# Reconstruction of Naturalized Daily Streamflow for the Upper Wabash River


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## Introduction

During the 1960s, the United States Army Corps of Engineers constructed a number of dams in the Upper Wabash watershed in Indiana, primarily for flood control, hydropower and recreation. In order to investigate the impact of other environmental changes, such as changes in land management and climate on streamflow, it is necessary to reconstruct what the natural flow of the impounded river would be without the influence of the upstream reservoirs.

## Study Area

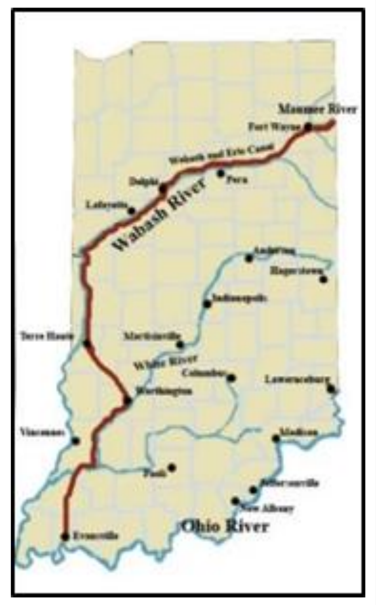

Figure 1: Wabash River in Indiana

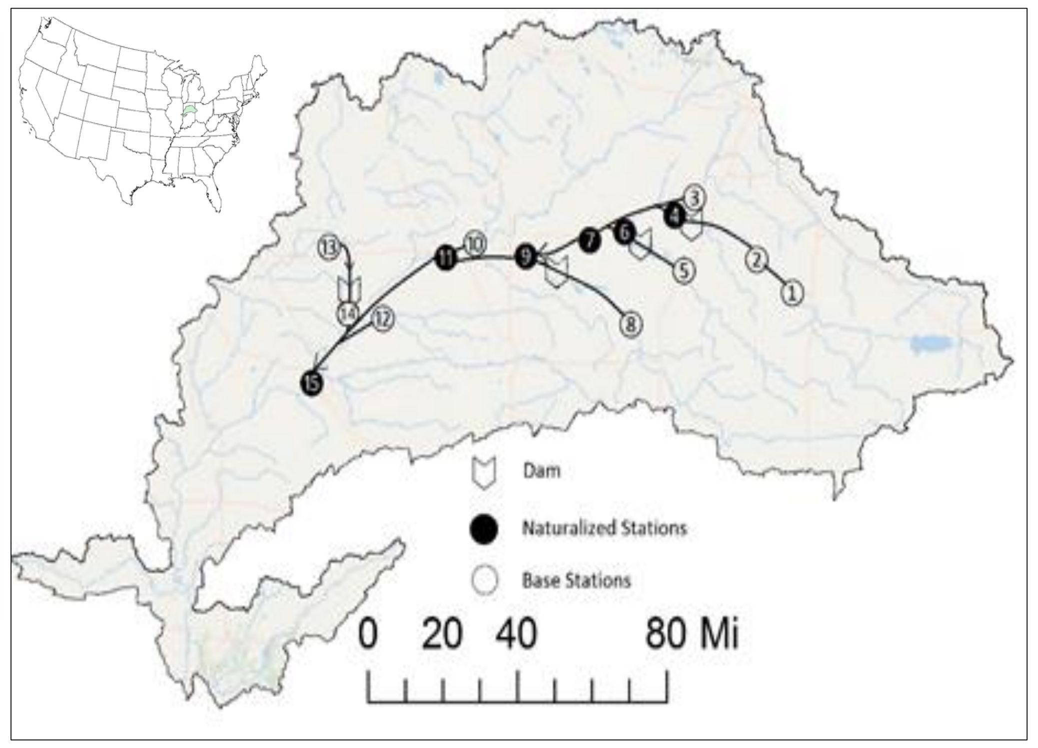


Figure 2: Locations of the streamflow gaging stations in the Upper Wabash Study Area

Table 1: USGS gauge sites in the Upper Wabash basin.
Base stations (BS01, BS02, etc.) historic daily streamflow used and Naturalized stations (NS04, NS06, etc.) natural streamflow estimated.

