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APPLICATION OF A PARAMETRIC MODEL TO SIMULATE FLOWS FROM AN URBAN WATERSHED

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TABLE OF CONTENTS

Subject Page

INTRODUCTION 1

DESCRIPTION OF AREA 2
  Hydrology 4
  Land Use 6
  Climatological Data 6
  Urban Influences 7

HYDROLOGIC MODELING OF THE WATERSHED 9
  Model Parameters 10
  Model Calibration 14

EVALUATION OF URBANIZATION ON HYDROLOGIC SEQUENCES 23

SUMMARY 29

BIBLIOGRAPHY 30

LIST OF TABLES

Table		Page
1	Classification of land use patterns in the Upper Ottawa River basin with percentage influence.	6
2	Summary of parameters required for the Kentucky Watershed Model.	10
3	Model parameters of the Upper Ottawa River basin, Ohio.	13
4	Recorded precipitation and runoff for the Upper Ottawa River, 1971-74.	14
5	Observed and Estimated monthly water yield estimates. Error summary presented as observed minus estimated. Upper Ottawa River basin, Ohio.	18
6	Comparison of observed and estimated flow sequences by season. Upper Ottawa River basin, Ohio.	19
7	Observed and Estimated extreme events for daily, monthly and annual occurence, 1971-74, Upper Ottawa River basin, Ohio.	19
8	Comparison of Estimated to Observed mean daily discharges for water years 1971-72 and 1973-74 for September 1 - 15. Upper Ottawa River basin, Ohio.	28

LIST OF FIGURES

Figure		Page
1	Ottawa River Basin, Ohio.	3
2	Water levels in observation wells located at Alger and Lima, Ohio.	5
3	Comparison of recorded and simulated mean daily flow for water year 1971-72, Upper Ottawa River basin, Ohio.	15
4	Comparison of recorded and simulated mean daily flow for water year 1972-73, Upper Ottawa River basin, Ohio.	16
5	Comparison of recorded and simulated mean daily flow for water year 1973-74, Upper Ottawa River basin, Ohio.	17
6	Comparison of recorded and simulated annual water yields for water years 1971-74, Upper Ottawa River basin, Ohio.	20
7	Comparison of recorded and simulated monthly water yields for water years 1971-74, Upper Ottawa River basin, Ohio.	21
8	Number of events having absolute error less than or equal to the indicated percentages for water years 1971-74, Upper Ottawa River basin, Ohio.	22
9	Effect of a ±10% error in precipitation and evapotranspiration on monthly and annual water yields for 1971-72, Upper Ottawa River basin, Ohio.	24
10	Effect of a ±10% error in precipitation and evapotranspiration on monthly and annual water yields for 1972-73, Upper Ottawa River basin, Ohio.	25
11	Effect of a ±10% error in precipitation and evapotranspiration on monthly and annual water yields for 1973-74, Upper Ottawa River basin, Ohio.	26
12	Comparison of recorded and simulated flow duration for water years 1971-74, Upper Ottawa River basin, Ohio.	27

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INTRODUCTION

The demand for adequate supplies of water increases as many regions are becoming increasingly urbanized. As watersheds are converted from a predominantly rural to an urban environment, many occurrences result which can cause alterations in the hydrological cycle. If these transitions are not monitored properly, our water resource, which is in such great demand, can become limited in both volume and quality.

The Ottawa River Basin in northwest Ohio is an example where regional water resource planning for both the present and future is urgently needed. The demand for domestic and industrial water supplies is increasing annually. Presently, the Ottawa River is supplying most of the area's industrial and municipal demands for high-quality water. An adequate water supply is maintained by storage in a series of upground reservoirs. Pumpage from the river into these reservoirs often nearly depletes the normal base flow of the river entering the city of Lima. The municipal waste-treatment plant for the city of Lima and several large industrial sources discharge their wastes into the river immediately below the city. The water quality of the Ottawa River for the duration of its flow into the Auglaize River (nearly 33 miles) is of an extremely low level, seldom supporting a natural aquatic ecosystem (Balduf and Harris, 1974), due primarily to the waste loadings introduced at Lima. Advanced waste treatment facilities are planned for all major municipalities and industrial dischargers to improve water quality. In order to meet the present demand of treated waters, a new upground reservoir was built in a neighboring watershed. These measures for attaining adequate volumes and quality of water are only limiting in scope. As the area continues to develop, not only will the demand increase, but also, alterations in the hydrological cycle will result which will amplify the need for adequate water resources.

The hydrology in a given watershed and the effects which can alter it can be simulated with mathematical models. The Stanford Watershed Model (Crawford and Linsley, 1966) has been shown to be an effective tool for simulating a discharge hydrograph from climatological data (precipitation and evapotranspiration) and watershed parameters (soil surface moisture and retention properties, interflow storage and flow conditions, ground water storage and flow conditions, and the physical state and geomorphological properties of the basin [Ricca, 1974]).

The purpose of the study was to evaluate the possibility of applying the Kentucky Watershed Model (James, 1965) -- a Fortran version of the Stanford Watershed Model -- to the upper Ottawa River Watershed. The model was first calibrated to the natural system and then watershed parameters were altered to reflect changes due to urbanization. Although in this report no attempt is made to evaluate all of the hydrological perturbations which can occur, it does further demonstrate the potential that parametric watershed models have in water resource planning.

To facilitate hydrograph simulation of the watershed which is affected by urban development, the U. S. Geological Survey river gaging station (No. 01487500), downstream of Lima, was used as a reference discharge point.

DESCRIPTION OF AREA

The Ottawa River Watershed is one of numerous sub-basins which flow together forming the Maumee River Basin in northwest Ohio. The Ottawa River is located in the south central region of the Maumee Basin, draining sections of Hardin, Allen, and Putnam counties (Figure 1). Its drainage area is 373 square miles, with a stream length of approximately 54 miles. Most of its tributaries, including the upper Ottawa River (Hog Creek) flow intermittently.

The watershed area included in this study covered 160 square miles above USGS station No. 01487500 located at Allentown, Pennsylvania. This area has a maximum elevation of 1,025 feet and decreases to 790 feet at Allentown, with an average channel slope of 5.1 feet per mile. The length of the main channel is 33.1 miles.

The general geologic formations of the basin are described in the Ohio Water Plan Inventory as follows (Walker, 1959):

> The entire Ottawa basin area is underlain by limestone and dolomites of Silurian Age. The bedrock is covered with glacial drift, averaging 30 feet in thickness, although in places it is exposed at the surface. Portions of three buried valleys are present in the basin. These valleys are remnants of old streams which had cut their courses deep into the bedrock before the area was glaciated. Later, with the coming of the glaciers, the valleys were completely filled with drift. The deepest and most extensive buried valley, west and southwest of Lima, contains over 200 feet of fill. The fill consists largely of clay with discontinuous lenses of coarse sand and gravel. . .. Sand and gravel layers in these areas range from 5 to 80 feet thick.

These sand and gravel layers yield potentially large ground water supplies, depending on their size, depth, and location. In areas where the drift is thick and the bedrock is highly fractured (for example the area around Lima), yields of 500 gallons per minute are obtained at depths of around 400 feet. Ground water yields decrease in the upper portion of the watershed, where only 15 - 30 gpm are obtained at depths usually less than 100 feet.

Figure 1. Ottawa River Basin, Ohio

The soils in this region were formed in a glacial drift which was derived from limestone and dolomite. The major types of soils are Blount, Pewamo, and Morley. The light-colored Blount soils are found on slight knolls or slopes and are poorly drained. The Blount soils are closely associated with the darker Pewamo soils. These are normally found in depressional areas and are also very poorly drained. The Morley soils are moderately well drained and are found on the more sloping areas.

Hydrology

The average annual surface runoff measured at Allentown is normally less than 17 inches. The seven-day-ten-year low flow at this point would approach zero cubic feet per second, if it were not for the combined volumes of effluents being discharged within the city of Lima, approximately three miles upstream.

The ground water level in the Ottawa River basin is monitored by a series of observation wells maintained by the U. S. Geological Survey and the Division of Water, ODNR, which reflects any fluctuations due to pumping and natural seepage. "The aquifers of the study area are generally recharged by vertical leakage thru the overlying glacial drift. Thus, water levels in the aquifers do not respond immediately to rainfall. Instead of the water level reaching a peak within hours after heavy rainfall, it may be a period of two or three days before the peak levels occur." (Anon., 1970).

The fluctuations in water level normally average three to seven feet, except for locations where heavy pumping occurs. Recharge becomes negligible from October through April. A normal ground water hydrograph is depicted in Figure 2, well Hn-1, at Alger, Ohio in Hardin County, typifying much of the upper Ottawa River basin where only minor domestic pumping occurs. "The effects of pumping on water levels vary with the amount pumped, the efficiency of the well, the hydraulic properties of the aquifer, the pumping time, and the spacing of the wells. Many times the water level fluctuations under pumping conditions are very similar to those under natural conditions with only slight modifications." (Anon., 1970).

"The hydrograph for well Al-4 at Lima, Figure 2, represents the effects of heavy industrial pumpage in excess of 5 mgd throughout the period of record. The pumping of this aquifer is from a large number of wells creating an extensive area of influence. All evidence of fluctuation from annual recharge and depletion is obscured by the widespread pumping. The only time the water levels in this area rise significantly are during extended periods of nonproduction, primarily "strike" periods. Even though rates of withdrawal have been periodically increased, the water level has only declined about 20 feet in 20 years." (Anon., 1970). The percolation rate of surface waters is greater in this area, due to this vast depletion of ground water. It has been observed during low flow conditions that as the Ottawa River moves through this area, there is an actual decrease in surface flow resulting from this influence.

