CALIBRATION AND VERIFICATION OF A RAINFALL-RUNOFF MODEL AND A RUNOFF-QUALITY MODEL FOR SEVERAL URBAN BASINS IN THE DENVER METROPOLITAN AREA, COLORADO

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

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4286

Prepared in cooperation with the

DENVER REGIONAL COUNCIL OF GOVERNMENTS

Lakewood, Colorado
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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METRIC CONVERSION FACTORS

The inch-pound units used in this report may be converted to the International System of Units (SI) by the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain SI unit*
acre	0.4047	hectare
cubic foot	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch	25.40	millimeter
inch per hour	25.40	millimeter per hour
mile	1.609	kilometer
pound	0.4536	kilogram

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ABSTRACT

The U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model--Version II (DR_3M-II) was calibrated and verified for five urban basins in the Denver metropolitan area. Land-use types in the basins were light commercial, multifamily housing, single-family housing, and a shopping center. The observation standard error of DR_3M-II predictions of peak flows and runoff volumes was within 35 percent for storms with runoff volume of greater than 0.01 inch for most sites.

The Distributed Routing Rainfall-Runoff Model-Quality (DR_3M-QUAL), a multievent urban runoff-quality model developed by the U.S. Geological Survey, was calibrated and verified for four of the five basins. DR_3M-QUAL was found to be more useful for the prediction of seasonal loads of constituents in the runoff resulting from rainfall than for the prediction of loads of constituents in the runoff resulting from individual storms. Simulated seasonal loads were within 33 percent of measured loads for all sites, but observation standard error in one basin was as much as 78 percent of the mean of individual storm loads.

INTRODUCTION

Urban runoff in the Denver metropolitan area (fig. 1) has been studied by Federal, State, and local agencies as well as by private firms for several years. Mathematical models of the processes of runoff from urban areas have been included in these studies since about 1975. Previous studies have used a variety of models including the Storm Water Management Model II (SWMM II), STORM, and Hydrocomp, developed by other agencies, and various U.S. Geological Survey rainfall-runoff models. This report describes one phase of a comprehensive urban study conducted in cooperation with the Denver Regional Council of Governments and is part of the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program (NURP). This report describes the process by which the U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model Version--II (DR_3-II) for predicting the quantity of storm runoff from urban areas (Alley and Smith, 1982a) and the U.S. Geological Survey's DR_3M-QUAL, a multievent urban-runoff quality model (Alley and Smith, 1982b) were calibrated and verified. The report also compares simulated with observed runoff volumes, peak flows, discharge hydrographs, and storm constituent loads for each basin.

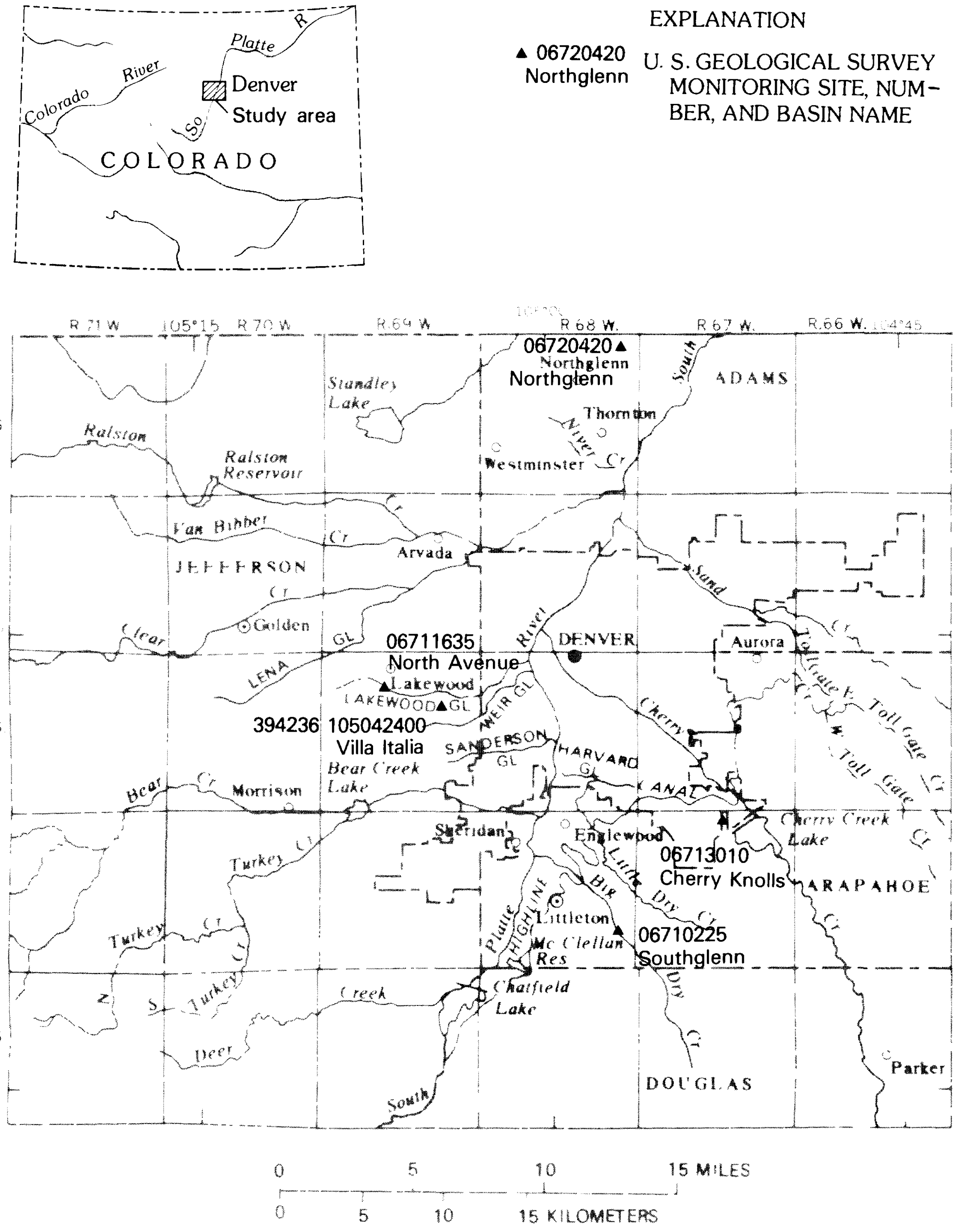

Figure 1.--Location of monitoring sites used in model calibration and verification, and general features of the study area.

BASIN DESCRIPTIONS

Six urban basins and one nearby rural basin were included in the comprehensive urban-runoff study. Rainfall-runoff models were calibrated for five of them and runoff-quality models were calibrated for four of them. (See table 1 and figure 1.) There was insufficient data to model the sixth basin. Because the models were not intended to be applied to rural basins, the rural basin was not modeled in this study. Because the soils of the rural and the urban basins are similar, the rural basin served as a good indicator of whether runoff from pervious portions of the urban basin was likely to have occurred. Most storms produced little or no runoff in the rural basin. The incremental storm data and a comprehensive description of the basins are given in Gibbs (1981) and Gibbs and Doerfer (1982).

The North Avenue basin is in southwest Lakewood, adjacent to the Denver Federal Center. Approximately 33 percent of the total area is multifamily housing, 30 percent light commercial land use (restaurants and office buildings), and 37 percent undeveloped land. The basin was included in a previous model study (Ellis, 1978, and Ellis and Alley, 1979).

The Northglenn basin, in eastern Northglenn, is the largest of the basins modeled. The land use in the basin is mainly single-family housing.

The Southglenn basin, in southwest metropolitan Denver, contains only multifamily housing and two small open areas (less than an acre each).

The Cherry Knolls basin is an area of multifamily housing in southeast Denver. There are 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.

The Villa Italia basin in eastern Lakewood contains about 90 percent of the Villa Italia Shopping Center. An unusually large proportion of the basin, about 91 percent, is effective impervious area--mostly parking lots. Effective impervious areas are those impervious areas that are directly connected to either the channel drainage system or to other effective impervious areas, such as a roof which drains onto driveways, streets, sidewalks, or paved parking lots. Runoff from the streets surrounding the shopping center does not enter the basin.

MODEL DESCRIPTIONS

DR_3M-II

DR_3M-II is a deterministic model designed to simulate urban storm-runoff quantity. 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 continuous simulation model, rather than a single-event model.

Table 1.--*Selected data for drainage basins used in calibration and verification of DR_3M-II and DR_3M-QUAL*

U.S. Geological Survey monitoring site		Name of monitored basin used in report	Location of monitoring site		Drainage area, in acres	Percentage of area covered by effective impervious surfaces	Predominant land use	Models calibrated and verified for basin
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	Light commercial and multifamily housing.	DR_3M-II and DR_3M-QUAL.
06710225	Big Dry Creek tributary at Easter Street, near Littleton.	Southglenn	39°35'17"	104°57'20"	33	41	Multifamily housing.	DR_3M-II
06720420	Storm Drain at 116th Avenue and Claude Court, at Northglenn.	Northglenn	39°54'23"	104°57'34"	167	24	Single-family housing.	DR_3M-II and DR_3M-QUAL.
06713010	Cherry Knolls storm drain, at Denver.	Cherry Knolls.	39°38'58"	104°52'47"	57	38	Multifamily housing.	DR_3M-II and DR_3M-QUAL[1]
394236105042400	Villa Italia storm drain, at Lakewood.	Villa Italia.	39°42'36"	105°04'24"	74	91	Commercial (shopping center).	DR_3M-II and DR_3M-QUAL.

[1]Not verified; see section on Cherry Knolls basin.

Input data required for detailed storm-runoff simulation include: (1) incremental precipitation data during storms (in this study, data were collected at 5-minute intervals) and daily rainfall for periods between storms chosen for detailed simulation; (2) soil-moisture and infiltration parameters and the depth of rain retained on impervious surfaces; (3) physical descriptions of the basin's drainage features, including a subdivision of the total drainage basin into homogeneous subbasins, each of which can be characterized by an average slope, roughness, and overland flow length, and the fraction of each subbasin that is effective impervious area; and (4) length, slope, roughness, and geometry of each segment of a channel network. Physical characteristics of the study basins and detailed aerial photographs of the basins showing the superimposed subbasin boundaries and channel network are published in Gibbs (1981).

DR_3M-QUAL

DR_3M-QUAL 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 accumulation and washoff is maintained.

DR_3M-QUAL can be run in either of two modes: (1) a distributed-parameter or (2) a lumped-parameter mode. The distributed-parameter mode requires flow hydrographs at many points in the basin as defined by basin segmentation. The lumped-parameter mode does not account for spatial variations in model parameters, and the input requires only flow hydrographs at the outlet of the basin. This report will present the lumped-parameter mode, because the limited water-quality data available does not support the detailed flow routing and multiple land-use simulation. Therefore no spatial variation in model parameters is accounted for in this study.