| Map No. | Code No.[1] | USGS Site No. | Site Name | Latitude | Longitude | Drainage (mi²) | Period of Record |
|---|---|---|---|---|---|---|---|
| 1 | BS01 | 03322900 | Wabash River at Linn Grove | 40°39′22″ | 85°01′58″ | 453 | 1964-10-01 to current |
| 2 | BS02 | 03323000 | Wabash River at Bluffton | 40°44'30" | 85°10'19" | 532 | 1930-10-01 to 1971-09-30 |
| 3 | BS03 | 03324000 | Little River near Huntington | 40°53'54.8" | 85°24'47.4" | 263 | 1944-04-01 to current |
| 4 | NS04 | 03323500 | Wabash River at Huntington | 40°51'11.7" | 85°29'23.2" | 721 | 1951-04-01 to 2003-02-10 |
| 5 | BS05 | 03324300 | Salamonie River near Warren | 40°42′45″ | 85°27′13″ | 425 | 1957-03-01 to current |
| 6 | NS06 | 03324500 | Salamonie River at Dora | 40°48′42″ | 85°41′02″ | 557 | 1924-04-01 to 2003-02-10 |
| 7 | NS07 | 03325000 | Wabash River at Wabash | 40°47′27″ | 85°49′13″ | 1768 | 1923-10-01 to current |
| 8 | BS08 | 03326500 | Mississinewa River at Marion | 40°34'35.1" | 85°39'34.3" | 682 | 1923-10-01 to current |
| 9 | NS09 | 03327500 | Wabash River at Peru | 40°45′00″ | 86°04′00″ | 2686 | 1943-10-01 to current |
| 10 | BS10 | 03328500 | Eel River near Logansport | 40°46′55″ | 86°15′50″ | 789 | 1943-10-01 to current |
| 11 | NS11 | 03329000 | Wabash River at Logansport | 40°44′47″ | 86°22′39″ | 3779 | 1904-04-01 to current |
| 12 | BS12 | 03329700 | Deer creek near Delphi | 40°35′25″ | 86°37′17″ | 274 | 1944-04-01 to current |
| 13 | BS13 | 03335000 | Wildcat creek near Lafayette | 40°26′26″ | 86°49′45″ | 794 | 1954-06-01 to current |
| 14 | BS14 | 03333000 | Tippecanoe River near Delphi | 40°37'02" | 86°45'39" | 1865 | 1903-04-01 to 1987-09-30 |
| | | 03333050 | Tippecanoe River near Delphi | 40°35'38.1” | 86°46'13.2" | 1869 | 1986-10-01 to current |
| 15 | NS15 | 03335500 | Wabash River at Lafayette | 40°25'30.6" | 86°53'47" | 7267 | 1923-10-01 to current |

## Methodology

A modified drainage-area ratio method (DA) and maintenance of variance extension type 1 (MOVE.1) method were used in this study to estimate streamflow for the Naturalized Sites. The drainage-area ratio method (Hirsch, 1979) is based on the assumption that streamflow can be estimated using the ratio of the drainage area for the site of interest and the drainage area for a nearby gaged site:

$$y_i = x_i (A_y / A_x)^{\alpha}$$

To estimate naturalized flow from more than one base station, the former equation is modified as follows:

$$y_i = x_{1i}(Ay_1/Ax_1)^{\alpha} + x_{2i}(Ay_2/Ax_2)^{\alpha} + \ldots\ldots + x_{ni}(Ay_n/Ax_n)^{\alpha}$$

The MOVE.1 method can be used when streamflow data are available for both the naturalized and base station for a period of N1 years and an additional N2 years data for the base station (Emerson, 2005) as follows:

$$y_i = \bar{y}_1 + \left( \frac{S_{y_1}}{S_{x_1}} \right) (x_i - \bar{x})$$

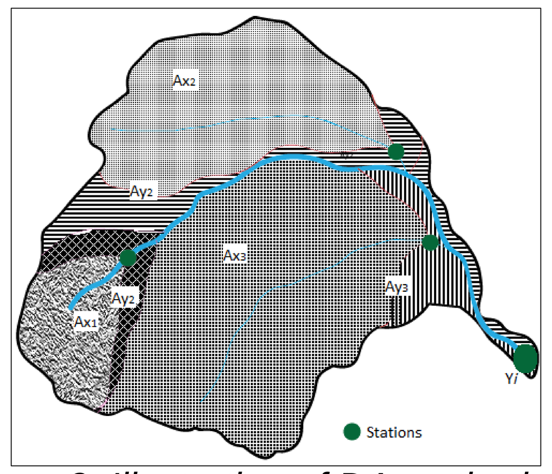

Figure 3: Illustration of DA method with multiple Base stations.

