COMPARISON OF CONCEPTUALLY BASED AND REGRESSION RAINFALL-RUNOFF MODELS, DENVER METROPOLITAN AREA, COLORADO, AND POTENTIAL APPLICATIONS IN URBAN AREAS

By Juli B. Lindner-Lunsford and Sherman R. Ellis

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4104

Denver, Colorado

1987

DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

Factors for converting inch-pound units used in this report to metric (International System) units are shown in the following table:

Multiply inch-pound unit	*By*	*To obtain metric unit*
acre	0.4047	hectare
cubic foot per second	0.02832	cubic meter per second
inch	2.540	centimeter
pound	0.4536	kilogram

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ABSTRACT

Multievent, conceptually based models and a single-event, multiple linear-regression model for estimating storm-runoff quantity and quality from urban areas were calibrated and verified for four small (57 to 167 acres) basins in the Denver metropolitan area, Colorado. The basins represented different land-use types--light commercial, single-family housing, and multifamily housing. Both types of models were calibrated using the same data set for each basin. A comparison was made between the storm-runoff volume, peak flow, and storm-runoff loads of seven water-quality constituents simulated by each of the models using identical verification data sets.

The multievent, conceptually based models studied were the U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model--Version II (DR_3M-II) (a runoff-quantity model designed for urban areas), and a multievent, urban runoff-quality model, DR_3M-QUAL. Water-quality constituents modeled were chemical oxygen demand, total suspended solids, total nitrogen, total phosphorus, total lead, total manganese, and total zinc.

A multiple linear-regression analysis, based both on log-transformed and untransformed data, was made. A separate regression equation was developed for each runoff characteristic or water-quality constituent, and all the regression equations were basin specific.

The two types of models produced comparable results for most runoff characteristics and water-quality constituents in the basins studied. However, development and implementation of multievent, conceptually based models are more costly and time consuming than development and implementation of single-event, multiple linear-regression models.

INTRODUCTION

Runoff from urban areas in the Denver metropolitan area (fig. 1) has been studied since the late 1960's by Federal, State, and local agencies as well as by private consultants. Mathematical models of the processes of runoff from urban areas have been included in these studies since about 1975 (Ellis and Mustard, 1984). These studies have used a variety of models of varying degrees of complexity; the time frames have been both continuous or multievent and single event, and the model basis has been both empirical and conceptual. This report compares results from multievent, conceptually based models and single-event, multiple linear-regression models. For both models, measured

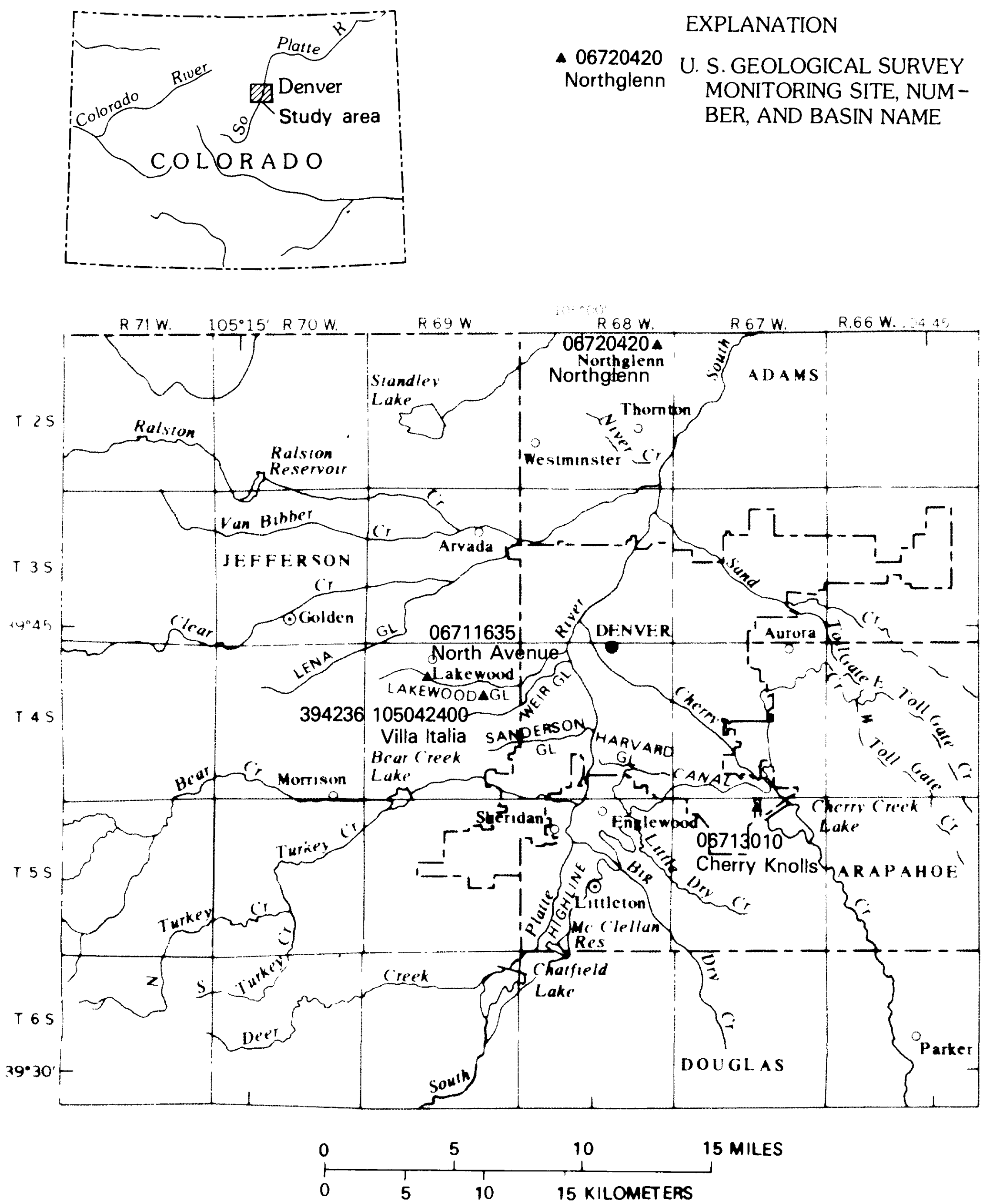

Figure 1.--Location of study area, monitoring sites, and general features.

data from a verification data set is used as a standard of model performance. Storm characteristics modeled include: measured storm-runoff volumes, peak flows, and water-quality constituent loads (referred to hereafter as storm-runoff loads). Data from four basins of different land-use classifications are used in the analysis.

BASIN DESCRIPTIONS

The North Avenue basin consists of 69 acres in southwestern Lakewood, Colo., a western suburb of Denver (fig. 1). At the time of the data-collection phase of this study (1980-81), about 33 percent of the basin was devoted to multifamily housing, 30 percent to restaurants and office buildings, and 37 percent to undeveloped land. Fifty percent of the basin was identified as effective impervious area (table 1).

The Northglenn basin in a northern suburb of Denver (fig. 1), was the largest of the basins modeled (167 acres). The major land use in the basin during 1980-81 was single-family housing. This basin had the smallest percentage of effective impervious area of the four basins, about 24 percent (table 1).

The Cherry Knolls basin consists of 57 acres in southeast metropolitan Denver (fig. 1). The land use during 1980-81 was multifamily housing, although there were several open areas in the basin. The monitoring site was located at the outlet of a small detention basin, which had no effect on the outflow for the storms monitored. Thirty-eight percent of the basin was effective impervious area (table 1).

The 74-acre Villa Italia basin (fig. 1) consists of a large shopping mall in eastern Lakewood, the Villa Italia Shopping Center. An unusually large proportion of the basin, about 91 percent, was effective impervious area--mostly parking lots (table 1).

METHOD OF STUDY

Multievent, conceptually based rainfall-runoff models previously were calibrated and verified for five urban basins, and runoff-quality models were calibrated and verified for four of the basins as part of a cooperative project by the U.S. Geological Survey, the Denver Regional Council of Governments, and the U.S. Environmental Protection Agency (Lindner-Lunsford and Ellis, 1984). The basins modeled were described in the previous section. Storm-runoff loads included in this study were chemical oxygen demand, total suspended solids, total nitrogen, total phosphorus, total lead, total manganese, and total zinc. (Throughout the report, the term total, as in "total lead," actually refers to "total recoverable" for trace elements.) Detailed discussions of calibration and verification procedures for these models and final values of model parameters were published by Lindner-Lunsford and Ellis (1984). Multiple linear-regression equations for storm-runoff volume and peak flow were developed for four of the basins studied by these authors as part of the present study; equations to simulate storm-runoff loads were developed for

Table 1.--*Selected data for drainage basins used in this study*

U.S. Geological Survey monitoring site		Name of monitored basin used in report	Location of monitoring site		Drainage area (acres)	Percentage of area covered by effective impervious surfaces	Predominant land use
Number	Name		Latitude	Longitude			
06711635	North Avenue storm drain at Denver Federal Center, at Lakewood.	North Avenue	39°43'21"	105°07'47"	69	50	Multifamily housing and light commercial.
[1]06720420	Storm drain at 116th Avenue and Claude Court, at Northglenn.	Northglenn	39°54'23"	104°57'34"	167	24	Single-family housing.
06713010	Cherry Knolls storm drain, at Denver.	Cherry Knolls	39°38'58"	104°52'47"	57	38	Multifamily housing.
394236105 042400	Villa Italia storm drain, at Lakewood.	Villa Italia	39°42'36"	105°04'24"	74	91	Commercial (shopping center).

[1]Insufficient data to model water quality in this study.

three of the basins. The Southglenn basin was completely eliminated from the present study, and the Northglenn basin was eliminated from the water-quality part of the present study, because there were insufficient data to establish meaningful regression equations.

Multiple linear-regression equations were developed for each of the basins. Separate regression equations were developed for storm-runoff volume, peak flow, and each of the water-quality-constituent storm-runoff loads. Only storms that had been used in the calibration of the conceptually based models were used to establish the regression coefficients, so that both models were calibrated using identical data sets. Calibration statistics are presented in this report to enable the reader to compare how accurately each of the models was able to match the given data. The conceptually based models and the regression models were verified using the same data sets, and only the statistics based on the verification data set were actually used to determine which of the models gave a better fit.

MODEL DESCRIPTIONS AND COMPARISONS

The U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model--Version II (DR_3M-II) (Alley and Smith, 1982a) is designed to simulate the quantity of storm runoff from urban areas. The model is based on a conceptualization of processes that occur in urban basins. The model provides detailed hydrographs at the outlet of the basin for selected storm-runoff periods and performs daily soil-moisture accounting for the periods between storms where detailed simulation is desired. Thus, the model is a multievent simulation model, rather than a single-event model.

