer outfall in the city

(U.S. Environmental Protection Agency, 1990, p. 47990-48091).

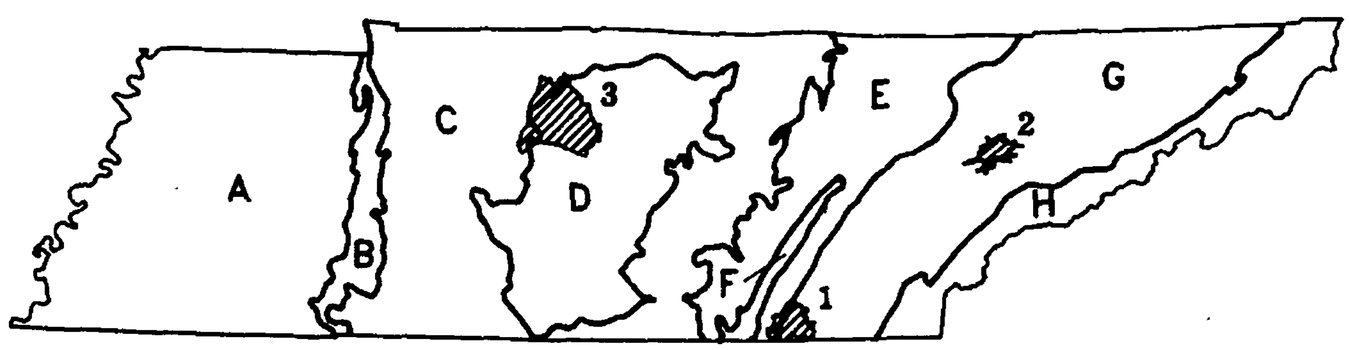
In 1989, the U.S. Geological Survey, in cooperation with the city governments of Chattanooga, Knoxville, and Nashville, Tennessee, began a study to characterize the water quality of storm runoff and to evaluate procedures for estimating storm-runoff loads and concentrations for selected constituents. To meet the first objective, rainfall, streamflow, and water-quality data were collected during the period January 1990 through May 1993 at five sites in each of the three cities (Outlaw and others, 1994; and U.S. Geological Survey unpublished data). To meet the second objective, procedures were developed (Hoos and Sisolak, 1993) to optimize predictive accuracy for storm-runoff quality by combining local data with regional regression models developed by Driver and Tasker (1990).

Purpose and Scope

This report presents the results of applying model-adjustment procedures (MAP's) to the combined data bases of storm-runoff quality from Chattanooga, Knoxville, and Nashville, Tennessee. Calibration coefficients are presented for 13 models: 10 load models and 3 concentration models. Simple estimators are presented for five constituent models for which the MAP approach could not be used. Also included are calibration error statistics, which can be used to compute the standard error of the adjusted prediction. An example illustrates the use of an adjusted model to estimate the load of total kjeldahl nitrogen in storm runoff from an unmonitored watershed.

Description of Study Area

Chattanooga and Knoxville lie within the Valley and Ridge physiographic province of Tennessee; Nashville lies partly within the Central Basin and partly within the Highland Rim physiographic provinces (fig. 1). The three cities share similarities in geology and climate. All three cities are underlain by limestone or alternating bands of limestone and shale, with predominantly gently to moderately sloping topography. Most soils are moderate- to fine-textured and are generally less than 20 feet thick. The smaller streams have well-defined channels cut into bedrock, except where they flow through the alluvial plain of large receiving water bodies. Modifications to small



EXPLANATION

STUDY AREA LOCATION – Number refers to metropolitan area listed below:

1 Chattanooga, Tennessee
2 Knoxville, Tennessee
3 Nashville, Tennessee

PHYSIOGRAPHIC DIVISIONS

A COASTAL PLAIN
B WESTERN VALLEY
C HIGHLAND RIM
D CENTRAL BASIN
E CUMBERLAND PLATEAU
F SEQUATCHIE VALLEY
G VALLEY AND RIDGE
H BLUE RIDGE

Figure 1. Locations of urban-runoff study areas and physiographic divisions in Tennessee.

stream channels to improve drainage are generally minimal.

Mean annual precipitation does not vary appreciably among the three cities, ranging from 47 to 53 inches (National Oceanic and Atmospheric Administration, 1980). Winter storms are of longer duration and greater total precipitation, but are less intense than summer storms. The coldest weather usually occurs during January; the mean minimum January temperature for the three cities ranges from 26 to 29° Fahrenheit (National Oceanic and Atmospheric Administration, 1980).

Acknowledgments

The authors gratefully acknowledge Tom Scott, City of Chattanooga, Ted Schuler, City of Knoxville, and Tom Palko and Gill Prichard, Metropolitan Government of Nashville, for providing data on basin characteristics, and for their support throughout this project. Tom Lopes, U.S. Geological Survey, made many revisions and improvements to the statistical-analysis software.

