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Flood-Hazard Analysis of Four Headwater Streams Draining the Argonne National Laboratory Property, DuPage County, Illinois

Scientific Investigations Report 2016–5132

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

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Conversion Factors

Inch/Pound to SI

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	0.4047	hectare (ha)
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
inch per hour (in/h)	0.0254	meter per hour (m/h)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F – 32) / 1.8.

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.

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Abstract

Results of a flood-hazard analysis conducted by the U.S. Geological Survey, in cooperation with the Argonne National Laboratory, for four headwater streams within the Argonne National Laboratory property indicate that the 1-percent and 0.2-percent annual exceedance probability floods would cause multiple roads to be overtopped. Results indicate that most of the effects on the infrastructure would be from flooding of Freund Brook. Flooding on the Northeast and Southeast Drainage Ways would be limited to overtopping of one road crossing for each of those streams. The Northwest Drainage Way would be the least affected with flooding expected to occur in open grass or forested areas.

The Argonne Site Sustainability Plan outlined the development of hydrologic and hydraulic models and the creation of flood-plain maps of the existing site conditions as a first step in addressing resiliency to possible climate change impacts as required by Executive Order 13653 "Preparing the United States for the Impacts of Climate Change." The Hydrological Simulation Program-FORTRAN is the hydrologic model used in the study, and the Hydrologic Engineering Center–River Analysis System (HEC–RAS) is the hydraulic model. The model results were verified by comparing simulated water-surface elevations to observed water-surface elevations measured at a network of five crest-stage gages on the four study streams. The comparison between crest-stage gage and simulated elevations resulted in an average absolute difference of 0.06 feet and a maximum difference of 0.19 feet.

In addition to the flood-hazard model development and mapping, a qualitative stream assessment was conducted to evaluate stream channel and substrate conditions in the study reaches. This information can be used to evaluate erosion potential.

Introduction

The Argonne National Laboratory (ANL) is a U.S. Department of Energy research and development facility established in 1942 and operated by UChicago Argonne, LLC. ANL is located near Lemont in DuPage County, Illinois (fig. 1). The facility is mostly within the southwestern part of Sawmill Creek watershed and is surrounded by the DuPage County Waterfall Glen Forest Preserve. More than 100 buildings are within the ANL property. The laboratory and support facilities occupy approximately 1,200 acres of land; the remaining 500 acres of land is forest and landscaped area.

ANL has developed and implemented an annual Site Sustainability Plan (SSP; Argonne National Laboratory, 2015a) in compliance with the Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance." Under Executive Order 13653 "Preparing the United States for the Impacts of Climate Change" (The White House, 2013), Federal agencies are required to find new strategies to improve climate change resilience and preparedness. In response to these two Executive Orders, ANL included stormwater management goals in the SSP. The U.S. Geological Survey (USGS), in cooperation with the ANL, conducted a hydrologic and hydraulic characterization of the site to identify areas with flood risk and areas where stormwater management can be used to meet planning and sustainability goals. Hydrologic and

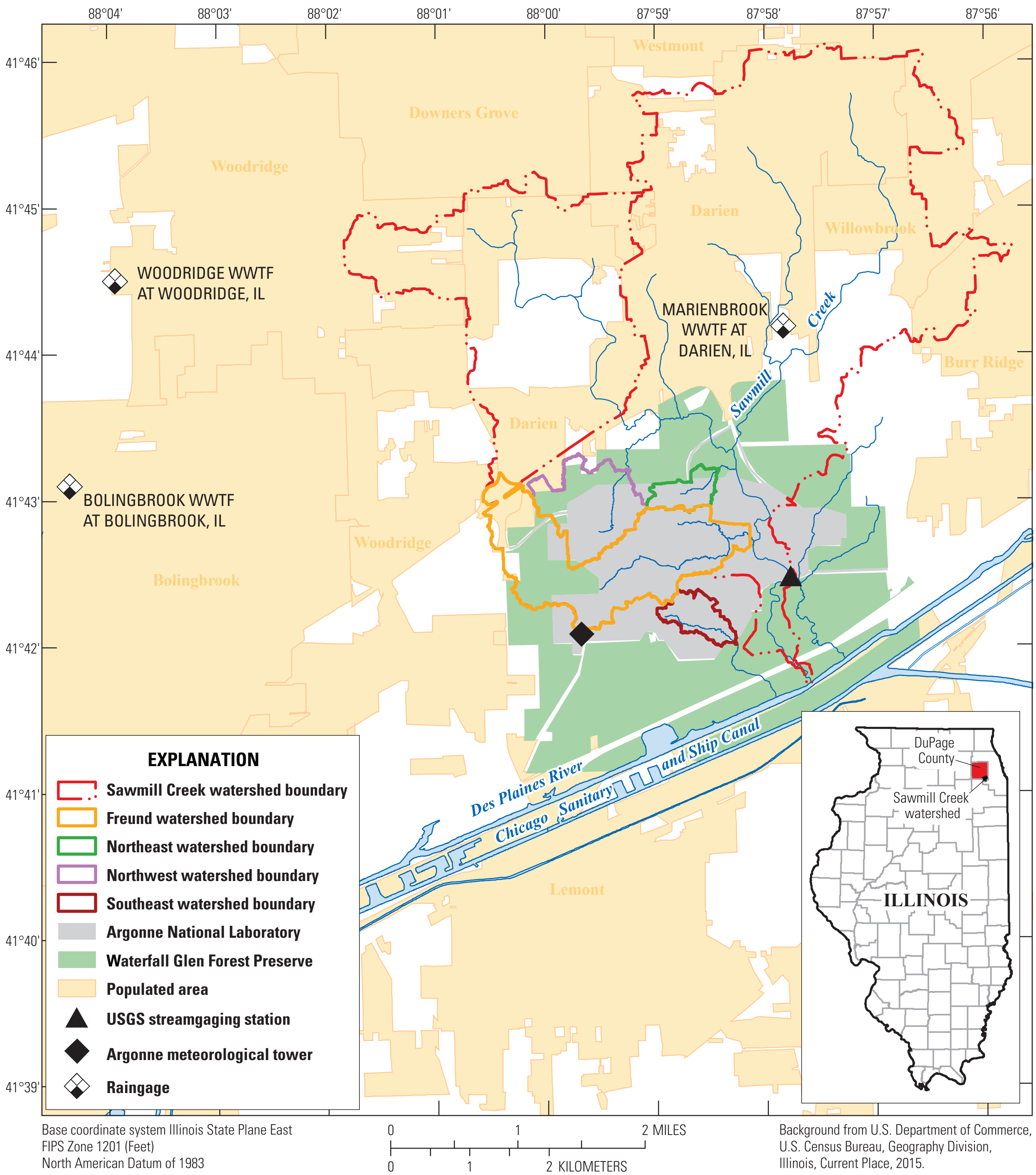

Figure 1. Location of Argonne National Laboratory in Sawmill Creek watershed in DuPage County, Illinois. (USGS, U.S. Geological Survey; WWTF, wastewater treatment facility)

hydraulic (H&H) modeling and analysis were used to identify site vulnerabilities (flooded areas) and can be used for future facility planning.

Purpose and Scope

The purpose of this report is to document the development of the ANL H&H models and the resulting flood-hazard maps. Four headwater streams that drain water from the ANL property were investigated during this study: Northwest Drainage Way, Northeast Drainage Way, Freund Brook (two branches and main stem), and Southeast Drainage Way. The hydrologic analysis is used to estimate peak-flow magnitudes with annual exceedance probabilities of 1-percent (100-year flood) and 0.2-percent (500-year flood), hereafter referred to as flood quantiles. The hydraulic analysis is used to estimate water-surface elevations corresponding to these flood quantiles. Flood-hazard maps are developed that show the area inundated by flows that correspond to the selected flood quantiles.

Approach

The watershed hydrology was simulated by using version 12.2 of the Hydrological Simulation Program-FORTRAN (HSPF) program (Bicknell and others, 2000) in Better Assessment Science Integrating point & Non-point Sources (BASINS) version 4.1 (http://www.epa.gov/exposure-assessment-models/basins). PeakFQ version 7.1 (Veilleux and others, 2014) was used to estimate flood quantiles from simulated streamflows with a flood-frequency analysis based on Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). The water-surface elevation profile was estimated by using the Hydrologic Engineering Center–River Analysis System (HEC–RAS) program Version 4.1 (U.S. Army Corps of Engineers, 2010a, b, c), and the inundated areas were mapped with the ArcMap geographic information system (GIS) program (Esri, 2016a).

The study included review of the historical Argonne meteorological data for input to HSPF and collection of additional field data for model verification. With the absence of on-site streamflow data for calibration of the rainfall-runoff parameters, the ANL HSPF models incorporated the calibrated and verified rainfall-runoff parameters from the Sawmill Creek watershed HSPF model developed for DuPage County Stormwater Management Department (Appendix 1; Price, 1996, 2011), a regional parameter approach. Overall, the study approach had six specific steps.

1. Conduct site and stream condition assessments to identify drainage characteristics and flow-constricting and ponding areas, and erosional issues. The assessment included measurement of channel bathymetry and hydraulic structures, and documentation of stream conditions through photographs and written notes. (Stream condition assessment is summarized in Appendix 2).
2. Install crest-stage gages to record peak water-surface elevations during storms. The collected peak-elevation data were used for validating the HSPF and HEC–RAS models for storms in water year (WY)[1] 2015.
3. Develop HSPF models for the four study watersheds using appropriate topographic, stream-network, land-use, and meteorological data to generate simulated streamflows. The period of simulation is WY 1949 to WY2014.
4. Conduct statistical flood-frequency analysis on the simulated streamflow time series to estimate peak-flood quantiles at appropriate stream locations.
5. Develop HEC–RAS models for the four study reaches using surveyed topographic data and supplemental cross-section data available from existing DuPage Sawmill Creek hydraulic models to generate water-surface profiles corresponding to the 1- and 0.2-percent flood quantiles.
6. Use water-surface profiles, in ArcMap, to estimate flood inundation boundaries for the 1- and 0.2-percent flood quantiles.

Description of Study Area

The ANL property extends approximately 1.5 miles in the north-south direction and 2 miles in the east-west direction. The extents of the four study reaches were selected by ANL staff. USGS developed appropriate watershed boundaries for these selected streams. The Northwest Drainage Way, Northeast Drainage Way, and Freund Brook eventually drain to the Sawmill Creek, whereas the Southeast Drainage Way drains directly to the Des Plaines River (fig. 1). Buildings are clustered in several areas and identified by either location (for example, East Area) or a number. Three building complexes within the study area are shown in figure 2: 200 Area (ANL main campus), 300 Area (service facilities) and 400 Area (Advanced Photon Source [APS] buildings). The Northwest and Northeast Drainage Ways drain water away from the 200 Area. The Southeast Drainage Way drains water away from the 300 and 400 Areas. The Lower Branch Freund Brook flows through the interior part of the ANL between 400, 200, and 300 Areas, and the Upper Branch Freund Brook drains the interior part of the 200 Area.

Watersheds

In general, the expected flow volume is proportional to the drainage area of a watershed; however, the flow patterns can be altered by channel characteristics such as bed slopes,

[1] A water year is the 12-month period from October 1 to September 30 and is designated by the calendar year in which it ends.

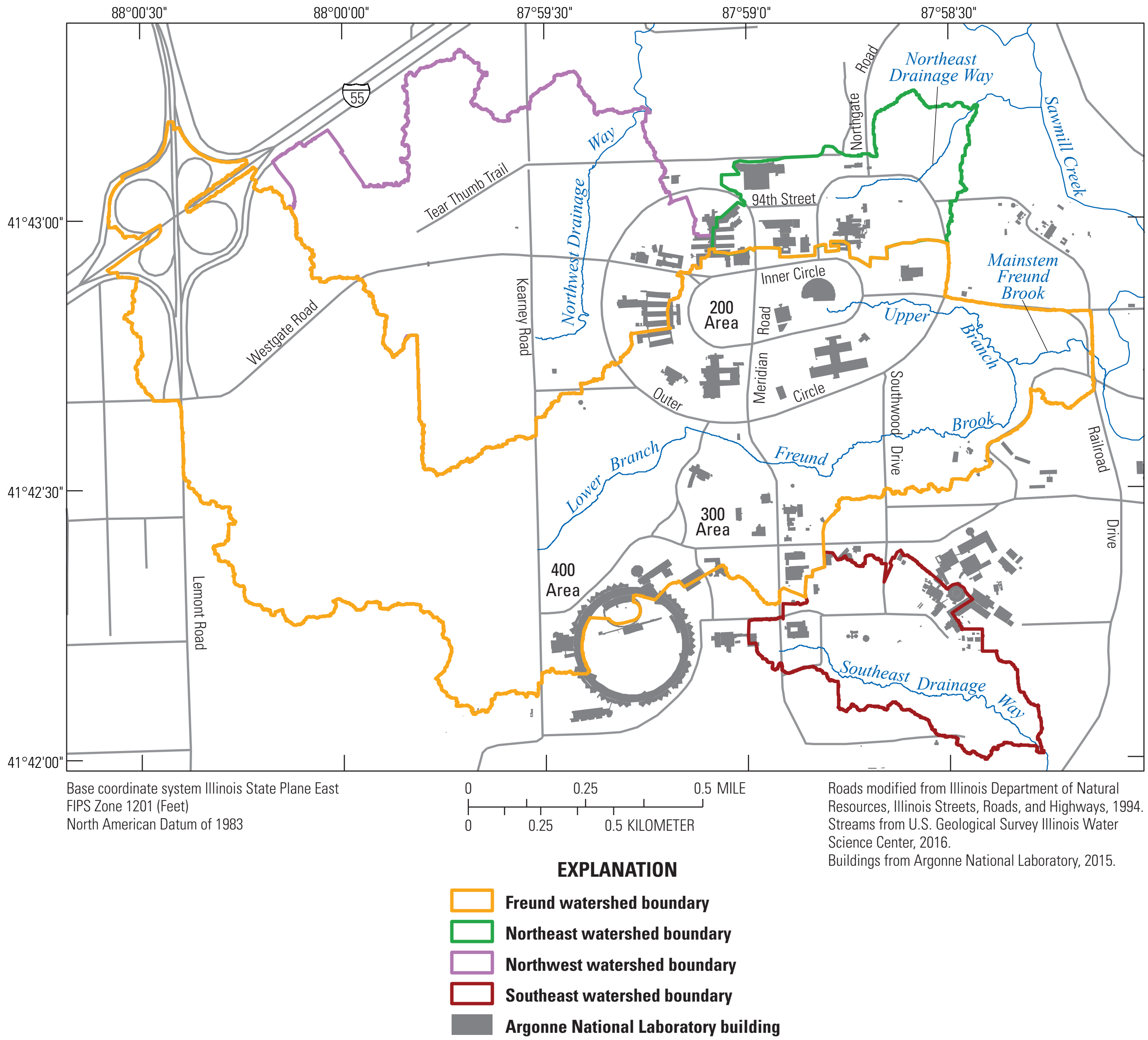

Figure 2. Location of four study streams with watersheds and Areas, Argonne National Laboratory, DuPage County, Illinois.

width and depth, obstacles and constrictions, longitudinal configurations, and man-made alterations.

Northwest Drainage Way

The drainage area of the Northwest Drainage Way is approximately 0.437 square miles (fig. 2). The Northwest Drainage Way drains storm runoff generated from buildings on the west side of the 200 Area. The length of the mapped study reach is approximately 0.52 mile with an elevation drop from 730 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88) to 715 ft (slope ≈ 29 feet per mile [ft/mile]). The main channel originates above the study reach in forested land in the southern part of the watershed. The study reach begins downstream from Kearney Road then flows northeast through a wetland west of Outer Circle. Upstream from the wetland, the stream narrows and passes under an abandoned road in the forested area south of Westgate Road, then passes through the Westgate Road culvert. North of Westgate Road, the stream passes through steeper and forested terrain. The study reach ends at the fence marking the ANL property line (Tear Thumb Trail). Beyond the ANL property, the Northwest Drainage Way joins Sawmill Creek.

Northeast Drainage Way

The drainage area of the Northeast Drainage Way is approximately 0.12 square miles (fig. 2). The Northeast Drainage Way drains storm runoff generated from the northern and northeastern parts of the 200 Area (buildings and parking lots north and south of Outer Circle/Northgate Road). The length of the study reach is approximately 0.31 mile with an elevation drop from 705 ft NAVD 88 to 675 ft (slope ≈ 97 ft/mile). The main channel originates at a swale and receives additional overland flow before becoming a channel along the south side of Outer Circle. The Drainage Way passes through a culvert under the northeast corner of Outer Circle, east of the intersection with Northgate Road and northwest of the intersection with 94th Street. After passing through the Outer Circle culvert, the channel flows into a valley area with steeper slopes.

Freund Brook

The drainage area of the Freund Brook modeled in this study is approximately 1.15 square miles (fig 2). Freund Brook is the largest stream within ANL property. Freund Brook has three reaches—Upper Branch, Lower Branch, and the main stem Freund Brook. The length of Upper Branch Freund Brook study reach is approximately 0.57 mile with an elevation change from 710 ft NAVD 88 to 670 ft (slope ≈ 70 ft/mile). The Upper Branch Freund Brook drains storm runoff from the central and southern parts of the 200 Area. The Upper Branch Freund Brook originates at a retention pond on the east side of the 200 Area, within Inner Circle. The Upper Branch Freund Brook then passes through culverts under a sidewalk path, Inner Circle, and Outer Circle before joining the Lower Branch Freund Brook.

The length of Lower Branch Freund Brook study reach is approximately 1.46 miles with an elevation drop from 725 ft NAVD 88 to 670 ft (slope ≈ 37 ft/mile). However, an appreciable drop in elevation occurs in the Lower Branch Freund Brook after the channel passes under Meridian Road. The channel slope is approximately 9.5 ft/mile upstream from Meridian Road, whereas it is approximately 47.1 ft/mile downstream from Meridian Road. The steep part of the reach includes a 10 ft dam structure between Southwood Road and the confluence of the Lower Branch with the Upper Branch Freund Brook. The Lower Branch Freund drains storm runoff from the 400 Area and the eastern part of the 300 Area. The Lower Branch Freund Brook originates west of the ANL property at a pond southeast of the Interstate 55 ramp with Lemont Road, then travels through wetlands and forested area. It enters the ANL property through a culvert under the fence near Kearney Road. The Lower Branch passes under Kearney Road through a culvert, then passes through a large wetland area. It passes through a culvert under an unnamed road, then through a culvert under Meridian Road. The stream passes under an old railroad trestle in a forested area downstream from Meridian Road and continues through the Southwood Drive culvert through more forested area before it joins the Upper Branch Freund Brook. The Upper and Lower Branches of Freund Brook converge and become the main stem Freund Brook before passing through a wetland area and then through the Railroad Drive culverts. Freund Brook joins Sawmill Creek east of the ANL property. The length of Freund Brook study reach after the confluence of the two branches is approximately 0.34 mile with an elevation drop from 670 ft to 650 ft (slope ≈ 59 ft/mile).

Southeast Drainage Way

The total drainage area of the Southeast Drainage Way is approximately 0.145 square miles (fig. 2). The length of the study reach is approximately 0.68 mile. The elevation change is 740 ft NAVD 88 to 640 ft at Railroad Drive (slope ≈147 ft/mile). The Southeast Drainage Way drains storm runoff from the southern and eastern parts of the 300 Area into the Des Plaines River (not shown in fig. 2). The study reach begins at Meridian Road; it does not pass through any structures before leaving the ANL property. The Southeast Drainage Way enters the Des Plaines River off the ANL property at an elevation of 590 ft. Because of the bluff, the backwater from the Des Plaines River likely has minimal effect on the flood plains on ANL property.

Geology and Soils

The regional geologic framework is Silurian dolomite at the bedrock surface overlain by the Lemont drift (silt, sand, gravel, cobbles, boulders, and silty till; highly variable) and with the Wadsworth Till Member of the Wedron Formation, which is at the surface (Killey and Trask, 1994). The Wadsworth is approximately 50 ft to as much as 80 ft thick and consists primarily of silty clay, clay loam, and silty clay loam diamicton. Information on the onsite soil profile within ANL can be found in Chang (1995).

Climate

Northeastern Illinois has a typical continental climate with cold winters, warm summers, and frequent short fluctuations in temperature, humidity, cloudiness, and wind direction. The sun, weather system, urban areas, and Lake Michigan are the four factors controlling the climate (Angel, 2016). With its proximity to Chicago, the climate at ANL site fits in this general pattern. Average yearly rainfall from the Argonne meteorological tower (MT; fig. 1) is 35.5 inches per year, based on data from WYs 1949–2014.

Streamflow

There are no continuous streamflow data records for the study watersheds. The closest USGS streamflow gage is Sawmill Creek near Lemont, Illinois (station number 05533400) east of the ANL property (fig. 1). Sawmill Creek at this location receives runoff from a drainage area about 13 square miles. Land use in the drainage area north of Interstate 55 is urban, whereas in the area to the south, the landscape is highly vegetated and in a more natural state (fig. 2).

Previous Studies

The DuPage County Stormwater Management Department (SMD) has developed watershed plans, including one for the Sawmill Creek watershed, which encompasses most of the ANL, for alleviating current and anticipated flooding problems; indexing significant natural areas, storage areas, and wetlands; and updating flood-plain maps (McLaughlin, 2004). The plans specify the use of the HSPF and the Full Equations model (FEQ; Franz and Melching, 1997) as the hydrological and hydraulic models, respectively. The continuous output from the HSPF model, as time series of streamflows, is input to the FEQ model to determine the propagation of flood waves and corresponding stages.