The U.S. Geological Survey's DR_3M-QUAL, a multievent, runoff-quality model (Alley and Smith, 1982b), is designed to simulate impervious area, pervious area, and precipitation contributions to quality of surface runoff in urban areas. Within-storm variations in runoff quality are simulated for selected storms; between these storms, a daily accounting of water-quality-constituent accumulation and washoff is maintained. Spatial variations in water-quality-constituent accumulation and washoff parameters can be considered in the simulation. However, these were not used in this study. The lumped-parameter mode that was used instead was more compatible with the limitations of the regression models and the present degree of understanding of some of the basin processes.

By contrast, the single-event, multiple-linear-regression modeling approach is empirical. Two sets of multiple linear-regression equations were developed using the SAS Institute's Statistical Analysis System[1]. The procedure used was the 'MAXR' option of the 'STEPWISE' procedure. Detailed discussion of these procedures can be found in Helwig and Council (1979, p. 391-392). These single-event, multiple-linear-regression models are

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[1]The use of trade names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey.

referred to as REG (for storm-runoff volume and peak flow) and REG-QUAL (for storm-runoff loads) in the tables showing comparisons of the predictions of the two types of models, and as "the regression models" throughout the rest of this report.

For each of the basins, one regression equation was developed for untransformed data and one for $\log_{10}$-transformed data. The dependent variables modeled were storm-runoff volume, peak flow, and storm-runoff load of each of seven water-quality constituents. Independent variables considered are listed in the next section, "Data Requirements." However, not all of the variables were used in the final models. Independent variables had to be significant at a 95-percent level of confidence as measured by an F-test in order to be included in the equations. Standard errors and plots of residuals were examined to select the appropriate model, and the equation with the best fit for each constituent, either untransformed or $\log_{10}$-transformed, was used for further study.

Log_{10}-transformed regression equations are negatively biased (Miller, 1984; B.M. Troutman, U. S. Geological Survey, written commun., 1985) and need to be corrected using a bias correction factor (F in table 2). If the $\log_{10}$-transformed form of the regression equation was used ("L" in form of equation, table 2), transformation bias was corrected using the method of Miller (1984):

$$Y = aX^{b}F, \tag{1}$$

where: Y = the dependent variable of interest,
X = some independent variable,
a and b = regression coefficients, and
F = the bias correction factor.

The bias correction factor is calculated by:

$$F = e^{0.5(SE^2)}, \tag{2}$$

where e = base of natural logarithm, 2.178, and
SE = standard error of regression of natural log-transformed values.

For $\log_{10}$ logarithms, the bias correction factor is calculated by:

$$F = 10^{2.303 \cdot 0.5\ (SE^2)}, \tag{3}$$

where SE = standard error of regression of $\log_{10}$ log-transformed values.

The bias correction factor for untransformed standard error of estimation, using Hardison's (1971) coversion of natural logarithms to standard error of estimation is calculated by:

$$F = e^{0.5(\text{Ln}(SEE) + 1)^2}, \tag{4}$$

where Ln = natural logarithm, and
SEE = standard error of estimation, untransformed, in percent, divided by 100.

Table 2.--*Coefficients and form of regression equations*

[Form of equation: U: load, in pounds = (A×antecedent dry days, in days) + (B×total rainfall, in hundredths of an inch) + (C×duration of storm, in minutes) + (D×maximum rainfall intensity, in hundredths of an inch during 5 minutes) + E; L: load, in pounds = 10^{E}×(antecedent dry days, in days)^{A}×(total rainfall, in hundredths of an inch)^{B}×(duration of storm, in minutes)^{C}×(maximum rainfall intensity, in hundredths of an inch during 5 minutes)^{D}×F. Dashes indicate an independent variable not significant at 95-percent confidence level and not used in equations. NA = not applicable]

Dependent variable	Coefficient						Form of equation	Coefficient of determination (R^2)
	A	B	C	D	E	F[1]		
				NORTH AVENUE BASIN				
Storm-runoff volume-----	--	1.16	--	--	-0.765	1.0401	L	0.934
Peak flow---------------	--	.0288	--	1.03	-.342	NA	U	.784
Chemical oxygen demand--	--	5.28	--	--	47.4	NA	U	.947
Total suspended solids--	[2]-0.412	.792	--	.479	1.45	1.0214	L	.948
Total nitrogen----------	--	.806	--	--	-.466	1.0644	L	.837
Total phosphorus--------	--	.0145	--	--	.316	NA	U	.556
Total lead--------------	--	.00568	--	--	.117	NA	U	.735
Total manganese---------	[2].335	.847	--	.450	-.172	1.0371	L	.382
Total zinc--------------	--	.00892	--	--	.144	NA	U	.830
				NORTHGLENN BASIN				
Storm-runoff volume-----	--	1.17	--	--	-1.03	1.0196	L	0.949
Peak flow---------------	--	.334	--	.844	-.114	1.0272	L	.941
				CHERRY KNOLLS BASIN				
Storm-runoff volume-----	--	0.187	-0.00247	0.329	-1.76	NA	U	0.999
Peak flow---------------	--	--	--	1.19	-1.41	NA	U	.979
Chemical oxygen demand--	--	.820	--	1.03	-.221	1.0325	L	.822
Total suspended solids--	--	.859	--	23.4	-69.4	NA	U	.918
Total nitrogen----------	--	1.32	-.766	--	.0976	1.0396	L	.787
Total phosphorus--------	--	2.00	-.747	.662	-2.34	1.0329	L	.927
Total lead--------------	--	1.21	-.955	--	-.720	1.0827	L	.633
Total manganese---------	--	1.13	-.330	1.12	-2.89	1.0065	L	.979
Total zinc--------------	--	1.15	-.435	.773	-2.26	1.0180	L	.922
				VILLA ITALIA BASIN				
Storm-runoff volume-----	--	0.886	--	--	-1.51	NA	U	0.996
Peak flow---------------	--	.486	--	.998	.0461	1.0351	L	.968
Chemical oxygen demand--	--	4.30	--	--	324	NA	U	.401
Total suspended solids--	--	-27.8	2.16	258	-121	NA	U	.995
Total nitrogen----------	--	.196	--	--	5.86	NA	U	.773
Total phosphorus--------	--	.622	--	.525	-1.17	1.0066	L	.979
Total lead--------------	--	--	--	.636	-.603	1.0391	L	.693
Total manganese---------	--	--	.492	.704	-1.81	1.0369	L	.842
Total zinc--------------	--	--	--	.127	.414	NA	U	.738

[1]F is a correction factor for transformation bias.

[2]A value for antecedent dry days of zero as reported in Lindner-Lunsford and Ellis (1984) was replaced with a value of 0.25 to avoid having to use log(0) in calculation.

No within-storm variations were studied, because the regression equations only simulate storm-runoff volumes, peak flows, and storm-runoff loads. The number of dry days between storms was used as one of the independent variables, and this number could be considered to be a rudimentary form of continuity in the simulation.

Data Requirements

Data requirements for the two types of models were different. The multievent, conceptually based models require detailed understanding of the storms and of the basin characteristics. The data required by the multievent, conceptually based models for detailed simulation include: (1) Incremental rainfall during storms and daily rainfall for periods between storms; (2) soil-moisture and infiltration parameter values; (3) area and percentage of effective impervious area of each subbasin within the basin; (4) extensive physical descriptions of the drainage features of the basin in terms of a series of overland flow planes and a channel drainage network, characterized by mean slope, roughness, and overland-flow path length; (5) impervious retention, the depth of rainfall retained on impervious surfaces; and (6) water-quality-constituent accumulation and washoff parameter values. (Effective impervious areas are those impervious areas that are hydraulically connected to either the channel drainage system or to other effective impervious areas, such as a roof that drains onto driveways, streets, sidewalks, or paved parking lots. A concrete slab that drains onto a lawn would be an example of an area that is not effectively impervious.) Physical characteristics of the study basins and detailed aerial photographs of the basins showing the superimposed subbasin boundaries and channel network, 5-minute rainfall and runoff data, and runoff water-quality analyses are published in Gibbs (1981) and Gibbs and Doerfer (1982).

The single-event, multiple-linear regression models were designed to use only readily available data summarizing storms. Models were designed not to require any extensive field work to characterize basins. Therefore, data requirements for the regression models were extremely simple. The only independent variables that were determined to be significant at a 95-percent level of confidence as determined by an F-test were: (1) Total rainfall, (2) maximum rainfall intensity for any 5-minute period during the storm, (3) duration of storm, and (4) number of antecedent dry days (less than 0.01 inch of precipitation). Not all of these variables were significant for all of the models. The coefficients derived for each of the equations are listed in table 2.

The first five data items required for the multievent, conceptually based models were used to simulate runoff with DR_3M-II. Measured-runoff hydrographs and water-quality-constituent accumulation and washoff parameters (item 6), were used to produce load estimates with DR_3M-QUAL. Because the soil-moisture, infiltration, and constituent-accumulation and washoff-parameter values are so difficult to measure, they virtually became empirically determined model-calibration parameters. These parameters were adjusted during model calibration by a combination of manual and automatic procedures (Lindner-Lunsford and Ellis, 1984). Although simulated runoff hydrographs from DR_3M-II could be used with the quality model, measured runoff data were used so that the input errors would be the same as the regression models.

Implementation Time

Possibly the most noticeable difference between the multievent, conceptually based models and the single-event regression models is in the time necessary to implement the two types of models. Time required for the user to become familiar with the models is greater for the more complex conceptually based models. Data-collection costs, such as installation and maintainance of a rain gage, runoff measurement, and water-quality sample collection and analysis, would be the same in either instance. The conceptually based models require development of physical descriptions of the basin as discussed in the previous section; the regression models developed in this study require no such data. In addition, the regression model using the SAS procedure required only one computer run to develop, whereas the conceptually based models required many runs and trial-and-error adjustment of parameters to achieve a best fit. In fact, although an objective function can be defined (Alley and Smith, 1982a), there is no absolute criterion of when the "best fit" for the conceptually based model has been achieved. The automatic optimization methods used in the model may stop at a local optimum, rather than the global minimum value of the objective function (W. M. Alley, U.S. Geological Survey, oral commun., 1985).

Detail of Results

One advantage of the multievent, conceptually based models is the detail of results. DR_3M-II provided a hydrograph at the outlet of the basin showing simulated flow in 5-minute increments throughout the duration of the storm and is capable of providing similar hydrographs for each subbasin in the basin. However, the single-event regression models only are able to predict storm-runoff volume and peak flow. Similar contrasts in the degree of detail produced were found in the predictions of storm-runoff loads. The conceptually based model produced: (1) Simulation of storm-runoff loads based on impervious area, pervious area, and precipitation contributions to runoff quality; (2) tables of time versus simulated discharge and water-quality constituent concentration for each storm; and (3) daily accounting of water-quality-constituent accumulation and washoff on effective impervious surfaces for periods between the storms of interest. The regression model, REG-QUAL, only predicted total storm-runoff loads.