URBAN-RUNOFF DATA BASE FOR CHATTANOOGA, KNOXVILLE, AND NASHVILLE, TENNESSEE

The urban-runoff quality data base used for this report combines data from monitoring networks in Chattanooga, Knoxville, and Nashville, and is referred to as the Tennessee data base. Data for 45 storms at 15 different sites (5 sites in each city) make up the data base. Values of storm-runoff mean concentration for each storm were obtained from Outlaw and others (1994; and U.S. Geological Survey unpublished data) for chemical oxygen demand (COD), suspended solids (SS), dissolved solids (DS), total nitrogen (TN), total ammonia plus organic nitrogen as nitrogen (TKN), total phosphorus (TP), dissolved phosphorus (DP), total-recoverable cadmium (CD), total-recoverable copper (CU), total-recoverable lead (PB), and total-recoverable zinc (ZN). Values of storm-runoff load were calculated as the product of storm-runoff mean concentration and storm-runoff volume, and also were provided by Outlaw and others (1994, table 2).

For some of the storms represented in the data base, samples were collected only during the first 3 hours of the hydrograph; values for storm rainfall and storm-runoff volume were corrected to account for this. Storm rainfall (TRN) was calculated by summing rainfall amounts before and during sampling only; any rainfall after sampling was not included. Storm-runoff volume was calculated by summing volume during sampling. Finally, storms were not included in the analysis of storm-runoff loads if (1) a significant part of the runoff volume occurred after sampling stopped and (2) the after-sampling runoff could not be clearly defined as a separate runoff event, caused by rainfall after sampling.

Basin characteristics in the data base include the following physical and land-use characteristics:

1. Total contributing drainage area (DA), in square miles.
2. Impervious area (IA), as a percent of total contributing drainage area.
3. Industrial land use (LUI), as a percent of total contributing drainage area.
4. Commercial land use (LUC), as a percent of total contributing drainage area.
5. Residential land use (LUR), as a percent of total contributing drainage area.
6. Nonurban land use (LUN), as a percent of total contributing drainage area.

Storm characteristics in the data base include:

1. Total storm rainfall (TRN), in inches.
2. Number of antecedent dry days (ADD), in days.

Climatic characteristics in the data base include:

1. Maximum 24-hour precipitation intensity that has a 2-year recurrence interval (INT), in inches.
2. Mean annual rainfall (MAR), in inches.
3. Mean annual nitrogen load in precipitation (MNL), in pounds of nitrogen per acre.
4. Mean minimum January temperature (MJT), in degrees Fahrenheit.

Values for basin characteristics were provided by the staffs of the Public Works Department of the three cities. Values for TRN were obtained from Outlaw and others (1994; and U.S. Geological Survey unpublished data). Values for ADD were determined from the daily rainfall record for each monitoring basin; days for which rainfall amounts were smaller than 0.05 inch were considered dry days. Values for MAR and MJT were obtained from the National Oceanic and Atmospheric Administration (1980), for INT from Hershfield (1961), and for MNL from the National Atmospheric Deposition Program/National Trends Network Coordination Office (1990).

Predicted values of storm-runoff load and event-mean concentration for each of the monitored storms were computed from the basin, storm, and climatic characteristics and from the single-storm regression models for region III (Driver and Tasker, 1990, tables 1 and 5). Predicted values for the constituent DS, for which Driver and Tasker did not develop a region III model, were computed from region II models.

MAP's can be expected to provide more accurate estimates (as compared to the regional models) of urban-runoff quality at a wide range of unmonitored sites only if the local data base used for the adjustment represents a wide range of physical, land-use, and storm characteristics. The minimum, maximum, and median values of these characteristics in the Tennessee data base are presented in table 1. For TRN, the range and median are determined from all 45 observations in the data base; these values may be slightly different for data sets from which certain storms were excluded.

Table 1. Ranges of values of each explanatory variable in the data base for Chattanooga, Knoxville, and Nashville, Tennessee

[TRN, total storm rainfall; DA, total contributing drainage area; IA, impervious area; LUI, industrial land use; LUC, commercial land use; LUR, residential land use; LUN, nonurban land use; INT, maximum 24-hour precipitation intensity that has a 2-year recurrence interval; MAR, mean annual rainfall; MNL, mean annual nitrogen load in precipitation; MJT, mean minimum January temperature; ADD, antecedent dry days]

	Minimum	Maximum	Median
TRN, inches	0.08	1.28	0.36
DA, square miles	.01	7.31	.52
IA, percent	9.6	94	53
LUI, percent	0	96	16
LUC, percent	0	91	6
LUR, percent	0	100	20
LUN, percent	0	57	10
INT, inches	3.2	3.8	3.5
MAR, inches	47.1	53.0	47.3
MNL, pounds of nitrogen per acre.	14	18	15
MJT, degrees Fahrenheit	26	29	27
ADD	0	32	4

For the characteristics IA, LUC, LUN, MAR, and MJT, the range and median values in the Tennessee data base were similar to those in the Nationwide Urban Runoff Program (NURP) region III data base (compare to Driver and Tasker, 1990, table 4). Maximum and median values for TRN and LUR, however, were smaller in the Tennessee data base than in the NURP region III data base. Maximum and median values for DA, LUI, INT, and MNL were larger in the Tennessee data base than in the NURP region III data base.

