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Effect of Detention Basin Release Rates on Flood Flows—Application of a Model to the Blackberry Creek Watershed in Kane County, Illinois

Scientific Investigations Report 2009–5106

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

Cover: Detention basin and inlet at Fox Hill Lane at the upper part of the East Run tributary of Blackberry Creek in North Aurora, Illinois, 2002. (Photograph by U.S. Geological Survey personnel.)

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KEN SALAZAR, Secretary

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Suzette M. Kimball, Acting Director

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	259.0	hectare (ha)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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).

Acronyms and Abbreviations

AMS	annual maximum series
CBBEL	Christopher B. Burke Engineering, Ltd.
HSPF	Hydrological Simulation Program–FORTRAN
KCDEM	Kane County Department of Environmental and Building Management
MWRD	Metropolitan Water Reclamation District
NIPC	Northeastern Illinois Planning Commission
USGS	U.S. Geological Survey
WY	water year
ft^3/s-acre	cubic foot per second per acre

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Abstract

The effects of stormwater detention basins with specified release rates are examined on the watershed scale with a Hydrological Simulation Program–FORTRAN (HSPF) continuous-simulation model. Modeling procedures for specifying release rates from detention basins with orifice and weir discharge configurations are discussed in this report. To facilitate future detention modeling as a tool for watershed management, a chart relating watershed impervious area to detention volume is presented. The report also presents a case study of the Blackberry Creek watershed in Kane County, Ill., a rapidly urbanizing area seeking to avoid future flood damages from increased urbanization, to illustrate the effects of various detention basin release rates on flood peaks and volumes and flood frequencies. The case study compares flows simulated with a 1996 land-use HSPF model to those simulated with four different 2020 projected land-use HSPF model scenarios—no detention, and detention basins with release rates of 0.08, 0.10, and 0.12 cubic feet per second per acre (ft^3/s-acre), respectively. Results of the simulations for 15 locations, which included the downstream ends of all tributaries and various locations along the main stem, showed that a release rate of 0.10 ft^3/s-acre, in general, can maintain postdevelopment 100-year peak-flood discharge at a similar magnitude to that of 1996 land-use conditions. Although the release rate is designed to reduce the 100-year peak flow, reduction of the 2-year peak flow is also achieved for a smaller proportion of the peak. Results also showed that the 0.10 ft^3/s-acre release rate was less effective in watersheds with relatively high percentages of preexisting (1996) development than in watersheds with less preexisting development.

Introduction

Urbanization increases impervious surfaces in residential, commercial and industrial areas and alters the hydrologic response of a watershed to rainfall. Altered hydrologic responses include reduced interception by vegetation and reduced detention capacity due to elimination of depressional storage. Consequently, storm runoff occurs faster and can have larger peak-discharges and runoff volumes from developed areas. Runoff corresponding to short-duration rainfall appears more frequently and less water infiltrates the soil, which decreases ground-water storage capacities in developed landscapes and alters baseflows (Konrad, 2003; Bedient and Huber, 2002). Urbanization can also impact water quality; storm runoff from urban areas may contain high concentrations of suspended solids and chemicals, such as nitrogen, phosphorus, trace elements, and organics, or oils and greases (Sherwood, 2001). Increases in flood-peak magnitude, flood-peak frequency, and runoff volumes, along with the resulting increases in sediment and pollutant loads, can cause more flooding, erosion, water pollution, and destruction of stream habitat.

Stormwater facilities, such as detention basins, retention basins, and infiltration areas, store storm runoff on site and reduce runoff rates from the site. Among stormwater facilities, detention or retention basins are the most widely used in practice. A detention basin temporarily stores storm runoff, and the stored storm runoff is later released downstream through a flow-control structure that regulates the rate of release. A retention basin retains a specified amount of stormwater runoff without releasing it except by means of evaporation, infiltration, emergency bypass, or pumping. Infiltration areas reduce runoff by moving water from the surface into the ground-water system through permeable soils. Devices or plants that filter or remove sediment, excess nutrients, and toxic chemicals can be installed on detention basins to enhance water-quality protection. Basins can be designed for multiple purposes and integrated into neighborhoods for open space and recreation, aesthetics, and wildlife-habitat enhancement (King County Stormwater Services, 2008). However, a detention basin can control runoff effectively only if its total volume is not exceeded. Once flows overtop the basin, the runoff is no longer controlled and damaging downstream flows are normally assumed. Thus basin volume is the ultimate determinant of detention basin performance. The primary factors for determining the basin volume are the contributing drainage area, basin release rate, local soil, hydrological, climatologic characteristics, and time to release the stored runoff.

Runoff from a natural watershed is inherently distributed in time and space, unlike the water released from a detention basin, which enters the stream at one location. Release rate is the amount of flow that a control outlet structure is designed to pass in a given duration. The release rate varies with the type of outlet structure implemented, such as a weir or orifice. Release rates are determined by the size of the contributing watershed area and the chosen goal of the detention, either mitigation of the effects of peak-flood discharge or duration. Typical release-rate design requirements do not consider modifications to the shape of the outflow hydrographs, such as longer postdevelopment flood-peak discharge than predevelopment flood-peak discharge given the increased volume and the timing of released flow. The prolonged release may cause flooding to continue or worsen in larger drainage systems. It is challenging to design release rates that produce outflow emulating storm events that vary both in intensity and duration and extend over long periods of time but still satisfy flood-peak reduction and flow-duration requirements (King County Stormwater Services, 2008).

The Kane County Department of Environmental and Building Management (KCDEM) developed a stormwater ordinance to manage continuing growth and to protect natural resources in Kane County (Kane County Stormwater Management, 2005). The ordinance specifies that detention storage should be constructed in all new development areas in the county and that detention basins should have a release rate set at 0.1 cubic feet per second per acre of developed area (ft^3/s-acre) for controlling the 100-year flood. However, uncertainty remains about the extent of protection given by this release rate on the watershed scale. The U.S. Geological Survey (USGS), in cooperation with the KCDEM, undertook this study to determine the effect of detention basin release rates on flood flows for stormwater management in the Blackberry Creek watershed in Kane County.

Purpose and Scope

The purpose of this report is to document the modeling approach used to simulate flows from detention basins with specified release rates. Modeling procedures for specifying release rates from detention basins with an orifice and weir discharge configuration are discussed. To facilitate future detention modeling as a tool for watershed management, a chart relating watershed impervious area to detention volume is presented. The report also presents a case study of the Blackberry Creek watershed in Kane County, a rapidly urbanizing area seeking to avoid future flood damages from increased urbanization, to illustrate the effects of various release rates on flood peaks and volumes, and the flood frequencies. The case study compares flows simulated with a 1996 land-use Hydrological Simulation Program-FORTRAN (HSPF) model (Bicknell and others, 2000) to those simulated with four 2020 land-use HSPF model scenarios—no detention, and detention basins with release rates of 0.08, 0.10, and 0.12 ft^3/s-acre, respectively.

Previous Studies

A literature review on the use of detention release rates in northeastern Illinois and the implementation of release rates in other HSPF models was completed.

Release Rates in Northeastern Illinois

Communities in northeastern Illinois began adopting stormwater detention requirements in the early 1970s. Approximately 80 percent of the municipalities and counties in the region have detention requirements for new development (Dreher and others, 1989). Local detention requirements vary widely, in terms of storage volumes, release rates, and suggested computational requirements. A brief review of the establishment of stormwater ordinances in areas of the Metropolitan Water Reclamation District of Greater Chicago (MWRD) and neighboring counties is presented to illustrate how communities in a rapidly developing region adopt detention basin and release rate ordinances. The MWRD area covers Cook County and parts of DuPage and Will Counties. More detailed information can be found in the reports prepared by Dreher and others (1989) and the Northeastern Illinois Planning Commission (NIPC) (1985).

In 1972, MWRD began to require that stormwater detention be provided for new development (Dreher and others, 1989). This detention ordinance called for all residential developments more than 10 acres and all commercial and industrial developments more than 5 acres to provide stormwater detention to limit postdevelopment 100-year event runoff peaks to predevelopment peak flows. The allowable postdevelopment release rate for the 100-year storm is equivalent to the predevelopment 3-year storm runoff rate based on the modified rational formula (Chow and others, 1988) with a maximum runoff coefficient "C" of 0.15. Given the rainfall statistics and physical characteristics of typical watersheds in northeastern Illinois, a typical maximum release rate is about 0.3 ft^3/s-acre, and it may range from 0.2 ft^3/s-acre to 0.5 ft^3/s-acre. Smaller release rates are used as watershed size increases. This MWRD detention ordinance has been the basis of other detention policies in northeastern Illinois (Dreher and others, 1989).

The NIPC (1985) examined 38 local stormwater detention requirements outside Cook County. Several ordinances eliminated the 10-acre minimum residential development size for required stormwater detention if the site impervious area exceeded 50 percent, and some ordinances required detention for all new development regardless of development size or amount of impervious area. The choice of the majority of the municipalities was to design the postdevelopment release rate for control of the 100-year event. In practice, the most widely used method of determining allowable detention release rate was the MWRD method using either a 3-year or a 2-year event. About one-third of the communities specified a fixed release rate; the rates were almost evenly divided between 0.1 and 0.12 ft^3/s-acre.

The effectiveness of existing detention policies in northeastern Illinois was evaluated by NIPC (Dreher and others, 1989). As a result, release rates for the 2-year and 100-year storm events were recommended for use in northeastern Illinois in the absence of a comprehensive stormwater management plan for a particular watershed. Price and Dreher (1991) found that the design storm methods appear to either over- or underpredict detention requirements based on different land-use assumptions. Because of the difficulty in using the design storm methods, the unit area-detention volume requirements were developed based on over 40 years of continuous hydrologic simulation (Price and Dreher, 1991; Price, 1997) as an alternative to the design storm approach for determining detention requirement and release rate. The resulting unit area-detention volumes requirements have been used in DuPage and Lake Counties to develop stormwater ordinances (Price, 1997).

