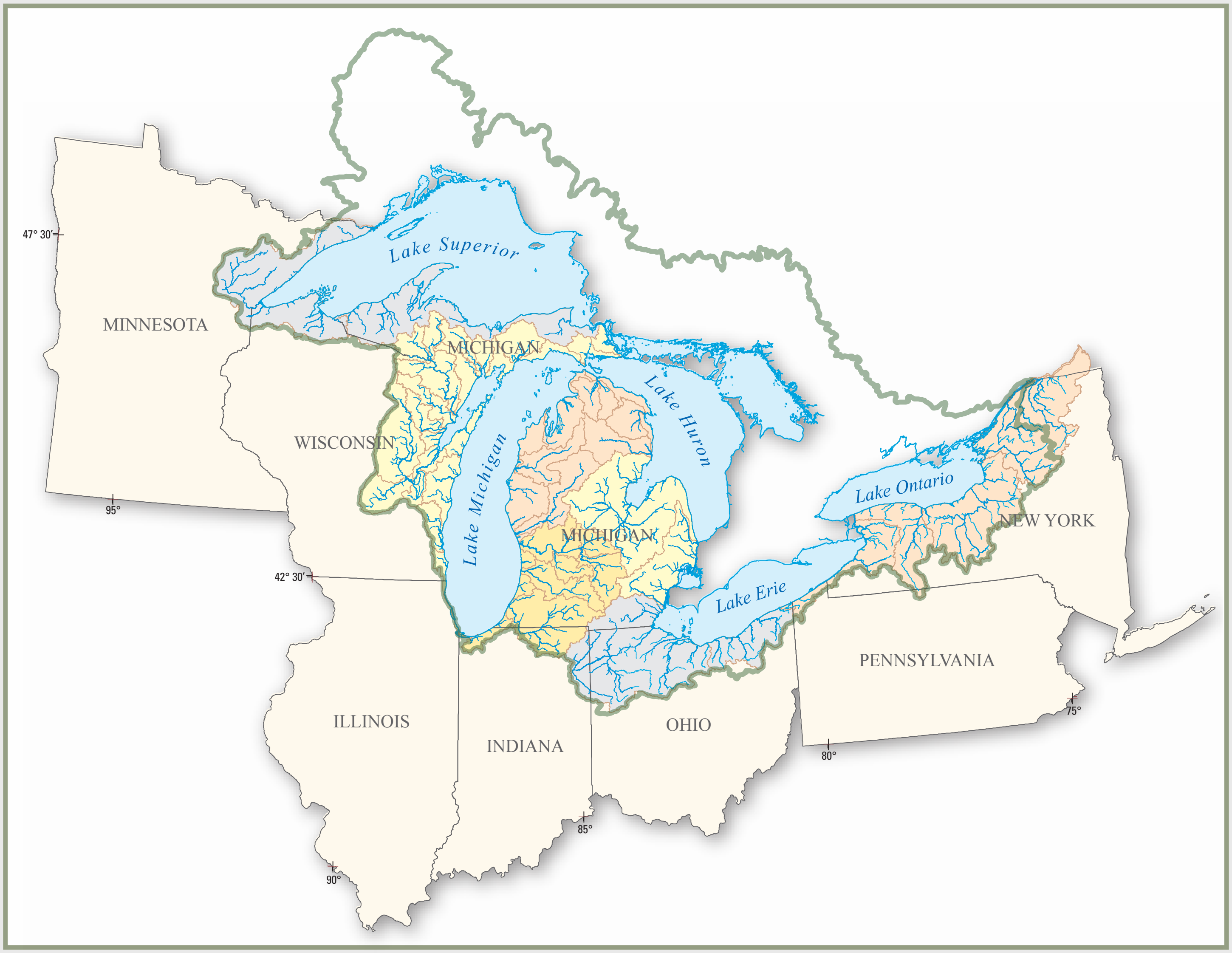
Estimation of Monthly Water Yields and Flows for 1951–2012 for the United States Portion of the Great Lakes Basin with AFINCH



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U.S. Department of the Interior
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Cover image. The United States portion of the Great Lakes Basin.

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By Carol L. Luukkonen, David J. Holtschlag, Howard W. Reeves, C.J. Hoard, and Lori M. Fuller

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
kilometer (km)	0.6214	mile (mi)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Vertical coordinate information is referenced to the North Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

A water year is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2002, is called the “2002 water year.”

Abbreviations

AFINCH	Analysis of Flows In Networks of CHannels
GAP	USGS National Gap Analysis Program
HUC	hydrologic unit code
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLCD	National Land Cover Data
NPDES	National Pollutant Discharge Elimination System
OLS	ordinary least square
POA	period of analysis
PRISM	Parameter-elevation Regressions on Independent Slopes Model
R^2	coefficient of determination
RMSE	root mean square error
SSURGO	Soil Survey Geography
USGS	U.S. Geological Survey
VAA	value-added attributes

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Abstract

Monthly water yields from 105,829 catchments and corresponding flows in 107,691 stream segments were estimated for water years 1951–2012 in the Great Lakes Basin in the United States. Both sets of estimates were computed by using the Analysis of Flows In Networks of CHannels (AFINCH) application within the NHDPlus geospatial data framework. AFINCH provides an environment to develop constrained regression models to integrate monthly streamflow and water-use data with monthly climatic data and fixed basin characteristics data available within NHDPlus or supplied by the user. For this study, the U.S. Great Lakes Basin was partitioned into seven study areas by grouping selected hydrologic subregions and adjoining cataloguing units. This report documents the regression models and data used to estimate monthly water yields and flows in each study area. Estimates of monthly water yields and flows are presented in a Web-based mapper application. Monthly flow time series for individual stream segments can be retrieved from the Web application, The Great Lakes Restoration Initiative (GLRI) Mapper for Monthly Streamflow and Yield of Catchments using Analysis of Flows in Networks of CHannels (AFINCH), *http://cida.usgs.gov/glri/afinch/*, and used to approximate monthly flow-duration characteristics and to identify possible trends.

Introduction

A regionally consistent estimate of streamflow provides unified information across the U.S. Great Lakes Basin for restoration, assessment, management, and conservation of stream ecosystems. These estimated flows provide information for natural resource professionals and the general public to assess stream ecosystems across State jurisdictional boundaries and provide a framework that can be used to help enhance existing data networks. In addition, this information can be used to assess the status of stream ecosystems, to identify and prioritize locations to focus stream restoration efforts, to plan and manage game and non-game species, to protect and enhance aquatic systems for recreational use, to provide tools for assessing disturbance of aquatic ecosystems, to plan adaptive management strategies, and to aid in implementation of the Great Lakes-St. Lawrence River Basin Water Resources Compact (Council of Great Lakes Governors, 2005).

The Analysis of Flows In Networks of CHannels (AFINCH) application (Holtschlag, 2009) was applied to estimate monthly time series of yields and flows for water years 1951–2012 within the U.S. Great Lakes Basin (Hydrologic Region 04) (Seaber and others, 1987). The resulting long-term flow time series can be used to describe monthly flow-duration characteristics and to investigate trends at 107,691 stream segments in the U.S. Great Lakes Basin. AFINCH is an interactive program used to facilitate the estimation of time series of monthly water yields from catchments and flows in stream reaches defined within the 1:100,000-scale NHDPlus geospatial data framework (McKay and others, 2012). NHDPlus is an integrated suite of application-ready geospatial-data products that includes features from the National Hydrography Dataset (NHD; U.S. Geological Survey, 2009a), the National Elevation Dataset (NED; U.S. Geological Survey, 2009b), and the National Watershed Boundary Dataset (U.S. Department of Agriculture-Natural Resources Conservation Service, 2009; U.S. Geological Survey, 2008), which describes the geometry and attributes of the hydrologic units. Monthly streamflow data at included streamgages, adjusted for upstream water use, along with monthly climatic data and land-cover or basin characteristics provide a basis for developing regression equations to estimate natural monthly water yields at individual catchments. Streamflows are estimated from the catchment yields and flow is conserved through the NHDPlus network. Chloropleth maps of monthly water yield and flow can be generated and analyzed. Estimated monthly flows can be displayed within AFINCH, examined for nonstationarity, and tested for monotonic trends. Monthly flows also can be used to estimate flow-duration characteristics at stream segments within AFINCH.

Purpose and Scope

The purpose of this report is to document regression models and estimates of monthly water yields and flows developed for seven study areas spanning the U.S. Great Lakes Basin for the period 1951–2012. These models were developed within the AFINCH modeling environment by using the NHDPlus geospatial data framework to estimate monthly water yields and flows for 105,829 catchments and 107,691 flowlines in the region. The estimated flows are constrained to be consistent with measured flows at 823 U.S. Geological Survey (USGS) streamgages. These constraints also adjust regression estimates upstream from streamgages to generally improve flow estimates from regression estimates. Monthly water-use data were applied, where available, to mitigate effects of water use on the regionalization process.

Description of the Great Lakes Basin

The Great Lakes Basin in the northeastern United States and southeastern Canada contains the five Laurentian Great Lakes of Superior, Michigan, Huron, Erie, and Ontario. These Great Lakes make up the largest surface freshwater system on Earth (U.S. Environmental Protection Agency, 2014), and contain approximately 5,500 cubic miles (mi^3) of water (Waples and others, 2008). The approximate land drainage area of the basin is 201,460 square miles (mi^2), water area is 94,250 mi^2, and the total area of the basin is 296,000 mi^2 (Government of Canada and U.S. Environmental Protection Agency, 1995). Parts of the States of Michigan, New York, Ohio, Wisconsin, Indiana, Minnesota, Illinois, and Pennsylvania, and the provinces of Ontario and Quebec drain into the Great Lakes.

Hydrologic Region 04 subdivides the U.S. Great Lakes Basin into 15 hydrologic subregions based on surface-water divides (watersheds) (U.S. Geological Survey, 2008) (fig. 1). The hierarchical hydrologic unit code (HUC) system describes increasingly refined levels of subdivision by appending a 2-digit code onto the end of the code identifying the previous level. In particular, the coding system divides surface-water drainage basins in the U.S. and the Caribbean into 21 hydrologic regions (2 digits), 221 subregions (4 digits), 378 accounting units (6 digits), and 2,264 cataloguing units (8 digits). The subregions and cataloguing units in the U.S. Great Lakes Basin were formed into seven study areas for analysis with AFINCH. These study areas facilitated the analysis by (1) combining hydrologically similar areas, (2) utilizing a larger pool of streamgaging stations than would have been possible by analyzing subregions individually, and (3) improving consistency of estimates between study areas.

Data Integration within AFINCH and NHDPlus

The AFINCH modeling approach and method of estimating flows along with descriptions of potential explanatory variables are described in the following sections.

AFINCH Modeling Approach

AFINCH implements a two-step predictor-corrector process. The predictor step is based on a user-specified multiple-linear-regression equation, which estimates monthly yields using selected monthly climatic and basin characteristics data and flows at streamgages. The corrector step adjusts the regression estimates to match measured flows at included streamgages.

Predictor Step

The predictor step in an AFINCH analysis is based on the statistical relation between a response variable that is a function of monthly flows and one or more explanatory variables that may be formed from time-varying monthly climatic data or fixed basin characteristics data. In particular, a user-specified multiple-linear-regression model is used to predict the response variable for each NHDPlus catchment in the study area. As discussed later in more detail, catchment yield (the response variable in this study) is defined as the streamflow contribution from the catchment divided by the catchment area. The estimated square root of yield is transformed and multiplied by catchment area to produce a runoff or catchment flow. The catchment flows are accumulated downstream by using the stream network topology described in NHDPlus. The following paragraphs develop the notational conventions underlying the AFINCH model.

Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 1. Hydrologic subregions and cataloguing units in the U.S. Great Lakes Basin.

A time series of monthly flows for the period of analysis at each NHDPlus flowline in the study area is the primary output from an AFINCH analysis. Monthly measured flows ${}^{mea}Q_{Gage(i,j)}$, for water year index i and streamgage index j, are critical to developing these estimates. Streamflow data are typically reported as mean daily flows at the streamgage; monthly flows used in this study are the mean of the daily flows for each month. This set of monthly measured flows at included streamgages in water year i can be formed into a column vector with length n_i, written ${}^{mea}Q_{n_i \times 1}$.

In some stream reaches, withdrawals, diversions, or augmentations associated with water use can augment or diminish flows measured at downstream streamgages. If monthly water-use data are available to document these uses, measured flows at streamgages can be adjusted to more accurately represent natural flow conditions, that is, without water use. For example, if a consumptive water use of 1 cubic foot per second (ft^3/s) is withdrawn from a reach upstream of one or more streamgages, the natural flow at the affected streamgages would be expected to have 1 ft^3/s more than the measured flow. Understanding natural flow conditions helps regionalize flow information with AFINCH. Measured flows that have been adjusted with available water use are designated as ${}^{mea}\tilde{Q}_{Gage(i,j)}$.

Streamflow generally occurs in dendritic drainage patterns in which headwater streams converge to form tributaries that combine flow from upstream branches. This process progresses downstream as tributaries continue to merge until only a main stem remains. A streamgaging network follows this pattern, so some streamflow is commonly measured by multiple streamgages. To avoid this redundancy in streamflow information, AFINCH computes an incremental flow, ${}^{mea}_{\Delta}Q_{Gage(i,j)}$, and a corresponding incremental drainage area, ${}^{ba\sin}_{\Delta}A_{Gage(i,j)}$, for each streamgage based on the stream network configuration. Consider, for example, a simple two-gage network in which the water measured at the upstream gage is combined with additional flow as it moves downstream and is re-measured at the downstream gage. In this network, the incremental flow and area for the upstream streamgage is the same as the measured flow and total area; at the downstream streamgage, however, the incremental flow is the measured flow minus the flow measured at the upstream gage. Similarly, the incremental area is the contributing drainage area at the downstream gage minus the contributing drainage area at the upstream gage.

Over a significant range of flows and drainage areas, (incremental) streamflow is proportional to the (incremental) drainage area. For example, all other factors being equal in a local flow system, the mean streamflow at a stream site with twice the drainage area of another stream site is likely to have twice the mean flow. The dominant effect of drainage areas on flows can mask more subtle effects statistically associated with the impact that land use and land cover, monthly precipitation and temperature, and other factors might have on streamflow. To increase the sensitivity of the analysis to these more subtle basin and climate effects, AFINCH analysis is based on water yield, which is obtained by dividing incremental flows by corresponding incremental areas as ${}^{mea}_{\Delta}Y_{Gage(i,j)} = {}^{mea}_{\Delta}Q_{Gage(i,j)} \,/\, {}^{ba\sin}_{\Delta}A_{Gage(i,j)}$ or in vector notation ${}_{\Delta}Y_{n_i \times 1} = {}_{\Delta}Q_{n_i \times 1} \circ {}^{ba\sin}_{\Delta}A^{-1}_{n_i \times 1}$. This approach removes drainage area as a possible explanatory variable, which also mitigates some concerns about developing parameter estimates from analysis of (incremental) streamgage basins, made up of hundreds of individual NHDPlus catchments, for prediction at individual catchments.

A multiple regression model provides a basis for prediction and for assessing the uncertainty of the prediction. This uncertainty is based on simplifying assumptions concerning the characteristics and distribution of model residuals ε formed by the differences between measured and predicted values of the response. In particular, model residuals are assumed to be independently and identically distributed with a normal (Gaussian) distribution having a mean of 0 and a variance of σ_{ε}^{2} (Draper and Smith, 1998). So that this assumption is more likely satisfied, a square-root transformation was applied to the incremental yield to reduce its skewness. Skewness is a measure of the departure of a distribution from a symmetric distribution like the normal distribution. The transformed yield data are denoted by ${}^{mea}_{\Delta}Y^{0.5}_{Gage(i,j)} = \sqrt{{}^{mea}_{\Delta}Y_{Gage(i,j)}}$ and the residuals are formed as $\varepsilon_{n_i \times 1} = {}^{mea}_{\Delta}Y^{0.5}_{n_i \times 1} - {}^{est}_{\Delta}Y^{0.5}_{n_i \times 1}$.

In the multiple regression model underlying AFINCH, the response variable of monthly water yields—expressed generically for any individual water year i with n_i streamgages in the study area as ${}^{mea}_{\Delta}Y^{0.5}_{n_i}$—is linearly related to a design matrix containing a column of 1’s, corresponding to an intercept term, augmented on the right with a set of explanatory variables. Explanatory variables are user specified, but generally include monthly climatic and basin characteristics. All columns have the same number of elements (lengths of n_i) and the rows must be independent as

$$
{}^{mea}_{\Delta}\tilde{Y}^{0.5}_{n_i\times 1} = \left[\mathbf{1}_{n_i\times 1} \quad X_{n_1\times k}\right]\cdot\beta_{k+1} + \varepsilon_{n_i}\,, \tag{1}
$$

where

${}^{mea}_{\Delta}\tilde{Y}^{0.5}_{n_i\times 1}$	is an n_i-column vector of the square-roots of measured incremental water yields, adjusted for water use;
$\left[\mathbf{1}_{n_i\times 1} \quad X_{n_i\times k}\right]$	is a design matrix of explanatory variables in which the first column is a n_i-vector of ones for the intercept term, which is augmented on the right by an $n_i\times k$ matrix of explanatory variables indexed over water years by *i*;
β_{k+1}	is a $k\times 1$ column vector of parameters relating the explanatory variables to the response variable; and
ε_{n_i}	is an n_i-column vector of regression residuals, which are assumed to be independent and identically distributed random variables following a normal (Gaussian) distribution with mean 0 and variance σ^2_ε.