Input data required for calibration of DR_3M-QUAL are detailed flow values and constituent concentrations for the storm periods, daily rainfall during the entire simulation period, basin area, and percentage of effective impervious area in the basin. Detailed flow data, daily rainfall, basin area, and percentage of effective impervious area are the only data required to run the model in the predictive mode. Monthly rainfall-quality data can be included in the model to account for seasonal variations in rainfall quality. However, rainfall quality in the study area was found to be too variable from one storm to the next for a monthly average value to be meaningful. In addition, low concentrations of some of the constituents of interest meant that analytical error could be significant. Therefore, rainfall-quality data were not used in this study.

CALIBRATION AND VERIFICATION

Procedures

The DR_3M-II was calibrated and verified for total volume of runoff, peak flow, and hydrograph timing. The model was considered calibrated when the observation standard error (standard error of estimate x 100 ÷ mean observed value; abbreviated OSE in the rest of this report) for volume and peak flow was less than 35 percent. A verification data set consisting of about as many storms as for the calibration data set was then run using the calibrated parameters, and it was required that these results also be within 35 percent of the observed values for the calibration to be considered adequate. It proved impossible to meet these criteria at all of the sites.

The DR_3M-QUAL was calibrated and verified for total storm loads of selected constituents. Initially the model was to be considered calibrated when the simulated total load summed from all storms in the data set was within 25 percent of the observed load and the individual storm loads were within 50 percent. However, it was not possible to meet these criteria in many cases. Therefore, the criteria were modified to require only that the difference between observed and simulated total loads from all storms in each of the data sets be less than 35 percent, and individual storm-load differences were not considered. OSE's also were calculated. These ranged from 14 to 78 percent.

DR_3M-II

During the data-collection period, 1980-81, 109 storms were monitored at all sites, with between 14 and 32 storms monitored at each site. Approximately one-half of the storms were chosen for model calibration, and the other one-half for model verification. Runoff volume as a percentage of total rainfall volume, called "runoff-rainfall ratio," was calculated for each storm before the storm was included in the model-calibration or model-verification data set. The ratios generally were consistent for each basin, usually higher for intense storms, such as summer thunderstorms, and lower for less intense storms, such as spring rains. Storms that had runoff-rainfall ratios outside the normal range of ratios for each basin (usually due to insufficient or inaccurate rainfall or flow data) were excluded from the data sets. Storm data used in the calibration and verification of the models are presented in tables 2 through 6.

The simulated runoff volume was most sensitive to the percentage of effective impervious area (controlled by model parameter EAC) and maximum depth of impervious retention (model parameter IMP). (See table 7, page 15, for an explanation of model parameters.) Soil-moisture parameters had a less significant effect on the total runoff volume, because only 14 of the 109 storms had more than 10 percent of the total calculated runoff originating from pervious areas as determined by the model. Therefore, any effect that soil moisture had on total runoff volume would have been masked by the much greater effects of impervious area on runoff. Pervious-area runoff was most sensitive to values of saturated hydraulic conductivity (model parameter KSAT). These results are consistent with results reported by Ellis and Alley (1979), who used SWMM-II to model three basins in the Denver metropolitan area.

Table 2.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the North Avenue basin*

Storm Date	Storm Time	Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
1980								
May 8	1110-2100	0.02	0.24	0.12	2.8	50	3	0
May 11	1240-2030	.01	.07	.03	[3]2.1	43	0	0
May 12	0515-0730	.01	.03	.01	1.7	33	0	0
May 15-16	1315-1000	.02	.52	.23	3.8	44	12	0
May 17	0645-2000	.01	.28	.16	[4]2.6	57	7	0
July 24	1530-2130	.05	.13	.04	2.8	31	7	7
Aug. 10	1805-2125	.01	.05	.01	.70	20	0	1
Sept. 8-9	2130-1245	.03	.74	.33	5.1	44	7	7
Sept. 10[5]	0330-0755	.01	.08	.02	.99	25	0	0
Sept. 10[6]	1745-1935	.07	.15	.03	7.0	20	16	0
Sept. 20	0425-0840	.04	.21	.06	4.1	28	9	8
1981								
Mar. 3	0040-1655	.01	.17	.03	1.1	18	0	Not available
Apr. 19-20	1620-0035	.03	.37	.08	5.1	22	4	10
Apr. 20	1245-1455	.04	.07	.02	2.8	28	0	0
May 3[5]	0150-0705	.02	.22	.05	1.7	23	3	12
May 3[6]	1250-2400	.02	.14	.02	1.3	16	0	0
May 5	1545-1840	.01	.08	.01	1.4	14	0	1
May 9	0410-1335	.03	.38	.09	3.1	24	4	3
May 16	1025-1635	.01	.14	.03	.82	20	0	3
May 17-18	0505-0600	.02	.78	.25	2.4	33	3	0
May 28	1345-1520	.02	.04	.01	1.5	22	0	0

Table 2.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the North Avenue basin*--Continued

Storm: Date	Storm: Time	Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
1981--Continued								
May 28-29	2020-0710	0.02	0.22	0.07	2.5	30	1	0
June 2-3	0005-0540	.03	.28	.07	4.1	24	6	2
July 2	1535-2255	.02	.12	.03	2.4	25	0	3
July 15	1920-2200	.10	.20	.05	11	25	14	1
July 22	1640-1815	.02	.05	.01	1.1	18	0	5
Aug. 9-10	1200-0215	.07	.44	.14	9.4	31	7	13
Aug. 12	0830-1250	.01	.08	.02	1.5	23	0	2
Aug. 12-13	1915-0305	.04	.16	.04	4.9	28	4	0
Aug. 16	2000-2215	.02	.04	.01	.38	14	0	3
Aug. 29[7]	1905-2015	.01	.03	.01	1.1	22	0	6
Aug. 31	1720-1830	.01	.05	.01	1.1	15	0	1
Sept. 6-7	2210-0645	.02	.18	.06	1.7	33	0	5

[1]Calculated as: $\text{Runoff (inches)} = \frac{\text{Total runoff volume (cubic feet)}}{\text{total area of basin (acres)}} \times \frac{12}{43560}$

[2]Determined from unrounded values.

[3]Result from DR_3M-II model calculation.

[4]Some baseflow present.

[5]First storm.

[6]Second storm.

[7]Storm not used for flow model but used for water-quality model.

Table 3.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the Southglenn basin*

Storm: Date	Storm: Time	Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
1980								
May 15-16[4]	1235-0545	0.02	0.65	0.31	4.1	48	0	0
May 17[4]	0705-1640	.02	.39	.21	2.3	53	1	0
July 1[4]	1620-2400	.02	.27	.13	2.8	48	0	0
1981								
Apr. 19[5]	0810-0940	.01	.06	.01	.66	12	0	10
Apr. 19[6]	1620-2350	.02	.16	.04	1.5	22	0	0
May 3[5]	0245-0510	.03	.22	.05	2.4	21	0	13
May 3[6]	1315-1405	.16	.38	.12	[7]16	31	9	0
May 9	0350-0845	.02	.21	.05	1.3	22	0	2
May 12-13	2000-0500	.02	.29	.08	2.2	26	0	2
May 16	0545-0800	.02	.11	.03	1.4	25	0	2
May 17-18	0505-0240	.02	1.12	.34	2.5	30	2	0
May 28	0140-0350	.05	.25	.06	3.4	26	3	0
May 28-29	2255-0655	.05	.55	.16	5.2	29	7	0
June 11-12	2320-0155	.17	.71	.39	[4]26	55	19	7
July 17	1725-1850	.24	.59	.19	[4]25	32	11	0
July 26	1950-2400	.07	.64	.16	5.9	24	3	8

[1]Calculated as: $\text{Runoff (inches)} = \dfrac{\text{Total runoff volume (cubic feet)}}{\text{total area of basin (acres)}} \times \dfrac{12}{43560}$

[2]Determined from unrounded values.
[3]Result from DR_3M-II model calculation.
[4]These storms included for comparison only; not used for model calibration or verification.
[5]First storm.
[6]Second storm.
[7]Estimated peak discharge.

Table 4.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the Northglenn basin*

Storm Date	Storm Time	Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
1980								
May 7-8	1700-0505	0.04	0.81	0.27	17	34	12	0
May 8	1420-1715	.02	.11	.02	3.1	17	0	0
May 11	0655-1735	.01	.12	.02	1.3	15	0	1
June 20	1720-1820	.06	.09	.01	7.7	16	0	21
July 1-2	1610-0015	.02	.19	.02	5.0	12	0	5
July 2	1555-1955	.12	.38	.07	30	19	5	0
Aug. 15	0045-1130	.05	.37	.06	7.0	15	1	0
Aug. 25-26	2130-0010	.03	.24	.03	5.4	13	2	5
Aug. 26-27	2120-0135	.08	.34	.06	16	18	3	0
Sept. 20	0355-0630	.07	.39	.06	11	17	4	7
1981								
Apr. 19-20	0655-0115	.03	.35	.05	6.6	15	0	10
May 3[4]	0145-0430	.02	.20	.04	5.2	22	0	12
May 3[5]	1445-2315	.14	.37	.08	29	22	4	0
May 12-13	1945-0015	.02	.31	.07	5.0	22	0	2
May 16-18	1220-0220	.02	1.2	.24	7.7	20	0	2

Table 4.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the Northglenn basin*--Continued

Storm		Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
Date	Time							
1981--Continued								
June 3	1405-1650	0.22	0.93	0.37	[6]123	39	34	0
July 11	1915-2050	.05	.16	.02	8.5	12	0	3
July 12	2055-2205	.03	.09	.01	2.9	12	0	0
July 26	1835-2400	.16	.62	.10	25	17	8	0
Aug. 9	1155-2240	.10	.29	.05	18	17	2	13
Aug. 16	1505-1625	.04	.11	.01	4.2	10	0	5
Aug. 22	1335-1510	.14	.34	.05	28	16	6	5
Aug. 28	1925-1810	.08	.10	.01	8.7	13	0	5

[1]Calculated as: $\text{Runoff (inches)} = \frac{\text{Total runoff volume (cubic feet)}}{\text{total area of basin (acres)}} \times \frac{12}{43560}$

[2]Determined from unrounded values.

[3]Result from DR_3M-II model calculation.

[4]First storm.

[5]Second storm.

[6]Estimated peak discharge.

Table 5.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the Cherry Knolls basin*

Storm Date	Storm Time	Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
1981								
May 3[4]	0300-0510	0.03	0.16	0.02	2.6	10	0	12
May 3[5]	1320-1420	.14	.36	.09	13	24	14	0
May 3-4	2120-0240	.03	.14	.01	1.8	6	0	0
May 12-13	2000-0100	.02	.28	.03	1.5	10	0	2
May 17-18[6]	0420-0125	.02	1.14	.14	2.3	12	3	0
May 27-28	2015-0355	.04	.26	.03	2.9	13	6	0
May 28	1425-1855	.16	.18	.03	9.8	19	2	0
May 29	0120-0625	.03	.35	.06	4.1	16	2	0
June 11-12	2330-0120	.15	.54	.13	16	25	21	7
June 29	1710-1905	.07	.20	.04	8.0	18	0	2
July 7	1715-1925	.08	.34	.07	10	22	17	4
July 12	1600-2135	.09	.62	.15	9.8	25	6	0
July 26-27	2015-0020	.08	.38	.05	7.7	14	6	6
Aug. 9	1200-2350	.04	.27	.03	2.3	10	0	13

[1]Calculated as: $\text{Runoff (inches)} = \frac{\text{Total runoff volume (cubic feet)}}{\text{total area of basin (acres)}} \times \frac{12}{43560}$

[2]Determined from unrounded values.