Calibration of the HSPF rainfall-runoff parameters for the DuPage County watersheds has been conducted by Price (1996). For the Sawmill Creek watershed, the model parameters have been calibrated (Price, 1996) and verified (Price, 2011). Meteorological database development, land-cover updates, model-calibration procedures, and calibration results for separate modeling periods are discussed in two reports (Price, 1996, 2011). In the 1996 report, HSPF parameters were calibrated for a period from WY 1986 to WY 1993, whereas in the 2011 report, the HSPF parameters were verified for the period from WY 1996 to WY 2008.

A modeling study, using FEQ as the hydraulic model, of DuPage County in 2010 by Nika Engineering included parts of two of the current study streams. The Northwest Drainage Way was modeled as Reach 7 in the DuPage County FEQ Sawmill Creek model (Nika Engineering, 2010). The Lower Branch Freund Brook was modeled as Reach 9 of the Sawmill Creek in the FEQ model (Nika Engineering, 2010), but the Upper Branch Freund Brook was not included in the study. These FEQ hydraulic models were not used in the current study; however, channel and structure geometry from these FEQ models were incorporated into the current study HEC–RAS models.

The Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for DuPage County, Ill., and Incorporated Areas (Federal Emergency Management Agency, 2004) includes a Zone A delineation of 1-percent annual chance flood for the Northwest Drainage Way and Lower Branch Freund Brook. A Zone-A delineation does not include any base flood elevations and implies that a detailed study (usually a hydraulic modeling study) was not conducted for the reach. The FIS states that regional equations were used to estimate discharge values for these ungaged reaches. Regulatory flood-plain boundaries were not developed for the other study reaches.

Hydrologic Modeling Input

The Hydrological Simulation Program-FORTRAN (HSPF) is a continuous hydrologic simulation model. The model uses precipitation and other meteorological time series as inputs and generates streamflow time series at the outlet of each designated catchment as output. In contrast to event models in which the antecedent moisture content must be estimated in order for the watershed models to produce realistic runoff volumes, continuous models account for soil moisture content continuously and are considered better approaches for simulating the long-term hydrological processes of a watershed. A model such as HSPF, with a more complex representation of the hydrologic processes, is also better suited to climate-change scenarios that may incorporate more than just changes in precipitation amounts during storms and instead look at changes over a series of years or seasons during the year.

Long-term measured meteorological records from WY 1949 to WY2014 were input to the four ANL watershed HSPF models to drive the runoff simulations at a 1-hour time step. Using the long-term meteorological data to generate a long-term peak-flood record yields representative flood quantiles. Subdividing a watershed into hydrologically consistent and connected catchments provides an opportunity for specifying output locations for runoff time series within the watershed. In this study, special consideration was given to buildings and parking lots in the watershed where higher runoff amounts are anticipated, and the storm sewer systems further distribute the discharge points of the storm runoff. Also an effort was made to configure the catchments to be compatible with future investigations of green infrastructure scenarios.

The runoff time series will resemble streamflow time series if the effects of geometry and hydraulic properties of the channels are incorporated, such as the flow patterns that one would expect from grass versus man-made channels, from ponds versus narrow channels, or from flat versus steep channels, even if the inflows feeding them are the same. For HSPF modeling this means that the reach-reservoir (RCHRES) module was used to simulate the hydrologic routing through each catchment. The RCHRES module describes the length, slope, and substrate of the stream reach. A function table, called an FTABLE, was developed to describe the geometric and hydraulic properties of each RCHRES (Bicknell and others, 2000). FTABLEs relate the flow, surface area, and channel volume in a stream reach to increases in channel depth.

Meteorological Data

Meteorological data collected at Argonne MT (fig. 1) were used for all four watersheds as the input meteorological data for long-term continuous simulations. Meteorological data, including measured cloud cover, solar radiation, air temperature, dewpoint temperature, and wind movement, and computed potential evapotranspiration (PET), were collected and quality-assured and quality-controlled (QA/QC; Over and others, 2010). PET is calculated from solar radiation, air temperature, dewpoint temperature, and wind movement by using the LXPET utility program (Murphy, 2005). Bera (2014) describes how meteorological data from Argonne MT are prepared for the near real-time forecast system for Salt Creek in DuPage County, Ill.

Hourly precipitation data measured at Argonne MT were obtained from DuPage SMD for the period from January 1, 1948, to September 30, 2008 (Christine Klepp, DuPage County, written commun., July 2015). This study extended the precipitation data by adding the period from October 1, 2008, to December 31, 2015. The following paragraphs describe how the hourly precipitation data were derived from measurements from Argonne MT and nearby USGS precipitation gages for the period from October 1, 2008, to December 31, 2015.

Precipitation data recorded at Argonne MT include hourly precipitation from a tipping-bucket gage and daily precipitation from a weighing-bucket gage. Tipping-bucket gages generally under-report rainfall amounts (Straub and Bednar, 2002; Straub and Parmar, 1998). To derive the hourly precipitation used as model input in this study, USGS followed the method used in the DuPage County models described in Price (1996) and disaggregated the daily weighing-bucket totals to hourly values, following the pattern observed in the collocated tipping-bucket gage. The daily total was disaggregated to an hourly amount by using the WDMUtil program V2.27 (Hummel and others, 2001) with a 20-percent tolerance.

To verify the amount, the USGS compared daily total rainfall amounts from the Argonne MT tipping-bucket gage, Argonne MT weighing-bucket gage, and a nearby USGS tipping-bucket gage (Sawmill Creek near Lemont; 05533400). Note that the tipping-bucket gages record hourly data, but the data have been summed to daily totals for comparison in these five steps.

1. If values from the Argonne MT weighing and tipping gages are zero, skip to next data point.
2. If the Argonne MT weighing gage and Sawmill tipping gage have registered rainfall, but none was recorded at the Argonne MT tipping gage, replace the hourly Argonne MT tipping-gage records with those of the Sawmill tipping gage for the same period.
3. If the Argonne MT tipping gage and Sawmill tipping gage have registered rainfall but none was recorded at the Argonne MT weighing gage, replace the weighing-gage value with the daily value from the Argonne MT tipping gage, unless the tipping-gage daily value differs from that of Sawmill tipping gage by more than 100 percent and demonstrates inconsistent consecutive daily patterns. If this happens, refer to step 5.
4. If the daily values from the Argonne MT tipping and weighing gages differ by more than 50 percent, and the Sawmill tipping gage has a value similar to that of rainfall measured at the Argonne MT tipping gage, use the Argonne MT tipping-gage daily value.
5. If Argonne MT tipping and weighing gages demonstrate inconsistent information and Sawmill tipping gage data are unavailable, refer to three USGS precipitation gages in the vicinity to determine a daily value for the weighing gage. The precipitation gages are 414430088035600 (Woodridge wastewater treatment facility [WWTF] at Woodridge, Ill), 414306088042100 (Bolingbrook WWTF at Bolingbrook, Ill), 414411087575000 (Marienbrook WWTF at Darien, Ill) (available at http://maps.waterdata.usgs.gov/mapper/index.html).

Topographic Data

A high-resolution digital elevation model (DEM) with a 3 ft by 3 ft grid size was used in the study. The DEM was received from DuPage County (Christine Klepp, DuPage County, written commun., 2015) but was produced by the Illinois State Geological Survey as part of the Illinois Height Modernization Program. The Countywide DEM was developed from lidar (Light Detection and Ranging) data collected in 2006. The horizontal accuracy of the lidar is 1.9 feet, and the vertical accuracy is 0.4 ft. The root mean square error of the vertical accuracy is 0.151 ft.

Land Use

Multiple land uses may be present in a watershed. Typically, generalized land-cover types are used to describe these land uses (fig. 3), and different hydrologic parameters are applied to distinguish the runoff potential from each type of land use in the watershed. Changes in land cover and landscapes modify the natural state of infiltration, streamflow, base flow, and evapotranspiration (National Research Council, 2009).

In modeling terminology, a designated land-cover type represents a hydrologic response unit (HRU) of the watershed. The six HRUs used in the Sawmill Creek watershed HSPF model (Price, 1996) are hydraulically connected impervious area; flat, moderate, and steep grassland; forest/lowland; and agricultural land. Each HRU has a unique set of parameters to describe its rainfall to runoff transformation capability. These parameter values are determined through calibration (Price, 1996).

In order to incorporate the Sawmill Creek HSPF parameters, watersheds of the ANL HSPF models were also described using these six HRUs. The study improved the land-parcel divisions for ANL and applied the digitized building/parking lot areas to determine impervious lands within the building areas within the ANL property. These steps enhanced the accuracy of delineated impervious areas within the ANL property.

Assigning the Sawmill Creek HRUs to catchments of the ANL HSPF watershed models involves adapting a set of

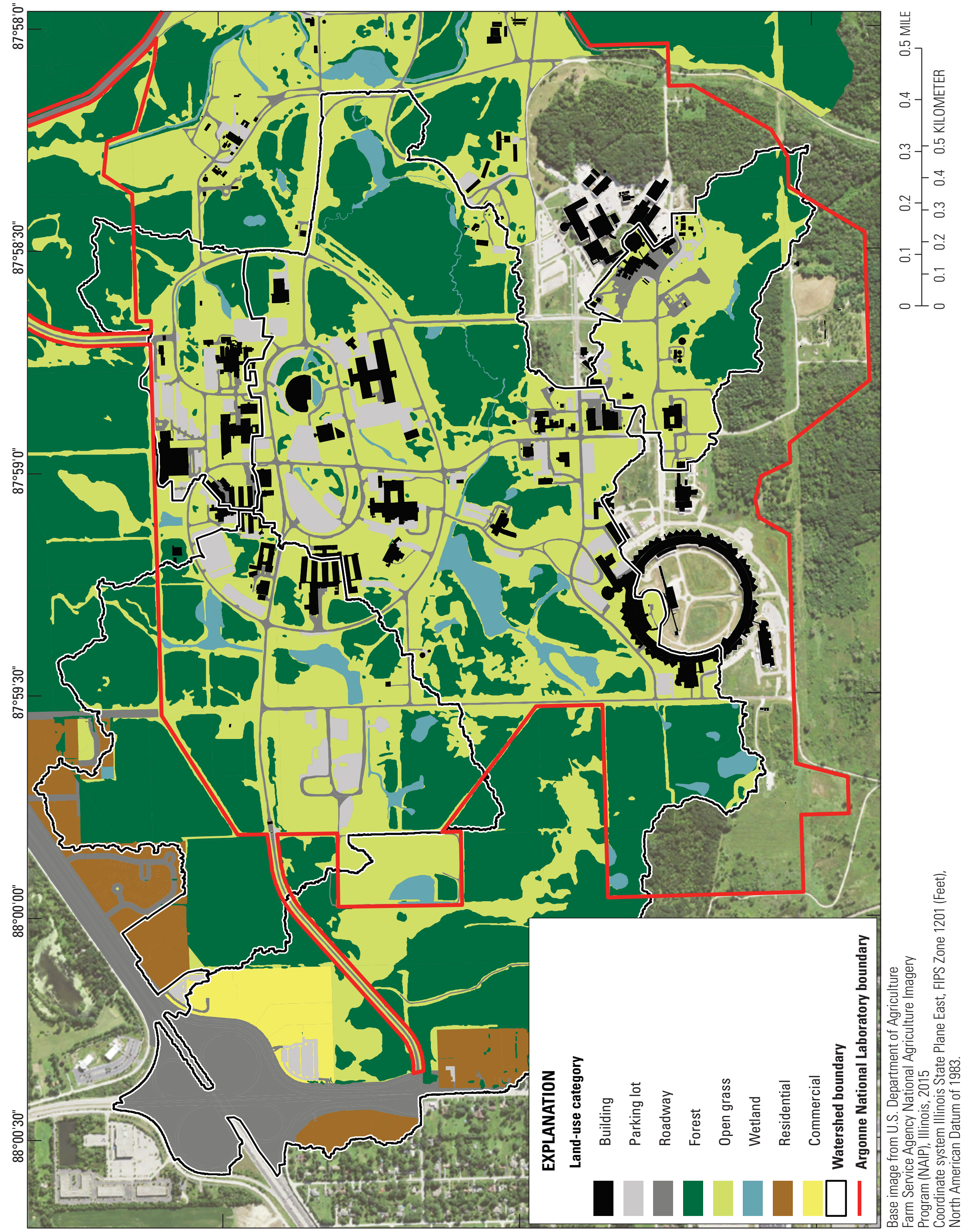

Figure 3. Land-use categories in Argonne National Laboratory, DuPage County, Illinois, that are translated to hydrologic response units used in the Hydrological Simulation Program-FORTRAN.

land-use codes developed by SMD and used by the SMD to break every parcel in the County into the limited land-use types used in the HSPF model. Specifically, the steps involved (1) assigning the land-use code following the DuPage definitions to a 2009 version of the land-use parcel database of the Sawmill Creek watershed produced by SMD (Christine Klepp, DuPage County SMD, written commun., 2015), (2) refining the land-use parcel within the ANL property, (3) assigning HRUs to each catchment, and (4) modifying HRUs in catchments covering ANL buildings and parking lots.

DuPage County SMD uses a land-use parcel (individual properties) database for tracking and updating the county's subwatershed model delineations. The parcel database contains a list of classified land parcels in the watershed. Each parcel is assigned a land-use code, which represents the land-cover of the parcel (table 1). For example, a multifamily unit is assigned to land-use code 120, which has 40 percent impervious land, 50 percent grass, and 10 percent forest (table 1). The DuPage County staff then computes the amount of acreage of each HRU within a catchment from the land use and slope.

For this study, the USGS updated the land-use codes of the Sawmill Creek watershed to the 2009 (latest) version of the land-use parcel. The classification of the ANL property, previously classified as land-use codes 403 and 404 and large parcel sizes, was revised to more refined land-use descriptions with smaller parcel sizes and was further updated to include buildings, parking lots, wetlands, grasslands, forests, roads, and detention areas with GIS layers provided by ANL staff (fig. 3). After the land-use codes and parcel updates, the acreages of the six land-cover classes in the watershed were computed with the assistance from SMD (Brad Acheson, DuPage County SMD, written commun., 2016). In the HSPF modeling, the USGS identified rooftops and parking lots in catchments covering the 200, 300, and 400 Areas, assigned representative impervious percentages to these specific land covers, and connected them through the storm sewer network and outfalls.

Model Development

The ANL site was divided into the four study watersheds described previously in the report. Each of the study watersheds was further divided into catchments. Hereafter, "watershed" is used to represent the entirety of the drainage basin under study, and "catchment" is used to describe a part of the watershed that is subdivided for modeling purposes.

Table 1. Land-use code and land-use type for the hydrologic model.

[IMPRV, impervious land; GRASS, grassland; FOREST, forested land; AG, agricultural land; S.F. Res, single family residential; <, less than; >, greater than; ac, acre; N/A, not applicable]

Land-use code	IMPRV	GRASS	FOREST	AG	Land-use code description	Land-use category (figure 3)
120	0.4000	0.5000	0.1000	0.0000	Multifamily	Residential
151	0.0312	0.9038	0.0650	0.0000	S.F. Res < 0.15 ac Unsewered	Residential
157	0.0048	0.9302	0.0650	0.0000	S.F. Res > 0.60 ac Unsewered	Residential
160	0.0009	0.9341	0.0650	0.0000	S.F. Res > 1.00 ac Unsewered	Residential
401	0.4000	0.5500	0.0500	0.0000	Office Research, General	Commercial
700	0.0200	0.9300	0.0500	0.0000	Open Space, General	Open Grass
701	0.0000	0.5000	0.5000	0.0000	Open Space, Forest Preserve	Forest
708	0.0200	0.8800	0.1000	0.0000	Open Space, Detention Area	Wetland
800	0.3500	0.4000	0.2500	0.0000	Transportation/Utility/ Infrastructure, General	Roadway
N/A	1.0000	0.0000	0.0000	0.0000	Parking Lot	Parking lot
N/A	1.0000	0.0000	0.0000	0.0000	Building	Building

The sections below describe the delineation of catchments and hydrologic routing in the four ANL HSPF models. The HSPF parameters used in the four study models were adopted from the calibrated and verified Sawmill Creek watershed models developed by Price (1996, 2011) and are presented in Appendix 1.

Delineation

The watershed boundaries were delineated by using the ArcHydro tool (Esri, 2016b) in ArcGIS with high-resolution DEM described previously and the 1:24,000-scale National Hydrography Dataset (NHD) (U.S. Geological Survey, 2016). The NHD stream network was further modified as follows: (1) streamlines were edited to follow local drainage patterns observed in high resolution aerial imagery (http://www.bing.com/mapspreview), and (2) broken streamlines were connected by identifying flow directions and hidden hydraulic structures. Specifically, for the 200, 300, and 400 Areas within the ANL property, the surface flow direction was adjusted to match existing ditches, culverts, and sewer lines provided by ANL personnel (Peter Lynch, Argonne National Laboratory, oral commun., 2015). By using the locally corrected stream network, new watershed boundaries were generated. Additional adjustments were made to divide rooftops or parking lots that drain into multiple sewer systems to account for the correct flow contributions. The final watershed delineations are shown in figure 4.

By using the refined stream network, the watershed was divided into hydrologically connected catchments so that each catchment has fairly consistent stream and geological/topographic characteristics. During this step, each catchment outlet was selected to best suit the location at which streamflow time series outputs were needed. The division into catchments was initiated for an approximately 0.1-square-mile drainage area. The catchment boundaries were then reviewed for necessary changes.

In the rural part of each watershed, a catchment boundary was accepted if the catchment enclosed reasonably consistent channel features and land-cover types. In the developed 200, 300, and 400 Areas, where there is a storm sewer system (fig. 4), catchment boundaries had to be adjusted to comply with the storm sewer system. Each storm sewer system drains to a designated outfall (Argonne National Laboratory, 2015b), which becomes a point source in the receiving catchment. This catchment design can generate runoff that reflects natural and altered land-cover conditions and provides adequate information for the flood inundation mapping. If the objective of the modeling is modified to analyze the effectiveness of end-of-pipe management units, such as bioswales and detention basins, for example, further review and modification of the delineation may be warranted.

In the developed areas, the watershed boundaries were adjusted to fit the edges of the building or parking lot to properly account for the runoff in the study watersheds. Because a building or parking lot can be drained by more than one storm sewer system, it is appropriate for the model to be divided into multiple catchments to comply with the sewer flow designations. Most ANL buildings have storm sewers, but exceptions are Buildings 400, 401, and 431–438 that have overflows discharging to the surface (Philip Rash, Argonne National Laboratory, written commun., 2015). Parking lots can drain to nearby swales. Subsequently, runoff enters local ditches then local sewers, or drains directly to local sewers. The watershed boundaries and catchment delineations, especially the revisions for the 200, 300, and 400 Areas, were reviewed and finalized by ANL personnel (Philip Rash, Argonne National Laboratory, written commun., 2015).

Flow Routing

The ANL-HSPF models use the RCHRES module to specify the connection of flows simulated by HRUs to stream reaches within a catchment and from catchment to catchment downstream in the stream network. RCHRES formulation and connections for catchments without sewers are straightforward. For catchments without sewers and with measured channel geometry and hydraulic properties from the HEC–RAS models, the routing characteristics are summarized in a function table, FTABLE. An FTABLE describes the rating relation among downstream depth, surface area, cumulative volume, and outflows.

When storm sewers are present in a catchment, multiple RCHRES may need to be used to properly route the flow. ANL storm sewers are designed to handle all runoff from roof tops or parking lots. For such cases very little surface runoff would be expected to enter nearby land surfaces (Philip Rash, Argonne National Laboratory, oral commun., 2015). Therefore, for catchments with storm sewers, runoff from grassland, forested land, and buildings or parking lots without sewer systems is routed through the stream network to the catchment outlet, whereas runoff through the storm sewer discharges to its outlet point, either in the same catchment or in another catchment. Another situation is when the discharge point of a sewer system is an end-of-pipe stormwater management unit, such as a dry pond. In these cases, a separate FTABLE, different from the sewer, may be needed to describe the routing characteristics of the stormwater management unit before connecting to the next downstream RCHRES. If the receiving RCHRES is another sewer system, the manner in which the inlet structure alters the flow hydrographs may require further attention when developing the FTABLE of the receiving RCHRES.

