EFFECTS OF CLIMATIC CHANGE IN WABASH RIVER BASIN

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ABSTRACT: The objective of this study is to investigate the effects of changes in precipitation and temperature on runoff from the Wabash River basin. A water-balance model is used in the study. The investigation is conducted using data from the Wabash River watershed in Indiana. A monthly water-balance model is used to simulate the monthly runoff. The calibrated water-balance model is used to perform sensitivity analyses of runoff under varying climatic conditions. Then it is used to investigate the effects of changes in temperature and precipitation on runoff in the Wabash River basin in Indiana. A significant conclusion from the study is that changes in rainfall have larger effects on runoff. The effect of changes in temperature on runoff is not as large.

INTRODUCTION

Recently, several scenarios have been proposed, based on climate models, that rainfall and temperature may show significant changes in the future (Waggoner 1990). Increase in the carbon dioxide content in the atmosphere and changes in forest cover are the main reasons suggested for these climatic changes. Changes in precipitation and temperature obviously affect runoff. Increased possibility of occurrence of droughts is one of the serious consequences of climatic changes.

Water-balance models have been used to estimate the impacts of global climatic changes (Gleick 1986, 1987a). Nemec and Schaake (1982) and Schaake (1990) have used water-balance models to investigate climate change effects on various aspects of the hydrologic cycle. The effect of carbon-dioxide-induced climatic change on water supply in the western United States has been investigated by Revelle and Waggoner (1983).

There have been several recent studies on the sensitivity of streamflows to climatic changes. Nash and Gleick (1991) studied the sensitivity of Colorado River flows to climatic changes by using a conceptual hydrologic model developed and operated by the National Weather Service. Allen et al. (1991) investigated the effects of CO_2-induced climatic changes on irrigation-water requirements in the Great Plains region. They used the results of global atmospheric-circulation models with a water-balance–irrigation water requirements model. Climatic inputs from general circulation models were used with two hydrologic models by Lettenmaier and Sheer (1991) to investigate the climatic sensitivity of California water resources.

In general, studies of hydrologic impacts of climatic change have been conducted mainly by using deterministic or conceptual models (Nemec and Schaake 1982; Cohen 1986; Gleick 1986, 1987a,b; Mather and Fedema 1986; Flaschka et al. 1987; Bultot et al. 1988; Nash and Gleick 1991; Allen et al. 1991; Lettenmaier and Sheer 1991; Mimikou et al. 1991). A few of these studies are based only on statistical techniques (Schwarz 1977; Stockton and Boggess 1979; Revelle and Waggoner 1983). Whether stochastic- or deterministic-model-based, these studies do not deal with the runoff characteristics of rivers in the midwestern United States. Because of its importance in the agricultural sector of the American economy, droughts in the midwestern United States can have serious consequences; therefore, the objective of the study reported herein is to investigate the effects of changes in rainfall and temperature on runoff in the Wabash River basin, a large watershed in the midwestern United States.

A monthly water-balance model developed by Mimikou et al. (1991) was calibrated by using observed climatic and runoff data. Model parameters were estimated by using an optimization method, a feature that is not present in the original model. After the parameters were calibrated, two types of simulations were conducted. In the first type, the observed rainfall and temperature sequences with changed means were used to simulate runoff. In the second type, stochastic precipitation sequences were used with the calibrated model to compute the runoff. The changes in runoff characteristics are examined and discussed.

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MODEL

The water-balance model considers the following monthly hydrological components: precipitation, snowmelt, evapotranspiration, soil moisture, ground-water storage, storm runoff, and base flow. Model inputs, parameters, and outputs are summarized in Table 1.