[3]Result from DR_3M-II model calculation.

[4]First storm.

[5]Second storm.

[6]Storm not used for flow model calibration or verification but used for water-quality model.

Table 6.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the Villa Italia basin*

Storm		Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
Date	Time							
1980								
July 1-2	1555-0025	0.03	0.44	0.37	21	84	0	0
July 11	1845-2215	.02	.13	.05	4.8	[4]38	0	9
July 30	1800-1925	.02	.06	.04	5.8	67	0	5
Aug. 7	1910-2005	.05	.07	.05	13	71	0	0
Aug. 10	1810-1925	.01	.04	.03	4.9	75	0	2
Aug. 25	2130-2400	.04	.34	.30	23	88	0	0
Sept. 8	1100-1645	.02	.05	.03	4.5	60	0	8
Sept. 10[5]	0015-0555	.01	.08	.05	50	63	0	0
Sept. 10[6]	1750-1830	.06	.08	.05	19	63	0	0
Sept. 20	0455-0550	.05	.19	.14	33	74	0	9
1981								
Mar. 20	1725-1855	.02	.13	.08	10	62	0	2
Apr. 19-20	1615-0040	.04	.33	[7].28	33	84	0	10
Apr. 20	1255-1435	.14	.55	.49	77	89	0	0
May 3[5]	0215-0525	.02	.18	[7].14	14	79	0	12
May 3[6]	1310-1425	.04	.09	[7].08	22	88	0	0

Table 6.--*Summary of rainfall-runoff data for storms used in calibration and verification of the models for the Villa Italia basin*--Continued

Storm Date	Storm Time	Maximum 5-minute rainfall (inches)	Total rainfall (inches)	Total runoff[1] (inches)	Maximum discharge (cubic feet per second)	Runoff-rainfall ratio[2] (percent)	Percent of total runoff originating on pervious areas[3]	Number of antecedent days with less than 0.01 inch of precipitation
1981--Continued								
May 3[8]	2100-2310	.01	.07	[7].04	4.6	58	0	0
May 12-13	2025-0400	.02	.35	[7].26	13	74	0	2
May 16	0840-1610	.02	.30	[7].25	8.8	83	0	2
May 17-18	0505-0130	.03	.79	[7].70	14	88	0	0
June 2-3	1855-0200	.24	.71	[9].49	[9]75	69	1	0
June 3	1425-1630	.24	.97	[7].91	77	94	1	0
July 12	2050-2300	.03	.15	[7].11	12	72	0	0
July 26	1920-2350	.13	.91	.81	66	89	0	3

[1]Calculated as: $\text{Runoff (inches)} = \frac{\text{Total runoff volume (cubic feet)}}{\text{total area of basin (acres)}} \times \frac{12}{43560}$

[2]Determined from unrounded values.

[3]Result from DR_3M-II model calculation.

[4]Storm not used for flow model calibration or verification but used in water-quality model.

[5]First storm.

[6]Second storm.

[7]Some baseflow present.

[8]Third storm.

[9]A small amount of the peak flow bypassed the gage.

Table 7.--*Definition of parameters used in DR_3M-II*

[Modified from Alley and Smith, 1982a]

ALPADJ	- A calibration factor for slope and roughness used in routing.
BMSN	- Soil-moisture storage at field capacity, in inches.
EAC	- A multiplication factor to adjust the initial estimates of effective impervious area. Effective impervious areas are those impervious surfaces that are directly connected to the channel drainage system.
EVC	- A pan coefficient for converting measured pan evaporation to potential evapotranspiration.
IMP	- The maximum depth of rainfall held in irregularities in impervious surfaces and unable to run off, in inches.
KSAT	- The effective saturated value of hydraulic conductivity, in inches per hour.
PSP	- Suction at wetting front for soil moisture at field capacity, in inches.
RGF	- Ratio of suction at the wetting front for soil moisture at wilting point to that at field capacity.
RR	- The proportion of daily rainfall that infiltrates into the soil for the period of simulation, excluding days for which detailed rainfall-runoff simulations are performed.

Calibration procedures for DR_3M-II were similar for all basins. In a preliminary model run, runoff volumes were optimized by adjusting KSAT and EAC (table 7). Impervious retention was held constant at an initial estimate of 0.05 for this simulation. The preliminary runs also were used to identify the storms for which the model predicted no pervious-area runoff. These storms were analyzed to obtain a more realistic value for impervious retention. The impervious retention for these small storms theoretically should be represented by the equation:

$$IMP=R_t \times EIA-R_o \qquad (1)$$

where IMP is the impervious retention, in inches;
R_t is rainfall depth, in inches;
R_o is runoff volume, in inches; and
EIA is effective impervious area, as a decimal fraction.

Therefore, the value of impervious retention is equal to the intercept of a line fitted through a plot of rainfall against runoff. This is a plot of equation 1. The resulting value of impervious retention (IMP) and the optimized values of KSAT and EAC were entered into the model, and KSAT and EAC were again optimized. The new optimized values of KSAT, EAC, and IMP were held constant, and the model was optimized on the other soil-moisture and infiltration parameters and pan-evaporation coefficient. Starting values and ranges for these parameters were those suggested by Alley and Smith (1982a).

During the next optimization run, the soil moisture, infiltration, and impervious retention were held constant and the model optimized again for KSAT and EAC. The observed runoff volume was compared with the model-simulated runoff volume for each storm in the calibration data set, and if the OSE was less than 35 percent, the model was considered calibrated for runoff volumes. The optimization procedure was repeated if the OSE was greater than 35 percent.

The verification procedure was to enter the verification data set into the model and allow the model to simulate runoff volume without adjusting any model parameters. If the OSE was less than 35 percent, the model was considered calibrated and verified for runoff volume. If the OSE was more than 35 percent, the model was recalibrated and verification was attempted again.

The next step after the model was calibrated for runoff volume was to calibrate the model for peak flow and, to a lesser extent, hydrograph timing. DR_3M-II is most sensitive to segment slope and roughness when simulating peak flow and hydrograph timing. Roughness and slope of the channels or subbasins are included in the model in the variable alpha:

$$\text{alpha}=K\sqrt{S/N} \qquad (2)$$

where K is a constant which depends on the geometry of the channel or subbasin;
S is the segment slope, in feet per foot; and
N is the Manning roughness coefficient, n, (a measure of roughness) (Alley and Smith, 1982a).

ALPADJ is a model parameter that modifies the value of alpha. A value of ALPADJ greater than 1 effectively increases the slope and decreases the roughness, resulting in an increased peak flow and decreasing the time to the peak since start of rainfall. A value of ALPADJ less than 1 produces the opposite results. In this study, the value of ALPADJ was changed until the best possible agreement between measured and simulated peak flow and timing was achieved.

Because the optimum value of ALPADJ may be a function of the number of subbasins into which the basin is divided (P. E. Smith, U.S. Geological Survey, oral commun., 1981), a test of the Southglenn basin was made with the model. The model was run twice, with the basin being divided into many more subbasins for the second run than for the first. All other factors were unchanged. Simulations using the different numbers of subdivisions produced similar hydrographs when the same value of ALPADJ was used. Thus, for this test, the hypothesis suggested by Smith was not substantiated.

The model was considered calibrated for peak flow when the OSE was less than 35 percent. Because the model was not able to predict peaks for very small storms (0.01 inch of runoff or less) accurately, only storms with 0.02 inch or more of runoff were used for peak-flow calibration and verification. The model was assumed to be verified when the OSE was less than 35 percent. The calibrated-model parameters for the five basins for which the model was calibrated and verified are presented in table 8.

Table 8.--*Final values for selected parameters for DR_3M-II*

Model parameter[1]	North Avenue basin	South-glenn basin	North-glenn basin	Cherry Knolls basin	Villa Italia basin
PSP---------	0.9	2.9	3.4	2.6	2.0
KSAT--------	.14	.34	.25	.29	.20
RGF---------	10	7.2	5.1	6.4	10
BMSN--------	2.4	2.9	4.5	7.1	4.0
EVC---------	.91	.50	.84	.98	.70
RR----------	.95	.90	.90	.90	.80
EAC---------	.65	.81	.95	.76	1.0
IMP---------	.05	.08	.05	.20	.03
ALPADJ------	1.0	3.5	2.2	2.4	1.7

[1]See table 7 for definitions of model parameters.

DR_3M-QUAL

Water-quality constituents for which DR_3M-QUAL was calibrated and verified are total suspended solids, chemical oxygen demand, total nitrogen, total phosphorus, total orthophosphate, total lead, total zinc, and total manganese. (Here and throughout the report, "total," as in "total nitrogen" actually refers to "total recoverable.") These constituents also are of interest to local governments and were on the list of recommended constituents to model in the U.S. Geological Survey/U.S. Environmental Protection Agency Technical Coordination Plan on urban runoff studies (written commun., 1979).

Three model parameters, K_1, K_2, and K_3, are used to calculate constituent accumulation and washoff. The parameters K_1 and K_2 are used to compute the accumulation of constituents on effective impervious surfaces according to the formula:

$$L=K_1(1-e^{-K_2 t}) \qquad (3)$$

where: L is the total accumulated load of a constituent available to be washed off, in pounds;
t is the accumulation time, in days (Alley and Smith, 1981 and 1982b);
K_1 is the maximum amount of a constituent that can be present on the effective impervious area, in pounds; and
K_2 is a rate constant for removal of constituents, in $days^{-1}$.

In a plot of time between storms versus load, L becomes asymptotic to the value of K_1. K_2 includes removal due to wind, vehicles, chemical and biological decay, and other processes. A higher value of K_2 would enable the constituent load to reach the limiting value of K_1 more quickly than a lower value of K_2. A lower value would mean a slower constituent-accumulation rate and, at the limit K_2=0, the accumulation rate would be zero.

Constituents are assumed washed off during a storm according to the following equation (Alley and Smith, 1981):

$$W=L(1-e^{-K_3 R\Delta t}) \tag{4}$$

where: W is the constituent load washed off from the effective impervious surface during time Δt, in pounds;
L is the constituent load available to be washed off from the effective impervious surface at the start of the time period, in pounds;
K_3 is the washoff coefficient, in inches^{-1};
R is the runoff rate, in inches per hour; and
Δt is the time period, in hours.

A value of 4.6 for K_3 and 0.50 inch of runoff in 1 hour would result in 90 percent of the available constituent load being washed off the effective impervious surfaces. The higher the value of K_3, the larger the percentage of constituent load washed off during the early part of the runoff. A detailed discussion of the theory and equations used in the DR_3M-QUAL was presented by Alley and Smith, 1982b. The final values of K_1, K_2, and K_3 for the constituents and basins modeled are presented in table 9.

Because the water-quality samples were not necessarily collected coincident with the first and last flows of the storms, users are cautioned that "observed storm loads" reported in the calibration tables were calculated from the flow between the first and last water-quality samples collected, rather than from the first to last measured flows. The storm load of constituents for storms used in the verification data set were computed by the model from the first flow to the last flow.