In the current study, FTABLEs for catchments having measured cross sections were developed by using the results of HEC–RAS analysis, which are suitable for open channels, ponds, and wetlands. The HEC–RAS model extent covers only the mapped stream reaches (fig. 2), whereas the network of flow paths extends into every catchment (fig. 4). The inline wetlands, bioswales, and detention ponds are described by

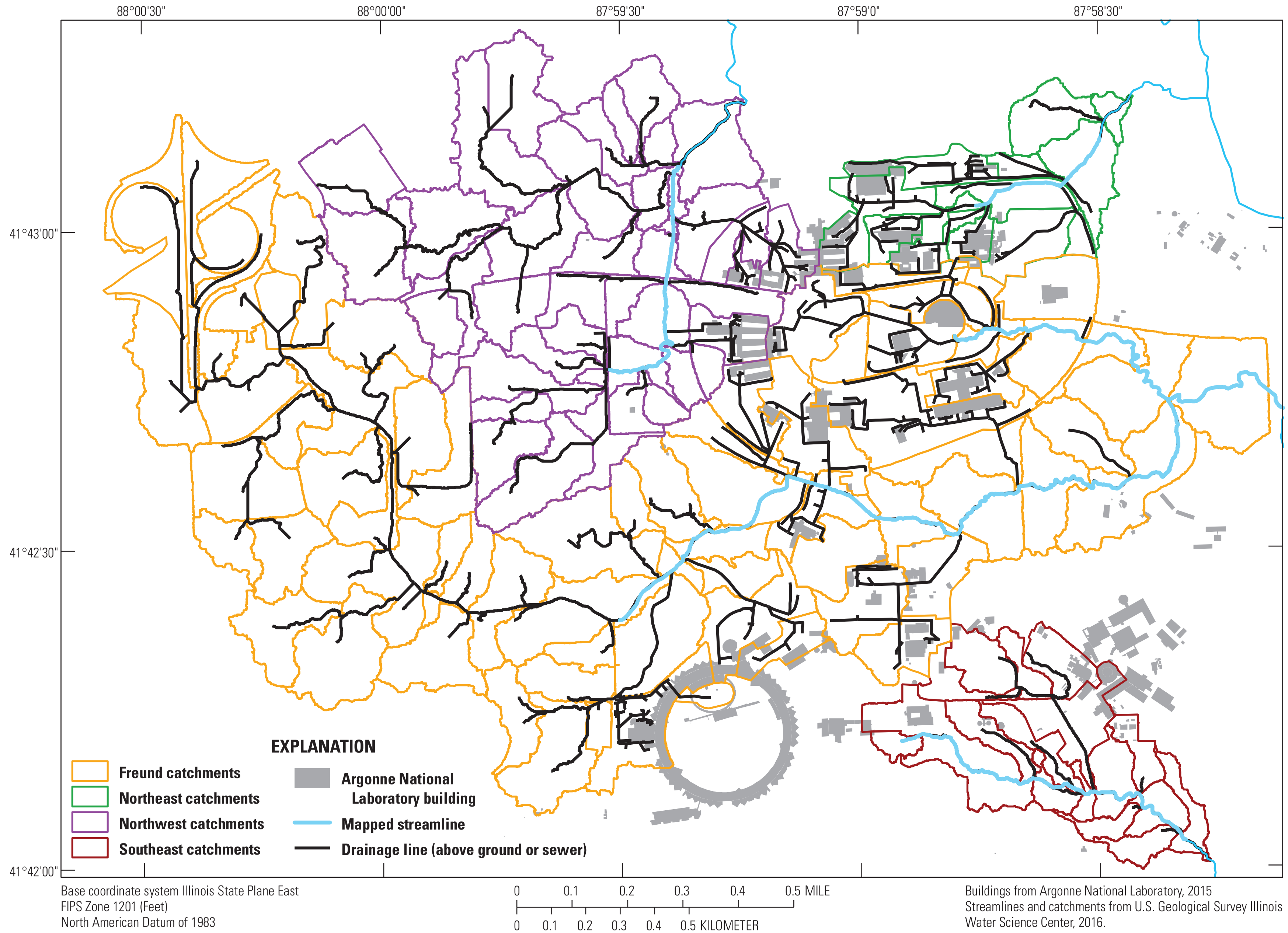

Figure 4. Location of drainage lines and delineated catchments, Argonne National Laboratory, DuPage County, Illinois.

channel geometry and specified as lakes in the routing function. The FTABLEs are developed through an iterative process of running flows through the HEC–RAS model and refining the relations among the hydraulic properties of the channel in the FTABLE in the HSPF model until consistent results are achieved. Catchment flow characteristics and routing properties can be improved through iterative simulation (Soong and others, 2006). The accuracy of the FTABLE is important for producing the estimated flood hydrograph and stages, especially for model simulation using short time intervals (hourly). For catchments without sewers and without measured cross sections, FTABLEs are developed by selecting representative cross sections from a similar measured channel.

The stormwater system was incorporated into the hydrological modeling by assuming the runoff from a specific roof top or parking lot comes out at the outlet instantaneously; in other words, the pipes provide no storage. The delay and attenuation of peaks caused by manholes and pipe configurations are considered to be comparatively small for the purpose of flood-hazard study. The instantaneous conveyance is achieved through a specific FTABLE. Schematics for the stormwater drainage have been digitized and provided for the study, along with the locations of culverts and outfalls as well as several detention basins, bioswales, and wetland in the open areas by ANL. However, using HSPF to describe the transport mechanisms through the stormwater drainage components was not possible because the model is limited by its simplified hydrological routing, and a detailed analysis of the stormwater collection system was beyond the scope of this project. Sewer FTABLEs are developed with an assumption of instantaneous flow transmission, without adhering to the detail variations in pipe size, manholes, and under-building storage.

Flood Quantiles

The flood quantile analysis involves (1) extracting an annual exceedance series (AES) from each streamflow time series generated from HSPF simulations and (2) analyzing the AES using the Bulletin 17B recommended Log-Pearson III distribution (U.S. Water Resources Council, 1976). HSPF simulations using observed meteorological data from WY 1949 to 2014 resulted in flow time series at the outlet of each catchment. From the continuous hourly flow time series, a series of annual maximums from WY 1949 to 2014 was compiled. These annual maximums are the peak flood magnitudes of each year and are called an AES because there is one peak selected for every year regardless of flow magnitude. The second step is flood-frequency analysis, and the USGS PeakFQ program that implements the Bulletin 17B and Expected Moments Algorithm (http://water.usgs.gov/software/PeakFQ/, accessed February 4, 2016) was used to determine the flood quantiles from each AES. With the emphasis on rare, large quantiles, the accuracy of the regional skew coefficients for weighting the systematic skew is critical (U.S. Water Resources Council, 1976). Over and others (2016) updated regional skew coefficients for northeastern Illinois. The regional skew coefficient used in the PeakFQ analysis for the ANL property was 0.39.

Flood quantiles estimated for a catchment were assigned to the cross section at the catchment outlet. To assign flood quantiles at other cross sections in the catchment, the difference in flood quantile magnitudes at the outlets of consecutive catchments along the channel was examined. If the difference in flood quantile magnitudes between two catchment outlets was negligible, then the quantile from the downstream catchment outlet was assigned to all the cross sections in the downstream catchment. However, when there was an appreciable difference in quantile magnitudes between the two adjacent catchment outlets, the flood quantiles were interpolated for each cross section in the downstream catchment based on the change in drainage area and storage between the upstream catchment outlet and the downstream catchment outlet. Flood quantiles corresponding to the 1-percent and 0.2-percent annual chance floods for each cross section of the study streams are presented in table 2.

Table 2. Flood quantiles for selected locations in four streams, Argonne National Laboratory, DuPage County, Illinois.

[ft^3/s, cubic feet per second; CS, cross section]

Stream and cross section station	1-percent quantile (ft^3/s)	0.2-percent quantile (ft^3/s)
Northwest Drainage Way		
CS 2604	47	81
CS 1923	63	110
CS 1641	70	118
CS 1168	70	118
CS 886	91	156
CS 523	111	188
CS 17.5	196	346
Northeast Drainage Way		
CS 1490	13	19

Table 2. Flood quantiles for selected locations in four streams, Argonne National Laboratory, DuPage County, Illinois.—Continued

[ft^3/s, cubic feet per second; CS, cross section]

Stream and cross section station	1-percent quantile (ft^3/s)	0.2-percent quantile (ft^3/s)
CS 1172	39	57
CS 580	43	61
CS 511	54	82
CS 361	61	91
CS 15	69	105
Southeast Drainage Way		
CS 3575	4	7
CS 3335	26	42
CS 3160	29	46
CS 1474	42	68
CS 1191	110	166
CS 918	116	176
CS 711	124	191
CS 559	129	199
Lower Branch Freund Brook		
CS 7395	308	492
CS 6938	348	556
CS 6408	362	571
CS 6020	373	589
CS 5920	386	609
CS 5520	415	643
CS 5295	418	646
CS 5122	438	679
CS 5004	434	675
CS 4713	441	683
CS 3681	390	606
CS 3471	439	678
CS 2606	470	710
CS 2003	440	650
CS 1497	498	739
CS 1234	437	652
CS 1004	448	668
CS 266	498	739
Upper Branch Freund Brook		
CS 2866	53	79
CS 2803	57	83
CS 2560	80	118
CS 2066	103	156
CS 1610	116	174
CS 895	123	185
CS 549	146	222
CS 202	498	739
Freund Brook		
CS 1700	496	758

Hydraulic Modeling

HEC–RAS version 4.1 (U.S. Army Corps of Engineers, 2010a, b, c) was used for the hydraulic modeling of the streams in the four watersheds. This version of HEC–RAS is a one-dimensional step-backwater model and was run in steady state for the simulation of the water-surface profiles. Unobstructed flow through structures was assumed for all the hydraulic model simulations. Data needed for the hydraulic model input included stream and flood-plain cross sections, control-structure geometry, and Manning's roughness coefficients.

The HEC–RAS models were used for (1) model validation by comparing simulated water-surface elevation to measured crest-stage-gage (CSG) data; (2) generation of the reach-wise rating relations among downstream depth, accumulated surface area, accumulated reach volume, and outflow discharges (FTABLEs); and (3) computation of water-surface profiles corresponding to the 1-percent and 0.2-percent flood quantiles.

Cross Sections

The geometry used in the hydraulic models was from a combination of survey data collected during the study, cross-section and control-structure geometry described in the FEQ model from DuPage County (Nika Engineering, 2010), and cross-sections cut from the high-resolution DEM. The USGS team collected survey data during June 22–25, 2015, from the four streams within the ANL property to describe natural stream and structure (bridge and culvert) geometry. These survey data were used to describe the stream and structures in the HEC–RAS model. The survey data defined the shape of the channel and were merged with topographic information from the DEM to define the overbank (flood plain) areas.

A total of 441 surveyed points in the flood plain of the study area were also used to evaluate the vertical accuracy of the DEM. The root mean square error accuracy, found by comparing the survey points to the DEM, was 0.254 ft.

Manning's Roughness Coefficients

Manning's roughness coefficients (*n*-values) were determined on the basis of observations made during field reconnaissance. Different *n*-values were typically specified for the left overbank, main channel, and right overbank, but sometimes additional horizontal variation in *n*-values was specified. In the Freund Brook model, the *n*-values range from 0.02 to 0.15 for the flood plain and 0.035 to 0.15 for the main channel. In the Northeast Drainage Way model, the *n*-values range from 0.02 to 0.15 for the flood plain and the main channel. In the Northwest Drainage Way, the *n*-values range from 0.03 to 0.15 for the flood plain and 0.048 to 0.15 for the main channel. In the Southeast Drainage Way model, the *n*-values range from 0.035 to 0.15 for the flood plain and 0.048 to 0.07 for the main channel. Many channels are full of vegetation or debris, so *n*-values are higher for these channels than for typical streams.

Model Verification

The ANL-HSPF models incorporated the rainfall-runoff parameter set developed for the DuPage County HSPF model of Sawmill Creek watershed (Appendix 1; Price, 1996, 2011); no hydrological data were available from the study streams for parameter calibration. Calibration of the HSPF rainfall-runoff parameters in the DuPage County watersheds was conducted by Price (1996), and the parameters were verified for the Sawmill Creek watershed, where ANL is located, by Price (2011) for the period from WY1995 to WY2008.

Five crest-stage gages (CSGs) were installed on the study streams for model verification (fig. 5). The data from these CSGs are online in the USGS National Water Information System (NWIS) database (http://waterdata.usgs.gov/nwis) for the station numbers listed in table 3. CSGs record the peak water-surface elevation during a storm. Because there were no discharge streamgages on the study streams with which to verify flow values, the study relied on the CSG data to verify the model results.

The CSG-measured peak elevations were compared with simulated peak elevations from the HEC–RAS that were generated from outflows from the HSPF model. In this way, the CSG comparison served as an evaluation of the combined HEC–RAS and HSPF modeling results. The simulated water-surface elevation and the measured peak elevation for several measured storms in 2015 are compared in table 3. The average absolute difference is 0.06 ft, and the maximum absolute difference is 0.19 ft. Although the initial results are very good, note that results of these relatively small storms are not representative of the flow conditions during 1-percent and 0.2-percent flood events.

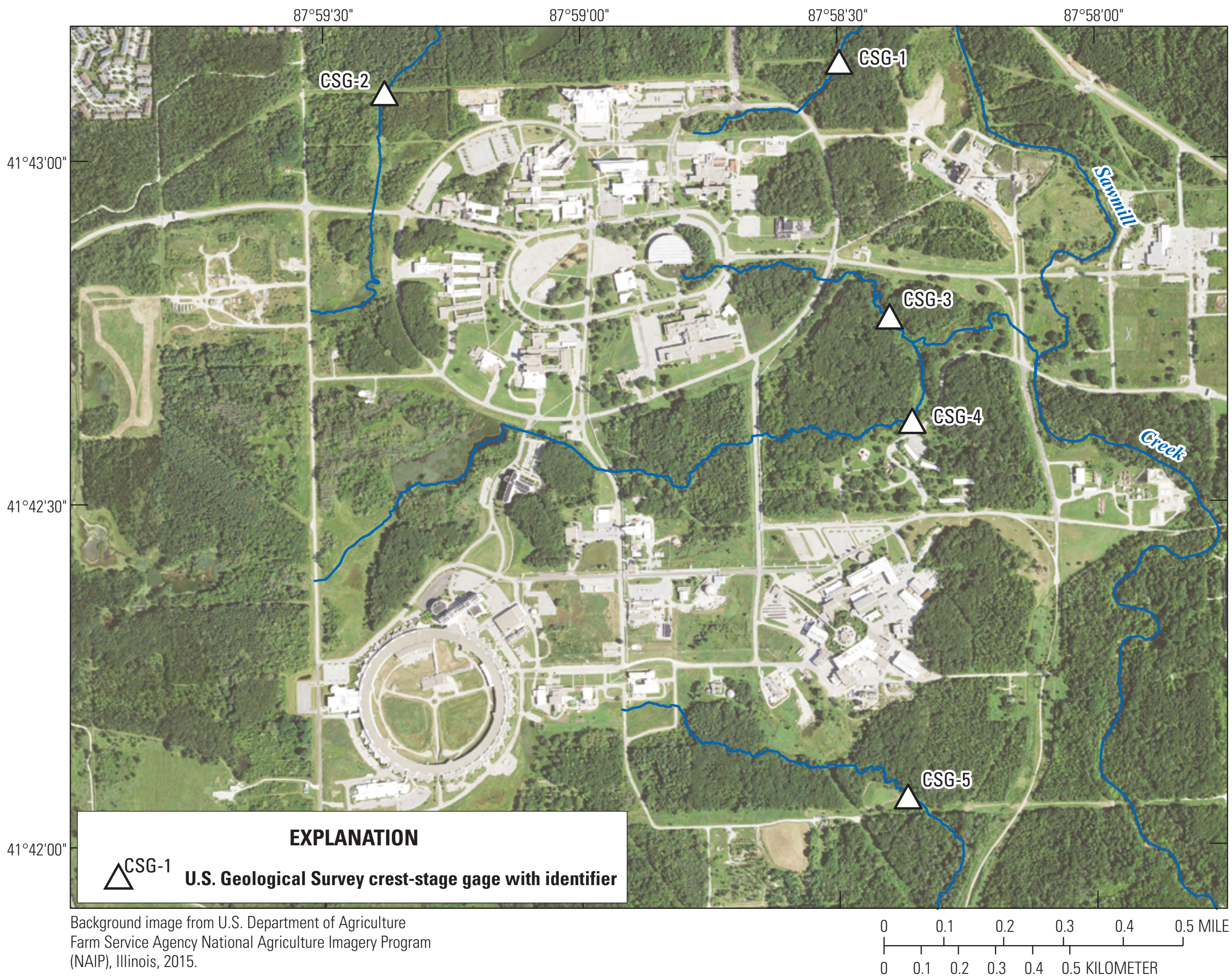

Figure 5. Location of five crest-stage gages on study stream reaches, Argonne National Laboratory, DuPage County, Illinois.

Table 3. Peak water-surface elevations measured at crest-stage gages at Argonne National Laboratory, DuPage County, Illinois, and simulated with HEC–RAS.

[NAVD 88, North American Vertical Datum of 1988; CSG, crest-stage gage, IL, Illinois; DOI for National Water Information System is http://dx.doi.org/10.5066/F7P55KJN; station number can be used to locate the peaks for the crest-stage gages]

Event Date (2015)	Peak water-surface elevation at CSG (feet NAVD 88)	Peak water-surface elevation HEC-RAS (feet NAVD 88)	Difference (feet)
CSG 1 - Northeast Drainage Way (USGS station number 05533350 Sawmill Creek Trib near 94th ST at Argonne Nat Lab, IL)			
15-June	676.48	676.49	-0.01
20-June	676.28	676.28	0.00
6-July	676.3	676.33	-0.03
7-July	676.28	676.26	0.02
13-July	676.14	676.23	-0.09
Aug. 3	676.23	676.25	-0.02
Aug. 18	676.49	676.38	0.11
CSG 2 - Northwest Drainage Way (USGS station number 05533320 Wards Creek tributary at Argonne National Lab, IL)			
15-June	717.18	717.16	0.02
20-June	716.25	716.13	0.12
7-July	716.03	715.94	0.09
Aug. 3	716.1	716.01	0.09
Aug. 18	716.38	716.44	-0.06
CSG 3 – Upper Branch Freund Brook (USGS station number 05533440 Des Plaines River Trib at Quarry Rd at Argonne Lab, IL)			
15-June	671.21	671.22	-0.01
20-June	670.88	670.68	0.2
6-July	670.66	670.65	0.01
7-July	670.77	670.83	-0.06
Aug. 2	670.51	670.52	-0.01
Aug. 3	670.71	670.9	-0.19
Aug. 18	671.22	671.18	0.04
CSG 4 – Lower Branch Freund Brook (USGS station number 05533380 Sawmill Creek Trib at Freund Rd at Argonne Lab, IL)			
15-June	677.1	677.2	-0.1
20-June	676.64	676.52	0.12
Aug. 3	676.35	676.4	-0.05
Aug. 18	676.58	676.56	0.02
CSG 5 - Southeast Drainage Way (USGS station number 05533430 Des Plaines River Trib at Argonne National Lab, IL)			
6-July	642.79	642.76	0.03
7-July	642.77	642.79	-0.02
13-July	642.76	642.76	0.00
Aug. 2	642.92	642.82	0.10
Aug. 18	642.98	642.98	0.00

Flood Plain Boundaries for 1- and 0.2-Percent Quantile Events

Figures 6–9 are maps of the estimated extents of the flood plains corresponding to the 1- and 0.2-percent flood quantiles. These maps show the areas that may be vulnerable to flooding under current site conditions and can be used for making future facility plans. Specific roads in each watershed that are expected to be overtopped are described in the following paragraphs.

On the Northwest Drainage Way, Westgate Road is not shown as overtopped by either mapped flood plain (fig. 6). This is the least affected of the study streams with no roads expected to be overtopped. There is a small discontinuity visible in the mapped flood plain in the forested area upstream from Westgate Road. This discontinuity is because of an abandoned bridge structure.

On the Northeast Drainage Way, Outer Circle is shown as flooded by the 0.2-percent flood plain (fig. 7). In both of the mapped flood plains, water intrudes on the road near the intersection of Northgate Road and Outer Circle. Flows over the road near the intersection of Northgate Road and Outer Circle (fig. 7) were observed during heavy rainstorms in 1996 and 2013 (Philip Rash, Argonne National Laboratory, written commun., 2015). When the culvert under Outer Circle is blocked for an estimated 0.7 ft out of a diameter of 1.6 ft, as was observed during the study survey data collection, the extent of flooding becomes similar to that of the 0.2-percent flood plain and covers the road.

The effects of flooding are seen primarily as overtopping of roads in multiple locations on Freund Brook. Starting at the upstream end of the Lower Branch Freund Brook, Kearney Road is overtopped by the 1-percent and the 0.2-percent flood plain (fig. 8). Downstream near the wetland area, Outer Circle is flooded. Further downstream, Meridian Road is not overtopped during the 1-percent flood plain, but is overtopped by the 0.2-percent flood plain. Southwood Drive is shown as flooded by both flood plains. There is a small discontinuity in the mapped flood plains between Meridian Road and Southwood Drive because of an old railroad trestle in this wooded area.

On the Upper Branch of Freund Brook, the Inner Circle and Outer Circle are not overtopped by either the 1-percent or 0.2-percent flood plains (fig. 8). The sidewalk near Inner Circle is flooded by both flood plains. At the downstream end of Freund Brook, Railroad Drive is overtopped by both flood plains as well. During site reconnaissance, it was noted that the culvert under Railroad Drive was significantly blocked (estimated to have 1.7 ft of blockage out of 3.9 ft diameter), reducing the amount of flow that can pass through it. The hydraulic model was run for both the observed, blocked condition and a completely open culvert. The blocked culvert flood inundation extent for the 1-percent flood plain was comparable to the flood inundation extent for the 0.2-percent flood with an open culvert.

On the Southeast Drainage Way, the first crossing of Meridian Road is shown as overtopped by both mapped flood plains, whereas the second crossing of Meridian Road is not overtopped by either mapped flood plain (fig. 9). This stream then drains down towards the Des Plaines River without crossing another road.

