Bias in Runoff Parameter Estimation Induced by Rainfall Data

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BIAS IN RUNOFF PARAMETER ESTIMATION INDUCED BY RAINFALL DATA

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ABSTRACT

Studies in Du Page County, Illinois found that a rainfall-runoff parameter set calibrated on the basis of the National Oceanic and Atmospheric Administration (NOAA) precipitation-gage network (non-recording and weighing bucket gages) could not be applied with data collected from a U.S. Geological Survey (USGS) tipping-bucket rain-gage network. The average yearly, average monthly, and average storm-event periods simulated based on USGS rainfall data in the hydrologic simulation model calibrated with NOAA rainfall data was consistently low compared to simulation results based on the NOAA data and recorded flows. Multiplying the hourly USGS rainfall data by a factor within the hydrologic simulation model aligned USGS simulated results with simulated results using the NOAA data for all periods. Other than applying a constant correction factor, there is no evidence that seasonal or wind induced corrections are needed for the USGS rainfall data used in model simulation to better match the simulated results based on NOAA data.

BACKGROUND

Hydrologic models often are calibrated using rainfall and streamflow data to facilitate simulation of the amount of runoff that will result from a watershed. A consistent record of rainfall data is vital to the accuracy of model simulation. Troutman (1983) has shown that the calibration process transfers errors and uncertainties in the data to the model parameters in the form of bias in the parameter values (i.e. deviation from true values). However, because of the curve-fitting properties of the calibration process, estimation performance of the model based on erroneous data and biased parameters is not greatly different from that using true data and parameter values in the range of the data. Therefore, accurate simulations can be obtained as long as the errors and uncertainties in the input data are similar to (consistent with) the errors and uncertainties in the data used to calibrate the model. This technical note provides a clear illustration of the magnitude of the simulation problems that can result when a model calibrated to one data set is applied using a different data set. Also, results indicate that it may be possible to develop a simple correction factor for the non-calibration data set to yield accurate simulation results.

Previous studies in Du Page County found that a rainfall-runoff parameter set calibrated on the basis of the NOAA precipitation-gage network (weighing bucket and non-recording gages) could not be applied with data collected from the USGS tipping-bucket rain-gage network (Tom Price, Northeastern Illinois Planning Commission (NIPC), written commun., 1997). A statistically significant difference was found between rainfall totals collected from USGS and NOAA precipitation-gage networks in and near Du Page County, Illinois (Straub and Parmar, 1998).

DATA COLLECTION AND PREPARATION METHODS

Ten tipping-bucket rain gages from the USGS rain-gage network were used in this study. Hourly rainfall totals from April 1990 to October 1993 were used as model input for the analysis of simulated runoff. The reciprocal distance squared method was used to estimate periods of missing record (U.S. Department of Commerce, 1972). Thiessen polygons were drawn to determine the area of influence of each of the 10 rain gages. Unheated tipping-bucket rain gages do not accurately record snowfall. For this reason, data from each USGS tipping-bucket rain gage were replaced with data from the nearest NOAA precipitation gage (U.S. Department of Commerce, 1990-1993) during periods of snowfall. Snowfall was determined using NOAA precipitation data published by the National Climatic Data Center (NCDC) (U.S. Department of Commerce, 1990-1993).

NOAA meteorological data were obtained from the NCDC and compiled for model input by NIPC. A summary of the meteorological data used in the model is presented by Price (1994b).

Streamflow data from seven stream gages were used to compare simulated rainfall-runoff results with the measured streamflow. Hourly streamflow data from April 1990 to October 1993 were used in the analysis. Land-cover data for the seven simulated watersheds were obtained from the Du Page County Department of Environmental Concerns.