Release Rates in Continuous Hydrologic Simulation

Donigian and others (1997) used HSPF to investigate improvements in flood control and water quality by including various detention basin design scenarios in a study of Calabazas Creek, California. A 50-year continuous simulation was performed at an hour time step, and the routing and release of flow through detention basins were described by a set of depth-surface area-volume-discharge relations called “Ftables” in the HSPF model. The surface runoff was routed from impervious areas to detention basins, and the amount of flow released from a detention basin to a downstream stream channel was determined from the detention Ftable. Typical detention basin design information was obtained from the Santa Clara Valley Water District to develop an appropriate Ftable, and the stage, volume, surface area, and discharge relation were calculated accordingly. The first Ftable was designed for an 800-acre drainage area. Ftables for other drainage-area sizes were developed by adjusting discharge, volume, and surface-area values proportionally to the drainage area. For the Calabazas Creek watershed, the results showed that none of the detention basin scenarios had a substantial impact on mean annual flow volumes, but daily peak discharge decreased for events of 10-year recurrence interval or less. However, flow rates for less frequent (more extreme) floods changed little, and some locations showed small increases in peak-flow rates in the simulation.

Detention Modeling

In an HSPF schematic, the inflow to a river reach (RCHRES) may consist of the flow entering the reach from an upstream reach, or flow from contributing pervious land and impervious land segments, or both. To describe outflows from a reach, an Ftable is needed that describes the relations among the outflow rates and channel-reach geometry including depth, surface area, and volume. Donigian and others (1997) suggested that the Ftable concept can be applied to outflow from a detention basin by:

1. Decreasing the outflow rates associated with the given storage volumes to simulate a flow-control structure across the channel, or
2. Increasing the channel-storage volumes associated with the given discharges to simulate creation of one or more storage pools adjacent to the channel or upstream from the discharge point.

Modifications to the outflow discharge and storage relations could be achieved by using either hypothetical or computed design based on field or proposed basin dimensions or a combination of both. Proper determination of these outflow discharge and storage relations is essential for sizing the detention basin and, therefore, also determines the how effective the detention basin is for stormwater management.

Detention Basin Volume Estimation

In a study for DuPage County, Price (1997) devised a method that uses the HSPF continuous simulation approach to estimate the sizing requirement for a 100-year detention basin with an outlet release rate of 0.1 ft^3/s-acre from a linear slot outflow structure (fig. 1). The design chart allows users to determine detention volumes based on the amount of hydraulically connected impervious area (expressed as a percentage) in the watershed. Price (1997) found that the required detention-basin storage ranged from 0.245 to 0.554 acre-ft/acre for contributing watersheds with impervious areas ranging from 0 to 100 percent. Price (1997) first assumed a group of 100-acre hypothetical watersheds with impervious land areas ranging from 0 to 100 percent. A trial-and-error approach was developed with the following steps:

1. Determine a set of assumed (initial) detention volume-discharge relations, which will be the data for constructing Ftables, for the linear slot outlet structure, then
2. Run the HSPF model with the Ftable implemented, and simulate hourly flow at the outlet using the long-term precipitation record from water years[1] (WY) 1949 to 1993 recorded at Wheaton, Ill., as the input.
3. Generate the annual maximum time series (AMS) from the simulated outflow, and determine flood frequencies from the AMS using the Log Pearson Type III distribution with procedures outlined in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982).
4. Stop the process if the 100-year discharge is equal to 0.1 ft^3/s-acre of the drainage basin; if not, then a new volume-discharge relation is chosen for the process until the desired release rate is achieved.

[1] A water year (WY) is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends. For example, WY 2007 is from October 1, 2006, through September 30, 2007.

In the current study, an orifice-weir outlet structure was modeled. Water is released from a detention basin first through an orifice and then over a weir if the storm exceeds the design storage of the detention basin. The orifice outlet is the structure specified by Kane County (Kane County Stormwater Management, 2005). The release rate discharge and detention storage volume relations for the linear slot and orifice outlet structures were computed for the release rate of 0.1 ft^3/s-acre and are compared in figure 1.

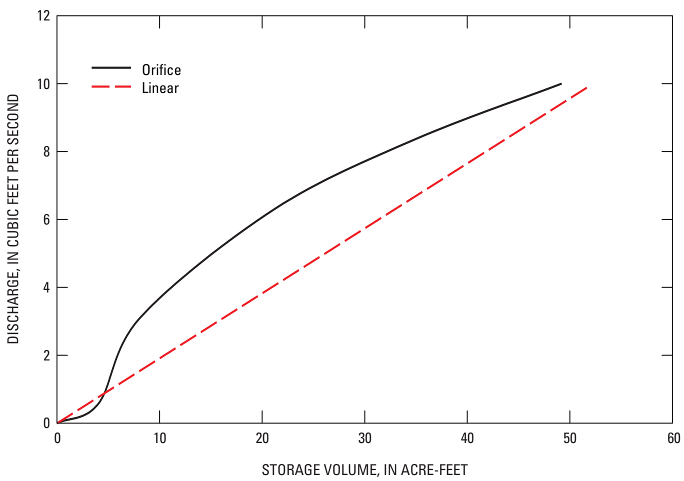

Figure 1. The differences in storage volume required by a linear slot volume-discharge relation and an orifice-controlled storage volume-discharge relation. A release rate of 0.1 cubic feet per second per acre was used in the analysis.

The volumetric requirement for the orifice structure is usually smaller than that required by the linear slot outlet except at a very small release discharge. The intent of the linear slot structure used by Price (1997) was to derive a simplified relation. Use of an orifice-outlet structure gives a more realistic estimate of detention basin volume and, therefore, more accurate analysis in the Blackberry Creek watershed. The Price (1997) method is modified in this study to size detention basins and outlet structures as outlined below.

1. Determine an initial set of depth-surface area-storage volume-discharge relations (Ftables) with a trial orifice diameter and weir elevation. For this study, the detention basin has a general trapezoidal shape, flat bottom, and side slope of 4 to 1. The orifice is placed at the bottom of the outlet structure and the diameter is determined in the subsequent trial-and-error exercise until the desired release rate is met at the outlet. The elevation of the weir is designed to detain runoff magnitudes up to the 100-year recurrence interval before water overtops the weir, and the effective weir width is designed to release discharge at a rate of 1 ft^3/s-acre for runoff exceeding the 100-year magnitude. This set of relations was developed with a spreadsheet modified from one obtained from CBBEL (Darren Olsen, Christopher B. Burke, Ltd., written commun., 2005) for detention basins.

2. Incorporate the Ftable determined in step 1 into the HSPF model, and simulate hourly flow at the outlet using precipitation data from Argonne National Laboratory, Argonne, Ill., for WY 1949 to WY 2003.

3. Generate an AMS from this simulated flow time series, and analyze flood frequency with the PEAKFQ program (Flynn and others, 2006) to estimate flood frequencies with the Bulletin 17B method. Note that the 1996 annual maximum was removed from the AMS because it is considered an outlier for the purpose of determining release rate. The 1996 annual maximum discharge measured at Yorkville, Ill., was larger than a 500-year peak discharge. Inclusion of this data point in the release rate analysis would have biased the flood frequencies computed for other recurrence intervals.

4. Stop the process if the 100-year discharge is equal to the desired release rate; if not, then a new diameter (and therefore detention basin volume) is tested until the desired release rate is achieved.

The procedure presented above presents an estimate of the total detention basin volume needed in each subbasin. For example, the resulting detention basin storage volume for subbasins in the Blackberry Creek watershed ranged in size from approximately 3 to 810 acre-ft. The detention basins larger than 400 acre-ft were judged to be unlikely to be constructed in residential developments and were split into detention basins of 350 acre-ft or less for modeling purposes.

Multiple Release Rates

The required 100-year detention volumes (in acre-ft/acre) for an orifice-outlet structure for different amounts of impervious area and for the multiple release rates of 0.08, 0.10, and 0.12 ft^3/s-acre are shown in figure 2. This diagram was developed to aid watershed planning for new development areas. When an orifice-outlet structure is used, approximately 0.47–0.52 acre-ft of storage per acre of impervious land is required to achieve a release rate of 0.10 ft^3/s-acre for the 100-year storm. In addition, 0.495–0.565 acre-ft of storage per acre of impervious land was required to achieve a release rate of 0.08 ft^3/s-acre, and 0.43–0.475 acre-ft of storage per acre of impervious land was required to achieve a release rate of 0.12 ft^3/s-acre.

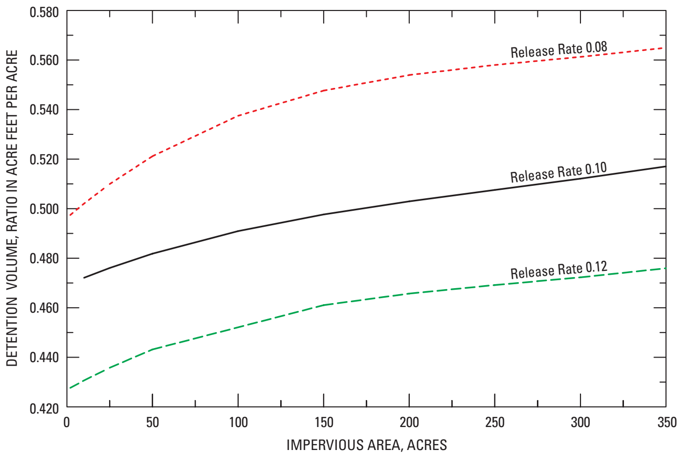

Figure 2. Detention storage volume required per acre to achieve a 0.08, 0.10, or 0.12 cubic feet per second per acre detention release rate for different amounts of impervious area.