Transferability

Ideally, the multievent, conceptually based models would be usable for an ungaged basin if soil-moisture and water-quality-constituent accumulation and washoff parameter values for the basin were known or could be derived by analogy to other similar basins, and physical descriptions of the drainage characteristics of the basin were available. In practice, soil-moisture parameters should have little effect on simulated storm-runoff volumes and peak flows for fairly urbanized basins. However, the other physical parameters are so difficult to measure that they virtually are model-calibration parameters and, hence, are not transferable. The single-event, multiple linear-regression models presented here were developed on a site-specific basis and, hence, are not transferable; however, Ellis and others (1984) developed regression equations that may be transferable to other similar basins.

COMPARISON OF MODEL RESULTS

Neither type of model was consistently more accurate than the other in simulating a storm characteristic or particular constituent, nor was one type of model more accurate than the other when applied to a particular basin. Five statistical measures of error were used to compare the results from the multievent, conceptually based models and single-event, multiple linear-regression models: total percentage difference, root-mean-square error (RMSE) of the untransformed and log-transformed values, and mean absolute deviation (MAD) of the untransformed and log-transformed values. Total percentage difference is the percentage difference between the sum of the measured and the simulated values, a measure of how well the simulating procedure can simulate storm-runoff volumes and peak flows, or storm-runoff loads from a series of storms. RMSE and MAD are measures of how well the simulating procedure simulated individual storm-runoff volumes, peak flows, or storm-runoff loads. Both untransformed and log-transformed measured and simulated values were used to calculate RMSE and MAD values.

In several instances, the various error data indicate contradictory conclusions. Usually this can be explained by the occurrence of one or two storms that are outliers compared to the others in the data set. Because the log-transformations tend to give less weight to large outlying values and proportionately more weight to small values than the untransformed statistics give, the log-transformed RMSE or MAD values can indicate that DR_3M-II is a better predictor than REG for a particular characteristic, whereas the untransformed RMSE or MAD values can indicate the opposite. Storm-by-storm examination is needed in these instances. Detailed discussions of the model results for the four basins follow.

North Avenue Basin

In the North Avenue basin, 32 storms were monitored for rainfall and runoff. Of these storms, 17 were chosen for the calibration data set and 15 for the verification data set. A comparison of the estimates of storm-runoff volumes and peak flows of the calibration and verification data sets for the conceptually based and regression flow models is presented in tables 3 and 4. Simulated values of storm-runoff volume and peak flow are plotted against measured values for the verification data set in figure 2. Both DR_3M-II and REG were able to simulate runoff volumes fairly well. Both methods were capable of simulating a seasonal or yearly series of storm-runoff volumes or the volumes of individual storms with about the same degree of accuracy. DR_3M-II was not as accurate as REG for estimates of peak flows from individual storms, as demonstrated by the larger RMSE and MAD values for both the untransformed and log-transformed values for DR_3M-II than for REG (table 3). (Peak flows from storms of less than 0.01 inch of runoff were not simulated because there were difficulties in measuring these flows during the earlier phase of the study.) However, both methods probably are accurate enough to obtain peak-flow data for planning purposes.

Table 3.--*Comparison of conceptually based and regression flow-model calibration results for the North Avenue basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second; dashes indicate not used for calibration]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1980						
May 11	0.03	0.02	0.01	2.1	0.44	0.89
May 15-16	.23	.18	.18	3.8	4.8	3.2
July 24	.04	.03	.03	2.8	1.4	5.2
September 8-9	.33	.24	.28	5.1	5.0	4.9
September 10[1]	.02	.02	.02	.99	.93	.92
September 20	.06	.06	.06	4.1	5.2	4.4
1981						
April 19-20	.08	.11	.12	5.1	2.5	3.8
May 3[1]	.05	.06	.06	1.7	2.0	2.4
May 5	.01	.01	.02	--	--	--
May 17-18	.25	.27	.29	2.4	2.8	4.0
May 28	.01	.01	.01	--	--	--
June 2-3	.07	.08	.08	4.1	5.4	3.6
July 2	.03	.02	.03	2.4	1.1	2.1
July 22	.01	.01	.01	--	--	--
August 9-10	.14	.14	.15	9.4	9.2	8.2
August 12-13	.04	.05	.04	4.9	4.5	4.3
September 6-7	.06	.04	.05	1.7	1.2	2.2
Mean	.09	.08	.09	3.6	3.3	3.6
Total percentage difference		-7.5	-.96		-8.1	-1.2
Root-mean-square error (RMSE)						
Untransformed, in percent		27	27		32	27
Log-transformed, in log units		.104	.122		.236	.163
Natural-log-transformed, in natural log units (LN)		.240	.280		.542	.375
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.016	0.016		0.880	0.826
Log-transformed, in log units		.077	.090		.166	.118

[1]First storm.

Table 4.--*Comparison of conceptually based and regression flow-model verification results for the North Avenue basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second; dashes indicate not used for verification]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1980						
May 8	0.12	0.06	0.07	2.8	2.4	2.4
May 12	.01	.01	.01	--	--	--
May 17	.16	.10	.08	2.6	2.3	1.5
August 10	.01	.01	.01	--	--	--
September 10	.03	.06	.04	7.0	8.9	7.3
1981						
March 3	.03	.03	.05	1.1	.77	1.2
April 20	.02	.02	.02	2.8	1.2	4.0
May 3[1]	.02	.04	.04	1.3	1.7	2.1
May 9	.09	.11	.12	3.1	6.0	3.9
May 16	.03	.03	.04	.82	.55	1.1
May 28-29	.07	.07	.06	2.5	2.0	2.4
July 15	.05	.06	.06	11	7.4	11
August 12	.02	.01	.02	1.5	.71	.92
August 16	.01	.01	.01	--	--	--
August 31	.01	.01	.01	--	--	--
Mean	.04	.04	.04	3.3	3.1	3.4
Total percentage difference		-5.9	-1.5		-7.1	3.6
Root-mean-square error (RMSE)						
Untransformed, in percent		42	43		50	21
Log-transformed, in log units		.17	.14		.20	.15
Natural-log-transformed, in natural log units (LN)		.40	.32		.46	.34
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.014	0.015		1.2	0.51
Log-transformed, in log units		.10	.10		.17	.11

[1]Second storm.

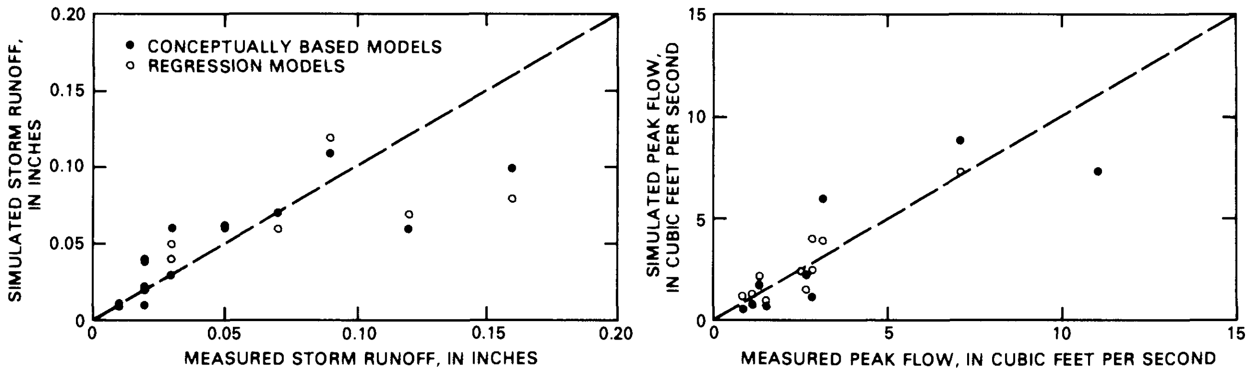

Figure 2.--Simulated versus measured storm-runoff volumes and peak flows for the verification data set for the North Avenue basin.

The water-quality models for the North Avenue basin were calibrated using data from 9 storms and verified using data from 11 storms. Comparisons of measured values of storm-runoff loads and simulated values produced by DR_3M-QUAL and by REG-QUAL are presented in tables 5 and 6. Measured values of storm-runoff loads and simulated storm-runoff loads for selected constituents for the verification data set are plotted in figure 3. The two models were about equally accurate in simulating the sum of storm-runoff loads of total suspended solids, total phosphorus, total lead, and total zinc. (Compare "total percentage difference" values in table 6 for the two models.) DR_3M-QUAL was a more accurate simulator of total manganese; REG-QUAL produced noticeably better results for storm-runoff loads of chemical oxygen demand and total nitrogen. However, REG-QUAL also was a more accurate (based on the test statistics in table 6) simulator of individual storm-runoff loads than DR_3M-QUAL for chemical oxygen demand, total suspended solids, and total nitrogen. For total phosphorus, total lead, total manganese, and total zinc, the RMSE and MAD data indicate conflicting evaluations of which model produced more accurate results.