DR_3M-QUAL was calibrated for constituent loads by adjusting K_1, K_2, and K_3 using a trial and error process. K_1 and K_2 were estimated initially using a graphical technique described by Alley and Smith (1981). K_3 was estimated initially by inspection of plots of cumulative measured storm load versus time.

Results

The OSE was lowest for runoff volume and peak flow from DR_3M-II for the Northglenn and Villa Italia sites. Two measures were used for the DR_3M-QUAL model. One was the OSE, which is a measure of how well the model can predict individual storms. The other measure is a comparison of observed and simulated total load during a season. A season was defined as April through September, the traditional period for measuring rainfall in the Denver metropolitan area. Often the two were very different. The lowest percentage difference between observed and simulated seasonal loads for most water-quality constituents was found at the Northglenn site. There were insufficient data to calculate OSE at this site. Of the three sites for which OSE's were calculated (North Avenue, Cherry Knolls, and Villa Italia), Cherry Knolls had the best fit.

Table 9.--*Final values of the parameters used in the DR_3M-QUAL*

Constituent	Parameter	North Avenue basin	North-glenn basin	Cherry Knolls basin	Villa Italia basin
Chemical oxygen demand----	K_1	30	20	10	15
	K_2	.20	.10	.10	.080
	K_3	3.7	5.6	4.6	4.6
Total suspended solids----	K_1	80	25	20	25
	K_2	.25	.15	.05	.060
	K_3	3.6	4.6	4.6	4.0
Total nitrogen------------	K_1	.80	.50	.40	.80
	K_2	.20	.10	.10	.060
	K_3	3.5	4.6	4.0	2.6
Total orthophosphate------	K_1	.040	.040	.030	.060
	K_2	.080	.070	.060	.020
	K_3	3.5	3.5	4.6	3.0
Total phosphorus----------	K_1	.10	.060	.070	.070
	K_2	.18	.20	.050	.070
	K_3	4.6	4.6	3.6	4.6
Total lead----------------	K_1	.035	.030	.015	.050
	K_2	.25	.070	.070	.025
	K_3	4.6	4.6	4.6	4.6
Total manganese-----------	K_1	.040	.013	.015	.020
	K_2	.30	.30	.10	.200
	K_3	5.6	5.6	3.6	4.6
Total zinc----------------	K_1	.040	.017	.020	.050
	K_2	.30	.30	.010	.050
	K_3	5.6	5.6	3.6	4.6

North Avenue Basin

The North Avenue basin had 32 storms monitored for rainfall and runoff. Of these storms, 17 were chosen for the calibration data set. The OSE was 27 percent for runoff volumes. For storms having more than 0.01 inch of runoff, the OSE was 33 percent for peak flows.

The verification data set included 15 storms. The OSE was 42 percent for both runoff volumes and peak flows for storms having greater than 0.01 inch of runoff.

Model calibration and verification results are presented in tables 10 and 11. Simulated peak flows for storms with 0.01 inch of runoff are reported, but were not considered in the calibration or verification of the model. Hydrographs showing observed and simulated runoff for selected storms are presented in figure 2.

Table 10.--*Summary of DR_3M-II calibration results for the North Avenue basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1980						
May 11------	0.03	0.02	-33	2.1	0.44	-79
May 15-16---	.23	.18	-22	3.8	4.8	26
July 24-----	.04	.03	-25	2.8	1.4	-50
Sept. 8-9---	.33	.24	-27	5.1	5.0	-2
Sept. 10[2]---	.02	.02	0	.99	.93	-6
Sept. 20----	.06	.06	0	4.1	5.2	27
1981						
Apr. 19-20--	.08	.11	38	5.1	2.5	-50
May 3[2]------	.05	.06	20	1.7	2.0	18
May 5-------	.01	.01	0	[3]1.4	[3].78	[3]-44
May 17-18---	.25	.27	8	2.4	2.8	17
May 28------	.01	.01	0	[3]1.5	[3].40	[3]-73
June 2-3----	.07	.08	14	4.1	5.4	32
July 2------	.03	.02	-33	2.4	1.1	-54
July 22-----	.01	.01	0	[3]1.1	[3].55	[3]-50
Aug. 9-10---	.14	.14	0	9.4	9.2	-2
Aug. 12-13--	.04	.05	25	4.9	4.5	-8
Sept. 6-7---	.06	.04	-33	1.7	1.2	-29
Observation standard error (percent)-----			27			32

[1]Determined from unrounded values.
[2]First storm.
[3]Peak flow not used for calibration.

Table 11.--*Summary of DR_3M-II verification results for the North Avenue basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1980						
May 8-------	0.12	0.06	-50	2.8	2.4	-14
May 12------	.01	.01	0	[2]1.7	[2].40	[2]-76
May 17------	.16	.10	-38	2.6	2.3	-12
Aug. 10-----	.01	.01	0	[2].70	[2].31	[2]-56
Sept. 10[3]---	.03	.06	100	7.0	8.9	27
1981						
March 3-----	.03	.03	0	1.1	.77	-30
Apr. 20-----	.02	.02	0	2.8	1.2	-57
May 3[3]------	.02	.04	100	1.3	1.7	31
May 9-------	.09	.11	22	3.1	6.0	94
May 16------	.03	.03	0	.82	.55	-33
May 28-29---	.07	.07	0	11	7.4	-33
July 15-----	.05	.06	20	11	7.4	-33
Aug. 12-----	.02	.01	-100	1.5	.71	-53
Aug. 16-----	.01	.01	0	[2].38	[2].27	[2]-29
Aug. 31-----	.01	.01	0	[2]1.1	[2].39	[2]-65
Observation standard error (percent)-----			42			42

[1]Determined from unrounded values.
[2]Peak flow not used for verification.
[3]Second storm.

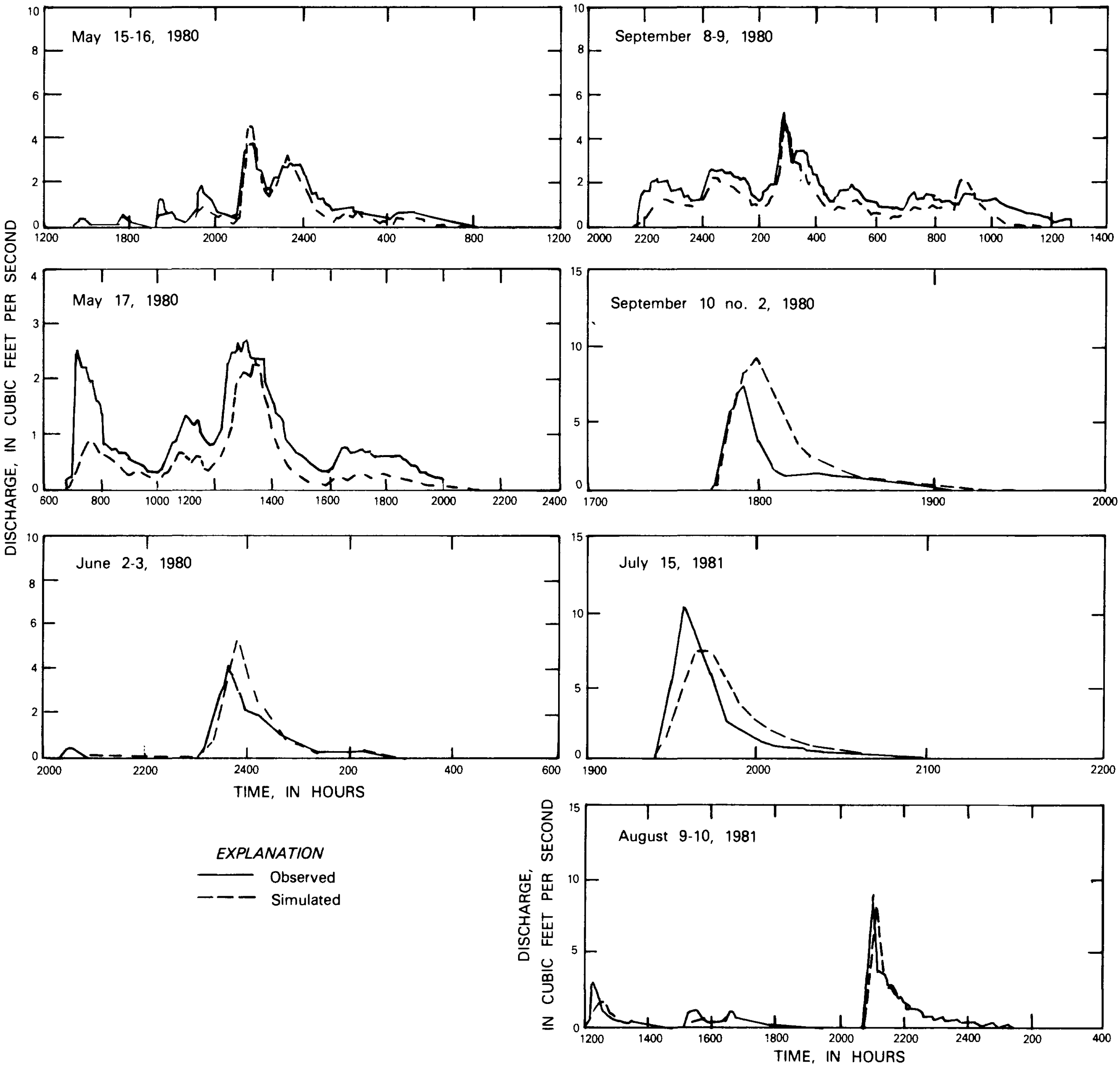

Figure 2.--Comparison of observed and simulated runoff for selected storms at the North Avenue basin.

The water-quality-calibration data set for the North Avenue basin contained data from nine storms for which discrete water-quality samples were collected over the hydrograph. The model-simulated constituent total seasonal loads (April through September) were within 19 percent of the observed values. OSE's ranged from 29 to 74 percent for individual constituents. The best fit for calibration for seasonal total loads was obtained for chemical oxygen demand (COD), the worst for total manganese and total zinc. Using OSE as a criterion, the best fit was still COD, and worst fit was obtained for total suspended solids (TSS). The results of the calibration of DR_3M-QUAL for North Avenue basin are presented in table 12.

Data from 11 storms were used for model verification. Discrete water-quality data were collected for three of these storms, and composite data were collected for the remaining eight storms. Model-simulated total loads for the verification storms differed from the observed loads by less than 35 percent. OSE ranged from 23 to 59 percent. The results of verification of DR_3M-QUAL are presented in table 13.

Southglenn Basin

Rainfall runoff from 16 storms was monitored in the Southglenn basin during the study. Structural changes were made to the channel network between 1980 and 1981; thus the three storms in 1980 were unsuitable for modeling purposes. The flow-calibration data set contained seven storms, and the flow-verification data set contained six storms. The OSE was 30 percent for calibration-runoff volumes and 5 percent for peak flows for storms having more than 0.01 inch of runoff. Verification-flow volumes had an OSE of 34 percent and 9 percent for peaks. Summaries of the results of model calibration and verification are presented in tables 14 and 15. Hydrographs showing simulated and observed runoff for selected storms are presented in figure 3.