Blackberry Creek Detention Modeling Case Study

The Blackberry Creek watershed is a 68.1 mi^2 (Murphy and others, 2007) watershed approximately 40 mi west of metropolitan Chicago in Kane and Kendall Counties, Ill. (fig. 3). Land use in the watershed is primarily agricultural; however, in the past few decades, urban areas have been developed throughout the watershed. In 2005, the USGS–Illinois Water Science Center, in cooperation with the KCDEM, developed, calibrated, and verified an HSPF hydrologic model to investigate flood-hazards in the watershed (Soong and others, 2005). This hydrologic model, based on 1996 land use, was modified in this study to incorporate projected 2020 land-use changes (Price, 2003) and detention basins simulated with Ftables incorporating the release rates as previously described.

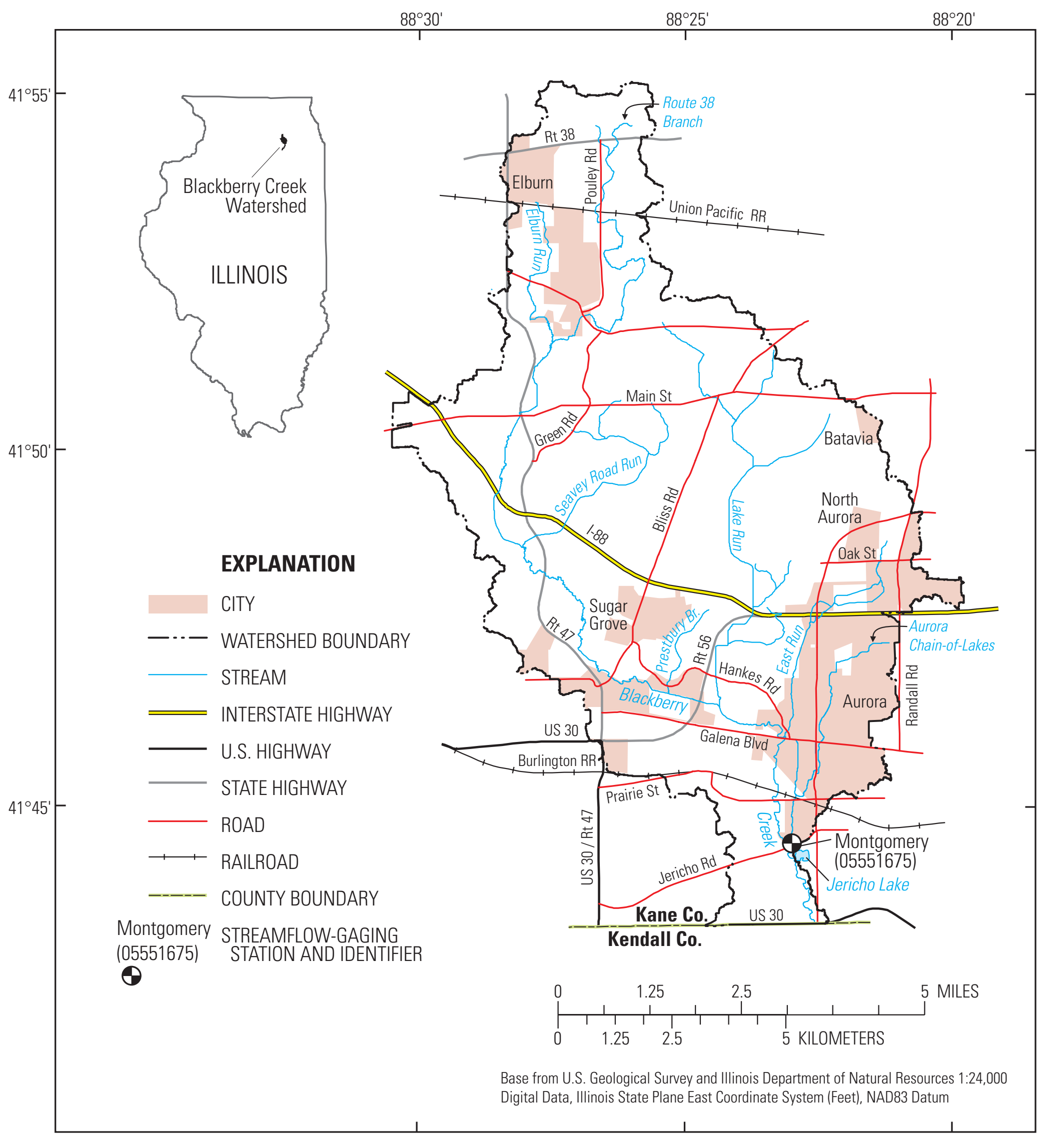

Figure 3. Location of the Blackberry Creek watershed in Kane County, Illinois.

Data

Meteorological data, geographic information system data layers for the analysis, subwatershed boundaries, and channel geometry are described in the 2005 flood-hazard study (Soong and others, 2005). However, the current study extended the meteorological data and the simulation period through WY 2003, whereas the 2005 study used the period WY 1950 to WY 1999. In addition, the Kane County projected 2020 land-use data (Price, 2003) were used as the basis for sizing the detention basins in this study. Changes in flood frequencies resulting from these additional four years of meteorological data can be observed in the two curves in figure 4. The flood frequency streamflow values from the WY 1950 to WY 2003 simulation period are slightly lower for the smaller exceedance probabilities. The slight changes in flood frequencies are expected because estimation of recurrence intervals is improved with longer records.

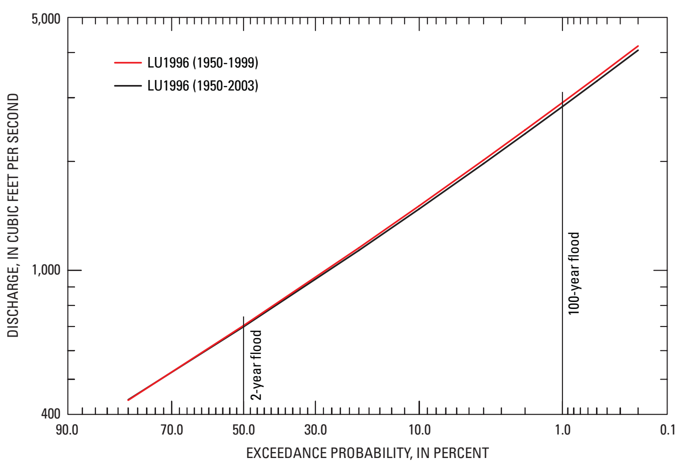

Figure 4. Comparison of flood frequency curves estimated at the U.S. Geological Survey streamflow-gaging station at Yorkville, Illinois, from Argonne National Laboratory precipitation data from 1950–99 and 1950–2003.

The projected 2020 land-use conditions (fig. 5) were based on the 2020 land-use map developed by Price (2003). The Price (2003) map used the Kane County data (Karen Kosky, Kane County Department of Environment and Building Management, written commun., October 2002) and incorporated urban development in the Blackberry Creek watershed. It also incorporated the municipal planning maps of Aurora, North Aurora, Batavia, Elburn, Montgomery, and Sugar Grove. For consistency of the analysis, the 2020 land-use categories were associated with the 1996 land-use categories used in the 2005 Blackberry Creek watershed flood-hazard study as described in table 1. The 2020 land-use category of "existing open space" was overwritten with the 1996 land-use category.

Table 1. Land-use categories from the 2005 Blackberry Creek flood-hazard study and associated 2020 land-use categories.

[1996 land-use categories from Soong and others (2005)]

1996 land-use category	2020 land-use category
Cropland	Agriculture
Grassland	Agriculture resource buffer, additional open space, proposed open space, existing rural grassland, urban grassland
High-density urban	Crossroad commercial, urban residential, commercial, office/research, industrial, light industrial, warehouse, urbanized municipality, rural municipality
Medium-density urban	Rural residential, agricultural business, institutional
Low-density urban	Countryside/estate residential
Transportation	Transportation
Water bodies	Water
Wetland	Wetland
Barren land	Barren land

After these land-use categories were incorporated in the watershed geographic information system (GIS) layer, the surface area for each land use in each subbasin (fig. 6) was calculated in acres and updated in the 1996 land-use HSPF model to create the 2020 land-use HSPF model. The key differences between the 1996 and 2020 land-use models were the increase in impervious land area and the corresponding decrease in pervious land area. The total drainage areas, percentage of impervious area in 1996, and percentage of increased impervious area by 2020 for each tributary subbasin are shown in table 2 and for the Blackberry Creek main stem subbasins in table 3. Note that the largest amounts of projected development are planned for the tributary subwatersheds of Elburn Run, Prestbury Branch, East Run, and Aurora Chain-of-Lakes, and along the main stem in subbasin 236.

Methods

The land areas that were reclassified from pervious areas in the 1996 land use to impervious area in the 2020 land use were considered new development that would require detention. Detention basins with the three different release rates of 0.08, 0.10, and 0.12 ft^3/s-acre were created in all Kane County subbasins of the Blackberry Creek watershed. A version of the model that incorporated the 2020 land use without detention basins was used as the "worst-case scenario" for comparison with the detention scenario model versions.