Northglenn Basin

In the Northglenn basin, 23 storms were monitored for rainfall and runoff, of which 13 were selected for the calibration data set and 10 for the verification data set. Comparisons of the storm-runoff volumes and peak flows simulated by the two models for the calibration and verification data sets are

Table 5.--*Comparison of conceptually based and regression*

[Measured and simulated

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N		
	Measured	Simulated		Measured	Simulated		Measured	Simulated	
		DR$_3$M-QUAL	REG-QUAL		DR$_3$M-QUAL	REG-QUAL		DR$_3$M-QUAL	REG-QUAL
1980									
May 8--------------	190	150	170	1,200	480	880	6.8	4.1	4.7
May 11-------------	110	80	84	240	240	240	2.4	2.0	1.8
May 12-------------	31	28	63	100	88	120	.77	.73	.88
May 15-16----------	260	210	320	1,100	660	1,600	7.8	5.8	8.8
July 24------------	120	160	120	190	420	210	4.0	4.1	2.9
September 8-9------	470	600	440	690	1,600	660	13	16	12
September 10[1]------	94	39	90	300	120	260	1.3	1.0	2.0
1981									
June 2-3-----------	200	160	200	510	460	510	3.4	4.1	5.3
July 15------------	160	200	150	940	680	930	2.3	5.1	4.1
Mean---------------	180	180	180	590	530	600	4.6	4.8	4.7
Total percentage difference-------		0	0		-10	3		3	0.48
Root-mean-square error (RMSE)									
Untransformed, in percent.		29	17		74	39		43	29
Log-transformed, in log units.		.162	.106		.280	.089		.176	.121
Natural-log-transformed, in natural log units (LN).		.374	.243		.645	.206		.406	.353
Mean absolute deviation (MAD)									
Untransformed, in same units as measured data.		48	21		310	110		1.34	1.18
Log-transformed, in log units.		.132	.072		.218	.058		.153	.135

[1]First storm.

quality-model calibration results for the North Avenue basin

values are loads, in pounds]

Total phosphorus as P			Total lead			Total manganese			Total zinc		
	Simulated			Simulated			Simulated			Simulated	
Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL
1.2	0.47	0.66	0.38	0.21	0.25	0.90	0.27	0.64	0.47	0.27	0.36
.24	.28	.42	.13	.12	.16	.21	.18	.16	.24	.18	.21
.09	.10	.36	.04	.04	.13	.05	.06	.08	.07	.06	.17
1.1	.61	1.1	.49	.27	.41	.88	.33	1.2	.59	.33	.61
.41	.62	.50	.16	.22	.19	.21	.30	.19	.22	.30	.26
1.2	1.9	1.4	.44	.73	.54	.57	.84	.65	.77	.84	.80
.32	.13	.43	.14	.06	.16	.20	.09	.18	.14	.09	.22
.51	.53	.72	.25	.23	.28	.40	.30	.43	.33	.30	.39
1.1	1.0	.61	.32	.36	.23	.64	.46	.71	.51	.46	.32
.69	.63	.69	.26	.25	.26	.45	.31	.47	.37	.31	.37
	-8.6	0		-4.7	0		-30	5		-15	0
	62	35		60	28		49	37		31	25
	.240	.122		.210	.112		.230	.117		.137	.113
	.553	.282		.482	.258		.530	.270		.316	.260
	0.277	0.235		0.099	0.066		0.219	0.101		0.090	0.074
	.178	.200		.152	.141		.226	.092		.126	.127

Table 6.--*Comparison of conceptually based and regression*

[Measured and simulated values are loads, in

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N		
	Measured	Simulated		Measured	Simulated		Measured	Simulated	
		DR_3M-QUAL	REG-QUAL		DR_3M-QUAL	REG-QUAL		DR_3M-QUAL	REG-QUAL
1981									
May 5	83	45	90	100	130	150	1.2	1.2	1.9
May 9	140	380	250	310	1,100	550	5.4	9.9	6.8
May 16	100	120	120	150	340	150	2.3	3.0	3.0
May 26-29	160	220	160	400	620	820	3.3	5.7	4.4
July 2	140	96	110	210	250	180	4.3	2.4	2.7
July 22	95	56	74	89	150	74	2.6	1.4	1.3
July 26-27	580	740	580	2,700	2,000	2,800	13	19	15
Aug. 12	94	69	90	150	200	110	1.8	1.8	1.9
Aug. 12-13	120	150	130	370	430	890	2.1	3.9	3.4
Aug. 16	---	---	---	22	61	76	.64	.54	1.1
Aug. 29	44	85	63	35	220	33	.92	2.2	.88
Mean	160	200	170	410	500	530	3.4	4.6	3.9
Total percentage difference		26	7		21	29		36	13
Root-mean-square error (RMSE)									
Untransformed, in percent.		54	26		61	49		50	31
Log-transformed, in log units.		.24	.12		.20	.23		.23	.17
Natural-log-transformed, in natural log units (LN).		.56	.27		.47	.53		.52	.40
Mean absolute deviation (MAD)									
Untransformed, in same units as measured data.		70	22		220	130		1.8	0.96
Log-transformed, in log units.		.19	.079		.28	.18		.19	.13

quality-model verification results for the North Avenue basin

pounds, dashes indicate not used for verification]

Total phosphorus as P			Total lead			Total manganese			Total zinc		
	Simulated			Simulated			Simulated			Simulated	
Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL
0.32	0.16	0.43	0.08	0.07	0.16	0.09	0.09	0.12	0.10	0.09	0.22
.62	1.4	.87	.25	.54	.33	.26	.73	.49	.30	.73	.48
.30	.42	.52	.12	.18	.20	.15	.26	.13	.15	.26	.27
.54	.72	.64	.20	.28	.24	.38	.38	.59	.27	.38	.34
.24	.39	.49	.13	.14	.18	.16	.19	.15	.20	.19	.25
.17	.22	.39	.06	.08	.14	.10	.12	.062	.11	.12	.19
2.7	2.5	1.8	.91	.94	.69	2.0	1.1	2.5	1.6	1.1	1.0
.37	.25	.43	.08	.10	.16	.12	.15	.091	.13	.15	.22
.50	.51	.55	.08	.21	.21	.29	.29	.62	.23	.29	.29
.04	.08	.37	.02	.03	.14	.027	.047	.061	.034	.047	.18
.07	.34	.36	.03	.12	.13	.048	.17	.028	.050	.17	.17
.53	.64	.63	.18	.24	.23	.33	.32	.42	.29	.32	.33
	19	18		37	32		-2.7	33		11	14
	51	15		50	14		50	34		52	19
	.24	.11		.19	.086		.18	.21		.18	.086
	.56	.26		.44	.20		.42	.48		.42	.20
	0.19	0.24		0.068	0.096		0.15	0.13		0.13	0.15
	.22	.29		.20	.32		.18	.18		.18	.28

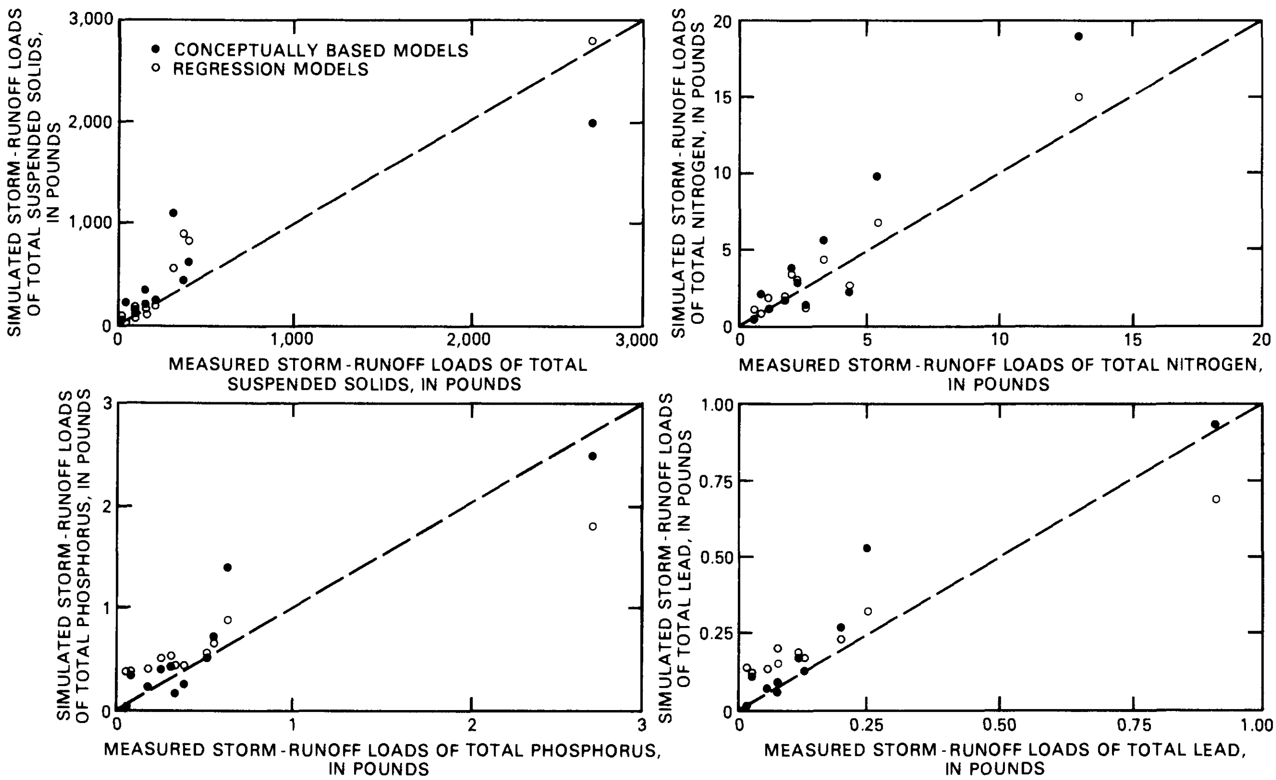

Figure 3.--Simulated versus measured storm-runoff loads for selected constituents for the verification data set for the North Avenue basin.

presented in tables 7 and 8. Simulated storm-runoff volume and peak flow are plotted against the measured values for the verification data set in figure 4. DR$_3$M-II was a more accurate simulator of both storm-runoff volumes and peak flows than REG. The total percentage difference for storm-runoff volumes and peak flows was significantly smaller for DR$_3$M-II than REG. Individual storm-runoff volumes simulated by the two models for all but the largest storms were comparable, although DR$_3$M-II had a slightly smaller MAD value. DR$_3$M-II was noticeably more accurate in simulating individual peak flows than was REG; DR$_3$M-II had much smaller RMSE and MAD values than did REG. However, much of the error was due to the fact that the regression model grossly underpredicted the storm of June 3, 1981.

Water-quality constituent-load data were available for only seven storms for this basin. Therefore, development of regression equations was not attempted.

Cherry Knolls Basin

In the Cherry Knolls basin, 13 storms were monitored for rainfall and runoff, of which 6 were selected for the calibration data set and 7 for the verification data set. A comparison of the measured values of storm-runoff volumes and peak flows with the simulated values predicted by DR$_3$M-II and REG

Table 7.--*Comparison of conceptually based and regression flow-model calibration results for the Northglenn basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second; dashes indicate not used for calibration]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1980						
May 8	0.02	0.02	0.02	3.0	3.4	3.2
May 11	.02	.02	.02	1.3	1.0	1.8
June 20	.01	.01	.01	--	--	--
August 15	.06	.07	.06	7.0	7.8	10
September 20	.06	.08	.07	11	13	14
1981						
May 3[1]	.04	.03	.03	5.2	4.1	3.9
May 3[2]	.08	.09	.06	29	27	24
May 12-13	.05	.05	.05	4.4	4.6	4.4
May 16-18	.24	.26	.26	7.7	7.7	6.9
July 11	.02	.02	.02	8.5	6.8	7.6
July 26	.10	.14	.12	25	28	33
August 22	.05	.07	.06	28	27	23
August 28	.01	.01	.01	--	--	--
Mean	.06	.07	.06	12	12	12
Total percentage difference		14	5		0.2	2.1
Root-mean-square error (RMSE)						
Untransformed, in percent		20	15		14	30
Log-transformed, in log units		.071	.085		.068	.101
Natural-log-transformed, in natural log units (LN).		.163	.196		.158	.231
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.010	0.008		1.14	2.36
Log-transformed, in log units		.053	.075		.055	.083

[1]First storm.
[2]Second storm.