In this model, precipitation $P(t)$ for each month is divided into rain (RA) and snow (SN) according to the mean monthly temperature $[T(t)]$. It is assumed that a portion of precipitation is rainfall regardless of the temperature.

$$RA(t) = \begin{cases} \alpha P(t); & T(t) \leq T0 \\ P(t); & T(t) \geq T1 \\ \alpha P(t) + \dfrac{T(t) - T0}{T1 - T0}(1 - \alpha)P(t); & T0 \leq T(t) \leq T1 \end{cases} \quad (1)$$

$$SN(t) = P(t) - RA(t) \quad (2)$$

where $T0$ = temperature at which snow content of $P(t)$ reaches its maximum; $T1$ = temperature above which $P(t)$ falls as rain; and α = minimum rain content coefficient.

The direct storm runoff $Q_s(t)$ is computed by

$$Q_s(t) = SRC(t) \cdot RA(t) \quad (3)$$

where $SRC(t)$ = storm runoff coefficient for month t. Snowmelt $[SNM(t)]$ (in mm) is computed by

$$SNM(t) = SNT(t - 1) \cdot DF \cdot T(t) \cdot \text{Days}(t) \quad (4)$$

where DF = melt-rate factor [mm/(°C·day)]; and Days(t) = number of days in month t; and $SNT(t)$, accumulated snow (mm), is calculated by

$$SNT(t) = \sum_{i=1}^{t} [SN(i) - SNM(i)] \quad (5)$$

The evapotranspiration $ET(t)$ is satisfied by the water from snowmelt and the portion of the rain that remains after direct surface runoff generation. However, if the available water is not sufficient to provide for evapotranspiration then water will be drawn from the soil moisture $S(t)$ of the previous month.

The evapotranspiration has an upper limit that is the potential evapotranspiration (ETP). The Blaney-Criddle method [(6)] is used to compute ETP (mm/day)

$$ETP(t) = c\{f[0.46T(t) + 8]\} \quad (6)$$

where f = mean daily percentage of total annual daytime hours depending on the latitude and the month of the year; and c = an adjustment factor, which depends on minimum relative humidity (RH), relative sunshine duration (SH), and daytime wind speed. After ET is satisfied,

TABLE 1. Summary of Water Balance Model Inputs, Parameters and Outputs

(1)	(2)
	(*a*) Input Data
T	Monthly average temperature (°C)
P	Monthly average aerial precipitation (mm)
RH	Monthly average relative humidity
W	Monthly average windspeed (knot)
SH	Monthly average relative sunshine duration
	(*b*) Parameters
$SMAX$	Maximum soil moisture (mm)
$K1$	Conversion factor (dimensionless)
$K2$	Groundwater reservoir coefficient (dimensionless)
$T0$	Temperature parameter (minimum) (°C)
$T1$	Temperature parameter (maximum) (°C)
α	Minimum rain content coefficient (dimensionless)
DF	Melt-rate factor (mm/°C·day)
$SRC(t)$	Storm runoff coefficient for month t
	(*c*) Outputs
QE	Monthly total runoff (mm)
S	Monthly soil moisture (mm)

the available water, if any, will be used for soil-moisture replenishment. Soil moisture is bounded by the maximum soil moisture [$SMAX$ (mm)].

A fraction of the amount of water remaining after the soil-moisture requirement is satisfied, $WS(t)$ (Fig. 1), will flow to the river as $Q_0(t)$ (mm) as defined in

$$Q_0(t) = K1\ WS(t) \tag{7}$$

where $K1$ = a dimensionless factor.

The remaining portion of $WS(t)$ will percolate to the ground-water reservoir. The model assumes that the ground-water reservoir has a base-flow discharge $Q_b(t)$ with an assumed lag time of 1 month and is computed by

$$Q_b(t) = K2\ G(t - 1) \tag{8}$$

where $G(t - 1)$ = amount of water available in the ground-water reservoir during the previous month and it is computed by [where $G(0)$ is assumed to be equal to zero]

$$G(t) = (1 - K1)WS(t) + (1 - K2)G(t - 1) \tag{9}$$

The total estimated runoff [$QE(t)$] is computed by

$$QE(t) = Q_s(t) + Q_0(t) + Q_b(t) \tag{10}$$

A flowchart that gives the structure of the model is shown in Fig. 1. The flowchart shows the steps of the model operation, which are as follows.