In cases where the *k* explanatory variables can be partitioned into a set of k_v time-varying characteristics such as monthly precipitation, and a set of k_f time-invariant (fixed) characteristics such as soil types, the design matrix for a selected month in the i^{th} year can be written as

$$
X^i_{n_i\times(1+k_v+k_f)} = \left[1_{n_i} \quad X^i_{n_i\times k_v} \quad X_{n_i\times k_f}\right] \tag{2}
$$

Ordinary least-square (OLS) estimates of the parameter vector β^i for monthly water yields in the i^{th} water year can be computed (Draper and Smith, 1998) as

$$
\begin{bmatrix} \hat{\beta}^i_0 \\ \hat{\beta}^i_{k_v} \\ \hat{\beta}^i_{k_f} \end{bmatrix} = \left[\left(X^i_{n_i\times(1+k_v+k_f)}\right)'\cdot X^i_{n_i\times(1+k_v+k_f)}\right]^{-1}\cdot\left(X^i_{n_i\times(1+k_v+k_f)}\right)'\cdot {}^{mea}_{\Delta}\tilde{Y}^{0.5}_{n_i\times 1} \tag{3}
$$

Annual estimates of parameters may be useful in cases where the relation between the explanatory and response variables is suspected of being time varying. For example, a trend in parameter estimates might occur if an explanatory variable, such as land use, is treated as fixed when it is actually time varying. More commonly, the design matrix for the user-specified period of analysis (POA) for *N* years can be developed by vertically stacking design matrixes for individual water years and corresponding water yield vectors ${}^{mea}_{\Delta}\tilde{Y}^{0.5}_{n_i\times 1}$ as

$$
\underline{X} = X_{\sum_i n_i,1+k_v+k_f} = \begin{bmatrix} X^1_{n_1\times(1+k_v+k_f)} \\ X^2_{n_2\times(1+k_v+k_f)} \\ \vdots \\ X^N_{n_N\times(1+k_v+k_f)} \end{bmatrix} = \begin{bmatrix} 1_{n_1} & X^i_{n_i\times k_v} & X_{n_i\times k_f} \\ 1_{n_2} & X^2_{n_2\times k_v} & X_{n_i\times k_f} \\ \vdots & \vdots & \vdots \\ 1_{n_N} & X^N_{n_N\times k_v} & X_{n_i\times k_f} \end{bmatrix} \tag{4}
$$

The corresponding OLS estimate of the regression parameter vector for the period of analysis is

$$\begin{bmatrix} \hat{\beta}_{0}^{poa} \\ \hat{\beta}_{k_v}^{poa} \\ \hat{\beta}_{k_f}^{poa} \end{bmatrix} = \left[\underline{X}' \cdot \underline{X} \right]^{-1} \cdot \underline{X}' \cdot {}^{mea}_{\Delta}\underline{\tilde{Y}}^{0.5}_{\sum\limits_i n_i \times 1} \tag{5}$$

In AFINCH, 12 equations are individually estimated for monthly yields (either annually or for the POA) providing the flexibility to include different explanatory variables, β, in different monthly equations. A stepwise-selection process is used to automate the selection process in which the user specifies an $\alpha -$ level (the probability of a type I error, which in this example, is incorrectly rejecting the null hypothesis that individual parameters are equal to zero) to control the apparent statistical significance of included explanatory variables. Stepwise selection is an iterative process in which *p*-values (the apparent probability that the magnitude of a parameter estimate, relative to its uncertainty, would occur by chance under the null hypothesis) are repeatedly computed and compared to the specified $\alpha -$ level. Explanatory variables with *p*-values smaller than the $\alpha -$ level are maintained in the equation. The user can override the stepwise-selection process by specifying which explanatory variables to include in the monthly regression equations regardless of their apparent statistical significance. Finally, the user can specify whether OLS or robust parameter estimates are to be used in the estimation of catchment water yields. Robust parameter estimates use a bisquare weight function with a tuning constant of 4.685 by default (The MathWorks, Inc., 2012). Robust estimates may be preferred to OLS estimates to reduce the sensitivity of parameter estimates to one or more irresolvable outliers in the water yield series; however, for the estimates presented in this report, OLS parameter estimates were used.

Once the monthly regression equations are developed from streamflow information at gaged basins, the results are applied to estimate water yields for all gaged and ungaged NHDPlus catchments. For the case where estimation equations are developed by using POA parameter estimates, monthly estimates of water yield for individual water years are computed as

$${}^{est}\underline{\tilde{y}}^{0.5}_{M\times 1} = \underline{x}_{M\times(k+1)} \cdot \hat{\beta}^{poa}_{k+1}, \tag{6}$$

where

${}^{est}\underline{\tilde{y}}^{0.5}_{M\times 1}$ is the estimated vector of natural water yields (adjusted for water use), in the square-root metric, for all *M NHDPlus* catchments-water years in the period of analysis;

$\underline{x}_{M\times(k+1)}$ are catchment characteristics that correspond to basin characteristics for all the water-years in equation [4]; and

$\hat{\beta}^{poa}_{k+1}$ is the vector of parameter estimates.

Estimated runoff (flows) from individual catchments are computed from estimated yields and catchment areas as

$$ {}^{est}\underline{\tilde{q}}_{M\times 1} = \left({}^{est}\underline{\tilde{y}}^{0.5}_{M\times 1} \right)^{2} \circ {}^{catch}\underline{a}_{M\times 1}, \tag{7} $$

where

${}^{est}\underline{\tilde{q}}_{M\times 1}$ is the vector of natural flows (runoff) for all catchments-water years in the period of analysis,

$\left({}^{est}\underline{\tilde{y}}^{0.5}_{M\times 1} \right)^{2}$ is the estimated natural catchment yield, and

${}^{catch}\underline{a}_{M\times 1}$ is a vector of *NHDPlus* catchment areas.

For notational simplicity, let ${}^{est}\underline{\tilde{q}}_{M\times 1} \rightarrow {}^{est}\tilde{q}^{i}_{m\times 1} \forall wy\left(i\right) \in poa$. Then accumulate monthly flows from catchments (runoff) forming the incremental areas upstream of included streamgages in water year *i* as

$$ {}^{est}_{\Delta}\tilde{Q}^{i}_{n_i\times 1} = \sum_{catch_{Gage(i,j)} = catch_{StudyArea} \cap {}^{nBa\sin}_{\Delta}A_{n_i\times 1}} {}^{est}\tilde{q}^{i}_{catch}, \tag{8} $$

where

${}^{est}_{\Delta}\tilde{Q}^{i}_{n_i\times 1}$ is the vector of accumulated AFINCH estimates of incremental flows at the n_i active streamgages in water year *i*,

catch is the set of all study area catchments in the incremental area of individual streamgages monitored in water year *i*, and

${}^{est}\tilde{q}^{i}_{catch}$ is the natural monthly runoff from the set of catchments forming the incremental streamgage areas in the i^{th} water year.

and compare with measured flows.

Corrector Step

A corrector step is used to adjust AFINCH estimated monthly water yields upstream from an included gage so that resulting AFINCH constrained monthly flows match measured flows at every streamgage for each water year in the period of analysis as ${}^{con}_{\Delta}\tilde{Q}^{i}_{Gage_j} \equiv {}^{mea}_{\Delta}\tilde{Q}^{i}_{Gage_j}$. The adjustment is applied to the catchment corresponding to the NHDPlus flowline where the streamgage is located and to estimated yields on all catchments upstream of the streamgage. The flow-based correction ratio is computed as

$$\tilde{q}Ratio^{i}_{Gage_j} = {}^{mea}_{\Delta}\tilde{Q}_{Gage_j \times 1} \circ {}^{est}_{\Delta}\tilde{Q}^{-1}_{Gage_j \times 1} \tag{9}$$

$${}^{con}\tilde{y}^{i}_{usGage_j} = {}^{est}\tilde{y}^{i}_{usGage_j} \cdot \tilde{q}Ratio^{i}_{Gage_j}, \tag{10}$$

where

${}^{con}\tilde{y}^{i}_{usGage_j}$	is the constrained estimate of water yields in *NHDPlus* catchments forming the incremental drainage area upstream of the j^{th} streamgage in the i^{th} water year,
$usGage_j$	is the set of catchments contributing to flowlines upstream from $Gage_j$, and
$\tilde{q}Ratio^{i}_{Gage_j}$	is a constant for the j^{th} streamgage and i^{th} water year. In ungaged areas and areas downstream from active gages, estimated water yields are unconstrained.

Constrained monthly water yields for each catchment and water year are used with corresponding catchment areas to compute constrained runoff ${}^{con}\tilde{q}^{i}_{catch} = {}^{con}\tilde{y}^{i}_{catch} \circ a_{catch}$. The constrained runoffs are accumulated downstream by using the NHDPlus flowline topology to compute constrained accumulated AFINCH flows ${}^{con}\tilde{Q}^{i}_{flowline}$. Lastly, water-use information is added to affected flowlines and combined with ${}^{con}\tilde{Q}^{i}_{flowline}$ so that ${}^{con}Q^{i}_{Gage_j} \equiv {}^{mea}Q^{i}_{Gage_j} \forall j \in$ Steamgage Network in water year i.

Model Limitations

The regression model structure underlying AFINCH has some inconsistencies with the data structure that may affect the reliability of reported statistics (p-values) used for assessing model suitability. In particular, model residuals are assumed to be independent in regression models, but the data structure provides repeated (annual) measures from a network of streamgages. Thus, residual series from individual streamgages may not be independent in time, and residual series from different streamgages may not be identically distributed. These limitations are likely to be exacerbated when there are few streamgages with relatively long periods of record. Lack of temporal independence and non-identically distributed residuals series could inflate the apparent significance (reducing p-values) of individual explanatory variables, thus leading to greater type I errors than what would be consistent with the specified $\alpha-$ level. To mitigate this potential problem, the number of explanatory variables potentially included in the regression model might be constrained, say to a number less than the square root of the number of included streamgages, or the $\alpha-$ level might be otherwise reduced.

NHDPlus Geospatial Data Frame

NHDPlus describes the geometry and the attributes of the hydrologic units and links flowlines to catchments and to other flowlines. Notably, NHDPlus includes the flowline topology, which is the routing information providing the upstream and downstream connections for each flowline. AFINCH estimates of water yields are based on incremental flows and areas within streamgage networks. These incremental flows are summed down the network from the headwaters to the downstream-most segment in the watershed under analysis. There are 105,829 catchments making up Hydrologic Region 04 (U.S. Great Lakes Basin), which have an average area of 1.16 mi^2. Each catchment, which is uniquely identified by a *Gridcode,* is associated with a flowline (stream segment), which is uniquely identified by a *ComID*, that drains the catchment.

The 107,691 flowlines characterizing the drainage network in the U.S. Great Lakes Basin include streams and rivers, canals and ditches, pipelines, artificial paths, coastlines, and connectors. Flowlines in the U.S. Great Lakes Basin average about 1 mile (mi) in length; some flowlines have no associated catchments. The topology of flowlines defined within NHDPlus provides a mechanism to accumulate flows from catchments and route flows through a drainage network. Initial inspection of some of the network design matrixes and the drainage area plots produced by AFINCH indicated the need for revisions to the flowline routing. In addition, early estimated flows also indicated the need for changes to the specified diversions for some flowlines. These revisions to flowline routing and diversion information are outlined in appendix 1, table 1–1.

Response Data

AFINCH uses multiple regression analysis to regionalize and spatially distribute water yields across catchments spanning (stream) gaged and ungaged basins in the study area. Monthly streamflow and water-use data are used together to describe the response variable.

Removing effects of artificial augmentations and diversions from directly impacted streamflow records helps describe natural streamflow conditions and associated yields, which can be regionalized. From these natural streamflow conditions, regression analysis describes how monthly climatic and basin characteristics affect the distribution of natural water yields across catchments. Catchment yields with corresponding drainage areas are used to compute runoff (flow), which can be accumulated downstream by using the NHDPlus streamflow topology. In gaged basins, the regression yield estimates are adjusted (constrained) so that resulting flows, with water-use data re-applied, match measured monthly flows. In ungaged basins, the natural water yields are used (without constraints) to estimate flows, with available water-use data re-applied to provide the final estimates of flow.

Monthly Streamflow Data

The NHDPlus GageLoc is a shapefile that locates USGS streamgages along flowlines. A USGS streamgage is uniquely identified by its station number; other information included in the analysis is the drainage area at the gage. In the U.S. Great Lakes Basin (Hydrologic Region 04), 1,339 streamgages are identified; however, stations that (1) represented lake sites, (2) had no specified drainage area, and (or) (3) did not have complete data for at least 1 water year within the period 1951–2012 were excluded from the analysis. Therefore, data from 823 streamgages were compiled for the AFINCH analysis. Time series of monthly streamflow values were computed from data obtained through the USGS cooperative streamgaging program (Wahl and others, 1995).

Occasionally, within NHDPlus, one or more streamgages may be located at different points along a single flowline. The streamgage that best represents flow conditions, for example the gage with the longer period of record, was selected for the analysis. In each subregion, flow at sites that were regulated or influenced by water withdrawals and diversions, as indicated by station descriptions or analysis of the water yield graphs, was not included in the analysis if water-use or routing data were not readily available to adjust the flow to more natural conditions. NHDPlus routing tables were used to route flow upstream to headwaters or downstream to discharge points. For each streamgaging station, all upstream flowlines (and associated catchments) were identified by using the NHDPlusV2 Flow Table Navigator Toolbar in ArcMap (Horizon Systems Corporation, 2014).

Monthly Water-Use Data

In AFINCH, water use (including withdrawals, augmentations, and diversions) can be associated with flowlines and accounted for along with catchment flows. Monthly flows can be adjusted for specified water uses by using a companion (currently (2014) unpublished) program to AFINCH, which aids with water-use accounting and tracks withdrawals or returns from their point of origin to the downstream-most segment in the analysis. The Water Use Data Tool is available upon request from the USGS Michigan Water Science Center. Water withdrawals are indicated by negative water-use values, and flow augmentations are indicated by positive water-use values. Monthly water-use data for each water year within the period of analysis were specified for those flowlines with readily available data; however, determination of monthly water use for the period of analysis at each possible location was beyond the scope of this study. In addition, much of these data are unavailable, incomplete, or are not in a format that is readily amenable for inclusion in this analysis. Collection of additional data would likely improve the estimates and permit inclusion of additional streamgage data in the analysis.

Water withdrawals, diversions, and augmentations were determined from available records for selected flowlines in hydrologic subregions 0402, 0403, and 0409 using data from the National Pollutant Discharge Elimination System (NPDES) permit program, USGS Annual Data Reports, and (or) other USGS studies. The NPDES permit program requires industrial, municipal, and other facilities to report point-source discharges to surface-water bodies. Data were retrieved using the Permit Compliance System (U.S. Environmental Protection Agency, 2001). Monthly discharges that could be linked to an adjacent flowline were included in the AFINCH analysis each year the discharge occurred for subregions 0403 and 0409. Other withdrawal and diversion data were available from USGS Annual Data Reports (U.S. Geological Survey Water-Data Reports for Michigan and the St. Lawrence River Basin, 1958–2012). For example, reservoir stage data are collected that can be related to a flow or change in storage in the reservoir or to a withdrawal and later release to a different flowline. Data from these sources were included in the AFINCH analysis for subregions 0402 and 0403. In addition, local data used in the Kalamazoo area study (Luukkonen and others, 2004), describing water diversions to Portage Creek for selected years during 1966–2002, were used to estimate water-use data for hydrologic subregion 0405 for this time period.

In hydrologic subregion 0402, at streamgaging station 04034000 Bond Falls Reservoir near Paulding, Michigan, water is diverted to South Branch Ontonagon River through Bond Falls Canal (streamgaging station 04033500), and water is used for power production at Victoria Dam near Rockland. Gage height data provided by Upper Peninsula Power Company are converted to acre-feet by USGS (Neal Craig, U.S. Geological Survey, oral commun., 2011). Water diverted from Schweitzer Reservoir to this subregion as described below also was included in the analysis. Data for 1950–2010 were used in the AFINCH analysis for subregion 0402.

In hydrologic subregion 0403, at streamgaging station 04057811 Greenwood Reservoir near Greenwood, Mich., water can flow over a concrete spillway into the Middle Branch Escanaba River below streamgaging station 04057814 Greenwood Release near Greenwood, Mich., with some downstream diversions by local industries above streamgaging station 04058000. An outlet structure also permits flow from the reservoir into the afterbay (conservation pool) where water can be diverted to Green Creek gaged at Greenwood Diversion (streamgaging station 04057813) or released to the Middle Branch Escanaba River below streamgaging station 04057814. Beginning in October 1979, some water also was released after use to the East Branch Escanaba River via Goose Lake Outlet. Since January 1973, Greenwood Reservoir diverts some impounded water to Schweitzer reservoir (streamgaging station 04058190 Schweitzer Reservoir near Palmer, Mich.) for use in iron ore processing. Some flow from this reservoir is diverted to the city of Ishpeming, Mich., for municipal supply and discharged to the Carp River Basin (in hydrologic subregion 0402). After processing, water is returned to Green Creek or, beginning in 1980, to Goose Lake Outlet. Data for 1963–2009 were used in the AFINCH analysis for hydrologic subregion 0403.

Explanatory Data

Multiple regression analyses relate explanatory variables consisting of time varying (monthly) climatic characteristics, and time invariant (fixed) catchment characteristics to monthly varying water yields. In this study, Parameter-elevation Regressions on Independent Slopes Model (PRISM) monthly precipitation and temperature data were used, and catchment characteristics in the National Land Cover Data (NLCD) set were supplemented or replaced with user-specified catchment characteristics. The source and characteristics of explanatory variables used in this analysis are described in the following sections.

PRISM Monthly Climatic Data

For this report, average monthly air temperature and total precipitation data were computed for each year during the period 1950–2012 for all catchments in the U.S. portion of the Great Lakes Hydrologic Region (04) (fig. 1). The climatic data are based on 2.5 arc-minute (approximately 4 kilometers) grids of PRISM data by Daly and Taylor (1998a, b). Monthly minimum and maximum air temperature and precipitation datasets for 1895–2012 from the PRISM Climate Group (2013) were overlain with polygons representing catchment boundaries to estimate spatially averaged precipitation and temperature values. The average of the minimum and maximum temperature values was used to estimate the average monthly temperature.

National Land Cover Data

Land-cover information for the conterminous United States for 2006 is available through the NLCD from the Multi-Resolution Land Characteristics Consortium (Fry and others, 2011). The 16-class land-cover classification scheme includes more broadly defined land-cover classes including water, developed, barren, forest, shrub land, herbaceous, planted or cultivated, and wetlands (appendix 1, table 1–2). Percentages of these categories were determined for each catchment in Hydrologic Region 04.

NHDPlus National Catchment Characteristics Data

NHDPlus includes a stream network based on the medium resolution (1:100,000 scale) NHD, with connectivity within the stream network and to associated catchments. Stream order is a method of assigning a numeric order to links within a stream network and in NHDPlus is a modified version of stream order as defined by Strahler (1957). The Strahler stream order algorithm does not account for flow splits in the network. The NHDPlus algorithm for stream order does take flow splits into consideration. These value-added attributes (VAA) are computed from upstream to downstream (McKay and others, 2012).

The NHDPlus suite of data includes information from the NED (Gesch and others, 2009). For each NHDPlus catchment, average catchment elevations were determined using the zonal statistics ArcMap toolbox command (ESRI, 2012). In a similar way, average and minimum catchment slope were determined for each catchment using the ArcMap toolbox commands for slope and zonal statistics (ESRI, 2012).

User-Supplied Catchment Characteristics Data

The user may provide one or more sets of shapefiles containing catchment attributes that can be used as explanatory variables in the subsequent regression analysis. User-specified variables for this analysis included soil information from the Soil Survey Geography (SSURGO) database (U.S. Department of Agriculture-Natural Resources Conservation Service, 2011), surficial and bedrock geology from the USGS National Gap Analysis Program (GAP), and growing degree day data (computed using PRISM air temperature data).