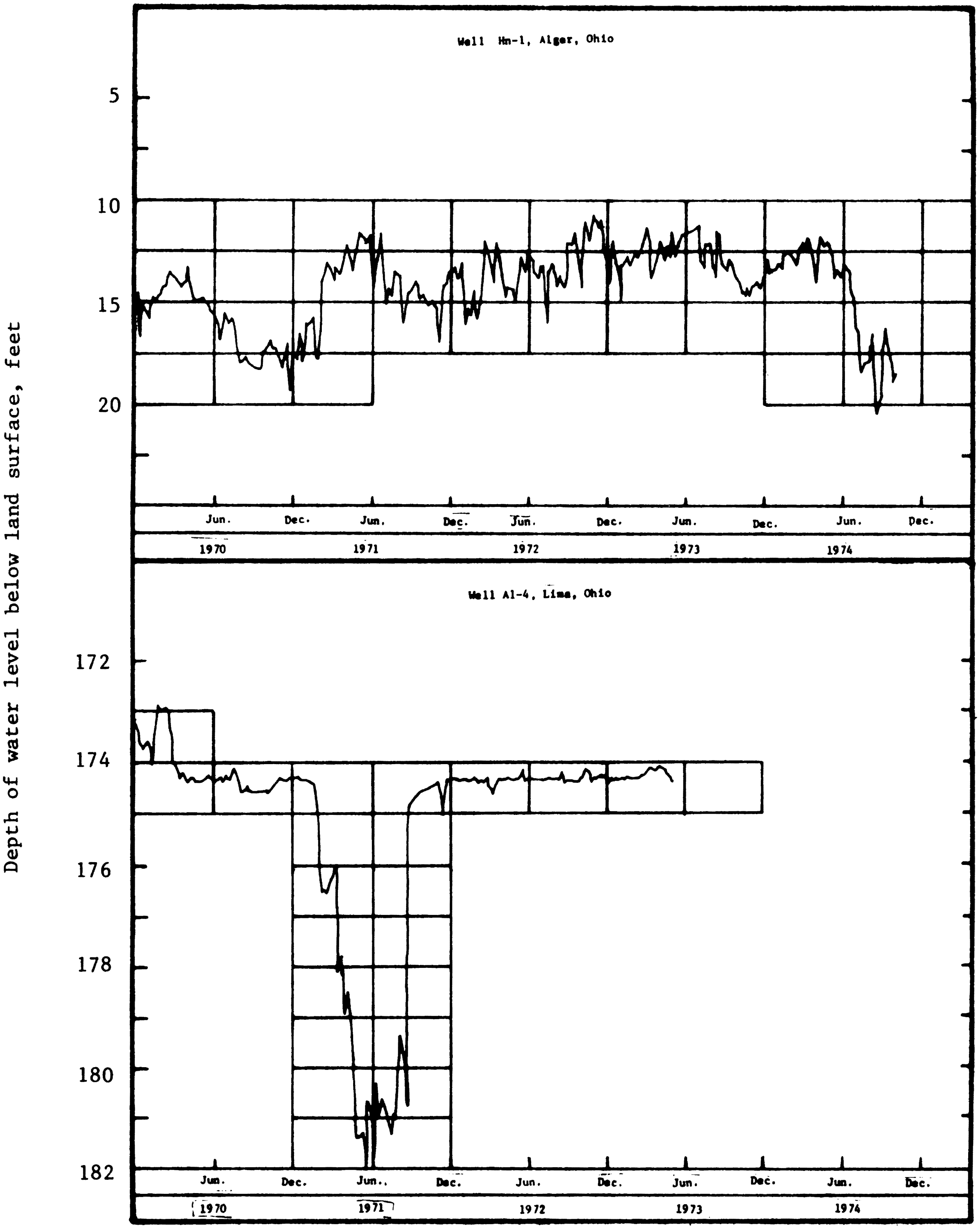

Figure 2. Water levels in observation wells located at Alger and Lima, Ohio.

Land Use

The Ottawa River Basin became a major agricultural center in Ohio in the early 1900's. This was in part due to the need for draining the land which was part of the Great Black Swamp. Continual maintainance of drainage systems are needed to sustain the area as fertile cropland. Most of the forests have been timbered leaving only small, scattered woodlots of sparse vegetation. These are primarily maintained by private ownership, with little potential for timber yield. Some of these woodlots are being razed to provide more land for cultivation. Only a small amount of the land is used for pasture. The city of Lima and its surrounding "suburbs" is the only major urban area in the watershed and is located in the southwest region of the basin. The remainder of the cities are small rural villages; the two larger being Ada and Cridersville.

A summary of land use patterns found in the watershed under study is compiled in Table 1. The data on area under urban influence and surface water were obtained through direct measurement by means of a planimeter and the use of U. S. Geological Survey topographic maps (7.5 minute series). Urban coverage was estimated for the cities of Lima, Ada, and Cridersville because the storm sewer system was used to define its aerial extent. Other forms of land use were obtained from the Soil and Water Conservation Needs Inventory for Ohio (Anon., 1971).

Table 1. Classification of Land Use Patterns in the Upper Ottawa River Basin, with Percentage Influence

Classification	Percentage of Area	Classification	Percentage of Area
Urbanized	10.0%	Forest (heavy)	0.0%
Pasture	4.3%	Forest (light)	9.1%
Cultivated	76.3%	Water Surface	0.3%

Climatological Data

The two essential climatological parameters needed for utilizing the Kentucky Watershed Model are precipitation and evapotranspiration. The Thiesson polygon method was used on precipitation data collected at stations in Lima, Pandora, and Kenton, Ohio, to determine a weighted average rainfall for the upper Ottawa River Watershed. Hourly totals were utilized in water year 1973, whereas, daily totals with hourly distribution of rainfall from 1000 to 1600 hours were used for water years 1972 and 1974. These time periods were determined from an analysis of rainfall distribution. Climatological data were acquired from the U. S. Department of Commerce, Environmental Science Services Administration.

The model utilized daily potential evapotranspiration values which were generated by a routine developed by Liou (1970) at the University of Kentucky. Inputs into this routine were mean annual lake evapotranspiration and mean number of rainy days per year. Monthly coefficients of 1.0 were set to represent values calculated in Kentucky. In order for the model to interpret variations in the potential evapotranspiration of the geographical area around the Ottawa River watershed, these monthly coefficients were adjusted to reflect known evapotranspiration rates which occurred there. These latter values were calculated by Papadakis (1961) from the Dalton-type evaporation formula using the equation

$$E = C(e_{ma} - e_d)$$

where C = 0.5625 (empirically determined constant), e_{ma} is the saturated vapor pressure at water surface temperature and e_d is the average vapor pressure of the air for the month. His results were based on data collected in Columbus, Ohio. A yearly total of 30.04 inches was calculated.

Urban Influences

Urbanization affects the hydrology in the upper Ottawa River watershed in two ways. The first is the direct discharge of effluents from waste treatment facilities into the river and the pumpage of surface waters for domestic water supplies and ground waters for industrial usage, and the second is the conversion from pervious soil profile to impervious profile (e.g. roads, parking lots, etc.). The rate at which these alter the hydrology are dependent upon climatological occurrences and daily interactions within the cities and industrial operations. Effluent discharge rates for each of the point source dischargers were acquired from the Ohio Environmental Protection Agency by means of monthly operating reports. Data concerning ground water pumpage rates and other in-plant operations were supplied by the respective industries through personal communication.

The municipal water supply for the city of Lima and surrounding area is maintained by pumpage of surface waters from the Ottawa River into a series of upground reservoirs. The pumping rate is primarily dependent upon the flow of the river, although the need for sustaining an ample supply does require pumping during low flow periods, which results in depleting the surface flow of the river upstream of the city. Several of the larger industries are also supplied with this water to meet their needs for high quality water for plant production. For the period of this study, the daily pumping rates varied from 0.0 to 99.9 cubic feet per second. These values were derived from weekly pumping averages; therefore, extremes in actual daily rates were not accurately represented (personal communication from the Public Utilities Director, City of Lima, 1975).

The smaller villages within the watershed obtain their municipal water supplies from ground water sources. Due to the low volumes of waters pumped, little impact results on the ground water supplies in the area. The cities of Ada and Cridersville have average pumpage rates of 0.59 and 0.27 cfs, respectively.

Discharges into the surface waters is attributed to domestic and industrial waste effluents. The city of Lima's waste water treatment plant (WWTP) is the largest single discharger in the basin, with flows ranging from 11 to 54 cfs, with an average discharge rate of approximately 22 cfs. The larger volumes discharged include flows by-passed during storm events. These figures also reflect quantities of partially treated waste which is "back-flowed" through the sewerage system and discharged through storm sewer outlets within the city during periods of low flow. The other municipal waste water treatment plants in the watershed are located at Ada and Cridersville. The Cridersville plant discharge location is in the headwaters of the Little Ottawa River, a tributary of the Ottawa River. The city of Ada has its waste water treatment plant located on Hog Creek, one of the main creeks forming the Ottawa River. Its average flow is 0.7 cfs, with a range of from 0.2 to 1.3 cfs. These daily flow rates again account for waters by-passed. Due to the location and volume of discharge, these smaller WWTP's have little significance in affecting the hydrograph at Allentown, although they provide much of the stream flow in their immediate vicinities through much of the year.

The three major industrial dischargers which were included, because of their volume and location of discharge, are Standard Oil Refinery, Vistron Corporation (both acrylonitrile and agricultural divisions), and Proctor and Gamble. The effluent from Standard Oil enters the Ottawa River approximately 1,000 feet below Lima's WWTP. The waste water originates both from in-plant processes and cooling water "blowdown." The refinery utilizes water from the reservoir system for most of the in-plant processes, while much of the water needed for cooling is derived from ground wells. The total well water flow rate is approximately 3.3 cfs, based on averaged pumping rates. Only about 50% of the ground water is actually discharged, due to losses through the cooling processes. The waste water is retained in a lagoon for about 14 days for biological treatment before it is discharged. During storm events, the runoff from within the plant property is also impounded to reduce peak flows. The average rate of flow is 6.9 cfs, with a range of from 2 to 17 cfs during the time of the study.

Vistron Corporation's effluent is comprised of wastes from both the acrylonitrile and agricultural complexes, along with the normal runoff which occurs within the plant. The source of water for in-plant production is also from the municipal reservoir system due to the need for higher quality waters than that which can be supplied from ground water sources. These wells supply about 5.9 cfs for cooling purposes, with 65% lost during the cooling process. The remaining cooling water combines with the other waste water and discharges at a rate of about 4.7 cfs, ranging from 3.2 to 5.2 cfs.