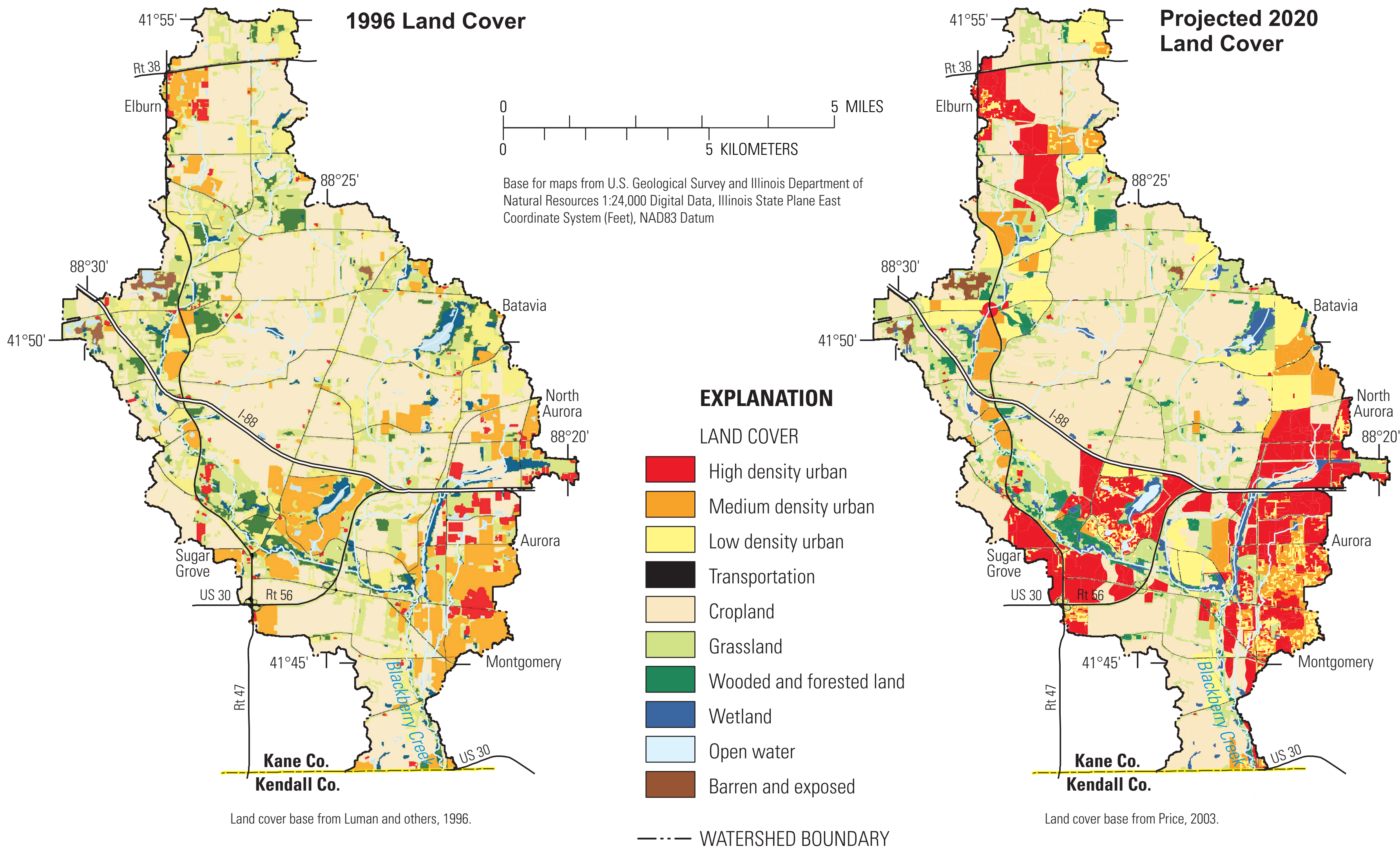

Figure 5. 1996 and projected 2020 land uses for the Kane County portion of the Blackberry Creek watershed.

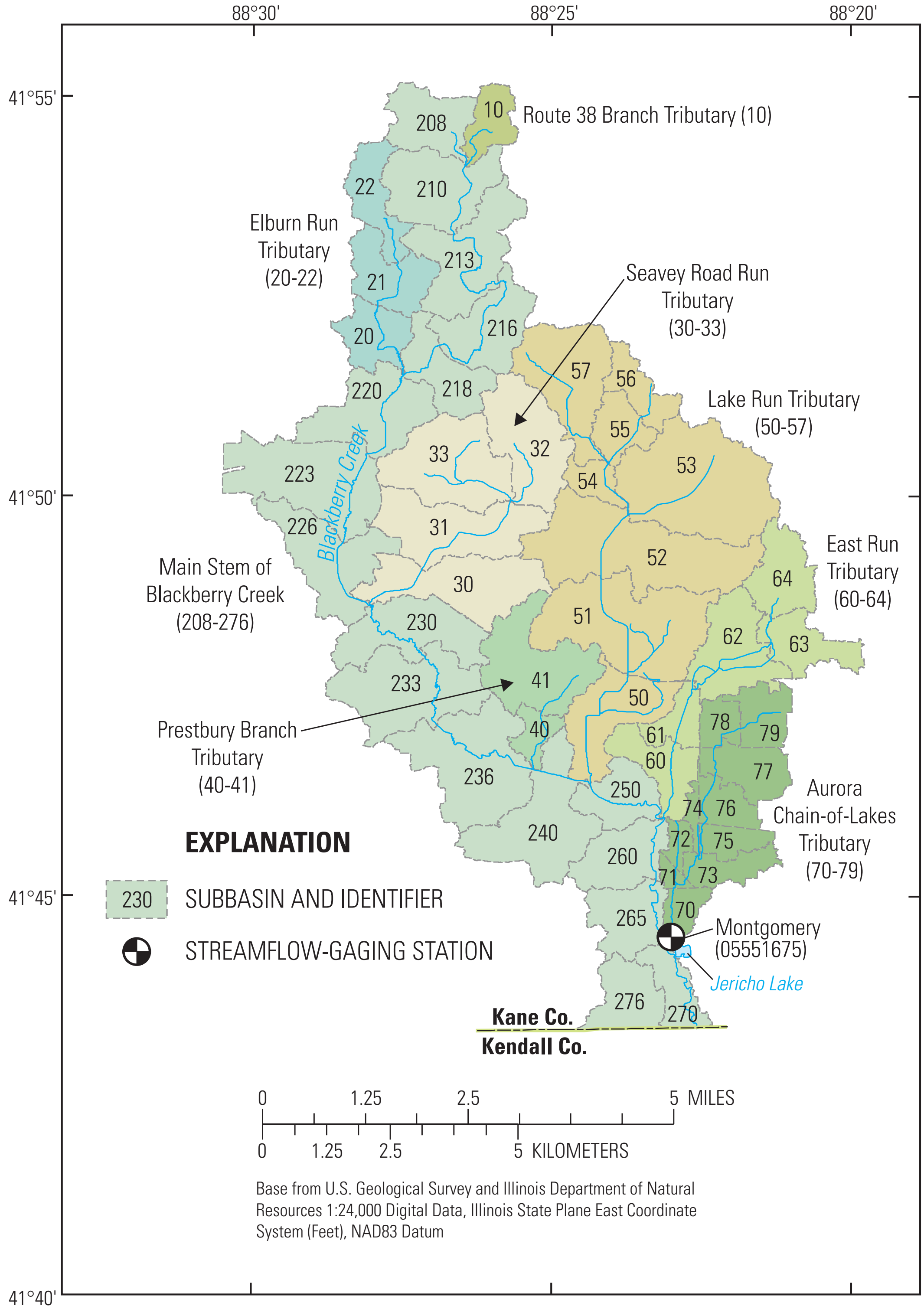

Figure 6. Subbasins and naming system used in the Hydrological Simulation Program–FORTRAN model for the Blackberry Creek watershed in Kane County, Illinois.

Table 2. Drainage area, impervious area determined from the 1996 land-use map, and projected additional impervious area by 2020 for tributary subbasins of the Blackberry Creek watershed in Kane County, Illinois.

[1996 land use from Luman and others, 1996; projected additional impervious area by 2020 from Price, 2003, and Karen Kosky, Kane County Department of Environmental and Building Management, written commun., October 2002]

Subbasin number (figure 6)	Subbasin drainage area (acres)	Impervious area in 1996 (percent)	Projected additional impervious area by 2020 (percent)
	Route 38 Branch		
10	367.4	1.06	9.99
	Elburn Run		
22	522.2	7.75	50.49
21	627.1	2.07	34.15
20	502.1	2.71	16.8
	Seavey Road Run		
33	1,204.20	1.53	2.43
32	1,044.30	.51	0
31	1,124.60	1.3	.48
30	1,124.80	1.52	1.94
	Prestbury Branch		
41	1,132.80	4.01	44.49
40	235.3	7.38	46.95
	Lake Run		
57	1,104.70	1.2	0
56	391	1.02	3.77
55	383.7	2.99	2.48
54	247.1	.63	0
53	1,915.00	2.46	9.08
52	1,902.10	1.4	2.39
51	1,741.60	1.13	2.17
50	903.4	2.97	30.03
	East Run		
64	613.2	4.54	38.82
63	518	7.93	56.8
62	879.4	3.25	66.46
61	312.6	2.6	43.81
60	557.2	5.61	25.24
	Aurora Chain-of-Lakes		
79	405.6	15.09	52.45
78	239.5	17.95	48.09
77	504.9	21.54	60.15
76	325.6	41.16	42.33
75	253.4	25.18	55.54
74	87.8	9.49	57.89
73	343.5	21.99	69.24
72	136.8	13.96	78.26
71	84.7	3.11	41.57
70	223.4	5.4	42.53

Table 3. Drainage area, impervious area determined from the 1996 land-use map, and projected additional impervious area by 2020 along the main stem of the Blackberry Creek watershed in Kane County, Illinois.

