Prepared in cooperation with the Metropolitan St. Louis Sewer District

# Missouri StreamStats—St. Louis County and the City of St. Louis Urban Application


Scientific Investigations Report 2020–5040

U.S. Department of the Interior
U.S. Geological Survey

**Cover.** Example of StreamStats delineated catchment areas for a small sewershed in the combined sanitary sewer network in the City of St. Louis area depicted on the Metropolitan St. Louis Sewer District orthophotograph.

# Missouri StreamStats—St. Louis County and the City of St. Louis Urban Application

By Rodney E. Southard, Tana Haluska, Joseph M. Richards, Jarrett T. Ellis, Christine Dartiguenave, and Dean Djokic

Prepared in cooperation with the Metropolitan St. Louis Sewer District

Scientific Investigations Report 2020–5040

**U.S. Department of the Interior**
**U.S. Geological Survey**

**U.S. Department of the Interior**
DAVID BERNHARDT, Secretary

**U.S. Geological Survey**
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov/.



Suggested citation:
Southard, R.E., Haluska, T., Richards, J.M., Ellis, J.T., Dartiguenave, C., and Djokic, D., 2020, Missouri StreamStats—St. Louis County and the City of St. Louis urban application: U.S. Geological Survey Scientific Investigations Report 2020–5040, 27 p., https://doi.org/10.3133/sir20205040.

Associated data for this publication:
U.S. Geological Survey, 2020, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, https://doi.org/10.5066/F7P55KJN.

ISSN 2328-0328 (online)

## Acknowledgments

The author would like to recognize Esri for their work on developing the Arc Hydro script to incorporate combined sanitary sewer networks into the stream drainage system of StreamStats.

Recognition is warranted for Phil Thiem of the U.S. Geological Survey National Geospatial Technical Operations Center for his support of writing a Python script to improve the delineation of stream lines through roadway crossings that are not hydrologically enforced. Appreciation is expressed for the support of the U.S. Geological Survey National StreamStats team consisting of Kernell Ries (retired), Dave Stewart, Pete Steeves, and Peter McCarthy.

# Contents



## Figures

## Tables



# Conversion Factors

U.S. customary units to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| acre | 4,047 | square meter ($m^2$) |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Flow rate | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |

International System of Units to U.S. customary units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| meter (m) | 3.281 | foot (ft) |

# Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

## Abbreviations

| | |
|---|---|
| 3DEP | 3D Elevation Program |
| CSS | combined sanitary sewer |
| DEM | digital elevation model |
| GIS | geographic information system |
| HUC | hydrologic unit code |
| lidar | light detection and ranging |
| MSD | Metropolitan St. Louis Sewer District |
| NHD | National Hydrography Dataset |
| NWIS | National Water Information System |
| USGS | U.S. Geological Survey |
| WBD | Watershed Boundary Dataset |

# Missouri StreamStats—St. Louis County and the City of St. Louis Urban Application

By Rodney E. Southard,[1] Tana Haluska,[1] Joseph M. Richards,[1] Jarrett T. Ellis,[1] Christine Dartiguenave,[2] and Dean Djokic[2]

## Abstract

To address a major limitation of the functionality of the Missouri statewide StreamStats application in the urban areas of St. Louis County and the City of St. Louis, Missouri, the U.S. Geological Survey, in cooperation with the Metropolitan St. Louis Sewer District, defined watershed boundaries and hydrography for the study area using high-resolution 3-meter digital elevation data derived from light detection and ranging sources, high-resolution 6-inch imagery, and storm sewer network geospatial data. The combined sanitary sewers, a part of the storm sewer network, were integrated into the open channel hydrography and elevation data using a new Arc Hydro stormwater tool developed to facilitate the incorporation of the combined sanitary sewer network into the StreamStats application.

The combined sanitary sewer network was edited for connectivity and flow direction before integration into the Missouri-St. Louis StreamStats application. Inlet structures in the geospatial data were defined as HydroJunction features that allow for stormwater runoff to enter the combined sanitary sewer network. An Arc Hydro stormwater processing workflow and a sewershed delineation tool were developed to integrate the combined sanitary sewer network with the hydrographic dataset and digital elevation model in the study area.

The StreamStats application developed for the study area provides various data exploration tools that can be used to examine the spatial data and to obtain general descriptive information and flow statistics at streamgages in the study area. Watersheds and sewersheds can be delineated and basin characteristics can be determined at any point on the open channel network or the combined sanitary sewer network in the study area. Peak-flow statistics can be computed at any point on the open channel network. A report summarizing the results is generated by the StreamStats application and can be downloaded and used in other software.

The Missouri-St. Louis StreamStats application is limited to the area inside St. Louis County and the City of St. Louis and excludes locations on the main stem of the Mississippi, Missouri, and Meramec Rivers. The limitations of the Missouri-St. Louis StreamStats application include possible inaccuracies using regression equations for peak-flow statistics developed assuming natural flow conditions and topographically derived watersheds determined from a coarser resolution of data than is used in this application. Additionally, published regression equations for peak-flow statistics did not incorporate any pipe flow or sewershed delineations when they were developed, which limits the applicability of peak-flow statistics to basins based on primarily topographic delineation. Inaccuracies in resolution, completeness, location, or attribution of geospatial elevation data, hydrographic data, derived stream lines, derived watershed boundaries, and combined sanitary sewer data can limit the accuracy and functionality of the Missouri-St. Louis StreamStats application.

## Introduction

The State of Missouri has implemented a web application, referred to as StreamStats, that incorporates a geographic information system (GIS) to provide users the capability to retrieve streamflow information at selected streamgages throughout the State, do analyses to determine basin characteristics, and estimate statistics from selected regression analyses of high and low flows (Ellis, 2018). StreamStats applications in Missouri and other States primarily are applicable for rural watersheds that are assumed to be moderately unaltered by anthropogenic features found in urban areas.

Statewide StreamStats applications require three geospatial datasets that form the foundation of most GIS functions to determine basin characteristics such as determining drainage area or the percentage of impervious area in the watershed. These datasets consist of (1) the 3D Elevation Program (3DEP) dataset (https://www.usgs.gov/core-science-systems/ngp/3dep, accessed December 18, 2019), (2) the National Hydrography Dataset (NHD; https://www.usgs.gov/core-science-systems/ngp/national-hydrography/national-hydrography-dataset?qt-science_support_page_related_con=0#qt-science_support_page_related_con, accessed December 18, 2019), and (3) the Watershed Boundary Dataset

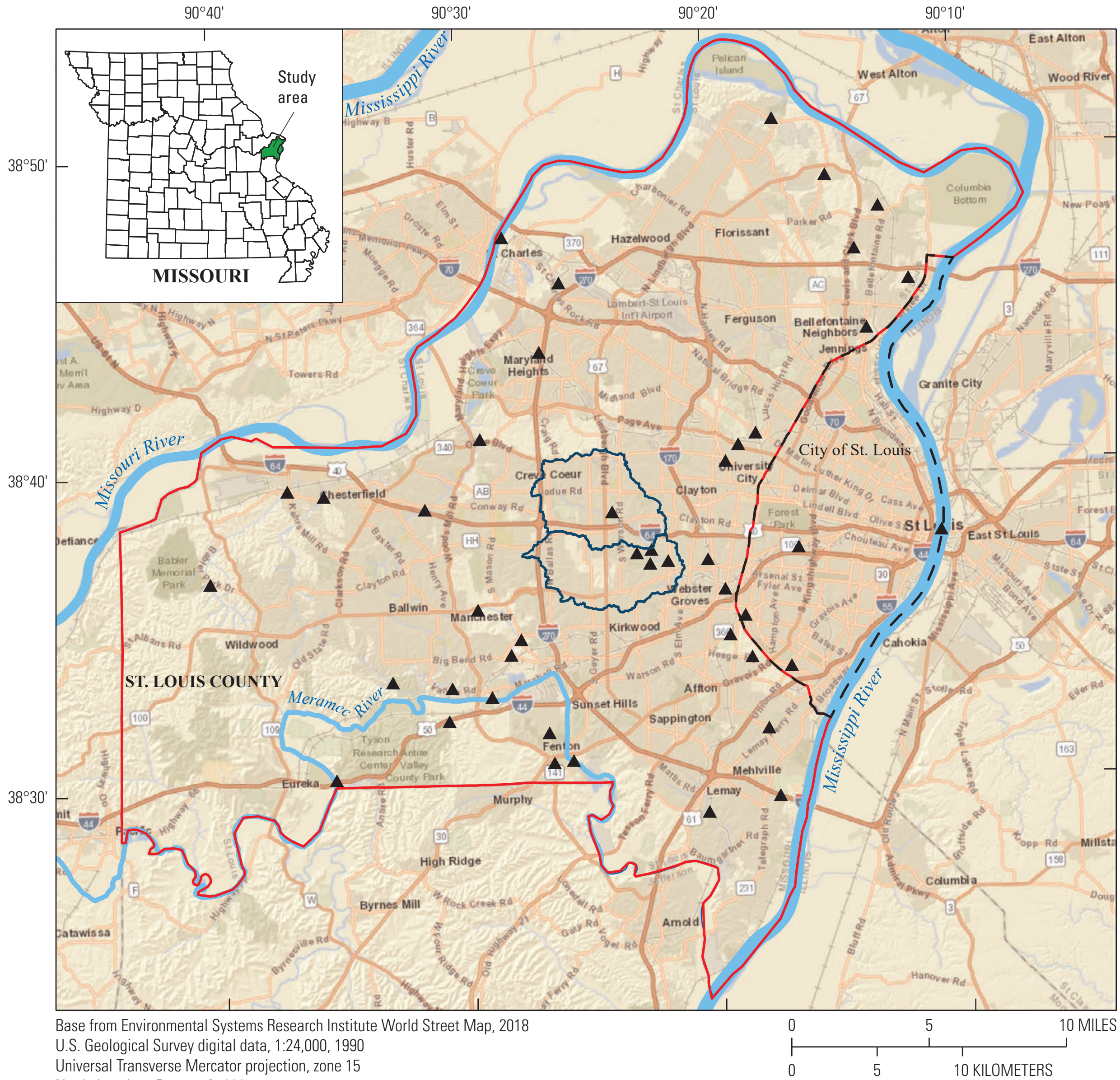
[1]U.S. Geological Survey.

[2]Esri.

(WBD; https://www.usgs.gov/core-science-systems/ngp/ngtoc/watershed-boundary-dataset, accessed December 18, 2019; U.S. Geological Survey, n.d.). The data processing steps for preparing data in the statewide StreamStats workflow use the NHD and WBD to modify the 3DEP dataset to create a hydrologically enforced elevation dataset (U.S. Geological Survey, 2004).

Major limitations of the functionality of the Missouri statewide StreamStats in urban areas such as St. Louis and Kansas City in Missouri include the age and resolution of the 3DEP dataset, a lack of detailed hydrographic data in the NHD, watershed boundaries in the WBD that do not account for anthropogenic structures, and the lack of a way to incorporate storm sewer networks into existing hydrographic datasets. The U.S. Geological Survey (USGS) completed a study, in cooperation with the Metropolitan St. Louis Sewer District (MSD), to apply the StreamStats methodology to improve the functionality of StreamStats in the dominantly urban study area of St. Louis County and the City of St. Louis in Missouri (fig. 1). Functionality was improved by using more recent (2012) higher resolution digital elevation model (DEM) data, by constructing improved hydrographic and watershed boundary data while accounting for anthropogenic structures, and by incorporating the storm sewer network into the hydrographic data.