The Proctor and Gamble Corporation is located on Lost Creek, a small tributary located immediately upstream of the city of Lima. The waste water is comprised almost entirely of cooling water and has a fairly constant flow rate of 0.4 to 0.5 cfs on days of operation, and 0.2 cfs on days the plant is shut down. This effluent comprises most of the stream flow on Lost Creek during dry periods, but is insignificant as part of the Ottawa River flow.

As noted by these various pumpage rates, there is a great demand placed on both the ground and surface waters. During low flow conditions, the effluents of the waste treatment facilities comprise nearly all of the river flow, and is reflected by the hydrographs produced at the Allentown gaging station. The flows measured at the gage are usually a little lower than the total of the effluent volumes because the ground water depletion is high, and the rate of recharge from surface supplies is such that some surface waters percolate through the stream bed into ground water storage.

HYDROLOGIC MODELING OF THE WATERSHED

The Kentucky Watershed Model (KWM), a Fortran version of the Stanford Watershed Model without snowmelt routine, was used to generate continuous stream flow sequences for the upper Ottawa River Watershed. This model is based upon a series of mathematical statements which reflect the interrelationships between the hydrological cycle and its components. "The model is normally calibrated with known input by repeatedly altering model parameters until an acceptable fit is achieved between estimated and actual discharge values. Input can be classified into six distinct groups: (a) program control options, (b) initial conditions, (c) climatological data, (d) time-area histogram, (e) watershed model parameters and (f) historical stream flow records." (Shanholtz, et al., 1972). For a detailed discussion on the model, a review of "Evaluation of a Model for Simulating Continuous Streamflow from Small Watersheds" by Shanholtz and Carr (1975) should be made. Once an "optimal" fit has been achieved, the model can be used as a tool to study how changes in the watershed can affect the hydrology of the area. This can be done by using the parameters within the model which reflect the changes that are to be studied, altering them, generating new flow sequences and comparing the resultant hydrographs with the previously optimized data.

This method was applied to evaluate the affect of increased urbanization in this portion of the Ottawa River basin. The model parameter which most directly reflects the degree of urbanized regions within the watershed is the percentage of impervious area (FIMP). It was also determined that to properly evaluate the urbanized influences, that a subroutine would need to be incorporated to summarize all discharges and withdrawals into and from surface waters which would cause significant changes in the natural flow. These values were then combined with the generated flows on a mean daily basis to produce the final synthesized flow routine. This procedure was acceptable, since all surface flow alterations were within the travel time of the watershed. In order to evaluate the effectiveness of the divergent flow subroutine, one of the three water years (1971-72) had it deleted. Modifications in the ground water supply, e.g., ground water pumpage, can be accounted for by altering those model parameters (e.g. BFRC, SUBWF, BFNLR) which affect interflow between surface and ground water sources.

One of the major problems encountered when utilizing this type of hydrologic model for regional analysis is that the area is treated as a lumped system; i.e., parameter estimates represent an average occurrence over the watershed, whereas, in reality, the data often represent localized characteristics; e.g., the degree of impervious area is not evenly distributed throughout the basin, but is measured in only a few areas. This problem was partially circumvented in this study because many of the watershed changes which are occurring have potential effect on the hydrology of the area. By assigning values to those specific parameters which reflect these influences, naturally occurring events, it is hoped, can be simulated more accurately.

Model Parameters

The watershed parameters quantify those specific characteristics of each watershed that govern its response to rainfall. The Kentucky Watershed Model utilizes thirty-two parameters divided into four categories: (a) initial moisture conditions, (b) parameters obtained from watershed characteristics, (c) parameters estimated from historical records, and (d) parameters estimated by trial and adjustment, and are presented in Table 2.

Table 2. Summary of Parameters Required for the Kentucky Watershed Model.

Parameter	Description
a. Initial Moisture Conditions:	
1. LZS	Current lower zone soil moisture storage
2. GWS	Current ground water storage
3. BFNX	Current value of base flow non-linear recession index
4. UZS	Current upper zone moisture storage
5. IFS	Current interflow storage
b. Parameters Obtained from Watershed Characteristics:	
1. AREA	Watershed area (square miles)
2. BTRI	Time delay histogram
3. FWTR	Fraction of area in stream surface
4. FIMP	Fraction of area having impervious area draining directly into a stream
5. GWETF	Ground water evaporation parameter. Equal to the fraction of area having water loss due to phreatophytes
6. OFSL	Average length of travel for overland flow (ft.)
7. OFMNIS	Average Mannings roughness coefficient for impervious surfaces
8. OFMN	Average Mannings roughness coefficient for pervious surfaces
9. OFSS	Average watershed slope (ft/ft.)
10. CHCAP	Index channel capacity providing an estimate of the flow at the mouth of the beginning of widespread flooding in tributaries
11. EXQPV	Exponent of flow proportional to velocity

Table 2. (cont.)

Parameter	Description
c. Parameters Estimated from Historical Records	
1. CSRX- - - - - - - - - - -	Stream flow channel routing parameter used to account for channel storage when flow less than 1/2 CHCAP
2. FSRX- - - - - - - - - - -	Stream flow channel routing parameter used to account for channel plus flood-plain storage when stream flow greater than twice channel capacity
3. VINTMR- - - - - - - - - -	Maximum interception rate for a dry watershed (in/hr)
4. FK1 - - - - - - - - - - -	Ratio of average rainfall on the watershed to the average rainfall at the recording gauge
5. ETLF- - - - - - - - - - -	A measure of the rate of loss through evapotranspiration
6. IFRC- - - - - - - - - - -	Interflow recession constant
7. BFRC- - - - - - - - - - -	Ground water recession index
8. DIV - - - - - - - - - - -	Daily flow diversions by water users
d. Parameters Estimated by Trial and Adjustment	
1. BMIR- - - - - - - - - - -	Infiltration index
2. BIVF- - - - - - - - - - -	Interflow index
3. BUZC- - - - - - - - - - -	Index for estimating soil surface moisture storage
4. SUZC- - - - - - - - - - -	Index for estimating soil surface moisture storage (adjust for seasonal variations)
5. SIAC- - - - - - - - - - -	Evaporation-infiltration factor (adjust for seasonal variations)
6. SUBWF - - - - - - - - - -	Indicator of subsurface water entering or leaving basin
7. BFNLR - - - - - - - - - -	An index used to provide curvilinear base flow recession
8. LZC - - - - - - - - - - -	Nominal lower zone storage index

Those parameters under category (a) - initial moisture conditions - were derived through experience and are based upon general information pertaining to the geological and climatological conditions at the beginning of the study period. These influences are only short-termed and do not normally affect the model results after the first few months.

The parameters obtained from watershed characteristics (b) are based upon data derived from an analysis of topographic maps and/or field inspections. The methodology for several of these parameters will be briefly discussed. The time-delayed histogram, BTRI, represents the fraction of the watershed having flow times equal to some preselected time increment, for example one hour. The channel flow time was determined by use of the Kirpich formula

$$t_c = 0.0078 \left[\frac{L}{S} \right]^{0.77}$$

where t_c is the flow time in minutes, L is channel length in feet and S is channel slop in ft/ft. The fraction of area in stream, lake, reservoir surface, FWTR, was estimated by several techniques. The total area of the lakes, reservoirs, and quarries was found from topographic maps by planimetering. The stream surface area was calculated with the formula

$$ETL_{STREAM} = \frac{WL}{55.76 \times 10^6 \text{ AREA}}$$

where W and L are the stream width and length in feet, respectively, at the watersheds discharge point and AREA is the total watershed area in square miles. The impervious fraction of the watershed is that area which has direct surface flow from the point that rainfall occurs to the main stream channel, preventing any form of seepage into lower zone storage, and is represented as FIMP. This value was calculated by estimating the area within each city and industry which is serviced by a storm sewer system. This was reasoned to be an appropriate procedure, because rainfall which occurs within these areas will be collected and subsequently discharged through the storm sewer system. The average length of travel for system overland flow, OFSL, in feet, represents the distance which water must flow from point of impact to a stream channel. Approximately 25 points were obtained and arithmetically averaged for the final value. The average slope, OFSS, within the watershed was calculated by dividing the change in contour elevation by the total length of the main stream channel. The values derived for these watershed parameters should be adjusted when basis for their calculation is in doubt, or direct watershed evaluation justifies it.

Those parameters estimated from historical records are best derived from data compiled on events occurring within the watershed. They are normally held constant with only minor adjustments to better fit hydrograph simulation. Information relating to land use patterns is required to determine the maximum interception rate for the dry state, VINTMR, and a measure of the rate of loss through evapotranspiration, ETLF. Both parameters are dependent upon the percentage of land being under grassland, open land, light forest and heavy forest conditions. The ratio of rainfall on the watershed to the recording stations is set at 1.0, since the precipitation data has already been Thiessen-weighted within the program. The remaining six parameters, CSRX, FSRX, FK1, IFRC, BFRC, and DIV are best estimated by various methods of hydrograph analysis.

The most difficult group of parameters to determine are those in the later group. Initial values are normally set by experience with the model and later altered to adjust the simulated hydrographs to observed data. To facilitate the determination of these parameters, a program was developed at the University of Kentucky called OPSET (Liou, 1970) to use with this version of the Stanford Watershed Model. The utilization of this optimizing program was somewhat limited in this study due to its lack of sensitivity to the large degree of urbanization which is occurring within the Ottawa River Watershed. However, it was capable of aiding in the setting of initial conditions. After several simulation runs, an "optimal set" of parameters was found (Table 3). The values finally derived are open to serious critical evaluation since they were calibrated on just three water years, where normally a minimum of five years of data is thought to be acceptable for simulation exercises. It is also important to note that the three years which were studied differed substantially in climatological and runoff characteristics, as seen in Table 4. Ross (1970) found that three water years representing extreme flows were sufficient to calibrate the KWM when applied to several watersheds located in Kentucky. Shanholtz and Carr (1975) reported similar results with data from watersheds located in Virginia, Tennessee, North Carolina and South Carolina. Based on these studies the three-year period represented by this report may be sufficient.