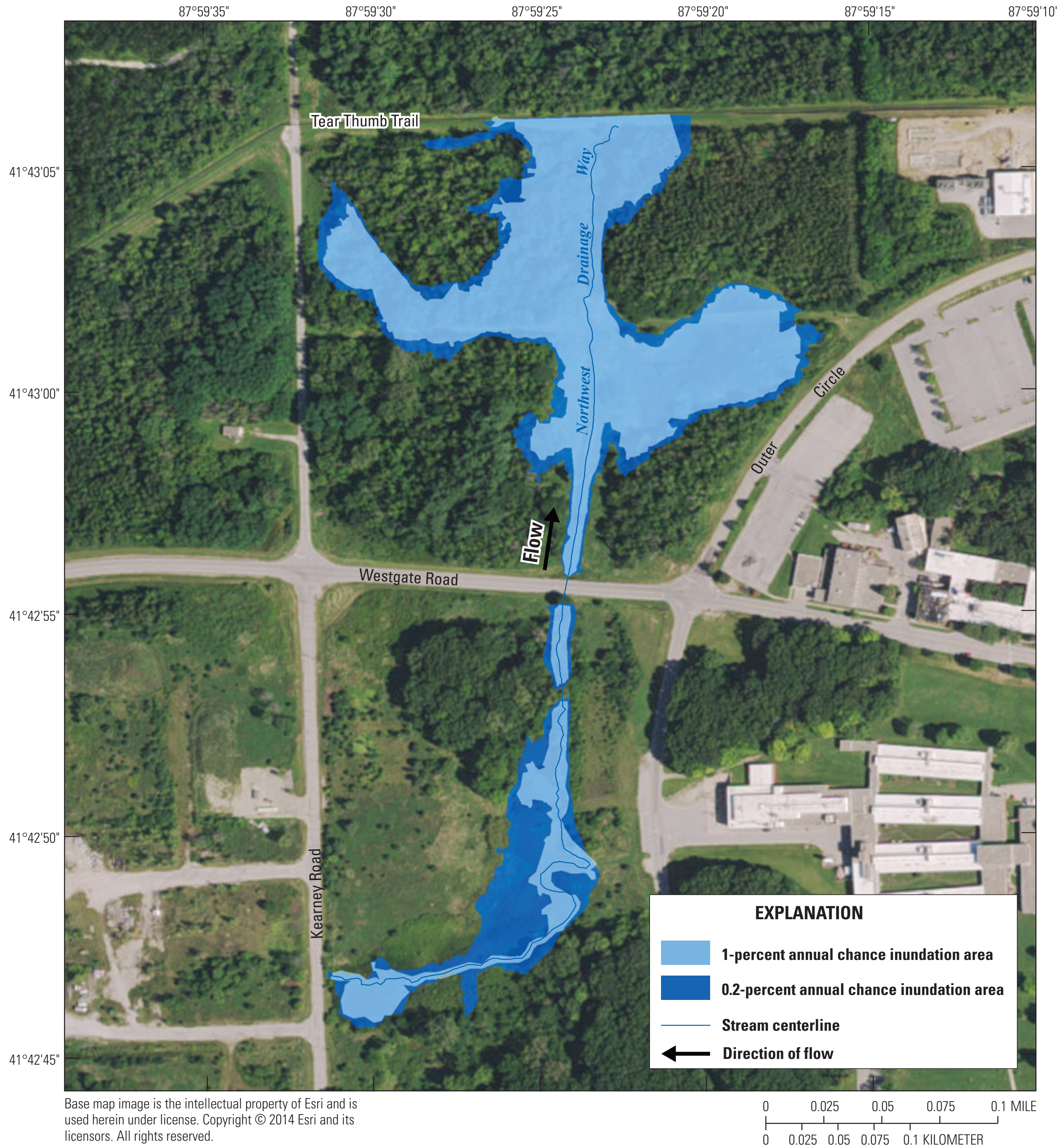

Figure 6. Flood-hazard map of Northwest Drainage Way, Argonne National Laboratory, DuPage County, Illinois.

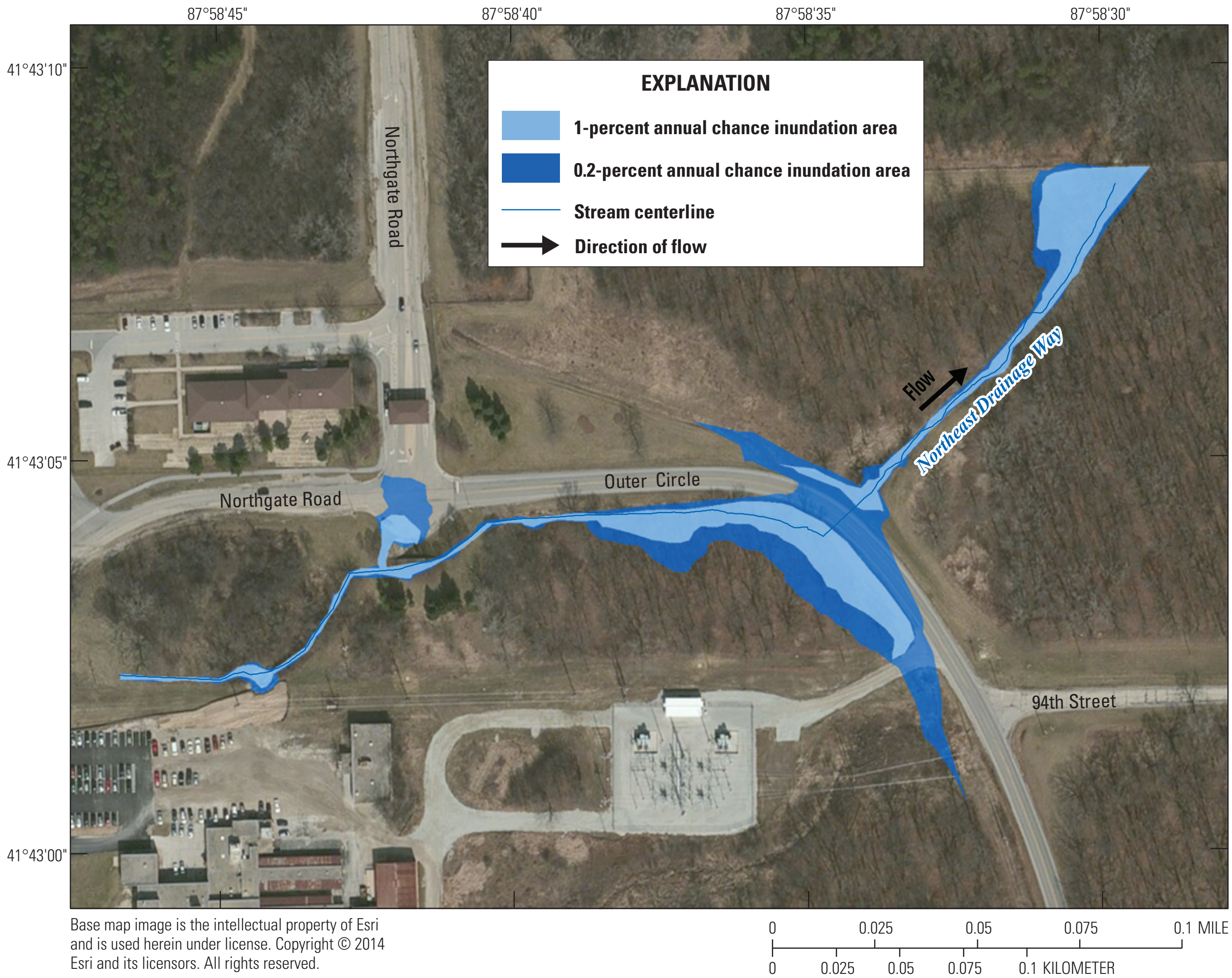

Figure 7. Flood-hazard map of Northeast Drainage Way, Argonne National Laboratory, DuPage County, Illinois.

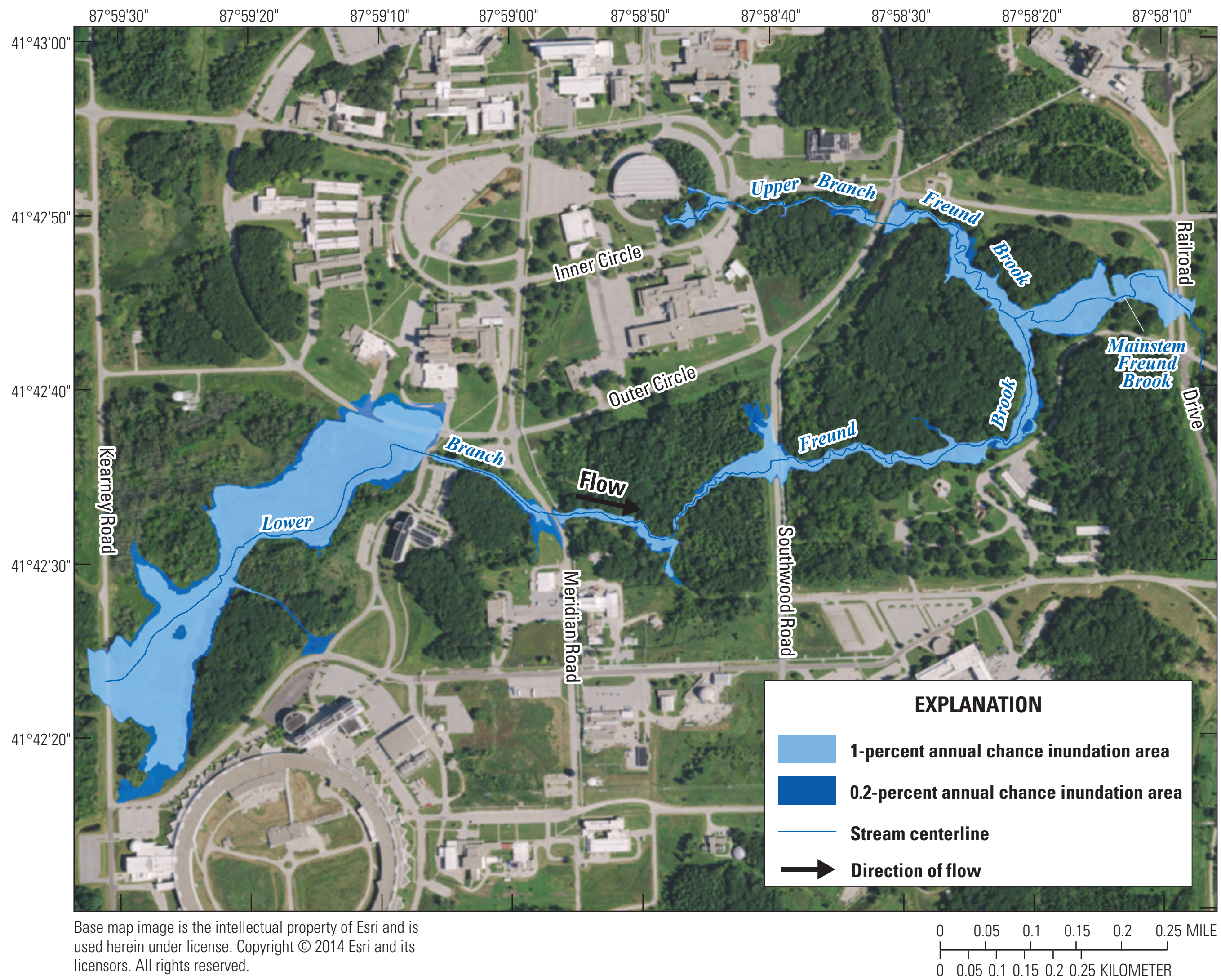

Figure 8. Flood-hazard map of Freund Brook, Argonne National Laboratory, DuPage County, Illinois.

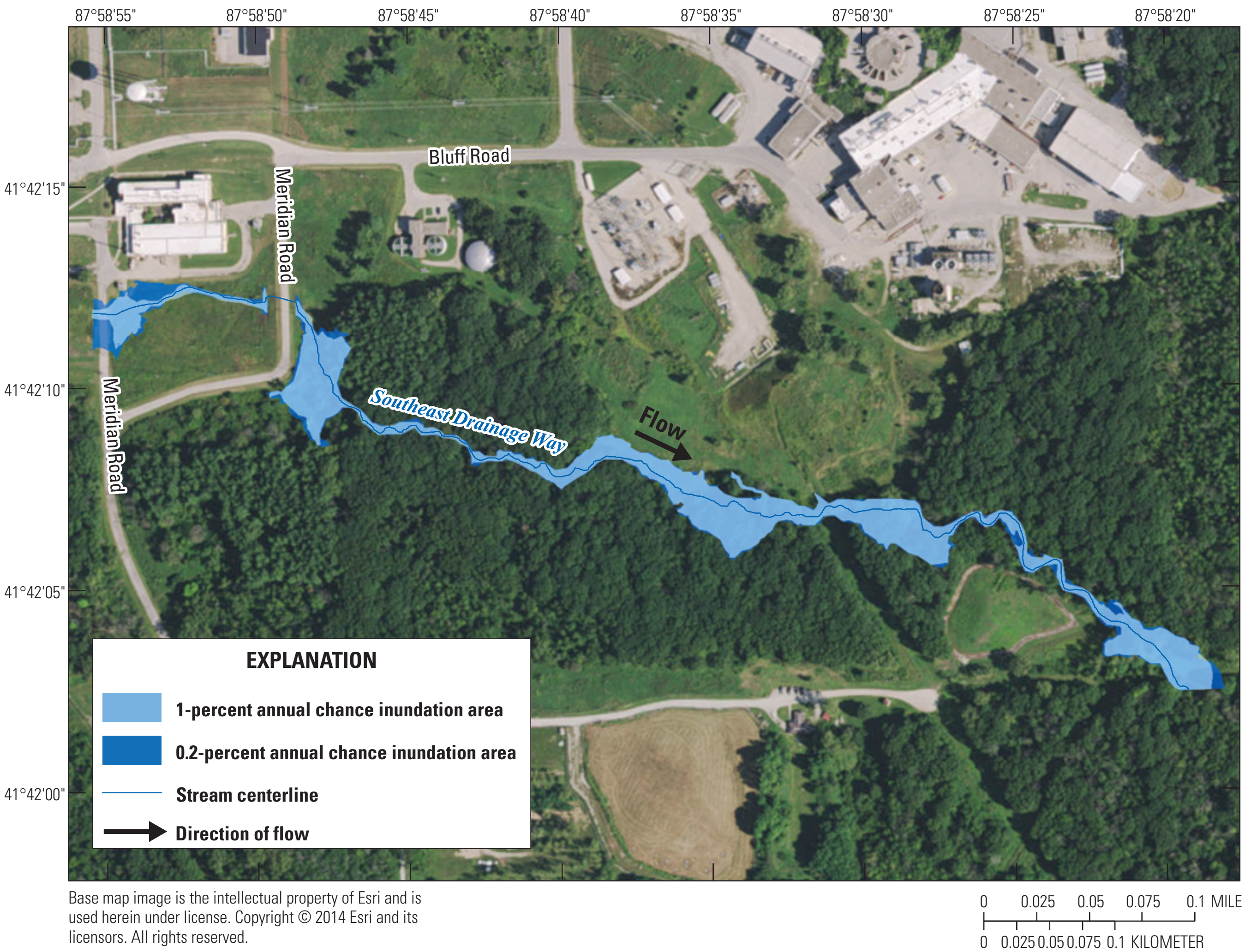

Figure 9. Flood-hazard map of Southeast Drainage Way, Argonne National Laboratory, DuPage County, Illinois.

Summary

A study was conducted by the U.S. Geological Survey, in cooperation with the Argonne National Laboratory (ANL), to analyze flood hazards within the ANL property in DuPage County, Illinois, along four stream reaches. The study delineated the boundaries of the four study watersheds and the flow network within each watershed. The flow network boundaries were based on a high-resolution digital elevation model (DEM) and the USGS National Hydrography Dataset (NHD) and were adjusted so that local areas would match drainage patterns visualized in high-resolution aerial photography. The Hydrological Simulation Program-FORTRAN (HSPF) model was used to simulate the watershed hydrology. Measured climate and precipitation data from Argonne meteorological tower were used as input to the HSPF model, which was run at a 1-hour time step for water years (WY) 1949–2014. Calibrated parameters from an existing Sawmill Creek HSPF model were used in the HSPF models developed for the four study watersheds. Flood quantiles were estimated by using PeakFQ on annual peak series generated from the simulated streamflow time series from HSPF. The Hydrologic Engineering Center–River Analysis System (HEC–RAS) hydraulic model was used to estimate water-surface elevation profiles corresponding to the estimated 1-percent and 0.2-percent flood quantiles. After converting the water-surface to inundation boundaries, the study results indicate that many roads would be overtopped by the mapped flood plains.

On Northeast Drainage Way, water intrudes on the road near the intersection of Northgate Road and Outer Circle during a 1-percent annual exceedance probability or greater flood and Outer Circle is expected to be flooded during a 0.2 percent annual exceedance probability or greater flood. The Freund Brook has many roads expected to be flooded during a 1-percent annual exceedance probability or greater flood. These roads include Kearney Road, Outer Circle, Southwood Drive, and Railroad Drive. Additionally, Meridian Road is expected to be flooded during a 0.2-percent annual exceedance probability or greater flood. On the Southeast Drainage Way, Meridian Road is expected to be flooded during a 1-percent annual exceedance probability or greater flood. No roads are expected to be overtopped on the Northwest Drainage Way.

The flood-plain maps produced for this study assumed all culverts were flowing freely without blockage. However, two culverts with blockage were observed during the site reconnaissance—the culvert under Outer Circle on Northeast Drainage Way and the culvert under Railroad Drive on Freund Brook. The blockage in these culverts could increase flooding in these areas beyond what is shown in the study maps.

Five crest stage gages were installed on the study streams and collected peak water-surface elevations for storms in WY 2015. These elevations were used to validate the models. The comparison between the crest stage gages and HEC–RAS elevations had an average absolute difference of 0.06 feet and a maximum absolute difference of 0.19 feet.

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Appendixes 1, 2, and 3

Appendix 1

Hydrological Simulation Program-FORTRAN Runoff Parameters.

Appendix 2

Stream Assessment.

Appendix 3

Maps of 1-Percent Quantile Water-Surface Elevation with 3 Feet of Freeboard.

Appendix 1—Hydrological Simulation Program-FORTRAN Runoff Parameters

The Hydrological Simulation Program-FORTRAN (HSPF) hydrologic model of the Sawmill Creek watershed was used as the starting point for development of the hydrologic models for the four study watersheds. The HSPF models simulate snow pack and melt, runoff from pervious land (PERLND), and runoff from impervious land (IMPLND) (Price, 1996, 2011). In HSPF, the PERLND segment is used to represent the pervious hydrologic response units (HRUs), and the IMPLND segment is used to represent the impervious HRUs. PERLND describes water movement over the pervious land surface and the percolation of groundwater after infiltration. IMPLND describes the water movement over the impervious land surface with mostly surface runoff instead of infiltration. Snowmelt is simulated using the snow water equivalent, in inches, as the input precipitation data for the days it snowed. The HSPF program uses an array of empirical equations to compute the flux, losses, and changes in storage in a continuous manner. By adjusting key parameters of these empirical equations using matching measured streamflow and other variables, the model can represent the streamflow response to meteorological conditions of a real watershed.

Descriptions of the HSPF parameters are given in table 1-1 (summarized from Bicknell and others, 2000). Calibrated parameter values for the six HRUs developed for the Sawmill Creek watershed HSPF model (Price, 1996) and used in the four Argonne National Laboratory study watersheds are listed in tables 1-2 and 1-3. In the Sawmill HSPF model, the functions for describing the Interception Storage Capacity (CEPSC), Nominal Upper Zone Soil Moisture Storage (UZSN), and Lower Zone Evapotranspiration (LZETP) vary monthly (table 1-3), whereas the other parameters have fixed values throughout the year (table 1-2). Monthly parameters supersede the annual values when they are specified in the model, but the annual values are still needed as a placeholder for the model to avoid an error during simulations.

As described in the body of the report, the HSPF parameters for the Sawmill Creek watershed were calibrated using data from 1986 to 1993 (Price, 1996) and validated using data from 1995 to 2008 (Price, 2011). The statistics quantifying the ability of the calibrated HSPF model to predict annual, monthly, and storm event flow volumes for Sawmill Creek are presented in table 1-4.

Table 1-1. Description of rainfall-runoff parameters used in the Hydrological Simulation Program-FORTRAN program and their effects on various components of the water budget. (From Bicknell and others, 2000)

[ET, evapotranspiration; in/hr, inch per hour; ft/ft, foot per foot; 1/in, inverse of one inch; Deg. F, degrees Fahrenheit]

Parameter	Description	Unit	Effects
Forest	Fraction of land covered in (for example, conifer) forest that can transpire when there is snow pack	None	Snowmelt amount in the water balance
LZSN	Lower zone nominal soil moisture storage	Inches	Affects annual and event runoff volumes through ET, base flows, and losses to inactive groundwater determined in the lower zone
INFILT	Index of infiltration capacity	in/hr	Affect water balance, high/low flow distributions, and stormflows through altering the relation between groundwater and direct runoff
LSUR	Length of overland flow plane	Feet	Storm peaks, no effect on annual runoff volumes
SLSUR	Average slope of assumed overland flow plane	ft/ft	Storm peaks, no effect on annual runoff volumes
KVARY	A constant describes the non-linear groundwater recession	1/in	Base flow, esp. seasonal variations, but has almost no effect on annual or event runoff volume

Table 1-1. Description of rainfall-runoff parameters used in the Hydrological Simulation Program-FORTRAN program and their effects on various components of the water budget. (From Bicknell and others, 2000)—Continued

[ET, evapotranspiration; in/hr, inches per hour; ft/ft, foot per foot; 1/in, inverse of one inch; Deg. F, degrees Fahrenheit]

Parameter	Description	Unit	Effects
AGWRC	A constant describes the base groundwater recession rate	None	Base flow, and therefore event runoff, in the context of amount assigned to infiltrated and active groundwater
PETMAX	Temperature below which ET is reduced to 50 percent of that in the input time series	Deg. F	ET and all related processes; used when SNOW is being simulated.
PETMIN	Temperature below which ET is zero	Deg. F	Like PETMAX, it affects ET and all related processes; used when SNOW is being simulated
INFEXP	Exponent in infiltration equation that determines how much a deviation from nominal lower zone storage affects the infiltration rate	None	Those affected by INFILT
INFILD	Ratio of maximum/mean soil infiltration capacities	None	This ratio has always been set to 2
DEEPFR	Fraction of infiltrating water lost to inactive groundwater (deep percolation)	None	Primarily the portion of base flow between storms but also event runoff volumes as groundwater discharge continues
BASETP	ET (specifies as fraction of potential evapotranspiration) lost to riparian vegetation as active groundwater enters streambed	None	Base-flow volume (as ET is exerted from the outflow portion of active groundwater); annual runoff volume in the context of base-flow generation
AGWETP	Fraction of pervious land (PERLND) subject to direct evaporation from groundwater storage	None	Base-flow volume (as ET is exerted from the storage portion of active groundwater); annual runoff volume in the context of base-flow generation
CEPSC	Interception storage capacity by vegetation	Inches	Event and annual runoff volume, especially to smaller storm events that are sensitive to interception
UZSN	Nominal upper zone soil moisture storage	Inches	Direct surface runoff and interflow, and runoff enters the upper zone and hence following processes. UZSN can vary seasonally
NSUR	Manning’s roughness for overland flows	None	Storm peaks and event volumes
INTFW	Determines interflow	None	Amount of interflows

Table 1-1. Description of rainfall-runoff parameters used in the Hydrological Simulation Program-FORTRAN program and their effects on various components of the water budget. (From Bicknell and others, 2000)—Continued

[ET, evapotranspiration; in/hr, inches per hour; ft/ft, foot per foot; 1/in, inverse of one inch; Deg. F, degrees Fahrenheit]

Parameter	Description	Unit	Effects
IRC	Interflow recession parameter	None	The rate of interflow becomes surface runoff, hence event runoff volume and timing as well as hydrograph shapes
LZETP	Parameter determines lower zone ET	None	Annual runoff and some storms through seasonal dormancy of vegetation that draws water from lower zone
RETSC	Retention storage capacity	Inches	Event and annual runoff volumes, especially to small storm events the retention storage has effects upon

Table 1-2. Annual rainfall-runoff parameters used in the Sawmill Creek Hydrological Simulation Program-FORTRAN model.