## Model Efficiency

| | DA | | MOVE.1 | | MOVE.1_Log | |
|---|---|---|---|---|---|---|
| ***Naturalized Station*** | NSE | %BIAS | NSE | %BIAS | NSE | %BIAS |
| *Salamonie at Dora* | 0.93 | 0 | 0.95 | 0.3 | 0.96 | -4.7 |
| *Wabash at Huntington* | 0.95 | 4.1 | 0.92 | 9.9 | 0.93 | 12.5 |
| *Wabash at Wabash* | 0.98 | 4.2 | 0.97 | -5.0 | 0.96 | -7.1 |
| *Wabash at Peru* | 0.97 | 0 | 0.97 | 4.2 | 0.97 | 2.1 |
| *Wabash at Logansport* | 0.99 | -0.9 | 0.99 | -0.9 | 0.99 | -1.1 |
| *Wabash at Lafayette* | 0.96 | 2.3 | -7.2 | 238.4 | -8.69 | 275.8 |

*Table 2: Model efficiency for all of the naturalized stations with DA, MOVE.1 and MOVE.1_Log methods. NSE= Nash–Sutcliffe Efficiency; and %BIAS = Percent Bias.*

## Results: Observed vs. Naturalized

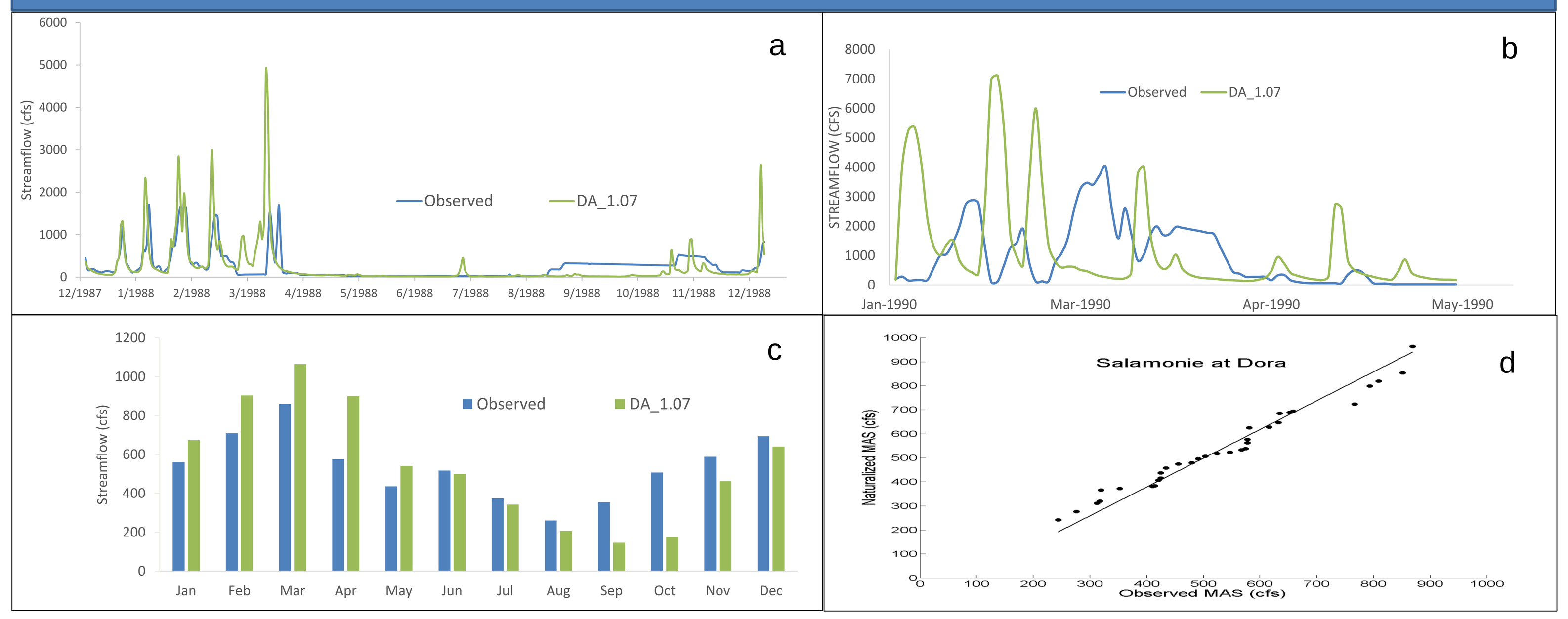


*Figure 4: Observed and Naturalized streamflow for Salamonie at Dora. a) daily streamflow with DA (α=1.07) for 1988, b) daily streamflow of the three wettest months of year 1990, c) mean monthly streamflow (1968-2001), and d) mean annual streamflow (1968 to 2001).*

