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SENSITIVITY OF HSPF-ESTIMATED FLOW-RATE TO TOPOGRAPHICAL PARAMETER VALUES FOR A COASTAL WATERSHED IN MISSISSIPPI

Vladimir J. Alarcon*, Charles G. O'Hara*, William McAnally**, James Martin**, Jairo Diaz**, Zhiyong Duan**

ABSTRACT: An HSPF application for the Jourdan River catchment (sub-basin of the Saint Louis Bay watershed in Mississippi) is generated using topographic data from the National Elevation Dataset (NED). The resulting model is then calibrated for flow rate and subsequently subjected to sensitivity experiments. Perturbations of ±100%, ±50%, ±10% and ±1% to calibrated-model base values of variables LSUR (length of the overland flow plane), SLSUR (slope of the overland flow plane), stream-length and stream-width, were implemented. Computed flow rate values were compared to flow rate estimations from the calibrated case. The purpose of those experiments was to identify how sensitive are the flow-rate estimations to small and big percent changes in the main topographical parameter used by HSPF. Results showed that HSPF-estimated flow is not very sensitive to LSUR and SLSUR. Relative changes in flow estimations to perturbations to these variables are lower than 1% from the base values. The variables stream-length and stream-width, however, seem to produce significant percent changes on simulated flow when small changes (1%) are made to base values of those variables. 20% of those changes are at least greater than 1.5% reaching up to 16% change from the base values. These results are significant for improvement of Digital Elevation Databases in the context of hydrological modeling.[1]
KEY TERMS: digital elevation; sensitivy analysis; HSPF; Mississippi

1. INTRODUCTION

The modeling of hydrologic phenomena usually requires input data from several types of databases. Each set of input data transfer inherent uncertainties to the estimated output and contribute to a global uncertainty. It is usual in current modeling of water resources to include some kind of assessment of the uncertainty that output results include. The main purpose of the uncertainty estimation is to provide confidence intervals to the output generated by the mathematical/numerical models. One of the most commonly used technique to begin assessing the uncertainty of a model output is sensitivity analysis.

Sensitivity analysis is concerned with the propagation of uncertainties in mathematical models, being its main task to assess the influence of parameters on the state of the modeled system (Ostermann, 2004). The analysis of sensitivity of state variables has been widely used in water resources modeling to quantify the reliability of the output or during the calibration process. Atkins et al., 2005; Francos et al., 2003; Alarcon et al., 2003, Veihe and Quinton, 2000, De Roo et al., 1996, and Brown and Barnwell, 1987, are just a few examples of a technique that has been used for decades.

The Jourdan River catchment is located in the Saint Louis Bay watershed in the Mississippi Gulf coast (see Figure 1.1). Meteorological data in the nearby area of the Jourdan River Catchment is available from two stations (MS220521-Bay Saint Louis and MS220519-Bay Saint Louis-NASA) at a daily frequency (Kieffer, 2002). The combined weather data covers the period 1931 to 2005. There is only one USGS gage station located at most downstream point of the Jourdan River catchment (USGS 02481570:1962-1966, at Santa Rosa). The limited amount of data (in the case of measured flow rate) and the sparse frequency of the available precipitation data (daily as opposed to hourly for optimal hydrological modeling), would certainly introduce some degree of uncertainty in any hydrological estimation for the Jourdan River catchment.

Along with these limitations on hydrological data, topographical data for the Jourdan River catchment also pose interesting questions. A previous paper (Alarcon et al., 2005) identified significant differences in topographical indicators exported from BASINS to HSPF when using different elevation datasets, for three catchments in Mississippi: Jourdan, Wolf and Luxapallila. From those three catchments, the differences in topographical parameters were more significant for the Jourdan River catchment. For example, overland flow plane slope values estimated using the National Elevation Dataset

(*) GeoResources Institute, Engineering Research Center, Mississippi State University, Box 9627, Mississippi State, MS 39762
(**) Civil Engineering Department, Mississippi State University, Box 9627, Mississippi State, MS 39762

(NED) were at least 190% and up to 1322 % smaller than those sub-basin slope values estimated using the Digital Elevation Model data from USGS-EPA (Alarcon et al., 2006).