The purpose of this report is to describe (1) the methods used to prepare geospatial data for a StreamStats application in an urban area, (2) the integration of an underground pipe drainage network with an open channel drainage network, and (3) the data exploration tools and the basin delineation and flow statistics options available to use with StreamStats in St. Louis County and the City of St. Louis urban area.




Base from Environmental Systems Research Institute World Street Map, 2018
U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection, zone 15
North American Datum of 1983

**EXPLANATION**

St. Louis County

City of St. Louis corporate boundary

Python script detailed evaluation watershed

U.S. Geological Survey streamgage

**Figure 1.** Location of St. Louis County and City of St. Louis, Missouri.

# Methods

The StreamStats application requires three geospatial datasets to delineate watersheds and determine basin characteristics for use in regression equations: a raster-based DEM representation of the land surface, a vector hydrographic data layer, and a vector watershed boundary data layer. The main task in processing the geospatial data for StreamStats is the hydrologic enforcement of the DEM. For this task, development of an accurate vector hydrographic data layer and vector watershed boundary data layer must first be created. In addition to the hydrologic enforcement effort for the StreamStats application in the urban area, a second task was to integrate the combined sanitary sewer (CSS) network that exists primarily within the City of St. Louis and partially in St. Louis County with the vector hydrographic data layer.

## Hydrologic Enforcement of the 3-Meter Digital Elevation Model

The StreamStats application uses a DEM to derive the contributing drainage area to any chosen point. The DEM is hydrologically enforced by artificially lowering the elevation of cells corresponding to the location of the vector drainage network and artificially raising the elevation of cells corresponding to the location of the vector watershed boundaries. This process ensures proper flow accumulation, flow direction, and watershed delineation.

### 3-Meter Digital Elevation Model

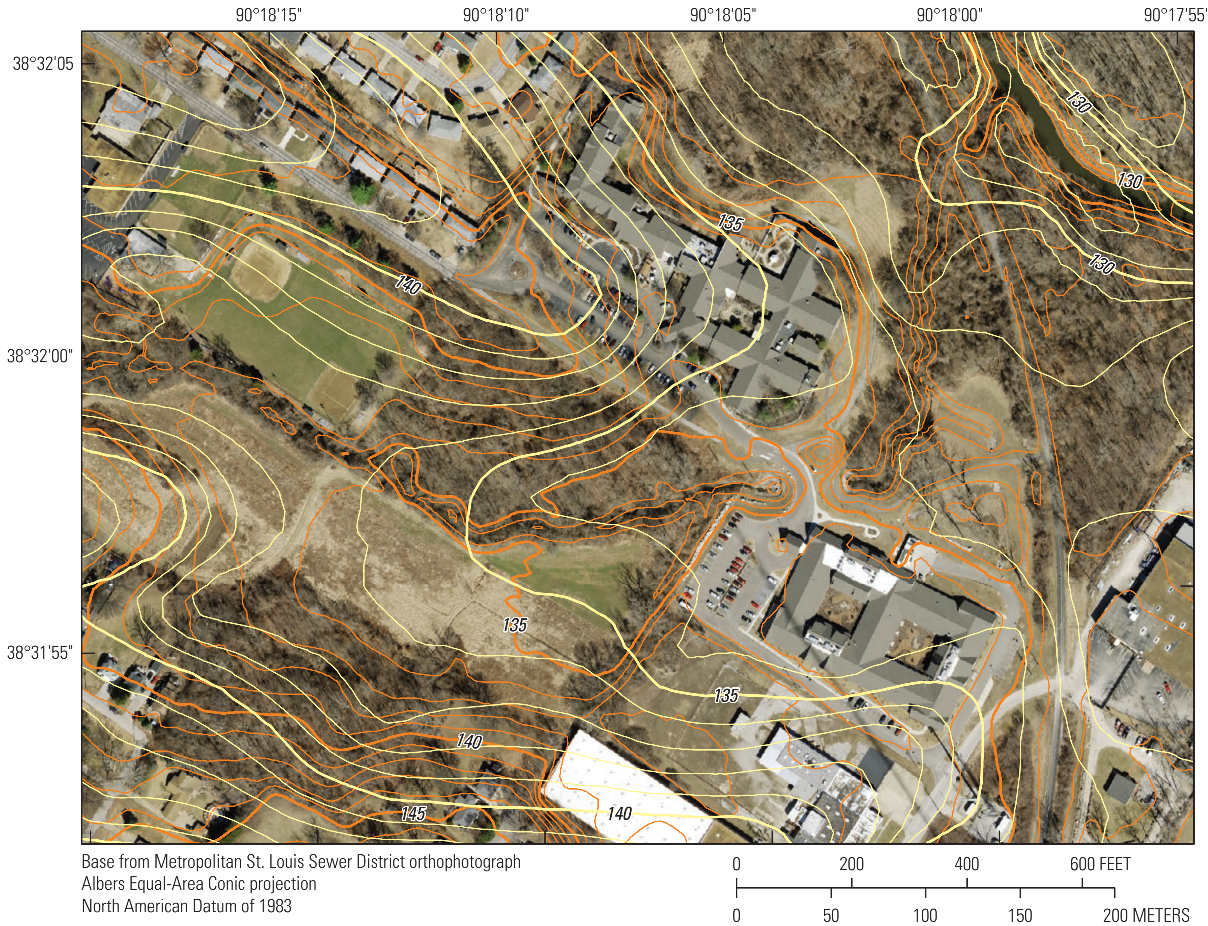
For engineering and planning purposes, MSD obtained light detection and ranging (lidar) data in 2012 for St. Louis County and the City of St. Louis. Lidar data are collected using remote sensing techniques from airborne systems using focused beams of light by measuring the time between the emission of light from the source and the detection of light reflecting from distant objects at the detector (National Oceanic and Atmospheric Administration Coastal Services Center, 2012). Lidar data are generally processed to remove details of the urban landscape, such as bridges and buildings, but some of the anthropogenic infrastructure that exists in an urban area, such as culverts under roads, is not removed. The quality of the lidar data collected by MSD meets the specifications (Heidemann, 2014) to develop a 1/9 arc-second DEM, commonly referred to as a 3-meter (m) DEM, resulting in improved topographic definition over the 10-m DEM of the 3DEP dataset. The DEM data were retrieved from The National Map (https://nationalmap.gov/elevation.html, accessed December 2014) for the development of this Missouri StreamStats application in the St. Louis County and the City of St. Louis urban area (termed the Missouri-St. Louis StreamStats application). The 3-m DEM data were retrieved for the study area of St. Louis County, the City of St. Louis, and watersheds draining into St. Louis County except for the large rivers of the Meramec, Missouri, and Mississippi. The 3-m DEM was the highest resolution data available for the area at the beginning of this study (2014).

To illustrate the difference in resolution between the 3-m DEM used in this study and 10-m DEM used in the statewide StreamStats application, 1-m elevation contours were produced from each raster surface and are shown together in figure 2. The small channel and road crossing that are visible in the background image can be resolved from the contours produced from the higher resolution 3-m DEM, whereas these features are not able to be determined from contours produced from the 10-m DEM. Despite having a more recent topographic surface (2012 compared to about 1980s or older) than is reflected in the 10-m DEM and being able to resolve smaller topographic features, the 3-m DEM does not reflect some of the anthropogenic infrastructure, such as culverts under roads or through levees, and must be hydrologically enforced to ensure surface flow is routed correctly in the StreamStats application.

### Drainage Network

The NHD (https://www.usgs.gov/core-science-systems/ngp/national-hydrography, accessed December 19, 2019) used in the statewide StreamStats application was retrieved and evaluated for use in the hydrologic enforcement process. Because the process of artificially lowering the DEM cells where the vector drainage network is depends on the positional accuracy of the drainage network, the NHD was overlain on the high-resolution orthophotograph (6-inch imagery), obtained from MSD, and visually inspected to evaluate its spatial accuracy. Examples are shown in figure 3 where the light blue line represents the location of the NHD drainage network. It is evident that the NHD drainage network does not lie within the unmodified channel (fig. 3*A*) in the image, and visual inspection showed that the NHD drainage network also deviated from the spatial location of improved channels (fig. 3*B*). After the NHD drainage network was evaluated for spatial accuracy, completeness, and density, it was determined that the NHD would not be sufficient to properly hydrologically enforce the 3-m DEM without substantial editing. The decision was made to create an independent drainage network based on the 3-m DEM. The resulting vector drainage network corresponds well to the 6-inch imagery because it was computationally derived from the 3-m DEM.

The process of deriving drainage networks from DEM data is well documented (Jenson, 1991; Esri, 2018). Flat areas, such as waterbodies, and depressions often are inaccurately represented when using these automated techniques for delineating drainage networks from DEM data. A common technique for the process begins by filling depressions in the DEM to remove internally draining features to create continuous drainage networks. Implicit in the filling process is the assumption that the depressions are not real, but instead




**EXPLANATION**

140 **Topographic contour from 10-meter digital elevation model**—Shows elevation of land surface. Principal contour interval 5 meters. Intermediate contour interval 1 meter. Datum is North American Vertical Datum of 1988

140 **Topographic contour from 3-meter digital elevation model**—Shows elevation of land surface. Principal contour interval 5 meters. Intermediate contour interval 1 meter. Datum is North American Vertical Datum of 1988

**Figure 2.** Example of topographic differences between the 10- and 3-meter digital elevation models.

are artifacts in the DEM; however, filling depressions often causes problems with the positional derivation of the drainage network through the depression.

The 3-m DEM used in this study can be used to resolve moderately subtle topographic features such as road ditches, levees, and road embankments that often are not able to be resolved in lower resolution (10-m, for example) DEMs. These subtle features, in combination with the inability to represent some urban infrastructure in the DEM, particularly culverts under roads or levees, sometimes cause problems with extracting continuous drainage networks. When a stream crosses a road through a bridge or culvert that has not been hydrologically represented in the DEM, there is no outlet for routing the drainage network across the road, which causes the area behind the road to be treated as a depression. The depression is subsequently filled, and the computer-derived drainage network tends to cross the obstruction in the wrong location (Poppenga and others, 2009). In some cases, the lack of a flow outlet in the DEM causes the drainage networks derived from the 3-m DEM to be in error at road crossings. As shown in figure 4, which is an enlarged view of the stream crossing a road through a culvert from figure 2, the road crossing is not hydrologically enforced as indicated because the road embankment disrupts the contours where the culvert is visible in the 6-inch imagery instead of depicting a continuous topographic gradient along the stream.


**Figure 3.** Stream lines from the National Hydrography Dataset (1:24,000) and 3-meter digital elevation model. *A*, for a natural channel; *B*, for an improved channel.