SSURGO Soil Data

The SSURGO database contains information about soil components and properties as collected by the National Cooperative Soil Survey and is available for most areas in the United States. The hydrologic group is based on estimates of runoff potential and are assigned according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms (appendix 1, table 1–3). If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

GAP Vegetation and Land-Use Pattern Data

The USGS National GAP Land Cover Data Set includes detailed vegetation and land-use patterns for the continental United States to aid in State or regional assessments of natural resources and to provide for a regionally consistent database with uniformity across State boundaries (U.S. Geological Survey, 2011). GAP is a nationwide effort under the direction of the USGS and provides information on the distribution of native vegetation types, modified and introduced vegetation, developed areas, and agricultural areas of the United States. Surficial and bedrock geology variables used in the AFINCH analysis are shown in appendix 1, table 1–4.

Growing Degree Day Data

Growing degree days provide a measure of heat accumulation because plant and animal development is related to the accumulation of heat or temperature units above a threshold or base temperature below which little growth occurs. The average annual growing degree days for the continental United States were calculated for 1971–2000 from downloaded PRISM air temperature datasets (Mike Slattery, U.S. Geological Survey, written commun., 2013). The base temperature (10 degrees Celsius (°C)) was subtracted from the average of the maximum and minimum monthly air temperatures. Only values equal to or greater than 0 °C were used and the resulting grid was then multiplied by the number of days in the month; the total from the previous month was added in a cumulative method to arrive at an approximation of the average annual growing degree days.

Output Data

The AFINCH program writes comma-delimited ASCII files with constrained and unconstrained monthly yields and flows for all the stream segments in the part of the NHDPlus area being analyzed and for each month and water year of the time period of the analysis. These flows and yields are indexed by the *ComID* of the stream segment or the *Gridcode* of the catchment. Headers in these files help document the analyses by describing explanatory variables, estimated parameters, and other user specifications. A representative chloropleth map showing the distribution of water yields for August averaged over 1951–2012 is shown in figure 2. An example time-series plot of monthly flows for a streamgaging station in hydrologic subregion 0403 showing the square root of measured flow with the square root of estimated incremental flow is shown in figure 3. Estimated flows and yields have been incorporated into a mapper application by the USGS Center for Integrated Data Analytics, *http://cida.usgs.gov/glri/afinch/*, for ease of use, display, and retrieval. These long-term flow series can be used to investigate trends or to characterize monthly flow durations.

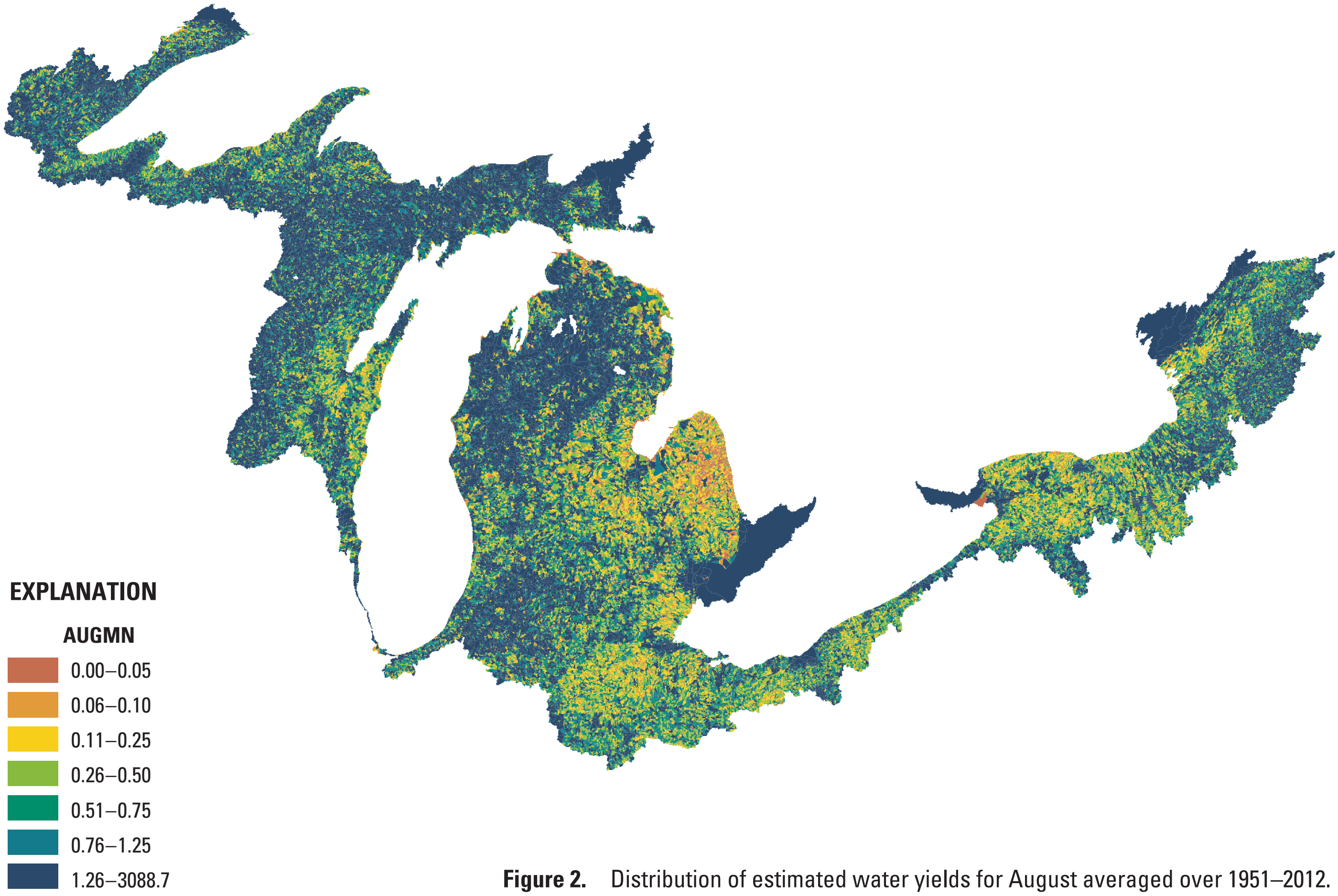
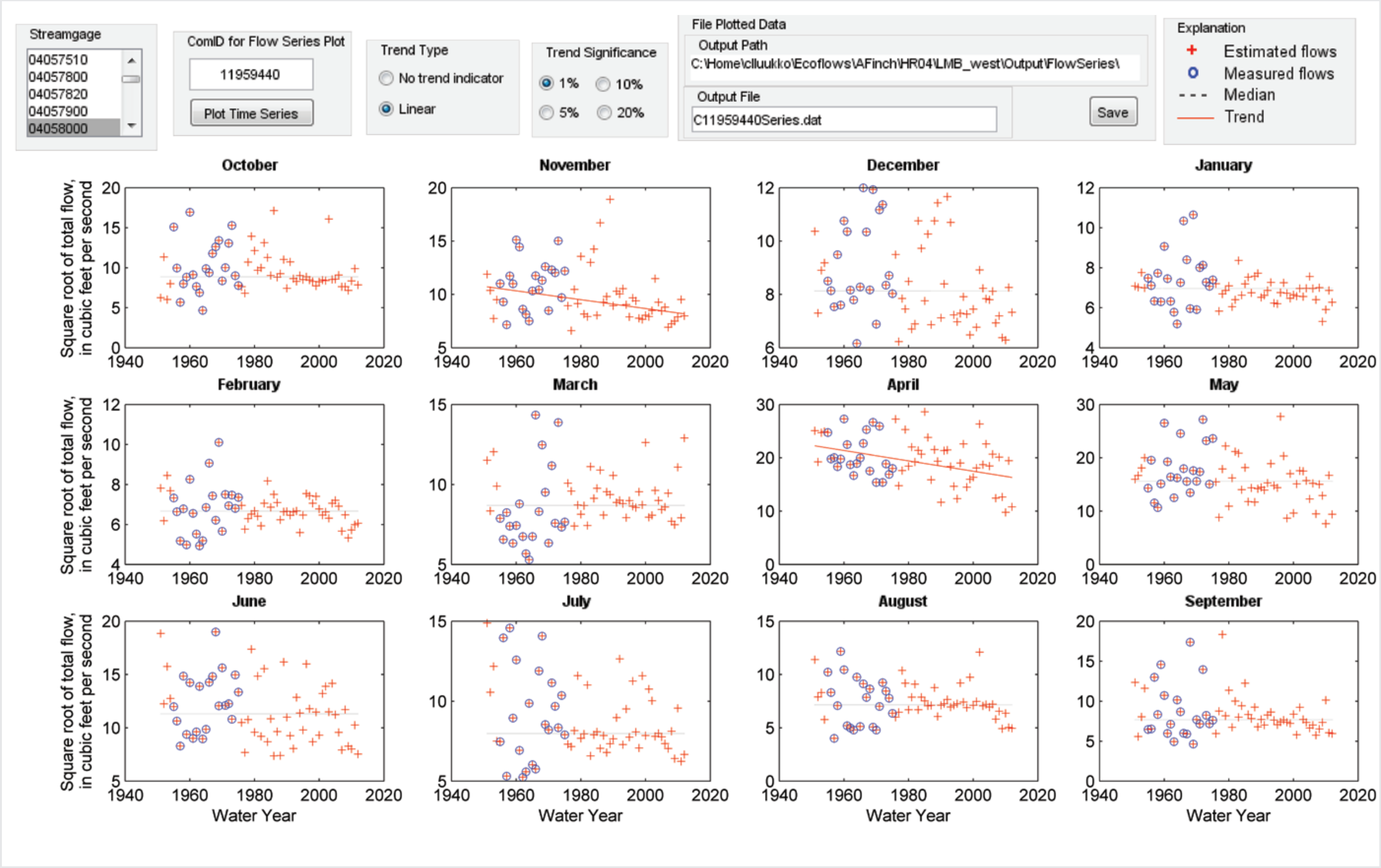


Figure 2. Distribution of estimated water yields for August averaged over 1951–2012.



Streamgage
04057510
04057800
04057820
04057900
04058000

ComID for Flow Series Plot: 11959440

Plot Time Series

Trend Type
○ No trend indicator
● Linear

Trend Significance
● 1% ○ 10%
○ 5% ○ 20%

File Plotted Data

Output Path: C:\Home\clluukko\Ecoflows\AFinch\HR04\LMB_west\Output\FlowSeries\

Output File: C11959440Series.dat

Save

Figure 3. Time-series plot of monthly flows at flowline 11959440, streamgaging station 04058000, Middle Branch Escanaba River near Ishpeming, Michigan.

Methods of Flow and Water-Yield Estimation for Study Areas

Flows and water yields for water years 1951–2012 were estimated for 107,691 flowlines and 105,829 catchments in Hydrologic Region 04 representing the portion of the Great Lakes Basin in the U.S. (fig. 1). The 15 hydrologic subregions were combined to form 7 study areas consisting of multiple subregions and (or) cataloguing units for analysis with AFINCH (table 1). Details on the analysis and estimation of flows and water yields are presented for each study area. Each section includes (1) location map, (2) table of the streamgaging stations in the study area indicating each year each streamgage was active during the analysis period and whether or not the streamgage data were included in the analysis, (3) the regression coefficients and fit statistics for each variable, and (4) graph showing the *t*-values for each explanatory variable by month.

The regression coefficients indicate the size and direction (positive or negative) of the effect that each variable has on the yield estimate. However, some of the differences in coefficient magnitudes are owing to the fact that the potential explanatory variables are in different units, for example, variables with larger values would likely have smaller coefficients. To aid in the interpretation of the effect of each variable, graphs of *t*-values for all variables in the multiple-linear-regression equation are shown for each study area. The magnitudes of the *t*-values are test statistics that are used to interpret the likelihood that individual parameters in the regression equation are equal to zero. The sign of the *t*-values indicate whether the corresponding parameter is positive or negative. The cells in the image are white if the magnitude of the corresponding test statistic did not indicate significance at the level prescribed by the user. Cells are graded with increasing tones of red for increasingly significant parameters with negative signs. Similarly, cells are graded with increasing tones of blue for increasingly significant parameters with positive signs. The color scale at the bottom indicates the magnitude of the *t*-statistics. This visual representation permits interpretation of the information used to estimate water yields by each variable and for each month. For example, parameters (represented in each horizontal band) with most months tinted in shades of blue and (or) red likely provide more information in estimating the water-yield response than would a variable where most months are white indicating that the test statistics were not significant. Likewise, months (represented in each vertical band) with most cells tinted blue and (or) red would be estimated using multiple parameters, whereas months where most cells are white would not be estimated using much parameter information. The regression-fit statistics include the root-mean-square error (RMSE), F statistic, and the coefficient of determination (R^2) for the fit to the square-root of water yield. As noted previously, drainage area is so strongly correlated to streamflow that this relation is built into the analysis by writing the regression equation in terms of yield (streamflow divided by drainage area). Examination of the tables reveals that the reported R^2 values for the fit to the square root of yield can be fairly low (0.2–0.7); however, the corresponding R^2 for the fit of estimated to measured streamflows can be quite high (0.8–0.9) because of the strong correlation between area and streamflow.

Selection of explanatory variables was guided by knowledge of each study area, identification of variables likely to affect water yields, and inspection of the images showing monthly parameter *t*-values. Furthermore, an additional consideration was to improve the estimation of yields and flows during April (higher flow month) and August (lower flow month) in order for the estimates to be more useful for

Table 1. Summary of study area information.

Study area	Hydrologic subregions (4-digits) and (or) cataloguing units (8-digits)	Drainage area (square miles)	Number of streamgages	Number of flowlines	Number of catchments
1	0401 and 0402	16,632	76	15,442	15,221
2	0403, 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002	23,133	177	16,529	16,153
3	0405 and 04040001	13,620	105	11,523	11,300
4	04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007	14,844	61	7,946	7,808
5	0408 and 0409	12,881	116	13,303	13,151
6	0410 and 0411	14,942	120	16,935	16,713
7	0412, 0413, 0414, and 0415	21,655	168	26,013	25,483

ecological stream-classification work. The variables selected for each study area represent those with the most significance of the combinations that were considered during the regression analysis; however, consideration of all possible variables and combinations was beyond the scope of this report. It is possible that there are areas where local conditions differ greatly from the variable characteristics that were selected for the study area and that in these areas flow and yield estimates are not as representative of actual conditions than they could be with a different variable set. It also is possible that a regionally important variable was not included in the analysis. Equally likely is the potential that major water uses (withdrawals, augmentations, or diversions) were not accounted for during the analysis. However, regionally these estimates present a reasonable, consistent, and defensible set of flow and yield estimates for the U.S. Great Lakes Basin.

Study Area 1

Study area 1 is formed by hydrologic subregions 0401 and 0402 in the western part of the U.S. Great Lakes Basin and encompasses parts of Minnesota, Wisconsin, and the Upper Peninsula of Michigan (fig. 4). The number of stations included in the analysis ranged from 17 (1986, 1998, 1999, 2001, 2007, 2008, and 2009) to 30 (1954 and 1955) (table 2). Nine explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 6 (June) to 8 (October, November, December, January, April, May, and August). Selected explanatory variables are summarized in table 3. Variables and regression statistics based on the stepwise regression for each month are indicated in table 4 and figure 5.

Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 4. Location of study area 1 (hydrologic subregions 0401 and 0402) in the U.S. Great Lakes Basin.

Table 2 Streamgaging stations considered for analysis of study area 1 (hydrologic subregions 0401 and 0402) in the U.S. Great Lakes Basin, by water year.

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04010500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
04010510																																
04010530																																
04012500			●	●	●	●	●	●	●	●	●																					
04014500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04015330																									●	●	○	●	●	●	●	●
04015410																																
04015455																												●	●	●		
04015475																													●	●	●	●
04015500						○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
04016000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○															
04016500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04017000	●	●	●	●	●	●	●	●	●	●	●	●	●	●																		
04018000				●	●	●	●	●	●	●	●	●																				
04018750															○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04018900																	●	●	●	●	●	●	●	●	●	●	●	●	●			
04019000				●	●	●	●	●	●	●	●	●				●	○	○	○	○	○	○	○	○	○	○	○	○	○			
04019300														●	●	●	●	●	●	○	●	●	●	●	●	●	○	●				
04019500				●	●	●	●	●	●	●	●	●			●	●	●	●														
04020000			●	●	●	●	●	●	●	●	●																					
04021520																																
04021530																																
04024000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04024090																											○	○				
04024093																											○	○				
04024098																											●	●	●	●	●	●
04024314																											●	●				
04024315																											○	○				
04024318																											○	○				
04024430																									●	●	●	●	●	●	●	●
04025500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04026190																																●
040263205																																
04026347																										●	●	●				
04026348																											○	○				
04026349																											●	●				
040263491																																

Table 2. Streamgaging stations considered for analysis of study area 1 (hydrologic subregions 0401 and 0402) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04010500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04010510										●																				
04010530										●																				
04012500																														
04014500	○	○	●	●	●	●	●	●	●	●	●																			
04015330	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	○	●	○	●	●	●	●	○	○	○	○	●	●	●
04015410											○																			
04015455																														
04015475	●	●	●	●	○	●																								
04015500																														
04016000																														
04016500	○	○	○	○	○																									
04017000																														
04018000																														
04018750	○	○	○	○	○	○	○																							
04018900																														
04019000																														
04019300																														
04019500																														
04020000																														
04021520																									○	○	○	○	○	○
04021530		●																												
04024000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04024090																														
04024093																														
04024098	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○											
04024314																														
04024315																														
04024318																														
04024430	●	●	●	○	●	●	●	●	●	●	○	○	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
04025500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04026190	●	●																												
040263205																		●	●	●	●	●	●	●	●	●	●	●	●	●
04026347																														
04026348																														
04026349																														
040263491								●	●				●	●	●				○	○	○	○	○	○	○	○	○	●		

Table 2 Streamgaging stations considered for analysis of study area 1 (hydrologic subregions 0401 and 0402) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04026450																					●	○	●	●	●							
04026500	○	○	●	●	●																											
04026870																							○	○	○	○	○					
04027000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●
04027500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04028000	●	●	●	●																												
04029990																																
04030000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04031000					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04031500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04032000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04032500			●	●	●	●	●																									
04033000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04033500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04034500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04035000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
04035500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04036000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04037500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04039500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
04040000	●	●	●	●	●	●	●	●	●	●	○	●	○	○	●	●	○	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
04040500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04041500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04042500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
04043000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●								
04043050																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04043140																																
04043150																																
04043238																																
04043244																																
04043275																																
04043800																																
04044400												●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04044563																														●	●	
04044573																														●	●	
04044583																○	○	○	○	○										○	○	
04044595																														●	●	
04044724																																
04045500				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 2. Streamgaging stations considered for analysis of study area 1 (hydrologic subregions 0401 and 0402) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04026450																														
04026500																														
04026870																														
04027000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04027500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04028000																														
04029990					○	○	○	○	○	○	●	●	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	●	●	●
04030000																														
04031000																			●	●	●	●	●	●	●	●	●	●	●	●
04031500																														
04032000																														
04032500																														
04033000	●	●	●	●	●	●	●	●	●	●	●	●	●						●	●	●	●	●	●	●	●	●	●	●	●
04033500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04034500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	
04035000																														
04035500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○				
04036000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04037500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04039500																														
04040000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●	●
04040500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04041500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04042500																														
04043000																														
04043050	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04043140																										○	○	○	○	○
04043150																				●	●	●	●	●	●	●	●	●	●	●
04043238																								○	○	○	○	○	○	○
04043244																								○	○	○	○	○	○	○
04043275																								○	○	○	○	○	○	○
04043800									○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○					
04044400	●	●	●	●																										
04044563																														
04044573																														
04044583																														
04044595																														
04044724												●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04045500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 3. Selected explanatory variables for each study area.