1. Total precipitation $P(t)$ is divided into rain $RA(t)$ and snow $SN(t)$ according to monthly average temperature $T(t)$.
2. Storm runoff $Q_s(t)$, and accumulated snow $SNT(t)$ are calculated via (3) and (5), respectively.
3. Snow melt $SNM(t)$ is computed using (4).

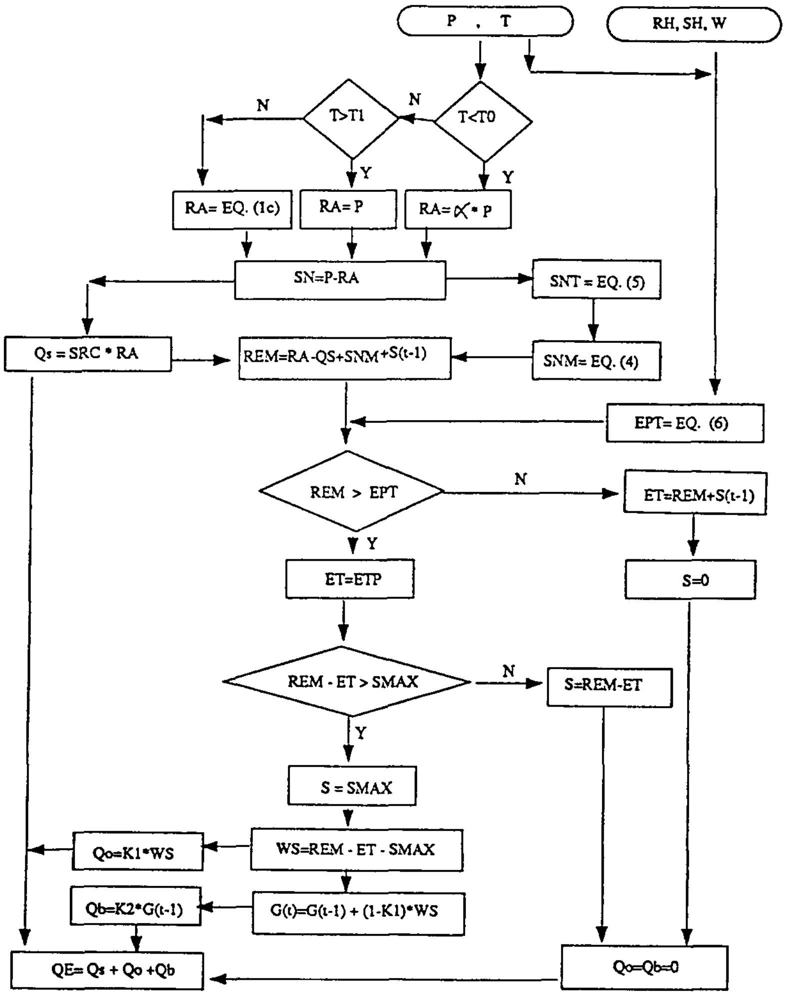

FIG. 1. Water-Balance Model

4. The available water $REM(t)$ for evapotranspiration and soil-moisture replenishment is computed by

$$REM(t) = RA(t) - Q_s(t) + SNM(t) + S(t - 1) \quad (11)$$

5. Potential evapotranspiration $ETP(t)$ is determined by (6).
6. If $REM(t)$ is less than $ETP(t)$, evapotranspiration $ET(t)$ is defined to be equal to $REM(t)$ and the soil moisture $S(t)$ is equated to zero.
7. If $REM(t)$ is greater than $ETP(t)$, evapotranspiration will be satisfied $ET(t) = ETP(t)$ and the excess water, $REM(t) - ET(t)$, is used for soil-moisture replenishment.
8. If $REM(t) - ET(t)$ is less than maximum soil moisture $SMAX$, water will not percolate to the ground-water reservoir and $REM - ET$ is used for soil-moisture replenishment so that, $S(t) = REM(t) - ET(t)$.
9. If $REM(t) - ET(t)$ is greater than $SMAX$, the soil-moisture reservoir will be full so that $S(t) = SMAX$. The surplus water $WS(t)$ is computed as $WS(t) = REM(t) - ET(t) - SMAX$.
10. Depending upon the value of $K1$, a fraction of surplus water will flow as outflow $Q_0(t)$.
11. Remaining portion of surplus water will percolate to the ground-water reservoir $G(t)$.
12. Base flow, $Q_b(t)$, is a fraction controlled by $K2$, of the ground-water storage $G(t)$ of the previous month.
13. Total estimated runoff $QE(t)$ is equal to the sum of $Q_s(t)$, $Q_0(t)$, and $Q_b(t)$.

DATA USED IN STUDY

Hydrological data for 20 years (1971–90) were used in this study. Monthly runoff records were available from the U.S. Geological Survey (USGS) Water Resources Data reports for the period 1971–90. Runoff data from station 03335500 located on the Wabash River main channel near Lafayette, Ind., were used in this study. Station 03335500 has a drainage area of 18,822 km^2. Two types of precipitation data were used in the study. The first type is the monthly precipitation from Logansport, Ind., which is located approximately at the center of the basin. The second type is precipitation data from seven rain gauge stations within the Wabash River basin. A map of the watershed and rainfall stations is given in Fig. 2. A list of the precipitation stations is given in Table 2.