Table 3. Model Parameters of the Upper Ottawa River Basin, Ohio

Parameter	Value	Parameter	Value
LZS	4.00	CSRX	0.90
		FSRX	0.85
GWS	0.07	VINTMR	0.105
BFNX	0.07	FK1	1.0
UZS	0.00	ETLF	0.60
IFS	0.00	IFRC	0.60
AREA	160.0	BFRC	0.93
BTRI	26.0	DIV	1.0
FWTR	0.0026		
FIMP	0.10	BMIR	0.80
GWETF	0.0	BIVF	2.50
OFSL	800.0	BUZC	0.20
OFMNIS	0.020	SUZC	1.75
OFMN	0.310	SIAX	4.00
OFSS	0.0096	SUBWF	0.0
CHCAP	460.0	BFMLR	0.97
EXQPV	1.0	LZC	9.0

Table 4. Recorded Precipitation and Runoff for the Upper Ottawa River Basin, 1971-74

Water Year	Annual Precipitation	Annual Runoff
	(ins)	(ins)
1971-72	41.00	12.73
1972-73	42.83	18.63
1973-74	34.30	14.01

Model Calibration

The ability to utilize a proven hydrological model, such as the Stanford Watershed Model, in simulating natural hydrological sequences is difficult, but applying it to a system for which it was not initially constructed is even more so. Incorporating the divergent flow subroutine was done in order to properly account for significant changes in the area's hydrology due to urbanization. However, this also will increase the probability of error in simulation due to the addition of a factor (divergent flows) which is based on figures calculated on a mean daily basis and separate from the remainder of the system. In order to analyze the effect of the subroutine, the first of the three water years had it deleted. This should be considered when reviewing the data.

Fairly good success was achieved in simulating the observed hydrographs generated at the Allentown gaging station. Comparison of estimated and observed flow sequences is presented in Figures 3 through 5. Observed and estimated monthly and annual water yields are presented in Table 5, along with an error summary analysis. Although there are some variations between values, the flow match was considered acceptable.

In order to better analyze the effectiveness of the simulation, several exercises were carried out. Seasonal correlations were made to evaluate goodness of fit during certain periods of the year. The summary of this analysis is presented in Table 6. Although fluctuations occur from year to year, there is a tendency for good correlation in the winter and spring, and wide variations in the summer and fall. Although part of this can be corrected by parameter adjustment within the model, it is felt that much of the variation is due to not being able to completely account for effects from urbanization with the divergent flow subroutine. The extreme events were compared with very close correlation, and are listed in Table 7. Scatter diagrams depicting annual and monthly water yield are constructed in Figures 6 and 7 in order to correlate the similarity of these intervals.

In general, relatively good agreement was noted between the accumulated observed and simulated water yeild estimates over the water year. More variability was observed when the results were compared over shorter time periods (Figure 8).

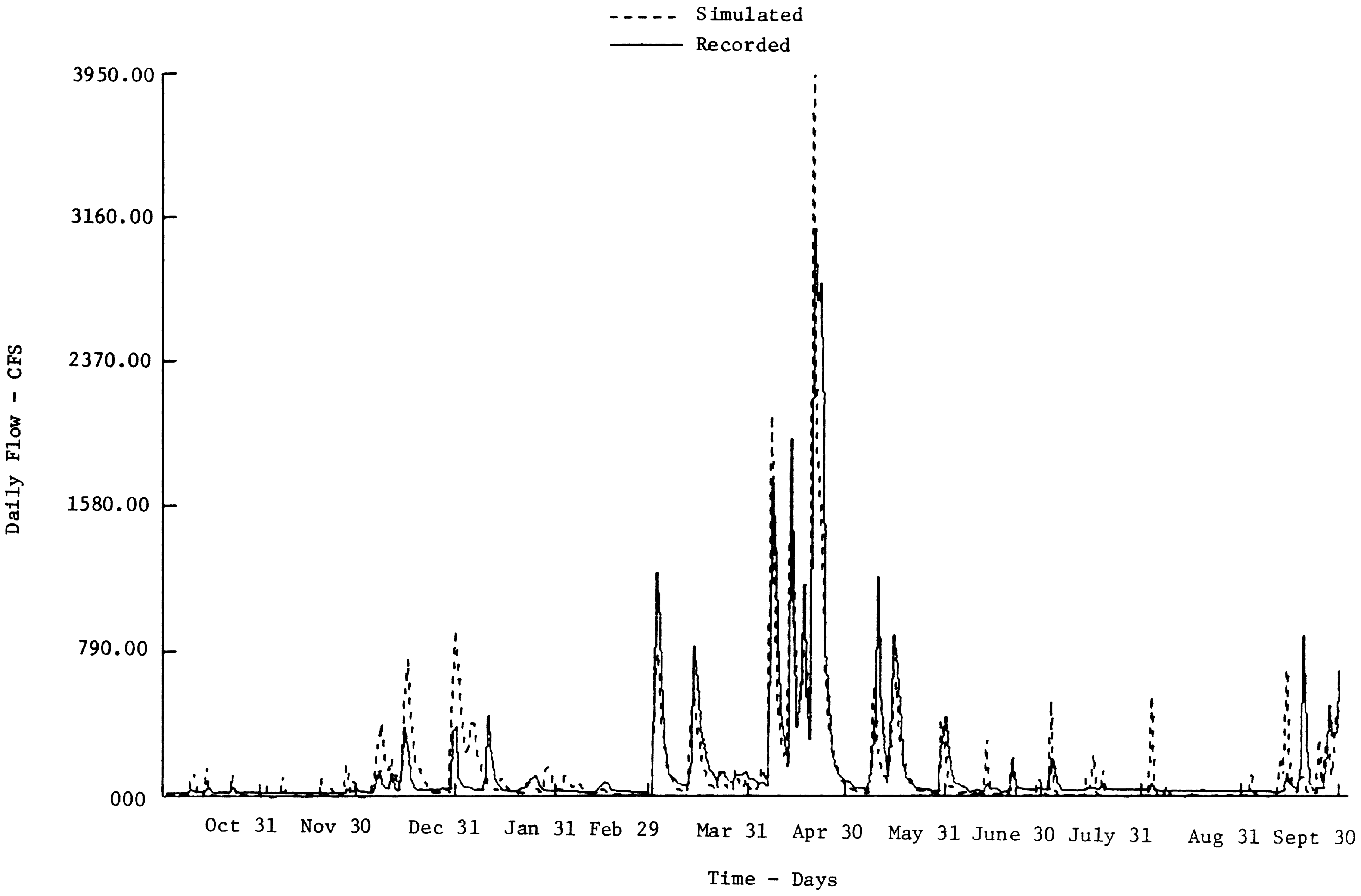

Figure 3. Comparison of recorded and simulated mean daily flow for water year 1971-72, Upper Ottawa River Basin, Ohio

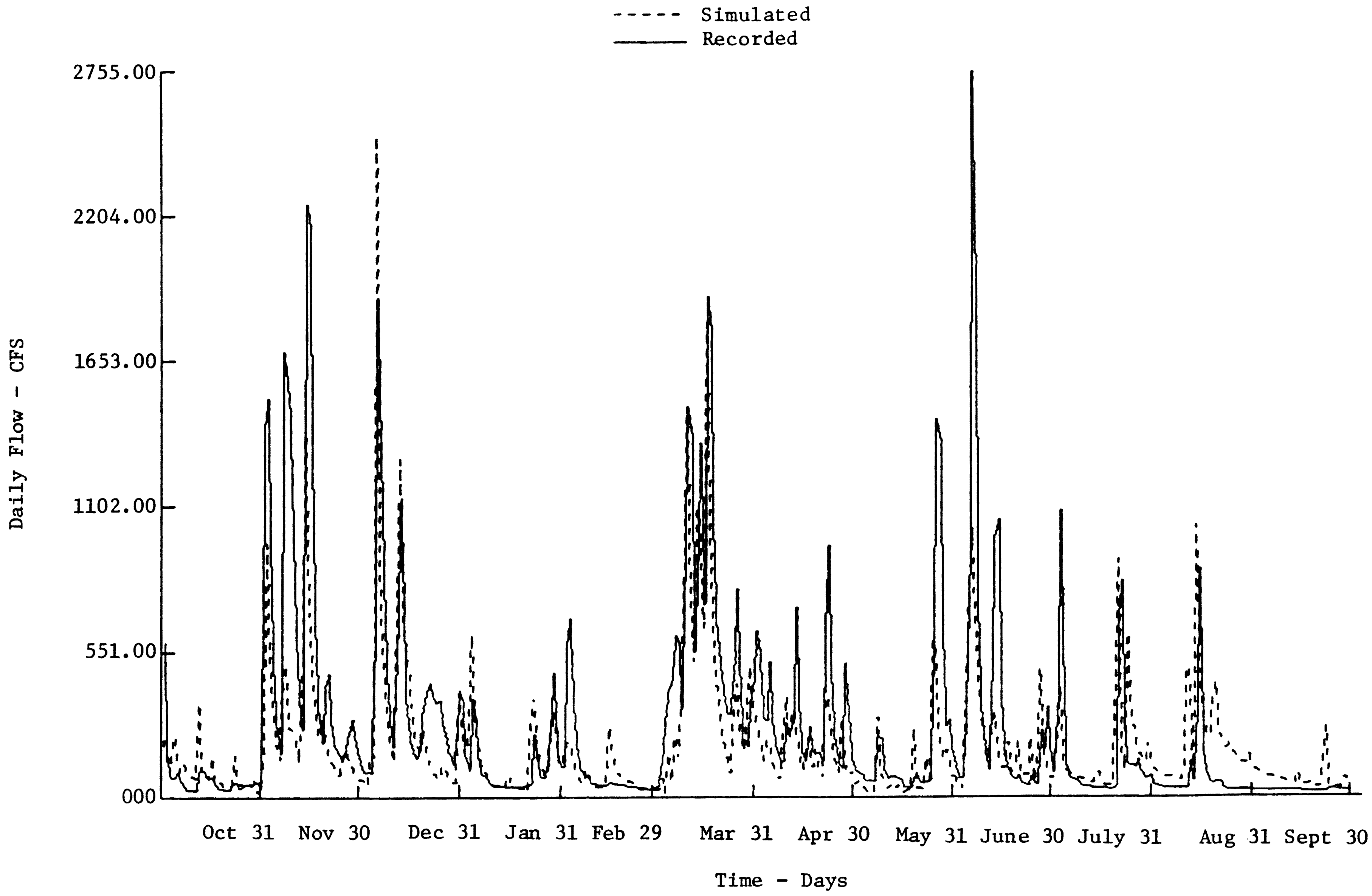

Figure 4. Comparison of recorded and simulated mean daily flour for water year 1972-73, Upper Ottawa River Basin, Ohio