[1996 land use from Luman and others, 1996; projected additional impervious area by 2020 from Price, 2003, and Karen Kosky, Kane County Department of Environmental and Building Management, written commun., October 2002]

Subbasin number	Subbasin drainage area (acres)	Impervious area in 1996 (percent)	Projected additional impervious area by 2020 (percent)
208	632.3	0.39	0.49
210	980.4	2.86	9.3
213	1,080.00	1.06	35.01
216	792.7	1.86	5.78
218	634.2	1.67	8.14
220	1,003.30	2.16	9.98
223	1,415.80	2.46	11.41
226	1,033.60	3.28	2.68
230	947.8	2.2	6.6
233	1,278.70	4.79	12.27
236	1,471.00	4.65	55.13
240	1,269.30	3.79	15.09
250	556.4	2.22	11.21
260	663.9	2.55	13.41
265	635.2	.87	4.61
270	428.5	3.66	13.54

The surface runoff from new impervious areas was routed to detention basins. The routing and release of flow through detention basins was described by using Ftables in the HSPF model as previously discussed. The amount of flow released from a detention basin to the channel was determined from the corresponding detention Ftable. The flow released from the detention basin plus the flow from the pervious and impervious surface areas were routed using the channel routing Ftable developed in the 1996 land-use HSPF model. The annual maximum series was compiled from the simulated flow time series. Design recurrence intervals flows were determined through statistical analysis of the annual maximum series.

The areas selected for analysis, listed from upstream to downstream along Blackberry Creek in Kane County, include: the confluences of Blackberry Creek with Route 38 Branch tributary, Elburn Run tributary, Seavey Road Run tributary, Prestbury Branch tributary, Lake Run tributary, East Run tributary, Aurora Chain-of-Lakes tributary; the stream crossing at Route 47 downstream from Elburn Run; the outlets of subbasins 230, 236, 240, 250, 260, 265; and at the Kane-Kendall county line (fig. 6). Flood-peak magnitudes for 2-, 10-, 100-, and 500-year recurrence intervals from selected storm events were analyzed.

Simulation Results

Simulated flood frequencies and flood hydrographs at the outlet of each tributary (table 4) and selected locations along the main stem of Blackberry Creek in Kane County (table 5) are presented in this section. For each selected subbasin, five scenarios were simulated: the 1996 and 2020 land uses and the 2020 land uses with the three detention basin release rates of 0.08, 0.10, and 0.12 ft^3/s-acre (figs. 7–21). The 1996 and 2020 land-use scenarios are plotted for the full range of recurrence intervals, whereas the detention basin scenarios are only plotted for the 2- through 100-year recurrence intervals. The results of the simulations for the five scenarios for one subbasin are grouped in a single illustration for a comparative evaluation. A summary table of estimated flood quantiles for the 2-, 10- , 50-, and 100-year recurrence intervals is presented in the appendix. Among the four storm runoff events selected, the July 1996 event is larger than a 100-year event, and the May 1999 event is approximately a 2-year event, according to the flood frequencies based on the 1950–2003 discharge record measured at the USGS streamflow-gaging station at Yorkville (station number 05551700).

Analysis of the flood frequencies and storm-runoff hydrographs for the five scenarios at different locations in the watershed (figs. 7–21) reveals the effectiveness of detention basins with different release rates and the effect of detention basins on downstream reaches. Some general observations from these plots include:

1. an increase in impervious area results in an increase in the storm-runoff magnitudes;
2. the addition of detention basins reduces flood peaks but also prolongs the release of stored flood water, thus producing a flood hydrograph that shows a longer recession time and larger discharge magnitude;
3. although the release rate is designed to reduce the 100-year peak flow, reduction of the 2-year peak flow is also achieved for a smaller proportion of the peak; and
4. the shape of the hydrographs generated by different detention basin release rates are similar but the magnitudes and duration of recessional flows tend to vary among storm events and locations.

The hydrographs from the July 1996 event (larger than a 100-year event) and the May 1999 event (approximately a 2-year event) can be used to examine the magnitude of flood-peak discharge increases with the 2020 land uses and no detention basins (figs. 7–21). The hydrographs demonstrate that projected new development occurring between 1996 and 2020 will increase flood peaks for both large and small storms.

Table 4. Tributaries in the Blackberry Creek watershed, Kane County, Illinois, with numerical codes for the most downstream subbasin, and figure numbers where the simulation results are shown.

Tributary name	Subbasin number	Figure number
Route 38 Branch	10	7
Elburn Run	20	8
Seavey Road Run	30	9
Prestbury Branch	40	10
Lake Run	50	11
East Run	60	12
Aurora Chain-of-Lakes	70	13

Table 5. Detention basin release-rate evaluation locations along the main stem of Blackberry Creek in Kane County, Illinois, numerical codes for the subbasin upstream from each location, and figure numbers where the simulation results are shown.

Location name	Subbasin number	Figure number
Stream crossing Route 47, downstream from the junction with Elburn Run	220	14
Stream crossing Route 47 downstream from the junction with Seavey Road Run	230	15
Stream crossing Village of Sugar Grove	236	16
Near Route 56 stream crossing upstream from the junction with Lake Run	240	17
Upstream from the junction with East Run	250	18
Downstream from the junction with East Run	260	19
Upstream from the junction with Aurora Chain-of-Lakes	265	20
At Kane and Kendall County line	270	21

The storm hydrographs also can show the effect of the land-use changes on the runoff-generation characteristics—storms that did not produce major runoff events with the 1996 land uses would produce runoff with the 2020 land uses—the June 1994 event, for example. Therefore, subbasins projected to have rapid development between 1996 and 2020 will have more frequent small flood runoffs than other subbasins even if climatic conditions are the same. Changes in the occurrences and magnitudes of small floods may contribute to the increase in flood frequencies at short recurrence intervals, such as a 2-year storm (Q_2). Examples of this increase can be seen in flood frequency curves for the 1996 and 2020 land uses such as those in figures 7, 8, 16, and 17.

On the watershed scale, implementing detention basins with a release rate of 0.1 ft^3/s-acre controls the Q_{100} from the 2020 land-uses level to close to the 1996 land-uses level at the Kane-Kendall county line (fig. 21). At the county line, implementation of detention basins reduced simulated flood quantiles of recurrence intervals shorter than 100 years from the 2020 land-use levels even though the detention basin were designed to control the Q_{100} peak flows. However, the effectiveness of detention-controlled Q_{100}'s for individual subbasins was shown to vary. This variation in effectiveness is due to the variation in the amount of urban development in each subbasin between the 1996 and 2020 land-use data. The detention-controlled Q_{100}'s are lower than the 1996 land-use levels at Route 38 Branch (subbasin 10), Elburn Run (20), Prestbury Branch (40), and Lake Run (50) tributaries,at the stream crossing Route 47 downstream from junction with Elburn Run (220), the stream crossing Route 47 downstream from junction with Seavey Road Run (230), and Village of Sugar Grove (236) on the main stem. The detention-controlled Q_{100}'s are higher than the 1996 land-use levels at East Run (60) and Aurora Chain-of-Lakes (70) tributaries. The 0.1 ft^3/s-acre release rate could not reduce the Q_{100}'s to the 1996 land-use levels at the outlet of East Run and Aurora Chain-of-Lakes tributaries. A smaller release rate, such as 0.08 ft^3/s-acre, would be required to achieve comparable flow reduction.

Existing channel-routing characteristics are an additional consideration in evaluating the effect of detention basins at downstream locations. The Prestbury Branch, East Run, and Aurora Chain-of-Lakes tributaries have higher projected urban development by 2020 (table 2) and have existing engineered channel modifications, such as flow-through lakes, incorporated in the 1996 land-use HSPF model. Although an in-depth evaluation of the effect of the channel modifications on the downstream flow conditions is beyond the scope of this study, appreciable peak attenuation and runoff smoothing can be observed in Prestbury Branch tributary (fig. 10). These hydrograph characteristics result from the tributary's comparatively large storage capacity in two large lakes and from mild channel slopes. This channel storage allows the Q_{100}'s to be controlled to the 1996 level for this subbasin despite the projected urban development.

Subbasins along the main stem of the Blackberry Creek in the middle part of the watershed have minimal impervious area (table 3) and are primarily agriculture and pasture land uses in the 1996 land-use data. Simulated detention-controlled Q_{100}'s lower than the 1996 levels could indicate an over-designed system from using an overly strict detention basin release rate. Over- and under-design of stormwater facilities such as detention basins can cause undesirable impacts to the aquatic habitat or channel stabilization, as well as flooding.

The changes in flood quantiles due to release rate controlled detention throughout the watershed are inconsistent. To illustrate this inconsistency, ratios of Q_T (T denotes a specific recurrence interval) to drainage area (*DA*) were computed for subbasins in the Blackberry Creek watershed. The Q_T/DA ratios with Q_T's simulated by the 1996 land-use HSPF model were compared to those Q_T's simulated with the 2020 land uses with 0.1 ft^3/s-acre release rate detention basins HSPF model (table 6). Ratios for two recurrence intervals, Q_2 and Q_{100}, were analyzed. In small headwater watersheds, runoff from rainfall begins more quickly and is less attenuated because of small available storage. Therefore, Q_{100}/DA ratios of small watersheds are higher (higher than 0.1 ft^3/s-acre) than larger watersheds. Requiring a low release rate for a watershed with higher initial urban development may result in a lower postdevelopment Q_{100}, such as in subbasin 240.

Table 6. Ratios of peak flow and drainage area for pre- and postdevelopment scenarios at selected locations in the Blackberry Creek watershed, Kane County, Illinois.