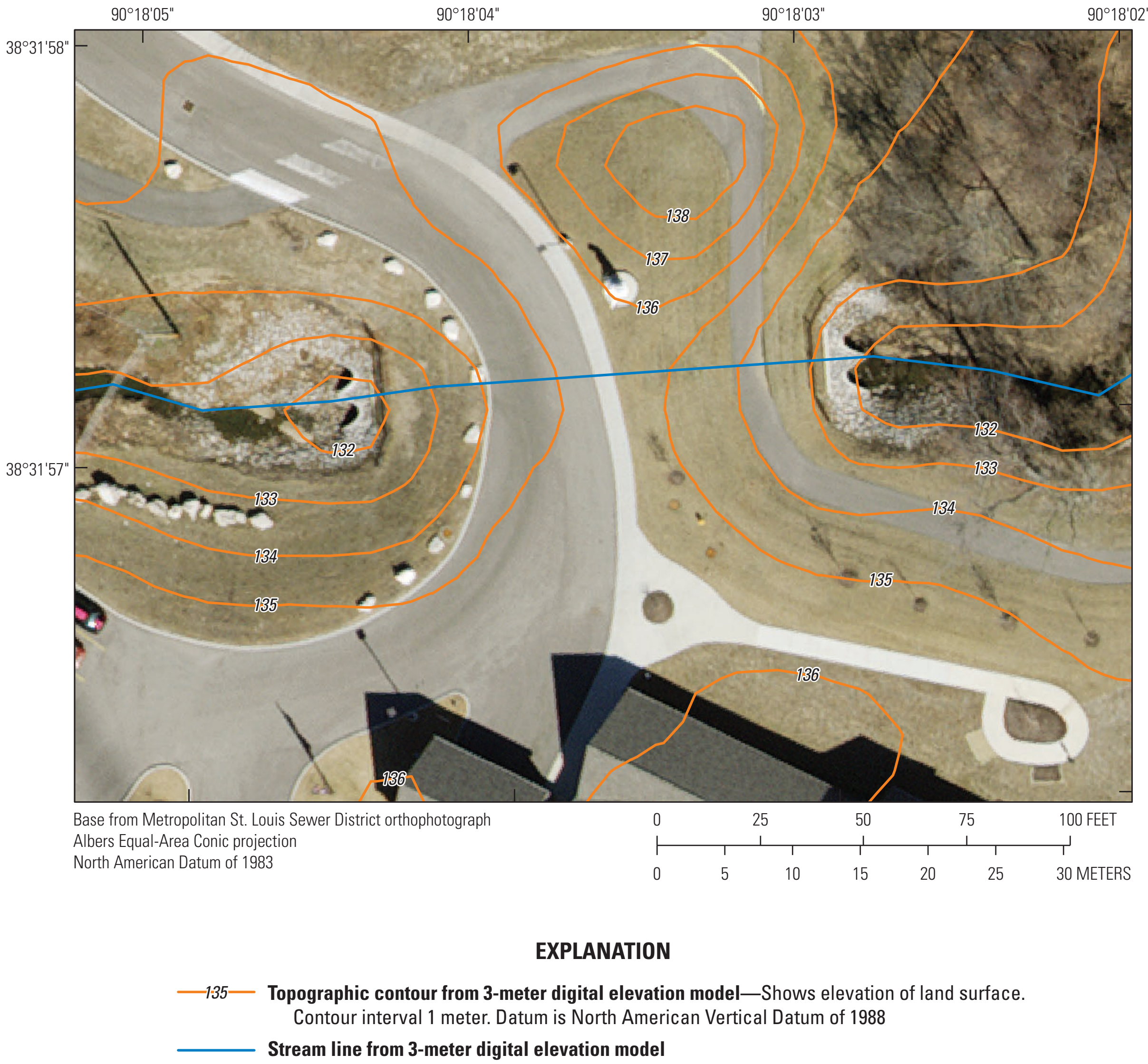



**Figure 4.** Example of stream crossing a road through a culvert where the elevation data are not hydrologically enforced.

To overcome the potential erroneous delineation of stream crossings at culvert structures and depressions, drainage networks for this study area were derived using a new delineation tool written in the Python scripting language. Personnel from the USGS National Geospatial Technical Operations Center developed the drainage network delineation tool (appendix) to improve the derivation of drainage networks in the study area and particularly across flat areas in the 3-m DEM and at stream crossings at roads or levees. The Python script requires three datasets as input: the unfilled 3-m DEM, a partially filled DEM using a fill threshold of 1.97 feet, and a raster, derived from the unfilled DEM, that contains the location of the origin of the stream line to be delineated with the first few cells of the stream line included. Partial filling of the DEM removes small surface undulations (up to the fill threshold) in the DEM so that they do not have to be processed with the Python script. The fill threshold of 1.97 feet used to partially fill the depressions in the original unfilled 3-m DEM was determined by experimentation using various fill thresholds and determining a reasonable balance between processing time of the script and reliable stream line delineations. GIS tools were used to determine the locations of the origin of the stream lines and to compute a filled DEM from the original 3-m DEM, a flow direction raster, and a flow accumulation raster (Esri, 2018). The flow accumulation raster was used to determine the stream lines that originated at an accumulation point of 9,000 3-m cells or approximately 20 acres of accumulated area. The drainage network obtained from the GIS tools was usually in error where the stream lines had to be routed across a flat area or where there was a road crossing at a stream that was not represented in the original 3-m DEM. Typically, the origin of the stream lines produced by the GIS tools were not in error.

The Python script computed the drainage network using the starting locations derived from the GIS tools by determining the direction of flow from the slopes of the surrounding cells and moving downslope until either a flat area (typically a waterbody) or a depression was found. Delineation of the stream line across flat areas was computed using the algorithm described in Garbrecht and Martz (1997). The continuation point across the obstacle (road, levee, or floodwall) of the stream line that enters into a depression was determined by searching for a cell that was lower than the lowest cell in the depression within a specified search distance and direction. The search distance was 80 cells and the initial search direction was determined from averaging the directional trend of stream lines entering into the depression. The search direction was varied to the left and right of the initial trend by as much as 100 degrees until a cell lower than the lowest cell in the depression was found. If a target cell was found, a line connecting the lowest cell in the depression to the target cell was computed and the slope wise delineation was continued from the target cell. If a target cell was not found within the search distance or the search angle, the script moved on to the next candidate in the list. After the Python script finished, cases where continuous drainage networks were not automatically delineated would be delineated by using heads-up digitizing techniques using the topographic contours and the 6-inch imagery. The Python script derived drainage network was finally visually spot checked with the 6-inch imagery, and edits were made if necessary.

A detailed evaluation of two small topographic watersheds (fig. 1) was done by comparing the results of the Python scripted stream line delineation with the GIS tools stream line delineation. In nearly all cases where the two methods differed substantially, the Python scripted stream line delineation was correct where a visual interpretation from the 6-inch imagery could be made (fig. 5*A*). In areas where the two methods differed substantially, and no visual confirmation could be made (fig. 5*B*), both delineations seemed to be reasonable interpretations of the location of the stream line. The Python scripted stream line delineation was incorrectly located in some instances (fig. 5*C*).

## Watershed Boundaries

The U.S. Department of Agriculture developed the WBD in cooperation with the USGS (U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013). The WBD is a set of polygons that divides and subdivides the country into successively smaller hydrologic units based on topographic surface features and identified by a unique hydrologic unit code (HUC). For this study, parts of three eight-digit HUC regions of the WBD are present in the study area of St. Louis County and the City of St. Louis. The regions are 07140101, Cahokia-Joachim; 07140102, Meramec; and 10300200, Lower Missouri (fig. 6). The 07140101 HUC region includes drainages into the Mississippi River just below the confluence of the Missouri and Mississippi Rivers. All or part of 23 12-digit HUC regions from the WBD are included in the study area and have a mean area of about 25,700 acres (40.2 square miles [$mi^2$]; fig. 6).

The WBD serves two purposes in the statewide StreamStats application: (1) to hydrologically enforce the 3DEP dataset to ensure that watershed delineations for a selected point on a stream do not cross known watershed boundaries and (2) to act as mapping units used to subdivide large watersheds so that geospatial data can be preprocessed to facilitate rapid watershed delineation and computation of selected basin characteristics (U.S. Geological Survey, 2004) in the web-based application. Each 8-digit and 12-digit HUC boundary was visually compared to the 1-m elevation contours derived from the 3-m resolution DEM, and it was determined that the WBD did not sufficiently reflect the higher resolution topography and would have to be redigitized. The updated HUC boundaries were digitized by a hand on the computer screen by following ridge lines in the 1-m elevation contours and taking into account inlet structures, where visible, in the 6-inch imagery. At the beginning of the project, the 12-digit HUC regions were further subdivided into smaller watersheds with the expectation that it would be necessary to preprocess the geospatial data and link the subdivided watersheds (a process called globalization) to accelerate the process of watershed delineation from the 3-m DEM on the web StreamStats application. The subdivided watershed boundaries, in general, follow the guidelines for subdividing 12-digit HUC regions using the "open option" defined by the U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service (2013). Possible exceptions are that some watershed boundaries follow parallel to a political boundary and the boundaries were not strictly delineated from topography (some urban infrastructure was taken into account). Advances in computer server speed and software technology, the moderately small watershed sizes, and the fact that the eight-digit HUC regions are independent in the study area (no globalization of the eight-digit HUC regions was required) negated the need to subdivide the watersheds to accelerate the speed of delineation. However, the additional subdivided watershed boundaries were retained in the data and used to hydrologically enforce the 3-m DEM to provide additional "fixed" topographic drainage boundaries that were developed considering anthropogenic features.

There were 161 subdivided watersheds digitized in HUC 07140101 with an area range of about 0.10 to about 9,302 acres and a mean area of about 860 acres (fig. 6). Subdivided 12-digit HUC regions in the City of St. Louis area were largely removed when the surface drainage network was integrated with the CSS network. After removal, 51 subdivided watersheds remained in HUC 07140101 with an area range of about 7.72 to about 9,302 acres and a mean area of about 1,805 acres (fig. 6). There were 129 subdivided watersheds digitized in HUC 07140102 with an area range of about 9.64 to about 8,755 acres and a mean area of about 1,704 acres