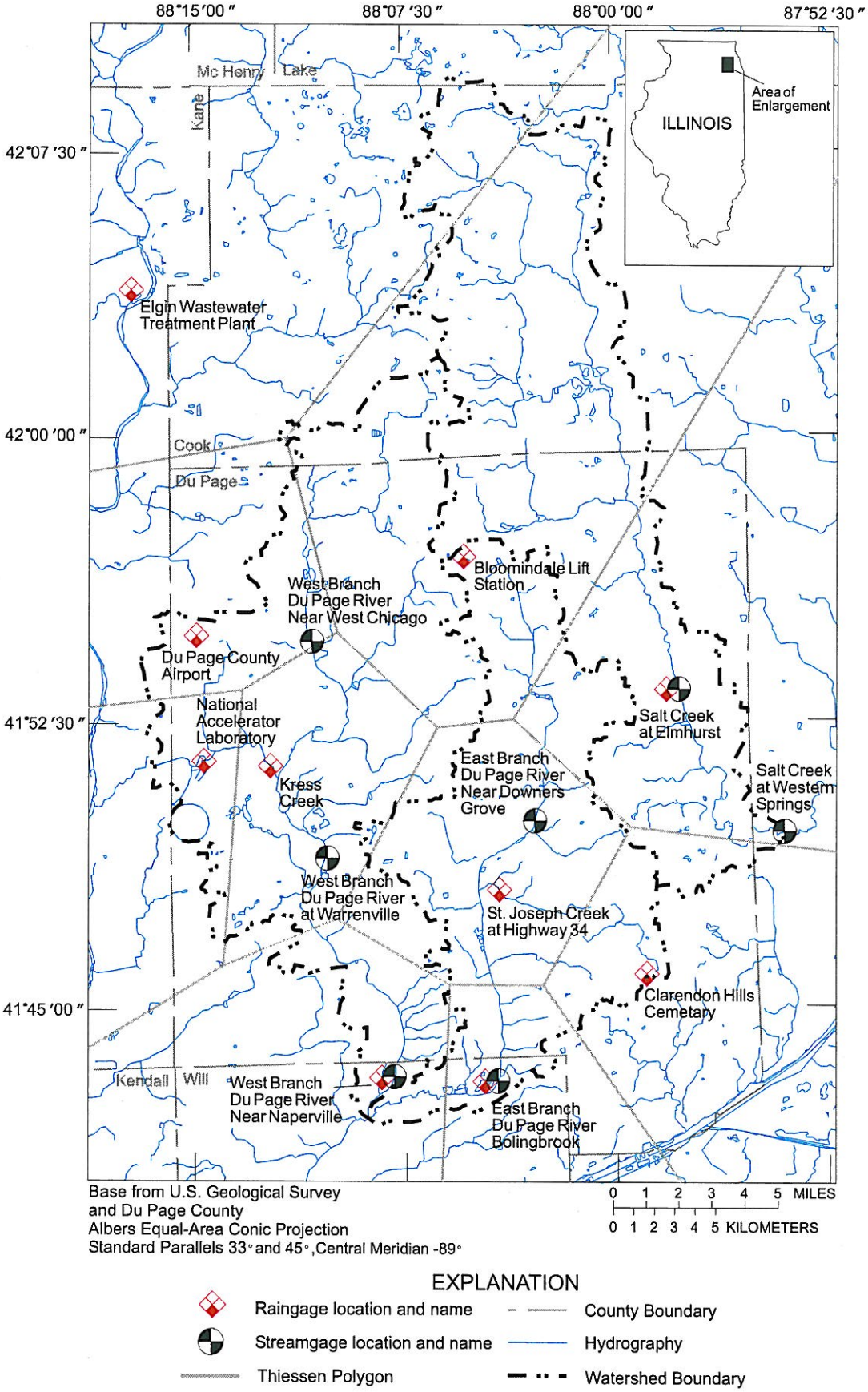

Figure 1. Location of U.S. Geological Survey Rain and Stream gages used in the study.

SIMULATION METHODS

NIPC Simulation Methods

The Hydrological Simulation Program – Fortran (HSPF) continuous hydrologic simulation model (Bicknell and others, 1993) was calibrated to data collected at four streamflow gages in Du Page County (Price, 1994a). The calibrated model was then verified with data from 10 streamflow gages in Du Page County (Price, 1994b). The results of the verification and calibration have been updated, but not formally published at the time of this study. Rainfall data from five NOAA precipitation gages (four non-recording and one weighing-bucket gage) and one weighing-bucket gage at Argonne National Laboratory were used as input data in the model for both the model calibration and verification. The updated verification results were obtained from Tom Price, NIPC, for comparison with simulation results based on USGS rainfall data.