[PRISM, Parameter-elevation Regressions on Independent Slopes Model; NLCD, National Land Cover Data; SSURGO, Soil Survey Geography; GAP, USGS National Gap Analysis Program; GDD, growing degree days]

Explanatory variables	Study area 1	Study area 2	Study area 3	Study area 4	Study area 5	Study area 6	Study area 7
PRISM							
Current precip, in hundredths of millimeters	X	X	X	X	X	X	X
Preced precip, in hundredths of millimeters	X	X	X	X	X	X	X
Current temp, in degrees Celsius * 100	X	X	X	X	X	X	X
NLCD							
Open water, in percent			X				X
Developed, in percent							X
Deciduous and evergreen forest, in percent				X			
Forest, in percent	X	X	X			X	X
Grass herbaceous, in percent					X		
Pasture hay, in percent			X		X		
Row crops, in percent			X	X	X		
Pasture hay and row crops, in percent		X				X	X
Wetland woody, in percent		X					
Wetland herbaceous, in percent		X	X				
NHDPlus catchment characteristics							
Stream order, dimensionless	X		X	X	X	X	
Mean elevation, in centimeters	X		X			X	
Mean slope, in centimeters/meter			X		X	X	X
SSURGO							
Hydric group A and AD, in percent				X			
Hydric group B and BD, in percent					X		
Hydric group C and CD, in percent		X					
Hydric groups C, CD, and D, in percent	X						X
GAP							
Coarse outwash, in percent			X		X		
Fine end and ground moraines, in percent						X	
Medium end and ground moraines, in percent						X	
Coarse end and ground moraines, in percent	X						X
Coarse outwash and ice contact, in percent						X	X
Coarse stratified sediment, in percent		X					
Till, in percent		X					
GDD							
Average GDD, in days			X		X		X

Table 4. Regression statistics and explanatory variables used in the AFINCH (Analysis of Flows In Networks of Channels) analysis of flows in study area 1 (hydrologic subregions 0401 and 0402), in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; RMSE, root mean square error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients									Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Forest	Coarse end and ground moraines	Mean elevation	Hydric groups C, CD, and D	Stream order	RMSE	F-statistic	R^2
October	0.797	0.116	0.080	–	–	–	–	–0.326	–0.203	0.236	391.3	0.537
November	1.133	0.120	0.068	–0.011	–	0.073	–6.0E-06	–0.379	–0.180	0.221	144.4	0.428
December	1.314	0.060	0.062	0.015	0.113	0.145	–7.0E-06	–0.496	–0.158	0.184	144.4	0.462
January	1.279	0.027	0.054	0.008	0.225	0.193	–9.0E-06	–0.547	–0.132	0.192	124.3	0.425
February	1.261	–	0.049	0.015	0.307	0.196	–9.0E-06	–0.498	–0.111	0.193	125.7	0.395
March	0.926	0.091	0.047	0.068	0.681	0.074	–7.0E-06	–	–	0.254	248.5	0.525
April	0.395	0.101	0.089	–0.036	0.887	–0.285	–	0.709	0.278	0.465	62.1	0.244
May	1.064	0.146	0.066	–0.048	–	–0.262	–	–0.121	0.169	0.343	137.1	0.379
June	0.818	0.133	0.071	–0.016	–	–0.134	–4.0E-06	–0.241	–	0.246	184	0.450
July	1.296	0.123	0.061	–0.037	0.150	–	–1.0E-05	–0.385	–	0.225	263.7	0.540
August	0.044	0.086	0.060	0.028	0.290	–	–9.0E-06	–0.470	–	0.217	213	0.486
September	0.781	0.100	0.064	–	0.156	–	–6.0E-06	–0.458	–0.158	0.222	229.5	0.505

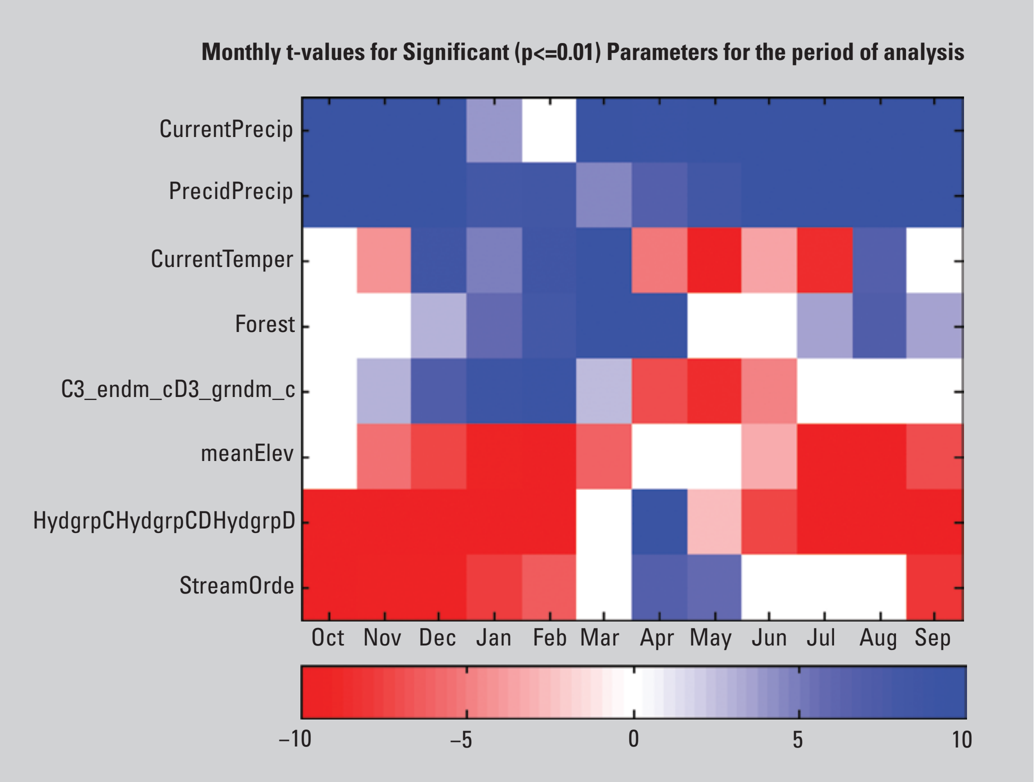
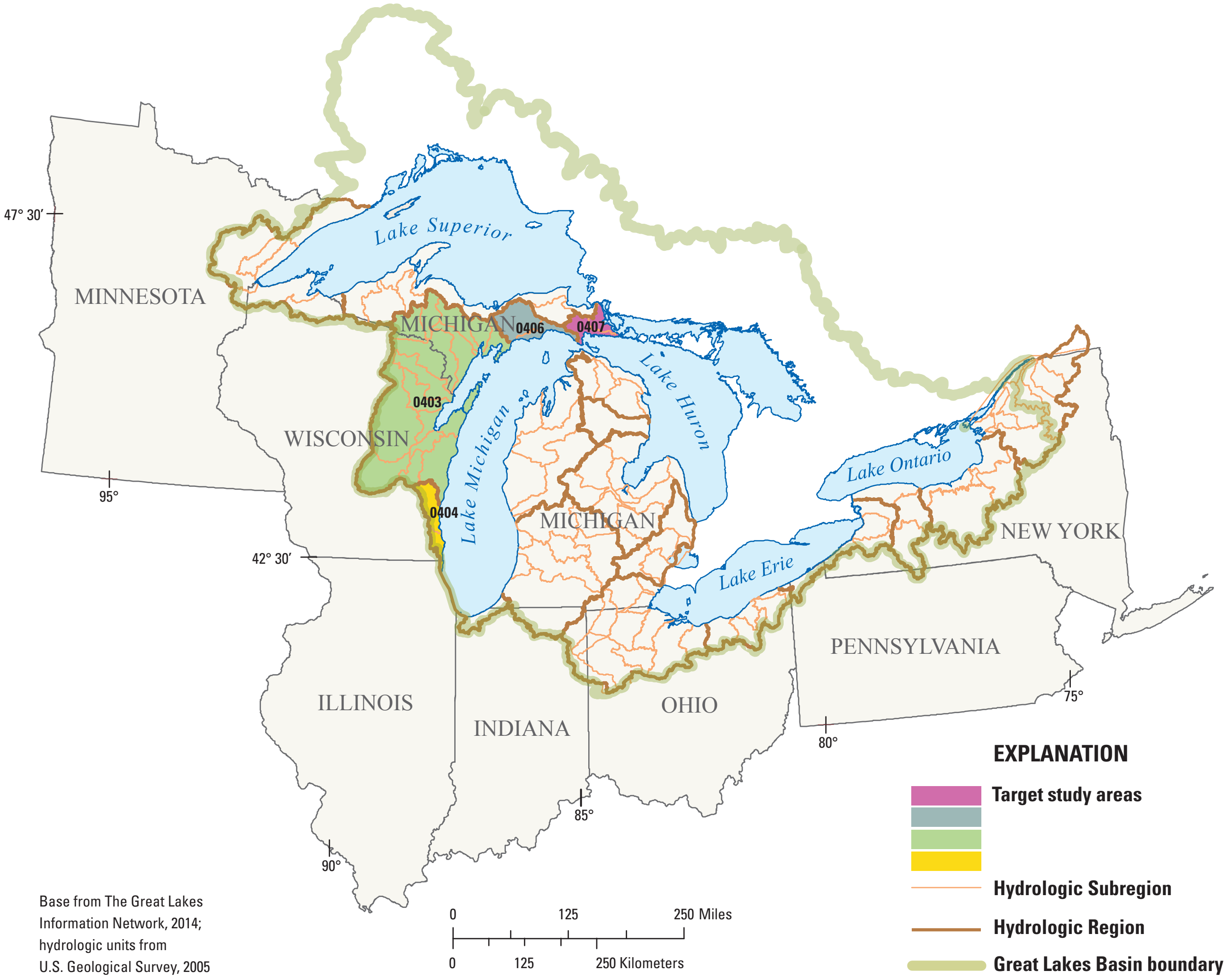


Figure 5. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 1 (hydrologic subregions 0401 and 0402) in the U.S. Great Lakes Basin.

Study Area 2

Study area 2 is formed by hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002 on the western and northern side of Lake Michigan and encompasses parts of Wisconsin, northern Illinois, and the Upper Peninsula of Michigan (fig. 6). The number of stations included in the analysis ranged from 21 (1951 and 1953) to 47 (2005) (table 5). Ten explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 6 (March and June) to 10 (February) (table 3). Variables and regression statistics based on the stepwise regression for each month are indicated in table 6 and figure 7.



Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 6. Location of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin.

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04046000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
04049500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04052500																																
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04054500	●	●	●	●																												
04055000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04056000	●	●	●	●	●	●																										
04056500	○	●	○	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04057000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
04057004																																
04057510																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04057800										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04057813																								○	○	○	○	○	○	○	○	○
04057814																							○	○	○	○	○	○	○	○	○	○
04057820																							●	●	●	●	●	●	●	●	●	●
04057900												●	●	●	●	●	●	●														
04058000					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04058100												●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04058130																											●	●	●	●	●	●
04058200											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04058300												●	●	●	●	●	●	●					●	●	●	●	●	●				
04058400																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04058500					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04059000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04059400																						●	●	●	●	●	●					
04059500					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04060500	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●		
04060993	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04061000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04061500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04062000			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04062011																																
04062100												●	●	●	●	●	●	●														
04062200												●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
04062230																			○	○	○	○	○	○	○	○	○	○	○	○	○	○
04062270															○	○	○	○	○													
04062300												○	○	○	○	○	○	○	○	○	○	○	○	○	○							
04062400															●	●	●	○	●	○	●	●	●	●	●	●	●	●	●	●		
04062500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04063000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04063500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04063640																	●															
04063700														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04064500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04065106																																

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04046000													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04049500																														
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04057000											●																			
04057004													●																	
04057510	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04057800	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04057813	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04057814	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04057820																														
04057900																														
04058000																														
04058100								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04058130																														
04058200	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○
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04059000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
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04059500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04060500																							●	●	●	●	●	●	●	●
04060993	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04061000	●	●	●	●	●	●	●	●	●	●	●																			
04061500	○	○	○	○	○	○	○	○	○	○	○	○	○	○																
04062000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04062011								○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04062100												●	●																	
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04062230																														
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04062500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04063000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04063500	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04063640																														
04063700	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04064500															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04065106											○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04065300									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04065393																								●	●	●	●	●	●	●	●	●
04065397																												○	○	○	○	○
04065500					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04065600																						●	●	●	●	●	●	●	●	●	●	
04065722																																
04066000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04066003																																
04066030																																
04066500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04066800	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
04067000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
04067500	○	○	○	○	○	○	○	○	○	○	○																			○	○	○
04067651																																
04067958																																
04069416																																
04069500				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04069530																																
04071000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04071765																																
04071775																																
04071795																																
04071858																							○	○	○	○	○	○	○	○	○	○
04072150																																
04072410																																
04072750																			●	●	●	●	●									
04072845																																
04073050																			●	●	●	●	●	●	●							
04073365																																
04073405														●	●																	
04073462																																
04073468																																
04073473																																
04073500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04073970																																
04074538																												●	●	●	●	●
04074548																												●	●			
04074950																	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○
04075200																		●	●	●	●	●	●									
04075365																																
04075500	●	●	●	●	●	●	●	●	●	●	●	●																				
04077000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04077400																																
04077630																																
04078500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

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Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04065300																														
04065393	●	●																												
04065397	○																													
04065500																														
04065600																														
04065722							○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04066000																														
04066003	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04066030																	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04066500																			●	●	●	●	●	●	●	●	●	●	●	●
04066800																	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04067000																														
04067500	○	○	○	○			○	○				○	○			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04067651							○	○					○																	
04067958																	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04069416																	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04069500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04069530							●	●																						
04071000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04071765							○	○								○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04071775							●																							
04071795												●	●																	
04071858	○	○	○	○	○	○	○	○	○	○	○	○	○	○																
04072150							○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04072410											○																			
04072750																														
04072845																										○	○	○	○	
04073050																														
04073365																				●	●	○	●							
04073405																														
04073462	○	○	○	○	○										○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04073468						●	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	○
04073473																○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04073500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04073970																										○	○	○	○	
04074538	●		●	●																●	●	●	●	●	●	●	●			
04074548	●	●																		●	○	○	●	●	●	●	●			
04074950	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04075200																														
04075365																						●	●	●	●	●				
04075500																														
04077000	●	●	●																											
04077400				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04077630											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04078500	●	●	●										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

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04079000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04079602																								●	●	●	●	●	●			
04079700															●	●																
04080000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04080798																																
04080950																			●	●	●	●	●	●								
04081000	●	●	●	●	●	●	●	●	●	●	●	●	●			●																
04081800																											○					
04082400																																
04083000	●	●	●	●																												
04083420																																
04083423																																
04083425																																
04083500	●	●	●	●																												
04083545																																
04084445																																
04084475																																
04084500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04085046																																
04085054																																
04085059																																
04085068																																
04085109																																
04085118																																
04085119																																
04085200																	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04085281																							●	●	●	●	●	●	●	●	●	●
04085330																																
04085395																																
04085427																							●	●	●	●	●	●	●	●	●	●
04085492																																
04085746																																
04085845																													●	●	●	●
04086000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04086150																			●	●	●	●	●	●	●	●	●	●	●	●	●	
04086175																																
04086200																			●	●	●	●	●	●	●	●	●	●	●	●	●	
04086340																			●	●	●	●	●	●	●	●	●	●	●	●	●	
04086360																			○	○	○	○	○	○	○	○	○	○	○	○	○	
04086488																																
04086500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●	●	●	●	●	●	
04086600																																
04087000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04087010																																
04087018																										●	●					

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

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04079000	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04079602																														
04079700																														
04080000	●	●	●																								●	●	●	●
04080798												●	●																	
04080950																														
04081000	●	●	●																								●	●	●	●
04081800																														
04082400										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04083000																														
04083420																	○	○												
04083423																	○	○												
04083425																	●	●												
04083500																														
04083545																										○	○	○	○	
04084445					○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04084475							●	●																						
04084500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04085046																						●	●	●						
04085054							●	●																						
04085059							○	○																						
04085068																						●	●	●						
04085109													●																	
04085118				○																										
04085119									○	○	○	○													○	○	○			
04085200	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○	○	○	○	○	○	○	○	○	○	○	○
04085281	●	●	●	●	●	●	●	●	●	●	●	●	●	●																
04085330																									○					
04085395												●	●	●	●	●	●	●	●	●	●	●	●							
04085427	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●
04085492												○																		
04085746																				●	●	●	●							
04085845																														
04086000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04086150																														
04086175															●															
04086200																														
04086340																														
04086360												○																		
04086488	○	○																												
04086500		●	●	●	●				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04086600	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04087010	○	○																												
04087018																														

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

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04087019																											○	○				
04087030																										●	●			●	●	●
04087040																										●	●	●	●			
04087047																																
04087048																																
04087050																										●	●	●	●			
04087060																										●	●	●	●			
04087070																										●	○					
04087088																										●	●	●	●		●	●
04087119																										●	●	●	●			
04087120												●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	●	●	●	●	●
04087125																										○	○	○	○			
04087138																																
04087140																										○						
04087142																																
04087159																																
04087160																											○	○	○	○	○	○
04087170																																
04087204														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087214																																
04087220														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087233														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087240														○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04087257																						●	●	●	●	●	●	●	●	●	●	●
04127918																							●	●	●	●	●	●	●	●	●	●
040445315																																
040590345																																
040734644																																
040851325																																
040851378																																
040851385																																
040857005																																
040860041																																
040863075																																
040869415																																
040869416																																
040871473																																
040871475																																
040871476																																
040871488																																
040874126																																
0407809265																																
0408570045																																

Table 5. Streamgaging stations considered for analysis of study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by water year.—Continued