ADJUSTMENT OF REGIONAL REGRESSION MODELS

Comparison of observed values (*O*) of storm-runoff load and event-mean concentration in the Tennessee data base to the predicted values from the regional regression models (P_u) shows large prediction errors for almost all constituent models. Comparison could not be made for CD, for which most observed values were below the minimum reporting level. Values of root mean square error (*RMSE*) range from 0.239 log units (59 percent) for TN event-mean concentration, to 1.842 log units (806,063 percent) for PB load (table 2, column 1). For each constituent model, *RMSE* is compared to calibration error for the unadjusted regional model (standard error of the estimate reported by Driver and Tasker, 1980, tables 2 and 6) to evaluate whether the regional regression can be used for sites represented by the Tennessee data base. For only three models, COD, DS, and TN event-mean concentration, *RMSE* is smaller than, or almost equal to, the corresponding standard error of the estimate, indicating that these three models may be used without adjustment.

Large values of *RMSE* are due to error in the regional models or to sampling error in the Tennessee data base. Sampling error occurs when the sites and storms in the data base do not represent typical storm-runoff conditions in the three cities. Average storm size in the data base (median TRN is 0.36 inch) is smaller than the average storm size in the three cities (between 0.60 and 0.80 inch, according to Steurer and Nold, 1986). In addition, many monitoring sites in the data base are in watersheds that may be too large (median DA is 0.52 mi^2) for these sites to be considered as storm-runoff discharge points, because discharge during storms at these sites may contain a substantial volume of base flow along with storm runoff.

For most constituents, however, *RMSE* is too large to be reasonably explained by sampling error alone; some of the error must be due to error in the regional models. Model error is probably not caused by temporal trend in runoff quality in the elapsed time between data collection for NURP (1979-83) and data collection for the Tennessee data base (1990-93), because the *RMSE*'s for the Knoxville NURP data base

Table 2. Exploratory data analysis of the Tennessee data base

[*RMSE*, root mean square error between observed and predicted (from unadjusted regional model) values of the response variable, in log units; Acceptably small? is evaluated by comparing *RMSE* with standard error of the estimate for the unadjusted regional model (published in Driver and Tasker, 1990, tables 2 and 6); r_s, Spearman's rho; 0.005 is the selected level of significance for the test statistic; *O*, observed value of the response variable; P_u, predicted value from the unadjusted regional model; TRN, total storm rainfall; DA, total contributing drainage area; IA, impervious area; LUI, industrial land use; ADD, antecedent dry days; COD, chemical oxygen demand; SS, suspended solids; DS, dissolved solids; TN, total nitrogen; TKN, total ammonia plus organic nitrogen as nitrogen; TP, total phosphorus; DP, dissolved phosphorus; CU, total-recoverable copper; PB, total-recoverable lead; ZN, total-recoverable zinc; LOAD, storm-runoff load; CONC, storm-runoff mean concentration; P, positive (model overestimates *O*); model-adjustment procedures (MAP's) explained in Hoos and Sisolak (1993)]

Constituent and model type	Prediction error: *RMSE*, log	Prediction error: *RMSE*, percent	Prediction error: Acceptably small?	*O* and P_U positively correlated: r_S	*O* and P_U positively correlated: Significant at 0.005?	Consistent direction of bias: p-value	Consistent direction of bias: Significant at 0.005?	Direction of bias	Correlation of variable with O: TRN	DA	IA	LUI	ADD	*O* significantly correlated with any variable?	Best MAP
COD.LOAD	0.639	277	N	0.766	Y	0.0001	Y	P	0.408	0.727	-0.310	0.542	0.127	Y	R-P
SS.LOAD	1.106	2,558	N	.878	Y	0	Y	P	.607	.669	-.460	.414	.011	Y	R-P
DS.LOAD	.655	295	N	.860	Y	.0001	Y	P	.509	.822	-.500	.461	.097	Y	R-P
TN.LOAD	.930	985	N	.735	Y	0	Y	P	.463	.810	-.410	.508	.157	Y	R-P
TKN.LOAD	.575	218	N	.715	Y	.185	N		.444	.799	-.420	.494	.147	Y	P+nV
TP.LOAD	.798	531	N	.747	Y	.0001	Y	P	.458	.773	-.480	.485	.132	Y	R-P
DP.LOAD	.741	417	N	.587	Y	1	N		.440	.767	-.510	.420	.172	Y	P+nV
CU.LOAD	1.635	119,597	N	.889	Y	0	Y	P	.309	.755	-.250	.648	.021	Y	R-P
PB.LOAD	1.842	806,063	N	.695	Y	0	Y	P	.398	.725	-.180	.639	-.072	Y	R-P
ZN.LOAD	.880	772	N	.897	Y	0	Y	P	.346	.609	-.120	.650	.081	Y	R-P
COD.CONC	.324	86	Y	.010	N	.233	N		-.444	.061	.071	-.110	.142	N	Use as is
SS.CONC	.754	440	N	.158	N	.001	Y	P	.295	.257	-.330	-.052	-.094	N	None[a]
DS.CONC	.287	74	Y	.327	N	.003	Y	P	-.171	.469	-.400	.158	.205	N	Use as is
TN.CONC	.239	59	Y	.257	N	.291	N		-.323	.144	.034	-.062	.192	N	Use as is
TKN.CONC	.435	131	N	.359	N	0	Y	P	-.277	.008	.008	.061	.127	N	None[a]
TP.CONC	.518	177	N	-.055	N	.233	N		.078	.462	.500	.068	.123	Y	R-P+nV
DP.CONC	.504	169	N	-.253	N	.451	N		-.108	.244	.257	-.093	.179	N	None[a]
CU.CONC	1.107	2,573	N	.395	Y	0	Y	P	-.365	.321	.349	.406	.237	N	R-P
PB.CONC	1.432	22,956	N	.034	N	0	Y	P	-.166	.137	.158	.368	-.008	N	None[a]
ZN.CONC	.424	126	N	.744	Y	0	Y	P	-.399	-.200	.070	.405	.080	N	R-P