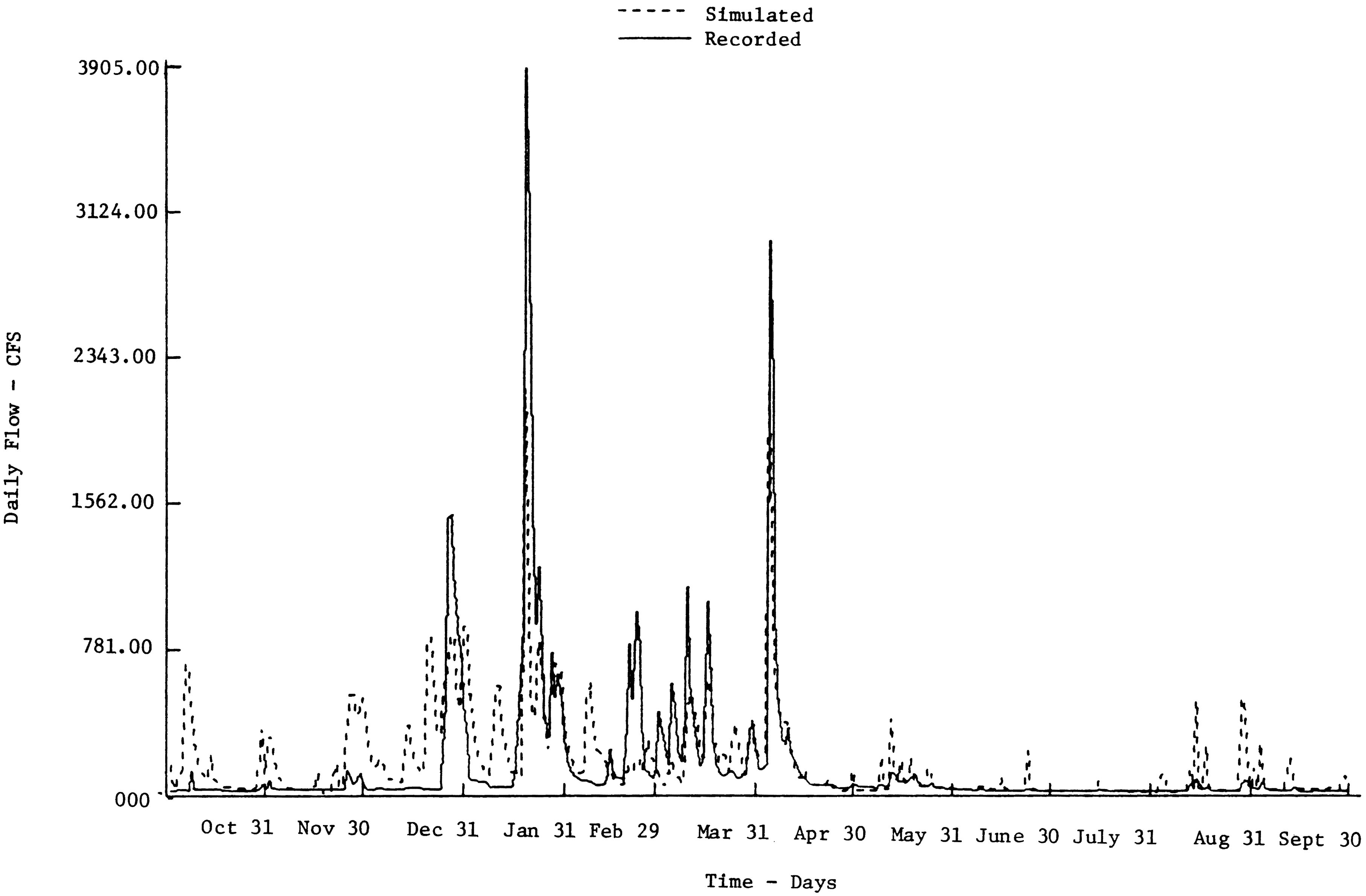

Figure 5. Comparison of recorded and simulated mean daily flow for water year 1973-74, Upper Ottawa River Basin, Ohio

Table 5. Observed and Estimated Monthly Water Yield Estimates. Error summary presented as observed minus estimated. Upper Ottawa River Basin, Ohio.

Water Year	Value[1/]	Discharge in inches for:												
		Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Year
1971-72	O	0.21	0.17	0.66	0.53	0.21	1.75	5.54	1.62	0.41	0.36	0.25	0.99	12.70
	E	0.18	0.17	1.37	0.98	0.20	1.25	5.04	1.13	0.28	0.29	0.20	0.85	11.94
	D	0.03	0.0	-0.71	-0.45	0.01	0.50	0.50	0.49	0.13	0.07	0.05	0.14	0.76
1972-73	O	0.57	4.91	3.04	0.95	0.73	4.63	2.26	1.53	2.80	1.27	0.60	0.18	23.47
	E	0.74	2.24	2.51	1.10	0.59	3.35	1.35	0.81	1.67	1.27	1.58	0.50	17.71
	D	0.17	2.67	0.53	-0.15	0.14	1.28	0.91	0.72	1.13	0.0	-0.98	-0.32	5.76
1973-74	O	0.27	0.37	1.78	4.14	1.44	2.33	2.27	0.46	0.23	0.21	0.28	0.24	14.02
	E	1.12	1.15	2.62	3.48	1.33	1.87	1.92	0.64	0.31	0.22	0.72	0.45	15.83
	D	-0.85	-0.78	-0.84	0.66	0.11	0.46	0.35	-0.18	-0.08	-0.01	-0.44	-0.21	- 1.81

[1/] O - Observed discharge in inches
E - Estimated discharge in inches
D - Difference (error) defined as O - E

Table 6. Comparison of Observed and Estimated Flow Sequences by Season, Upper Ottawa River Basin, Ohio.

Season	Water Year	Water Yield		Statistics[1]	
		Observed	Estimated	R	N
		(ins)	(ins)		
Oct.-Dec	1971-72	1.05	1.71	0.88	92
	1972-73	8.51	5.48	0.74	92
	1973-74	2.42	4.89	0.58	92
	1971-74	11.98	12.08	0.68	276
Jan.-Mar.	1971-72	2.49	2.43	0.75	91
	1972-73	6.31	5.04	0.90	90
	1973-74	7.91	6.69	0.76	90
	1971-74	16.72	14.16	0.81	271
Apr.-June	1971-72	7.57	6.45	0.93	91
	1972-73	6.59	3.84	0.77	91
	1973-74	2.95	2.87	0.97	91
	1971-74	17.11	13.15	0.88	273
July-Sept.	1971-72	1.60	1.35	0.47	92
	1972-73	2.05	3.35	0.50	92
	1973-74	0.72	1.39	0.88	92
	1971-74	4.38	6.09	0.48	276
Total	1971-72	12.71	11.93	0.89	366
	1972-73	23.47	17.71	0.75	365
	1973-74	14.01	15.83	0.78	365
	1971-74	50.19	45.47	0.80	1096

[1] R = Correlation coefficient
N = Sample size

Table 7. Observed and Estimated Extreme Events for Daily, Monthly, and Annual Occurrence, 1971-74, Upper Ottawa River Basin, Ohio.

Yield	High Day	Low Day	High Month	Low Month	High Year	Low Year
	(ins)	(ins)	(ins)	(ins)	(ins)	(ins)
Observed	0.91	0.0	5.54	0.17	23.47	12.71
Estimated	0.92	0.0	5.04	0.17	17.71	11.93

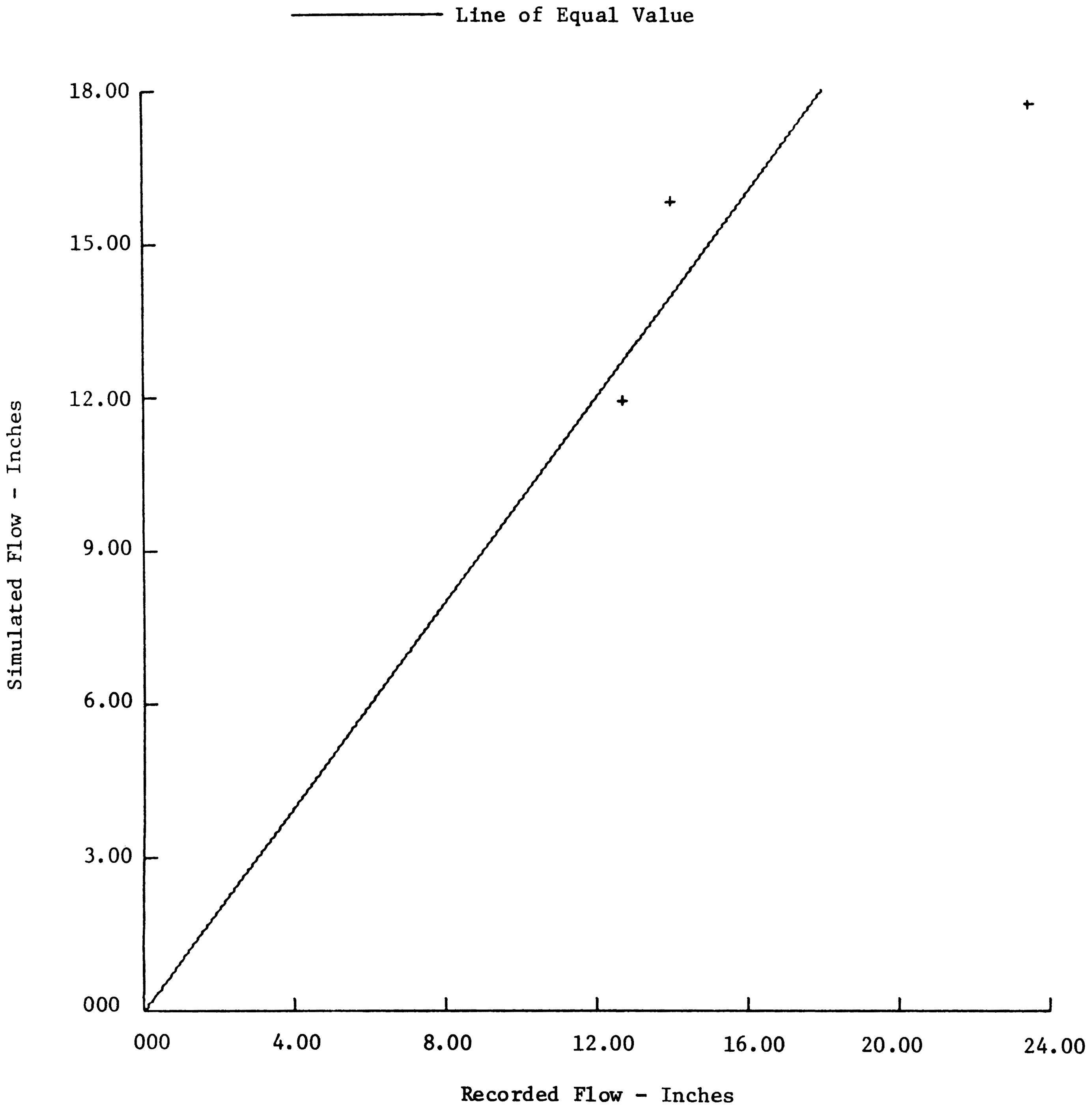

Figure 6. Comparison of Recorded and Simulated Annual Water Yields for Water Years 1971-74, Upper Ottawa River Basin, Ohio