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04087019																														
04087030	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087040																														
04087047																										○				
04087048																										○				
04087050																										●	●	●	●	●
04087060																														
04087070																							●	●	●	●	●	●	●	●
04087088	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087119																							●	●	●	●	●	●	●	●
04087120	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
04087125																														
04087138	○	○																												
04087140																														
04087142																											○	○	○	○
04087159	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087160																														
04087170													●							●	●				●	●	●	●	●	●
04087204	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087214																							○	○	○	○	○	○	○	○
04087220	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087233	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04087240	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04087257	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04127918	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
040445315																○	○													
040590345							○	○																						
040734644						●	●	●	●	●	●	●	●	●																
040851325																						●	●	●	●					
040851378																							●	●	●					
040851385							○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
040857005									●	●	●	●	●	●	●	●	●	●	●	●										
040860041												○	○																	
040863075												●	●																	
040869415												○																		
040869416																						●	●	●	●	●	●	●	●	●
040871473																	○	○	○	○	○	○	○	○	○	○	○	○	○	○
040871475																								○	○	○	○	○	○	○
040871476																	○	○	○	○	○	○	○	○	○	○	○	○	○	○
040871488																	○	○	○	○	○	○	○	○	○	○	○	○	○	○
040874126														○																
0407809265								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●						
0408570045													○	○																

Table 6. Regression statistics and explanatory variables used in the AFINCH (Analysis of Flows In Networks of Channels) analysis for study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; RMSE, root mean squared error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients											Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Pasture hay and row crops	Forest	Wetland woody	Wetland herbaceous	Hydric group C and CD	Coarse stratified sediment	Till	RMSE	F-statistic	R^2
November	0.336	0.139	0.076	–0.006	–0.167	0.131	–	–	–0.100	0.125	–	0.194	408.2	0.579
January	0.411	0.091	0.086	0.020	–0.077	0.510	–0.585	0.525	–	0.309	0.111	0.194	150.4	0.395
March	0.653	0.119	0.097	0.029	0.225	–	–	0.839	0.293	–	–	0.285	282.8	0.450
May	1.238	0.134	0.068	–0.033	–0.221	–	0.537	–	–	–0.430	–0.390	0.271	345.3	0.538
July	1.057	0.103	0.066	–0.028	–0.518	–0.232	–0.800	–	–0.176	0.231	–	0.197	404.7	0.609
September	0.411	0.106	0.050	–	–0.410	–	–0.600	–0.341	–0.189	0.159	–	0.203	446	0.601

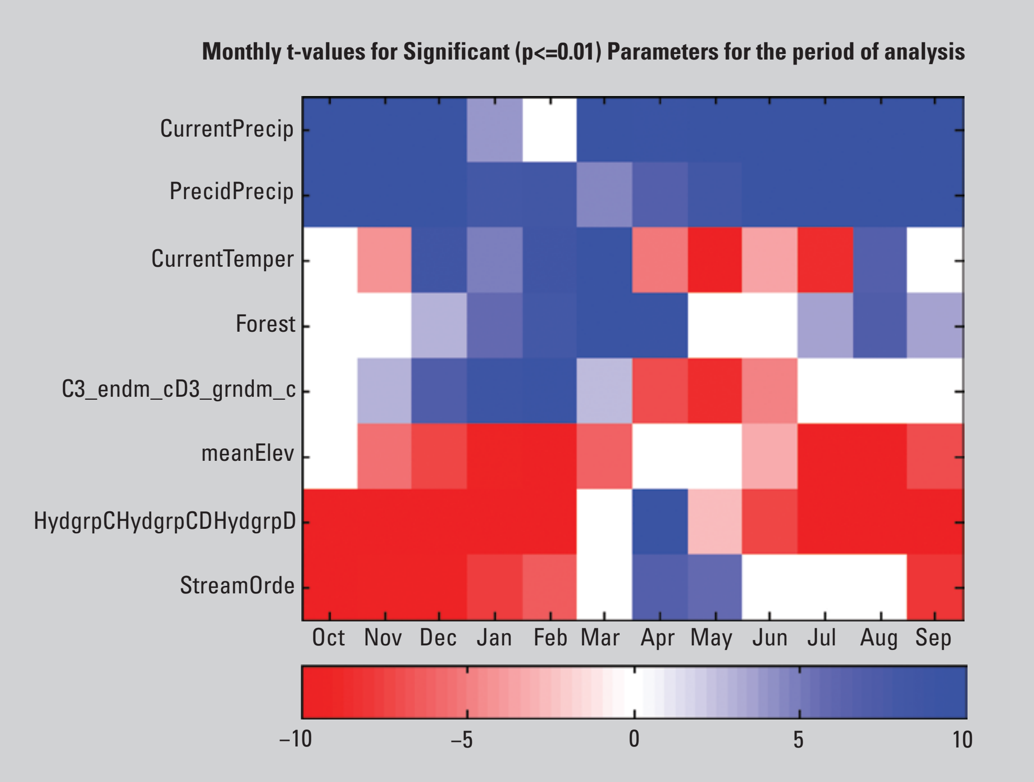
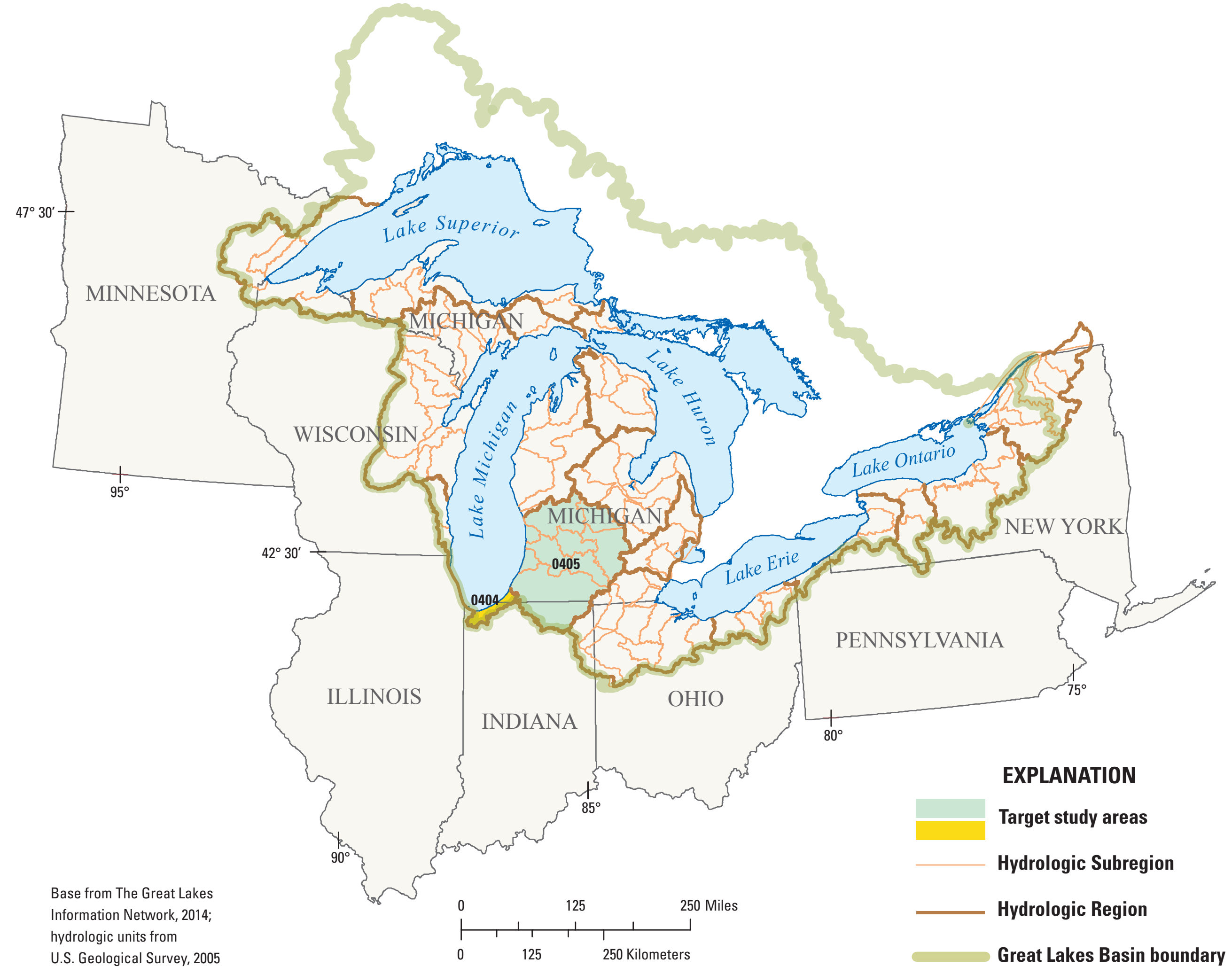


Figure 7. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 2 (hydrologic subregion 0403 and cataloguing units 04040002, 04040003, 04060106, 04060107, 04070001, and 04070002) in the U.S. Great Lakes Basin.

Study Area 3

Study area 3 is formed by hydrologic subregion 0405 and cataloguing unit 04040001 in the south-central part of the U.S. Great Lakes Basin along the southeastern side of Lake Michigan and encompasses parts of Michigan, Indiana, and a small part of Illinois (fig. 8). The number of stations included in the analysis ranged from 27 (1951) to 54 (1976) (table 7). Thirteen explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 5 (April) to 12 (September) (table 3). Variables and regression statistics based on the stepwise regression for each month are indicated in table 8 and figure 9.



Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 8. Location of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin.

Table 7. Streamgaging stations considered for analysis of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04092677																																
04092750																																
04093000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04093200									○	○	○	○	○	○	○	○	○		○	○	○											
04093500						○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○				○
04094000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04094500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04095050																													○	○	○	
04095090																																
04095092																													○	○	○	
04095100																														○		
04095300																				●	●	●	●	●	●	●	●	●	●	●	●	●
04095380																																
04096015																																
04096100																				●	●	●	●	●	●	●	●	●	●	●	●	●
04096272																									●	●	●	●				
04096312																									●	●	●					
04096325																									●	●	●					
04096340																									●	●	●					
04096400													○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04096405													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04096500	●	●	●	●	●	●	●	●	●	●	●	●																				
04096515																				●	●	●	●	●	●	●	●	●	●	●	●	●
04096600													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04096900																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04097060															●	●	●															
04097170	●														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
04097195																○	○	○	○	○	○	○										
04097200															●	●	●	●	●	●	●	●										
04097500				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04097540													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04097970																				●	●	●	●	●	●	●	●	●	●	●	●	●
04098500								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04099000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●
04099510	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04099610														○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
04099750																			●	●	●	●	●	●	●	●	●	●	●	●	●	●
04099808																														●	●	●
04099850																														●	●	●
04100000	●																															
04100222																						●	●	●	●	●	●	●	●	●	●	●
04100252																				●	●	●	●	●	●	●	●	●	●	●	●	●
04100295																															●	●
04100377																																
04100465																				●	●	●	●	●	●	●	●	●	●	●	●	●
04100500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04101000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04101370																																
04101500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 7. Streamgaging stations considered for analysis of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04092677													○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04092750													○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04093000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04093200																														
04093500						○	○	○	○																					
04094000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04094500	●	●	●	●	●	●	●	●	●																					
04095050																														
04095090													○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04095092																														
04095100																														
04095300	●	●	●	●	●	●	●	●	●	●	●	●														●	●	●	●	○
04095380													○			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04096015														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04096100	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04096272																														
04096312																														
04096325																														
04096340																														
04096400	○	○	○	○	○	○	○	○	○																					
04096405	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04096500																														
04096515	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04096600	●	●	●	●	●	●	●																							
04096900	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●															
04097060																														
04097170																														
04097195	○	○	○	○	○	○	○	○	○																					
04097200																														
04097500	●										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04097540	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04097970	●	●	●	●																										
04098500																														
04099000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04099510	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04099610																														
04099750	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04099808	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04099850	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04100000																														
04100222	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
04100252	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04100295	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
04100377						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04100465	●	●	●	●	●																									
04100500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
04101000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●
04101370											○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04101500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 7. Streamgaging stations considered for analysis of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04101800											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04102000		●	●	●	●	●																										
04102320																															●	●
04102420																															●	●
04102500		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04102700																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04102776																																
04102850																						●	●	●	●	●						
04103010																																
04103500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04104000	●	●	●	●																												
04104500	●	●	●																													
04104945																																
04105000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04105500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●	●
04105700															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04105800															●	●	●	●	●	●	●	●										
04106000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
04106180																																
04106190															○	○	○															
04106300															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04106320																							○	○	○	○	○	○	○	○	○	○
04106400										○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04106500	○	○	○	○	○	○	○	○																		○	○	○	○	○	○	○
04106906																																
04107850																																
04108500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04108600																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04108670																																
04108800											○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04108801											○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04109000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04109500	●	●	●	●	●	●																										
04110000	●	●	●	●	●	●																										
04111000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04111379																										●	●	●	●	●	●	●
04111500					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04112000					○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04112500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 7. Streamgaging stations considered for analysis of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04101800	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04102000																														
04102320																														
04102420																														
04102500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04102700	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04102776													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04102850																														
04103010					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04103500																				●	●	●	●	●	●	●	●	●	●	●
04104000																														
04104500																														
04104945													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04105000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04105500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04105700	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04105800																														
04106000			○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04106180	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
04106190																														
04106300	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
04106320	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				
04106400	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04106500	○	○	○	○																										
04106906																			○	○	○	○	○							
04107850																			○	○	○	○	○							
04108500	●	●	●	●	●	●	●	●	●	●	●																			
04108600	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04108670													○								○	○	○	○	○	○	○	○	○	○
04108800	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04108801	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○					
04109000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04109500																														
04110000																														
04111000														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04111379	●	●	●	●	●	●	●													●	●	●	●	●	●	●	●	●	●	○
04111500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04112000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04112500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 7. Streamgaging stations considered for analysis of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04112850																										●	●	●	●	●		
04112904																										●						
04113000	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●
04113097																										●	●	●	●	●		
04114000			○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	○	●	●	
04114498	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04114500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04115000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04115265																																
04116000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04116500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04117000					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04117500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04118000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04118500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04119000	●	●	●	●	●	●	○	●	●	○	●	●	●	●	●	●	○	○	●	●	○	●	●	●	●	●	●	●	●	●	○	●
04119300																											●					

Table 7. Streamgaging stations considered for analysis of study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04112850								●					●	●	●															
04112904																														
04113000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04113097																														
04114000							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04114498	●	●	●	●	●	●	●	●	●	●	●	●	●	●						●	●	●	●	●	●	●	●	●	●	●
04114500	○	○	○	○	○	○	○	○	○	○	○	○	○	○																
04115000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04115265						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04116000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04116500	●	●	●	●																										
04117000													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04117500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04118000		●	●	●	●	●	●	●	●	●	●	●																		
04118500						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04119000	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04119300																														

Table 8. Regression statistics and explanatory variables used in the AFINCH (Analysis of Flows In Networks of CHannels) analysis for study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; GDD, growing degree days; RMSE, root mean square error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients														Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Pasture hay	Row crops	Forest	Open water	Wetland herbaceous	Stream order	Mean elevation	Mean slope	Coarse outwash	Average GDD	RMSE	F-statistic	R^2
October	0.529	0.091	0.055	–	–0.289	–	0.277	–2.622	–	–2.2E-05	0.110	0.077	0.501	–	0.181	496.8	0.641
November	0.648	0.103	0.065	–0.011	–0.334	–	0.490	–1.802	–2.646	–2.0E-05	0.065	–	0.359	4.8E-05	0.181	355.4	0.609
December	0.710	0.110	0.074	0.016	–0.337	–	0.545	–1.131	–3.075	–1.4E-05	–	–	0.236	4.5E-05	0.199	296.8	0.542
January	0.805	0.120	0.104	0.032	–0.286	–	0.305	–	–4.094	–1.2E-05	–	–	0.183	4.9E-05	0.223	315.5	0.531
February	0.972	0.155	0.049	0.021	–0.586	–	–	–1.331	–3.384	–1.3E-05	0.042	–	0.145	5.0E-05	0.228	202.8	0.447
March	1.161	0.118	0.094	–	–0.331	–	–	–2.131	–	–7.0E-06	–	–	–0.057	–	0.235	227.4	0.352
April	1.039	0.080	0.070	–0.013	–0.568	–	–	–1.655	–	–	–	–	–	–	0.214	209.4	0.294
May	0.818	0.094	0.074	–0.015	–0.439	–	–	–2.226	–	–9.0E-06	0.043	0.090	0.202	–	0.184	354.7	0.560
June	0.412	0.103	0.072	–	–0.593	–	–	–2.306	–2.858	–1.2E-05	0.070	0.082	0.355	–	0.201	362.8	0.566
July	0.372	0.069	0.066	–	–0.661	–0.115	–	–2.336	–4.678	–1.5E-05	0.099	0.127	0.472	–	0.17	335.5	0.572
August	0.449	0.057	0.058	–	–0.595	–0.187	–	–2.584	–4.794	–1.9E-05	0.120	0.139	0.509	–	0.171	305.6	0.549
September	0.711	0.076	0.047	–0.016	–0.571	–0.172	–	–2.538	–5.036	–2.2E-05	0.114	0.129	0.523	2.9E-05	0.171	355.1	0.630

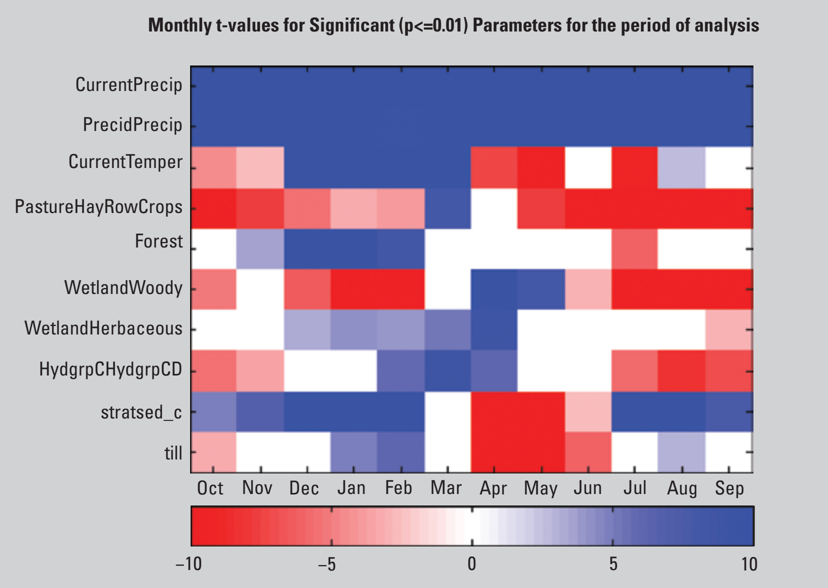


Figure 9. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 3 (hydrologic subregion 0405 and cataloguing unit 04040001) in the U.S. Great Lakes Basin.

Study Area 4

Study area 4 is formed by cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007 near the central part of the U.S. Great Lakes Basin in the northern part of the Lower Peninsula of Michigan (fig. 10). The number of stations included in the analysis ranged from 15 (1994) to 30 (1970) (table 9). Seven explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 5 (May) to 7 (December, January, February, and July) (table 3). Variables and regression statistics based on the stepwise regression for each month are indicated in table 10 and figure 11.

Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 10. Location of study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin.

Table 9. Streamgaging stations considered for analysis of study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04120293																									●							
04121000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04121300																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04121500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04121650																																
04121900																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04121944																																
04121970																																
04122000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04122100																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04122150																																
04122200								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04122500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04123000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04123500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04124000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04124200																																
04124500			●	●	●	●	●	●	●	●	●	●	●																			
04125000			●	●	●	●	●	●	●	●	●	●	●																			
04125200																		●	●	●												
04125210																				●												
04125350																				○												
04125450																			●	●												
04125460			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04125500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04125510																		○	○	○												
04125550																																
04126000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04126200							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04126740																																
04126802																																
04126970																																
04127000			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04127565																																
04127800																	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04127997	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04128000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04128500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04128990	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 9. Streamgaging stations considered for analysis of study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04120293																														
04121000																														
04121300	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04121500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04121650																		●	●	●										
04121900	●	●	●	●	●	●	●	●	●	●	●	●	●	●																
04121944														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04121970														○	●	●	●	○	●	○	●	●	●	●	●	●	●	●	●	●
04122000	●	●	●	●	●	●	●	●	●	●	●																			
04122100	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04122150													●																	
04122200	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04122500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04123000																														
04123500																														
04124000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04124200																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04124500										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04125000																														
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04125460															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
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04125550															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04126000	●	●	●	●	●	●	●	●	●	●	●																			
04126200																														
04126740									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04126802																						●	●	●						
04126970																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04127000	●	●	●	●	●	●	●																							
04127565									●																					
04127800	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04127997	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04128000	●	●	●	●	●	●	●	●	●	●	●	●																		
04128500																														
04128990	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 9. Streamgaging stations considered for analysis of study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04129000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04129500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04130000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04130500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04131000	●	●																														
04131500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
04132000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○								
04132500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
04133000	●	●	●																													
04133500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
04133501	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04134000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
04134500	●	●	●																													
04135000																														●	●	●
04135500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04135600									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04135700																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04136000																																
04136500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04136900																																
04137005																																
04137500																																

Table 9. Streamgaging stations considered for analysis of study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04129000	○	○	○	○	○	○	○	○																						
04129500																														
04130000																														
04130500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04131000																														
04131500																														
04132000																														
04132500																														
04133000																														
04133500																														
04133501																					●	●	●	●	●	●	●	●	●	●
04134000																														
04134500																														
04135000	●	●	●	●	●	●	●	●	●	●	●																			
04135500	●	●	●	●	●	●	●	●	●	●	●																			
04135600	●	●																												
04135700	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04136000														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04136500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04136900															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04137005															○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04137500						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 10. Regression statistics and explanatory variables used in the AFINCH (Analysis of Flows In Networks of CHannels) analysis for study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; RMSE, root mean square error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients								Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Deciduous and evergreen forest	Row crops	Hydric group A and AD	Stream order	RMSE	F-statistic	R^2
November	–0.086	0.053	0.043	–	0.839	0.763	0.200	0.122	0.147	208.1	0.481
January	0.093	0.040	0.054	0.021	0.766	0.979	0.243	0.139	0.152	166.6	0.464
March	0.497	0.072	0.057	0.028	0.366	0.830	–	0.138	0.177	144	0.390
May	0.332	0.062	0.033	–	0.565	0.285	–	0.122	0.154	154.8	0.364
July	–0.379	0.039	0.035	–0.008	0.945	0.724	0.468	0.207	0.141	268.4	0.582
September	–0.642	0.043	0.030	–	1.127	0.958	0.457	0.186	0.144	359.4	0.615

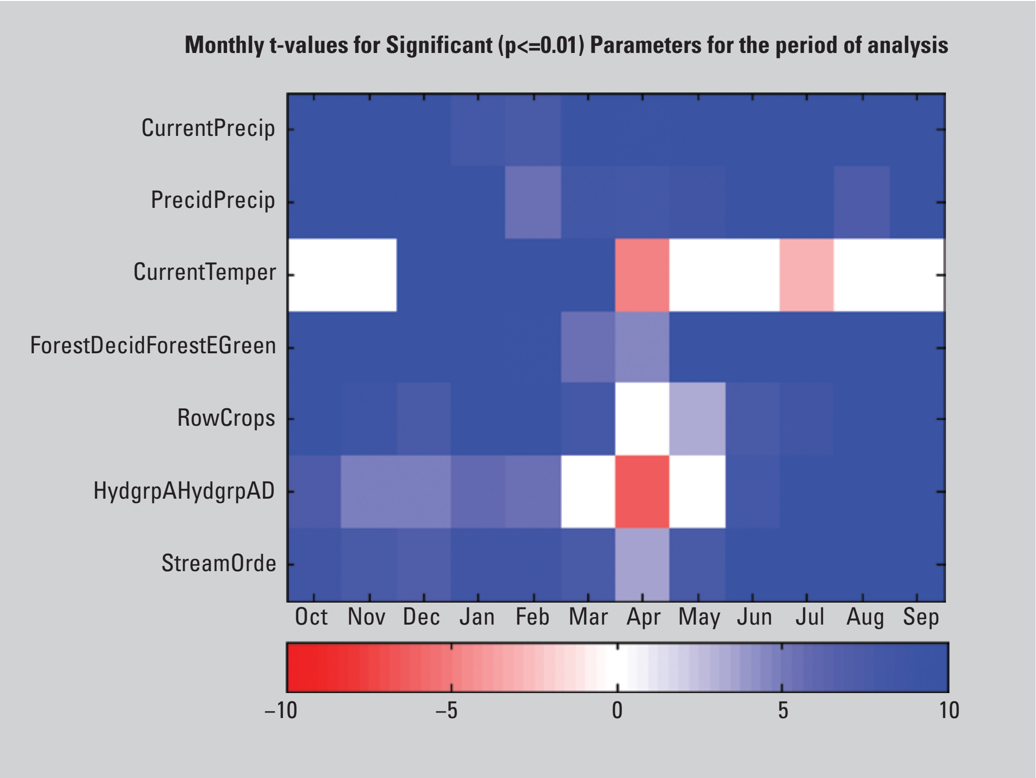


Figure 11. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 4 (cataloguing units 04060101, 04060102, 04060103, 04060104, 04060105, 04070003, 04070004, 04070005, 04070006, and 04070007) in the U.S. Great Lakes Basin.

Study Area 5

Study area 5 is formed by hydrologic subregions 0408 and 0409 near the central part of the U.S. Great Lakes Basin along the southwestern side of Lake Huron in the Lower Peninsula of Michigan (fig. 12). The number of stations included in the analysis ranged from 21 (2008) to 52 (1966) (table 11). Eleven explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 6 (March) to 10 (August) (table 3). Variables and regression statistics based on the stepwise regression for each month are indicated in table 12 and figure 13.

Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 12. Location of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin.

Table 11. Streamgaging stations considered for analysis of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by water year.

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04138000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04138500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04139000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○										
04139500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○											
04140000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○									
04140500		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04141000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
04141500		●	●	●	●	●	●	●	●	●	●	●	●																			
04142000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04143500		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04143900																		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04144000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04144500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	○	●	○	●	●
04145000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04145500	○	○	○	○	○	○	○	○	○																							
04146000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04146063																															●	●
04146500	○	○																														
04147500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●
04147990																					●	●	●	●	●	●	●	●	●	●	●	●
04148000	●	●																														
04148140																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04148160																					●	●	●	●	●	●	●	●	●	●	●	●
04148200							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04148300																					●	●	●	●	●	●	●	●	●	●	●	●
04148440																					●	●	●	●	●	●	●	●	●	●	●	●
04148500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04148720																					●	●	●	●	●	●	●	●	●	●	●	●
04149000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04150000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04150500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04150800																			●	●	●	●	●	●	●	●	●	●	●	●	●	●
04151000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04151500	●	●	●	●	○	○	●	●	○	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	○	○	●	●	●	●	●
04152238																																
04152500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04153500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
04154000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04154500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
04155000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04155500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04156000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04157000																																

Table 11. Streamgaging stations considered for analysis of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04138000																														
04138500																														
04139000																														
04139500																														
04140000																														
04140500																														
04141000																														
04141500																														
04142000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04143500																														
04143900	○	○	○	○	○	○	○	○	○	○	○	○								○	○									
04144000	●																													
04144500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04145000	○	○					○	○	○	○	○	○								○	○	○	○	○	○	○	○	○	○	
04145500																														
04146000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04146063	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04146500																														
04147500	●	●	●	●	●	●	●		●	●	●	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	●	●	●
04147990	●																													
04148000																														
04148140	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04148160	●																													
04148200																														
04148300	●																													
04148440	●																													
04148500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04148720	●																													
04149000	●	●				●	●	●	●	●										●	●	●	●	●	●	●	●	●	●	
04150000																														
04150500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●					●	●	●	●	●	●	●	●	●	●	
04150800	●	●	●	●	●	●	●	●	●	●	●	●																		
04151000																														
04151500	●	●	○	○	○	●	●	●	○	●	○	○	●	○	●	●	●	●	●	●	●	●	●	●	○	○	○	●	●	●
04152238						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04152500																														
04153500																														
04154000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04154500																														
04155000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
04155500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○	○	○	○	○	○	○	○	○	○
04156000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04157000										○	○				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 11. Streamgaging stations considered for analysis of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04157500	○	○	○	○																												
04158000	○	○	○	○																												
04158500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04159000	○	○																														
04159010																																
04159488																													○	○	○	○
04159492																																
04159500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●
04159900														●	●	●	●	●	●	●	●	●	●	●	●	●							
04160000	●	●	●	●	●	●	●	●	●	●	●	●	●	●																		
04160398																																
04160570																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04160600													●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04160625																																
04160800										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04160900										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04161000							○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04161100										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04161500																																
04161540										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04161580															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04161800									●	○	○	●	○	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●
04161820																													●	○	●	●
04162010																														○	○	○
04162400					○	○	○																								
04162900									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○
04163000					●	●	●	●																								
04163030																																
04163400																●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04163500					●	●	●	●	●	●	●	●	●	●	●	○																
04164000	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●	●	●
04164010													●	●	●	●	●	●														
04164050															●	●	●	●	●													
04164100									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04164150																		○	○	●	●	●										
04164200																●	●	●	●	●												
04164250										○	○	○	○	○																		
04164300									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	○	○
04164350																○	○	○	○	○												
04164360																		○	○	○	○	○										
04164400											●	●	●	●	●																		
04164450										●	●	●	●	●																			
04164500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 11. Streamgaging stations considered for analysis of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04157500																														
04158000							○	○																						
04158500																														
04159000																														
04159010					●	●	●	●	●	●	●																			
04159488																														
04159492										●	●	○	●	●	●	●	○	○	●	●	●	○	●	●	●	○	○	●	●	●
04159500	●	●	○	○	●	●	●	●	●																					
04159900						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●
04160000																														
04160398																							●							
04160570	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○											
04160600	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04160625																							○							
04160800	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	●	●	●	○	●			
04160900	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	○			
04161000																				○			○	○	○	○	○	○	○	○
04161100	●	●	●	●	●	●	●	●	●																					
04161500								●	●																					
04161540	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04161580	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04161800	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	●	●	●
04161820															●					○	●	○	○	●	●	○	○	●	●	●
04162010	○	○	○	○	○	○																								
04162400																														
04162900	○	○	○	○	○	○																								
04163000																														
04163030																							○							
04163400	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			○	●	●	●	●	●	●	●	●	●	●	●	●
04163500																														
04164000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04164010																														
04164050																														
04164100	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04164150																														
04164200																														
04164250																														
04164300	●	●	●	○	●	●	●	●	●	●	●	○	●	●	●	●	○	●	○	●	○	○	○	●	●	○	●	●	●	●
04164350																														
04164360																														
04164400																														
04164450																														
04164500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 11. Streamgaging stations considered for analysis of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04164600															●	●	●	●	●													
04164800													●	●	●	●	○	○		●	●	●	●	●	●	●	●	●	●	●	●	●
04164980																																
04165200										●	●	●	●	●																		
04165500	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	●	○	●	●	●	●	●	●	●	●	●	●	●
04165557																																
04165559																																
04166000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166040																																
04166100									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166200									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166300									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166470																																
04166500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04166750																																
04167000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○					
04167150																																
04167625																																
04168000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	○	●	●	○	●	●	●	●	●	●	●	●
04168400																																
04168530																																
04168580																																
04169500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
04170000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04170500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04171500		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●														
04172000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04172500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
04173000	●	●	●	●	●	●	○	●	●	●	●	●	●	○	○	●	○	●	○	●	○	●				●	●					
04173500			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04174500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04174518																																
04174800																									○	○	○	○	○	○	○	○

Table 11. Streamgaging stations considered for analysis of study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04164600																														
04164800																														
04164980																							●							
04165200																														
04165500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
04165557																							○							
04165559																							○							
04166000	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166040																							●	●	●					
04166100	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166200	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	○	●			
04166300	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04166470																●	●	●	●	●	●	●	●							
04166500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04166750																					●	●	●							
04167000		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04167150																○	○	○	○	○	○	○	○							
04167625																				○	○	○	○	○						
04168000	●	●	●	○	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●
04168400																○	○	○	○	○	○	○	○	○						
04168530																				○	○									
04168580																					○	○	○	○	○	○	○	○	○	○
04169500																														
04170000	●	●	○	●	●	●	●	●	●	●	●	○	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●	
04170500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04171500																														
04172000	●	●	●	●	●	●	●	●	○	●	●	○	●	●	●	●	○	○	●	●	●	●	●	●	○	○	●	●	●	●
04172500																														
04173000																														
04173500													●	●	●	●	●	○	●	●	●	●	●	●	●	○	●	●	●	●
04174500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04174518																		●	●	●	●	○	○	●	●	○	●	●	●	●
04174800	○	○						○	○	○	○	○																		

Table 12. Regression statistics and explanatory variables used in the AFINCH (Analysis of Flows In Networks of CHannels) analysis for study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; GDD, growing degree days; RMSE, root mean square error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients												Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Pasture hay	Row crops	Grass herbaceous	Stream order	Mean slope	Hydric group B and BD	Coarse outwash	Average GDD	RMSE	F-statistic	R^2
November	0.0815	0.1212	0.0795	–0.0137	–0.5761	–0.1675	–	0.1342	0.1100	–0.1647	–	–	0.203	292.3	0.512
January	0.1645	0.1383	0.1078	0.0443	–0.5149	0.1856	1.5386	0.2060	0.1442	–0.2622	–	–	0.232	280.1	0.530
March	1.0156	0.1500	0.1153	–	–0.2659	0.3633	–	–	–	–	–0.1671	–9.5E-05	0.284	174.3	0.319
May	0.2966	0.1606	0.0782	–0.0242	–0.7910	–	2.5436	0.1041	0.0765	–	–0.1402	4.0E-05	0.184	515.9	0.675
July	–0.3059	0.0998	0.0745	–	–1.0679	–	2.3501	0.1598	0.1173	–0.2079	–0.1211	4.8E-05	0.186	286	0.536
September	0.1771	0.1088	0.0530	–0.0180	–0.7754	–0.2785	–	0.1527	0.1148	–0.1551	–0.1159	–	0.200	328.7	0.57

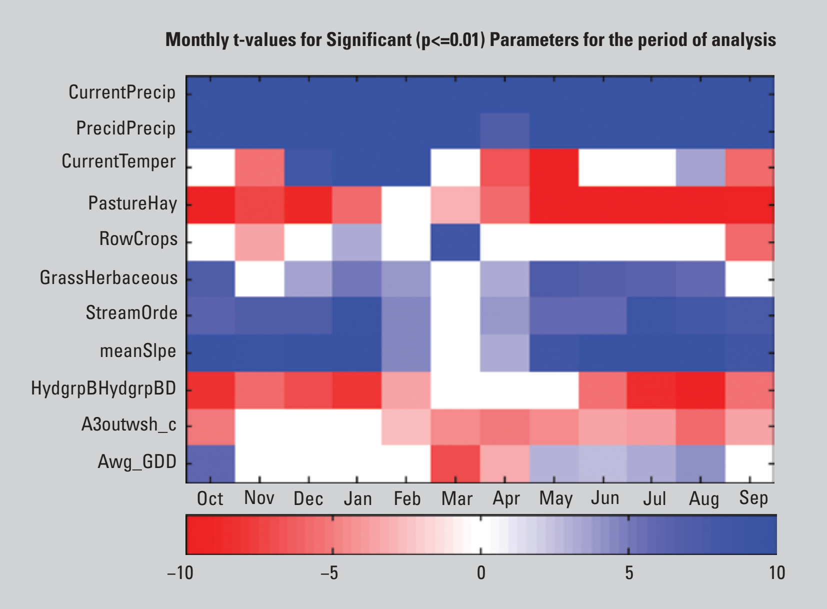
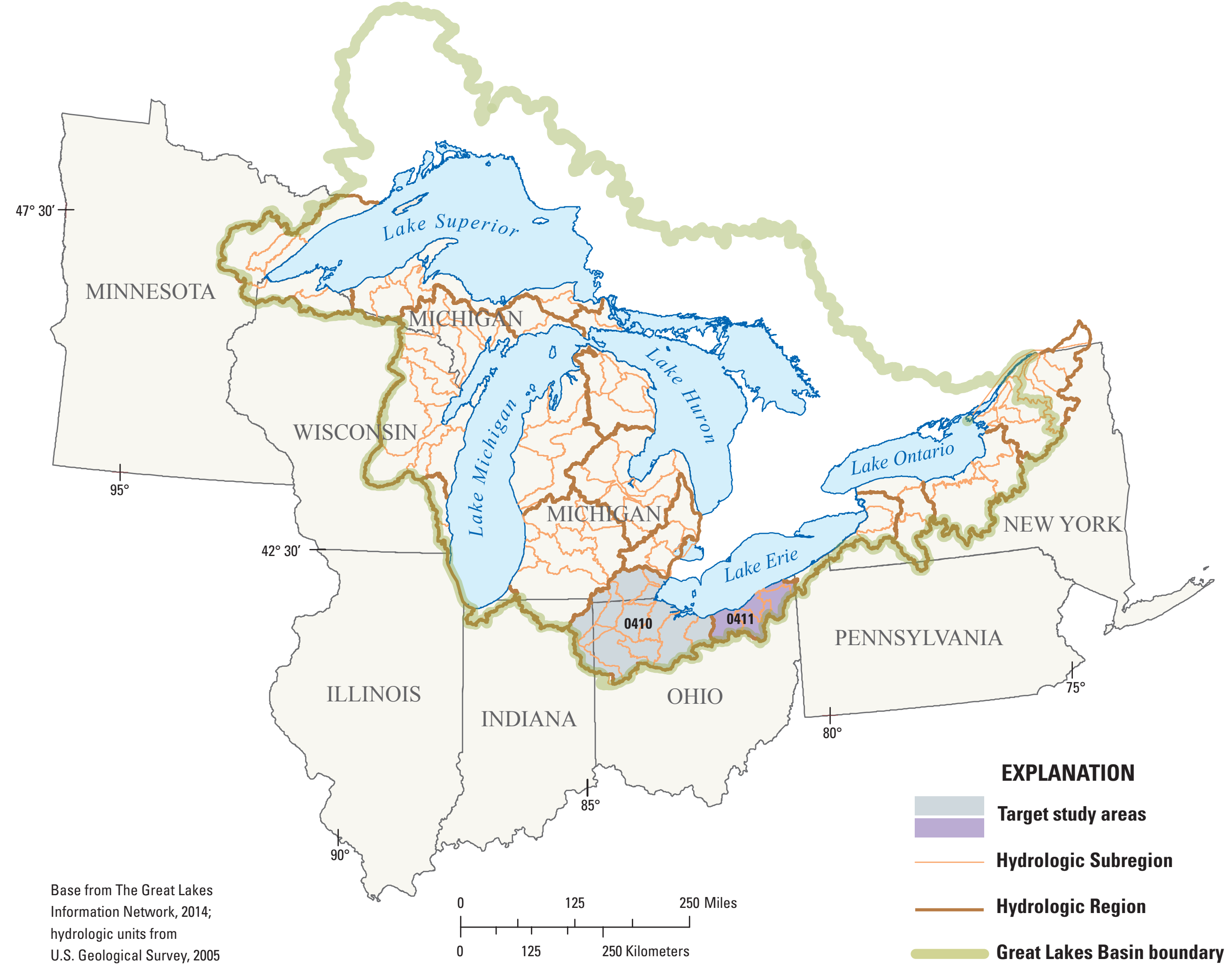


Figure 13. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 5 (hydrologic subregions 0408 and 0409) in the U.S. Great Lakes Basin.