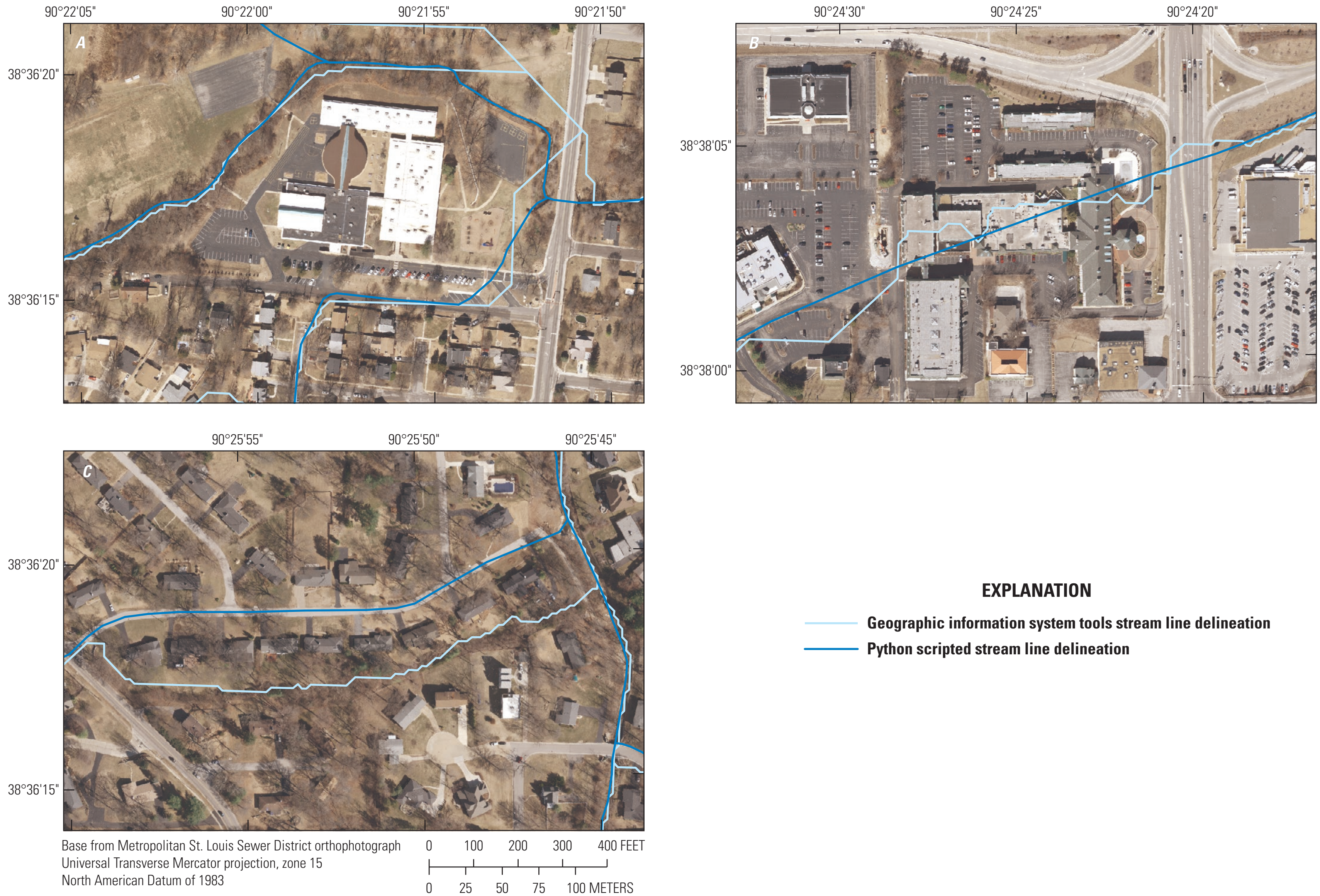



**Figure 5.** Examples of comparisons between Python scripted stream line delineation with the geographic information system tools stream line delineation. *A*, correct Python scripted stream line delineation; *B*, no visual confirmation can be made; *C*, incorrect Python scripted stream line delineation.

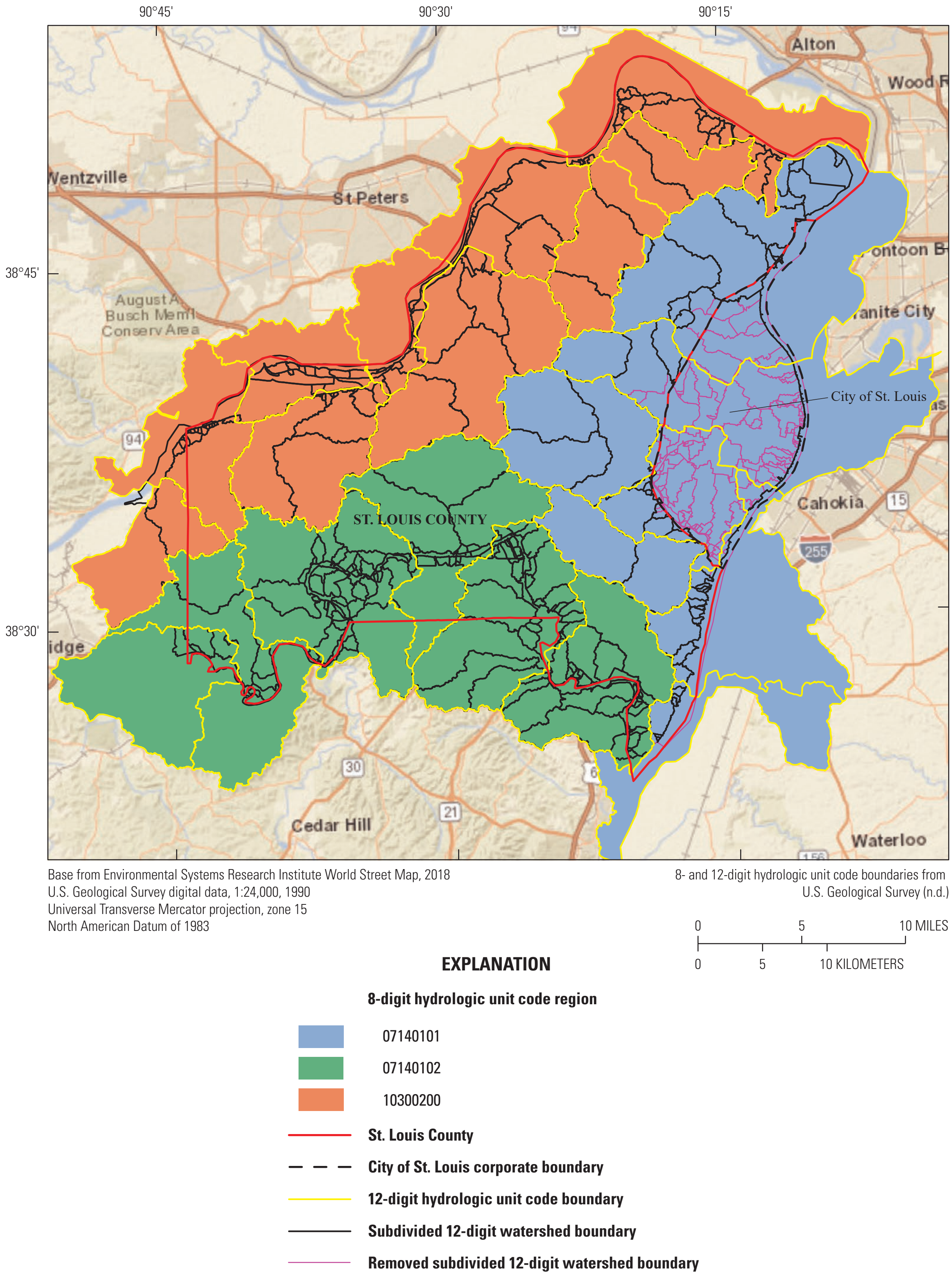



**Figure 6.** The 8-digit hydrologic unit code boundary dataset, 12-digit hydrologic unit code boundary dataset, and subdivided 12-digit watershed boundary dataset derived from 3-meter digital elevation model and high-resolution imagery, for St. Louis County and the City of St. Louis.

(fig. 6). There were 104 subdivided watersheds digitized in HUC 10300200 with an area range of about 3.33 to about 11,713 acres and a mean area of about 1,375 acres (fig. 6).

In areas where extensive CSS structures exist (City of St. Louis area and parts of St. Louis County; figs. 6 and 7), watershed boundaries are superseded by catchment areas defined by drainage that flows into individual inlet structures (fig. 8). The collection of catchment areas and the associated topographic watersheds of open channels that discharge into inlet structures that direct flow to a point (whether on a pipe network or an open channel) is termed a sewershed.

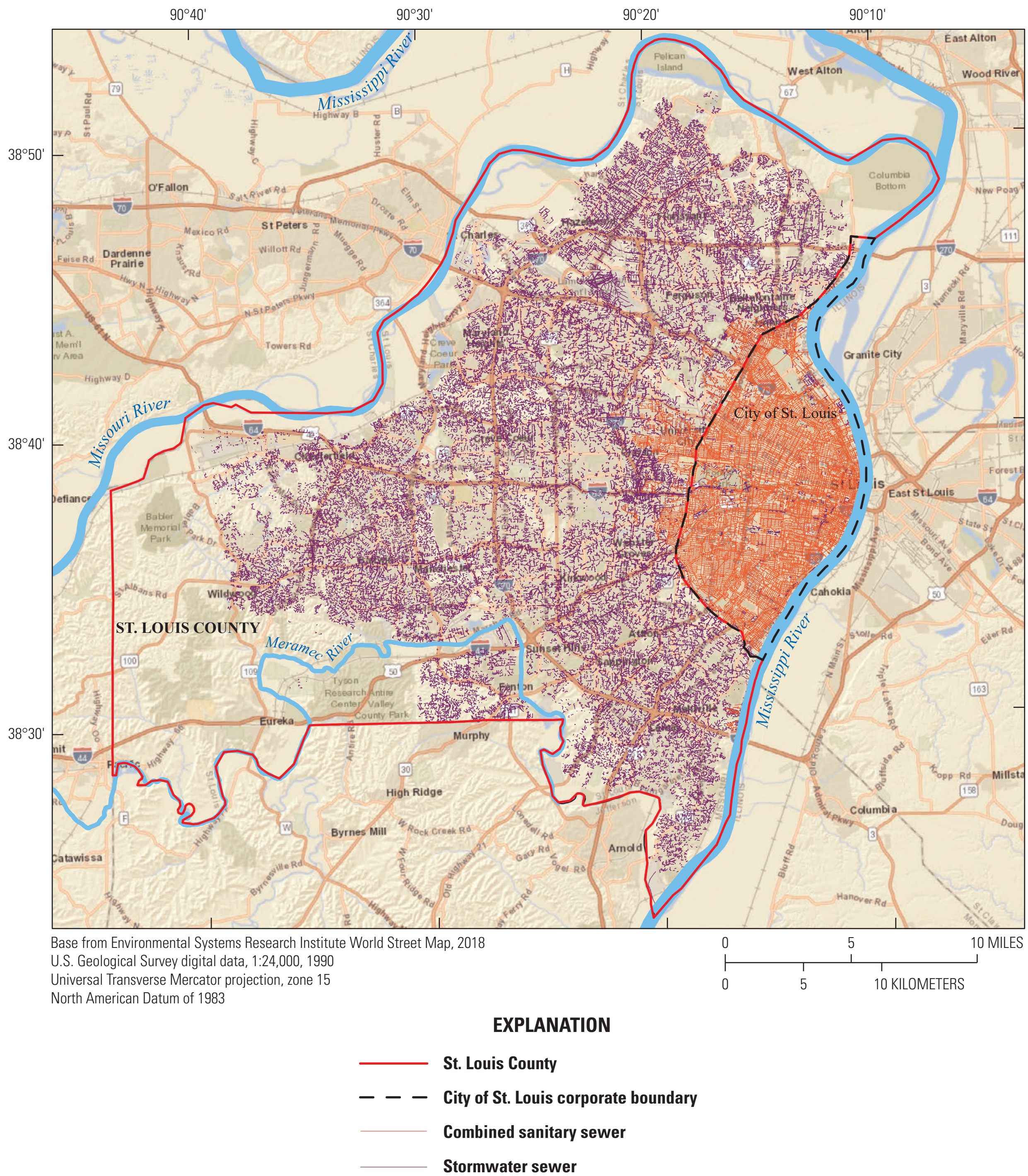



**Figure 7.** Location of stormwater sewer network and combined sanitary sewer network in the study area.


**EXPLANATION**

**Combined sanitary sewer catchment**

148 **Topographic contour from 3-meter digital elevation model**—Shows elevation of land surface. Contour interval 2 meters. Datum is North American Vertical Datum of 1988

**Combined sanitary sewer pipe**—Arrow indicates flow direction

**HydroJunction (inlet)**

**Figure 8.** Example of delineated catchment areas for a small sewershed in the combined sanitary sewer network in the City of St. Louis area.

## Storm Sewer Network

Three components make up the storm sewer network in the study area (fig. 7). Stormwater runoff is managed in the study area by overland flow that directs runoff to open channels, directs runoff to inlet structures to the stormwater sewer system, and directs runoff to inlet structures to the CSS. Stormwater runoff is either directed straight to a discharge point on a nearby stream or, in the case of the CSS network, typically to a treatment facility. The stormwater sewer system and the CSS vector data in combination with the 6-inch imagery and the 3-m DEM were used to verify and refine the 12-digit HUC boundaries and the subdivided topographic watershed boundaries. The CSS vector data were processed and included as a component of the watershed delineation tool in StreamStats.