The predicted peak flows from the Southglenn basin were somewhat low despite an extremely high value of 3.5 for ALPADJ. The optimum value of ALPADJ remained at about 3.5 when the basin was subdivided into more subbasins as discussed in the section "Procedures." Examination of the hydrographs in figure 3 shows that even with this high value of ALPADJ, the correlation between observed and simulated hydrographs remained fairly good with respect to timing and peaks.

Water-quality data were obtained from five storms monitored at the Southglenn basin. The water-quality data was insufficient to calibrate the DR_3M-QUAL because the structure of the basin was so complex.

Table 12.--*Summary of DR_3M-QUAL calibration results for the North Avenue basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
May 8-------	190	150	-21	1,200	480	-60	6.8	4.1	-40	1.2	0.47	-61
May 11------	110	80	-27	240	240	0	2.4	2.0	-16	.24	.28	16
May 12------	31	28	-10	100	88	-12	.77	.73	-5	.09	.10	11
May 15-16---	260	210	-19	1,100	660	-40	7.8	5.8	-26	1.1	.61	-45
July 24-----	120	160	33	190	420	118	4.0	4.1	2	.41	.62	51
Sept. 8-9---	470	600	28	690	1,600	131	13	16	23	1.2	1.9	58
Sept. 10[2]---	94	39	-58	300	120	-60	1.3	1.0	-23	.32	.13	-59
1981												
June 2-3----	200	160	-20	510	464	-9	3.4	4.1	21	.51	.53	4
July 15-----	160	200	25	940	680	-28	2.3	5.1	122	1.1	1.0	-9
Total load percent difference			0			-10			-3			4
Observation standard error (percent)			29			74			43			62

Table 12.--*Summary of DR$_3$M-QUAL calibration results for the North Avenue basin*--Continued

Storm date	Total orthophosphate			Total lead			Total manganese			Total zinc		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
May 8-------	0.38	0.10	-74	0.38	0.21	-45	0.90	0.27	-70	0.47	0.27	-42
May 11------	.01	.05	---	.13	.12	-8	.21	.18	-14	.24	.18	-25
May 12------	.01	.02	---	.04	.04	0	.05	.06	20	.07	.06	-14
May 15-16---	.22	.15	-32	.49	.27	-45	.88	.33	-62	.59	.33	-44
July 24-----	.08	.18	125	.16	.22	38	.21	.30	33	.22	.30	36
Sept. 8-9---	.55	.59	7	.44	.73	66	.57	.84	47	.77	.84	9
Sept. 10[2]---	.04	.02	-50	.14	.06	-57	.20	.09	-55	.14	.09	-35
1981												
June 2-3----	.14	.11	-21	.25	.23	-8	.40	.30	-25	.33	.30	-9
July 15-----	.28	.30	7	.32	.36	13	.64	.46	-28	.51	.46	-10
Total load percent difference			11			5			-19			-15
Observation standard error (percent)			57			60			49			31

[1]Determined from unrounded values.
[2]First storm.

Table 13.--*Summary of DR_3M-QUAL verification results for the North Avenue basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]
1981												
May 5-------	83	45	-46	100	130	26	1.2	1.2	0	0.32	0.16	-50
May 9-------	140	380	163	310	1,100	247	5.4	9.9	83	.62	1.4	126
May 16------	100	120	13	150	340	122	2.3	3.0	36	.30	.42	40
May 26-29---	160	220	38	400	620	54	3.3	5.7	73	.54	.72	33
July 2------	140	96	-31	210	250	18	4.3	2.4	-44	.24	.39	63
July 22-----	95	56	-27	89	150	111	2.6	1.4	-44	.17	.22	57
July 26-27--	580	740	28	2,700	2,000	-26	13	19	46	2.7	2.5	-7
Aug. 12-----	94	69	-27	150	200	37	1.8	1.8	20	.37	.25	-32
Aug. 12-13--	120	150	18	370	430	17	2.1	3.9	86	.50	.51	2
Aug. 16-----	---	21	---	22	61	177	.64	.54	-4	.045	.080	78
Aug. 29-----	44	85	93	35	220	543	.92	2.2	178	.072	.34	372
Total load percent difference			26			21			7			20
Observation standard error (percent)			53			59			51			51

Table 13.--*Summary of DR_3M-QUAL verification results for the North Avenue basin*--Continued

Storm date	Total orthophosphate			Total lead			Total manganese			Total zinc		
	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]
1981												
May 5-------	0.10	0.032	220	0.078	0.066	-15	0.092	0.093	1	0.10	0.093	-7
May 9-------	-----	.083	---	.25	.54	116	.26	.73	181	.30	.73	143
May 16------	.064	.058	-9	.12	.18	50	.15	.26	73	.15	.26	73
May 28------	.02	.18	-10	.20	.28	0	.38	.38	0	.27	.38	41
July 2------	.13	.11	-15	.13	.14	8	.16	.19	19	.20	.19	-5
July 22-----	.019	.058	---	.060	.083	66	.10	.12	50	.11	.12	33
July 26-27--	1.8	.81	-55	.91	.94	3	2.0	1.1	-45	1.6	1.1	-31
Aug. 12-----	.043	.054	---	.08	.10	25	.12	.15	25	.13	.15	15
Aug. 12-13--	.10	.12	20	.076	.21	176	.29	.29	0	.23	.29	26
Aug. 16-----	.006	.017	183	.019	.033	73	.027	.047	74	.034	.047	38
Aug. 29-----	.018	.087	387	.031	.12	287	.048	.17	254	.050	.17	240
Total load percent difference			-30			33			3			12
Observation standard error (percent)			23			51			52			56

[1]Determined from unrounded values.

Table 14.--*Summary of DR_3M-II calibration results for the Southglenn basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1981						
Apr. 19[2]----	0.04	0.05	25	1.5	1.7	13
May 3[3]------	.05	.05	0	2.4	2.1	-12
May 12-13---	.08	.07	-12	2.2	1.5	-32
May 17-18---	.34	.37	9	2.5	2.5	0
May 28------	.07	.06	-14	3.4	2.8	-18
June 11-12--	.39	.26	-33	[4]26	23	-12
July 17-----	.19	.19	0	[4]25	21	-16
Observation standard error (percent)--			30			5

[1]Determined from unrounded values.
[2]Second storm.
[3]First storm.
[4]Estimated.

Table 15.--*Summary of DR_3M-II verification results for the Southglenn basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1980						
May 15-16---	0.31	[2]0.19	---	4.1	[2]2.7	---
May 17------	.21	[2].13	---	2.3	[2]1.8	---
July 1------	.13	[2].07	---	2.8	[2]1.2	---
1981						
Apr. 19[3]----	.01	.01	0	.66	[2].67	1
May 3[4]------	.12	.14	17	[5]16	17	6
May 9-------	.05	.04	-20	[5]1.3	.77	-41
May 16------	.03	.02	-30	1.4	.91	-35
May 28-29---	.16	.20	25	5.2	6.1	17
July 26-----	.16	.18	12	5.9	6.4	8
Observation standard error (percent)--			34			9

[1]Determined from unrounded values.
[2]Not used for verification.
[3]First storm.
[4]Second storm.
[5]Estimated.

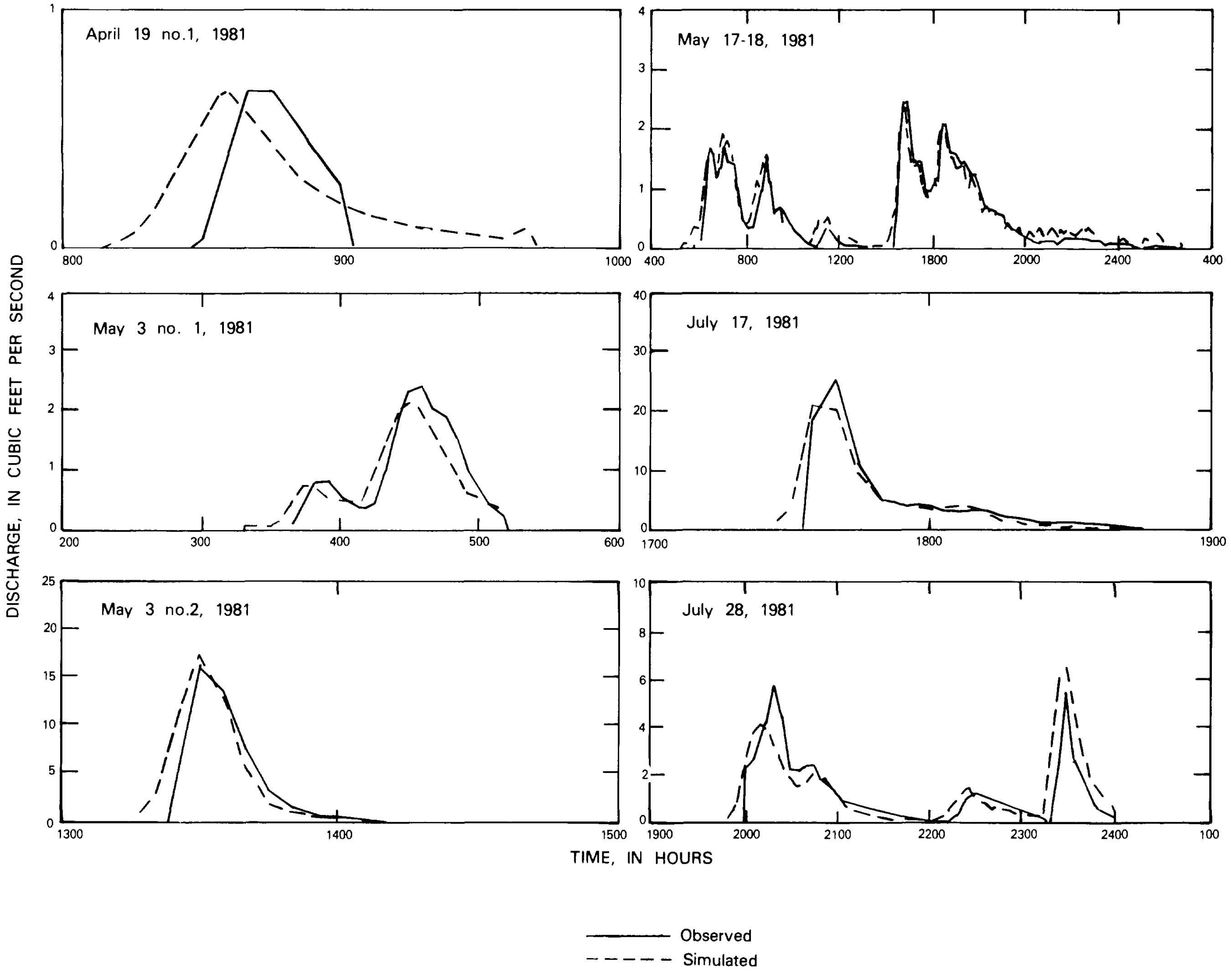

Figure 3.--Comparison of observed and simulated runoff for selected storms at the Southglenn basin.

Northglenn Basin

In the Northglenn basin, 23 storms were monitored for rainfall runoff. Thirteen storms were selected for calibration of DR_3M-II and 10 were selected for verification. The OSE for runoff volumes for the calibration data set was 20 percent. The model-simulated peak flows from storms having runoff greater than 0.01 inch had an OSE of 14 percent. The results of model calibration are presented in table 16.