Monthly temperature records were available from seven meteorological stations within the study area. Monthly relative humidity data were obtained from the Purdue University Agronomy farm meteorological station, located 6 mi northwest of West Lafayette, Ind. Wind-speed and relative sunshine records were available only from the Indianapolis meteorological station. These data were assumed to represent the aerial average temperature, relative humidity, wind speed, and relative sunshine duration over the entire study area. According to Mimikou et al. (1991), accurate wind-speed data are not necessary for accurate runoff predictions from the model. Wind speed and sunshine duration were used in the model to compute potential evapotranspiration. The most important factor in evapotranspiration computation is the mean monthly temperature for which records are available for the entire study period (1971–90) from the seven stations in the basin.

One of the meteorological inputs is relative sunshine duration. Relative sunshine duration is

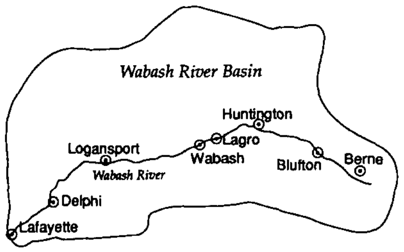

FIG. 2. Map of Wabash River Watershed and Location of Rainfall Stations

TABLE 2. Precipitation Stations used in the Study

NWS number (1)	Location (2)
120676	Berne, Ind.
120830	Bluffton, Ind.
124181	Huntington, Ind.
129138	Wabash, Ind.
125117	Logansport, Ind.
122149	Delphi 3N NE, Ind.
129424	West Lafayette FAA AP, Ind.

computed by dividing the actual sunshine duration by the maximum possible sunshine duration, which is obtained from Chow (1964) for the latitude of 40° N.

APPLICATION OF MODEL TO WABASH RIVER BASIN

To apply the water-balance model, initial values for the model parameters should be provided. Monthly runoff coefficients were computed by dividing the average monthly equivalent runoff depth for station 03335500 by the average monthly precipitation depth for each month of the year. These computed values were used as initial values for the model parameters *SRC*(*t*) (Table 4). Initial values for the other seven model parameters are shown in Table 3.