USGS Simulation Methods

The calibrated HSPF model for DuPage County, updated by NIPC, was used as the hydrologic simulation model. The rainfall data input was the only difference between the USGS simulation and the NIPC simulation. The USGS simulation was based on data collected from the 10 USGS tipping-bucket rain gages in and near Du Page County. Both the type of rain gages and the rain-gage network densities (10 USGS gages and 6 NOAA gages) differed. The simulated time period was from April 1, 1990, to September 30, 1993. Antecedent conditions for April 1, 1990, were computed using NOAA rainfall data from October 1, 1988, to March 31, 1990, as input to the model. Simulation results from April 1, 1990, to September 30, 1990, were not used in the analysis so that the effect of the initial conditions using the NOAA rainfall data would be minimized.

RAINFALL-RUNOFF SIMULATION RESULTS

The magnitude of the difference between simulated and recorded flow was compared simply by calculating the simulated to recorded ratio (S/R) ((calculated as averageSi/averageRi) for all stream gages "i") for per unit-area values ((m^3/s)-day/km^2) of annual, monthly, and event runoff.

Annual S/R

The S/R value for average annual flow from October 1, 1990, to September 30, 1993 using USGS rainfall data in the hydrologic simulation model calibrated with NOAA rainfall data was 0.84 (table 1). Multiplying the hourly USGS rainfall data by 1.14 within the hydrologic simulation model improved the S/R for average annual flow to 1.00 (table 1). A factor of 1.14 was chosen based on the results of Straub and Parmar (1998). The adjusted USGS rainfall data produce simulated results comparable to the simulated results using NOAA rainfall data, which yield an S/R value of 0.97 for average annual flow (table 1).

TABLE 1: Average annual flow comparisons for seven watersheds in Du Page County, Illinois

1	2	3	4	5	6	7	8
Year	Average Measured Flow ((m^3/s)-day/km^2) $*10^{-2}$	Average Simulated Flow Using USGS Rainfall Data ((m^3/s)-day/km^2) $*10^{-2}$	S/R for Column 3	Average Simulated Flow Using USGS ([1]1.14) Rainfall Data ((m^3/s)-day/km^2) $*10^{-2}$	S/R for Column 5	Average Simulated Flow Using NOAA Rainfall Data ((m^3/s)-day/km^2) $*10^{-2}$	S/R for Column 7
1991	1.63	1.25	0.77	1.49	0.91	1.39	0.85
1992	1.36	1.19	0.88	1.39	1.03	1.33	0.98
1993	2.19	1.89	0.87	2.29	1.05	2.26	1.04
Average	1.72	1.44	**0.84**	1.72	**1.00**	1.66	**0.97**

[1] USGS rainfall data multiplied by 1.14

Monthly S/R

The S/R values for average monthly flow for each month using USGS rainfall data in the hydrologic simulation model calibrated with NOAA rainfall data is shown in table 2. The S/R values for average monthly flow obtained by multiplying the hourly USGS rainfall data by 1.14 within the hydrologic simulation model also is shown in table 2. The adjusted USGS rainfall data produce simulated results comparable to the simulated results using NOAA rainfall data for S/R values for average monthly flow (table 2—columns 6 and 8).

TABLE 2: Average monthly flow comparisons (Water Years[1] 1990-93) for seven watersheds in Du Page County, Illinois