### Stormwater Sewer Network

The stormwater sewer network uses open channel and underground pipes to manage stormwater runoff in most of the study area except for the City of St. Louis and its surrounding area. In the dominantly rural western parts of the study area, stormwater runoff is usually managed with open channels. In the other more urbanized areas, the stormwater runoff is usually managed by a combination of open channels and underground stormwater sewers. Because most of the stormwater sewers operate under gravity flow conditions, the contributing catchment area (stormwater sewershed) directing water to a particular location on the stormwater sewer typically is similar to the topographic area (topographic watershed) that contributes flow to the surface stream at that location.

The goal of the StreamStats application is to delineate the contributing area of flow to a particular location and then determine the drainage area and necessary basin characteristics required to compute the streamflow statistics for the selected regression-based scenario at that point. Because of the relation between the stormwater sewershed and the topographic watershed, it was assumed that the topographic watershed would be similar to the stormwater sewershed and so the stormwater sewers were ignored in HUCs 07140102 and 10300200 and parts of HUC 07140101 not covered by the CSS network in the City of St. Louis.

### Combined Sanitary Sewer Network

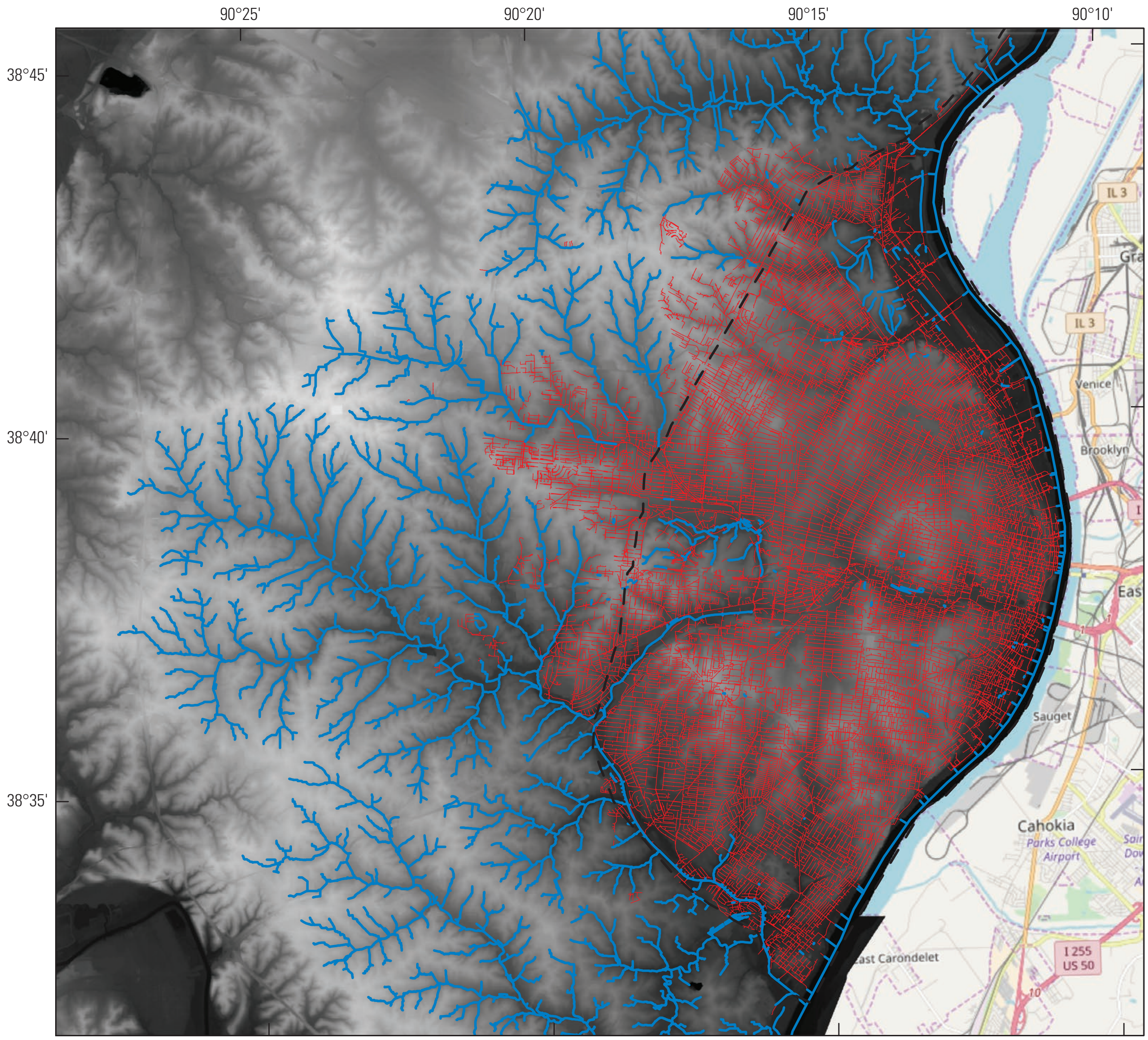
The City of St. Louis CSS network (fig. 9) is used to remove stormwater runoff from the City of St. Louis and surrounding areas of St. Louis County. A digital database of the mapped location of the pipes, surface channels, inlet structures, manholes, and other structures was obtained from MSD. The pipe network was evaluated and edited for connectivity and flow direction. Disconnected CSS pipes were joined to the body of the network using topography and by combining pipes that were as large as, or larger than, the disconnected pipe to ensure flow capacities were not incorrectly exceeded. Mapped inlet structures and manholes in the MSD data were considered to be locations where stormwater runoff can enter the CSS network. In some cases, inlet structures and manholes visible in the 6-inch imagery were added to the CSS network where appropriate. The resolution of the 3-m DEM is not sufficient to define curbs and small changes in elevation that might affect the shape and area of a catchment for a given inlet structure. However, at the street, subdivision, or city block level, it is assumed that stormwater runoff will be captured in the appropriate CSS pipes for personnel to evaluate the stormwater load entering the system. The assumption is based on the likelihood that a large enough collective area of overland flow to a group of inlet structures will adequately represent the combination of multiple smaller catchments that might be affected by subtle elevation changes. This is because the catchment area domain is finite.

## Urban Infrastructure

St. Louis County and the City of St. Louis are between two of the Nation’s largest waterways, the Missouri and Mississippi Rivers (fig. 1). To protect the billions of dollars of infrastructure from flood waters, the City of St. Louis built a floodwall along the Mississippi River in the 1960s (fig. 10). Linear features such as the floodwall, with widths less than 1 m, were not consistently integrated into the 3-m DEM. The floodwall represents a feature in the watershed boundary dataset, which was uniquely digitized using 6-inch imagery.

A second anthropogenic group of features in St. Louis County are the earthen levees constructed along the Missouri River to protect substantial development within the floodplain (fig. 11). For this study, the levees were considered to be watershed boundaries and were uniquely digitized as boundaries. The levees were sufficiently large enough to be defined in the 3-m DEM, and their position and continuity were verified with 6-inch imagery. Similar to road crossings with culverts, the levees were not hydrologically enforced in the source datasets. The 6-inch imagery was used to detect structures such as culverts and built-in gated structures that allow inland runoff to flow to the Missouri River. These structures also can be closed, preventing floodwater from entering the levee-protected area during flooding on the mainstem river. The 6-inch imagery also was critical to help define the drainage network within the floodplain because relief alone was not definitive enough to determine stream lines.

The third major anthropogenic structure found within the urban study area was complex interstate interchanges (fig. 12). The storm sewer network did not include the as-built drainage structure of interstate road systems in the study area. Where the structures were located on topographic divides, they were evaluated with the use of 6-inch imagery and elevation data, and best professional judgement was used to define the stormwater flow within the in-ground drainage systems. In most cases, stormwater flow was routed based on the topography,




Base from Environmental Systems Research Institute OpenStreetMap, 2018
U.S. Geological Survey digital data, 1:24,000, 1990
U.S. Geological Survey 3-meter digital elevation model, 2012
Universal Transverse Mercator projection, zone 15
North American Datum of 1983

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

**EXPLANATION**

City of St. Louis corporate boundary

Stream line from 3-meter digital elevation model

Combined sanitary sewer

**Figure 9.** Combined sanitary sewer network for St. Louis County and the City of St. Louis.


**Figure 10.** Typical section of City of St. Louis floodwall along the Mississippi River.

but in the absence of a definitive topographic flow direction, stormwater flow was routed to the nearest surface drainage or storm sewer network inlet structure.

## Arc Hydro Stormwater Terrain Processing Workflow

A new stormwater terrain processing workflow was developed by leveraging existing Arc Hydro terrain preprocessing tools (Maidment, 2002) and combining them into a new process that integrates the surface drainage network derived from the DEM and the underground pipe network defined by the CSS (Esri, 2017; table 1). The data components of the stormwater terrain processing workflow consist of the DEM and the stormwater network. The stormwater network is made up of the pipe network (the CSS network near the City of St. Louis for this study) and the stream network (stream lines derived from the 3-m DEM for this study). The pipe network consists of lines representing pipe locations and HydroJunction points (locations where stormwater runoff can enter the pipe network). Conceptually, HydroJunctions function as a flow collection point (sink) where stormwater runoff at the surface is conveyed into the pipe network. HydroJunctions must exist anywhere stormwater enters a pipe. HydroJunctions are not required where flow is transferred between pipe sections, but pipes may end at a HydroJunction as a sink. The stream network consists of open channels that convey stormwater runoff into the pipe network at inlet structures, or between pipe segments in some cases.

Quality control checks were completed on the stormwater network to define zero length lines, multipart lines, overlapping lines, and lines connecting to themselves. Surface streams that are connected to the stormwater network or exit the DEM must be connected with a HydroJunction, which will allow stormwater runoff to pass in or out of the stormwater network.


**Figure 11.** Example of watershed boundary from 3-meter digital elevation model near a levee along the Missouri River and stream lines from the 3-meter digital elevation model in the Missouri River floodplain.