Runoff computed by using the initial parameter estimates were very inaccurate compared to observed runoff. The model calibration criteria used, the Nash parameter (*NTD*) and annual runoff ratio (*RE*), also gave unacceptable values. The model calibration criteria *NTD* and *RE* are defined in

$$NTD = 1 - \frac{\sum_{t=1}^{12} [QM(t) - QE(t)]^2}{\sum_{t=1}^{12} [QM(t) - \overline{QM}]^2}; \quad RE = \frac{\sum_{t=1}^{12} QE(t)}{\sum_{t=1}^{12} QM(t)} \qquad (12, 13)$$

where $QM(t)$ = measured runoff for month t; $QE(t)$ = estimated runoff for month t; and $\overline{QM}$ = mean monthly runoff for the year. The closer the values of *NTD* and *RE* to unity, the better the model performance.

When the model parameters were varied around their initial values, no significant improvement was noticed in the model performance. An optimization program was developed and used to find the optimal parameter estimates. A multivariable unconstrained optimization method, the Rosenbrock optimization algorithm (Kuester and Mize 1973) was used to optimize the model parameters. The objective function minimized was the sum of squared differences between observed and estimated monthly runoff. Only an executable program of the water-balance model provided by Mimikou et al. (1991) was available. To incorporate the optimization program into the model, a FORTRAN version of the water-balance model program was developed and used (Al-Wagdany and Rao 1993).

The results from the water-balance model and the original executable program were compared and found to be very close to each other. The new program was incorporated into the optimization routine. The initial and optimized values of the parameters of the water-balance model are given in Tables 3 and 4.

The optimized values of all 19 parameters are significantly different from initial values and were found to be physically meaningful. Optimum value of *SMAX* is 93 mm, which implies that all the water available at that depth (93 mm) is available to satisfy evapotranspiration. Optimum value of *T*1, −1.20, is also reasonable because it implies that when temperature is below −1.20°C

TABLE 3. Initial and Optimized Model Parameters

Parameter (1)	Initial value (2)	Optimum value (3)
SMAX	300	93
*K*1	0.60	0.37
*K*2	0.50	0.23
*T*0	−3.5	−14.0
*T*1	2.0	−1.2
α	0.30	0.13
DF	0.45	2.42

TABLE 4. Initial and Optimized Model Parameters

Month (1)	Initial *SRC*(*t*) (2)	Optimal *SRC*(*t*) (3)
Oct.	0.18	0.18
Nov.	0.24	0.16
Dec.	0.21	0.28
Jan.	0.26	0.34
Feb.	0.31	0.37
Mar.	0.48	0.27
Apr.	0.52	0.18
May	0.34	0.15
June	0.37	0.15
July	0.20	0.08
Aug.	0.15	0.05
Sep.	0.22	0.07

TABLE 5. Calibration Measures of Model using Precipitation and Temperature Data from Logansport and from Seven Stations

Year	Logansport		Seven Stations	
	NTD	*RE*	*NTD*	*RE*
(1)	(2)	(3)	(4)	(5)
1970–71	0.70	1.13	0.68	0.83
1971–72	0.59	1.32	0.87	1.14
1972–73	0.25	1.29	0.80	0.93
1973–74	0.31	0.80	0.66	0.87
1974–75	0.26	0.98	0.73	0.99
1975–76	0.70	0.99	0.85	1.10
1976–77	0.57	1.24	0.66	1.32
1977–78	0.27	0.89	0.66	1.05
1978–79	0.85	1.03	0.82	1.14
1979–80	0.68	0.91	0.63	0.95
1980–81	0.16	0.54	0.44	1.77
1981–82	0.49	0.64	0.62	0.79
1982–83	0.52	1.04	0.72	0.98
1983–84	0.77	0.93	0.86	1.14
1984–85	0.32	1.66	0.44	1.07
1985–86	0.56	0.81	0.54	0.87
1986–87	−1.50	0.73	0.03	0.85
1987–88	0.68	1.22	0.87	1.15
1988–89	−0.52	1.01	−0.04	1.05
1989–90	0.54	0.83	0.31	0.70
Average	0.36	1.00	0.63	0.99