[a]None of the MAP's considered can be expected to provide more accurate estimates than the unadjusted regional model. Alternatives are to collect additional data to calibrate a local model, or use a simple estimator such as mean or median value.

(Hoos and Sisolak, 1993, table 4) and for the Tennessee data base (table 2) are comparable. The load and event-mean concentration models for PB are an exception: *RMSE* for the Tennessee data base far exceeds *RMSE* for the Knoxville NURP data base, indicating a change in PB loading characteristics in storm runoff over time. Because values of load and event-mean concentration of PB in the Tennessee data base are smaller than values in the Knoxville NURP data base, the change over time is a downward trend, possibly caused by reduction of lead emissions in automobile exhaust.

The model error for some constituents may be caused by differences in physiographic setting: 8 of the 11 cities in the NURP region III data base are in, or are very close to, a coastal setting. Topography and geology are important controls on storm-runoff quality, even in urban areas. Furthermore, most cities in the NURP region III data base are larger and older than the three Tennessee cities.

It is, therefore, inappropriate to use the regional regression models to estimate storm-runoff quality in Tennessee for most constituents. An estimating technique based only on the Tennessee data base, however, would be simple and empirical, because the maximum data set size is 45. An additional available option is the use of model-adjustment procedures (MAP's) to combine the regional model predictions with local data, thereby effectively increasing the size of the local data base. The reader is referred to Hoos and Sisolak (1993) for detailed description and evaluation of four possible MAP's. Hoos and Sisolak developed a scheme, based on exploratory data analysis of the local data base, for selecting the appropriate MAP for each constituent model (fig. 2).

The selection scheme was modified slightly for this analysis. The MAP that weights P_u with a prediction from a local regression model, MAP-W, was excluded from consideration because the weighting coefficient could not be calculated reliably. The reason for this is that the matrix of explanatory variables from the NURP region III calibration data set is unavailable.

Exploratory Data Analysis

The MAP selection scheme based on exploratory data analysis (fig. 2) was applied to the Tennessee data base to select the most appropriate MAP for each constituent model. Values for test statistics are presented in table 2. For most of the load models, the variation in P_u explains much of the variation in O, and the direction of bias of P_u relative to O is consistent and positive; that is, P_u consistently overestimates O. The MAP based on regression against P_u alone, MAP-R-P, is therefore favored for most of the load models. The MAP based on regression against P_u and additional local variables, MAP-R-P+nV, is favored for the TKN and DP load models.

For the event-mean concentration models, MAP-R-P is favored for CU and ZN, and MAP-R-P+nV is favored for TP. For the remaining seven constituents, the variation in P_u does not sufficiently explain the variation in O and, furthermore, correlation between O and each of the additional explanatory variables is not significant. None of the MAP's is, therefore, appropriate for the concentration models for these seven constituents. For three of the seven constituents, COD, DS, and TN, the prediction error is small enough that the analyst may use the regional regression model without adjustment. For the other four, SS, TKN, DP, and PB, a simple estimator such as the mean of the observed concentration values may be used, or additional data could be collected to calibrate a local model.

The three models for which MAP-R-P+nV was favored (TKN load, DP load, and TP event-mean concentration) required additional exploratory analysis: multiple regression analysis of all possible combinations of five explanatory variables was done to determine the most suitable regression model. The explanatory variables considered in this analysis were TRN, DA, IA, LUI, and ADD. Inclusion of P_u in all of the multiple regressions was forced by regressing the residuals from the regression, O against P_u, against all possible combinations of the residuals from five regressions (each of the five explanatory variables against P_u).