The DR_3M-II simulated runoff volumes for the verification data set had an OSE of 15 percent. The model-simulated peak flows for storms with greater than 0.01 inch of runoff had an OSE of 9 percent. A summary of model verification results is presented in table 17, and hydrographs showing observed and simulated runoff for selected storms are presented in figure 4.

Table 16.--*Summary of DR_3M-II calibration results for the Northglenn basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1980						
May 8------	0.02	0.02	0	3.0	3.4	13
May 11-----	.02	.02	0	1.3	1.0	-23
June 20-----	.01	.01	0	[2]7.7	[2]3.9	-49
Aug. 15-----	.06	.07	17	7.0	7.8	11
Sept. 20----	.06	.08	33	11	13	18
1981						
May 3[3]-----	.04	.03	-25	5.2	4.1	-21
May 3[4]-----	.08	.09	12	29	27	-7
May 12-13--	.05	.05	0	4.4	4.6	4
May 16-18--	.24	.26	8	7.7	7.7	0
July 11-----	.02	.02	0	8.5	6.8	-20
July 26-----	.10	.14	40	25	28	12
Aug. 22-----	.05	.07	40	28	27	-4
Aug. 28-----	.01	.01	0	[2]8.7	[2]3.2	-63
Observation standard error (percent)--			20			14

[1]Determined from unrounded values.
[2]Not used for calibration.
[3]First storm.
[4]Second storm.

Table 17.--*Summary of DR_3M-II verification results for the Northglenn basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
<u>1980</u>						
May 7-8----	0.27	0.20	-26	17	14	-18
July 1-2----	.02	.03	50	5.0	3.7	-26
July 2------	.07	.09	29	30	36	20
Aug. 25-26--	.03	.04	33	5.4	4.7	-13
Aug. 26-27--	.06	.07	17	16	18	12
<u>1981</u>						
Apr. 19-20--	.05	.07	40	6.6	5.3	-20
June 3------	.37	.30	-19	[2]123	140	14
July 12-----	.01	.01	0	[3]2.9	[3]2.3	-21
Aug. 9------	.05	.05	0	18	15	-17
Aug. 16-----	.01	.01	0	[3]4.2	[3]2.6	-38
Observation standard error (percent)--			15			9

[1]Determined from unrounded values.
[2]Estimated.
[3]Not used for verification.

Discrete water-quality samples were collected from the runoff for 11 storms in the Northglenn basin. However, one storm occurred immediately after a snowstorm when the street had been sanded. This storm was not included in model calibration or verification because normal accumulation of constituents was masked by the sanding. Three other storms were not included in the data sets because a significant (more than 10 percent) part of the total runoff was from pervious areas, or channel scouring occurred. The model cannot account for scouring, and three storms are not sufficient to determine pervious-area accumulation and washoff parameters. The seven remaining storms were used in the calibration and verification of DR_3M-QUAL.

Results of the calibration of DR_3M-QUAL were satisfactory (total seasonal load was within 25 percent) for all simulated constituents. The verification of the model of Northglenn basin also was within 25 percent for all constituents. There were insufficient data to compute OSE's for this basin. The results of DR_3M-QUAL calibration and verification are presented in tables 18 and 19, respectively.

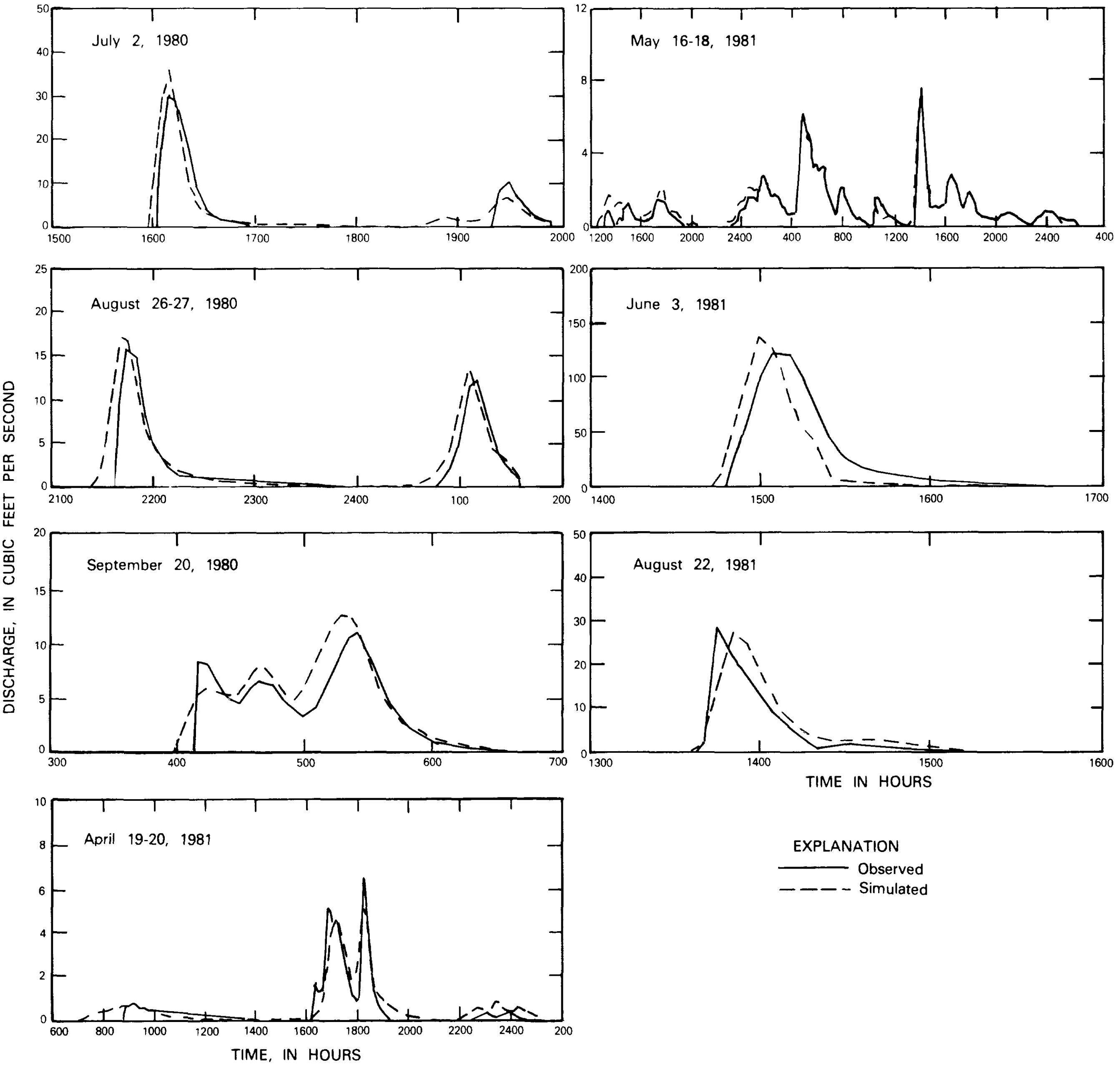

Figure 4.--Comparison of observed and simulated runoff for selected storms at the Northglenn basin.

Table 18.--*Summary of DR_3M-QUAL calibration results for the Northglenn basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]	Ob-served	Simu-lated	Percent difference[1]
1980												
Aug. 25-26--	130	200	54	130	340	162	5.5	5.7	4	0.72	0.91	26
Aug. 26-27--	210	140	-33	250	280	12	7.0	4.7	-33	1.0	.76	-24
1981												
Apr. 19-20--	150	170	13	230	280	22	1.1	1.8	64	.50	.71	42
July 26-----	290	350	21	670	650	-3	10	12	20	1.4	1.6	14
Total load percent difference--			10			21			3			10
Observation standard error (percent--			(2)			(2)			(2)			(2)

Table 18.--*Summary of DR_3M-QUAL calibration results for the Northglenn basin*--Continued

Storm date	Total orthophosphate			Total lead			Total Manganese			Total zinc		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
Aug. 25-26--	0.38	0.31	-18	0.16	0.28	75	0.13	0.25	93	0.15	0.28	87
Aug. 26-27--	.28	.30	7	.45	.23	-49	.32	.18	-44	.31	.22	-29
1981												
Apr. 19-20--	.13	.29	123	.25	.26	4	.15	.18	20	.19	.21	11
July 26-----	.56	.78	39	.50	.60	20	.40	.38	-5	.53	.44	-17
Total load percent difference--			24			1			-1			-3
Observation standard error (percent)			(2)			(2)			(2)			(2)

[1]Determined from unrounded values.
[2]Not enough data for meaningful statistic.

Table 19.--*Summary of DR_3M-QUAL verification results for the Northglenn basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1981												
May 3-------	370	270	-27	450	450	0	6.8	8.0	18	1.1	1.1	0
May 16-18---	270	260	-3	750	570	-24	14	9.0	-36	2.1	1.6	-24
Aug. 9------	250	280	12	369	470	27	6.8	8.1	19	1.1	1.2	9
Total load percent difference			-9			-5			-9			-9
Observation standard error (percent)			([2])			([2])			([2])			([2])

Table 19.--*Summary of DR_3M-QUAL verification results for the Northglenn basin*--Continued

Storm date	Total orthophosphate			Total lead			Total manganese			Total zinc		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1981												
May 3-------	0.57	0.46	-19	0.63	0.41	-35	0.28	0.30	7	0.34	0.38	12
May 16-18---	.90	.63	-30	.55	.43	-22	.45	.39	-13	.54	.52	-4
Aug. 9------	.36	.46	28	.45	.41	-9	.27	.21	-12	.47	.40	-15
Total load percent difference--			-15			-23			-10			-4
Observation standard error (percent)--			([2])			([2])			([2])			([2])

[1]Determined from unrounded values.
[2]Not enough data for meaningful statistic.

Cherry Knolls Basin

Data from 13 storms for the Cherry Knolls basin were available for the calibration and verification of DR_3M-II. Data from six storms were chosen for the calibration data set. The results of the runoff-volume calibration were satisfactory, and the average simulated runoff volume had an OSE of 14 percent. However, the simulated peak flows had an OSE of 25 percent, and all were lower than measured peak flows. ALPADJ was increased to 2.4 in an attempt to increase peak flow. The value 2.4 was not high enough to make simulated peak flows correspond with observed flows, but further increases in ALPADJ produced unacceptable distortions in the simulated hydrograph.

The results of the simulation using the verification data set were less satisfactory; the OSE for runoff volumes was 29 percent, and 37 percent for peak flows. Most of the simulated peak flows for the verification data set were too low. A possible explanation for the unsuccessful calibration of the model was inaccuracy in flow determinations--flows were determined by relating observed gage height to discharge via a theoretical rating curve computed for a culvert at the gage site. The model calibration and verification results are presented in tables 20 and 21, and hydrographs showing observed and simulated runoff for selected storms are presented in figure 5.