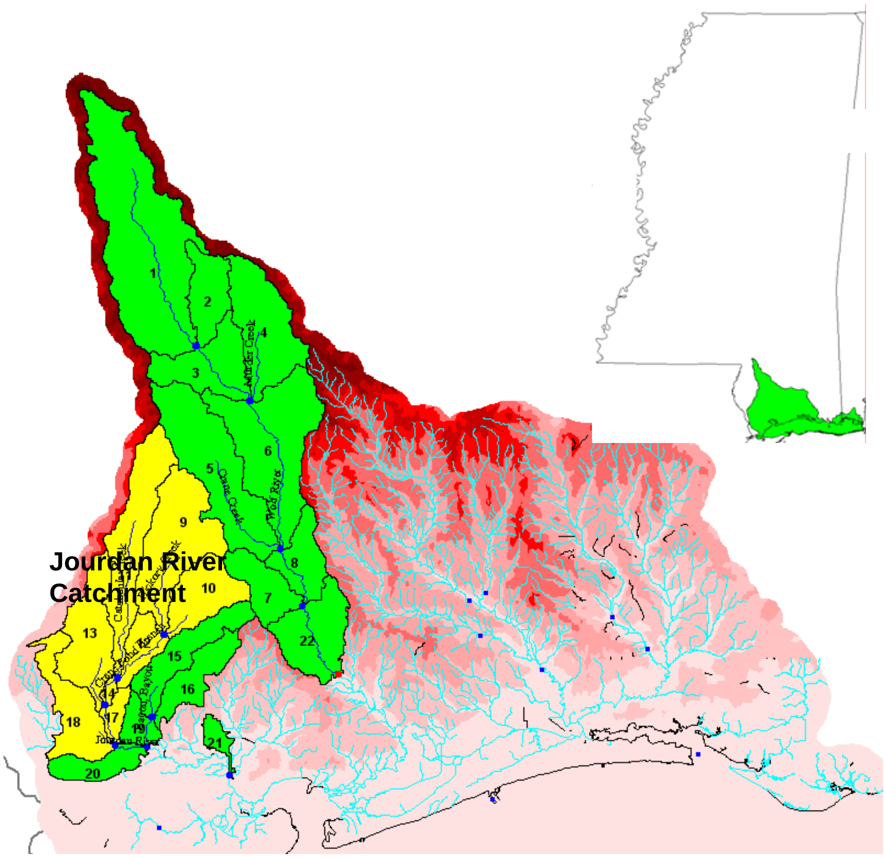


Figure 1.1. Jourdan River catchment location.

In this paper, an HSPF application for the Jourdan River catchment is generated using topographic data from the National Elevation Dataset (NED). The resulting model is then calibrated for flow rate and subsequently subjected to sensitivity experiments. The purpose of those experiments is to identify how sensitive are the flow-rate estimations to perturbations in the main topographical parameter used by HSPF.

2. MATERIALS AND METHODS

2.1 Jourdan River catchment delineation and hydrological calibration

The Jourdan River catchment was delineated using elevation data from the National Elevation Dataset (NED). These elevation data (NED seamless mosaic) are the best-available elevation data (EPA, 2004) having the following specifications: 30 Meter Resolution, One-Sixtieth Degree (1 arc-second), horizontal datum of NAD83, vertical datum of NAVD88.

The Jourdan River catchment delineation was performed using the BASINS-ArcView interface. After the segmentation of the catchment, a HSPF application was generated from within BASINS that was subsequently calibrated for flow rate. Daily precipitation data from MS220521-Bay Saint Louis and MS220519-Bay Saint Louis-NASA (disaggregated to hourly frequency) was used for calibration. Flow rate model-estimated values were compared to measured flow rate data from USGS station 02481570at Santa Rosa for the period 1962-1966

In order to isolate the effects of topography-related parameters during the sensitivity analysis, the calibration was performed using parameters that are not related to topography:

- LZSN: Lower zone nominal soil moisture storage
- INFILT: Index to the infiltration capacity of the soil
- UZSN: Upper zone nominal soil moisture storage

And parameters that are mildly dependent on topography
- INTFW: Interflow inflow parameter

2.2 Sensitivity analysis

The calibrated applications were then used to study the sensitivity of flow rate estimations to perturbations in the following variables:

- Length of the overland flow plane: LSUR
- Slope of the overland flow plane: SLSUR
- F-tables
  - Stream width (WID1),
  - stream length (LEN2), and

Sensitivity analysis was done using a one-variable-at-a-time approach. Percent perturbations to the variables included in this study were increased/decreased in: ±100%, ±50%, ±10% and ±1% from the base values. The estimations of flow for the calibrated case were considered the base case. The combination of small and big perturbations allowed identifying non-linear sensitivities. Normalized sensitivity values (Equation 1) were calculated for each perturbation. Normalized sensitivity coefficients represent the percentage change in the output variable resulting from a 1 percent change in each input variable Brown and Barnwell (1987). They are calculated with:

$$S_{ij} = \frac{\frac{\Delta y_j}{y_j}}{\frac{\Delta x_i}{x_i}} \qquad (1)$$

Where: S_{ij} is the normalized sensitivity coefficient for output y_j to inputs x_i , x_i = base value of input variable, Δx_i = magnitude of input perturbation, y_j = base value of output variable, and Δy_j = sensitivity of output variable.

3. RESULTS

Figure 3.1 shows the BASINS and HSPF applications resulting for Jourdan, Wolf and Luxapallila watersheds. Notice that each subwatershed in the BASINS project generates a Reach/Reservoir box (RCHRES) in the HSPF application. Hence, all topographical parameters are summarized in a set of numerical values per RCHRES. This characteristic of lumped-parameter models produces an easier computational handling of calculations. However, the obligated summarization of topographical information per RCHRES, in the case of HSPF, may cause a rough representation of the real world if the segmentation of the watershed (delineation) is too coarse.

3.1 Hydrological calibration

The calibration of the HSPF applications for Jourdan, Wolf and Luxapallila watersheds was performed by a trial and error process adjusting the values of the following parameters:

- **LZSN**: Lower zone nominal soil moisture storage
- **INFILT**: Index to the infiltration capacity of the soil
- **UZSN:** Upper zone nominal soil moisture storage
- **INTFW**: Interflow inflow parameter

These parameters were chosen because its relationship with topography is null to mild, so that influence of topographical indicators in the flow rate estimations could be isolated through the sensitivity experiments.