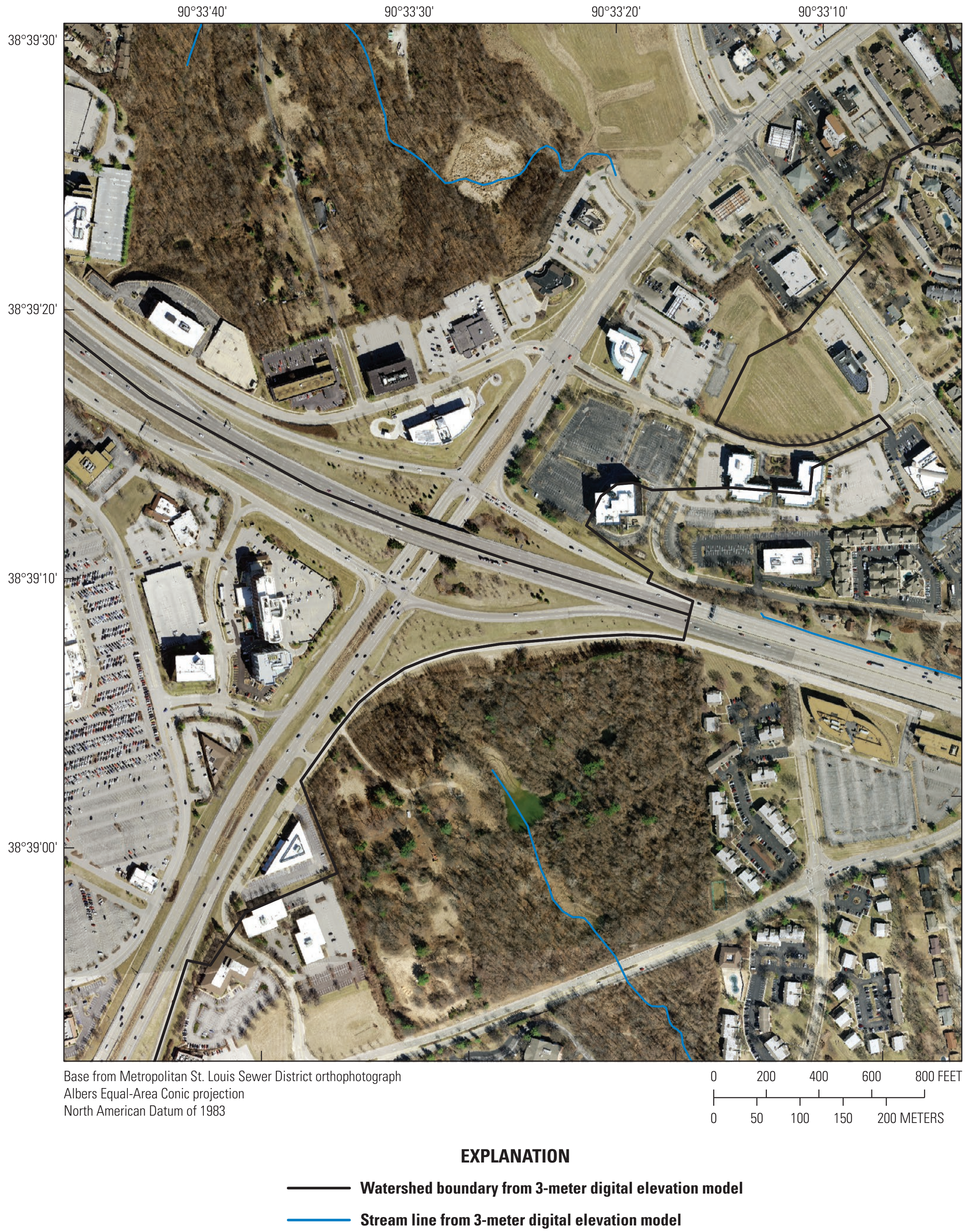



**Figure 12.** Example of watershed boundary from 3-meter digital elevation model near a complex interstate interchange in St. Louis County.

**Table 1.** Arc Hydro stormwater network processing steps (modified from Esri, 2017).

[DEM, digital elevation model; ID, identifier]

| Step | Tool | Objective |
|---|---|---|
| 1 | Create Drainage Line Structures | Create rasterized vector representation of the input streams as Drainage Line features. |
| 2 | Create Sink Structures | Create Sink Points and Polygons associated to DraftSinkPoly (inlet structures and sinks created at end of drainage line). |
| 3 | DEM Reconditioning from Stream Grid | Burn the stream grid generated in step 1 into the DEM to enforce the location of the streams and force water near the streams to flow toward the closest stream. |
| 4 | Level DEM | Level DEM within terrain and structure sink polygons using the lowest elevation along the sink polygon boundary. |
| 5 | Fill Sinks | Fill the DEM at all locations except within the sink polygons (both terrain and structure). |
| 6 | Flow Direction | Generate flow direction grid. |
| 7 | Adjust Flow Direction in Sinks | Modify flow direction within sink polygons so that water flows toward the sink point in the sink polygon. |
| 8 | Adjust Flow Direction in Stream | Modify flow direction in the streams so that the water flows in the digitized direction along the streams. |
| 9 | Combine Stream Link and Sink Link | Combine link grids generated from the streams and from the sinks. |
| 10 | Catchment Area Grid Delineation | Delineate catchment areas for each link. |
| 11 | Catchment Area Polygon Processing | Convert catchment area grid to vector. |
| 12 | Adjoint Catchment Area Processing | Generate Adjoint Catchment area associated to each input Catchment area and set the connectivity between Catchment areas. |
| 13 | Sink Watershed Delineation | Delineate watershed associated to terrain sinks. |
| 14 | Link Sink Watershed to HydroJunction | Create and populate JunctionID in SinkWatersheds with HydroID of associated HydroJunction. Create relationship. |
| 15 | Create Stormwater Network | Create geometric network from HydroJunction, Pipe, and Stream layers and set flow direction in digitized direction. |
| 16 | Flow Accumulation | Create Flow Accumulation to support next step, Create Snap Data. |
| 17 | Create Snap Data | Create snap raster to support snapping when delineating. |

The stormwater network also is checked for "dangles" (over and under shoots with no HydroJunction) and locations where intersections occur but do not connect at nodes.

In the Missouri-St. Louis StreamStats application, the pipe layer is used only to convey stormwater runoff; it does not directly collect stormwater runoff along its length. Stream network features convey stormwater runoff and collect surface stormwater runoff along their length. They are used as the source for stream line raster creation and for DEM reconditioning where the DEM is hydrologically enforced to follow paths defined by the stream network. A HydroJunction is the point feature class storing all the junctions used as inlet structures or sinks. Where HydroJunction points exist, the buffering tool is used to create sink polygon features or sink structures that are used in DEM preprocessing. The sink polygon features are used to set the elevations of the DEM cells within them much lower than surrounding cells, causing stormwater runoff to "flow" into the lowered cells.

Once the stream network, pipe network, and HydroJunction features are properly established, the following key steps are completed in the Arc Hydro stormwater terrain preprocessing workflow:

1. Use open channels to establish drainage lines and for DEM reconditioning.
2. Use HydroJunctions to establish sink polygons and for DEM leveling.
3. Establish surface (overland) flow direction (includes selective filling of sinks and adjustment of flow direction in streams and sinks).
4. Delineate catchment areas that define drainage areas draining to open channels and sinks.
5. Build geometric network consisting of open channels, pipes, and HydroJunctions.
6. Incorporate catchment areas into network elements.

The pipe network, stream network, and HydroJunctions form the geometric network, and standard geometric network tracing tools can be used to complete upstream and downstream traces through combined pipe network and stream network features. A relationship class developed between HydroJunctions and catchment areas allows for quick selection of contributing catchment areas to the resulting HydroJunctions from a network trace.

### Error Checking and Validation Using the Arc Hydro Stormwater Tool

A new Arc Hydro tool was developed to complete watershed delineation based on the Arc Hydro stormwater representation. The tool allows the user to interactively delineate a watershed anywhere within the preprocessed area. It will distinguish between the locations within the CSS network (pipes) and terrain (open channels, overland flow) and allows the user to select delineation of a local or global contributing area. Local refers to the contributing drainage area of the topographic watershed only and can be delineated by selecting the “Surface Contributing Basin only” checkbox in the Arc Hydro stormwater tool. Global refers to the contributing drainage area of the sewershed, which is the combined topographic watershed and the catchment areas of the inlet structures and is the default delineation with the “Surface Contributing Basin only” checkbox unchecked in the Arc Hydro stormwater tool.

Results of the Arc Hydro stormwater processing were then evaluated to ensure the CSS network was developed and integrated correctly. Upstream flow tracing was used to define if all elements were connected appropriately. The data were examined after using the results of the Arc Hydro stormwater tool to look for errors that included (1) catchment areas not defined for each HydroJunction, (2) lowering of the cells at HydroJunctions was not sufficient to create “flow” into a sink, (3) flow direction within a sink was set in the wrong direction, (4) stream does not match stream link or stream grid precisely, and (5) missing HydroJunction at junction of stream and pipe.

Potential errors may exist in the CSS network and stream network because of errors in inlet structure locations, accuracy and resolution in elevation data, and network definition. Errors in the spatial location of inlet structures can result in inlet structures on highway shoulders being located off the raised highway embankments, resulting in flow being captured erroneously from embankments and ditches. Also, the accuracy of the DEM is not sufficient to define curbs and gutters along elevated roadway features that would confine the flow into the inlet structures from only the lanes of traffic. Accuracy of the DEM in highly developed business districts and subdivisions is degraded by the process of removing the structures and creating a bare earth DEM. In some locations, the DEM was observed to have depressions where buildings existed, affecting the catchment area boundaries between CSS lines. A combination of lack of accuracy and resolution resulted in catchment area boundaries not following road centerlines as would be expected. How well the network is defined directly affects the accuracy of the catchment areas. Missing inlet structures or CSS lines affect the catchment area boundaries of nearby inlet structures. In the downtown area of the City of St. Louis, it was difficult to identify inlet structures from 6-inch imagery in parking lots and parking garages because they were sometimes obscured by vehicles. There was a lack of detailed drain locations in the digital data in some places. Where large structures existed, such as shopping malls, sports stadiums, and commercial buildings, inlet structure locations were frequently unavailable for inclusion into the CSS network. Improvements in the vertical accuracy and horizontal resolution of the DEM and additional infrastructure being added to the CSS network over the study area could improve the accuracy of the drainage network and the associated catchment area delineation.

## Missouri-St. Louis StreamStats Application Functions

The Missouri-St. Louis StreamStats application (https://streamstats.usgs.gov), available for the urban study area of St. Louis County and the City of St. Louis, has several tools that can be used to explore the spatial data, determine flow statistics at streamgages, delineate watersheds and sewersheds, and compute flow statistics at selected user locations. The Missouri-St. Louis StreamStats application operates similar to and has many of the same capabilities of the statewide StreamStats application (Ries and others, 2008; Ellis, 2018).

### Data Exploration Tools and Streamgage Information and Flow Statistics

Various data exploration tools are available to examine the spatial data including measuring distance, developing an elevation profile, determining the flow path of water downstream from a user selected point, tracing relations between two specified points through the network, and network tracing to identify available data selections, such as streamgages, dams, and water-quality sites. These data exploration tools operate the same in the areas outside the CSS as they do in the Missouri statewide StreamStats application (Ries and others, 2008; Ellis, 2018). Network trace operations such as determining the downstream flow path of water, determining traces between two specified points, and identifying available data do not operate on the CSS lines.

General descriptive information and more detailed information about the available flow data can be obtained by selecting a streamgage point in the map area (fig. 1) and following the “NWIS page” link; NWIS is the USGS National Water Information System database (U.S. Geological Survey, 2020). Streamgage flow statistics based on data in the NWIS database can be obtained by selecting a streamgage point and following the “StreamStats Gage page” link.

## Delineation of Watershed or Sewershed, Determination of Basin Characteristics, and Computation of Peak-Flow Statistics

Basin delineation in the Missouri-St. Louis StreamStats application is similar to the process used in the statewide StreamStats application. The exception being that because the CSS was integrated into the open channel hydrography in part of the study area, the basin delineation can consist of a watershed or a sewershed depending on where in the study area the basin is delineated. The steps required to use the Missouri-St. Louis StreamStats application to delineate a basin in the study area are as follows:

1. Using a web browser, navigate to https://streamstats.usgs.gov, and click on “Access application.”

2. Zoom in to the area of interest (near St. Louis, Mo.; fig. 13*A*).

3. Select the “Missouri St. Louis” region button.

4. Zoom in to the location where you want to delineate a watershed or sewershed (fig. 13*B*). Note that it may be necessary to change the base map to one of the following to be able to zoom to a higher level: streets, world topographic, or imagery.

5. If the delineation is in HUC 07140101 (fig. 6) where CSS exists, you have the option to delineate the watershed area using only the topography (select the “Surface Contributing Basin only” checkbox; fig. 14). The default (unchecked) is to use the combined topographic and CSS contribution. Shown in figure 14 is an example of a basin delineated in HUC 07140101 with the “Surface Contributing Basin only” checkbox unchecked, and the same basin with it checked.