Table 20.--*Summary of DR_3M-II calibration results for the Cherry Knolls basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1981						
May 3[2]-----	0.02	0.02	0	2.6	2.0	-30
May 27-28--	.03	.04	33	2.9	2.1	-28
June 11-12--	.13	.12	-8	16	15	-6
June 29-----	.04	.04	0	8.0	4.7	-41
July 12-----	.12	.12	0	9.8	5.2	-47
Aug. 9------	.03	.05	66	2.3	1.6	-30
Observation standard error (percent)			14			25

[1]Determined from unrounded values.
[2]First storm.

Table 21.--*Summary of DR_3M-II verification results for the Cherry Knolls basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1981						
May 3[2]-----	0.09	0.10	11	13	17	31
May 3-4----	.01	.04	--	1.8	1.7	-6
May 12-13--	.03	.05	67	1.5	1.0	-33
May 28-----	.03	.04	30	9.8	7.0	-29
May 29-----	.06	.10	67	4.1	3.1	-24
July 7------	.07	.07	0	10	8.1	-19
July 26-27--	.05	.06	20	7.7	4.6	-40
Observation standard error (percent)			29			37

[1]Determined from unrounded values.
[2]Second storm.

Discrete water-quality data during the period of runoff were available for eight storms for the calibration and verification of DR_3M-QUAL. All data were placed in the calibration data set because there were an insufficient number of storms with complete data for both a calibration and a verification data set. DR_3M-QUAL calibrated very well, with at most a 15-percent difference between the simulated and observed data. The OSE's for this site ranged from 14 to 41 percent. Two storms had composite water-quality data of sufficient quality to be used for verification. The results of the verification using these two storms indicated that the model tended to greatly overpredict loads of all constituents. Therefore, DR_3M-QUAL may be used with the calibration parameters listed in table 18, but users are cautioned that the model was not verified. The results of model calibration are presented in table 22.

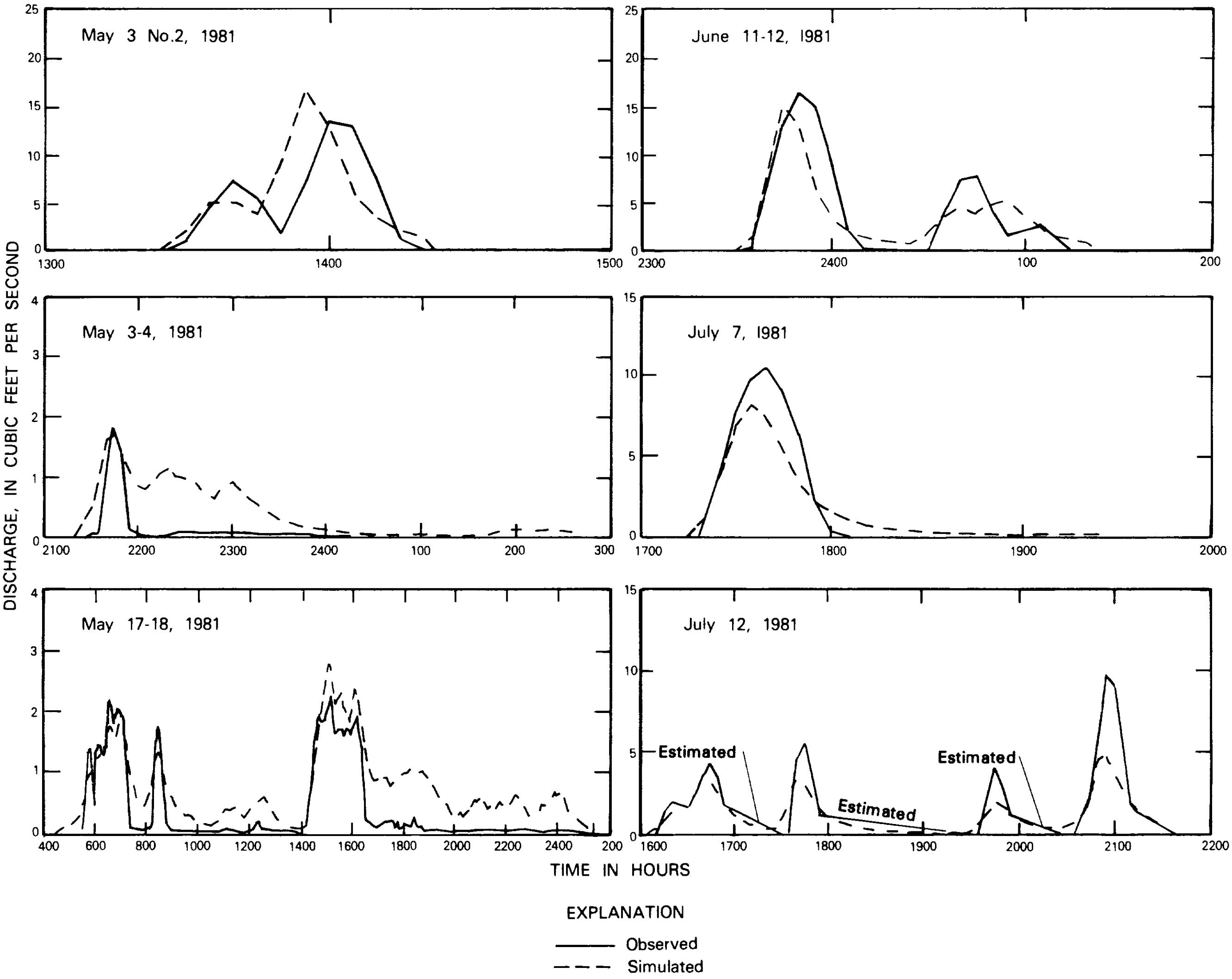

Figure 5.--Comparison of observed and simulated runoff for selected storms at the Cherry knolls basin.

Table 22.--*Summary of DR_3M-QUAL calibration results for the Cherry Knolls basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1981												
May 12-----	18	32	78	14	40	186	0.85	1.2	41	0.07	0.12	71
May 17-18--	65	82	26	77	110	43	3.1	3.3	6	.48	.37	-23
May 27-28--	46	36	-22	44	46	4	.80	1.1	38	.10	.14	40
May 29-----	33	40	21	25	51	104	1.3	1.6	-23	.14	.18	28
June 29-----	59	55	-7	130	86	-34	2.2	2.0	-9	.19	.26	37
July 7------	130	84	-35	120	130	8	4.3	3.2	-26	.77	.42	-45
July 26-27--	66	56	-15	170	77	-55	1.8	2.0	11	.27	.23	-15
Aug. 9------	28	35	25	32	52	62	.90	1.3	44	.06	.15	150
Total load percent difference--			-5			4			-3			-10
Observation standard error (percent)--			21			35			15			14

Table 22.--*Summary of DR_3M-QUAL calibration results for the Cherry Knolls basin*--Continued

Storm date	Total orthophosphate			Total lead			Total manganese			Total zinc		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1981												
May 12-----	0.00	0.07	---	0.02	0.04	100	0.02	0.04	100	0.03	0.05	66
May 17-18--	.22	.18	-18	.08	.10	25	.06	.12	100	.11	.16	45
May 27-28--	.04	.08	100	.05	.04	-20	.03	.05	66	.05	.06	20
May 29-----	.07	.09	28	.04	.05	25	.03	.06	100	.06	.08	33
June 29-----	.16	.14	-12	.12	.07	-42	.08	.07	-12	.13	.09	-38
July 7------	.51	.21	-63	.16	.11	-31	.14	.12	-14	.19	.15	-21
July 26-----	.11	.13	18	.07	.07	0	.13	.07	-38	.12	.10	-17
Aug. 9------	.05	.08	60	.02	.05	150	.03	.04	33	.04	.06	50
Total load percent difference--			-15			-5			8			4
Observation standard error (percent)--			15			23			41			28

[1]Determined from unrounded values.

Villa Italia Basin

The Villa Italia basin is unusual in that 91 percent of the basin is effective impervious area, consisting of buildings and a parking lot. Pervious-area runoff contribution is virtually nonexistent. The DR_3M-II was calibrated with data from nine storms in 1980 and verified with data from 13 storms in 1981. Normally both the calibration and verification data sets should contain storm data from both 1980 and 1981 to account for different hydrologic conditions. However, since the Villa Italia basin is mostly effective impervious area, and the different hydrologic conditions mainly affect runoff from pervious area, the possible bias in the data set is not important for this basin.

Calibration using the 1980 storm data resulted in an 11-percent OSE for runoff volumes and a 20-percent OSE for peak flows. The verification using the 1981 storms produced model-simulated flow volumes and peak flows that had OSE's of 8 percent and 22 percent, respectively. A possible source of error in both the flow volumes and peak flows may be the inaccurate determination of base flows. Base flow at this site varied considerably (from about 0.1 to 5 ft^3/s), sometimes even during the relatively short duration of a single storm event. Possible sources of the base flow are overspray from lawn irrigation, washing of parking area, and air-conditioning water. It was usually difficult to determine how much of the total flow at the gage was due to storm runoff and how much was base flow. The results of calibration and verification of DR_3M-II are presented in tables 23 and 24. Hydrographs showing observed and simulated runoff for selected storms are presented in figure 6.

Six storms at the Villa Italia basin provided sufficient water-quality data for calibration of DR_3M-QUAL, three storms each from 1980 and 1981. The very intense storms of August 14, 1980, and June 3, 1981, were not included in the calibration or verification, because some of the runoff from each of these storms overflowed the sewer drains, left the basin, and was not recorded. The Villa Italia basin was difficult to calibrate with DR_3M-QUAL, which may be partly due to the difficulty in subtracting the contribution from base flow to the total load. Difficulty in calibration probably also was due to physical factors not accounted for in this application of the model. Examples of some of these physical factors are the amount of automobile traffic between storms, quantity of constituents tracked into the basin by automobiles, number of automobiles parked on the basin during a storm, and the time since the basin was swept. The results of the basin calibration of DR_3M-QUAL are presented in table 25.

Seven storms were used for the verification data set. Verification runs of DR_3M-QUAL for the basin indicated a need to recalibrate the model for total lead, total zinc, total phosphorus, and total manganese. The simulated constituent loads in the calibration set were slightly too large, but the verification loads were as much as 33 percent too low. OSE's ranged from 24 to 78 percent for calibration values and from 27 to 57 percent for verification values. The best data fits were obtained for total suspended solids and total phosphorus. Results of the verification are presented in table 26.

Table 23.--*Summary of DR_3M-II calibration results for the Villa Italia basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1980						
July 1-2----	0.37	0.37	0	21	19	-9
July 30-----	.04	.03	-25	4.8	3.5	-27
Aug. 7------	.05	.04	-20	11	8.8	-20
Aug. 10-----	.03	.02	-33	3.4	2.0	-41
Aug. 25-----	.30	.28	-7	23	22	-4
Sept. 8-----	.03	.02	-33	4.5	3.2	-29
Sept. 10[2]---	.05	.06	-20	2.2	3.4	55
Sept. 10[3]---	.05	.07	40	19	21	11
Sept. 20----	.14	.13	-7	33	24	-27
Observation standard error (percent)--			11			20

[1]Determined from unrounded values.
[2]First storm.
[3]Second storm.