Table 8.--*Comparison of conceptually based and regression flow-model verification results for the Northglenn basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second; dashes indicate not used for verification]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1980						
May 7-8	0.27	0.20	0.16	17	14	11
July 1-2	.02	.03	.03	5.0	3.7	3.8
July 2	.07	.09	.07	30	36	22
August 25-26	.03	.04	.04	5.4	4.7	5.8
August 26-27	.06	.07	.06	16	18	15
1981						
April 19-20	.05	.07	.06	6.6	5.3	6.5
June 3	.37	.30	.19	[1]123	140	49
July 12	.01	.01	.01	--	--	--
August 9	.05	.05	.05	18	15	17
August 16	.01	.01	.02	--	--	--
Mean	.09	.09	.07	28	30	16
Total percentage difference		-7.4	-27		7.2	-41
Root-mean-square error (RMSE)						
Untransformed, in percent		15	12		9.4	14
Log-transformed, in log units		.093	.092		.060	.088
Natural-log-transformed, in natural log units (LN)		.22	.21		.14	.20
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.021	0.033		4.3	11
Log-transformed, in log units		.084	.12		.080	.12

[1]Estimated.

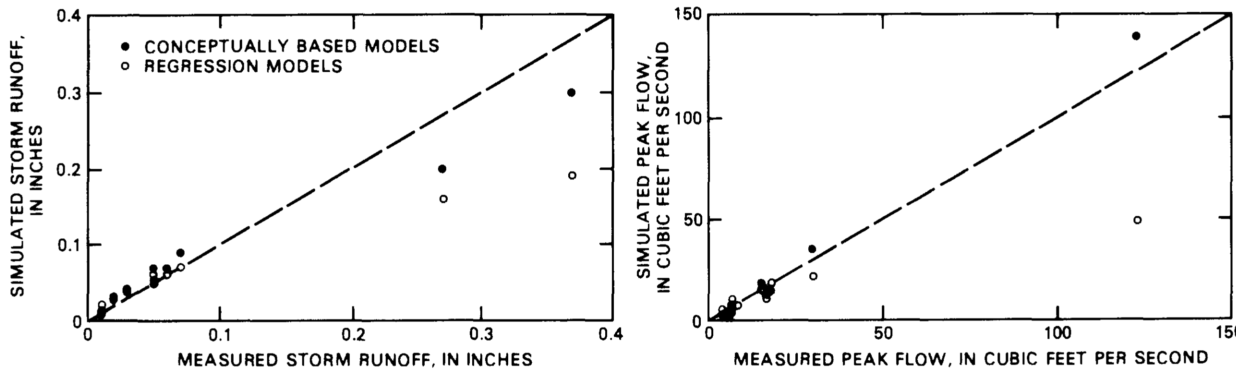

Figure 4.--Simulated versus measured storm-runoff volumes and peak flows for the verification data set for the Northglenn basin.

is presented in tables 9 and 10 and plotted in figure 5. REG had a smaller total percentage difference for storm-runoff volumes than did DR$_3$M-II. Individual storm-runoff volumes also seemed to be more accurately simulated by REG than by DR$_3$M-II; although the RMSE values were slightly larger for REG than for DR$_3$M-II, the MAD values for REG were much smaller than the values for DR$_3$M-II for the untransformed and log-transformed data. Peak flows were somewhat more accurately simulated by DR$_3$M-II; DR$_3$M-II had slightly smaller RMSE, MAD, and total percentage difference values for the untransformed and log-transformed data than did REG.

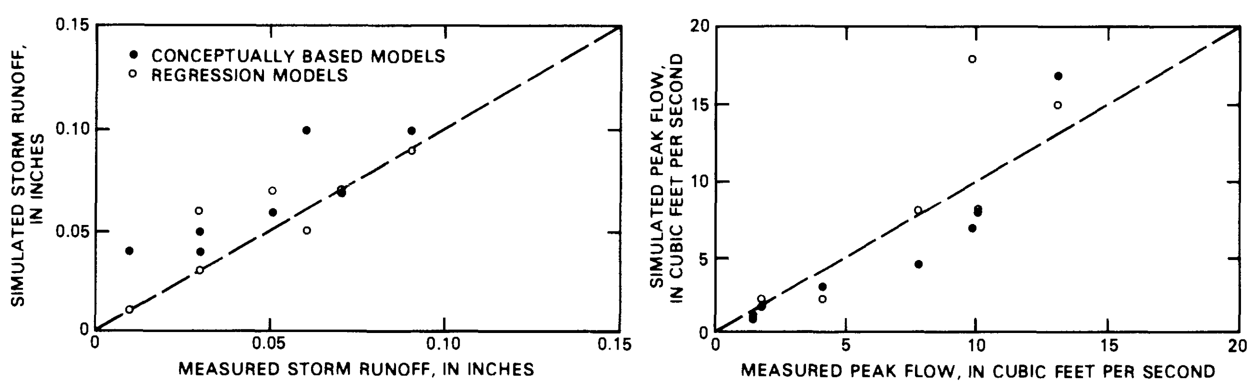

Figure 5.--Simulated versus measured storm-runoff values and peak flows for the verification data set for the Cherry Knolls basin.

Water-quality constituent data were available for eight storms for the Cherry Knolls basin. After calibration, DR$_3$M-QUAL was not able to be verified acceptably. Data that had been designated for the verification data set was included in the calibration data set, and the model was recalibrated, but no data were left for model verification. Therefore, the same procedure was followed for REG-QUAL, and all available data were added to the calibration data set. A comparison of the predictions of the two models with measured data is presented in table 11, and plotted in figure 6 for selected constituents.

Table 9.--*Comparison of conceptually based and regression flow-model calibration results for the Cherry Knolls basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1981						
May 3[1]	0.02	0.02	0.02	2.6	2.0	2.2
May 27-28	.03	.04	.03	2.9	2.1	3.4
June 11-12	.13	.12	.13	16	15	16
June 29	.04	.04	.04	8.0	4.7	6.9
July 12	.12	.12	.12	9.8	5.2	9.3
August 9	.03	.05	.03	2.3	1.6	3.4
Mean	.06	.06	.06	6.9	5.1	6.9
Total percentage difference		5.4	0		-26	0
Root-mean-square error (RMSE)						
Untransformed, in percent		14.4	2.7		25	12.6
Log-transformed, in log units		.097	.025		.098	.093
Natural-log-transformed, in natural log units (LN)		.223	.057		.225	.214
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.00667	0.000951		1.833	0.6615
Log-transformed, in log units		.0636	.0413		.1577	.0673

[1]First storm.

Table 10.--*Comparison of conceptually based and regression flow-model verification results for the Cherry Knolls basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1981						
May 3[1]	0.09	0.10	0.09	13	17	15
May 3-4	.01	.04	.01	1.8	1.7	2.2
May 12-13	.03	.05	.03	1.5	1.0	.97
May 28	.03	.04	.06	9.8	7.0	18
May 29	.06	.10	.05	4.1	3.1	2.2
July 7	.07	.07	.07	10	8.1	8.1
July 26-27	.05	.06	.07	7.7	4.6	8.1
Mean	.05	.07	.05	6.8	6.1	7.8
Total percentage difference		35	12		-11	14
Root-mean-square error (RMSE)						
Untransformed, in percent		29	30		37	51
Log-transformed, in log units		.10	.14		.12	.18
Natural-log transformed, in natural log units (LN).		.23	.32		.28	.42
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.017	0.0086		1.9	2.2
Log-transformed, in log units		.19	.075		.13	.14

[1]Second storm.

Table 11.--*Comparison of conceptually based and regression*

[Measured and simulated

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N		
	Measured	Simulated		Measured	Simulated		Measured	Simulated	
		DR_3M-QUAL	REG-QUAL		DR_3M-QUAL	REG-QUAL		DR_3M-QUAL	REG-QUAL
1981									
May 12-------------	18	32	19	14	40	1.5	0.85	1.2	1.3
May 17-18----------	65	82	62	77	110	75	3.1	3.3	2.9
May 27-28----------	46	36	37	44	46	47	.80	1.1	.88
May 29-------------	33	40	35	25	51	31	1.3	1.6	1.8
June 29------------	59	55	54	130	86	110	2.2	2.0	1.8
July 7-------------	130	84	95	120	130	150	4.3	3.2	3.3
July 26-27---------	66	56	100	170	77	150	1.8	2.0	2.4
August 9-----------	28	35	39	32	52	47	.90	1.3	.66
Mean---------------	56	52	55	76	74	76	1.9	2.0	1.9
Total percentage difference-------		-5.6	-0.90		-3.3	0.08		3.2	0
Root-mean-square error (RMSE)									
Untransformed, in percent--------		21	31		35	24		9.7	21
Log-transformed, in log units.		.083	.11		.12	.34		.035	.12
Natural-log-transformed, in natural log units (LN).		.19	.25		.27	.79		.080	.28
Mean absolute deviation (MAD)									
Untransformed, in same units as measured data.		14	12		32	14		0.31	0.43
Log-transformed in log units.		.12	.083		.21	.19		.088	.11

quality-model calibration results for the Cherry Knolls basin

values are loads, in pounds]

Total phosphorus as P			Total lead			Total manganese			Total zinc		
	Simulated			Simulated			Simulated			Simulated	
Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL
0.07	0.12	0.08	0.02	0.04	0.05	0.02	0.04	0.02	0.03	0.05	0.04
.48	.37	.46	.08	.10	.07	.06	.12	.06	.11	.16	.10
.10	.14	.08	.05	.04	.03	.03	.05	.03	.05	.06	.05
.14	.18	.16	.04	.05	.06	.03	.06	.04	.06	.08	.06
.19	.26	.19	.12	.07	.08	.08	.07	.07	.13	.09	.10
.77	.42	.56	.16	.11	.14	.14	.12	.14	.19	.15	.19
.27	.23	.43	.07	.07	.09	.13	.07	.13	.12	.10	.16
.06	.15	.06	.02	.05	.02	.03	.04	.03	.04	.06	.04
.26	.23	.25	.07	.07	.07	.06	.07	.06	.09	.09	.09
	-10	-2.9		-5.4	-3.6		9.6	0		2.7	1.4
	14	32		23	28		41	8.5		28	23
	.061	.11		.11	.18		.13	.052		.092	.080
	.14	.25		.25	.41		.30	.12		.21	.18
	0.099	0.055		0.024	0.020		0.029	0.0025		0.028	0.011
	.18	.071		.17	.15		.21	.023		.14	.051