[--, no value]

Parameter name (units)	Impervious	Flat-sloped grassland	Moderate-sloped grassland	Steep-slope grassland	Forest	Agricultural land
CEPSC (inches)	--	0.2	0.2	0.2	0.2	0.25
UZSN (inches)	--	1.72	1.62	1.52	2.9	1.62
LZSN (inches)	--	9.0	9.0	9.0	9.0	9.0
LZETP (none)	--	0.32	0.32	0.32	0.72	0.32
AGWETP (none)	--	0.05	0.05	0.05	0.15	0.05
INFILT (inches/hour)	--	0.04	0.04	0.04	0.05	0.07
DEEPFR (none)	--	0.10	0.10	0.10	0.10	0.10
INTFW (none)	--	5.0	5.0	5.0	7.0	7.0
LSUR (feet)	180	350	310	300	310	310
SLSUR (feet/feet)	0.02	0.003	0.02	0.06	0.02	0.02
NSUR (none)	0.1	0.2	0.2	0.2	0.25	0.2

Table 1-2. Annual rainfall-runoff parameters used in the Sawmill Creek Hydrological Simulation Program-FORTRAN model.—Continued

[--, no value]

Parameter name (units)	Impervious	Flat-sloped grassland	Moderate-sloped grassland	Steep-slope grassland	Forest	Agricultural land
IRC (none)	--	0.3	0.3	0.3	0.5	0.1
KVARY (1/inch)	--	1.7	1.7	1.7	1.7	1.7
AGWRC (none)	--	0.98	0.98	0.98	0.98	0.98
INFEXP (none)	--	4.0	4.0	4.0	4.0	4.0
INFILD (none)	--	2.0	2.0	2.0	2.0	2.0
BASETP (none)	--	0.0	0.0	0.0	0.0	0.0
RETSC (inches)	0.40	--	--	--	--	--
PETMAX (degrees Fahrenheit)	48	50	50	50	48	50
PETMIN (degrees Fahrenheit)	43	43	43	43	43	43

Table 1-3. Monthly rainfall-runoff parameters used in the Sawmill Creek Hydrological Simulation Program-FORTRAN model.

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
Monthly CEPSC, in inches												
Flat-sloped grassland	0.1	0.1	0.1	0.15	0.2	0.25	0.3	0.3	0.3	0.25	0.15	0.1
Moderate-sloped grassland	0.05	0.05	0.05	0.05	0.05	0.3	0.35	0.35	0.35	0.25	0.1	0.05
Steep-slope grassland	0.1	0.1	0.1	0.15	0.2	0.25	0.3	0.3	0.3	0.25	0.15	0.1
Forest	0.1	0.1	0.15	0.2	0.3	0.4	0.45	0.45	0.45	0.35	0.25	0.1
Agricultural land	0.05	0.05	0.05	0.05	0.05	0.3	0.35	0.35	0.35	0.25	0.1	0.05
Monthly UZSN, in inches												
Flat-sloped grassland	1.54	1.86	1.58	1.46	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Moderate-sloped grassland	2.64	3.12	2.64	2.4	2	1.92	1.88	1.8	1.8	1.8	2.4	2.4
Steep-slope grassland	1.38	1.7	1.42	1.3	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23

Table 1-3. Monthly rainfall-runoff parameters used in the Sawmill Creek Hydrological Simulation Program-FORTRAN model.—Continued

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
Forest	2.88	3.56	2.97	2.75	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Agricultural and	2.64	3.12	2.64	2.4	2	1.92	1.88	1.8	1.8	1.8	2.4	2.4
Monthly LZETP, a scalar												
Flat-sloped grassland	0	0	0	0.05	0.2	0.4	0.4	0.4	0.4	0.35	0.2	0
Moderate-sloped grassland	0	0	0	0	0	0.4	0.6	0.6	0.4	0	0	0
Steep-slope grassland	0	0	0	0.05	0.2	0.4	0.4	0.4	0.4	0.35	0.2	0
Forest	0.2	0.2	0.2	0.3	0.5	0.9	0.9	0.9	0.9	0.8	0.4	0.2
Agricultural land	0	0	0	0	0	0.4	0.6	0.6	0.4	0	0	0

Table 1-4. Sawmill Creek Hydrological Simulation Program-FORTRAN modeling results statistics. (from Price, 1996, 2011)

[S/R; ratio of simulated flow quantity to recorded or measured flow quantity; --, no value; %, percent; #, number]

	Calibration (Price, 1996) (Water years 1987–1993)	Verification (Price, 2011) (Water years 1996–2008)
Annual/monthly results		
Average annual S/R	1.03	1.0
Coefficient of model fit efficiency	0.86	--
Correlation coefficient	0.93	0.91
Average absolute percent error*	--	62.40%
Average absolute error**	40.2%	27.10%
Percent of months within 10%	19.0%	19.9%
Percent of months within 25%	48.8%	45.50%
Event Volume Results		
# of events	18	32
# of events simulated high	7	16
# of events simulated low	11	16
Volume weighted S/R	0.96	0.99
Correlation coefficient	0.80	0.92
Average absolute percent error*	29%	22.6%
Percent of events within 10%	33%	28.1%
Percent of events within 25%	61%	59.4%

* Average absolute percent error is the average of the percent errors for each month (or event).

** Average absolute error as a percentage of average annual recorded flow.

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Price, T., 2011, Meteorological database extension and verification of HSPF model for Sawmill Creek watershed, Sawmill Creek near Lemont: Elmhurst, Ill., Conservation Design Forum, Inc., prepared for the DuPage County Stormwater Management Division, 52 p.

Appendix 2. Stream Assessment

A qualitative stream assessment was conducted during August 13–14, 2015, as part of the broader flood-hazard study of four headwater streams within the Argonne National Laboratory property. The purpose of the stream assessment was to evaluate stream channel and substrate conditions in the project reaches. U.S. Geological Survey, Illinois Water Science Center, personnel conducted the assessment with Argonne National Laboratory personnel providing current and historical site background information.

The stream substrate descriptions (from visual observation) and main channel velocity (1-percent quantile flows from the hydraulic model) for selected locations (fig. 2-1) are summarized (table 2-1) for evaluation of erosion potential. Selected photos from the assessment are presented to show representative stream channel and substrate conditions, including erosional or other features. The stream assessment did not include wetland areas. The following sections are designated by each stream name as presented in table 2-1.

Southeast Drainage Way

Stations 11-711 (fig. 2-2): This reach of stream has relatively high channel velocities (3.65–6.33 feet per second [ft/s]) (table 2-1), but predominantly cobble substrate and low flood plain help maintain a non-erosive channel (fig. 2-3). However, there is a bluff (fig. 2-3) and a landfill (fig. 2-2) in the vicinity of this reach. Periodic assessments would be beneficial to determine whether the channel is migrating towards either of these features.

Stations 918-1681 (fig. 2-2): This reach of stream has a large range of channel velocities (2.10–5.81ft/s) in the study area (table 2–1). There are some signs of erosion, especially about 75 feet (ft) downstream from the stormwater structure at station 1190 (WP02) (fig. 2-4). A combination of the following substrates helps to minimize erosion: cobble, rock, and hardpan clay (fig. 2-5). However, there are signs that streambed incision and nickpoints have moved through this reach; subsequently, concrete and rock were placed in the stream to help mitigate the incision and protect utilities (fig. 2-6). A nickpoint is an over-steepened reach of a stream where erosion can occur if the eroding forces of the flow are greater than the resisting forces of bed material (fig. 2-7*A*).

Stations 2322-3054 (fig. 2-2): A gradual nickpoint was found at WP10 near station 2761. The channel was noticeably steeper at this location. The channel at the nickpoint was relatively narrow and relatively wide downstream from the nickpoint (fig. 2-7). These are classic signs of the channel evolution model that qualitatively shows the stages of channel changes caused by nickpoint migration. The first step is degradation, then rapid widening and meandering (Schumm and others, 1984). Eventually, the channel reaches a new stable slope and cross section (Schumm and others, 1984). A representative cross section approximately 400 ft downstream from the nickpoint is shown in figure 2-8*A*, and it appears the channel is still adjusting. The stream headwaters are in a wet marsh area (fig. 2-8*B*) with low velocities, which will slow the progression of the nickpoint into this area.

Freund Brook Reaches (F, Freund Brook; UF, Upper Branch Freund Brook; LF, Lower Branch Freund Brook)

Stations F58-F456 (fig. 2-9): This reach of Freund Brook has relatively low channel velocities (0.86–2.33 ft/s) (table 2-1). The downstream channel at WP 26 near station F58 is a silt and clay streambed (fig. 2-10 *A* and *B*) with some apparent deposition at lower flows that is likely flushed during higher flows. The substrate transitions to more of a cobble bed at WP27 near station F456 with some woody debris present in the channel (fig. 2-10 *C* and *D*). Erosional features from streambed incision are not present in this reach, but there are some signs of bank erosion from lateral migration (fig. 2-10 *A*).

Stations UF549-UF2697 (fig. 2-9): This reach of Upper Branch Freund Brook has a relatively wide range of channel velocities (0.69–6.30 ft/s) (table 2-1). The reach that contains stations UF549 and UF894 has a fairly narrow channel, low banks, cobble substrate, and limited erosional features (fig. 2-11). In the reach that contains stations UF1609 and UF2066, the channel is wider with higher banks, and the substrate is a combination of gravel, cobble, and hardpan clay (fig. 2-11). There are limited erosional features in this reach. In the reach at WP17 near station UF2697, the channel becomes narrower (fig. 2-12). The banks are still relatively high with some undercutting on the outside of meander bends. The substrate is a combination of gravel and hardpan clay (fig. 2-12).

Stations LF646-LF2465 (fig. 2-9): This reach of Lower Branch Freund Brook has a wide range of channel velocities (2.33-6.96 ft/s) (table 2-1) because of the presence of a stone dam at WP 39 near station LF960 (fig. 2-13). The velocity at the dam is 2.33 ft/s, and the velocity downstream from the dam is 6.96 ft/s, which are the high and low values for this reach. The remaining velocities range from 3.40 to 5.05 ft/s. The substrate downstream from the dam to station 646 (near WP 40) is primarily cobble (fig. 2-13). The impoundment upstream from the dam is filled with sediment, and the substrate in the active channel is a soft silt and clay (fig. 2-13). By station 1497 (WP37), there is no evidence of effect of the dam on substrate which is a gravel, and erosional features are not significantly prevalent (fig. 2-14).

Stations LF2924-LF5294 (fig. 2-9): This reach of Lower Branch Freund Brook has a wide range of channel velocities (0.57-4.64 ft/s) (table 2-1). The streambed is a clay, silt, sand mixture at WP35 near station LF2924 (fig. 2-15) that transitions to sand, gravel, and cobble at WP36 and WP37 near stations LF3680 and LF4047, respectively (fig. 2-16). Some

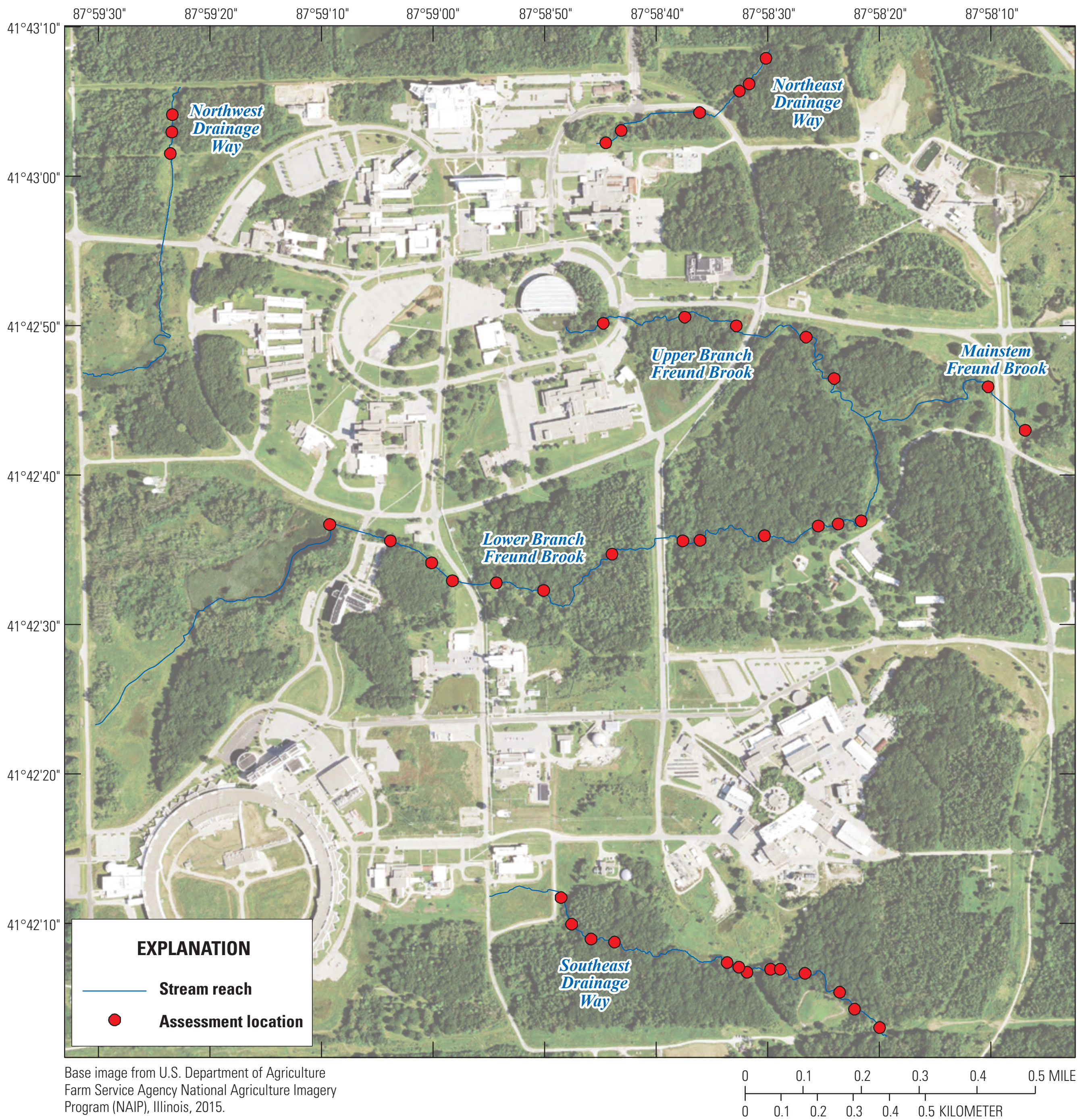

Figure 2-1. Project stream reaches (blue lines) and assessment sites (red dots), Argonne National Laboratory, DuPage County, Illinois.

Table 2-1. Stream station, bed material description, main channel velocity for selected locations along streams, Argonne National Laboratory, DuPage County, Illinois.

[ID, waypoint identification]

HEC-RAS cross section station nearest to waypoint	Substrate description	Main channel 1-percent mean flow velocity (foot per second)	Assessment location waypoint ID	Latitude (decimal degrees)	Longitude (decimal degrees)
		Southeast Drainage Way			
11	Cobble	4.78	WP07	41.7008	-87.9722
441	Cobble	4.56	WP09	41.7013	-87.9728
558	Gravel/Cobble	3.65	WP08	41.7015	-87.9732
711	Cobble	6.33	WP01	41.7018	-87.9743
918	Cobble	4.2	WP03	41.7021	-87.9750
1190	Cobble	5.81	WP02	41.7021	-87.9750
1473	Cobble	2.39	WP04	41.7020	-87.9753
1473	Rock seal	2.39	WP05	41.7019	-87.9754
1681	Hardpan clay	2.1	WP06	41.7020	-87.9760
2322	Cobble/Gravel	4.58	WP12	41.7026	-87.9793
2505	Clay/Cobble	2.31	WP11	41.7026	-87.9796
2761	Clay/Gravel/Hardpan clay	3.62	WP10	41.7029	-87.9800
3054	Silt/Clay	4.11	WP13	41.7030	-87.9798
		Freund Brook			
58	Silt/Clay	2.33	WP26	41.7119	-87.9686
456	Cobble	0.86	WP27	41.7128	-87.9700
		Upper Branch Freund Brook			
549	Cobble	0.69	WP29	41.7129	-87.9733
1162	Cobble	5.21	WP28	41.7138	-87.9743
1609	Gravel/Cobble/Hardpan Clay	1.74	WP19	41.7141	-87.9759
2066	Gravel/Cobble/Hardpan Clay	6.3	WP18	41.7141	-87.9772
2697	Gravel/Hardpan clay	0.92	WP17	41.7140	-87.9790
		Lower Branch Freund Brook			
646	Cobble/Boulder	3.43	WP40	41.7103	-87.9728
960	Dam	6.96	WP39	41.7102	-87.9734
1004	Soft silt/Clay	2.33	WP38	41.7101	-87.9740
1497	Gravel	3.79	WP37	41.7100	-87.9753
2003	Cobble	3.4	WP41	41.7099	-87.9768

Table 2-1. Stream station, bed material description, main channel velocity for selected locations along streams, Argonne National Laboratory, DuPage County, Illinois.—Continued

[ID, waypoint identification]

HEC-RAS cross section station nearest to waypoint	Substrate description	Main channel 1-percent mean flow velocity (foot per second)	Assessment location waypoint ID	Latitude (decimal degrees)	Longitude (decimal degrees)
2465	Gravel	5.05	WP42	41.7099	-87.9770
2924	Silt/Clay/Sand	3.07	WP35	41.7096	-87.9789
3680	Sand/Gravel	1.63	WP36	41.7089	-87.9806
4047	Cobble	4.32	WP34	41.7091	-87.9818
4331	Soft silt/Clay	2.73	WP33	41.7092	-87.9828
4713	Silt/Clay	2.47	WP32	41.7094	-87.9833
5004	Silt/Clay	4.64	WP31	41.7099	-87.9842
5294	Beaver Dam	0.57	WP30	41.7103	-87.9857
Northeast Drainage Way					
15	Sand/Gravel/Cobble	1.43	WP20	41.7190	-87.9750
159	Cobble/Gravel	1.01	WP21	41.7183	-87.9754
361	Clay/Gravel/Cobble	2.5	WP23	41.7183	-87.9756
786	Gravel/Cobble	5.21	WP24	41.7179	-87.9769
1375	Silt/Clay	0.96	WP25	41.7175	-87.9786
1453	Gravel	3.93	WP22	41.7173	-87.9790
Northwest Drainage Way					
18	Silt/Clay	0.5	WP15	41.7179	-87.9898
257	Silt/Clay	0.35	WP14	41.7175	-87.9898
523	Silt/Clay	0.53	WP16	41.7171	-87.9897

erosional features are present (fig. 2-16), but from visual indicators, the rate of erosion is most likely slow. Between sections LF4331 (WP33) and LF5294 (WP30), there are three beaver dams (fig. 2-17), and the lowest velocity of the stream occurs at the first dam. The streambed in this reach is composed of silt and clay, and there are minimal erosional features (fig. 2-17).

Northeast Drainage Way

Stations 15-1453 (fig. 2-18): This reach of Northeast Drainage Way has main channel velocities ranging from 0.96 to 5.21 ft/s (table 2-1). The channel downstream from Outer Circle is well defined and primarily has a gravel and cobble controlled streambed (fig. 2-19). Bank erosion was present in this reach, and representative undercut and eroded banks are shown in figure 2-20. Upstream from Outer Circle, the channel is not as well defined and has more of a gravel streambed (fig. 2-21). The reach starts as a stormwater outfall near section 1453 (fig. 2-21*B*).

Northwest Drainage Way

Stations 18-523 (fig. 2-22): This reach of Northwest Drainage Way has relatively low main channel velocities (0.35 to 0.53 ft/s) (table 2-1). The channel is relatively small with low banks (fig. 2-23). The streambed is composed of silt and clay (fig. 2-23). Given the low velocities and stream channel characteristics, erosion potential is judged to be low in this reach of stream.