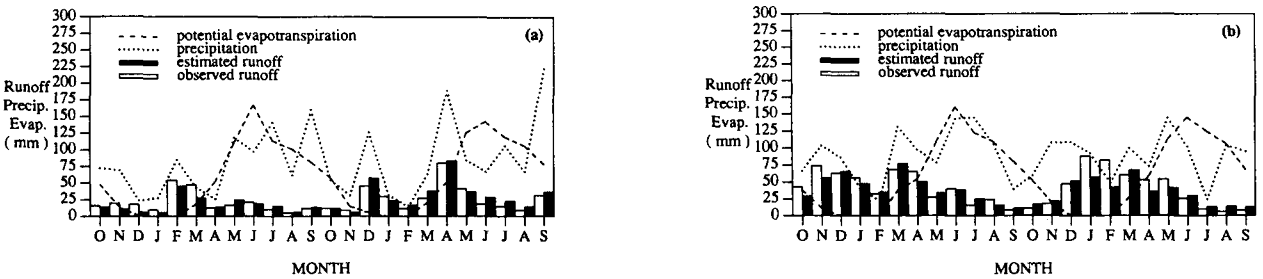

FIG. 3. Typical Observed and Computed Monthly Flows, Potential Evapotranspiration and Precipitation: (a) Years 1970–72; (b) 1972–74

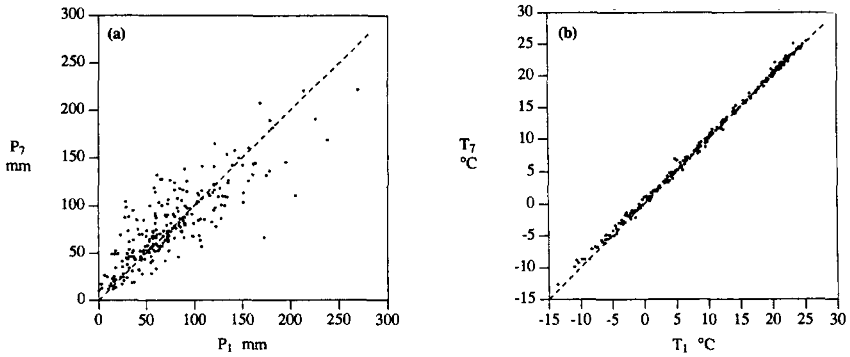

FIG. 4. (a) Precipitation at Longansport versus Average Precipitation of Seven Stations; (b) Temperature at Logansport versus Average Temperature of Seven Stations

a portion of precipitation has to fall as snow. At −1.20°C it is usual for precipitation to fall as snow. The optimum value of *DF* is 2.42 mm°C day, which indicates that with a 10°C increase in mean monthly temperature, 24.4 mm of snow will melt per day. This value, once again, is reasonable, because when there is a large increase in temperature (such as 10°C), significant amounts of snow will melt each day. However, the parameters that are obtained from the model optimization should be considered the best estimates applicable to Wabash River basin only.

The values for the calibration measures are presented in Table 5 for the 20 hydrological years (1971–90). Examples of observed and estimated runoff hydrographs as well as precipitation and evapotranspiration for the study period (1971–90) are presented in Fig. 3. The model accurately estimates the observed values for most years for the study period (1971–90). The model performance when the temperature and precipitation data from only Logansport were used was not satisfactory (Table 5). The performance index (NTD) for correspondence of computed and observed flows is only 0.36 when the data from only Logansport is used. This improves to 0.63 when average rainfall data from seven stations are used. The parameter *RE*, which represents the ability of the model in estimating annual flows, does not depend on the rainfall data used. It is very good whether data from a single station or the average from a number of stations are used. Plots of average monthly rainfall and average temperature against the corresponding values at Logansport (Fig. 4) shows that rainfall at Logansport is not as well correlated as temperature data.