The best combination of explanatory variables was selected for each size category (table 3) based on values of r^2 and Cp: largest r^2 and smallest Cp. (The reader is referred to Draper and Smith, 1981, for a detailed description of Mallow's coefficient, Cp.) Ideally, the most suitable regression model from among the best in each size category would be selected by comparing r^2 and Cp. For the Tennessee data base, however, the size of the calibration data set constrained the choice to the size category n =1 or, in the

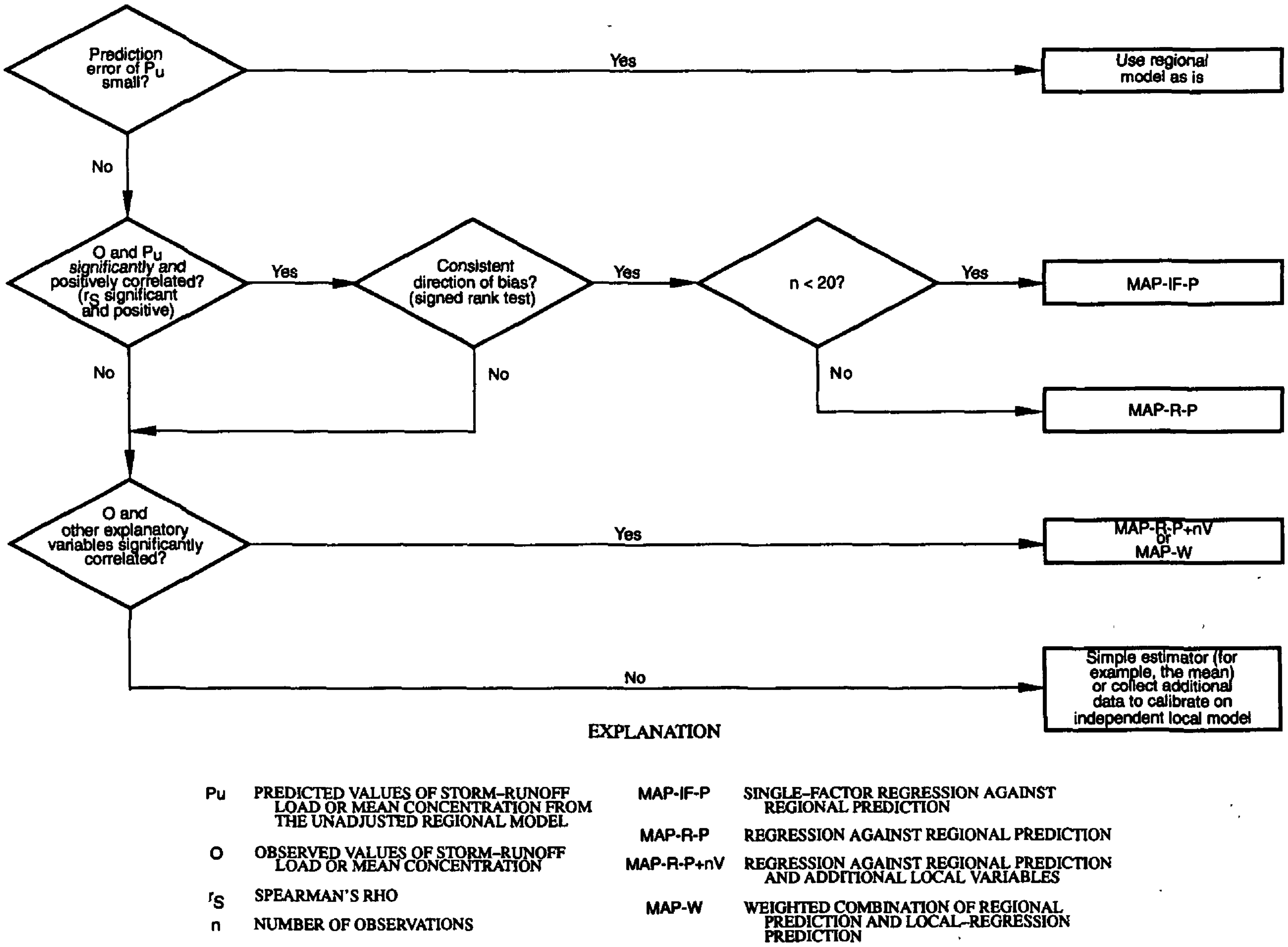


Figure 2. Flowchart for selection of model-adjustment procedure (MAP) based on exploratory data analysis of the calibration data set (from Hoos and Sisolak, 1993).

case of TP event-mean concentration, to $n \leq 2$, where n is the number of explanatory variables (table 3).

Calibration and Error Analysis

Observations in the Tennessee data base were used to derive coefficients for the selected MAP for each constituent model (table 4). Calibration error is reported as standard error of the estimate (*SE*); *SE* measures how well the estimated values from the MAP agree with the observed values for the calibration data set. Calibration results may be biased due to sampling error in the Tennessee data base.