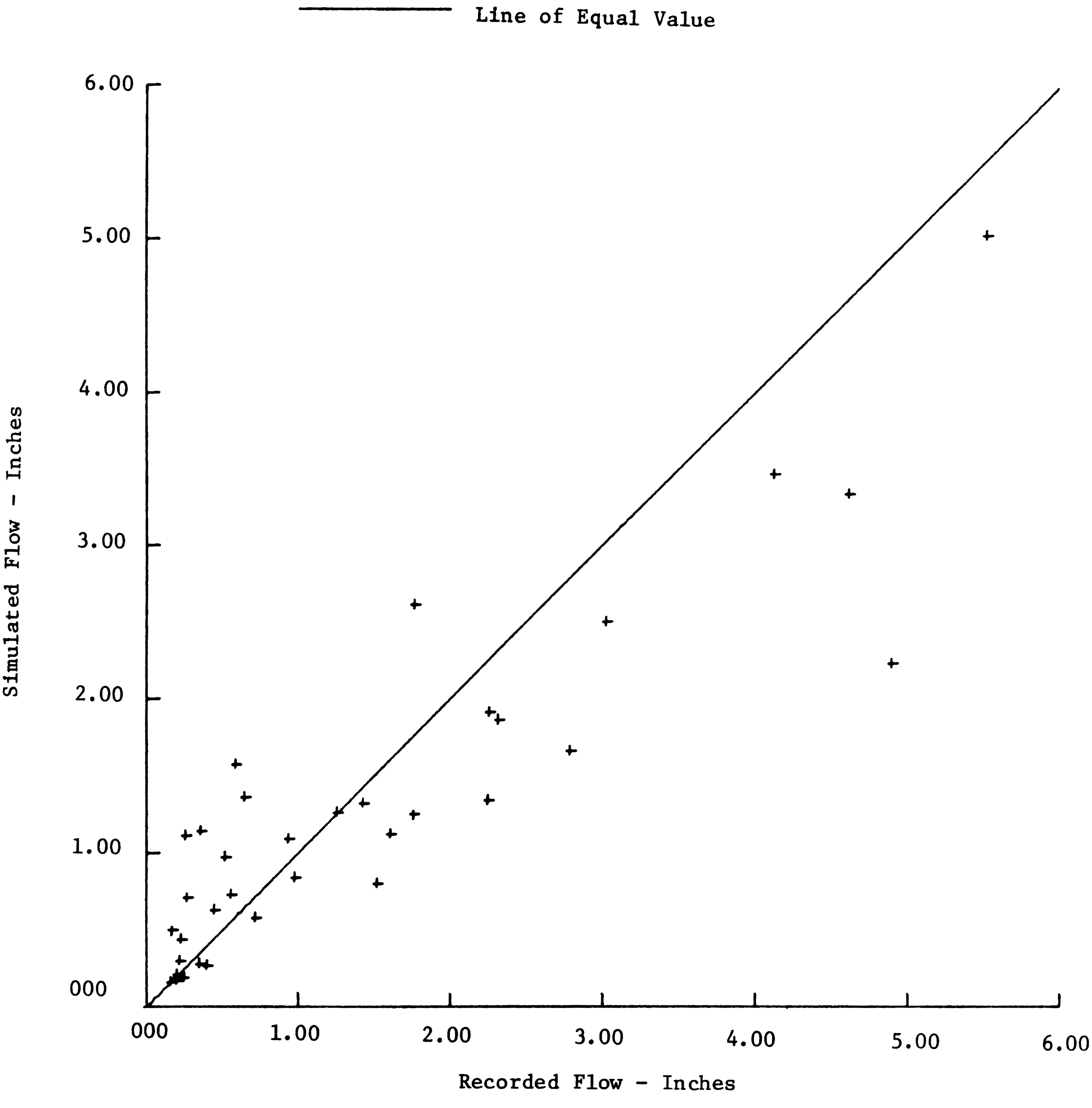

Figure 7. Comparison of Recorded and Simulated Monthly Water Yields for Water Years 1971-74, Upper Ottawa River Basin, Ohio

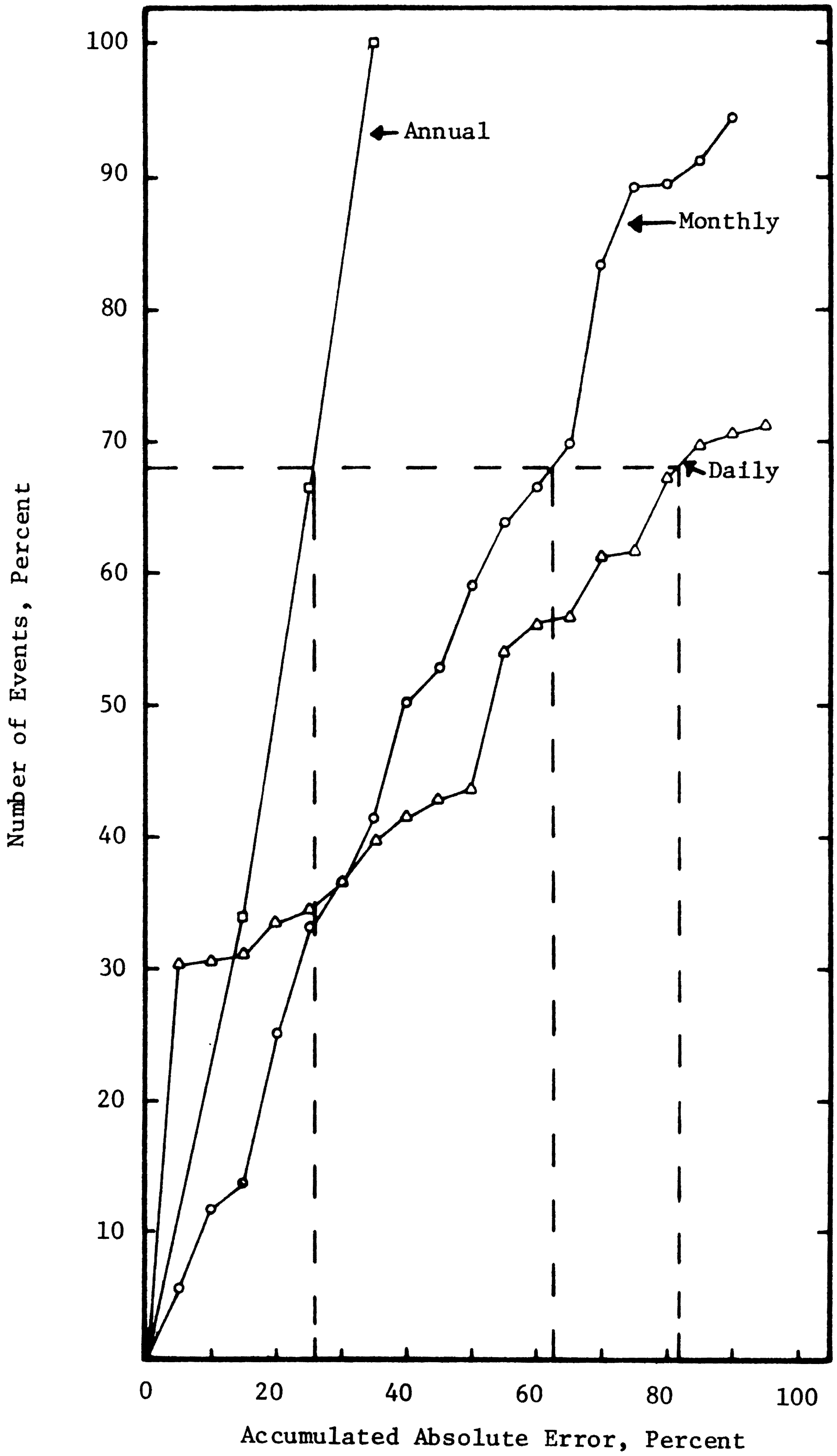

Figure 8. Number of Events Having Absolute Error less than or Equal to the Indicated Percentages. Water yield estimates for water years 1971-74, Upper Ottawa River Basin, Ohio

The two most significant sets of data which are required for proper simulation, precipitation and potential evapotranspiration, are often open to extreme degrees of error due to their methods of compilation. Rainfall data is normally averaged or weighted from several measuring stations to represent what is occurring throughout the watershed, while potential evapotranspiration data is normally derived through empirical calculations by any of several techniques. For determining the effect such possible error in data could have on the final estimated values, several simulations were carried out producing an error band around those predicted values which were otherwise optimally simulated. A ± 10% error limit was made with the upper bound being representative of an over estimation of rainfall by 10% and an underestimation of potential evapotranspiration by 10% (Shanholtz and Lillard, 1971). The lower bound was constructed in an identical manner, but with reverse allowances. This will thereby produce a boundary in which expected flows would be expected to fall with random errors not exceeding ± 10%. The results for the monthly and annual data is shown in Figures 9 through 11. As can be seen, the latter two years which contained the divergent flow subroutine had a greater number of observed events occurring outside of the predicted boundary limits. This would be expected, since in these simulation runs, the divergent flows which were included became a dominant factor in the estimation of flow sequences and were not as accurate as mean daily values, as were many of the other inputs.