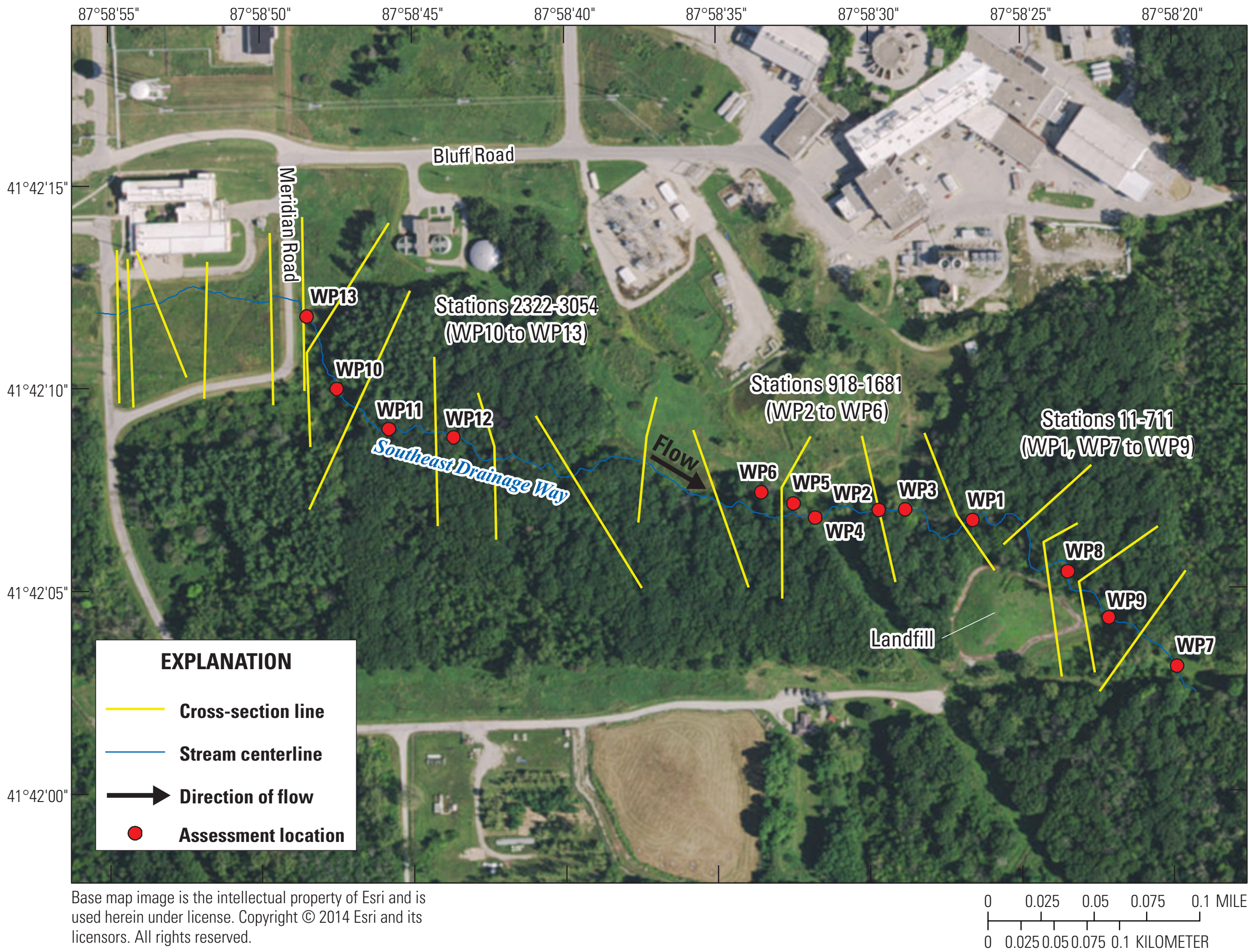

Figure 2-2. Southeast Drainage Way reach, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-3. Southeast Drainage Way, *A*, looking upstream from WP08 near station 558. The streambed is predominantly cobble, and the right bank has a low flood plain. In the background of the left bank is a bluff and *B*, predominantly cobble streambed near station 211, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-4. Southeast Drainage Way: *A*, stormwater inlet to the drainage way at station 1190 (WP02) and *B*, bank erosion approximately 75 feet downstream from station 1190, Argonne National Laboratory, DuPage County, Illinois.

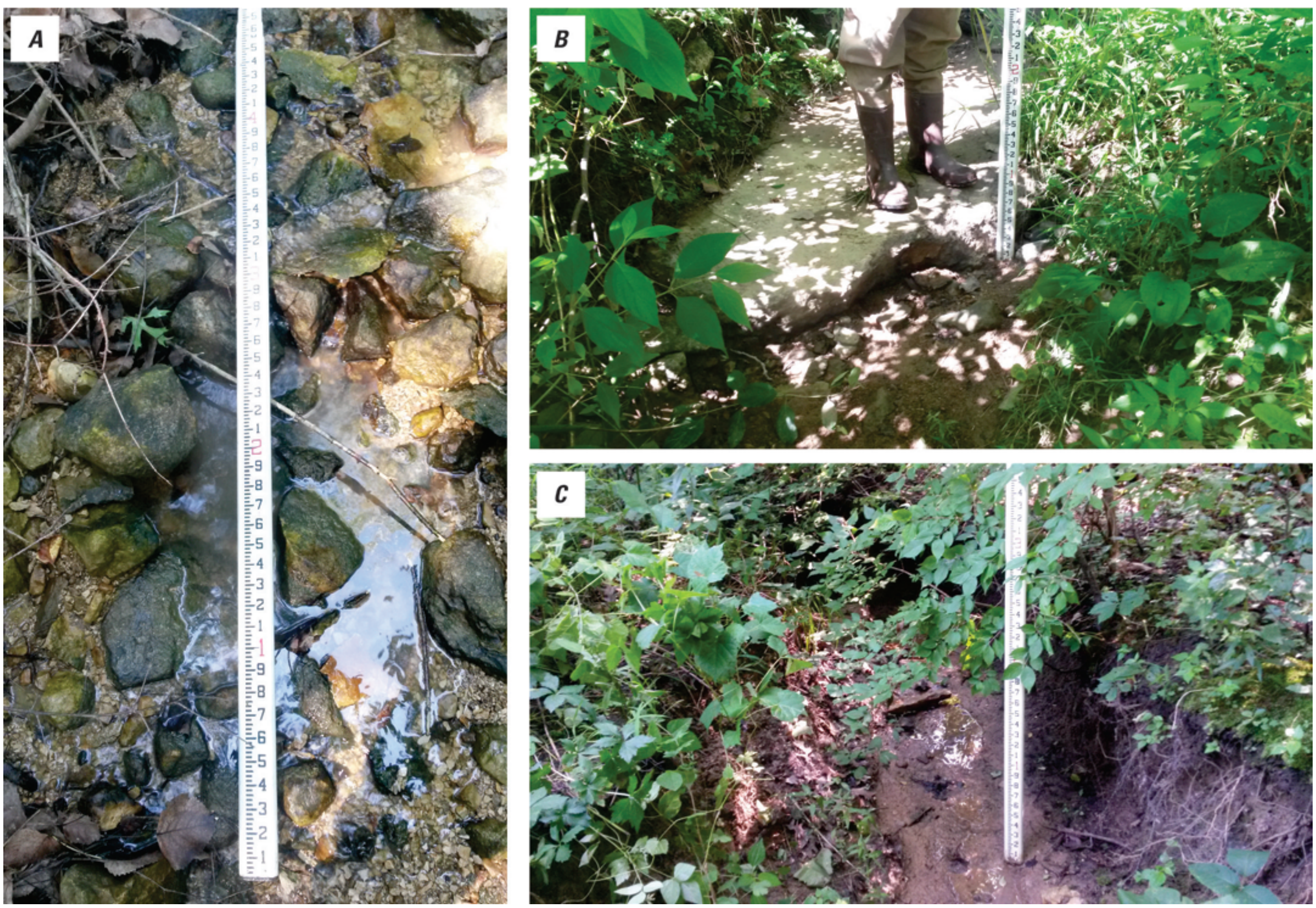

Figure 2-5. Representative substrate in the reach of Southeast Drainage Way *A*: cobble, *B*, rock, and *C*, hardpan clay, Argonne National Laboratory, DuPage County, Illinois.

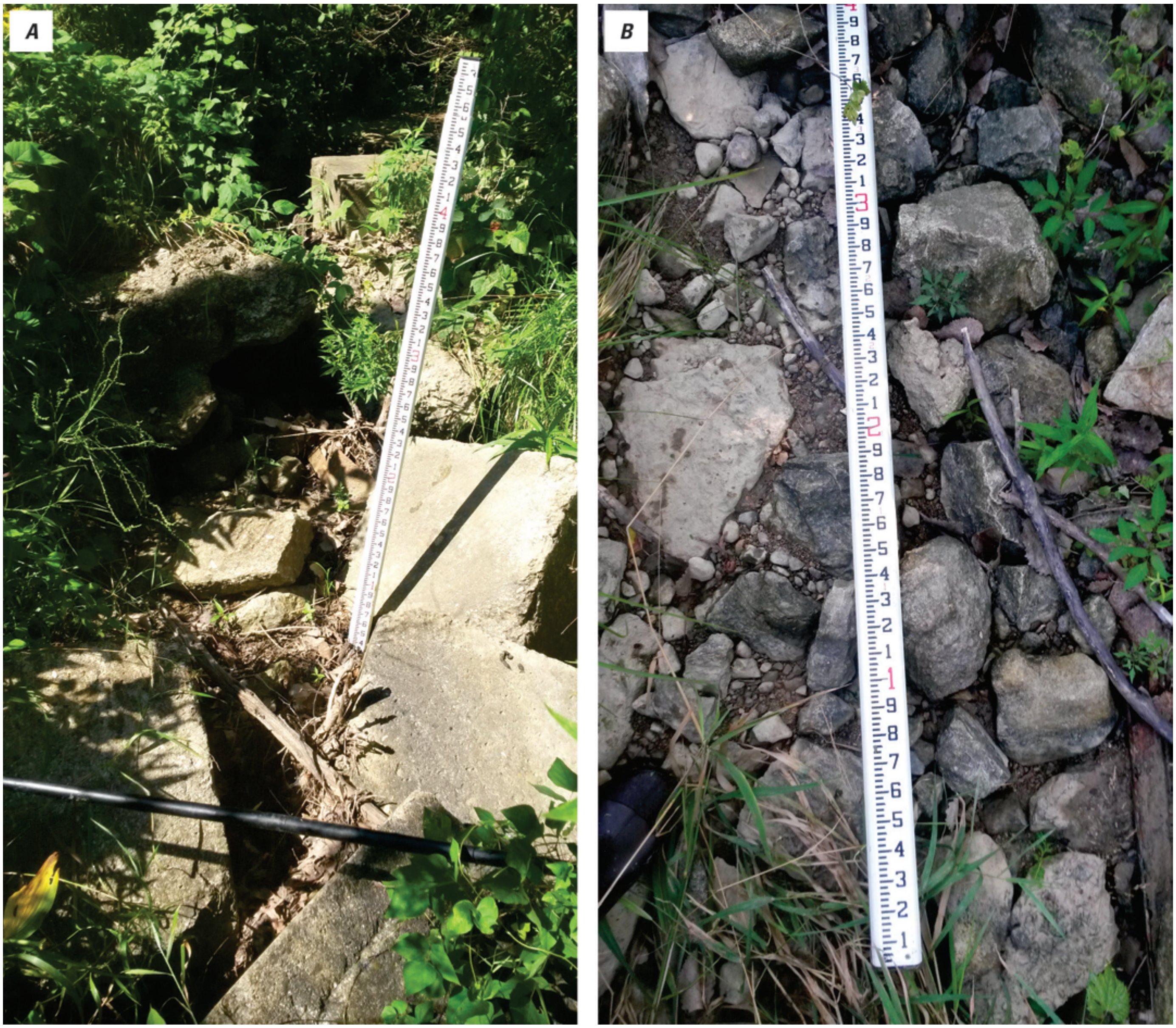

Figure 2-6. Concrete and rock that has been placed in the Southeast Drainage Way to *A*, help mitigate the nickpoint migration at WP04 near station 1473 and *B*, protect utilities at WP02 near station 1190, Argonne National Laboratory, DuPage County, Illinois.

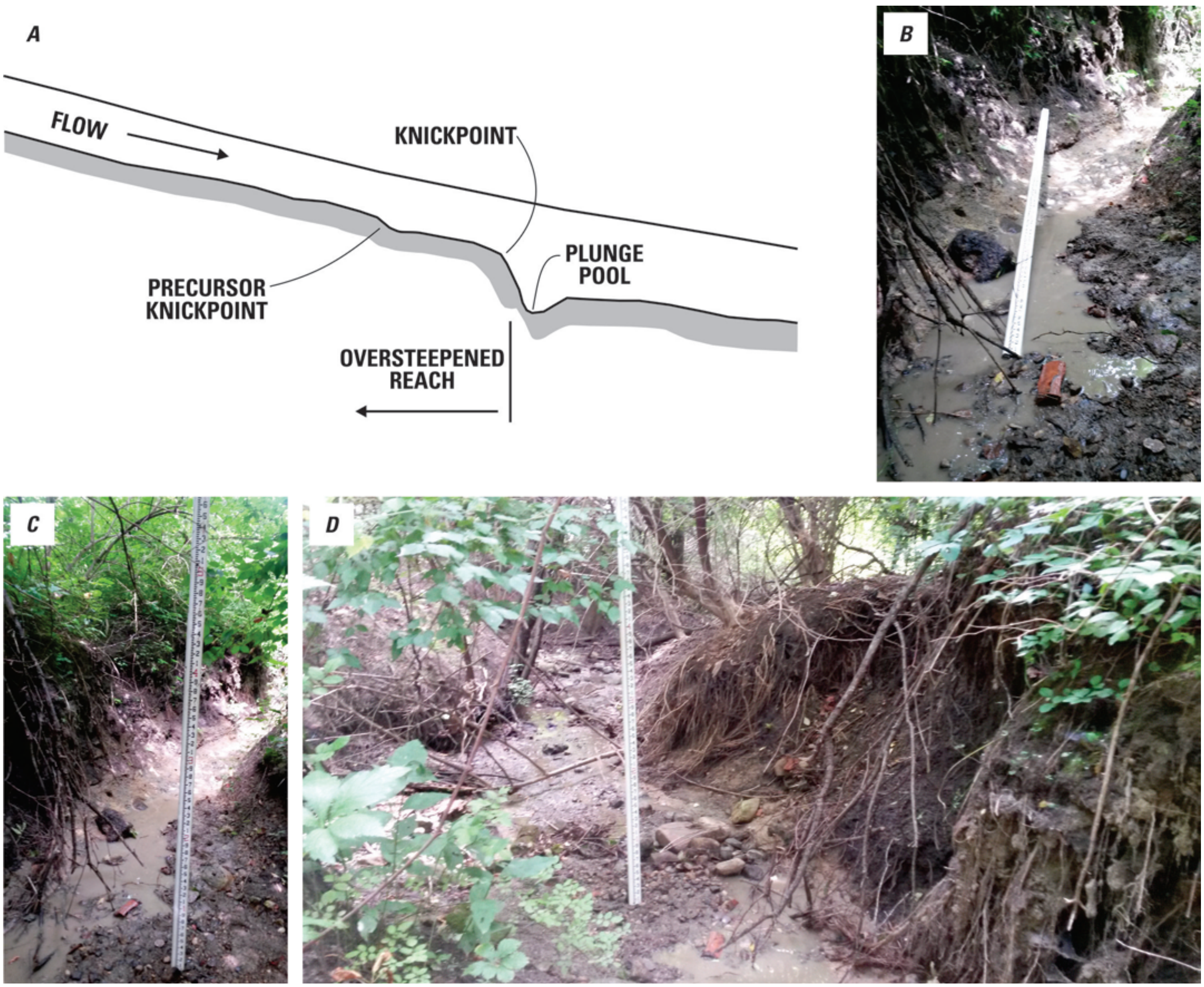

Figure 2-7. *A*, Diagram of a nickpoint (modified from Schumm and others, 1984). On Southeast Drainage Way, *B*, example of gradual nickpoint at WP10 near station 2761, *C*, nickpoint, looking upstream, and *D*, looking immediately downstream from the nickpoint showing the widened channel from the nickpoint moving through the reach, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-8. Representative stream conditions in Southeast Drainage Way: *A*, at WP12 near station 2322 and *B*, at WP13 near station 3054, Argonne National Laboratory, DuPage County, Illinois.

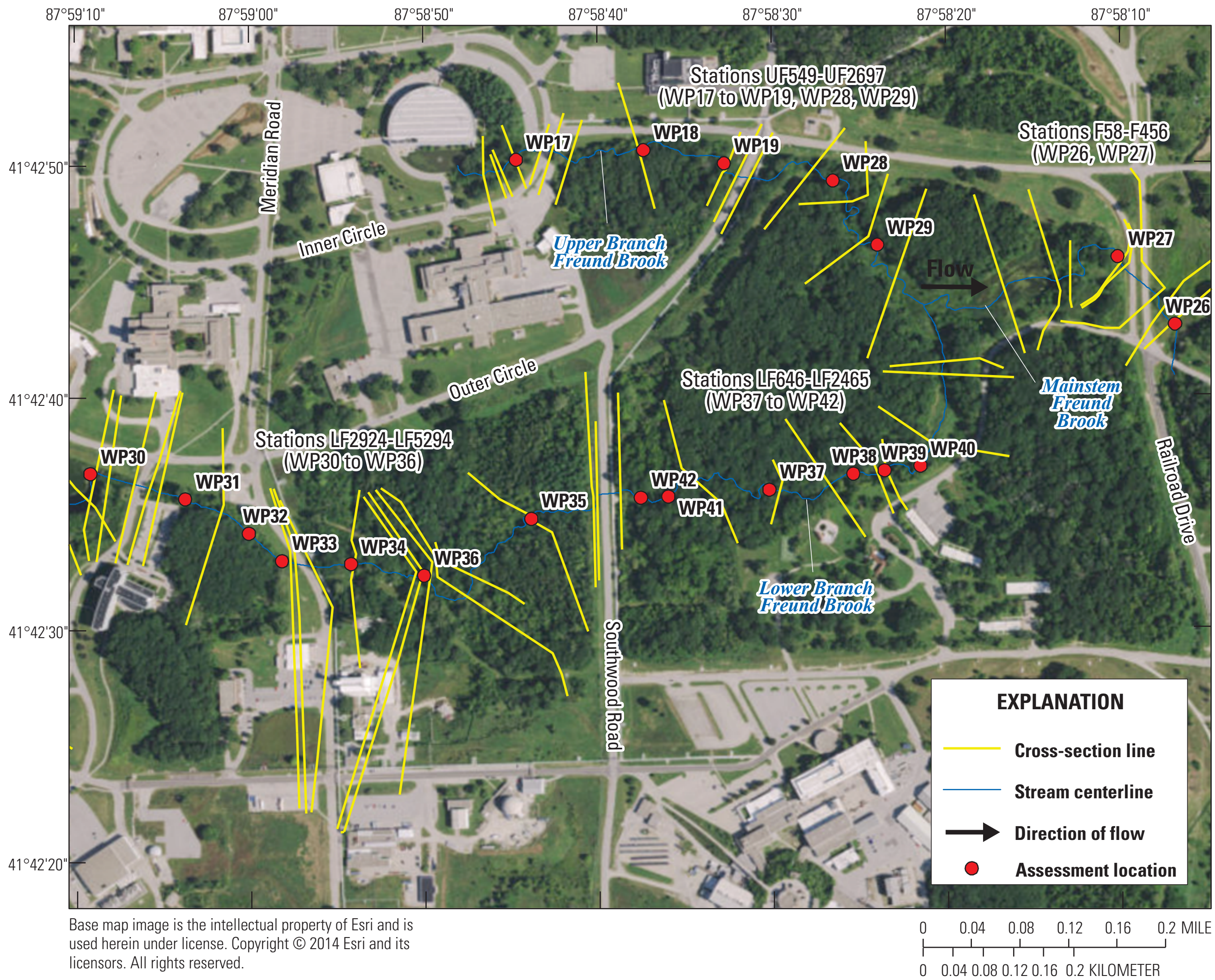

Figure 2-9. Freund Brook reaches, Argonne National Laboratory, DuPage County, Illinois. (F, Freund Brook; UF, Upper Branch Freund Brook; LF, Lower Branch Freund Brook)

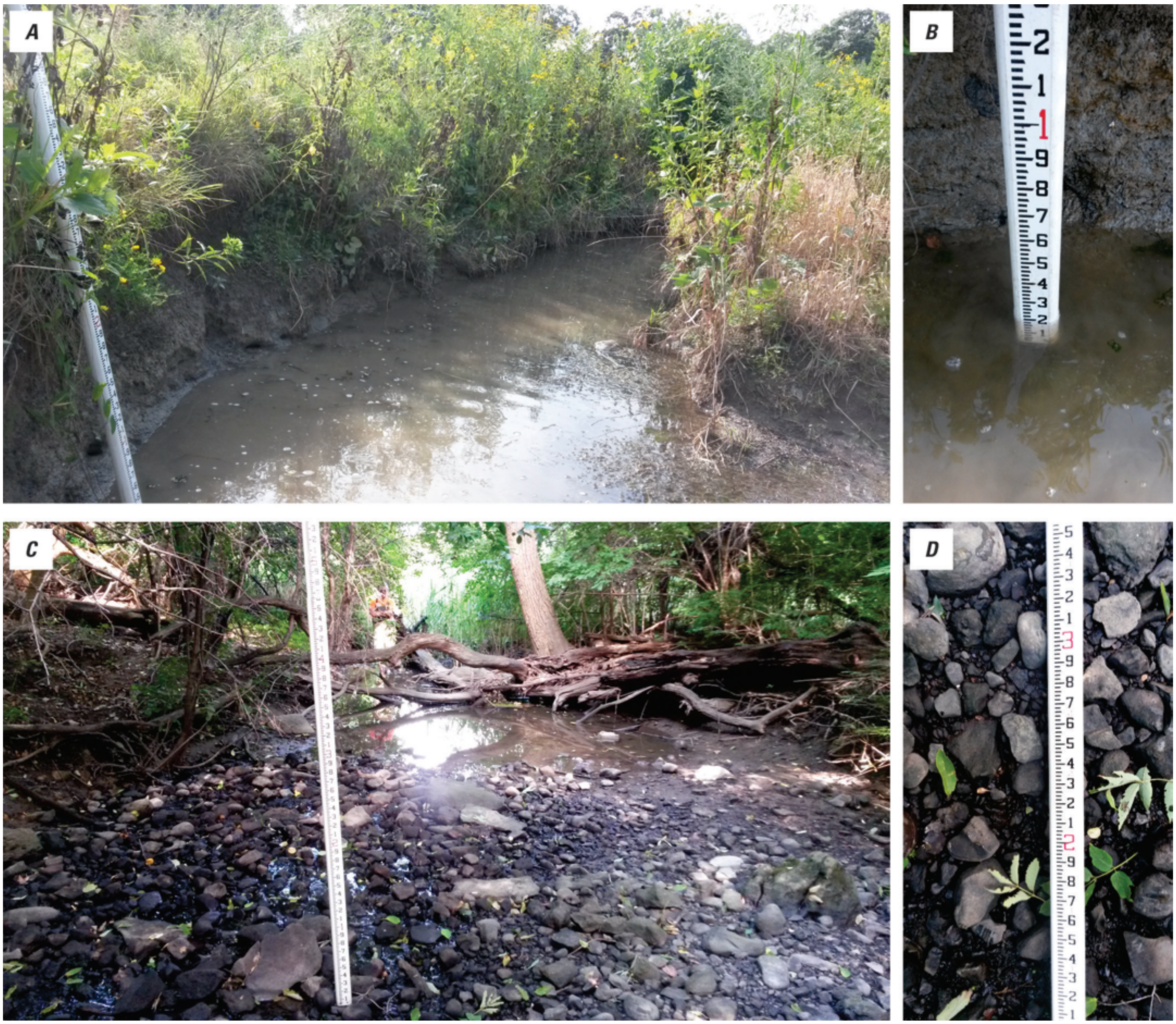

Figure 2-10. Freund Brook, *A*, looking upstream, *B*, at streambed at WP26 near station F58, *C*, looking downstream, and *D*, streambed at WP27 near station F456, Argonne National Laboratory, DuPage County, Illinois.