SE for the selected MAP's ranges from 0.263 log units (67 percent), for the ZN event-mean concentration model, to 0.677 log units (322 percent), for the SS load model. The relatively large values of *SE* for adjusted models for some of the constituent models, although representing significant reduction (by at least 50 percent) in prediction error compared to estimation with P_u, may be unacceptable for some applications. Furthermore, values of r^2 for adjusted models for TP, CU, and ZN event-mean concentration are small (0.264, 0.185, and 0.381, respectively). The user may wish to collect additional local data for these constituents and repeat the MAP analysis, or calibrate an independent local regression model.

SE for adjusted load models is larger than for the corresponding adjusted concentration model. Compare, for example, *SE* for the adjusted CU load model, 135 percent, to *SE* for the adjusted CU concentration model, 79 percent. This disparity should not encourage the user, however, to use an estimate from the adjusted CU concentration model, in conjunction with an estimated runoff volume, to estimate CU load. *SE* values are larger for load models partly because the variation in load values is naturally greater, which is caused in turn by the greater variability in values of runoff volume.

Table 3. Multiple regression analysis of data sets for which MAP-R-P+nV is favored

[Regression analysis forces inclusion of the predicted value from the unadjusted regional model, P_u; n, number of explanatory variables; Cp, Mallow's coefficient (Draper and Smith, 1981); r, correlation coefficient; TKN, total ammonia plus organic nitrogen as nitrogen; DP, dissolved phosphorus; TP, total phosphorus; LOAD, storm-runoff load; CONC, storm-runoff mean concentration; TRN, total storm rainfall; DA, total contributing drainage area; IA, impervious area; LUI, industrial land use; ADD, antecedent dry days]

Constituent name. model type	Best P + nV regression model														Most suitable model	
	Best n=1			Best n=2			Best n=3			Best n=4			All variables (n=5)			
	Variable	Cp	r^2	Variable	Cp	r^2	Variable	Cp	r^2	Variable	Cp	r^2	Cp	r^2	Selected variables	P-value
TKN.LOAD	DA	4.16	0.252	DA IA	3.18	0.305	TRN DA LUI	3.54	0.323	TRN DA LUI ADD	4.11	0.336	6.0	0.301	n=1(DA)[1]	0.038
DP.LOAD	DA	9.51	.299	TRN DA	6.59	.376	TRN DA LUI	5.37	.422	TRN DA LUI ADD	5.54	.438	Not physically reasonable (coefficient on IA negative)		n=1(DA)[1]	.0012
TP.CONC	IA	1.34	.234	DA IA	.58	.271	TRN DA IA	2.14	.262	TRN DA IA ADD	4.00	.246	5.99	.227	n=2 (DA,IA)[2]	.0005

[1]Data set size constrains n to 1.
[2]Data set size constrains n to 2 or less.

Table 4. Calibration coefficients and error statistics for selected model-adjustment procedures for the data base for Chattanooga, Knoxville, and Nashville, Tennessee

[Model-adjustment procedures (MAP's) and bias correction factor (BCF) explained in Hoos and Sisolak (1993); r, correlation coefficient; SE, standard error of the estimate; RMSE, root mean square error between observed and predicted (from unadjusted regional model) values of the response variable; COD, chemical oxygen demand; SS, suspended solids; DS, dissolved solids; TN, total nitrogen; TKN, total ammonia plus organic nitrogen as nitrogen; TP, total phosphorus; DP, dissolved phosphorus; CD total-recoverable cadmium; CU, total-recoverable copper; PB, total-recoverable lead; ZN, total-recoverable zinc; LOAD, storm-runoff load, in pounds; CONC, storm-runoff event-mean concentration, in milligrams per liter (except for CD, CU, PB, and ZN, which are in micrograms per liter); P_{ui}, predicted value of response variable from the unadjusted regional model for unmonitored site and storm i; DA, drainage area, in square miles; IA, impervious area, in percent; --, not calculated]

Constituent name. model type	Best MAP	Equation form	Calibration coefficients					Calibration error statistics			Prediction error without MAP
			β'_0	β_1	β_2	β_3	BCF	r^2	SE, log	SE, percent	RMSE, percent
COD.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-0.650}$	1.068			1.506	0.679	0.451	139	277
SS.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-1.224}$	1.114			2.164	.629	.677	322	2,558
DS.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$; P_{ui} *from region II*	$10^{-.380}$	.961			1.520	.725	.453	140	295
TN.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$;	$10^{-1.654}$	1.688			1.576	.613	.484	157	985
TKN.LOAD	R-P+nV	$\beta'_0 \times P_{ui}^{\beta_1} \times DA^{\beta_2} \times BCF$	$10^{.285}$	.421	0.747		1.528	.642[a]	.450	139	218
TP.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-.557}$	1.235			2.948	.629	.639	277	531
DP.LOAD	R-P+nV	$\beta'_0 \times P_{ui}^{\beta_1} \times DA^{\beta_2} \times BCF$	$10^{-.124}$	.143	1.157		1.850	.560[a]	.633	271	417
CD.LOAD	None										--
CU.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-1.564}$	1.052			1.395	0.763	0.443	135	119,597
PB.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-1.853}$	1.609			1.897	.709	.516	176	806,063
ZN.LOAD	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-.714}$	1.059			1.778	.648	.533	187	772