1	2	3	4	5	6	7	8
Month	Average Measured Flow ((m^3/s)-day/km^2) *10^{-2}	Average Simulated Flow Using USGS Rainfall Data ((m^3/s)-day/km^2) *10^{-2}	S/R for Column 3	Average Simulated Flow Using USGS ([2]1.14) Rainfall Data ((m^3/s)-day/km^2) *10^{-2}	S/R for Column 5	Average Simulated Flow Using NOAA Rainfall Data ((m^3/s)-day/km^2) *10^{-2}	S/R for Column 7
January	1.73	1.54	0.89	1.74	1.01	1.75	1.01
February	1.24	0.87	0.70	0.93	0.75	0.94	0.76
March	2.38	2.20	0.92	2.69	1.13	2.51	1.05
April	3.28	2.31	0.70	2.78	0.85	2.67	0.81
May	1.53	1.29	0.84	1.52	0.99	1.26	0.82
June	1.57	1.25	0.79	1.52	0.97	1.73	1.10
July	1.14	1.05	0.92	1.20	1.05	1.14	1.00
August	0.93	0.84	0.90	0.94	1.01	0.96	1.03
September	1.22	1.01	0.83	1.22	1.00	1.30	1.07
October	1.36	1.31	0.96	1.55	1.14	1.40	1.03
November	2.46	2.02	0.82	2.61	1.06	2.33	0.95
December	1.85	1.63	0.88	1.97	1.06	1.94	1.05

[1] The water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and includes 9 of the 12 months.
[2] USGS rainfall data multiplied by 1.14

Event S/R

Multiple-day storm events (41 events for the 7 watersheds (4 to 9 events per watershed)), selected by NIPC, throughout water years 1990-93 were extracted from the NIPC and USGS simulation results. The S/R results for these events are shown in table 3. The S/R value for average event flow using USGS rainfall data in the hydrologic simulation model calibrated with NOAA rainfall data was 0.76 (table 3). Multiplying the hourly USGS rainfall data by 1.14 within the hydrologic simulation model improves the S/R for average event flow to 1.00 (table 3). The adjusted USGS rainfall data produce simulated results comparable to the simulated results using NOAA rainfall data, which yield an S/R value of 0.99 for average event flow (table 3).

TABLE 3: Average event flow comparisons for seven watersheds in Du Page County, Illinois

1	2	3	4	5	6	7
Average Measured Flow ((m^3/s)-day/km^2) *10^{-2}	Average Simulated Flow Using USGS Rainfall Data ((m^3/s)-day/km^2) *10^{-2}	S/R for Column 2	Average Simulated Flow Using USGS ([1]1.14) Rainfall Data ((m^3/s)-day/km^2) *10^{-2}	S/R for Column 4	Average Simulated Flow Using NOAA Rainfall Data ((m^3/s)-day/km^2) *10^{-2}	S/R for Column 6
41.49	31.62	0.76	41.52	1.00	40.90	0.99

[1] USGS rainfall data multiplied by 1.14

Seasonal Variations

Seasonal variations in simulated flow were analyzed to determine if seasonal adjustment factors would be more appropriate in model simulation than applying one factor for the entire year. No difference is apparent between the NOAA S/R variation and the USGS S/R variation throughout the year (figs. 1 and 2). The primary difference between the NOAA S/R and USGS S/R variation is the consistently lower USGS S/R.