Figure 3.2 and Table 3.1 show results of the hydrological calibration of Jourdan River watershed. Santa Rosa flow gage station data (USGS 02481570:1962-1966) were used as the flow rate reference values for the calibration process. The quality of the calibration was controlled using three indicators: water balance, coefficient of determination (r^2) and the Nash-Sutcliffe coefficient (NS). The latter has been recommended by the American Society of Civil Engineers (ASCE, 1993) for use in hydrological studies. NS coefficient values equal to 1 indicate a perfect fit between observed and predicted data, and values equal to 0 indicate that the model is predicting no better than using the average of the observed data (Evans et al., 2003). Therefore, any positive value above 0 suggests that the model has some utility, with higher values indicating better model performance (Evans et al., 2003).

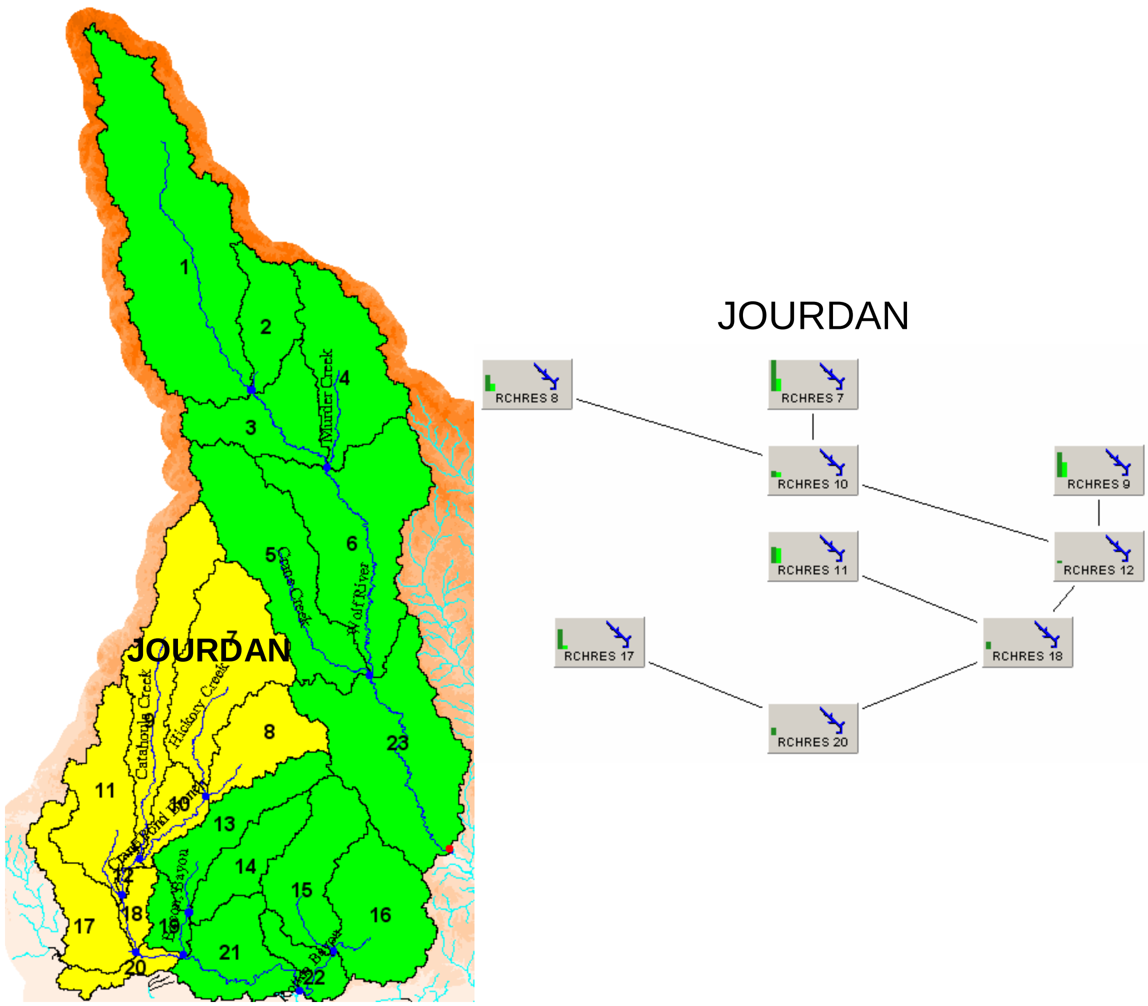


Figure 3.1 HSPF applications for Jourdan River catchment

Table 3.1 below shows that with the exception of year 1964 where r^2 equals 0.51 and NS equals 0.49, r^2 is greater than 0.73 and NS is greater than 0.67 for all simulation years. These coefficient values indicate that the HSPF model calibration for Jourdan River watershed is good.