[ft^3/s-acre, cubic foot per second per acre; Q_2 and Q_{100} are the 2-year and 100-year flood quantiles, respectively; 0.1 RR, 0.1 ft^3/s-acre release rate]

Subbasin number (figure 6)	Total drainage area (acres)	100-year flood/drainage area (ft^3/s-acre)		2-year flood/drainage area (ft^3/s-acre)	
		Q_{100} based on 1996 land uses	Q_{100} based on 2020 land uses and 0.1 RR	Q_2 based on 1996 land uses	Q_2 based on 2020 land uses and 0.1 RR
10	367	0.29	0.27	0.07	0.07
20	1,651	.54	.42	.09	.08
30	4,498	.16	.16	.03	.03
40	1,368	.05	.05	.01	.02
50	8,588	.12	.11	.03	.03
60	2,880	.06	.08	.01	.02
70	2,605	.03	.07	.01	.01
220	7,142	.19	.16	.04	.03
230	15,037	.13	.12	.03	.03
236	17,787	.11	.1	.03	.03
240	20,424	.1	.1	.02	.03
250	29,569	.09	.09	.02	.02
260	33,113	.09	.09	.02	.02
265	33,748	.08	.08	.02	.02
270	36,782	.07	.08	.01	.02

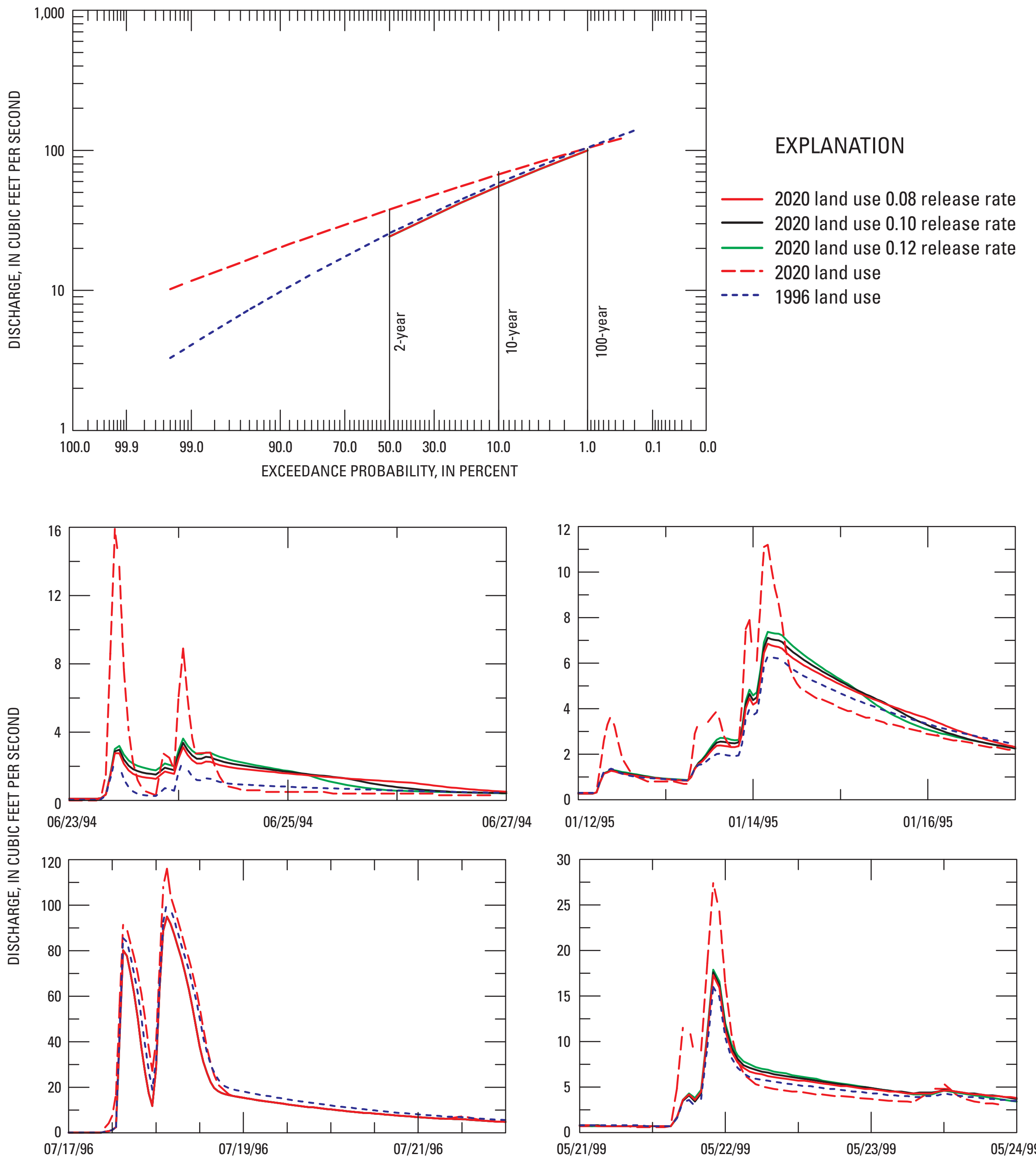

Figure 7. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from Route 38 Branch tributary to Blackberry Creek, Kane County, Illinois.

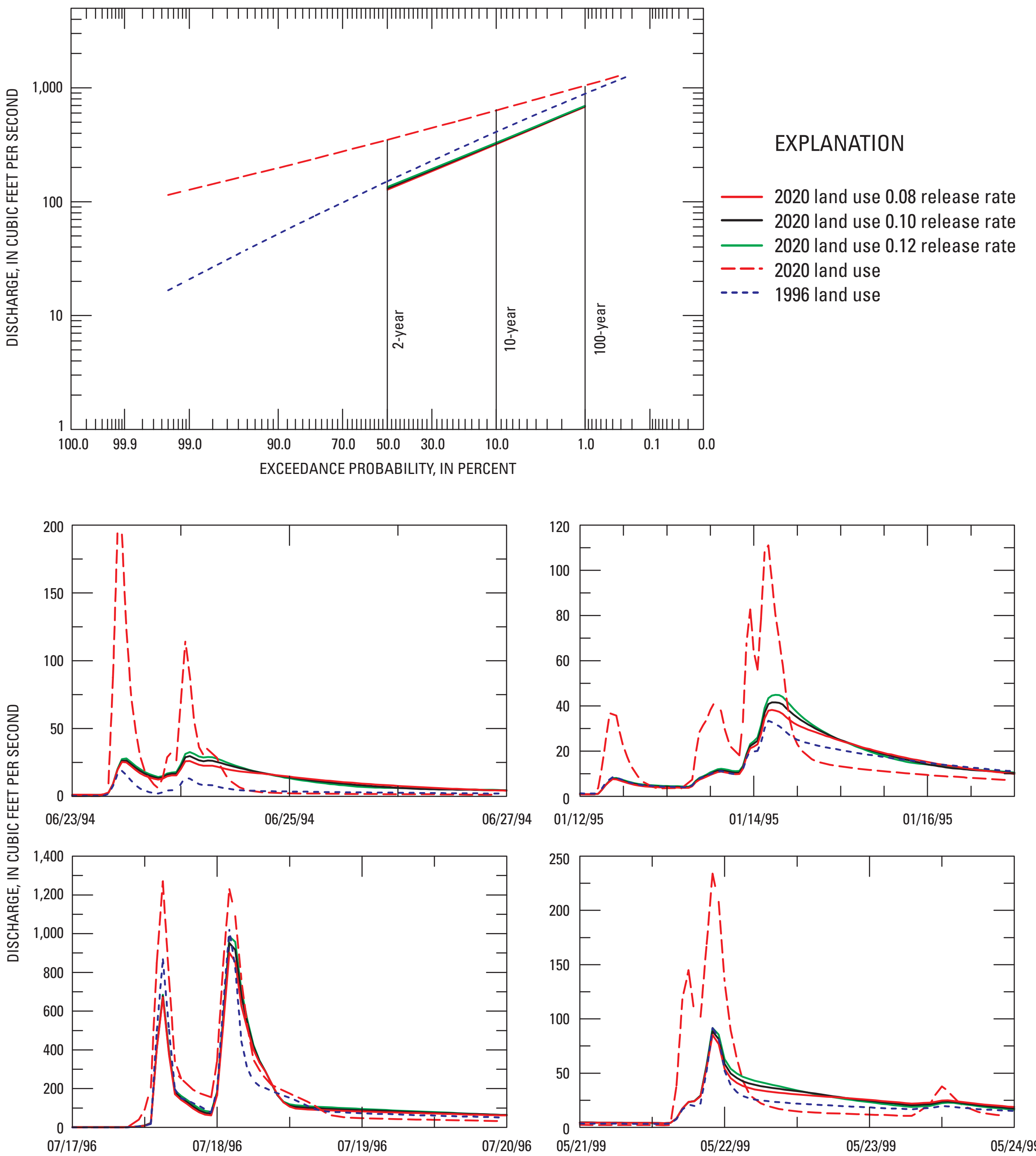

Figure 8. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from Elburn Run tributary to Blackberry Creek, Kane County, Illinois.