## Results: Streamflow Trends

| | | Trend Slope |
|---|---|---|
| Salamonie at Dora | RBI | 0.002 $yr^{-1}$ |
| | MAF | -0.385 cfs/yr |
| | AMS | -20.00 cfs/yr |
| | MIN | 0.18 cfs/yr |
| Wabash at Huntington | RBI | 0.003* $yr^{-1}$ |
| | MAF | -4.60 cfs/yr |
| | AMS | 25.26 cfs/yr |
| | MIN | 0.13 cfs/yr |
| Wabash at Wabash | RBI | 0.001 $yr^{-1}$ |
| | MAF | -3.67 cfs/yr |
| | AMS | 93.75 cfs/yr |
| | MIN | 0.59 cfs/yr |
| Wabash at Peru | RBI | 0.001 $yr^{-1}$ |
| | MAF | -2.96 cfs/yr |
| | AMS | 55.56 cfs/yr |
| | MIN | 0.80 cfs/yr |
| Wabash at Logansport | RBI | 0.001 $yr^{-1}$ |
| | MAF | -3.84 cfs/yr |
| | AMS | 300** cfs/yr |
| | MIN | 1.61 cfs/yr |
| Wabash at Lafayette | RBI | 0.001* $yr^{-1}$ |
| | MAF | -8.73 cfs/yr |
| | AMS | 452.63 cfs/yr |
| | MIN | 4.00 cfs/yr |

**Statistically significant trends at $\alpha = 0.01$
*Statistically significant trends at $\alpha = 0.05$

*Table 3 (left): Mann-Kendall trend results and sen's slope estimator (Trend Slope) for selected annual naturalized streamflow statistics: Richards-Baker Flashiness Index (RBI), Mean Annual Flow (MAF), Annual Maximum Series (AMS), and Annual Minimum Flow (MIN). Length of data 30 years (1971-2000).*

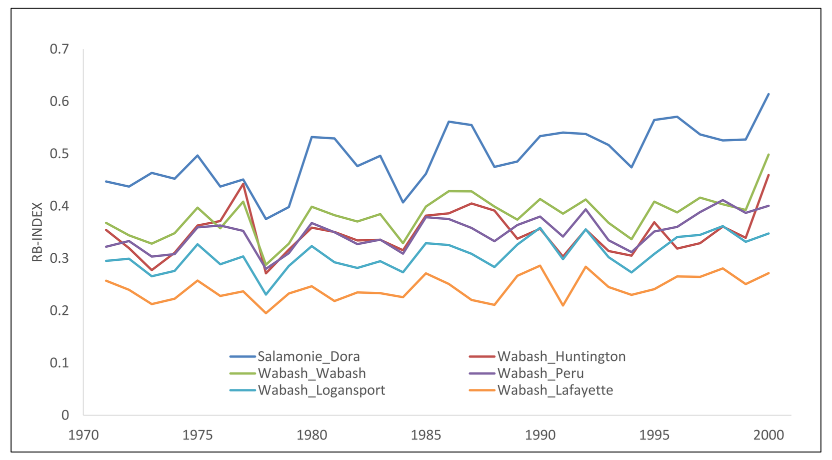


*Figure 5: Richards-Baker Flashiness Index (RB-Index) showing increasing frequency and rapidity of short-term changes in streamflow for the naturalized stations.*

## Conclusions

- The DA method with a constant exponent, α, of 1.07 worked better than MOVE.1 method for all of the naturalized stations studied.
- Using site specific exponents resulted in lower bias for individual stations, but were not used here.
- The accuracy of the estimated streamflow somewhat reduced when streamflow of a particular station is estimated from multiple base stations.
- Comparison of the naturalized and observed hydrograph shows the effect of reservoir management, including: reduced and delayed daily peaks, suppressed monthly cycle, and little change in mean annual flows.
- Trend analysis of the naturalized flow revealed:
  - Statistically significant increasing trends in the Annual Maximum Streamflow (AMS) statistics for Wabash at Logansport Station.
  - Statistically significant increasing trends in The Richards-Baker Flashiness Index (RBI) for Wabash at Huntington and Wabash at Lafayette station.


**Literature Cited:** Hirsch, R.M., 1979, An evaluation of some record reconstruction techniques: Water Resources Research, v. 15, no. 6, p. 1781-1790.



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