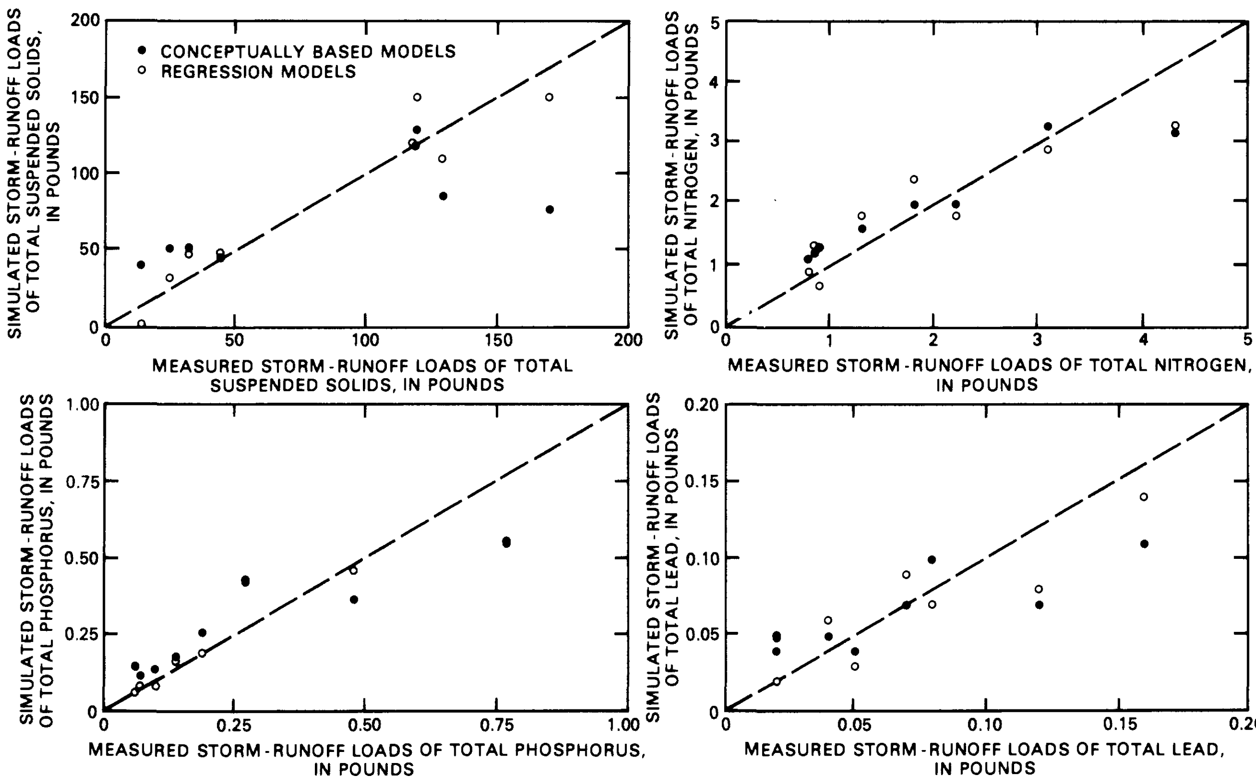

Figure 6.--Simulated versus measured storm-runoff loads for selected constituents for the verification data set for the Cherry Knolls basin.

For both models, the total percentage difference is within 10 percent for all water-quality constituents except total zinc.

The data presented here are the data that were used to calibrate the equation rather than verification data, so the small total percentage difference values are not unexpected. The REG-QUAL method, because of its nature, should result in compensating errors in the storm-runoff loads. Theoretically, coefficients in the regression equation can be adjusted on calibration until simulated values that are too large are balanced by some simulated values that are too small, and the total percentage difference is exactly zero. (Differences from zero primarily are due to rounding.) The DR_3M-QUAL also was calibrated to result in a small total percentage difference. However, because this model is conceptually based, the parameter values must make physical sense. In some instances, combinations of parameter values that are required mathematically to make the total percentage difference equal zero do not make physical sense, so the DR_3M-II calibration results may not equal zero.

Analysis of the RMSE and MAD values for both types of models indicate that there is very little difference in the abilities of the models to simulate individual storm-runoff loads, except for total manganese, where REG-QUAL produced more accurate estimates than did DR_3M-QUAL. However, in general, both models were able to be calibrated fairly accurately for individual storm-runoff loads.

Villa Italia Basin

The Villa Italia basin is unusual in that 91 percent of the basin is effective impervious area, consisting of buildings and parking lots. Pervious-area runoff contribution virtually is nonexistent. The DR_3M-II and REG were calibrated using data from 9 storms and verified using data from 12 storms. A comparison of the simulated storm-runoff volumes and peak flows simulated by the two models are presented in tables 12 and 13. Comparisons for the verification data set also are plotted in figure 7.

DR_3M-II and REG produced comparable values of total percentage differences, RMSE, and MAD for storm-runoff volume. The differences between the results of the two types of models is well within the error of the measured data. However, REG greatly overestimated the three largest peak flows in the verification data set, whereas DR_3M-II simulated the three largest peak flows within the accuracy of the measured data. The Villa Italia basin has a storm-sewer network that limits the peak flow to about 80 cubic feet per second. No storms producing flows of this magnitude were included in the calibration data set of the earlier DR_3M-II study, and, therefore, they were not included in the calibration of REG either. REG was not able to accurately simulate peak flow in response to intense rainfall that would cause a flow of more than 80 cubic feet per second, but accurate simulation was possible using DR_3M-II. DR_3M-II, with the physical description of the drainage features of the basin, was able to account for the limited capacity of the storm-sewer network. More careful division of available data into calibration and verification data sets may be able to produce more accurate results for basins with complex drainage networks than those obtained in this analysis. Of course, it is not desirable to extrapolate with any model so far beyond the range of calibration data. What is important here (or probably in any complex basin) is that given the same limited calibration data, the conceptually based model was far more effective at extrapolation than the regression model. This feature would make the conceptually based models more useful in some applications.

Water-quality constituent data from six storms were available for calibration, but DR_3M-QUAL was difficult to calibrate for the Villa Italia basin. This difficulty was due to the difficulty in determining the storm-runoff loads and physical factors not accounted for in this application of the model. Storm-runoff loads could not be accurately determined because of variations in base flow during many of the storms. Because storm-runoff load is defined as the total-runoff load minus the base-flow load (if base flow is present during the storm runoff), inaccurate estimation of base-flow loads could result in inaccurately calculated storm-runoff loads. The storms for which base flow was present are tabulated in Lindner-Lunsford and Ellis, (1984, table 6), or in Gibbs and Doerfer (1982). Physical factors affecting storm-runoff loads that were not accounted for in the modeling include vehicular traffic during and between storms, quantity of water, water-quality constituents transported into the basin by various means, time since the parking lots were swept, and the efficiency of each sweeping of the parking lots.

Seven storms were used for the verification data set for DR_3M-QUAL and REG-QUAL. A comparison of the measured and simulated values of DR_3M-QUAL and REG-QUAL are presented in tables 14 and 15, and data for selected constituents in the verification data set are plotted in figure 8.

Table 12.--*Comparison of conceptually based and regression flow-model calibration results for the Villa Italia basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1980						
July 1-2	0.37	0.37	0.37	21	19	24
July 30	.04	.03	.04	4.8	3.5	6.0
August 7	.05	.04	.05	11	8.8	16
August 10	.03	.02	.02	3.4	2.0	2.5
August 25	.30	.28	.29	23	22	28
September 8	.03	.02	.03	4.5	3.2	5.6
September 10[1]	.05	.06	.06	2.2	3.4	3.5
September 10[2]	.05	.07	.06	19	21	20
September 20	.14	.13	.15	33	24	26
Mean	.12	.11	.12	13.5	11.9	13.4
Total percentage difference		-3.8	0		-12	-0.8
Root-mean-square error (RMSE)						
Untransformed, in percent		0.11	7.6		20	24
Log-transformed, in log units		.111	.067		.133	.114
Natural-log-transformed, in natural log units (LN)		.257	.155		.307	.263
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.0111	0.00654		2.378	2.154
Log-transformed, in log units		.0957	.0434		.1162	.0855

[1]First storm.
[2]Second storm.

Table 13.--*Comparison of conceptually based and regression flow-model verification results for the Villa Italia basin*

[Storm-runoff volume is in inches; peak flow is in cubic feet per second]

Storm date	Storm-runoff volume			Peak flow		
	Measured	Simulated		Measured	Simulated	
		DR_3M-II	REG		DR_3M-II	REG
1981						
March 20	0.08	0.08	0.10	10	6.8	8.0
April 19	.28	.27	.28	33	19	25
April 20	.49	.49	.47	77	67	110
May 3[1]	.14	.13	.14	14	6.9	9.4
May 3[2]	.08	.08	.06	22	16	13
May 3[3]	.04	.06	.05	4.6	4.1	3.0
May 12-13	.26	.29	.29	13	11	13
May 16	.25	.24	.25	8.8	11	12
May 17-18	.70	.70	.68	14	15	29
June 3[4]	.91	.89	.84	77	91	250
July 12	.11	.11	.12	12	11	13
July 26[4]	.81	.79	.79	66	74	130
Mean	.35	.34	.34	29	28	51
Total percentage difference		-0.48	-1.9		-5.3	75
Root-mean-square error (RMSE)						
Untransformed, in percent		3.8	5.1		26	120
Log-transformed, in log units		.050	.058		.13	.20
Natural-log transformed, in natural log units (LN).		.11	.13		.30	.46
Mean absolute deviation (MAD)						
Untransformed, in same units as measured data.		0.010	0.018		5.7	26
Log-transformed, in log units		.026	.040		.11	.19

[1]First storm.
[2]Second storm.
[3]Third storm.
[4]Measured storm-runoff volume adjusted for flow that bypassed gage.