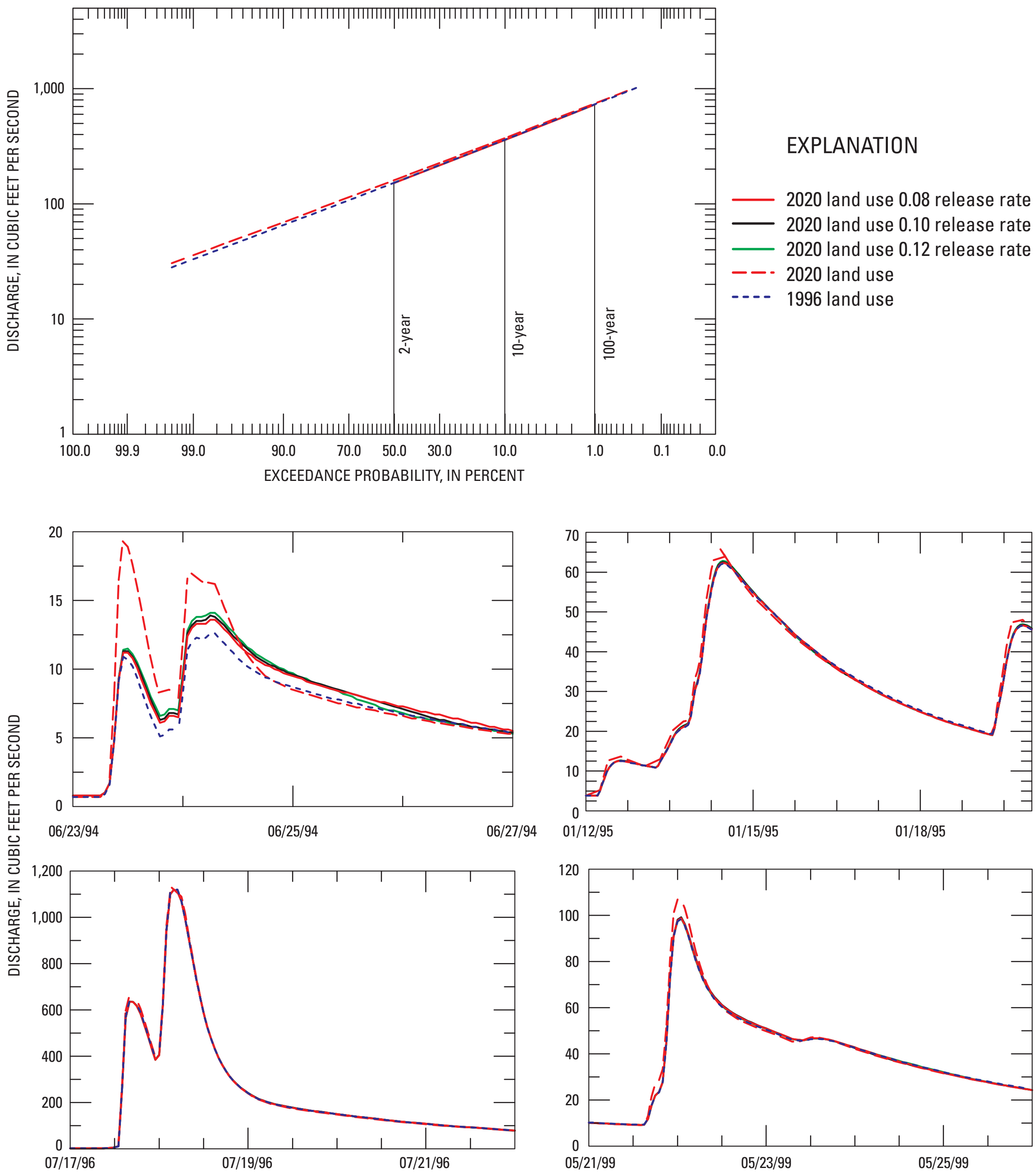

Figure 9. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from Seavey Road Run tributary to Blackberry Creek, Kane County, Illinois.

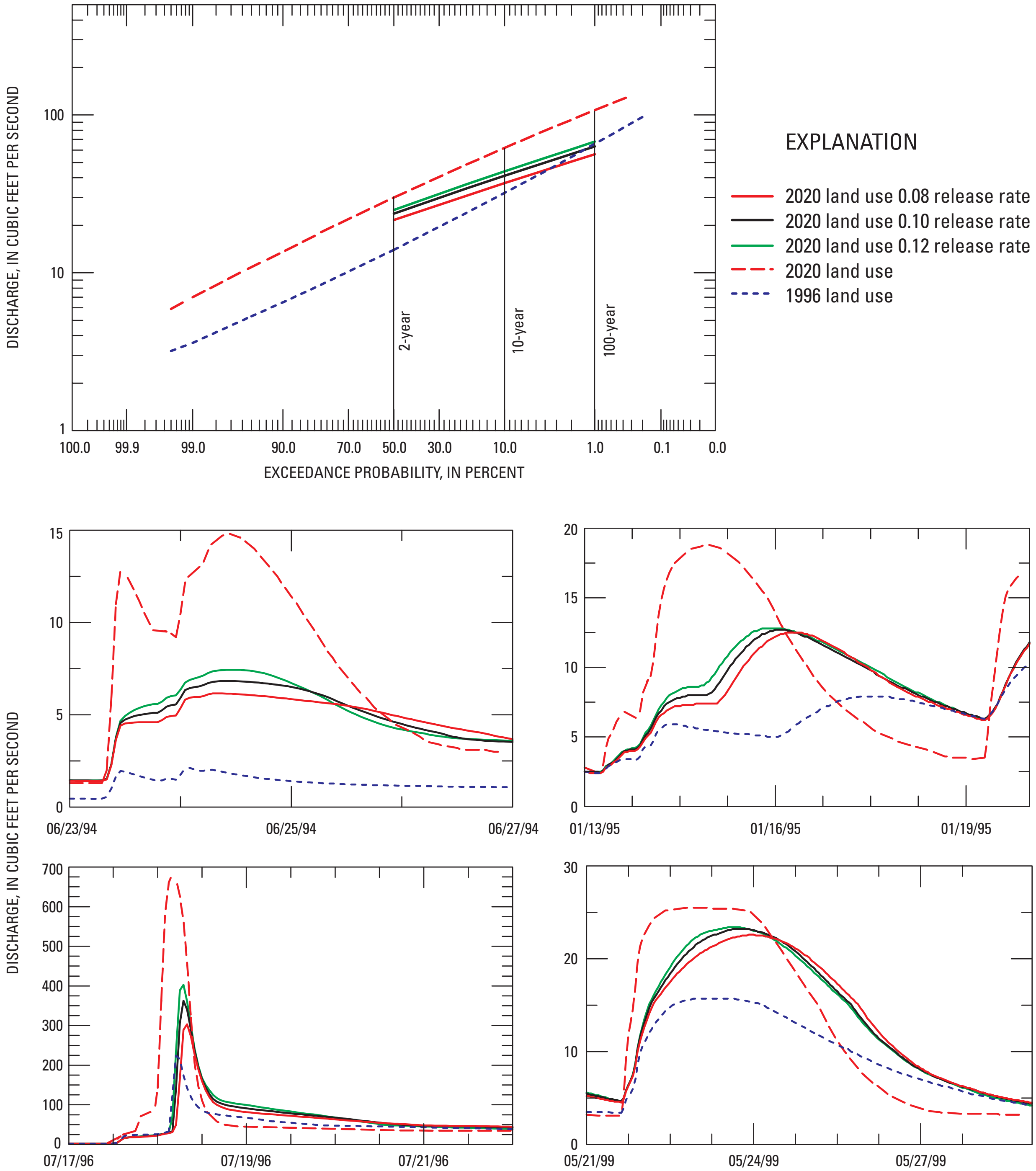

Figure 10. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from Prestbury Branch tributary to Blackberry Creek, Kane County, Illinois.