Table 3.1 Goodness of fit for Jourdan River's HSPF model

Year	1963	1964	1965	1966
Mean (observed) (m3/s)	2.84	8.93	5.27	11.03
Mean (simulated) (m3/s)	2.85	8.83	4.95	12.13
Geometric Mean Obs.	1.72	5.66	2.86	6.34
Geometric Mean Sim.	1.26	3.80	2.25	4.90
Correlation Coefficient	0.91	0.72	0.86	0.90
Coefficient of Determination	0.84	0.51	0.73	0.81
Model Fit Efficiency (NS)	0.81	0.49	0.67	0.78

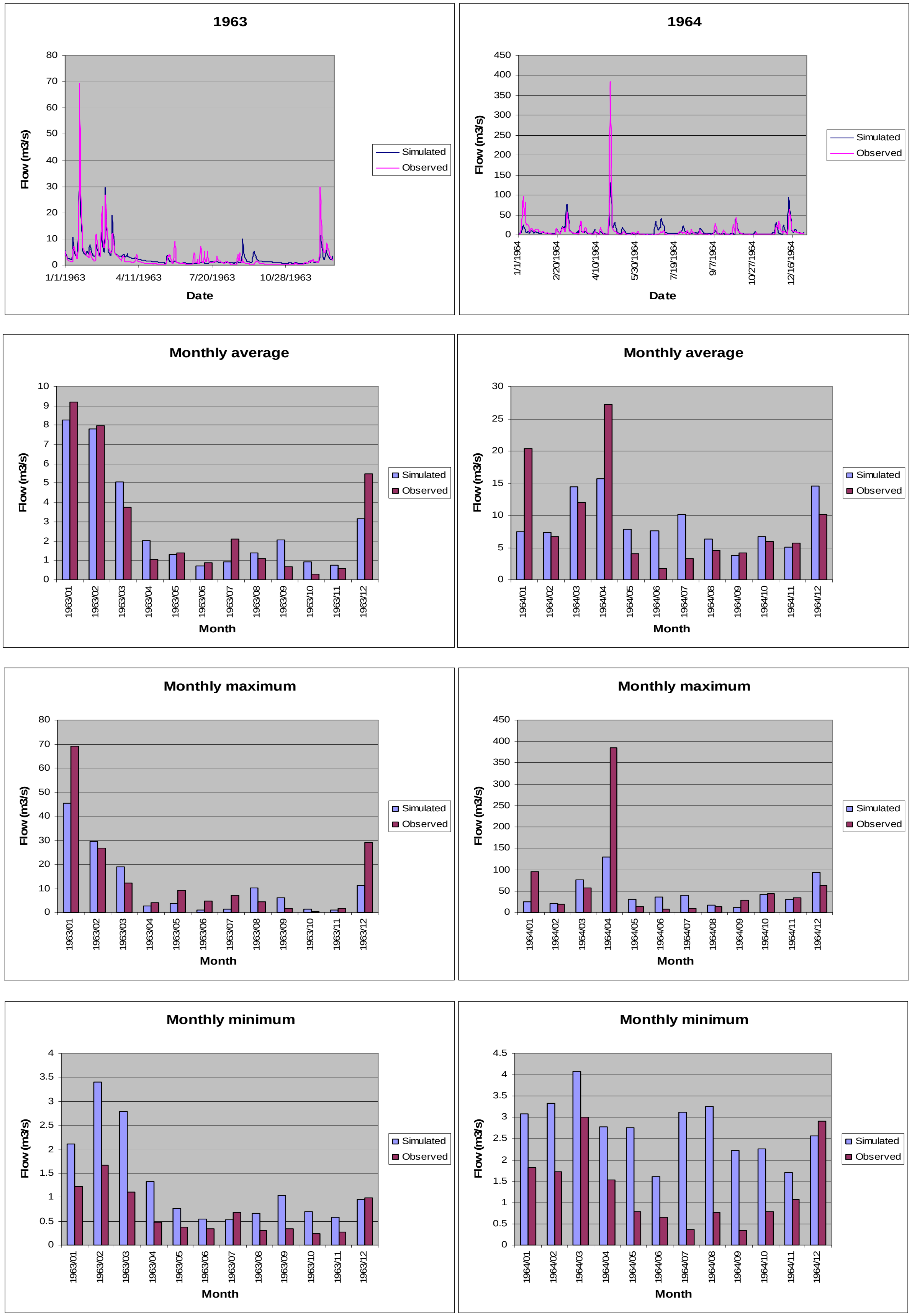


Figure 3.2 Hydrological calibration of Jourdan River watershed

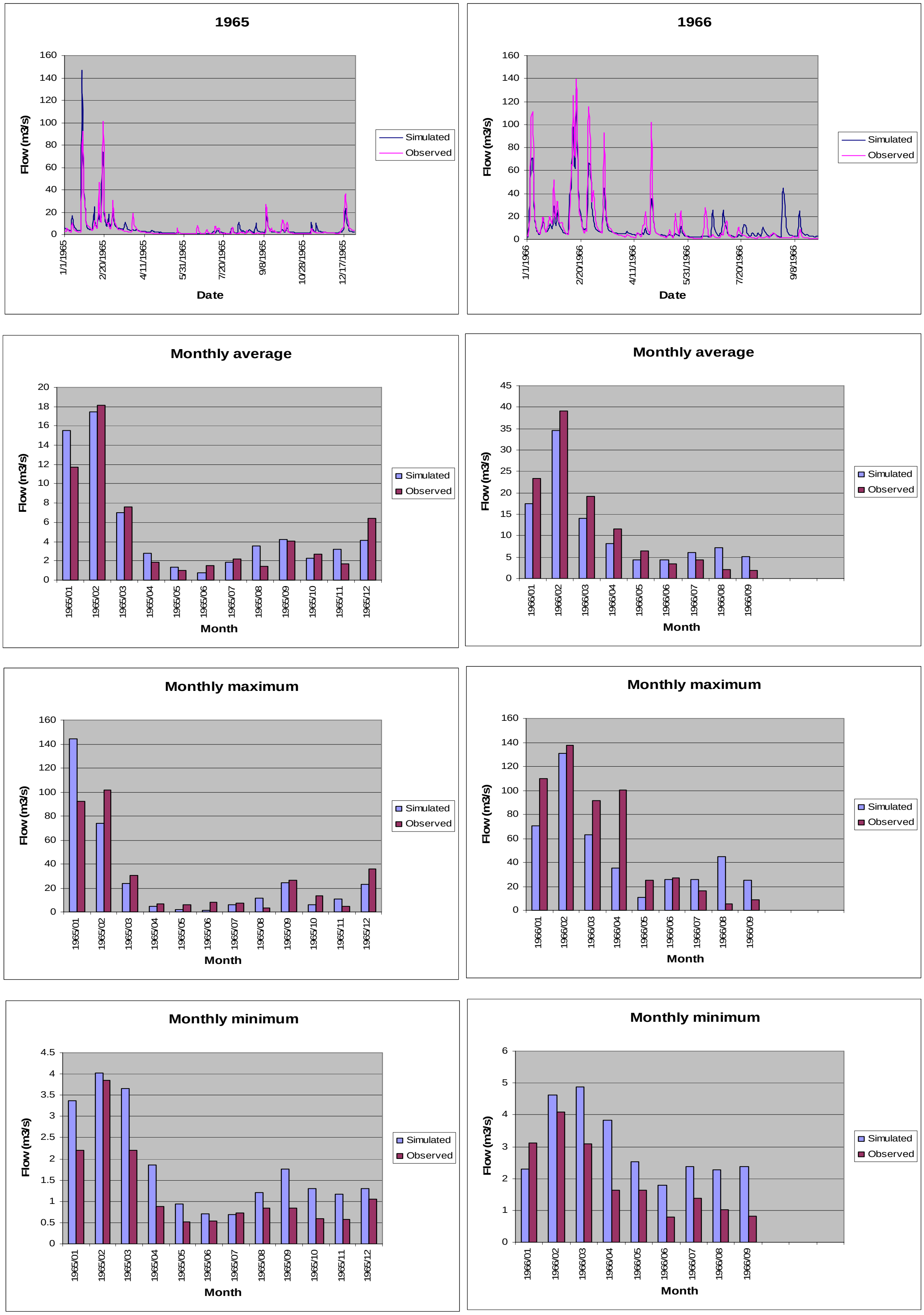


Figure 3.2 Hydrological calibration of Jourdan River watershed (continued)

3.2 Sensitivity analysis

3.2.1 Moderated to low sensitivity (LSUR and SLSUR)

Figure 3.3 shows normalized sensitivity values during the calibration period 7/62 to 9/66. The estimations of flow values are shown to have low sensitivity to perturbations to length of the overland flow plane (LSUR) or slope of the overland flow plane (SLSUR). Table 3.2 summarizes some statistical indicators for the calculated normalized sensitivity.

Table 3.2 Normalized sensitivity statistics for LSUR and SLSUR