6. Choose the delineate basin button.

7. Select the point on a stream (blue line) or, if in HUC 07140101, a CSS pipe (maroon line) where you want your delineation to be determined.

8. The watershed will be delineated, and a yellow shaded polygon (generalized watershed or sewershed boundary) will be displayed on the screen (fig. 13*B*).

9. You have the option to edit or download the delineated watershed if you choose.

10. Choose regression-based scenario or basin characteristics.

    a. If your delineated area is in HUCs 07140102, 10300200, or the area of HUC 07140101with no CSS (figs. 6 and 7), you now have the option to choose the regression-based scenario you would like to have computed (there is only one applicable scenario in the study area, “Peak-Flow Statistics” based on equations of Southard [2010]). Choosing the regression-based scenario automatically selects the appropriate basin characteristics necessary to compute the flow statistics. You may at this time choose to determine additional basin characteristics as well.

    b. If your delineated area is in the CSS area of HUC 07140101, a warning message, “Failed to load scenarios or no scenarios available,” will appear because the flow statistics are not applicable, and no regression-based scenario will be available. However, you can choose to determine basin characteristics for the delineated sewershed by selecting the checkboxes next to the characteristic you would like computed in the “Basin Characteristics” dropdown menu.

11. After the regression-based scenario or basin characteristics are chosen, selecting “Continue” will produce a report (fig. 13*C*). The report contains a map of the delineated area, basin characteristics, general disclaimers, peak-flow statistics parameters, and a peak-flow statistics flow report (if in the area described in 10a). The data in the report can be downloaded for use in other software or the report can be printed. One or more general disclaimers may be observed in an orange box on the report and include the following:

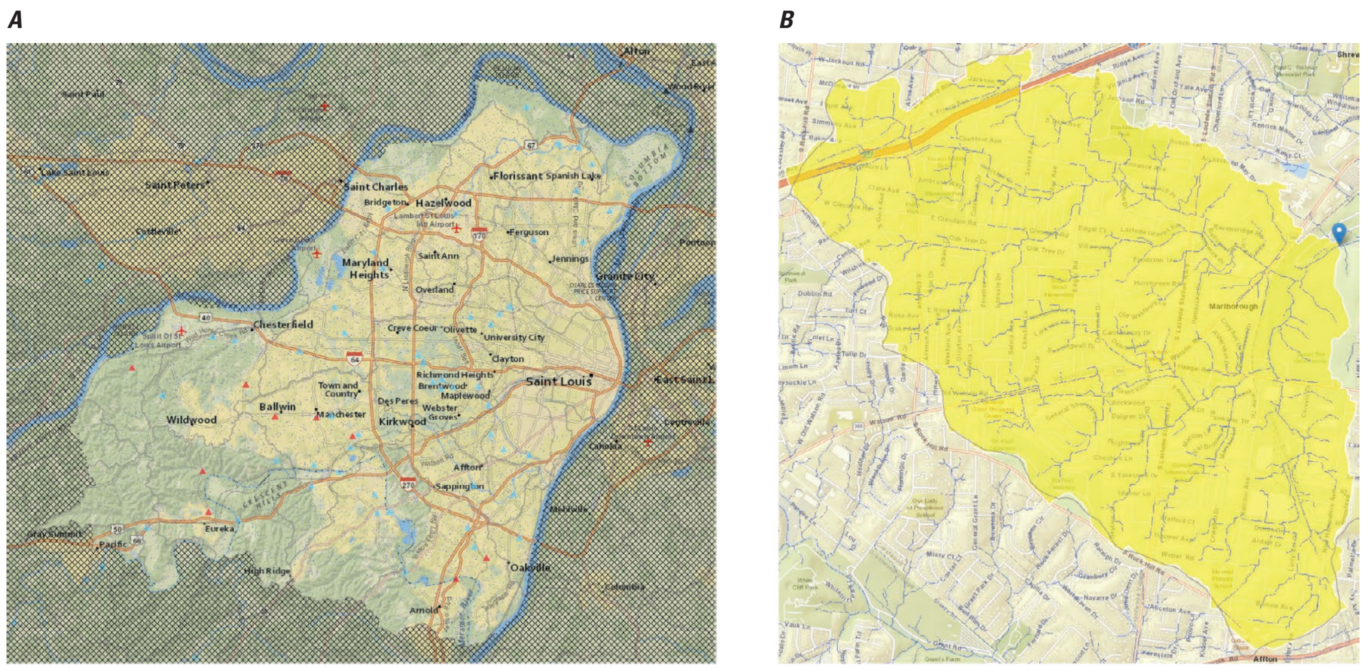
    - “The resulting delineations are derived from digital elevation data and storm drain vectors that have been processed to enforce drainage through storm drains.”

    - “Urban regression equations for peak flows were not developed using streamgages which incorporate storm drain delineations and therefore should be used with caution.”

    - “One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.”

## Limitations

The Missouri-St. Louis StreamStats application provides basin delineations, basin characteristics, and peak-flow statistics for urban areas using 3-m data resolution. The equations used to compute flow statistics (Southard, 2010) were based on the basin delineations and basin characteristics developed using a coarser resolution of data (10-m) than is present in this application. Testing at 11 streamgage sites in the study area that were among those used to develop the Southard (2010) equations has indicated that the 3-m data resolution reasonably reproduced the basin characteristic values at the gaged locations. For the 11 streamgage sites tested, the mean drainage area difference was −0.86 percent and the mean impervious




*C*

Basin Characteristics

| Parameter Code | Parameter Description | Value | Unit |
|---|---|---|---|
| DRNAREA | Area that drains to a point on a stream | 3.13 | square miles |
| IMPNLCD01 | Percentage of impervious area determined from NLCD 2001 impervious dataset | 36.9 | percent |

General Disclaimers

The resulting delineations are derived from digital elevation data and storm drain vectors that have been processed to enforce drainage through storm drains.

Urban regression equations for peak flows were not developed using streamgages which incorporate storm drain delineations and therefore should be used with caution.

Peak-Flow Statistics Parameters[Peak Urban StLouis SIR 2010 5073]

| Parameter Code | Parameter Name | Value | Units | Min Limit | Max Limit |
|---|---|---|---|---|---|
| DRNAREA | Drainage Area | 3.13 | square miles | 0.28 | 189 |
| IMPNLCD01 | Percent Impervious NLCD2001 | 36.9 | percent | 2.3 | 46 |

Peak-Flow Statistics Flow Report[Peak Urban StLouis SIR 2010 5073]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

| Statistic | Value | Unit | SEp |
|---|---|---|---|
| 5 Year Peak Flood | 1760 | ft^3/s | 23.3 |
| 10 Year Peak Flood | 2230 | ft^3/s | 22.1 |
| 25 Year Peak Flood | 2620 | ft^3/s | 22.1 |
| 50 Year Peak Flood | 3250 | ft^3/s | 23.3 |
| 100 Year Peak Flood | 3590 | ft^3/s | 25.6 |
| 500 Year Peak Flood | 4790 | ft^3/s | 35.2 |
| 2 Year Peak Flood | 1220 | ft^3/s | 26.7 |

*Peak-Flow Statistics Citations*

Southard, R.E.,2010, Estimation of the Magnituude and Frequency of Floods in Urban Basins in Missouri: U.S. Geological Survey Scientific Investigations Report 2010-5073, 27 p.

**Figure 13.** Examples from the Missouri-St. Louis StreamStats application. *A*, a Missouri-St. Louis StreamStats application valid study area extent; *B*, a Missouri-St. Louis StreamStats application delineated watershed polygon; *C*, a part of the output of the report indicating basin characteristics, peak-flow statistics, and warning messages.


**Figure 14.** Example of a basin delineated with the "Surface Contributing Basin only" option. *A*, checkbox unchecked; *B*, the same basin with the checkbox checked.

surface difference was 2.18 percent; however, the user should be cautioned that the spatial resolution is different in this application and that the values obtained from the regression equations may be affected.

The urban regression equations (Southard, 2010) were based on natural flow conditions and topographic watershed delineations and did not incorporate any pipe flow or sewershed delineations when they were developed. Because of this, an exclusion area was developed in the CSS area of HUC 07140101 to prevent the Missouri-St. Louis StreamStats application from calculating flow statistics where CSS exists. If the user computes estimated flow statistics outside the application with the Missouri-St. Louis StreamStats application derived basin characteristics, then the user is reminded that the equations are most applicable to topographic watershed delineations under natural flow conditions, and the results may not be applicable to areas with pipe flow. Topographic watershed delineations in the study area outside the excluded CSS area will compute flow statistics using the urban regression equations.

Because of the higher resolution of the data used in this application, a user can delineate small drainage areas that can be outside the range of the drainage areas used to develop the regression equations. If a user delineates a drainage area or obtains a basin characteristic value outside the intended range of valid equation parameters (0.28 to 189 $mi^2$ for drainage area and 2.3 to 46 percent for impervious surface; Southard, 2010), the Missouri-St. Louis StreamStats application will provide a warning that extrapolation has happened. Users should not assume that streamflow statistics are accurate when basin characteristics are estimated using extrapolation and should be cautious with the results.

The CSS network was assumed to be as complete and accurate as possible, but missing, mislocated, or misattributed pipes and inlet structures could affect how the sewersheds are delineated. The accuracy of the delineation of sewersheds is difficult to verify because the flow largely occurs underground, and as such, only a small amount of quality assurance data, obtained from MSD, were available to validate some sewershed delineations. It is possible that there are errors in the way the flow is accumulated in inlet structures and routed through the pipe network that could cause inaccuracies in the sewershed delineations. There are potential inaccuracies in the watershed boundaries and surface stream network determined from the 3-m DEM that could introduce error into topographic watershed delineations.

The Missouri-St. Louis StreamStats application only operates inside St. Louis County and the City of St. Louis but excludes locations on the main stem of the Mississippi, Missouri, and Meramec Rivers because upstream parts of those rivers have data that are not included in the Missouri-St. Louis StreamStats application. Areas of exclusion for these rivers are symbolized by a crosshatched pattern in the Missouri-St. Louis StreamStats application. Users who would like flow statistics on the Meramec River in the study area are referred to the Missouri statewide StreamStats application.

# Summary


The State of Missouri has recently (2018) implemented a web application, referred to as StreamStats, that incorporates a geographic information system to provide users the capability to retrieve streamflow information at selected streamgages throughout the State, do analyses to determine basin characteristics, and estimate statistics from selected regression analyses of high and low flows. StreamStats applications in Missouri and other States primarily are applicable for rural watersheds or watersheds with limited urban development.

Source data for statewide StreamStats applications require three national scale geospatial datasets that form the foundation of most geographic information system functions to determine basin characteristics. These datasets consist of (1) the 3D Elevation Program dataset; (2) the National Hydrography Dataset; and (3) the Watershed Boundary Dataset. A major limitation of the functionality of Missouri statewide StreamStats in urban areas such as St. Louis and Kansas City is a lack of resolution and excessive age of the elevation data in the rapidly changing urban landscape, lack of detailed hydrographic data, and watershed boundaries that do not account for anthropogenic structures. Additionally, a way of incorporating a pipe network, which is important to the management of stormwater runoff in urban areas, into an open channel flow system did not previously exist in the StreamStats application. For these reasons, the U.S. Geological Survey completed a study, in cooperation with the Metropolitan St. Louis Sewer District, to apply the StreamStats methodology to the dominantly urban study area of St. Louis County and the City of St. Louis in Missouri.