INVESTIGATION OF CLIMATIC CHANGE SCENARIOS

Global climate change may occur due to the increase of CO_2 and other radiative trace gases in the atmosphere. The temperature is expected to increase with increases in CO_2 and other gases. Changes in regional distribution of precipitation are not easy to establish (U.S. National Academy of Sciences 1979, 1983). However, even the precipitation is expected to change. The effects of changes in precipitation and temperature on runoff were investigated in this study.

It is conceivable that climate change could result in a significant change in the atmospheric circulation pattern over a region. Such a change could alter the temporal distribution of rainfall. For example the shift in circulation may result in a change in the trajectory of the mean air flow, which might drastically change the characteristics of the climate. Such changes would affect $SRC(t)$ values. It is possible to simulate such changes by varying the $SRC(t)$ values, although it was not done in the present study. Instead, the following two types of simulations were conducted.

In the first case, the mean values of observed rainfall and temperature series were altered. These altered temperature and rainfall sequences were used with the calibrated water-balance model to compute runoff. Changes in observed and simulated runoff were computed and analyzed. In the second type of simulation stochastic models were developed for monthly precipitation. Realizations from this stochastic model were used with the watershed model and the results were examined.

Simulations with Observed Temperature and Precipitation Sequences

Two scenarios with 1 and 3°C increases in mean month temperature were chosen for temperature changes. Four scenarios for precipitation changes were chosen with changes of −20%,

TABLE 6. Percent Changes of Mean Monthly Flows with Changes of Mean Precipitation (*P*) and Temperature (*T*)

ΔP%	10	10	20	20	−10	−10	−20	−20
ΔT°C	1	3	1	3	1	3	1	3
Oct.	15	−3	46	20	−28	−40	−47	−59
Nov.	23	−1	63	34	−35	−44	−51	−59
Dec.	19	12	40	34	−25	−33	−47	−53
Jan.	21	24	41	45	−17	−15	−34	−32
Feb.	19	18	40	36	−15	−15	−31	−32
Mar.	12	−4	28	12	−20	−32	−34	−45
Apr.	8	04	27	12	−23	−31	−37	−43
May	14	1	33	21	−22	−29	−36	−42
Jun.	12	3	30	19	−19	−26	−34	−39
Jul.	16	−2	43	21	−27	−39	−44	−54
Aug.	20	0	50	27	−29	−40	−46	−56
Sep.	17	1	47	24	−32	−44	−52	−62

TABLE 7. Percentage Change of Mean Monthly Flows of The Generated Data

Month (1)	Observed (mm) (2)	ΔP%					
		−30 (3)	−20 (4)	−10 (5)	10 (6)	20 (7)	30 (8)
1	17.4	−35	−40	−18	11	45	54
2	20.2	−44	−33	−22	−24	69	92
3	34.0	−52	−30	−38	−3	43	58
4	25.7	−46	−37	−15	20	55	72
5	35.2	−31	−26	−37	20	35	49
6	50.4	−45	−22	−21	3	30	51
7	39.2	−37	−37	−17	12	32	60
8	31.9	−34	−30	−20	13	33	52
9	27.8	−45	−31	−16	10	34	53
10	16.9	−41	−32	−15	9	39	58
11	12.9	−42	−30	−22	14	41	89
12	12.7	−38	−47	−29	17	41	63

−10%, 10%, and 20% in mean monthly precipitation. The percent changes in mean monthly runoff compared to observed monthly mean flows for each of the proposed scenarios are presented in Table 6.

The results in Table 6 show that Wabash River runoff is very sensitive to changes in precipitation. When precipitation increases by 10%, runoff increases for all months even when temperature increases by 1°C. For example, an increase of 10% in precipitation in October will cause a corresponding increase of 15% in runoff compared to observed runoff when temperature increase is 1°C, and runoff will decrease by 3% compared to observed runoff when temperature increase is 3°C. Results for other months are similar. Increases in precipitation cause a significant increase in runoff, and the effect of temperature increase on runoff is not as significant as increases in precipitation. The increase of temperature is found to cause runoff to increase during winter and to decrease during summer for the same rate of precipitation increase. This is reasonable since a temperature increase increases snowmelt during winter and increases evaporation during summer.