LSUR	**-100%**	**-50%**	**-10%**	**-1%**	**1%**	**10%**	**50%**	**100%**
Mean	0.005683	0.00565	0.004041	0.004454	0.004475	0.004111	0.003549	0.003064
Standard Error	0.001273	0.000739	0.000692	0.002318	0.001436	0.000598	0.000412	0.000334
Mode	0	0	0	0	0	0	0	0
Standard Deviation	0.050163	0.029136	0.027286	0.091335	0.056599	0.02357	0.016227	0.013171
Sample Variance	0.002516	0.000849	0.000744	0.008342	0.003204	0.000556	0.000263	0.000173
Minimum	-0.36719	-0.25194	-0.25194	-0.81301	-0.38911	-0.21318	-0.16667	-0.13178
Maximum	0.071429	0.07309	0.09901	0.990099	0.884956	0.097087	0.04878	0.036364

SLSUR	**-100%**	**-50%**	**-10%**	**-1%**	**1%**	**10%**	**50%**	**100%**
Mean	-0.00958	-0.0031	-0.00313	-0.00443	-0.00288	-0.00212	-0.00169	-0.00139
Standard Error	0.000918	0.000359	0.000449	0.001441	0.001252	0.000404	0.000242	0.000193
Mode	0	0	0	0	0	0	0	0
Standard Deviation	0.036189	0.014138	0.017695	0.056778	0.049353	0.015921	0.009517	0.007588
Sample Variance	0.00131	0.0002	0.000313	0.003224	0.002436	0.000253	9.06E-05	5.76E-05
Minimum	-0.15758	-0.04636	-0.09709	-0.88496	-0.91743	-0.09901	-0.02857	-0.02
Maximum	0.37785	0.147287	0.116279	0.389105	0.408163	0.116279	0.096899	0.075581