EVALUATION OF URBANIZATION ON HYDROLOGIC SEQUENCES

As has been previously noted, the two manners in which the Kentucky Watershed Model was used to monitor effects on the hydrological cycle were through use of the model parameters representing percent impervious area within the watershed and the incorporation of a divergent flow subroutine to account for augmentations of flows due to pumpage and waste discharge by municipal and industrial sources.

In evaluating the effect of increased urbanization within the watershed, the impervious area had its initial value of 10% increased to 13%. This was done in response to estimated growth which could occur due to the increase in areas serviced by sewerage systems. The resultant simulations from these two runs were compared producing several expected results. There was an increase in surface runoff, reflected by an increase in discharge at the gaging station. Such increases in daily flows is apparent in Figure 12 and is only significant with flows greater than 40 cfs. This would be in response to more rainfall running directly to the river through the sewerage systems, with less percolating into the ground water system. A decrease in ground water supply can result over long periods of time, and has already been shown to be occurring in the area around Lima (Figure 2). During high flow events, the hydrograph's peaks increased and recessions were steeper. This indicates that there will be more water during flood conditions and that the surface water during these same periods is taking less time to discharge. One effect of this can be seen with the river's transporting capacity, e.g., an increase in sediment movement could occur.

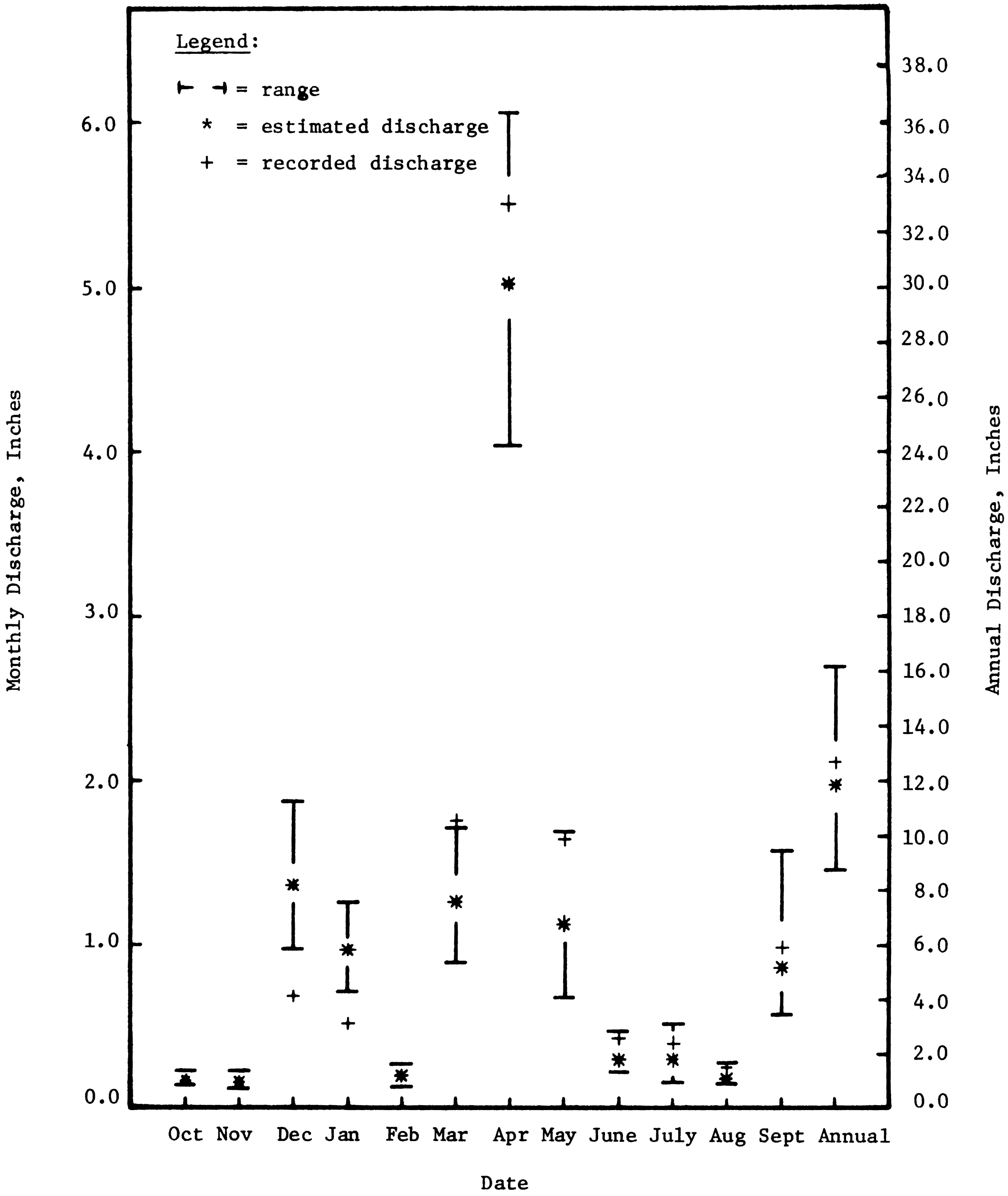

Figure 9. Effect of a ± 10 Percent Error in Precipitation and Evapotranspiration on Monthly and Annual Water Yields for 1971-72, Upper Ottawa River Basin, Ohio

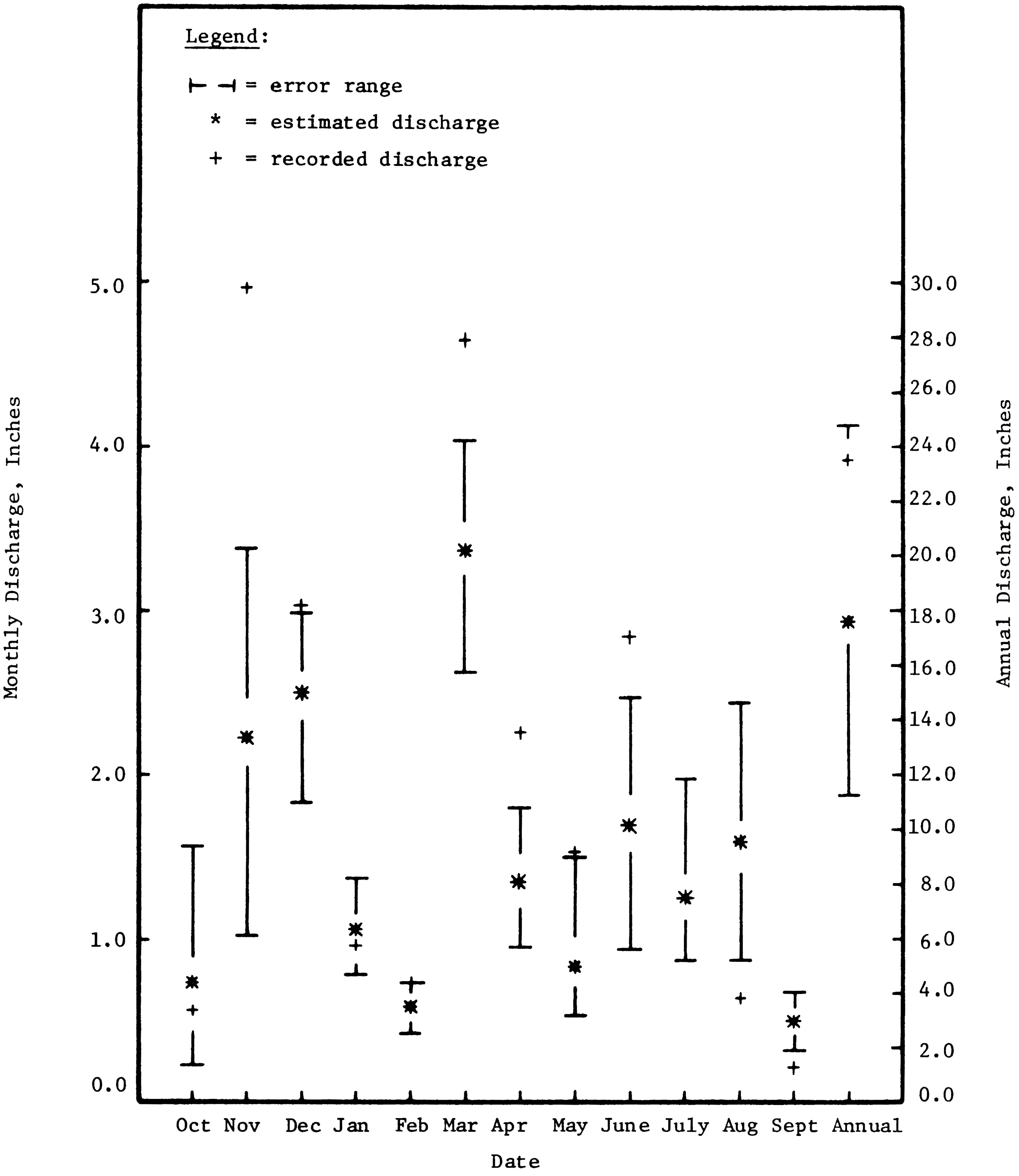

Figure 10. Effect of a ± 10 Percent Error in Precipitation and Evapotranspiration on Monthly and Annual Water Yields for 1972-73, Upper Ottawa River Basin, Ohio