Study Area 6

Study area 6 is formed by hydrologic subregions 0410 and 0411 in the southeastern part of the U.S. Great Lakes Basin and encompasses parts of Michigan, Ohio, Indiana, and a small part of Pennsylvania (fig. 14). The number of stations included in the analysis ranged from 26 (1953, 1963, 1982, and 1983) to 48 (2002) (table 13). Eleven explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 7 (July) to 11 (April and September) (table 3). Variables and regression statistics based on the stepwise regression for each month are indicated in table 14 and figure 15.



Base from The Great Lakes Information Network, 2014; hydrologic units from U.S. Geological Survey, 2005

Figure 14. Location of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin.

Table 13. Streamgaging stations considered for analysis of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by water year.

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04175340																					●	●	●	●	●	●	●	●	●	●	●	
04175600																					●	●	●	●	●	●	●	●	●	●	●	
04175700							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04175957																																
04176000				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
04176400																●	●	●	●	●	●	●	●	●	●	●	●					
04176500	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	○	○	○	●	○	○	●	●	●	●	●	●	●
04176605																																
04177000																											●	●	●	●	●	●
04177720																				●	●	●	●	●	●	●	●	●	●	●	●	●
04178000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04179000						●	○	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	○	
04179500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
04179520																																
04180000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04180500																																
04180988																																
04181500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04182000	●	●	●	●	●	○	●	●	●	○	●	●	○	●	●	○	●	●	○	●	●	●	●	●	●	○	○	●	●	●	●	●
04182590															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04182810																																
04182950																																
04183000							○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04183500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
04184500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04185000	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	○	○	○	●	○	●	○	●
04185440																																
04186500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04187100																																
04187500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04188337																																
04188400																																
04188433																																
04188496																																
04188500	●	●	●	●	●	●																										
04189000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04189500	●																															
04189950																																
04191000	○	○	○																													

Table 13. Streamgaging stations considered for analysis of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04175340																					●									
04175600				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04175700																														
04175957										●	●	●	●																	
04176000			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04176400																														
04176500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
04176605						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04177000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04177720	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04178000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04179000																														
04179500																														
04179520																				●	●	●	●	●	●	●	○	●	●	●
04180000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04180500		●	●	○	●	●	●	○	●	●	●	●	○	○	●	●	●	●	●	●	●	●	○	●	○	○	●	○	○	○
04180988																								●	●	●	●	●	●	●
04181500	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●
04182000	●	●	●	●	○	●	○	○	●	●	○	○	●	●	●	●	○	●	●	●	○	●	●	●	●	●	○	○	●	○
04182590	●	●	●	●	●	●	●	●	●																					
04182810		●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●											
04182950																							○	○	○	○	○	○	○	○
04183000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04183500																														
04184500																				●	●	●	●	●	●	●	●	●	●	●
04185000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	●	●	●	○	●	○	●	●	●
04185440				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	○	○	○
04186500	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04187100							●	●	●	●	●	●	●	●	●	●	●													
04187500																														
04188337																										●	●	●	●	●
04188400																										●	●	○	●	●
04188433																										●	●	●	●	●
04188496																										●	●	●	●	●
04188500																														
04189000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	○	○
04189500																														
04189950																								●						
04191000																														

Table 13. Streamgaging stations considered for analysis of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04191500	●	○	○	○	●	●	●	●	●	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	○	●
04192000			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○													
04192500	●	○	○	○	○	○	○	●	○	●	●	○	○	○	○	●	○	○	○	○	●	●	●	●					○	●	○	●
04193500	○	●	●	●	●	○	●	●	○	●	○	●	○	○	○	●	●	●	○	○	●	●	●	●	●	●	●	○	●	○	●	○
04194085																																
04195500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04195600	○		○																													
04195820																																
04195825																																
04195830																																
04196000	●														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04196200																											●	●	●	●	●	
04196500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	
04196800															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04197000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04197020																														●	●	●
04197100																											●	●	●	●	●	●
04197170																																
04197300																											●	●	●	●	●	
04197450																											●	●	●	●	●	
04198000	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	○	●	●	○	○	●	●	○	○
04199000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
04199155																																
04199287																																
04199500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	
04200430																															○	○
04200500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04201300																															○	
04201404																																
04201495																																
04201500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04202000											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04203900																																
04204000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
04204500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
04205000											●	●	●	●	●	●	●	●	●	●	●	●	●	●								
04205700																								●	●	●	●	●	●			
04206000	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04206014																																
04206021																																
04206029																																
04206038																																
04206043																																

Table 13. Streamgaging stations considered for analysis of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04191500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04192000																														
04192500	●	○	●	●	○	○	○	○	○	●	○	○	●	●	●	●	●	○	○	●	●	●	●	●	○	●	●	○	○	○
04193500	○	○	○	○	○	○	●	●	●	●	●	○	○	●	○	○	○	●	○	○	○	○	○	○	○	●	○	●	○	●
04194085																									○	○	○	○	○	○
04195500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04195600																														
04195820																	●	●	●	●	●	●	●	●	●	●	○	●	○	●
04195825							●			●																				
04195830							●			●																				
04196000														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04196200																														
04196500																				●	●	●	●	●	●	●	○	●	●	●
04196800	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04197000																														
04197020	●	●	●	●	●	●	●																							
04197100	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04197170		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04197300																														
04197450																														
04198000	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	○
04199000						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04199155						●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04199287						●	●		●	●	●																			
04199500																				●	●	●	●	●	●	●	●	●	●	●
04200430	○	○																												
04200500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04201300																														
04201404																				●										
04201495																				●										
04201500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04202000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04203900																		●												
04204000																														
04204500																														
04205000																														
04205700																														
04206000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04206014																			●	●	●	●								
04206021																			●	●	○	●								
04206029																			●	●	●	●								
04206038																			●	○	○	●								
04206043																			●	○	○	○								

Table 13. Streamgaging stations considered for analysis of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04206208																																
04206210																																
04206211																																
04206212																																
04206215																																
04206220																																
04206250																								●	●	●	●	●	●			
04206420																																
04206448																																
04207016																																
04207200														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04207500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
04208000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●	●
04208460																																
04208501																																
04208502																							●	●	●	●	●	●	●	●	●	●
04208504																																
04208690																												●	●	●		
04209000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04210000	●	●	●	●	●	●	●	●																								
04211000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○																
04211500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○								
04211820																																
04212000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
04212100																									●	●	●	●	●	●	●	●

Table 13. Streamgaging stations considered for analysis of study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04206208										●	●	●	●	●	●	●														
04206210										●	●	●	●	●	●	●														
04206211										●	●	●	●	●	●	●														
04206212										●	○	●	●	○	○	●	●	●	●	●	●	●								
04206215										●	●	●	●	●	●	●														
04206220										○	●	●	●	●	●	●	●	●	●	●	●									
04206250																														
04206420																				●										
04206448																				●										
04207016																				●										
04207200	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04207500																														
04208000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●
04208460																				○	○	○	○	○	○	○	○	○	○	○
04208501																				●										
04208502	●	●	●	●																●										
04208504										○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04208690		●	●																	●										
04209000	●	●					●	●	●	●	●	●		●	●	●	●			●	●	●	○	●	●	●	●	●	●	●
04210000																														
04211000																														
04211500																														
04211820															●	●														
04212000																														
04212100	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 14. Regression statistics and explanatory variables used in the AFINCH (Analysis of Flows In Networks of CHannels) analysis for study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; RMSE, root mean square error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients												Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Pasture hay and row crops	Forest	Fine end and ground moraines	Medium end and ground moraines	Coarse outwash and ice conract	Stream order	Mean elevation	Mean slope	RMSE	F-statistic	R^2
November	0.421	0.226	0.090	–0.015	–0.355	–0.063	0.076	0.259	–	–	–1.5E-05	0.074	0.267	516.5	0.661
January	0.495	0.288	0.081	0.037	–	0.406	0.128	0.448	–	0.084	–1.9E-05	0.075	0.310	442.9	0.653
March	0.930	0.254	0.047	–0.035	–	0.677	0.177	0.527	–	0.095	–2.3E-05	0.047	0.335	224.9	0.488
May	0.985	0.200	0.072	–0.018	–0.218	–	–	0.263	0.105	–	–2.4E-05	0.104	0.244	528.7	0.666
July	0.029	0.160	0.079	–	–0.406	–0.668	–	–	–	0.077	–7.0E-06	0.106	0.246	478.4	0.612
September	0.338	0.141	0.077	–0.011	–0.521	–0.601	0.113	0.156	0.339	0.099	–1.2E-05	0.080	0.218	364	0.654

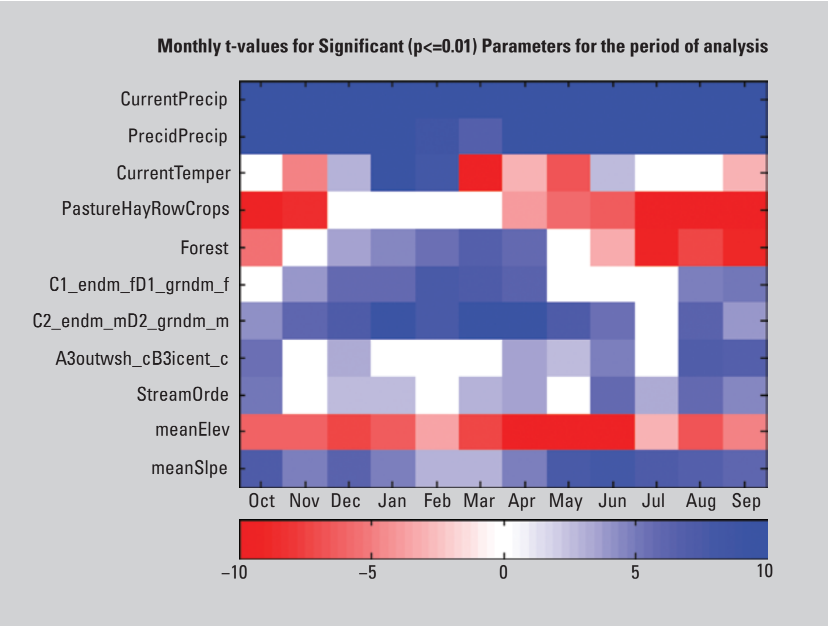


Figure 15. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 6 (hydrologic subregions 0410 and 0411) in the U.S. Great Lakes Basin.

Study Area 7

Study area 7 is formed by hydrologic subregions 0412, 0413, 0414, and 0415 in the eastern part of the U.S. Great Lakes Basin and encompasses parts of Pennsylvania, New York, and a small part of Ohio (fig. 16). The number of stations included in the analysis ranged from 31 (1951 and 1953) to 65 (1967) (table 15). Twelve explanatory variables were selected during the regression analysis with the number of variables specified for each monthly equation ranging from 6 (February) to 11 (March) (table 3). Variables and regression statistics based on the stepwise regression for each month are indicated in table 16 and figure 17.

Figure 16. Location of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin.

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04213000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04213040																			●	●	●	●	●	●	●	●	●	●	●	●	●	●
04213075																																
04213410														●	●	●	●															
04213440																											○	○	○			
04213450												●	●		●	●	●	●														
04213492																														●	●	
04213500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04214200														●	●	●	●	●														
04214400														●	●	●	●	●														
04214500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04215000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							●	●	●	●	●	●	●	●
04215500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04216000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04216200								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04216418																												●	●	●	●	●
04216500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										●	●	●	●	●
04217000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●
04217500						●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	○	○	●	●	●	●	●	●	○	●	●	●
04217750																																
04218000						●	●	●	●	●	●	○	●	●	●															●	●	●
04218450														●	●	●	●	●														
04218500						●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●										
04218518																							●	●	●	●	●	●	●	●	●	●
04219940																									○	○						
04220250																																
04220470															●	●	●	●														
04220500						●	●	●	●	●																						
04221000						●	●	●															●	●	●	●	●	●	●	●	●	●
04221500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
04221600															●	●	●	●														
04221720															●	●	●	●														
04221820															●	●																
04221991																				●	●	●	●		●	●	●	●	●	●	●	●
04222000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○														
04222900															●	●	●	●														
04223000	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04224650															●	●	●	●														
04224775																									●	●	●	●	●	●	●	●

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04213000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
04213040	●	●	●	●	●	●	●	●	●	●	●	●	●																	
04213075					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04213410																														
04213440																														
04213450																														
04213492																														
04213500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●
04214200																														
04214400																														
04214500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04215000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04215500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04216000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04216200	●	●	●	●	●	●	●	●	●	●	●	○																		
04216418	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04216500	●	●	●	●	●	●	●	●	●	●																				
04217000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
04217500	●	●	●	●	●	●	●																							
04217750		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●													
04218000	●	○	○	○	○	●	○	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04218450																														
04218500																														
04218518	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04219940																														
04220250																							●	●	●	●	●	●		
04220470																														
04220500																														
04221000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04221500																														
04221600																														
04221720																														
04221820																														
04221991																														
04222000																														
04222900																														
04223000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04224650																														
04224775	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04225000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●						
04225500						●	●	●	●	○	●	●	●	●																		
04226000																										●	●					
04227000										●	●	●	●	●	●	●	●	●	●	●					●	●	●	●	●	●	●	●
04227500		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04227995																																
04228900															○	○	○	○														
04229500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○			○	○	○	○	○	○	○	○	○	○
04230380															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04230500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04231000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04231600	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232034																																
04232040																															●	●
04232046																															●	●
04232047																								●	●	●	●	●	●	●	●	●
04232050											○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232100								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04232482																○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232630															●	●	●	●														
04232650	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○	○	○	○	○	○	○	○			
04232730																																
04233000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04233286																																
04233300																																
04233678																								○								
04233700																								●	●							
04234000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04234018															●	●	●	●														
04234055															●	●	●	●														
04234061	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○																	
04234200																●	●	●														
04234232																																
04234270															●	●	●	●														
04235000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04235150															●	●	●	●			●	●	●	●	●	●	●	●				
04235250										●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04235271	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○																

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04225000																														
04225500																														
04226000																														
04227000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04227500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04227995															○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04228900																														
04229500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04230380	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04230500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●
04231000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04231600	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
04232034										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
04232040	●	●	●	●	●	●	●	●																						
04232046	●	●	●	●	●	●	●																							
04232047	●	●	●	●	●	●																								
04232050	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232100	●	●	●	●	●	●	●	●	●	●	●	●																		
04232482	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04232630																														
04232650																														
04232730																									○	○	○	○	○	○
04233000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
04233286																						●	●	●	●	●	●	●	●	●
04233300														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04233678																														
04233700																														
04234000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04234018																														
04234055																														
04234061																														
04234200																														
04234232													●	●	●	●	●	●	●	●	●	●								
04234270																														
04235000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04235150																														
04235250	●	●	●	●	●	●	●	●	●	●	●	●									●	●	●	●	●	●	●	●	●	●
04235271																														

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																															
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04235276																																
04235300											○	●	●	●	●	●	●	●														
04235440																																
04235500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04235600																																
04235820																																
04237500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04237944																																
04237946																																
04237962																																
04239000		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04240010																					○	○	○	○	○	○	○	○	○	○	○	○
04240100										○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04240105																					○	○	○	○	○	○	○	○	○	○	○	○
04240120																								●	●	●	●	●	●	●	●	●
04240145																																
04240150																																
04240180															○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04240200									○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04240300																						○	○			○	○	○	○	○	○	○
04241200																	●	●														
04242500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04243500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04244000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●														
04245000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04245200									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04245236																						○							○	○	○	○
04245250															○																	
04245840																	●	●														
04246500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04246601																																
04247000																																
04249000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04249910																									○							
04250200																																
04250750								○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04252000																			○													
04252500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04253000																		●														

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04235276					●	●	●	●	●	●	●	●	●																	
04235300																														
04235440																	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04235500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○														
04235600															●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04235820															○	○	○													
04237500	○	○		○						○	○	○	○			○														
04237944										○	○	○																		
04237946											○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
04237962																				●	●	●	●	●	●	●	●	●	●	●
04239000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04240010	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04240100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○
04240105	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04240120	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
04240145	○																													
04240150	●																													
04240180	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04240200							○	○	○	○	○	○	○	○	○	○									○					
04240300	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04241200																														
04242500	○	○		○	○	○	○	○	○	○	○	○															○	○	○	○
04243500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04244000																														
04245000	●	●	●	●																										
04245200	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●													
04245236	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○					
04245250																														
04245840																														
04246500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●														
04246601		○																												
04247000																●	●	●	●	●	●	●	●	●	●	●	●	●	○	○
04249000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04249910																														
04250200												○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04250750	○	○	○	○	○	○	○	○	○	○	○	○									○	○	○	○	○	○	○	○	○	○
04252000																														
04252500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04253000																														

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
04253275																												○	○	○	○	
04253500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○									
04254000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●														
04254500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
04256000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04256460																																
04256485																												○	○	○	○	
04257000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04258000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04258500	●	●	●	●	●	●																										
04258700							●	●	●	●	●	●	●	●	●	●	●	●														
04260500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04261000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04262000	●	●	●	●	●	○	●	●	●	○	●	●	●	●	●	●	●	●														
04262500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04263000	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04264331	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04264700									●	●	●	●	●																			
04265000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●					
04265100									●	●	●	●	●	●	●	●	●	●														
04265432																																
04265605																																
04266500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04267500				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04268000				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04268390																							●	●	●							
04268600									●	●	●	●	●	●	●	●	●	●														
04268700									●	●	●	●	●	●	●	●	●	●														
04268800									●	●	●	●	●	●	●	●	●	●														
04269000	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04269043																								●	●	●	●	●				
04269500									●	●	●	●	●	●	●	●	●	●														
04270000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04270200									●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04270500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●																
04270510																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
0422026250																																
0423204140																																
0423204141																																

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
04253275																														
04253500																														
04254000																														
04254500																														
04256000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04256460			○	○																										
04256485			○	○	○	○	○		○	○																				
04257000	○	○	○	○	○																									
04258000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04258500																														
04258700																														
04260500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04261000																														
04262000						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04262500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04263000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
04264331	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
04264700																														
04265000																														
04265100																														
04265432																						●	●	●	●	●	●	●	●	●
04265605			●	●	●																									
04266500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04267500	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○										
04268000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○
04268390																														
04268600																														
04268700																														
04268800										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04269000	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04269043																														
04269500																														
04270000					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
04270200	●	●	●	●	●	●	●	●	●	●	●	●									●	●	●	●	●	●	●	●	●	●
04270500																														
04270510	●	●	●	●	●	●	●	●	●	●	●	●																		
0422026250								○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
0423204140															○	○	○													
0423204141															○	○	○													

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																														
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
0423204920																																
0423205010																																○
0423205023																																○
0423205025																																
0423368620																																
0424014980																																
0424016205																																
0424016825																																
0424016975																																
0426545290																													●	●		
0426545295																												○	○	○	○	

Table 15. Streamgaging stations considered for analysis of study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by water year.—Continued

[●, station active and included in the analysis; ○, station active but not included in the analysis]

Station number	Water year																													
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0423204920									●	●	●	●	●	●	●	●	●	●	●	●										
0423205010	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				
0423205023	○																													
0423205025									○	○	○	○	○	○	○	○	○	○	○	○										
0423368620																						○								
0424014980																○	○	○	○	○	○									
0424016205	●																													
0424016825	●																													
0424016975	●																													
0426545290																														
0426545295																														

Table 16. Regression statistics used in the AFINCH (Analysis of Flows In Networks of CHannels) analysis for study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin, by month.