As seen in the table above, maximum normalized sensitivity values occur for perturbations of 1% and – 1% to LSUR and SLSUR respectively. Since the normalized sensitivity values represent the percent change in the flow values resulting from a 1 percent change in LSUR and SLSUR, the table shows that estimations of flow rate change less than 1% after perturbations to LSUR and SLSUR. These results are similar to those reported by other researches. Atkins et al. (2005) reports that during their sensitivity analysis flow rate estimations were relatively insensitive to perturbations to LSUR. Alarcon et al. (2003) also reported that perturbations to SLSUR did not produce big changes on flow rate estimations either.

3.2.2. Medium to high sensitivity (F-tables: stream width and stream length)

In HSPF, stream width and stream length for hydraulic calculations are specified in the form of F-tables. The tables are built from topographic data summarized by BASINS and exported to HSPF as a *project.ptf* file. From the several parameter values specified in this file (Stream length, mean depth, mean width, stream slope), stream length and stream width were chosen for testing. Table 3.3 summarizes the results of the sensitivity experiments using the F-table parameter values stream-width and stream-length. Figure 3.4 shows normalized sensitivities along the calibration period 1962 to 1966.

Table 3.3 shows that ± 1% perturbations produce the highest values of normalized sensitivity. These small perturbations on the stream length and stream width parameter values generate changes ranging from -10% to +15% in the estimated flow values. The sensitivity to these variables is shown to be non-linear, since the normalized sensitivity values decrease with increasing perturbation percentages. It is also interesting to notice that the mode values are 0 (as is also the case in Table 3.1) meaning that the sensitivity is null in a good number of cases. For the ±1% perturbation, the standard deviation and mean are 2.22 and ±0.4 respectively, i.e., 95% of the normalized sensitivity values are in the ranges: -4.88 to 4.04 (for the 1% perturbation) and -4.04 to 4.88 for the -1% perturbation.

In order to have a better picture of the values of normalized sensitivity and the relative values that they assume, Figure 3.5 shows sensitivity values plotted against percentiles.