Table 4. Calibration coefficients and error statistics for selected model-adjustment procedures for the data base for Chattanooga, Knoxville, and Nashville, Tennessee—Continued

Constituent name. model type	Best MAP	Equation form	Calibration coefficients					Calibration error statistics			Prediction error without MAP
			β'_0	β_1	β_2	β_3	BCF	r^2	SE, log	SE, percent	RMSE, percent
COD.CONC	Use as is	P_{ui}									86
SS.CONC	None[b]										440
DS.CONC	Use as is	P_{ui} *(region II)*									74
TN.CONC	Use as is	P_{ui}									59
TKN.CONC	None[b]										131
TP.CONC	R-P+nV	$\beta'_0 \times P_{ui}^{\beta_1} \times DA^{\beta_2} \times IA^{\beta_3} \times BCF$	$10^{-0.347}$	0.198	0.264	0.186	1.510	0.264[a]	0.397	114	177
DP.CONC	None[b]										169
CD.CONC	None[b]										--
CU.CONC	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{-0.099}$	.524			1.241	.185	.302	79	2,573
PB.CONC	None[b]										22,956
ZN.CONC	R-P	$\beta'_0 \times P_{ui}^{\beta_1} \times BCF$	$10^{0.075}$	.832			1.261	.381	.263	67	126

[a]r^2 value differs from value reported in table 3. In the regression analysis for table 3, the response and explanatory variables were transformed to residuals of regression against P_u (see text for explanation).

[b]See suggested estimator in table 5.

The predictive accuracy of the MAP for a particular unmonitored site and storm i is estimated by the standard error of prediction (SEP). The SEP_i is computed as a function of the SE of the MAP as well as the difference between explanatory-variable values for the unmonitored site and the mean values of the calibration data set. The equations for computing SEP_i for each MAP are presented in Hoos and Sisolak (1993, Supplement C).

Simple estimators are given in table 5 for the constituents for which model adjustment was not appropriate.

Table 5. Simple estimators for constituents for which models were not adjusted

[SS, suspended solids; TKN, total ammonia plus organic nitrogen as nitrogen; DP, dissolved phosphorus; CD, total-recoverable cadmium; PB, total-recoverable lead; CONC, storm-runoff event-mean concentration, in milligrams per liter (except for CD and PB, which are in micrograms per liter); --, not calculated; <, less than]

Constituent name, model type	Simple estimator: mean of observed value[a]	Calibration error: standard deviation[a]
SS.CONC	65	3.74
TKN.CONC	1.04	1.95
DP.CONC	.165	2.51
CD.CONC	<1	--
PB.CONC	16.9	2.51

[a] Computed from log-transformed data, then detransformed.

EXAMPLE APPLICATION

An estimate of TKN storm-runoff load is needed for an unmonitored site and storm i in Hixon, Tennessee: DA is 0.20 square mile, LUN is 30 percent, and TRN is 0.3 inch. MAR for the Hixon area is 53 inches. First, the TKN load model for region III (Driver and Tasker, 1990, table 1) is used to calculate the value for unmonitored site and storm i predicted from the unadjusted regional model (P_{ui}):

$$P_{ui}(TKN) = 199,572 \times TRN^{(0.875)} \times DA^{(0.393)} \times (LUN+2)^{(0.082)} \times MAR^{(-2.643)} \times 1.736;$$

$$P_{ui}(TKN) = 199,572 \times 0.3^{(0.875)} \times 0.20^{(0.393)} \times 32^{(0.082)} \times 53^{(-2.643)} \times 1.736;$$

$$P_{ui}(TKN) = 2.36 \text{ pounds}$$

Before adjusting this estimate with results from the MAP analysis, consideration should first be given to whether the characteristics of unmonitored site and storm i are within the range of site and storm characteristics in the Tennessee data base (presented in table 1). In this example, values for unmonitored site and storm i are within the range for the data base.

The selection procedure based on exploratory data analysis (fig. 2) favors MAP-R-P+nV for the TKN load model (table 2) with DA as the additional explanatory variable (table 3). Calibration of MAP-R-P+nV yields values of $10^{0.285}$, 0.421, 0.747, and 1.528 for β'_0, β_1, β_2, and BCF, respectively (table 4). P_{ui} is adjusted to P_{ai} using these coefficient values, the value for DA (0.20 square mile), and the MAP-R-P+nV adjustment equation (table 4):

$$P_{ai}(TKN) = 10^{(0.285)} \times P_{ui}(TKN)^{(0.421)} \times DA^{(0.747)} \times 1.528;$$

$$P_{ai}(TKN) = 10^{(0.285)} \times 2.36^{(0.421)} \times 0.20^{(0.747)} \times 1.528;$$

$$P_{ai}(TKN) = 1.27 \text{ pounds}$$

where P_{ai} = adjusted model-predicted value of storm-runoff load for unmonitored site and storm i. Therefore, the adjusted estimate of TKN load for a 0.3-inch storm at unmonitored site i is 1.27 pounds.