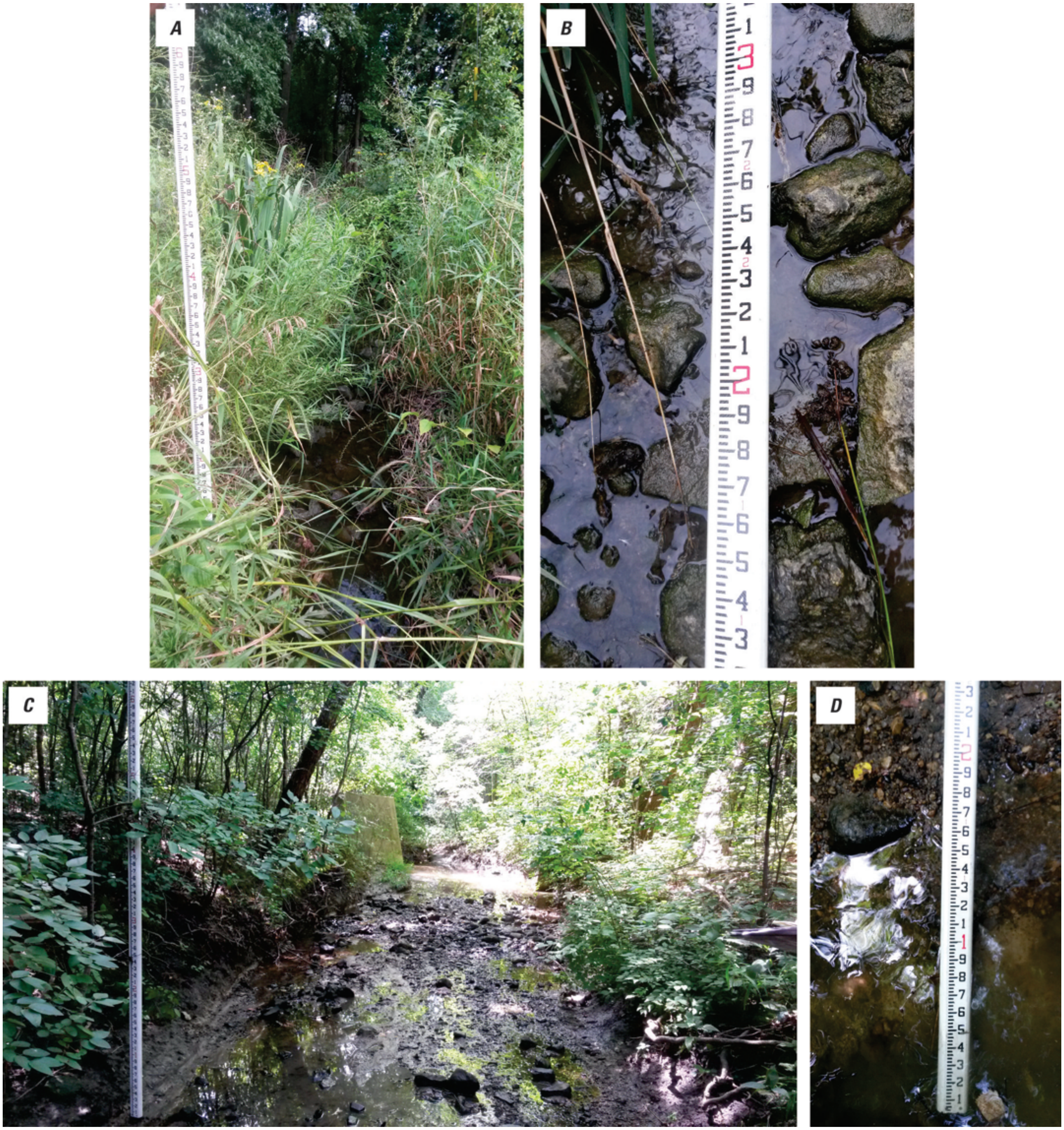

Figure 2-11. Upper Freund Brook, *A*, looking downstream, *B*, at streambed at WP28 near station UF1162, *C*, looking upstream at WP18 near station UF2066, and *D*, at streambed at WP19 near station UF1609, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-12. Upper Freund Brook, *A*, looking downstream and *B*, at streambed at WP17 near station UF2697, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-13. Lower Freund Brook, *A*, looking upstream at the dam at WP39 near station LF960, *B*, looking upstream at the channel, *C*, streambed at WP38 near station LF1004 that is just upstream from the dam, and *D*, looking downstream at WP40 near station LF646, which is downstream from the dam, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-14. Lower Freund Brook, *A*, looking upstream and *B*, at streambed at WP37 near station LF1497, Argonne National Laboratory, DuPage County, Illinois.

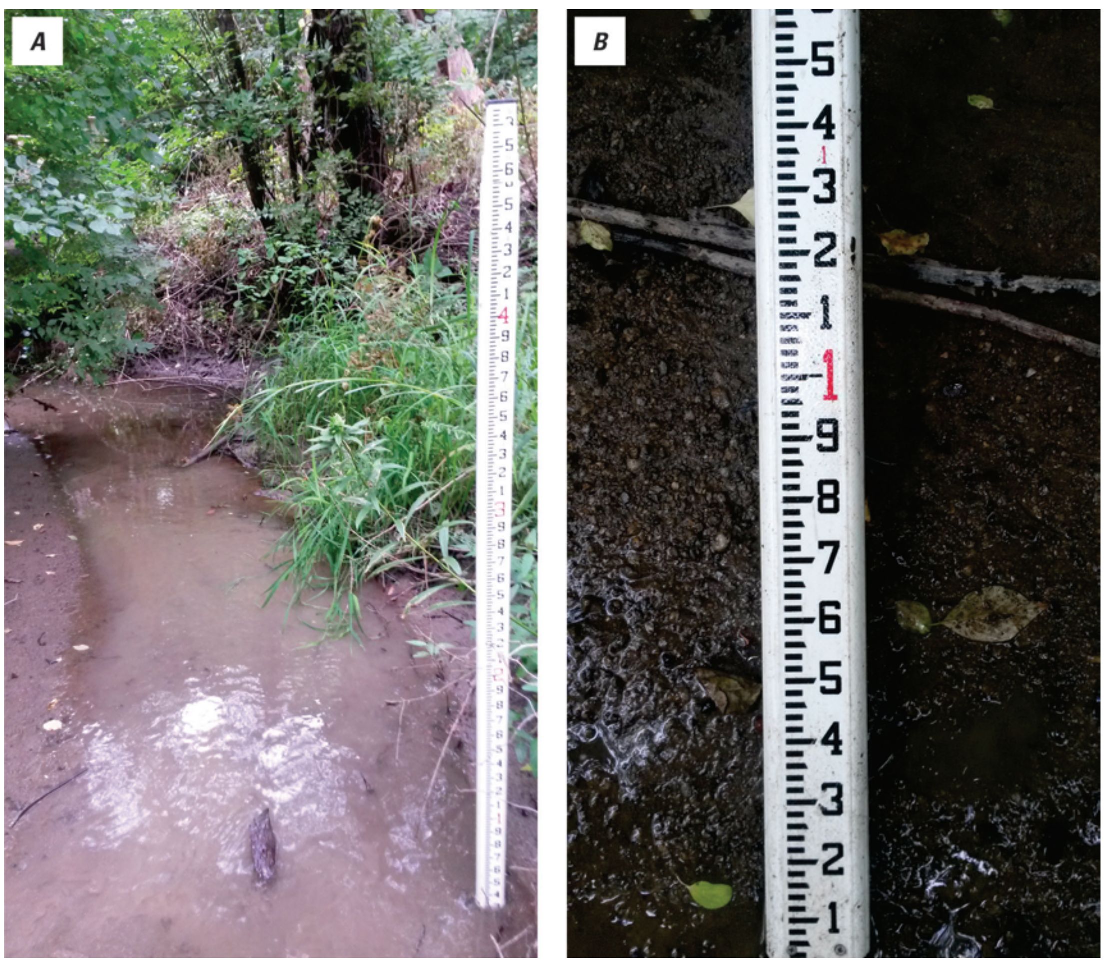

Figure 2-15. Lower Freund Brook, *A*, looking downstream and *B*, at streambed at WP35 near station LF2924, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-16. Lower Freund Brook, *A*, looking downstream at WP36 near station 3680 and *B*, looking upstream at WP34 near station LF4047, Argonne National Laboratory, DuPage County, Illinois.

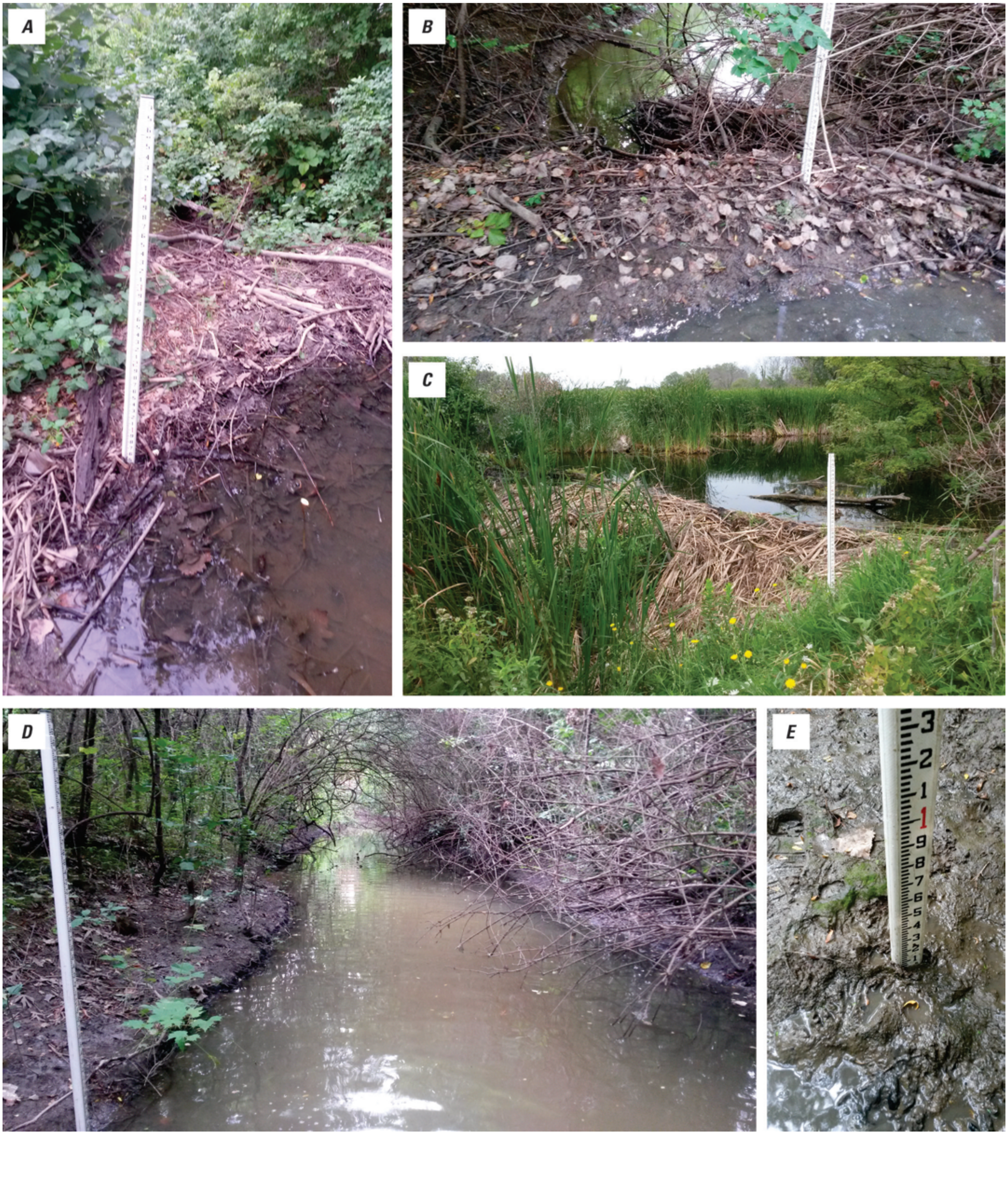

Figure 2-17. Lower Freund Brook, *A*, Looking downstream at a beaver dam at WP31 near station LF5004, *B*, looking downstream at a beaver dam near station LF4331, *C*, looking upstream at a beaver dam at WP30 near station 5294, *D*, looking downstream at WP32 near station LF4713, and *E*, streambed at WP31 near station LF5004, Argonne National Laboratory, DuPage County, Illinois.

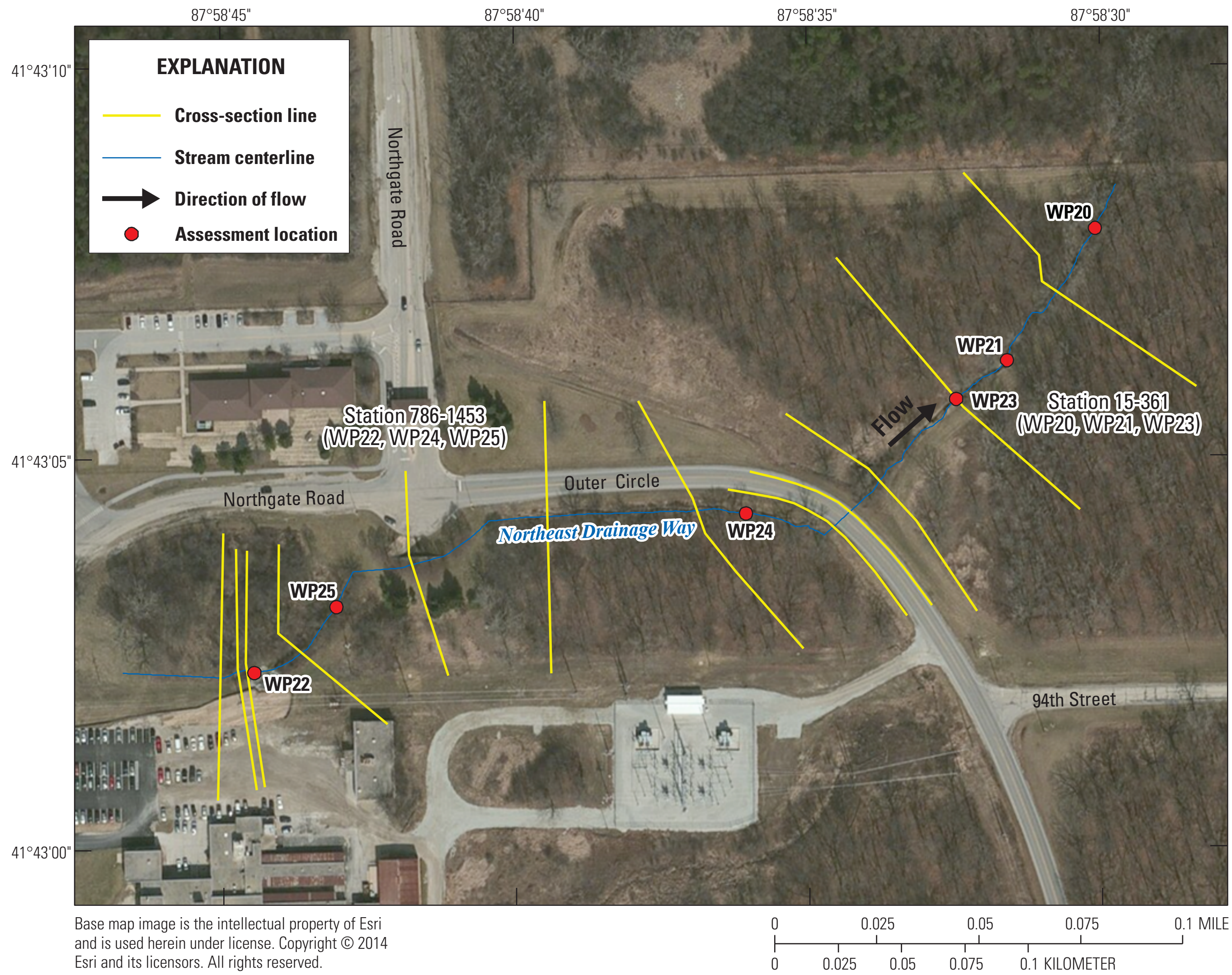

Figure 2-18. Northeast Drainage Way reach, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-19. Northeast Drainage Way, *A*, looking downstream at WP21 near station 159 and *B*, at streambed at WP23 near station 361, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-20. Northeast Drainage Way, *A*, looking at left bank downstream from section 361 (WP21) and *B*, looking upstream at station 361 (WP23), Argonne National Laboratory, DuPage County, Illinois.

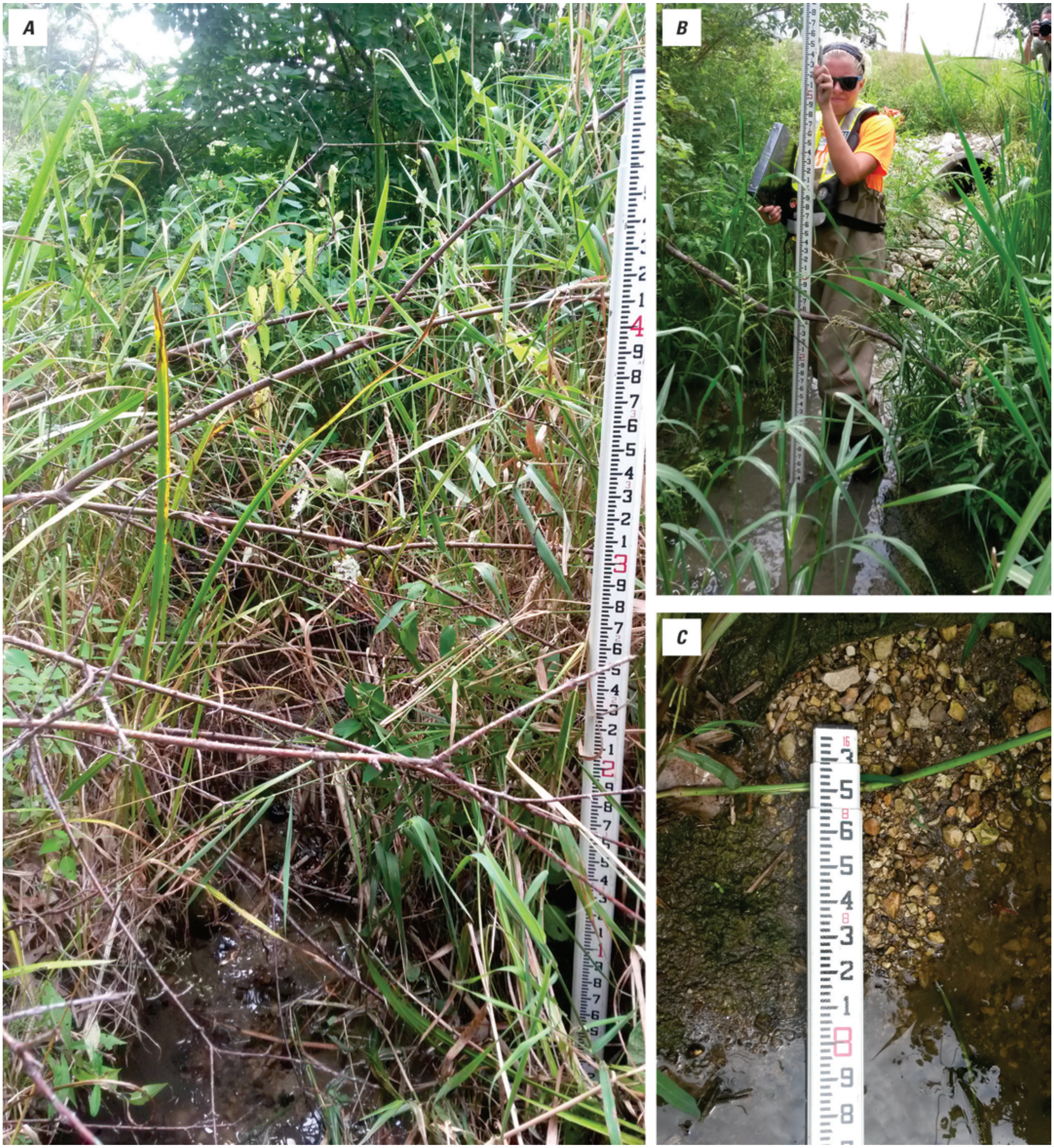

Figure 2-21. Northeast Drainage Way, *A*, looking downstream at WP24 near section 786, *B*, looking upstream at station 1453 (WP22), and *C*, at streambed near station 1453, Argonne National Laboratory, DuPage County, Illinois.