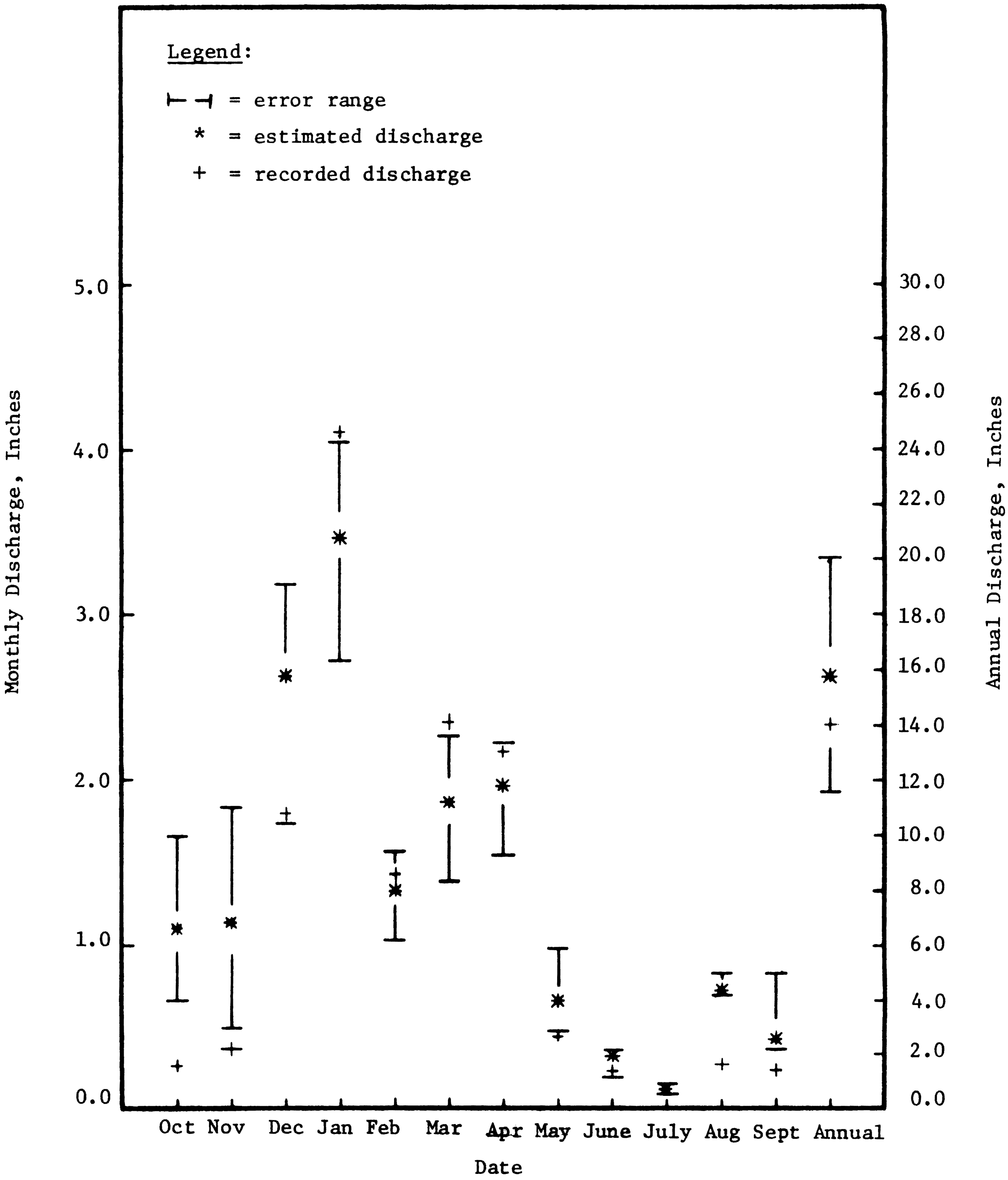

Figure 11. Effect of a ± 10 Percent Error in Precipitation and Evapotranspiration on Monthly and Annual Water Yields for 1973-74, Upper Ottawa River Basin, Ohio

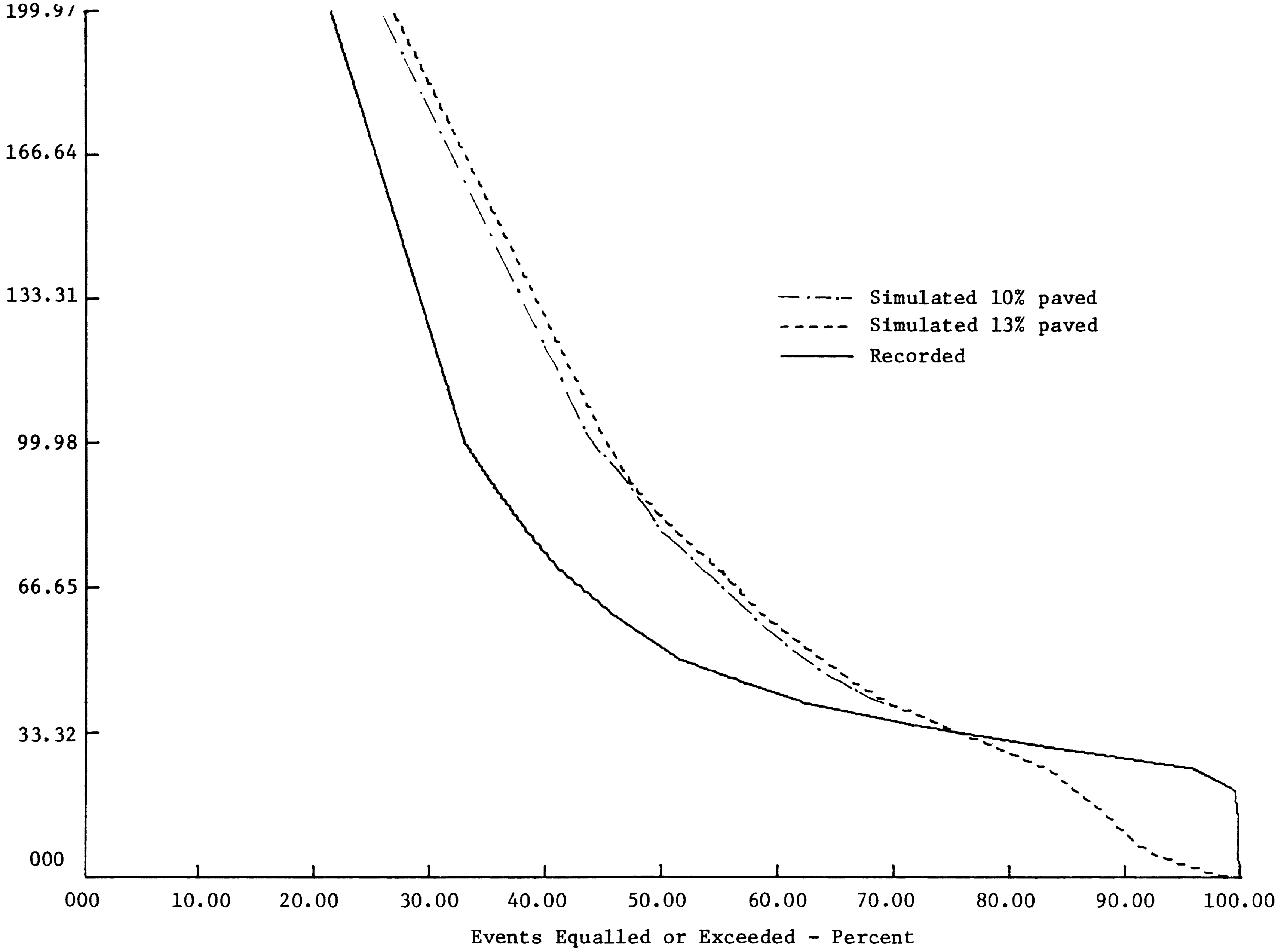

Figure 12. Comparison of Recorded and Simulated Flow Duration for Water Years 1971-74, Upper Ottawa River Basin, Ohio

The effectiveness of the divergent flow subroutine was mainly seen during low flow periods. By comparing observed with estimated flows, a greater correlation existed in the water years (1972-73, 1973-74) which included divergent flows whereas 1971-72 did not. Table 8 illustrates this for the first half of September for the first and last years. For example, the recorded flow for the period September 6 - 11, water year 1971-72, varied from 23 to 29 cfs while corresponding estimated flows based on actual precipitation ranged from 0.5 to 0.8 cfs. This can be accounted for by the fact that during these periods, the majority of the flow is comprised of effluents discharged. The inclusion of pumpage and discharge with the divergent flow subroutine gave more consistent results as can be seen for the interval September 5 - 10, water year 1973-74. Therefore, the actual significance of the divergent flows is dependent on the level of the stream flow which is naturally occurring. During periods of moderate to high flow conditions, correlations fluctuate greatly. In addition, variations in rainfall patterns, can be attributed to changes within the industries or cities' daily operations.

Table 8. Comparison of Estimated to Observed Mean Daily Discharges for Water Years 1971-72 and 1973-74 for September 1-15, Upper Ottawa River Basin, Ohio

Day	1971-72[1/]		1973-74	
	Observed	Estimated	Observed	Estimated
	(cfs)	(cfs)	(cfs)	(cfs)
1	25.0	0.9	46.0	152.4
2	25.0	0.8	34.0	49.4
3	35.0	113.1	77.0	284.3
4	26.0	20.6	49.0	65.1
5	28.0	2.1	40.0	41.6
6	29.0	0.8	35.0	38.4
7	29.0	0.7	30.0	39.1
8	29.0	0.7	29.0	42.7
9	25.0	0.6	28.0	41.1
10	23.0	0.6	30.0	37.6
11	23.0	0.5	29.0	113.0
12	36.0	194.6	38.0	197.0
13	36.0	119.0	48.0	91.2
14	130.0	698.3	34.0	51.0
15	72.0	211.1	29.0	45.0

[1/] Divergent flow subroutine not used.

SUMMARY

Past studies utilizing parametric watershed models for simulating the hydrology of agricultural watersheds have been proven effective. Applications with this basic form with several changes has shown that they can also be used when studying watersheds containing significant urban influence. Although there may be a minor decrease in overall correlation between observed and simulated sequences with this application, these can most likely be overcome utilizing more detailed data concerning the urban influences.

The application of a divergent flow subroutine within the model was found to be an effective method of introducing a summary of direct waste discharges and pumpages by municipal and industrial sources, especially during low flow periods when they are a significant part of the surface flow. The applicability of this subroutine is greatly dependent on the accuracy of the individual data from the point sources and should be introduced as mean daily flow rates.

Utilization of the percent impervious area parameter for reflecting the degree of urban influence within the watershed was shown to be a valid approach. This method can also be used in regional planning, when information is needed concerning effects on the watershed hydrology from urban growth.

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