For a given precipitation change, changes of runoff were found to vary from month to month. For a 20% increase in precipitation ($\Delta T = 1°\mathrm{C}$), runoff will increase by 46% in October, and when precipitation decreases by 20% ($\Delta T = 1°\mathrm{C}$) runoff will decrease by 47%. On the other hand, for the month of September a 24% increase in runoff is predicted due to a 20% change in precipitation ($\Delta T = 3°\mathrm{C}$). If precipitation is reduced by the same percentage (20%) with a temperature increase of 3°C, September runoff decreases by 62%.

For most of the scenarios just presented, changes in runoff due to temperature increase from 1 to 3°C were not found to be very significant. On the other hand, precipitation changes (−20%, −10%, 10%, and 20%) have a very significant effect on runoff magnitude. This result is expected because increased temperature will first affect soil moisture. Soil-moisture reduction will reduce the overflow and base-flow components of the total runoff of the basin. Since the values of model parameters $K1$ and $K2$ are small, the contribution of $Q_0(t)$ and $Q_b(t)$ to the total runoff should be small. This leads us to conclude that temperature increase will cause small changes on the magnitude of total runoff, particularly during fall and summer seasons.

Simulation Using Generated Data

As seen from the results obtained by using observed data, changes in runoff are more sensitive to changes in rainfall than to temperature. Consequently, in this simulation, rainfall sequences were generated and used with the calibrated water-balance model to investigate the corresponding changes in runoff. The observed temperature sequences were used with the generated rainfall sequences.

The observed rainfall series P_i were standardized by using the monthly means $\bar{P}_\tau$ and monthly standard deviations σ_τ, $\tau = 1, 2, \ldots, 12$ to get the standardized sequence z_i.

$$z_i = (p_i - \bar{p}_\tau)/\sigma_\tau \tag{14}$$

Autoregressive models of different orders were fitted to the z_i sequence and the residuals were checked for whiteness. An AR(3) model was found to be acceptable. z_i in (15) is normally distributed with mean zero and standard deviation unity.

$$z_i = 0.0426z_{i-1} - 0.1662z_{i-2} - 0.0093z_{i-3} + \tau_i\sigma \tag{15}$$

where σ = standard deviation of the residuals. z_i sequences were generated from (15), and these generated rainfall sequences were used with the water-balance model to estimate the runoff. The number of rainfall values generated is equal to the number of observed runoff values. The observed temperature sequence with altered means were used in the simulation.

The simulation results are presented in Table 7. The results of the simulation study are similar to those obtained by using the observed data.

SUMMARY AND CONCLUSIONS

A water-balance model (Minikou et al. 1991) was applied to Wabash River basin. Model input data are precipitation, relative humidity, wind speed, and sunshine duration. Precipitation records from seven meteorological stations in the basin were used. Other input data available from the Purdue University Agronomy farm meteorological station located 6 mi northwest of West Lafayette, Ind., were used. Runoff records for the period of (1971–90) were used. The model was calibrated by using the Rosenbrock optimization algorithm to determine optimum model parameters. The two basic assumptions made in the simulation are (1) $SRC(t)$ values remain the same, although the temperature and rainfall change; and (2) that the temporal distributions of rainfall and temperature remain the same.

Results from the model shows that it can satisfactorily simulate the general trend of the observed hydrographs. The model is used to predict runoff variations of the basin using eight possible scenarios of climatic changes. Changes in precipitation will cause significant runoff changes for all seasons. Changes in temperature have less effect on runoff production compared to changes in precipitation for the model structure. When precipitation decreases, it causes significant runoff reduction during summer and fall seasons. Model performance is promising and it may be used to investigate changes in climatic conditions.

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APPENDIX. REFERENCES

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