[–, indicates variable not included in monthly regression equation; GDD, growing degree days; RMSE, root mean square error; R^2, coefficient of determination. See appendix tables for variable descriptions]

Month	Regression coefficients													Regression fit statistics		
	Intercept	Current precipitation	Preceding precipitation	Current temperature	Open water	Forest	Developed	Mean slope	Hydric group C, CD, and D	Coarse outwash and ice conract	Coarse end and ground moraines	Average GDD	Pasture hay and row crops	RMSE	F-statistic	R^2
November	0.462	0.179	0.107	–0.011	–	–	–0.221	–0.726	–0.030	–	–	–	5.1E-05	0.266	709.8	0.658
January	1.061	0.170	0.085	0.045	–	–	–0.480	–0.403	–0.017	0.071	–	–	–	0.285	398.1	0.519
March	2.051	0.155	0.046	0.039	–3.962	–0.520	–1.088	–0.817	–	0.253	–0.203	–0.263	–1.1E-04	0.349	101.1	0.302
May	1.208	0.165	0.067	–0.024	1.809	–0.383	–0.543	–0.778	–	–	0.178	0.140	–	0.222	847.6	0.748
July	0.772	0.119	0.077	–0.018	1.089	–0.459	–	–0.562	–	–0.115	0.359	0.082	–	0.182	732.2	0.719
September	0.061	0.152	0.094	–	1.058	–0.305	–	–0.671	–	–0.133	0.304	–	4.0E-05	0.224	761.5	0.703

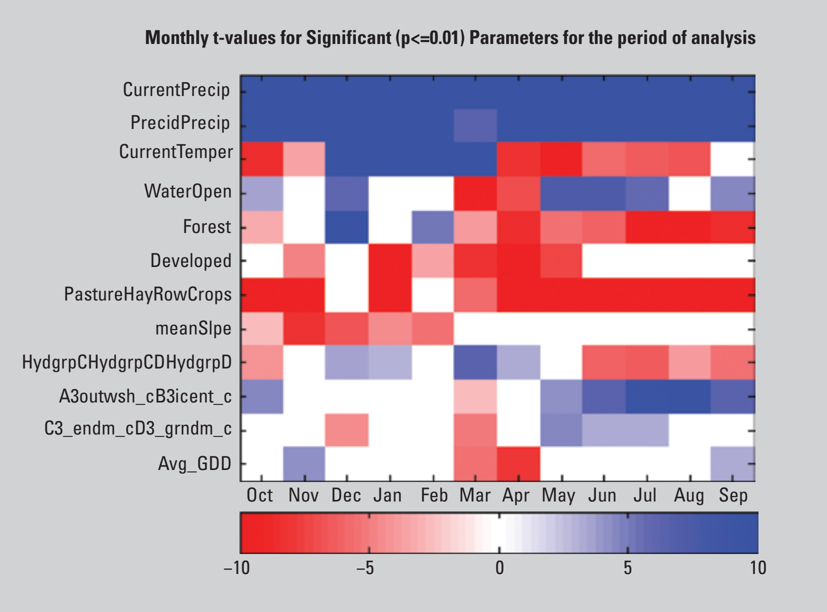


Figure 17. Image showing the t-value-indexed colors corresponding to each explanatory variable in the monthly regression equation for estimating water yield for study area 7 (hydrologic subregions 0412, 0413, 0414, and 0415) in the U.S. Great Lakes Basin.

Summary

A regionally consistent estimate of streamflow provides unified information across the United States portion of the Great Lakes Basin for restoration, assessment, management, and conservation of stream ecosystems. Monthly water yields from catchments and corresponding flows for stream segments (flowlines) were estimated for water years 1951–2012 for the U.S. Great Lakes Basin by using the computer application Analysis of Flows In Networks of CHannels (AFINCH). The AFINCH approach to estimate ungaged flows is a two-step process. The predictor step is based on a user-specified multiple-linear-regression equation to estimate monthly yields using selected monthly climatic and basin characteristics data and flows at streamgages. The corrector step adjusts the regression estimates to match measured flows at the streamgages.

The 15 hydrologic subregions comprising the U.S. Great Lakes Basin were combined to form 7 study areas consisting of multiple subregions and (or) cataloguing units for analysis with AFINCH. Input data, explanatory variables, and regression details used in the estimation of water yields and flows are described for each study area. Data from 823 streamgages were compiled for the AFINCH analysis and were used to estimate monthly flows and water yields for 107,691 stream segments (flowlines) and 105,829 catchments in Hydrologic Region 04 for 1951–2012. These long-term flow series can be used to describe monthly flow-duration characteristics and to investigate trends for the stream segments in the U.S. Great Lakes Basin.

AFINCH utilizes the NHDPlus geospatial framework to provide a basis for integrating monthly flow measured at U.S. Geological Survey (USGS) streamgages, available water-use data, monthly climatic data, land-cover characteristics, and catchment attributes described in user-defined shapefiles to develop sets of multiple-linear-regression equations for estimating monthly water yields. The explanatory variables describing monthly precipitation for the current month, monthly precipitation for the preceding month, and average monthly temperatures were included in the multiple-linear-regression equations for all seven study areas. National land-cover characteristics defining forest, pasture, and cultivated areas were significant explanatory variables in most of the study areas. NHDPlus variables defining stream order, as well as catchment elevation and (or) slope, and Soil Survey Geography (SSURGO) soil data also were significant explanatory variables in most of the study areas. Surficial areas of coarse outwash tended to be included in the regression equations for study areas in the southern and eastern parts of the U.S. Great Lakes Basin. Growing degree day data and areas with end and ground moraines also were important in several study areas. In general, coefficient of determination (R^2) values and F-statistics for the study areas were lowest in the late spring and early summer months (February–April) and higher in the late summer and early winter months (July–October). Considering a potential additional variable, such as an index relating to snow pack, would likely be significant and might improve the estimates during months of lower flow conditions. Regionally, however, these estimates present a reasonable, consistent, and defensible set of flow and yield estimates for the U.S. Great Lakes Basin.

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Table 1–1. Revisions to NHDPlus flowline value-added attribute (VAA) information.

[--, not changed]

Subregion	ComID	Original values					Modified values				
		FromNode	ToNode	Hydroseq	Divergence	Startflag	FromNode	ToNode	Hydroseq	Divergence	Startflag
0401	1798775	--	--	90072931	1	--	--	--	90072920	0	--
	1798903	90003017	90003052	90072920	2	0	9003052	9003017	90072931	0	1
	1771252	--	--	--	1	--	--	--	--	0	--
	1772034	--	--	--	2	0	--	--	--	0	1
0402	11951467	90021466	90021629	90046042	1	--	90021629	90021466	90046053	0	--
	11952189	90021629	90021470	90040541	--	--	90021470	90021629	90046185	--	--
	11951469	90021470	90021630	90036575	--	--	90021630	90021470	90046186	--	--
	11952191	90021630	90021472	90033483	--	--	90021472	90021630	90046187	--	--
	11951473	90021472	90021631	90031008	--	--	90021631	90021472	90046188	--	--
	11952193	90021631	90021628	90028979	--	0	90021628	90021631	90046189	--	1
	11951459	--	--	--	1	--	--	--	--	0	--
	11930450	--	--	--	1	0	--	--	--	0	1
	11930458	--	--	--	2	--	--	--	--	0	--
	11929798	--	--	--	1	--	--	--	--	2	--
	11929802	--	--	--	2	--	--	--	--	1	--
	11930458	--	--	--	2	--	--	--	--	0	--
	11930450	90019836	90023688	--	1	--	90023688	90019836	--	0	--
	12027444	--	--	--	--	0	--	--	--	--	1
0403	14444692	--	--	--	1	--	--	--	--	0	--
	6820848	--	--	--	1	0	--	--	--	0	1
	6849469	--	--	--	2	--	--	--	--	0	--
	11959514	--	--	--	--	0	--	--	--	--	1
	14444674	--	--	--	--	--	--	--	--	--	--
	9027663	--	--	--	2	0	--	--	--	0	1
	6809298	--	--	--	1	--	--	--	--	0	--
	14444312	--	--	--	--	0	--	--	--	--	1
	12006809	--	--	--	2	--	--	--	--	1	--
	12006813	--	--	--	1	--	--	--	--	2	--
	6865517	--	--	--	1	0	--	--	--	0	1
	6866125	--	--	--	2	--	--	--	--	0	--
	6821620	--	--	--	2	--	--	--	--	1	--
	6821578	--	--	--	1	--	--	--	--	2	--

Table 1–1. Revisions to NHDPlus flowline value-added attribute (VAA) information.—Continued

[--, not changed]

Subregion	ComID	Original values					Modified values				
		FromNode	ToNode	Hydroseq	Divergence	Startflag	FromNode	ToNode	Hydroseq	Divergence	Startflag
0403 (continued)	12174040	--	--	--	2	0	--	--	--	0	1
	12174028	--	--	--	1	--	--	--	--	0	--
	9036437	--	--	--	2	0	--	--	--	0	1
	9036449	--	--	--	1	--	--	--	--	0	--
	11959396	--	--	90098082	--	1	--	--	90017082	--	0
	11959398	--	--	--	--	0	--	--	--	--	1
	11959926	--	90021774	--	--	--	--	90082911	--	--	--
0404	3397118	--	--	--	2	--	--	--	--	0	--
	3396784	--	--	--	1	0	--	--	--	0	1
0405	12261958	--	--	--	1	--	--	--	--	0	--
	12260476	--	--	--	2	0	--	--	--	0	1
	13032275	90030086	90040059	90051985	2	--	90040059	90030086	90044497	0	--
	13032045	90040059	90040060	90044497	--	0	90040060	90040059	90051985	--	1
	12233796	--	--	--	1	--	--	--	--	0	--
	12260238	--	--	--	1	--	--	--	--	0	--
	12263234	--	--	--	2	0	--	--	--	0	1
	12258396	--	--	--	1	0	--	--	--	0	1
	12258498	--	--	--	2	--	--	--	--	0	--
	12263190	--	--	--	2	0	--	--	--	0	1
	12260112	--	--	--	1	--	--	--	--	0	--
0406	12222264	90029225	90029214	90067021	2	0	90029214	90029225	90067041	0	1
	12221900	--	--	--	1	--	--	--	--	0	--
	12222160	--	--	--	2	--	--	--	--	0	--
	12221662	--	--	--	1	--	--	--	--	0	--
0407	12502899	--	--	--	1	--	--	--	--	2	--
	12502901	--	--	--	0	--	--	--	--	1	--
	12962413	--	--	--	2	0	--	--	--	0	1
	12962487	--	--	--	1	--	--	--	--	0	--

Table 1–1. Revisions to NHDPlus flowline value-added attribute (VAA) information.—Continued

[--, not changed]

Subregion	ComID	Original values					Modified values				
		FromNode	ToNode	Hydroseq	Divergence	Startflag	FromNode	ToNode	Hydroseq	Divergence	Startflag
0408	12944858	--	--	--	2	--	--	--	--	0	--
	12944468	90036462	90036538		1	0	90036538	90036462		0	1
	12944860	--	--	--	1	0	--	--	--	0	1
	13046031	--	--	--	2	0	--	--	--	0	1
	13016527	--	--	90044601	--	--	--	--	90018387	--	--
	13016547	--	--	90052133	1	--	--	--	90018934	0	--
	13016565	90038914	90039104	90052132	2	--	90039104	90038914	90019518	0	--
	13019475	90039104	90039109	90044580	--	--	90039109	90039104	90020159	--	--
	13019493	90039109	90039117	90035767	--	--	90039117	90039109	90020830	--	--
	13019523	90039117	90039292	90032845	--	--	90039292	90039117	90021565	--	--
	13020129	90039292	90039294	90030478	--	--	90039294	90039292	90022385	--	--
	13020133	90039294	90039129	--	--	--	90039129	90039294	--	--	--
	13019559	90039129	90039298	90022385	--	--	90039298	90039129	90030478	--	--
	13020141	90039298	90039135	90021565	--	--	90039135	90039298	90032845	--	--
	13019577	90039135	90039138	90020830	--	--	90039138	90039135	90035500	--	--
	13019583	90039138	90039142	90020159	--	--	90039142	90039138	90035550	--	--
	13019591	90039142	90039300	90019518	--	--	90039300	90039142	90044601	--	--
	13020145	90039300	90039299	90018934	--	0	90039299	90039300	90052132	--	1
	13020143	--	--	90018387	--	0	--	--	90052133	--	1
	13019637	--	--	90052102	--	--	--	--	90064410	--	--
	13020157	--	--	90044561	--	--	--	--	90064405	--	--
	13019631	--	--	90039494	--	--	--	--	90064400	--	--
	13020155	--	--	90035756	--	--	--	--	90064395	--	--
	13019605	--	--	90032841	--	--	--	--	90064390	--	--
	13020147	--	--	90030477	--	--	--	--	90064385	--	--
	13007650	--	--	--	1	0	--	--	--	0	1
	13007796	--	--	--	1	0	--	--	--	0	1
	13007622	--	--	--	1	0	--	--	--	0	1
	13020539	--	--	--	1	0	--	--	--	0	1
	13031999	--	--	--	2	--	--	--	--	0	--
	13017263	--	--	--	1	--	--	--	--	0	--
	13028773	--	--	--	2	0	--	--	--	0	1

Table 1–1. Revisions to NHDPlus flowline value-added attribute (VAA) information.—Continued

[--, not changed]

Subregion	ComID	Original values					Modified values				
		FromNode	ToNode	Hydroseq	Divergence	Startflag	FromNode	ToNode	Hydroseq	Divergence	Startflag
0408 (continued)	13029155	--	--	--	2	0	--	--	--	0	1
	13028795	--	--	--	1	--	--	--	--	0	--
	13006714	--	--	--	1	--	--	--	--	0	--
	13009450	--	--	--	2	0	--	--	--	0	1
	13008924	--	--	--	1	--	--	--	--	0	--
0409	13192736	--	--	--	2	--	--	--	--	0	--
	13192794	--	--	--	2	--	--	--	--	0	--
	13192762	--	--	--	2	--	--	--	--	0	--
	13192474	--	--	--	2	0	--	--	--	0	1
	13194146	--	--	--	2	0	--	--	--	0	1
	13194090	--	--	--	1	--	--	--	--	0	--
	13193728	--	--	--	1	0	--	--	--	0	1
	13193748	--	--	--	2	--	--	--	--	0	--
0410	15612436	90060257	90060500		1	0	90060500	90060257		0	1
	15613610	--	--	--	--	0	--	--	--	--	1
	15644452	--	--	--	2	--	--	--	--	0	--
	15627609	--	--	--	1	0	--	--	--	0	1
	15627613	--	--	--	2	0	--	--	--	0	1
	15636243	--	--	--	2	0	--	--	--	0	1
	15627291	--	--	--	1	--	--	--	--	0	--
	15610538	--	--	--	2	0	--	--	--	0	1
	15605172	--	--	--	1	--	--	--	--	0	--

Table 1–2. Description of classes in the 2006 National Land Cover Database.

Class	Code	Description
Open water	11	areas of open water, generally with less than 25 percent cover of vegetation or soil
Perennial ice/snow	12	areas characterized by a perennial cover of ice and (or) snow, generally greater than 25 percent of total cover
Developed-open space	21	areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed-low intensity	22	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 to 49 percent of total cover. These areas most commonly include single-family housing units.
Developed-medium intensity	23	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover. These areas most commonly include single-family housing units.
Developed-high intensity	24	highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.
Barren land	31	areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.
Deciduous forest	41	areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen forest	42	areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed forest	43	areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
Shrub/scrub	52	areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
Grassland/herbaceous	71	areas dominated by gramanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Pasture/hay	81	areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
Cultivated cropland	82	areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
Woody wetlands	90	areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water
Herbaceous wetlands	95	areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water

Table 1–3. Description of soil groups in the Soil Survey Geography (SSURGO) database.

Group	Description
A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
B	Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
C	Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
D	Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Table 1–4. Description of variables from Aquatic Gap Analysis Program (GAP) used in the analysis.

Code	Group	Landform (texture)
	Surficial geology	
1	A3	outwash (coarse)
2	B3	ice-contact (coarse)
3	C1	end-moraine (fine)
4	C2	end-moraine (medium)
5	C3	end-moraine (coarse)
6	D1	ground-moraine (fine)
7	D2	ground-moraine (medium)
8	D3	ground-moraine (coarse)
	Bedrock geology	
		Coarse-grained stratified sediment
		Till

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