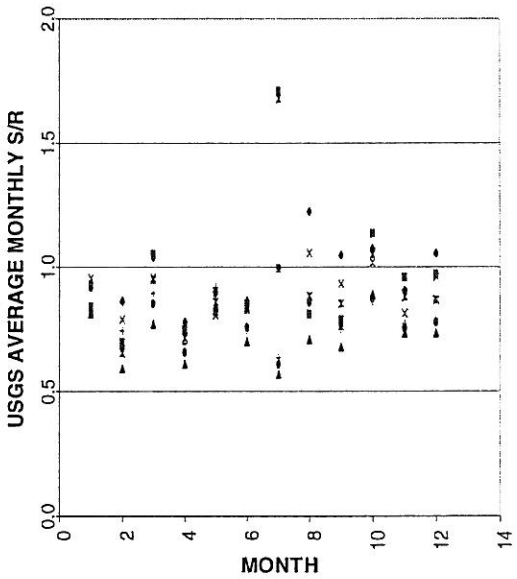

FIGURE 1: Monthly S/R for each stream gage using USGS rainfall data

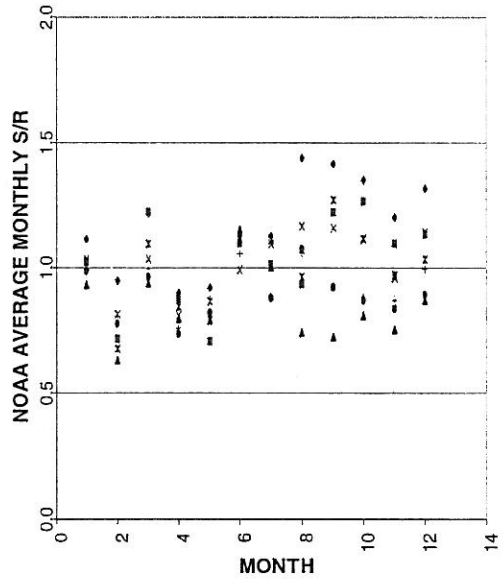

FIGURE 2: Monthly S/R for each stream gage using NOAA rainfall data

Wind Effect

Wind blowing on certain orifice types and at different heights can reduce the amount of catch in a rain gage (Sevruk, 1996). Because the USGS rain gages used in the study have a different orifice type and are, on average, installed approximately 1.2 m higher than the NOAA precipitation gages, wind effect was analyzed for the event simulations. The wind effect was used to determine a correlation between wind and the difference between simulations based on the USGS and NOAA rain-gage networks (fig. 3). Hourly wind data from O'Hare International Airport in Chicago were averaged for each event only during the time when it was raining. No apparent correlation was found between the O'Hare wind data and the simulated differences between the use of USGS and NOAA rainfall data for each storm event.

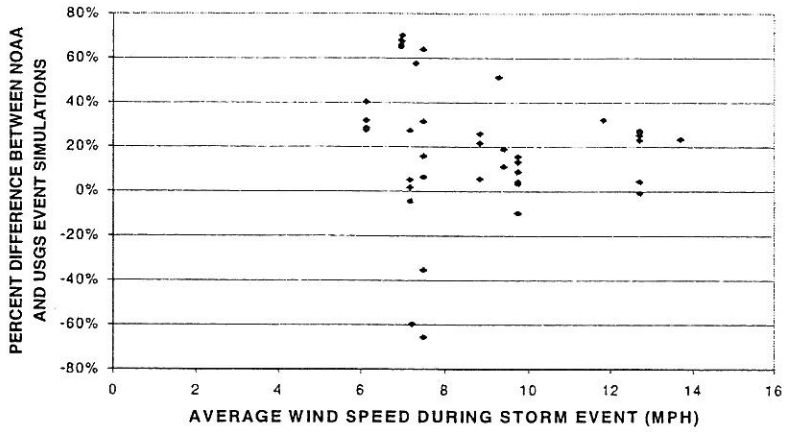

FIGURE 3: NOAA and USGS simulation differences compared with average wind speed at O'Hare International Airport during the storm event and percent difference between NOAA and USGS event simulation.

CONCLUSIONS

The S/R for average yearly, average monthly, and average event periods simulated using USGS rainfall data in the hydrologic simulation model calibrated with NOAA rainfall data is consistently below 1. The use of different input data (USGS) resulted in underestimation of annual flow by about 13 percent, of monthly flow between 6 and 21 percent, and in storm runoff of about 23 percent relative to the use of the NOAA input data, which are consistent with the calibration data set. In this case, the bias in the simulation results could be removed by applying a simple correction factor to the different input data (USGS). Multiplying the hourly USGS rainfall data by 1.14 within the hydrologic simulation model improves the S/R and aligns simulated results with simulated results obtained using NOAA rainfall data for annual, monthly, and storm-event data. No difference is apparent between the NOAA S/R variation throughout the year and the USGS S/R variation. Therefore, there is no evidence that a season-dependent factor is needed to better align USGS simulated results with the simulated results based on NOAA data. No correlation is apparent between the O'Hare wind data and the USGS and NOAA simulation differences for each storm event, indicating that no wind-dependent correction factor is needed to better match USGS simulated results with the simulated results based on NOAA data.

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