Table 14.--*Comparison of conceptually based and regression*

[Measured and simulated

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N		
		Simulated			Simulated			Simulated	
	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL	Measured	DR_3M-QUAL	REG-QUAL
1980									
July 1-2	730	930	510	570	1,000	530	20	27	15
August 25	440	570	470	260	550	290	11	12	13
September 8-9	520	770	630	190	800	210	16	23	20
1981									
March 20	170	110	380	260	95	230	7.2	2.1	8.4
May 27	560	490	410	890	470	920	10	12	10
July 26	710	730	720	1,300	850	1,300	25	29	24
Mean	520	600	520	580	630	580	15	18	15
Total percentage difference		15	0		8.5	0		18	0
Root-mean-square error (RMSE)									
Untransformed, in percent.		27	21		60	6		24	21
Log-transformed, in log units.		.109	.089		.396	.045		.209	.081
Natural-log-transformed, in natural log units (LN).		.251	.488		.911	.103		.482	.186
Mean absolute deviation (MAD)									
Untransformed, in same units as measured data.		122	120		394	27		4.35	2.26
Log-transformed, in log units.		.108	.125		.349	.032		.167	.064

quality-model calibration results for the Villa Italia basin

values are loads, in pounds]

Total phosphorus as P			Total lead			Total manganese			Total zinc		
Measured	Simulated DR_3M-QUAL	Simulated REG-QUAL	Measured	Simulated DR_3M-QUAL	Simulated REG-QUAL	Measured	Simulated DR_3M-QUAL	Simulated REG-QUAL	Measured	Simulated DR_3M-QUAL	Simulated REG-QUAL
1.5	3.3	1.3	0.80	1.67	0.52	1.1	0.94	0.76	1.3	2.0	0.80
1.3	1.6	1.3	.47	.56	.63	.36	.76	.51	.66	.88	.92
1.3	2.3	1.4	.33	.83	.40	.54	.95	.73	.86	1.3	.67
.43	.62	.48	.32	.22	.40	.26	.28	.24	.32	.33	.67
1.1	1.5	1.0	.92	.48	.72	.61	.66	.60	.93	.75	1.0
4.0	2.4	4.3	1.1	1.0	1.3	1.5	.88	1.6	2.1	1.3	2.1
1.6	2.0	1.6	.66	.79	.66	.73	.74	.73	1.0	1.1	1.0
	22	0		21	0		2	0		6	0
	56	10		78	33		31	27		49	29
	.175	.050		.288	.120		.160	.117		.169	.140
	.403	.115		.664	.277		.369	.269		.390	.321
	0.882	0.132		0.350	0.169		0.277	0.126		0.392	0.243
	.199	.037		.214	.114		.156	.082		.134	.141

Table 15.--*Comparison of conceptually based and regression*

[Measured and simulated

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N		
	Measured	Simulated		Measured	Simulated		Measured	Simulated	
		DR_3M-QUAL	REG-QUAL		DR_3M-QUAL	REG-QUAL		DR_3M-QUAL	REG-QUAL
1980									
July 6-------------	240	100	380	160	100	490	7.1	2.6	8.4
July 30------------	140	280	350	200	290	410	6.9	6.5	7.0
August 10----------	470	270	340	200	280	190	4.0	6.8	6.6
September 8--------	210	110	350	130	110	1,000	4.4	2.5	6.8
September 10[1]------	100	120	360	61	140	650	9.5	6.1	7.4
1981									
May 3[2]-------------	380	340	350	52	330	220	6.7	8.0	7.2
May 16-------------	790	330	450	600	320	530	14	10	12
Mean---------------	330	220	370	200	220	500	7.5	6.1	7.9
Total percentage difference-------		-33	11		12	150		-19	5.3
Root-mean-square error (RMSE)									
Untransformed, in percent.		27	8.8		51	150		32	12
Log-transformed, in log units.		.21	.039		.24	.28		.23	.055
Natural-log-transformed, in natural log units (LN).		.49	.090		.56	.64		.52	.13
Mean absolute deviation (MAD)									
Untransformed, in same units as measured data.		160	180		130	320		2.6	1.6
Log-transformed in log units.		.24	.26		.29	.49		.19	.099

[1]First storm.
[2]Second storm.

quality-model verification results for the Villa Italia basin

values are loads, in pounds]

Total phosphorus as P			Total lead			Total manganese			Total zinc		
	Simulated			Simulated			Simulated			Simulated	
Measured	DR3M-QUAL	REG-QUAL	Measured	DR3M-QUAL	REG-QUAL	Measured	DR3M-QUAL	REG-QUAL	Measured	DR3M-QUAL	REG-QUAL
0.35	0.38	0.48	0.25	0.12	0.40	0.21	0.15	0.37	0.32	0.21	0.67
1.4	1.2	.30	.52	.41	.40	.39	.32	.24	1.1	.65	.67
.71	1.1	.16	.32	.40	.26	.42	.32	.14	.53	.63	.54
.36	.43	.27	.15	.13	.45	.17	.15	.47	.28	.24	.67
.65	.43	.25	.20	.13	.26	.26	.19	.29	.35	.24	.54
.78	1.2	.23	.17	.38	.26	.23	.42	.18	.32	.70	.54
1.5	.99	.81	1.2	.29	.40	.84	.54	.54	1.2	.58	.67
.82	.82	.36	.40	.27	.34	.36	.30	.32	.59	.46	.61
	-.35	-57		-34	-15		-17	-12		-21	4.9
	.37	.26		36	18		27	42		35	12
	.16	.25		.25	.10		.15	.24		.21	.051
	.36	.56		.57	.23		.35	.54		.47	.12
	0.26	0.50		0.22	0.22		0.12	0.18		0.26	0.30
	.13	.40		.25	.23		.14	.25		.20	.23

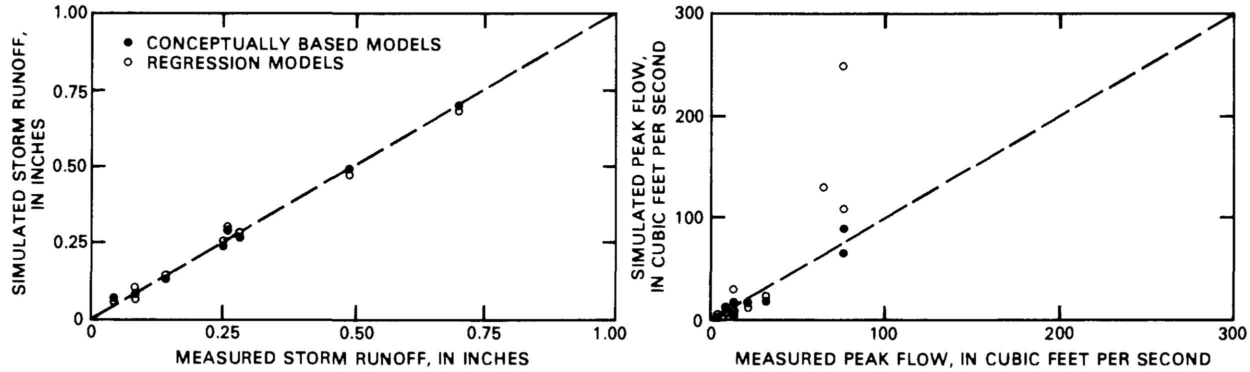

Figure 7.--Simulated versus measured storm-runoff volumes and peak flows for the verification data set for the Villa Italia basin.

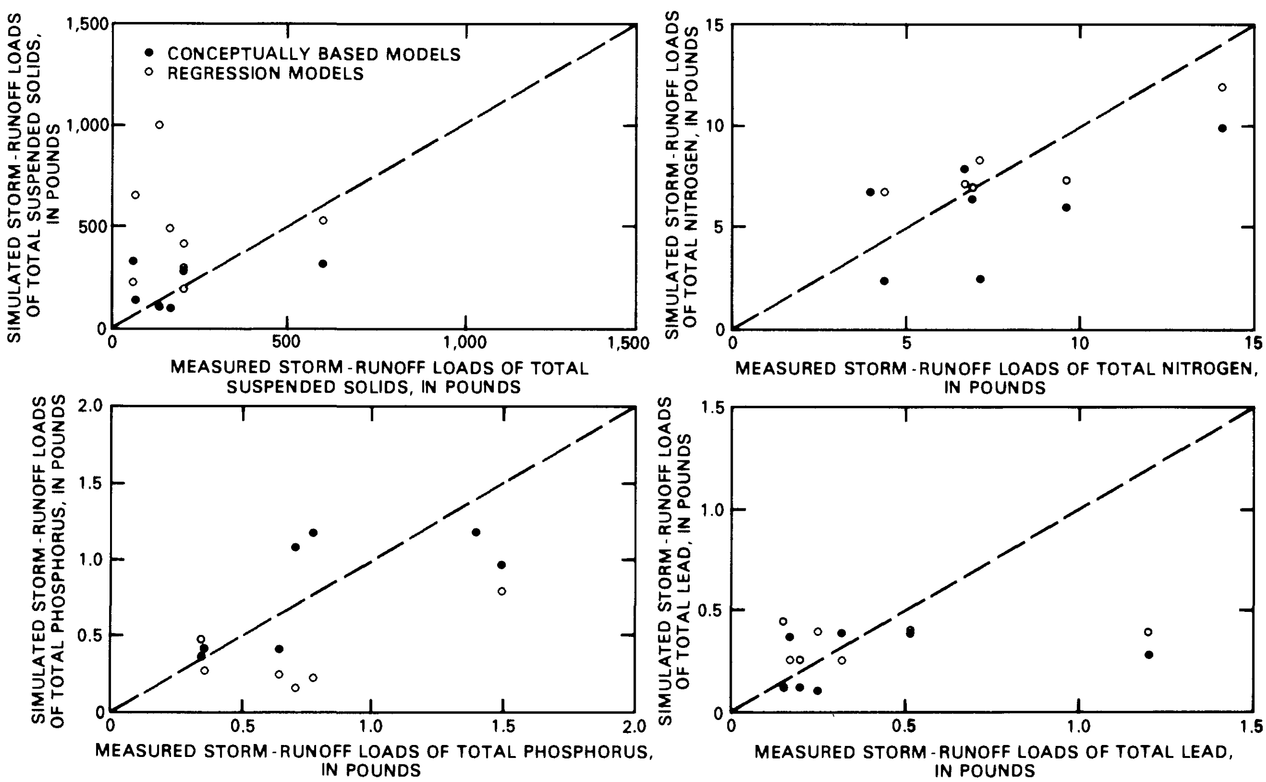

Figure 8.--Simulated versus measured storm-runoff loads for selected constituents for the verification data set for the Villa Italia basin.

Neither DR_3M-QUAL nor REG-QUAL was capable of simulating total or individual storm-runoff loads very accurately. RMSE and MAD values for both types of models are very large when compared to the mean of the measured values; thus, any estimate of storm-runoff loads from individual storms could contain large errors. At best, the models could be used to simulate total storm-runoff loads on a seasonal basis to an acceptable degree of accuracy for planning purposes.

POTENTIAL APPLICATIONS IN URBAN AREAS

The comparison between conceptually based and regression models in this report is a site-specific comparison, but the concepts are transferable to other urban areas. Ellis and others (1984) have determined that regression models may be regionalized for the Denver metropolitan area. The results of Ellis and others (1984) and Driver and Lystrom (1986) indicate that the urban-runoff process is not unique or site specific, but the urban-runoff process is similar in areas with similar yearly precipitation. Therefore, the conclusions of this study should be valid for other semiarid areas.