Figure 2-22. Northwest Drainage Way reach, Argonne National Laboratory, DuPage County, Illinois.

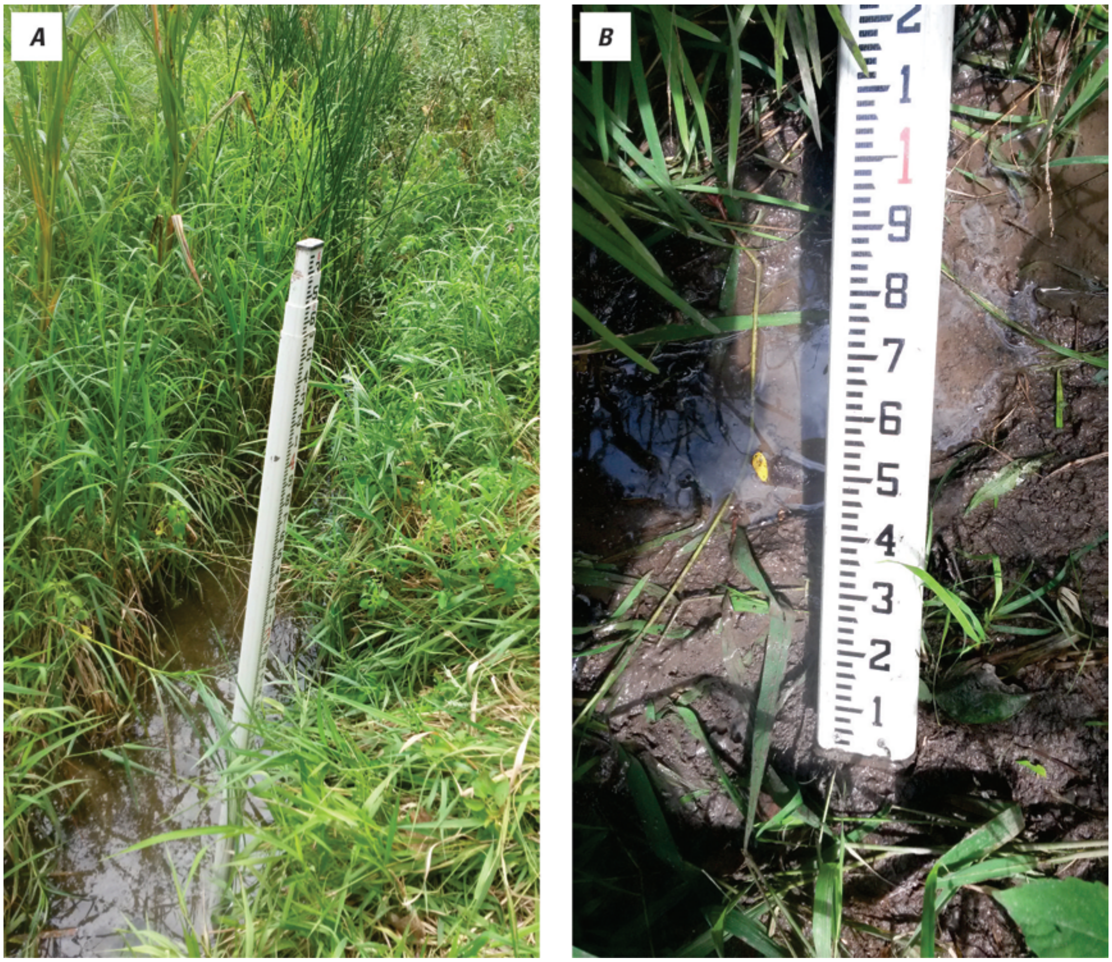

Figure 2-23. Northwest Drainage Way, *A*, looking upstream at WP15 near section 18, and *B*, at streambed at WP16 near station 523, Argonne National Laboratory, DuPage County, Illinois.

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Schumm, S.A., Harvey, M.D., and Watson, C.C., 1984, Incised Channels: Morphology Dynamics, and Control: Littleton, Colo., Water Resources Publications, 200 p.

Appendix 3. Maps of 1-Percent Quantile Water-Surface Elevation with 3 Feet of Freeboard

In order to generate estimated flood-hazard maps for possible future conditions resulting from climate change, meteorological scenarios would need to be produced and run through hydrologic models to produce estimated streamflows. Estimated streamflows would then be routed through a hydraulic model to determine water-surface elevations for these flows. For this study, as an alternative, 3 feet of freeboard was added to water-surface elevations corresponding to the 1-percent quantile flows; then those elevations were mapped. No additional model analysis was done to produce these maps; they are the result of increasing the water-surface elevation in the geographic information system (GIS) and determining how the flood inundation extent increased.

This GIS-only approach impacted the extent of inundation for the Northeast Drainage Way map (fig. 3-2). The inundation extent shown is larger than would be realistically expected because it does not take into account the hydraulic interaction with the road and culvert. It is expected that water would pass over Outer Circle and reduce the ponding behind the road. The 1-percent quantile flow event does not overtop Outer Circle and pools upstream from the road, whereas the 0.2-percent quantile flow does overtop the road and lowers the pool depths in some locations as compared to the 1-percent event. Additionally, with the higher water-surface elevations mapped in this figure, the inundation would continue up Northgate Road, but the mapping extent was limited because of the uncertainty introduced by the approach. It is recommended that this area gets a more in-depth analysis at a higher flow taking the hydraulics of the road crossing into account.

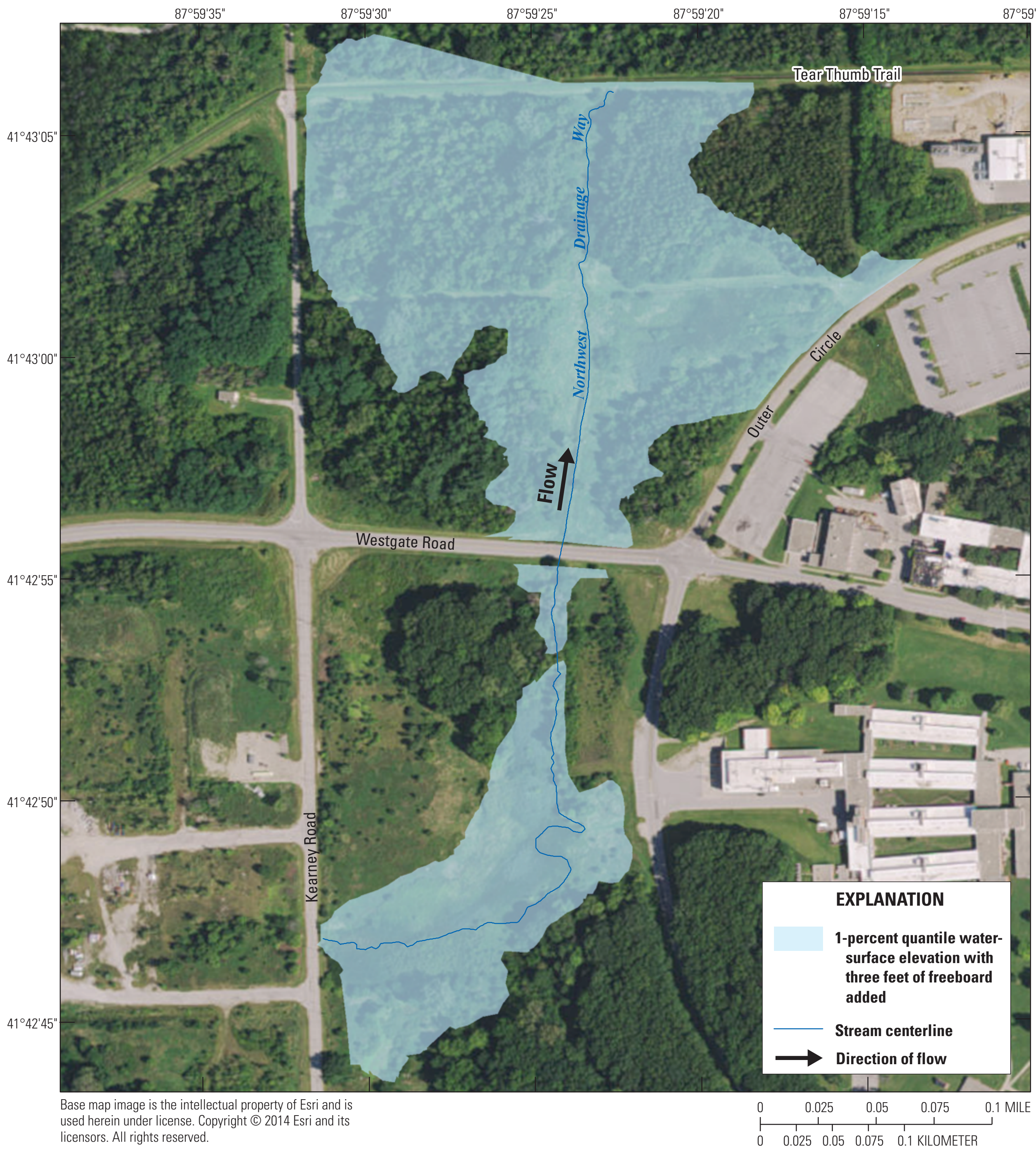

Figure 3-1. Flood-hazard map of Northwest Drainage Way representing 1-percent quantile water-surface elevations with 3 feet of freeboard added, Argonne National Laboratory, DuPage County, Illinois.

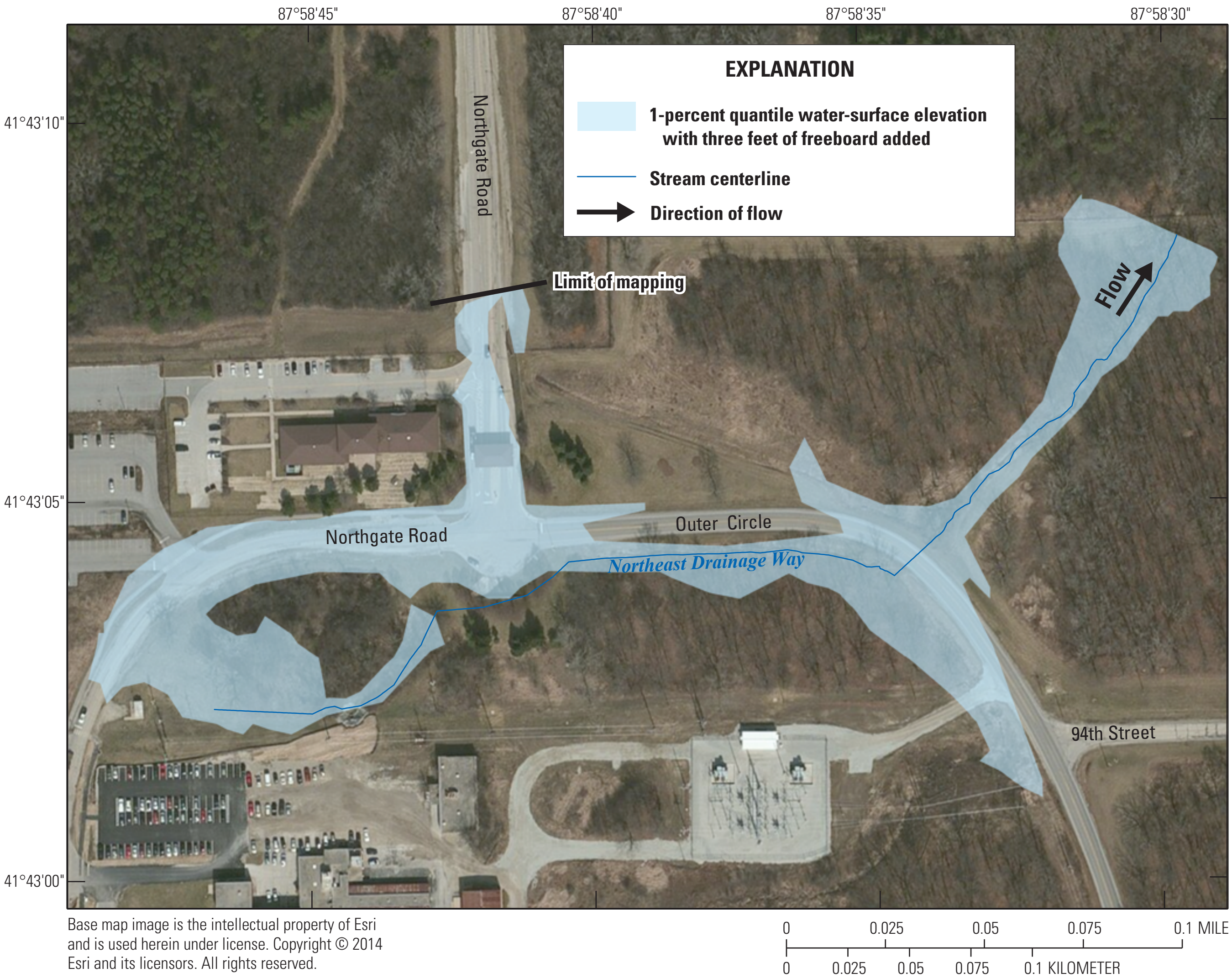

Figure 3-2. Flood-hazard map of Northeast Drainage Way representing 1-percent quantile water-surface elevations with 3 feet of freeboard added, Argonne National Laboratory, DuPage County, Illinois.

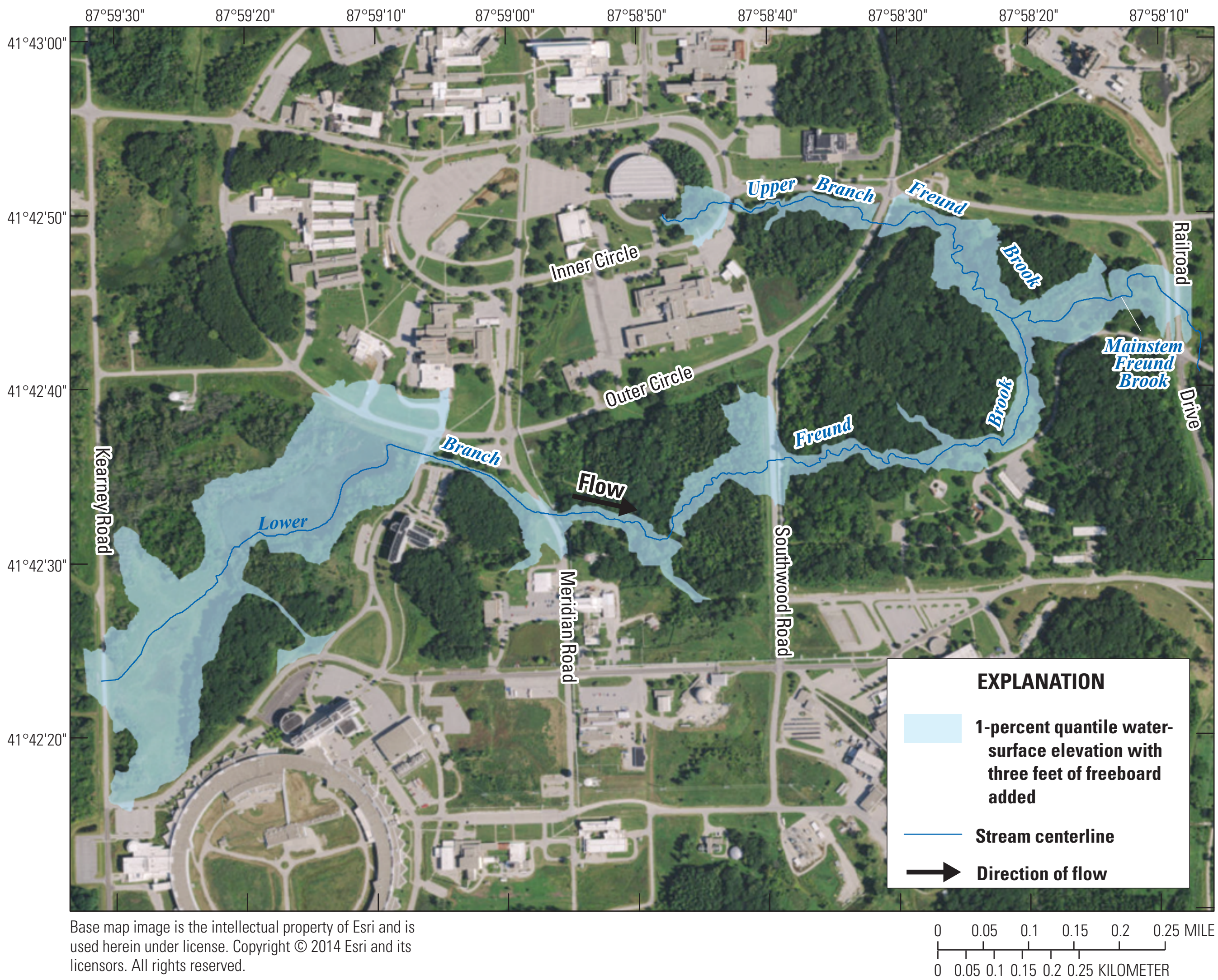

Figure 3-3. Flood-hazard map of Freund Brook representing 1-percent quantile water-surface elevations with 3 feet of freeboard added, Argonne National Laboratory, DuPage County, Illinois.

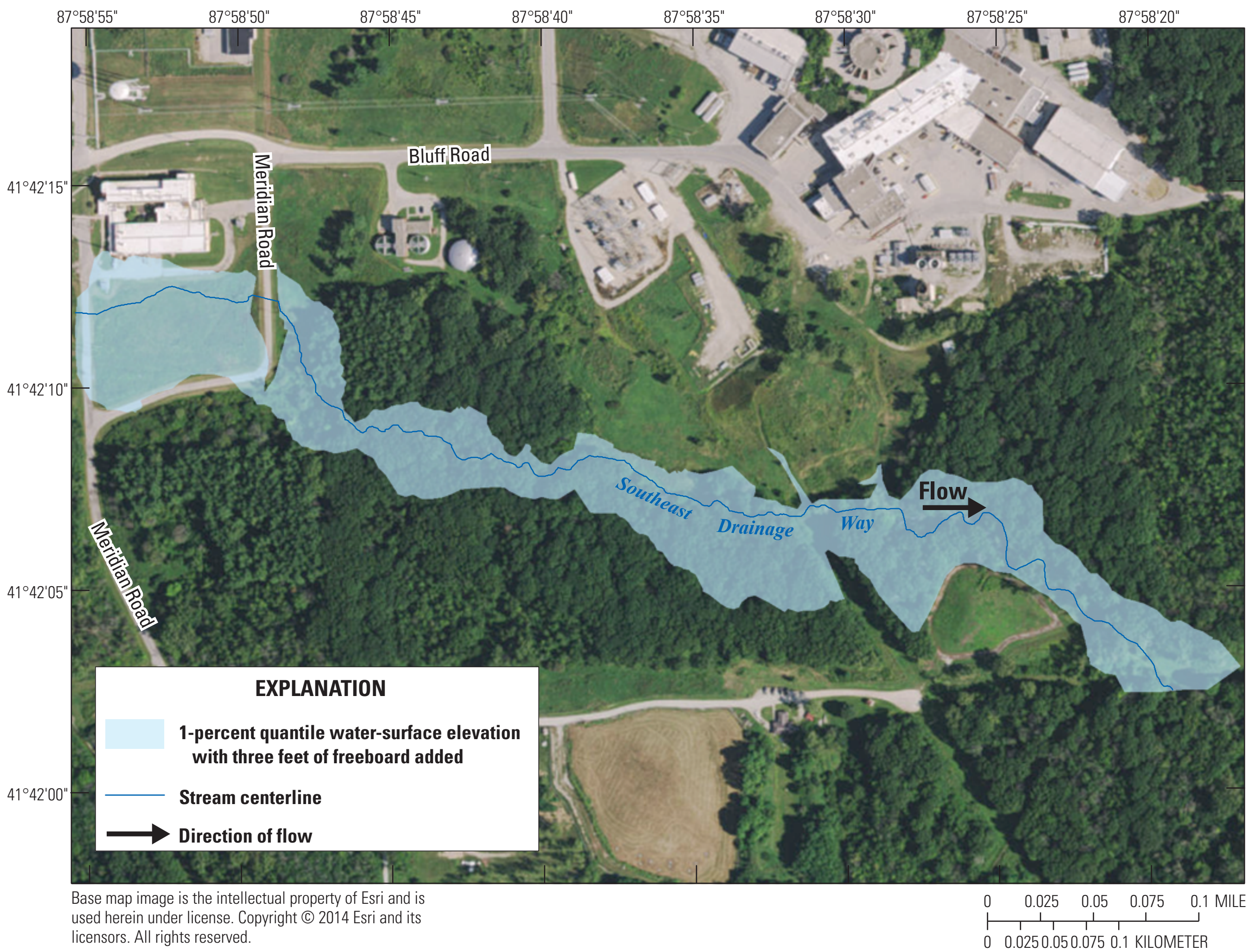

Figure 3-4. Flood-hazard map of Southeast Drainage Way representing 1-percent quantile water-surface elevations with 3 feet of freeboard added, Argonne National Laboratory, DuPage County, Illinois.

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