A 3-meter digital elevation model dataset was used in the study area derived from light detection and ranging data sources. Hydrography for the study area was created from the 3-meter digital elevation model and verified with the high-resolution orthophotograph (6-inch imagery) for accuracy. The hydrographic network for open channels was defined for watersheds greater than 20 acres. The 3-meter digital elevation model was hydrologically enforced at roadways and levees using a Python script to properly locate the stream line through the roadway or levee embankment. The 3-meter digital elevation model, 6-inch imagery, and digital geospatial data of the stormwater and combined sanitary sewer network allowed for verification and modification of the watershed boundary dataset. Some watersheds defined at the 12-digit hydrologic unit code level were further subdivided by digitizing the watershed boundaries by hand from contour data while considering anthropogenic features. These subdivided watershed boundaries were used to further hydrologically enforce the 3-meter digital elevation model.

The combined sanitary sewer network for the City of St. Louis and surrounding areas of St. Louis County was edited for connectivity and flow direction. Inlet structures in the geospatial data were defined as HydroJunction features that allow for stormwater runoff to enter the combined sanitary sewer network. An Arc Hydro stormwater processing

workflow and a sewershed delineation tool for determining the collection of catchment areas and the associated topographic watersheds of open channels that discharge into inlet structures were developed to integrate the combined sanitary sewer network with the hydrographic dataset and digital elevation model in the study area.

The StreamStats application developed for the study area provides various data exploration tools that can be used to examine the spatial data including distance measurement, developing an elevation profile, determining the flow path of water downstream from a user selected point, trace relations between two specified points through the network, and a network trace to identify available data selections, such as streamgages, dams, and water-quality sites. Network trace operations such as determining the downstream flow path of water, determining traces between two specified points, and identifying available data do not operate on the combined sanitary sewer lines. In addition, general descriptive information, information about the available flow data, and flow statistics can be obtained at streamgages in the study area. Watersheds can be delineated, basin characteristics can be calculated, and peak-flow statistics can be computed at any point on the open channel network. Within the area of the combined sanitary sewer network, sewersheds can be delineated and basin characteristics can be determined. A report summarizing the basin characteristics and the peak flows from published regression equations (where applicable) is generated, and the results can be downloaded and used in other software.

The limitations of the Missouri-St. Louis StreamStats application include possible inaccuracies using regression equations for peak-flow statistics developed assuming natural flow conditions and topographically derived watersheds determined from a coarser resolution of data than is used in this application. Additionally, regression equations for peak-flow statistics did not incorporate any pipe flow or sewershed delineations when they were developed, but the Missouri-St. Louis StreamStats application does delineate sewersheds. As a result, peak-flow statistics will not be computed within the combined sanitary sewer area. The Missouri-St. Louis StreamStats application results from drainage area delineations or basin characteristics values outside the range of the parameters used to develop the regression equations should be used with caution.

Potential limitations may exist in the geospatial accuracy of the combined sanitary sewer network because of errors in missing, mislocated, or misattributed inlet structures, and there are potential errors in the way the flow is accumulated in inlet structures and routed through the pipe network that could cause inaccuracies in the sewershed delineations. Potential limitations may exist in the location of the derived drainage network and watershed boundaries because of inaccuracy or insufficient resolution in elevation data, which may affect the accuracy of watershed delineations. The Missouri-St. Louis StreamStats application is limited to the area inside St. Louis County and the City of St. Louis and excludes locations on the main stem of the Mississippi, Missouri, and Meramec Rivers.

# References Cited

Ellis, J.T., 2018, Missouri StreamStats—A water-resources web application: U.S. Geological Survey Fact Sheet 2018–3003, 6 p. [Also available at https://doi.org/10.3133/fs20183003.]

Esri, 2017, Arc Hydro stormwater processing: Redlands, Calif., Esri, 72 p., accessed May 29, 2018, at http://downloads.esri.com/archydro/ArcHydro/Doc/Arc%20Hydro%20Stormwater%20v1%2010032017.pdf.

Esri, 2018, How to—Convert flow accumulation lines from a DEM file to a polyline shapefile in ArcMap: Esri web page, accessed May 1, 2018, at https://support.esri.com/en/technical-article/000012577.

Garbrecht, J., and Martz, L., 1997, The assignment of drainage direction over flat surfaces in raster digital elevation models: Journal of Hydrology (Amsterdam), v. 193, no. 1–4, p. 204–213. [Also available at https://doi.org/10.1016/S0022-1694(96)03138-1.]

Heidemann, H.K., 2014, Lidar base specification (ver. 1.2, November 2014): U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 67 p. with appendixes, accessed July 27, 2017, at https://doi.org/10.3133/tm11B4.

Jenson, S.K., 1991, Applications of hydrologic information automatically extracted from digital elevation models: Hydrological Processes, v. 5, no. 1, p. 31–44. [Also available at https://doi.org/10.1002/hyp.3360050104.]

Maidment, D.R., 2002, Arc Hydro—GIS for water resources: Redlands, Calif., Esri Press, 203 p.

National Oceanic and Atmospheric Administration Coastal Services Center, 2012, Lidar 101—An introduction to lidar technology, data, and applications: Charleston, S.C., National Oceanic and Atmospheric Administration Coastal Services Center, 72 p. [Also available at https://coast.noaa.gov/data/digitalcoast/pdf/lidar-101.pdf.]

Poppenga, S.K., Worstell, B.B., Stoker, J.M., and Greenlee, S.K., 2009, Comparison of surface flow features from lidar-derived digital elevation models with historical elevation and hydrography data for Minnehaha County, South Dakota: U.S. Geological Survey Scientific Investigations Report 2009–5065, 24 p. [Also available at https://doi.org/10.3133/sir20095065.]

Ries, K.G., III, Guthrie, J.D., Rea, A.H., Steeves, P.A., and Stewart, D.W., 2008, StreamStats—A water resources web application: U.S. Geological Survey Fact Sheet 2008–3067, 6 p., accessed April 30, 2018, at https://doi.org/10.3133/fs20083067.

Southard, R.E., 2010, Estimation of the magnitude and frequency of floods in urban basins in Missouri: U.S. Geological Survey Scientific Investigations Report 2010–5073, 27 p. [Also available at https://doi.org/10.3133/sir20105073.]

U.S. Geological Survey, 2004, NHD Watershed Tool—Instructions for preprocessing supporting data layers: U.S. Geological Survey web page, accessed April 30, 2018, at https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhd-watershed-tool#Instructions.

U.S. Geological Survey, 2020, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed April 15, 2020, at https://doi.org/10.5066/F7P55KJN.

U.S. Geological Survey, n.d., Watershed Boundary Dataset: U.S. Geological Survey web page, accessed December 18, 2019, at https://www.usgs.gov/core-science-systems/ngp/ngtoc/watershed-boundary-dataset.

U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013, Federal standards and procedures for the National Watershed Boundary Dataset (WBD) (4th ed.): U.S. Geological Survey Techniques and Methods, book 11, chap. A3, 63 p., accessed March 5, 2015, at https://pubs.usgs.gov/tm/11/a3/.

# Appendix

Python code used to delineate stream lines from 3-meter digital elevation model (DEM) data is contained in the zipped archive UrbanPourFlow_python_script.zip (available for download at https://doi.org/10.3133/sir20205040). This code allows for traversing flat areas such as lakes or filled sinks and allows for a continuous path to be determined across urban streamflow barriers such as road embankments and levees. Road embankments and levees are not typically hydrographically enforced in high resolution DEM data and ordinary stream line delineation processes (like those found in standard geographic information systems [GIS] software packages) often have trouble correctly delineating stream lines across these features.

## Software Author

All code in this script archive was developed by the author listed below to solve a specific issue described in this report and may not apply generally to other specific problems. All questions regarding the script should be directed to the author below.

Philip Thiem
U.S. Geological Survey
National Geospatial Technical Operations Center
1400 Independence Road
Rolla, MO 65401
pthiem@usgs.gov
573–308–3652

## Python Packages Required

The following Python packages are required.

- arcpy
- collections
- numpy
- os
- usgs.gp
- itertools
- bisect

## Inputs Required

The following inputs are required and are defined in this section.

**unfilled DEM** Unaltered 3-meter DEM data.

**filled DEM** A 3-meter DEM that has been filled to the desired fill threshold. Determination of a satisfactory fill threshold may require some experimentation. A fill threshold of 1.97 feet was used to delineate stream lines for the project this software was written to support. DEM filling is done outside the script in a stand-alone GIS software package such as ArcGIS.

**raster of starting locations** A raster of upstream locations where stream line delineation should originate. This dataset is created in a stand-alone GIS software package, such as ArcGIS, using the standard tools available.

## Workflow

Compute, using GIS tools, a filled 3-meter DEM from the unfilled 3-meter DEM. Compute a flow direction raster and a flow accumulation raster from the filled DEM. Using the flow direction raster and a flow accumulation raster, compute a raster of the origin of the stream lines to be delineated using the script.

## Generalized Function of the Script

This script, using the raster of starting locations derived from the GIS tools, computes the drainage network by determining the direction of flow from the slopes of the surrounding cells and moving downslope until either a flat area is encountered (a partially filled sink or a waterbody) or a sink is encountered. Delineation of the stream line across flat areas was computed using the algorithm described in Garbrecht and Martz (1997). The continuation point across an obstacle (road, levee, or floodwall) of a stream line that enters a sink is determined by searching for a cell that is lower than the lowest cell in the sink within a specified search distance and direction. The search distance was 80 cells, and the initial search direction is determined from averaging the directional trend of stream lines entering the sink. The search direction is varied to the left and right of the initial trend by as much as 100 degrees until a cell lower than the lowest cell in the sink is found. If a target cell is found, a line connecting the lowest cell in the sink to the target cell is computed and the slope-wise delineation is continued from the target cell. If a target cell is not found within the search distance or the search angle, the script moves on to the next location in the raster of starting locations.

## Output

The associated output is defined as follows:

**stream line raster** A raster that depicts the stream lines that are derived from the 3-meter DEM and that correctly cross flat areas and traverse road embankments and levees.

## Distribution Liability

Unless otherwise stated, all data, metadata, and related materials are considered to satisfy the quality standards relative to the purpose for which the data were collected. Although these data and associated metadata have been reviewed for accuracy and completeness and approved for release by the U.S. Geological Survey (USGS), no warranty expressed or implied is made regarding the display or utility of the data for other purposes, nor on all computer systems, nor shall the act of distribution constitute any such warranty. The software has been approved for release by the USGS. Although the software has been subjected to rigorous review, the USGS reserves the right to update the software as needed pursuant to further analysis and review. No warranty, expressed or implied, is made by the USGS or the U.S. Government as to the functionality of the software and related material nor shall the fact of release constitute any such warranty. Furthermore, the software is released on condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from its authorized or unauthorized use. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The names mentioned in this document may be trademarks or registered trademarks of their respective trademark owners.

## Reference Cited

Garbrecht, J., and Martz, L., 1997, The assignment of drainage direction over flat surfaces in raster digital elevation models: Journal of Hydrology (Amsterdam), v. 193, no. 1–4, p. 204–213. [Also available at https://doi.org/10.1016/S0022-1694(96)03138-1.]

For more information about this publication, contact:
Director, USGS Central Midwest Water Science Center
1400 Independence Road
Rolla, MO 65401
573–308–3667

For additional information, visit:
https://www.usgs.gov/centers/cm-water

Publishing support provided by the
Rolla Publishing Service Center

Southard and others—**Missouri StreamStats—St. Louis County and the City of St. Louis Urban Application**—Scientific Investigations Report 2020–5040

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20205040