Annual and seasonal urban-runoff load at the unmonitored site i can be estimated by calculating P_{ai} for a recorded series of storms, thereby producing a synthetic record of storm loads. The synthetic record is reduced to an estimate of mean annual load by first summing loads from each storm, then dividing by the number of years in the period of synthetic record. Mean seasonal load can be estimated by summing loads only from the season of interest before dividing by the number of years of record.

SUMMARY

This report presents the results of applying model-adjustment procedures (MAP's) to the combined data bases of storm-runoff quality from Chattanooga, Knoxville, and Nashville, Tennessee (Tennessee data base). Data for 45 storms at 15 different sites (5 sites in each city) constitute the data base.

Comparison of observed values (O) to the predicted values from the regional regression models (P_u) shows large prediction errors for almost all constituent models. Discrepancies between P_u and O are caused by error in the regional models or by sampling error in the Tennessee data base. Some sampling error may be present: average storm size in the data base is smaller than the average storm size in the three cities, and many monitoring sites in the data base are in watersheds that may be too large for these sites to be considered as storm-runoff discharge points.

For most constituents, however, the prediction error is too large to be reasonably explained by sampling error alone; some of the error must be due to error in the regional models. MAP's, which combine the regional model predictions with local data, are applied to improve predictive accuracy.

For most of the load models, the variation in P_u explains much of the variation in O, and the direction of bias of P_u relative to O is consistent and positive; that is, P_u consistently overestimates O. The MAP based on regression against P_u alone (MAP-R-P) is favored for most of the load models. The MAP based on regression against P_u and additional local variables (MAP-R-P+nV) is favored for only the TKN and DP load models.

For the event-mean concentration models, MAP-R-P is favored for CU and ZN, and MAP-R-P+nV is favored for TP. For the remaining seven constituents, the variation in P_u does not sufficiently explain the variation in O and, furthermore, correlation between O and each of the additional explanatory variables is not significant. None of the MAP's is appropriate for the concentration models for these seven constituents. For three of the seven constituents, COD, DS, and TN, the prediction error is small enough that the analyst may use the regional regression model without adjustment. For the other four, SS, TKN, DP, and PB, a simple estimator such as the mean of the observed concentration values may be used, or additional data could be collected to calibrate a local model.

SE for the selected MAP's ranges from 0.263 log units (67 percent), for the ZN event-mean concentration model, to 0.677 log units (322 percent), for the SS load model. Calibration results may be biased due to sampling error in the Tennessee data base. The relatively large values of *SE* for adjusted models for some of the constituent models, although representing significant reduction (by at least 50 percent) in prediction error compared to estimation with P_u, may be unacceptable for some applications. The user may wish to collect additional local data for these constituents and repeat the MAP analysis, or calibrate an independent local regression model.

REFERENCES CITED

Draper, N.R., and Smith, H., 1981, Applied regression analysis: New York, John Wiley and Sons, Inc., 709 p.

Driver, N.E., and Tasker, G.D., 1990, Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2363, 44 p.

Fenneman, N.M., 1946, Physical divisions of the United States: Washington, D.C., U.S. Geological Survey special map, scale 1:7,000,000.

Hershfield, D.M., 1961, Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: U.S. Weather Bureau Technical Paper No. 40, 71 p.

Hoos, A.B., and Sisolak, J.K., 1993, Procedures for adjusting regional regression models of urban-runoff quality using local data: U.S. Geological Survey Open-File Report 93-39, 39 p.

Miller, R.A., 1974, The geologic history of Tennessee: Tennessee Division of Geology Bulletin 74, 63 p.

National Atmospheric Deposition Program/National Trends Network Coordination Office, 1990, NADP/NTN annual data summary - precipitation chemistry in the United States - 1990: Fort Collins, Colorado State University, Natural Resource Ecology Laboratory, 475 p.

National Oceanic and Atmospheric Administration, 1980, Climates of the states (2d ed.): Detroit, Gale Research Company, 2 v.

Outlaw, G.S., Hoos, A.B., and Pankey, J.T., 1994, Rainfall, streamflow, and water-quality data for five small watersheds, Nashville, Tennessee, 1990-92: U.S. Geological Survey Open-File Report 94-68, 43 p.

Steurer, P.M., and Nold, A., 1986, Climatic data summaries from hourly precipitation data and state climatic divisions: National Oceanic and Atmospheric Administration and U.S. Environmental Protection Agency, Interagency Agreement # DE-AIO5-86OR21617.

U.S. Environmental Protection Agency, 1990, National pollutant discharge elimination system permit application regulations for storm water discharges: U.S. Federal Register, v. 55, no. 222, p. 47990-48091.