Comparison of estimates of storm-runoff quantity and quality from urban areas produced by multievent, conceptually based and single-event multiple linear-regression models for small urban basins in the Denver metropolitan area has indicated a need for careful consideration of the type of storm-runoff model to apply in a given situation. The estimates obtained from the conceptually based models generally are no more accurate than those of the regression models. Choice of which type of model to use then becomes a question of context; the questions that the study addresses need to be examined in terms of the types of predictions needed and whether the greater detail required by the conceptually based models is justified by the necessity of producing vastly more detailed results.

Both the conceptually based and regression models provided accurate estimates of storm-runoff volumes (usually within 0.02 inch). Because, for most storms in semi-arid regions, only the effective impervious areas contributed runoff, even simple calculations could provide estimates of storm-runoff volumes. For small storms, storm-runoff volume can be calculated by:

$$RO = (RF \cdot EIA) - IR, \qquad (5)$$

where RO = storm-runoff volume, in inches;
RF = rainfall, in inches;
EIA = effective impervious area, expressed as a percentage of total basin area; and
IR = depth of impervious retention, in inches,

as shown in Lindner-Lunsford and Ellis (1984, p. 15). Therefore, if the purpose of a study is just to obtain an estimate of storm-runoff volume, it is not necessary to use a complex model.

Peak flows for most basins also can be simulated reasonably accurately by both conceptually based and regression models. Peak flows from basins that have simple drainage networks can be simulated using a regression model; thus the more time-consuming and data-intensive conceptually based models need not be applied to these basins. Peak flows from basins that contain complex drainage networks, such as the Villa Italia basin in this study, can be more accurately simulated using conceptually based models.

A consistent disadvantage of the regression models when compared to the conceptually based models is that the regression models are incapable of making accurate predictions outside of the range of data in the calibration data set. In this study, the choice of which storms from a given basin were to be included in the calibration data set and which were to be included in the verfication data set was biased toward a division of storms that would better represent the real world--calibrations on limited data, usually small storms, and applications on larger storms. When the conceptually based part of the study was conducted there were no plans to model the same data using a regression model and, hence, there was no incentive to divide the storms in a manner that might aid development of a regression model. Because the regression model is less physically based, it is more important to have a full range in sizes of storms in the calibration data set for this model than it is for the conceptually based model. The fact remains, however, that the conceptually based model was more accurate in prediction of runoff characteristics for storms of a magnitude outside of the range of calibration than the regression model. In particular, peak flows in the verification data sets for the Northglenn and Villa Italia basins were larger than any in the calibration data sets for these two basins. For the Northglenn basin, the largest measurement of peak flow in the calibration data set was 29 cubic feet per second, compared to a peak-flow measurement of 123 cubic feet per second in the verification data set. The largest peak-flow measurement in the calibration data set for the Villa Italia basin was 33 cubic feet per second; the verification data set had measurements from three storms whose peak flows were twice this flow or more.

Multievent models as opposed to single-event models of either the conceptually based or the regression type may not be necessary in the Denver area, except possibly for flood-frequency studies. For all but the largest storms in this study, about 90 percent or more of the total runoff originated from the impervious areas. Therefore, the multievent, conceptually based model was not very sensitive to previous rainfall or soil-moisture conditions. The single-event, multiple linear-regression model also indicated that antecedent conditions were not significant in the simulation of peak flows. Few coefficients are shown in the antecedent dry days and storm-duration columns of table 2. These variables would affect runoff from pervious soil and have virtually no effect on runoff from effective impervious areas. The fact that these variables are not significant may indicate that pervious areas have little effect on rainfall-runoff in semiarid locations such as Denver. Multievent models may not be warranted, and single-event models may be considered as alternatives to multievent models for the simulation of storm-runoff volumes and peak flows for urban basins with over about 25 percent effective impervious area for the more frequent smaller storms in semiarid areas similar to the Denver metropolitan area.

Neither the multievent, conceptually based nor the single-event, multiple linear-regression models were capable of accurately simulating storm-runoff loads. The representation of accumulation and washoff processes of water-quality constituents on impervious surfaces used in the conceptually based model may be oversimplified. Small-scale, rainfall-simulation studies have verified the concept of nonlinear water-quality constituent accumulation and washoff (Mustard and others, 1985), but other factors appear to dominate in larger basins. Some of these factors include vehicular traffic, wind, and activities of people within the basin. Both vehicular traffic and wind can transport constituents into or out of basins. The direction of origin of the traffic or wind can transport different types of constituents. For example, traffic or wind from an urban area can transport nitrogen, carbon, or lead (from gasoline) into a basin, whereas traffic or wind from an open field can transport nitrogen and phosphorus compounds from decaying vegetation or soil particles. Vehicular traffic within the basin also can grind larger particles into smaller particles, which then can become adsorption surfaces for constituents, or increase the ability of constituents to dissolve in the runoff. Human activities, such as construction within a basin, obviously can alter the runoff characteristics of the basin by changing pervious areas into impervious areas, but more subtle processes such as household refuse-disposal practices, walking of pets, and disposal of leaves, grass, and oil also can greatly affect the quality of runoff from the basin. These processes are difficult to quantify and usually are not included in conceptually based models.

SUMMARY

Multievent, conceptually based models and single-event, multiple-linear regression models for predicting urban storm-runoff quantity and quality were compared with data from four small (57 to 167 acres) urban basins in the Denver metropolitan area. The basins represented different land-use types--light commercial, single-family housing, and multifamily housing. Both types of models were calibrated using the same data set for each basin. A comparison was made between storm-runoff volumes, peak flows, and storm-runoff loads of seven water-quality constituents simulated by the models, which used identical verification data sets. The multievent, conceptually based models studied were the U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model--Version II (DR_3M-II), the flow model--and the DR_3M-QUAL, the quality model. The regression models were developed by multiple linear regression analysis which used both log-transformed and untransformed data.

The regression models produced estimates of storm-runoff volumes that were comparable to those produced by the conceptually based model, but produced less accurate estimates of peak flows for three of the four basins. The peak-flow estimates from the regression models were more accurate than those from the conceptually based model for only the North Avenue basin. The regression model was not capable of producing satisfactory estimates of peak flows for basins that had the more complex drainage networks, such as the Villa Italia basin. The conceptually based model more accurately extrapolated predictions beyond the range of the data used for calibration; this was most apparent in predictions of peak flows for the larger or more intense storms at the Northglenn and Villa Italia basins.

The multievent conceptually based runoff-quality model, DR_3M-QUAL, was applied to three of the four basins--North Avenue, Cherry Knolls, and Villa Italia. Water-quality constituents modeled included chemical oxygen demand, total suspended solids, total nitrogen, total phosphorus, total lead, total manganese, and total zinc. DR_3M-QUAL was not noticeably more accurate than REG-QUAL in simulating any particular storm-runoff constituent load nor more accurate for any particular basin.

The results of the conceptually based runoff-quality model probably are not sufficiently accurate to be used to simulate an individual storm-runoff load of any water-quality constituent. The model did not accurately simulate the apparently complex accumulation and washoff of water-quality constituents on impervious surfaces in the Denver metropolitan area. Possible reasons for the failure of the model include: (1) The models do not account for all of the factors that affect water-quality-constituent accumulation and washoff; (2) storm-runoff loads could not be measured accurately and, therefore, accurate data for model calibration are not available; and (3) accumulation and washoff processes are not understood well enough to estimate physically based (as opposed to empirically determined) parameters.

The regression model (REG-QUAL) was applied to the same three small urban basins as DR_3M-QUAL. REG-QUAL was not applied to the Northglenn basin because the small number of storms in the calibration and verification data sets was insufficient to develop statistically significant regression relations. The regression model, as with the conceptually based model, generally was not capable of simulating storm-runoff loads of the selected water-quality constituents accurately.

Both multievent, conceptually based models, DR_3M-II and DR_3M-QUAL, and single-event regression models (REG and REG-QUAL) produced comparable results for storm-runoff volumes and storm-runoff loads for the small storms and small urban basins used in this study. Neither type of model is capable of simulating storm-runoff loads accurately enough to be useful for the prediction of individual water-quality constituent loads.

Calibration and verification of the conceptually based models is more costly and time consuming than for regression models, and about the same accuracy of prediction is obtainable from each. Regression models are not suitable for studies where detailed output hydrographs are needed, or where the simulations of the models will be required to be extended past the range of the calibration data set. For studies of small urban basins with greater than about 25 percent effective impervious area in semiarid areas such as the Denver metropolitan area, single-event regression models may be a viable alternative to multievent, conceptually based models in the simulation of storm-runoff volumes, peak flows, and storm-runoff loads.

REFERENCES CITED

Alley, W.M., and Smith, P.E., 1982a, Distributed routing rainfall-runoff model--Version II: U.S. Geological Survey Open-File Report 82-344, 199 p.

_____1982b, A multievent urban runoff quality model: U.S. Geological Survey Open-File Report 82-764, 175 p.

Driver, N.E., and Lystrom, D.J., 1986, Estimation of urban storm-runoff loads: *in* Urbonas, Ben, and Roesner, L.A., eds., Engineering Foundation Conference on Urban Runoff Quality, New England College, Henniker, N.H., 1986, Proceedings: New York, American Society of Civil Engineers, p. 122-132.

Ellis, S.R., Doerfer, J.T., Mustard, M.H., Blakely, S.R., and Gibbs, J.W., 1984, Analysis of urban storm-runoff data and the effects on the South PLatte River, Denver metropolitan area, Colorado: U.S. Geological Survey Water-Resources Investigations Report 84-4159, 66 p.

Ellis, S.R., and Mustard, M.H., 1984, A summary of urban runoff studies in the Denver metropolitan area, Colorado: U.S. Geological Survey Water-Resources Investigations Report 84-4072, 31 p.

Gibbs, J.W., 1981, Hydrologic data for urban storm runoff from nine sites in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 81-682, 142 p.

Gibbs, J.W. and Doerfer, J.T., 1982, Hydrologic data for urban storm runoff in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 82-872, 552 p.

Hardison, C.H., 1971, Prediction error of regression estimates of streamflow characteristics at ungaged sites, *in* Geological Survey Research, 1971: U.S. Geological Survey Professional Paper 750-C, p. C228-C236.

Helwig, J.T. ,and Council, K.A., 1979, SAS Users Guide: Raleigh, N.C., SAS Institute, Inc., 494 p.

Lindner-Lunsford, J.B., and Ellis, S.R., 1984, Calibration and verification of a rainfall-runoff model and a runoff-quality model for several urban basins in the Denver metropolitan area, Colorado: U.S. Geological Survey Water-Resources Investigations Report 83-4286, 52 p.

Miller, D.N., 1984, Reducing transformation bias in curve fitting: The American Statistician, v. 38, no. 2, p. 124-126.

Mustard, M.H., Ellis, S.R., and Gibbs, J.W., 1985, Runoff characteristics and washoff loads from rainfall-simulation experiments on a street surface and a native pasture in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 84-820, 44 p.

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