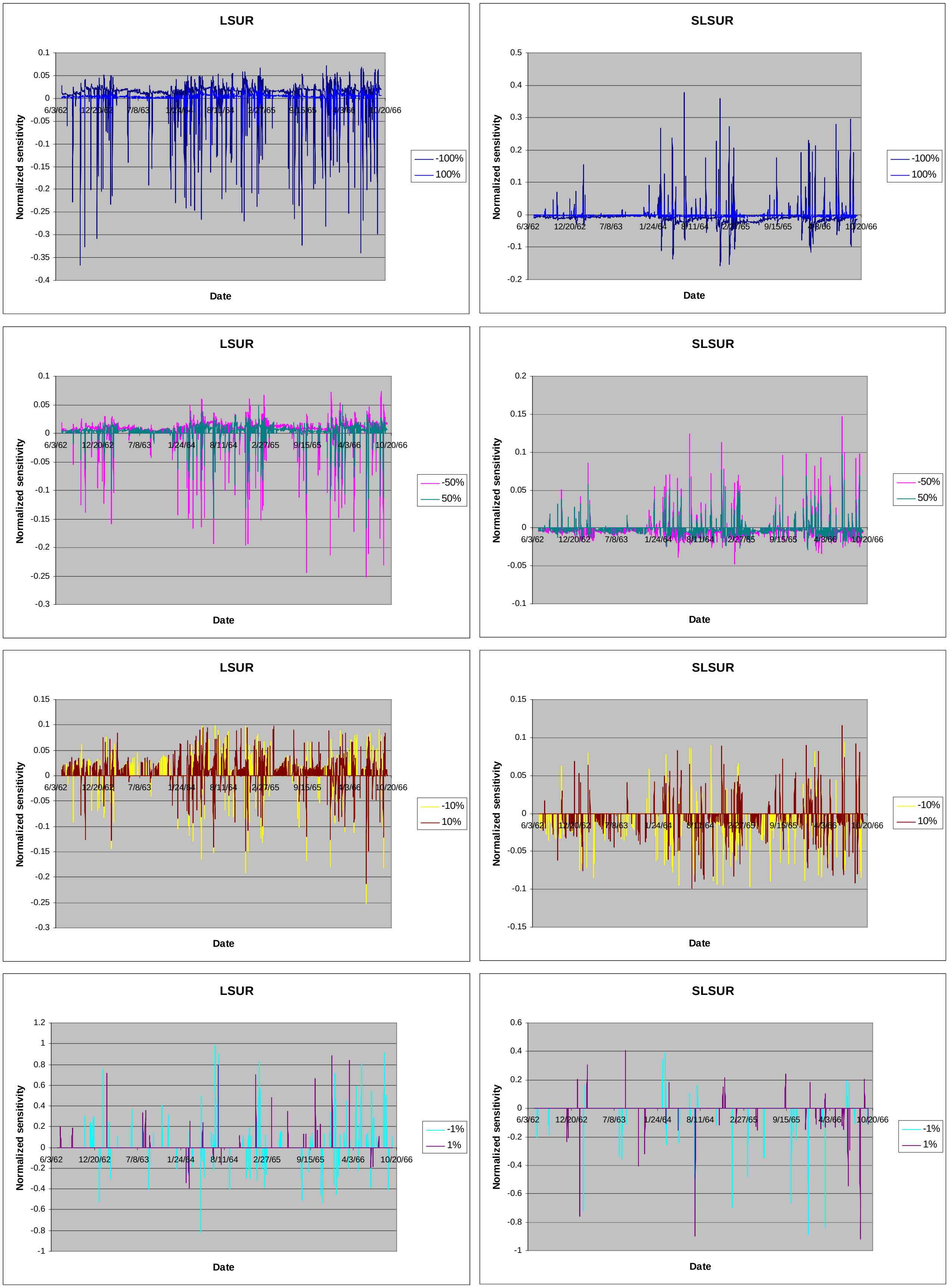


Figure 3.3 LSUR and SLSUR normalized sensitivity values during the calibration period 7/62 to 9/66.

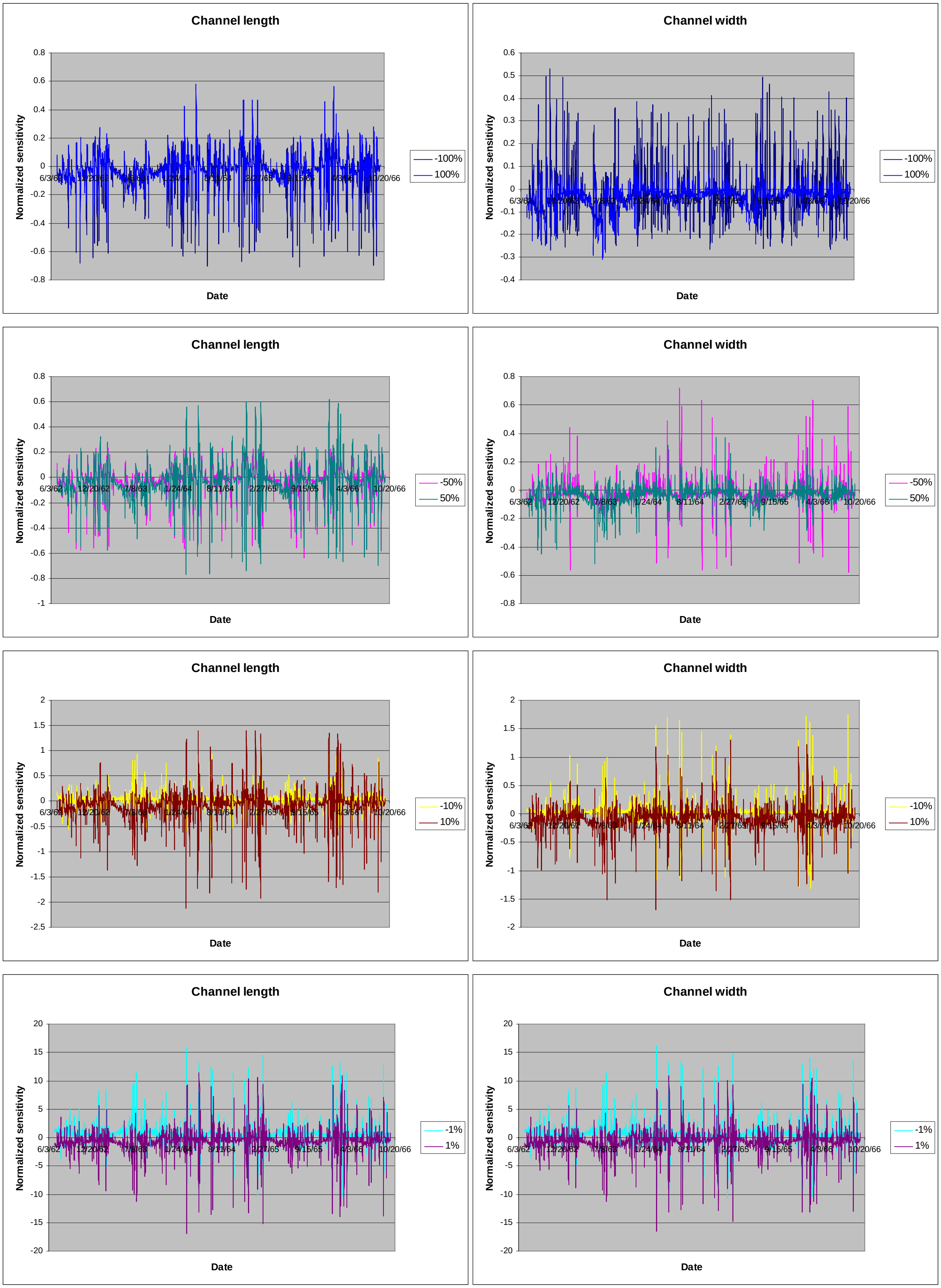
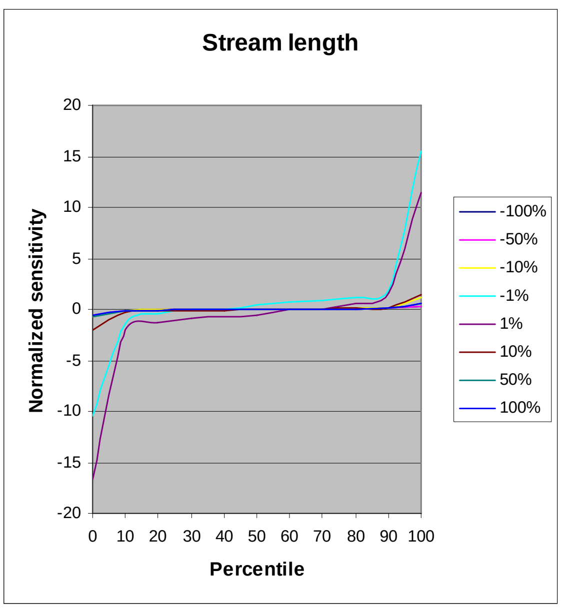