Table 24.--*Summary of DR_3M-II verification results for the Villa Italia basin*

[Runoff is in inches and peak flow is in cubic feet per second]

Storm date	Runoff volume		Percent difference[1]	Peak flow		Percent difference[1]
	Observed	Simulated		Observed	Simulated	
1981						
Mar. 20-----	0.08	0.08	0	10	6.8	-32
Apr. 19-----	.28	.27	-4	33	19	-42
Apr. 20-----	.49	.49	0	77	67	-13
May 3[2]-----	.14	.13	-7	14	6.9	-51
May 3[3]-----	.08	.08	0	22	16	-27
May 3[4]-----	.04	.06	50	4.6	4.1	-11
May 12-13--	.26	.29	12	13	11	-15
May 16-----	.25	.24	-4	8.8	11	25
May 17-18--	.70	.70	0	14	15	7
June 2-3----	[5].49	.57	20	[6]75	79	5
June 3------	[5].91	.89	-2	[6]77	91	18
July 12-----	.11	.11	0	12	11	-8
July 26-----	[5].81	.79	-2	[6]66	74	12
Observation standard error (percent)			8			22

[1]Determined from unrounded values.
[2]First storm.
[3]Second storm.
[4]Third storm.
[5]Observed runoff adjusted for flow which bypassed gage.
[6]Some of the peak flow bypassed gage.

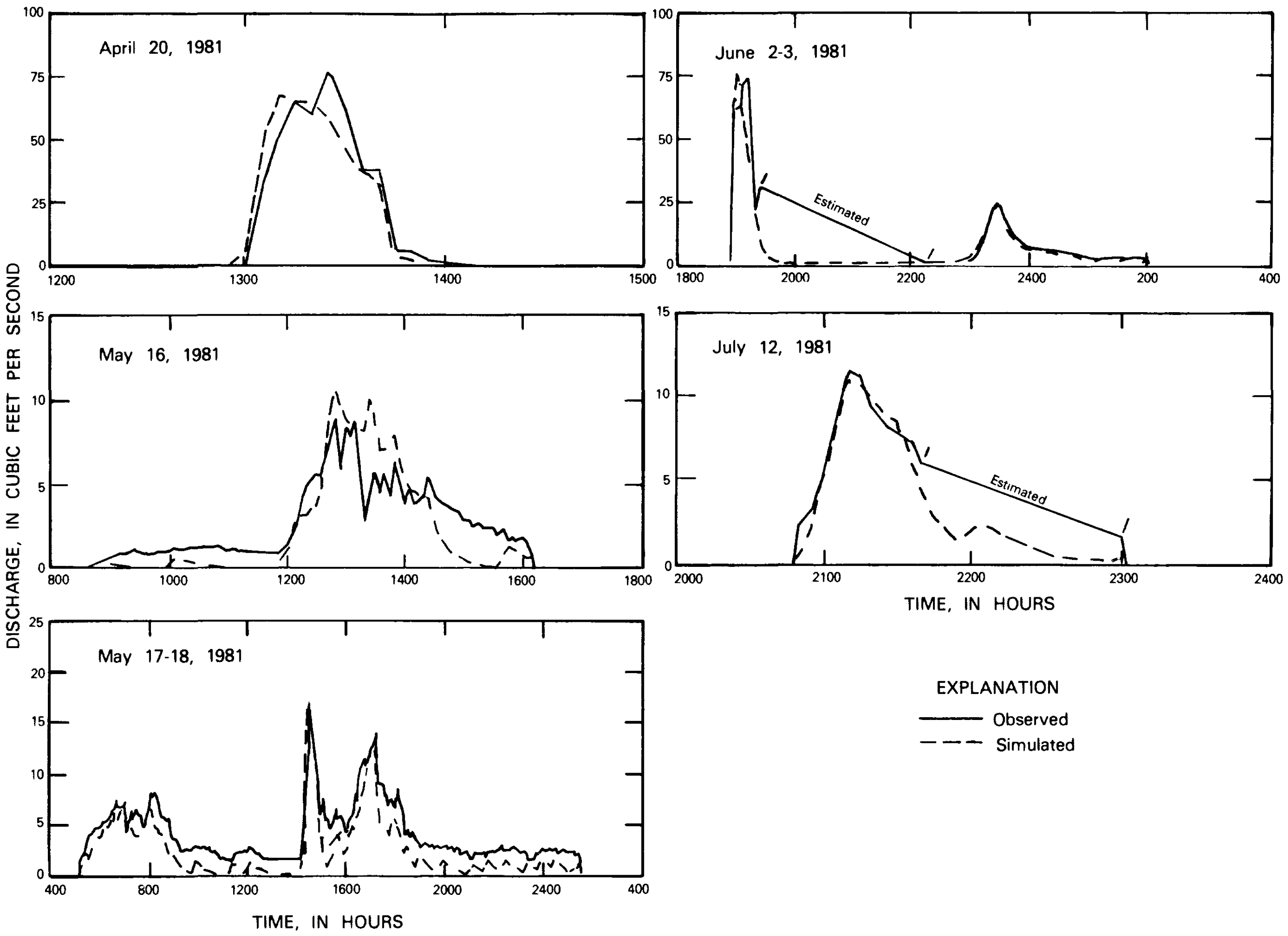

Figure 6.--Comparison of observed and simulated runoff for selected storms at the Villa Italia basin.

Table 25.--*Summary of Dr_3M-QUAL calibration results for the Villa Italia basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
July 1-2----	730	930	27	570	1,000	75	20	27	35	1.5	3.3	120
Aug. 25-----	440	570	30	260	550	112	11	12	9	1.3	1.6	23
Sept. 8-9---	520	770	48	190	800	321	16	23	44	1.3	2.3	77
1981												
Mar. 20-----	170	110	-35	260	95	-63	7.2	2.1	-71	.43	.62	44
May 27-----	560	490	-12	890	470	-47	10	12	20	1.1	1.5	36
July 26-----	710	730	3	1,300	850	-34	25	29	16	4.0	2.4	-40
Total load percent difference--			15			-8			18			22
Observation standard error (percent)			27			60			24			56

Table 25.--*Summary of DR_3M-QUAL calibration results for the Villa Italia basin*--Continued

Storm date	Total orthophosphate			Total lead			Total manganese			Total zinc		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
July 1-2----	0.37	1.4	278	0.80	1.67	109	1.1	0.94	-15	1.3	2.0	54
Aug. 25-----	.41	.47	15	.47	.56	20	.36	.76	111	.66	.88	30
Sept. 8-9---	.70	.82	17	.33	.83	152	.54	.95	76	.86	1.3	48
1981												
Mar. 20-----	.18	.06	-67	.32	.22	-31	.26	.28	8	.32	.33	3
May 27-----	.18	.40	120	.92	.48	-48	.61	.66	8	.93	.75	-19
July 26-----	2.2	1.2	-45	1.1	1.0	-9	1.5	.88	-41	2.1	1.3	-40
Total load percent difference--			8			25			2			5
Observation standard error (percent)			71			78			31			49

[1]Determined from unrounded values.

Table 26.--*Summary of* DR_3M*-QUAL verification results for the Villa Italia basin*

[Observed and simulated values are loads in pounds]

Storm date	Chemical oxygen demand			Total suspended solids			Total nitrogen as N			Total phosphorus as P		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
July 6------	235	100	-57	160	100	-38	7.1	2.6	-63	0.35	0.38	9
July 30-----	140	280	100	200	290	45	6.9	6.5	-6	1.4	1.2	-15
Aug. 10-----	470	270	-43	200	280	40	4.0	6.8	70	.71	1.1	55
Sept. 8-----	210	110	-47	130	110	-15	4.4	2.5	-43	.36	.43	19
Sept. 10[2]---	100	120	20	61	140	130	9.5	6.1	38	.65	.43	-34
1981												
May 3[3]-----	380	340	-10	52	330	520	6.7	8.0	19	.78	1.2	54
May 16-----	790	330	-58	600	320	-47	14	10	-29	1.5	.99	-34
Total load percent difference--			-33			11			-19			0
Observation standard error (percent)--			27			57			32			37

Table 26.--*Summary of DR_3M-QUAL verification results for the villa Italia basin*--Continued

Storm date	Total orthophosphate			Total lead			Total manganese			Total zinc		
	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]	Observed	Simulated	Percent difference[1]
1980												
July 11-----	0.065	0.16	146	0.25	0.12	-52	0.21	0.15	-29	0.32	0.21	-34
July 30-----	.41	.44	7	.52	.41	-21	.39	.32	-18	1.1	.65	-41
Aug. 10-----	.34	.48	41	.32	.40	25	.42	.32	-24	.53	.63	19
Sept. 8-----	0	.13	---	.15	.13	-13	.17	.15	-12	.28	.24	-14
Sept. 10[2]---	.26	.26	0	.20	.13	-38	.26	.19	-27	.35	.24	-31
1981												
May 3[3]-----	.29	.36	24	.17	.38	124	.23	.42	83	.32	.70	119
May 16-----	.51	.36	-29	1.2	.29	-76	.84	.54	-36	1.2	.58	-52
Total load percent difference--			17			-33			-17			-21
Observation standard error (percent)--			30			36			27			35

[1]Determined from unrounded values.
[2]First storm.
[3]Third storm.

APPLICATION OF DR_3M-II and DR_3M-QUAL

DR_3M-II has several applications in the Denver metropolitan area. Calibrated models of basins can be used with historical rainfall data to construct runoff volume and peak-flow probability distributions for these basins. The model also may be used to estimate the effect of increased urbanization and the corresponding increase in effective impervious area on the runoff volumes and peak flows in the basins. The effect of storm-water detention on the peak flows also could be modeled. The values of the calibration parameters found in this study could be used in DR_3M-II or other models to simulate flow in ungaged basins if the physical characteristics of the basins are similar to the characteristics of the basins studied in this investigation.

DR_3M-QUAL may be used to predict seasonal loads, but it has only limited use in prediction of loads of water-quality constituents for individual storms. The model may be used to construct load frequency tables using historical flow data. DR_3M-QUAL could be used to evaluate the effect of increased urbanization on seasonal loads of water-quality constituents. The model parameters may be used to provide initial estimates of similar parameters in other water-quality models.

CONCLUSIONS

DR_3M-II was calibrated and verified for five basins--North Avenue, Southglenn, Northglenn, Cherry Knolls, and Villa Italia. The model is most accurate in the prediction of rainfall-runoff volumes, but may be used for peak-flow prediction with somewhat less accurate results. The observation standard error of the model prediction of runoff volume and peak flow for storms having runoff volumes greater than 0.01 inch generally is less than 40 percent. The most useful application of the calibrated DR_3M-II probably is in obtaining peak-flow probability distributions for the monitored basins.

DR_3M-QUAL was calibrated and verified for four basins--North Avenue, Cherry Knolls, Northglenn, and Villa Italia. The model is most useful in prediction of seasonal loads of constituents in storm runoff. The model is not very accurate in the prediction of loads resulting from individual storms. The model does provide substantial insight into the buildup and washoff processes that occur in the Denver area urban basins. The calibrated buildup and washoff coefficients may be used in other similar models as initial estimates for calibration. The model is not, however, applicable to ungaged basins using the calibration parameters listed in this report.

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U.S. GOVERNMENT PRINTING OFFICE: 1984—778-823/9231 REGION NO. 8