Figure 3.4 Normalized sensitivities for channel length and width along the calibration period 1962 to 1966.

Table 3.3 Normalized sensitivity statistics for stream length and stream width

STREAM WIDTH	-100%	-50%	-10%	-1%	1%	10%	50%	100%
Mean	-0.03007	-0.02221	0.017884	0.417068	-0.47364	-0.07144	-0.03438	-0.0297
Standard Error	0.002736	0.002285	0.006017	0.058363	0.05859	0.00631	0.001946	0.001472
Mode	0	0	0	0	0	0	0	0
Standard Deviation	0.107807	0.090031	0.237125	2.29997	2.308934	0.248675	0.076706	0.058007
Sample Variance	0.011622	0.008106	0.056228	5.28986	5.331176	0.061839	0.005884	0.003365
Minimum	-0.26829	-0.57757	-1.30081	-10.8911	-16.3424	-1.67315	-0.51685	-0.30808
Maximum	0.524528	0.718784	1.733945	15.95331	10.89109	1.235521	0.370861	0.208609

STREAM LENGTH	-100%	-50%	-10%	-1%	1%	10%	50%	100%
Mean	-0.02022	-0.01256	0.026739	0.425844	-0.46368	-0.06046	-0.02163	-0.0138
Standard Error	0.003442	0.003027	0.00459	0.05644	0.060395	0.008178	0.003723	0.003083
Mode	0	0	0	0	0	0	0	0
Standard Deviation	0.135647	0.119299	0.180871	2.224178	2.380057	0.322271	0.146725	0.121512
Sample Variance	0.0184	0.014232	0.032714	4.946967	5.664673	0.103859	0.021528	0.014765
Minimum	-0.70743	-0.63789	-0.79365	-10.4265	-16.7315	-2.10117	-0.77043	-0.57012
Maximum	0.218182	0.25641	1.128405	15.5642	11.38614	1.396648	0.614286	0.582524



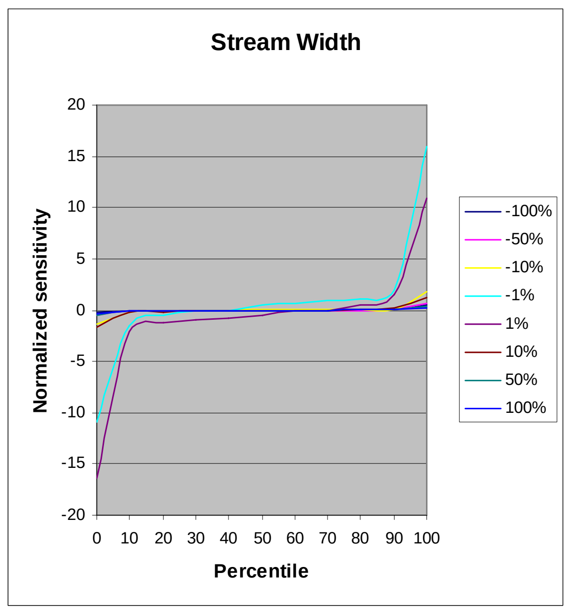


Figure 3.5. Plots of percentile versus normalized sensitivity values for stream length and stream width

The percentile versus normalized sensitivity plot (Figure 3.5) shows that 10 % of the sensitivity values (corresponding to a perturbation of ±1% range within 1.5 to 16. Correspondingly, 10% of normalized sensitivity values range within -2 to -16.5. This means that at least 20 percent of the normalized sensitivity values corresponding to perturbations of ±1% to stream length and stream width parameters generate medium to high percent changes (between 1.5% to 16 %) in flow rate estimations.

4. CONCLUSIONS

HSPF-estimated flow is not very sensitive to LSUR (length of the overland flow plane) and SLSUR (slope of the overland flow plane). Relative changes in flow estimations to perturbations to these variables are lower than 1% from the base values. The variables stream length and stream width, however, seem to produce significant percent changes on simulated flow when small changes (1%) are made to base values of those variables. 20% of those changes are at least greater than 1.5% reaching up to 16% change from the base values. Since stream length and stream width are highly dependant from the size and shape of the corresponding sub-catchment, the delineation of the watershed will drive the value of those variables.

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