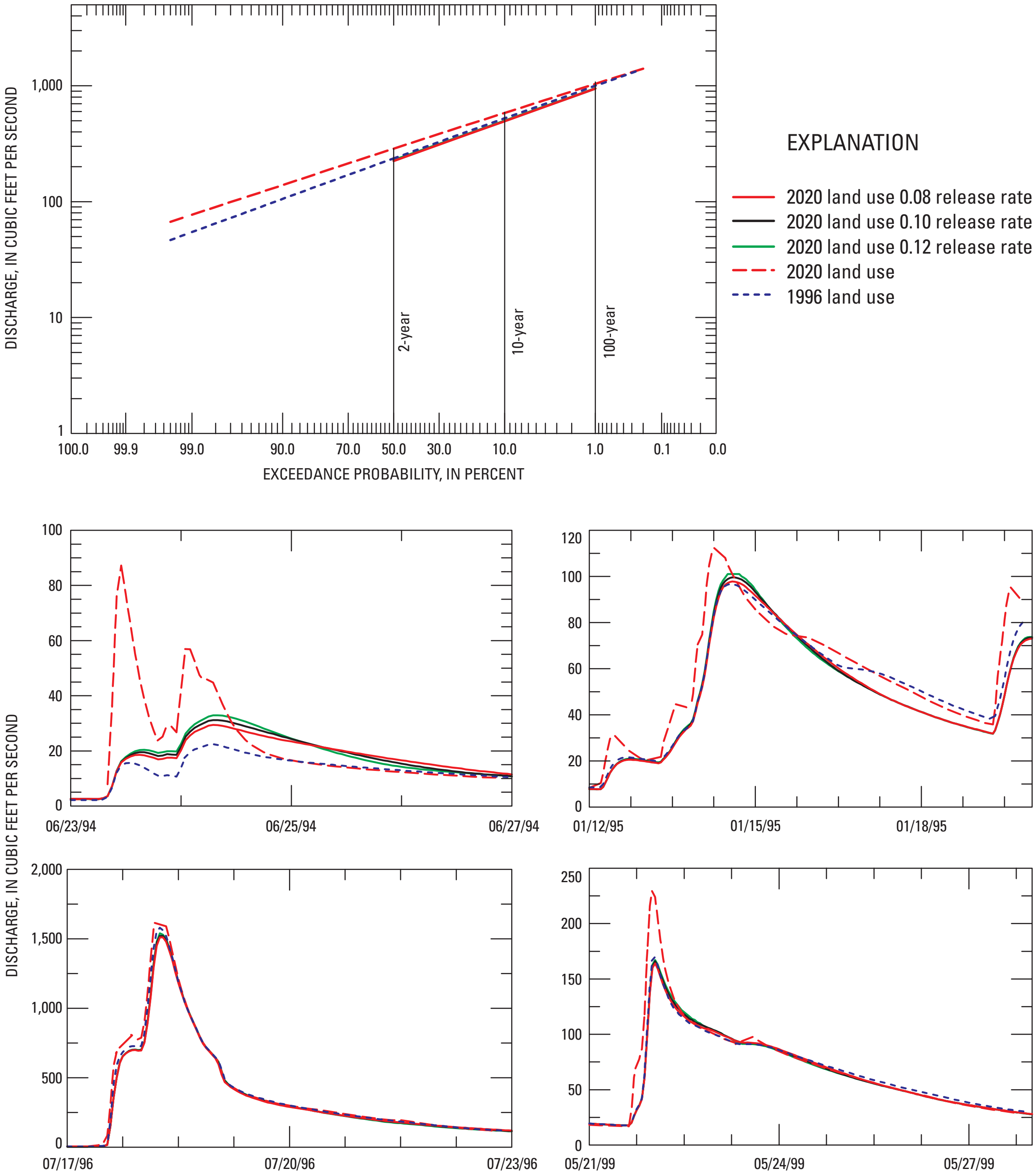

Figure 11. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from Lake Run tributary to Blackberry Creek, Kane County, Illinois.

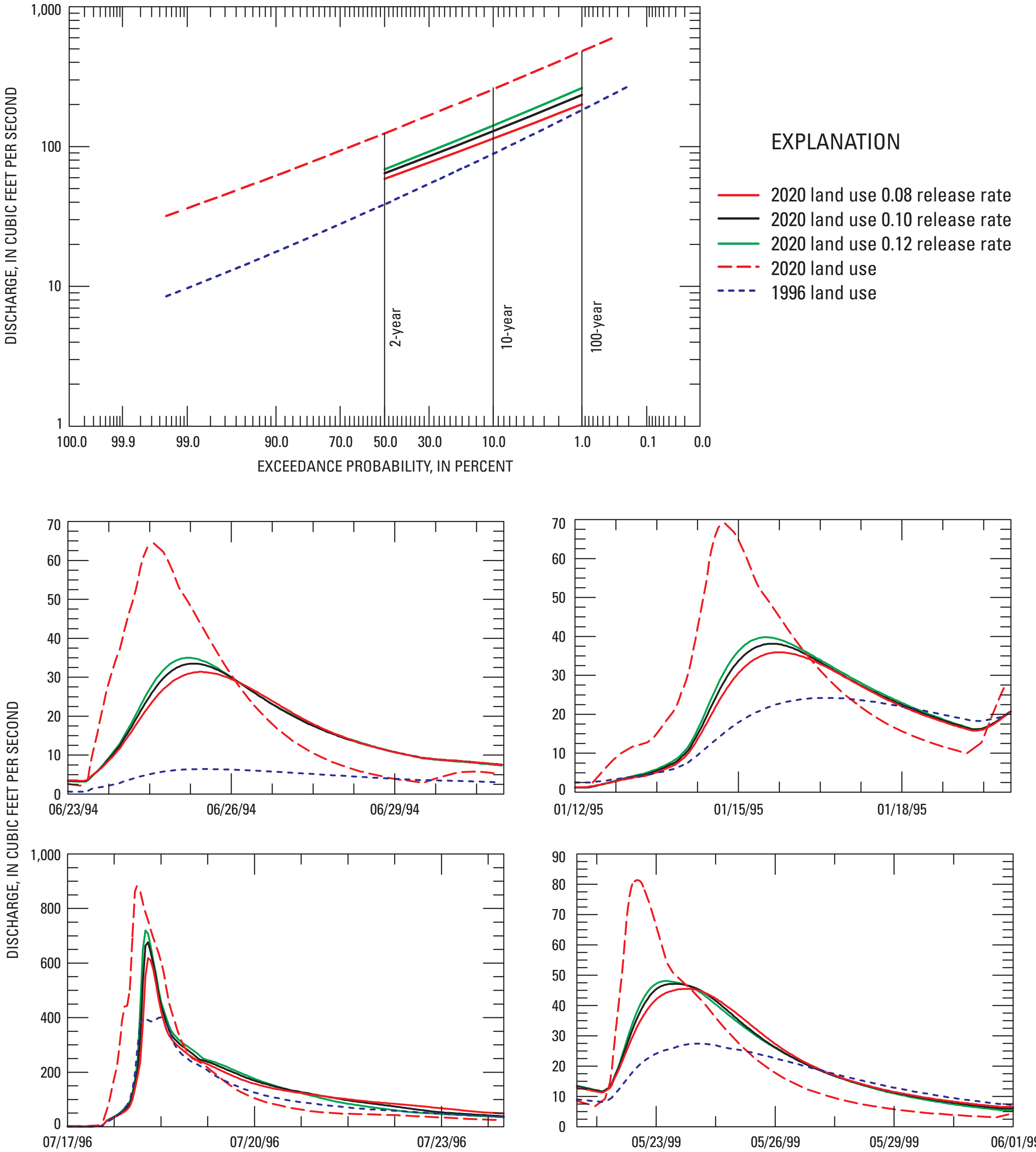

Figure 12. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from East Run tributary to Blackberry Creek, Kane County, Illinois.

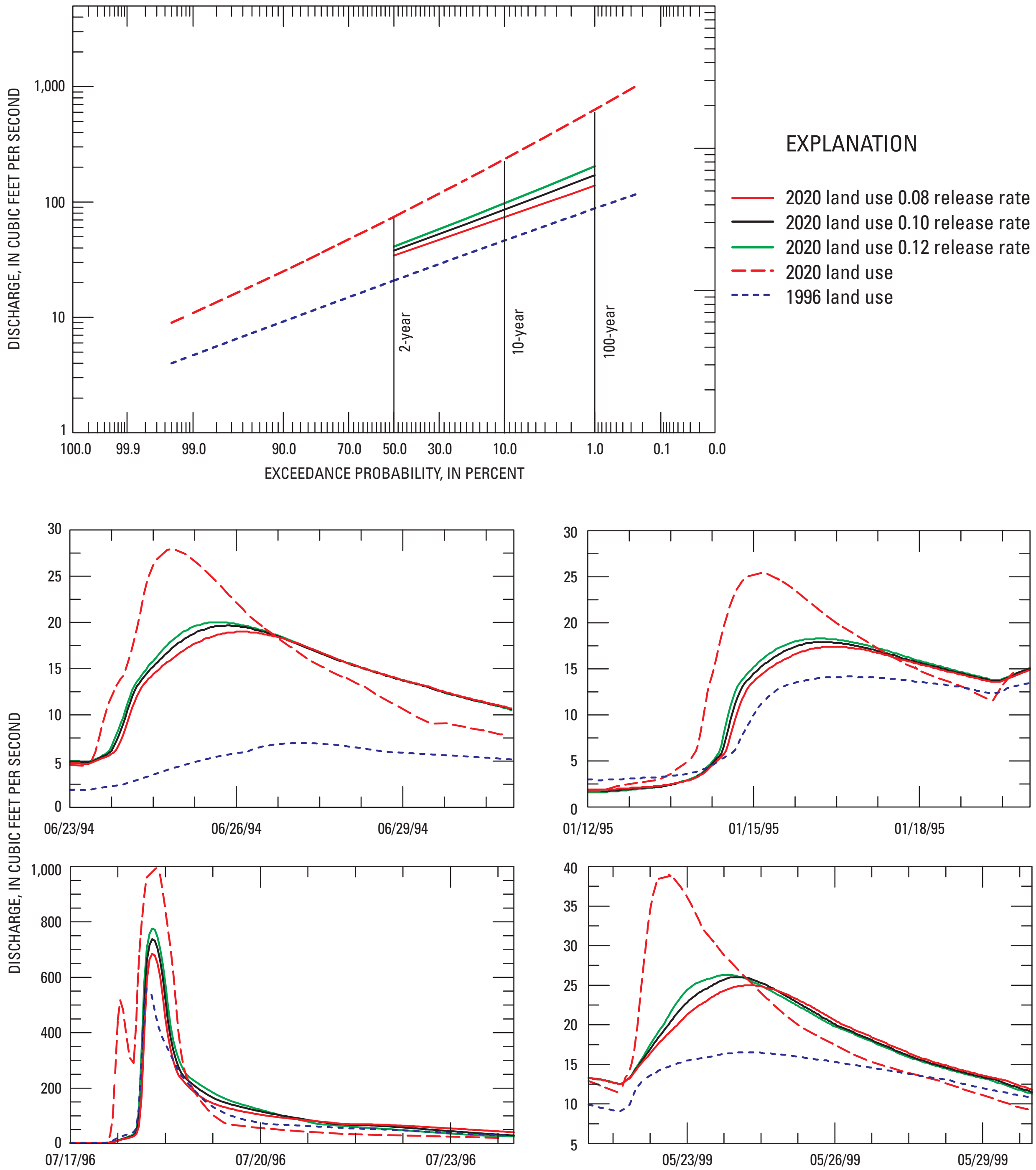

Figure 13. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates downstream from Aurora Chain-of-Lakes tributary to Blackberry Creek, Kane County, Illinois.

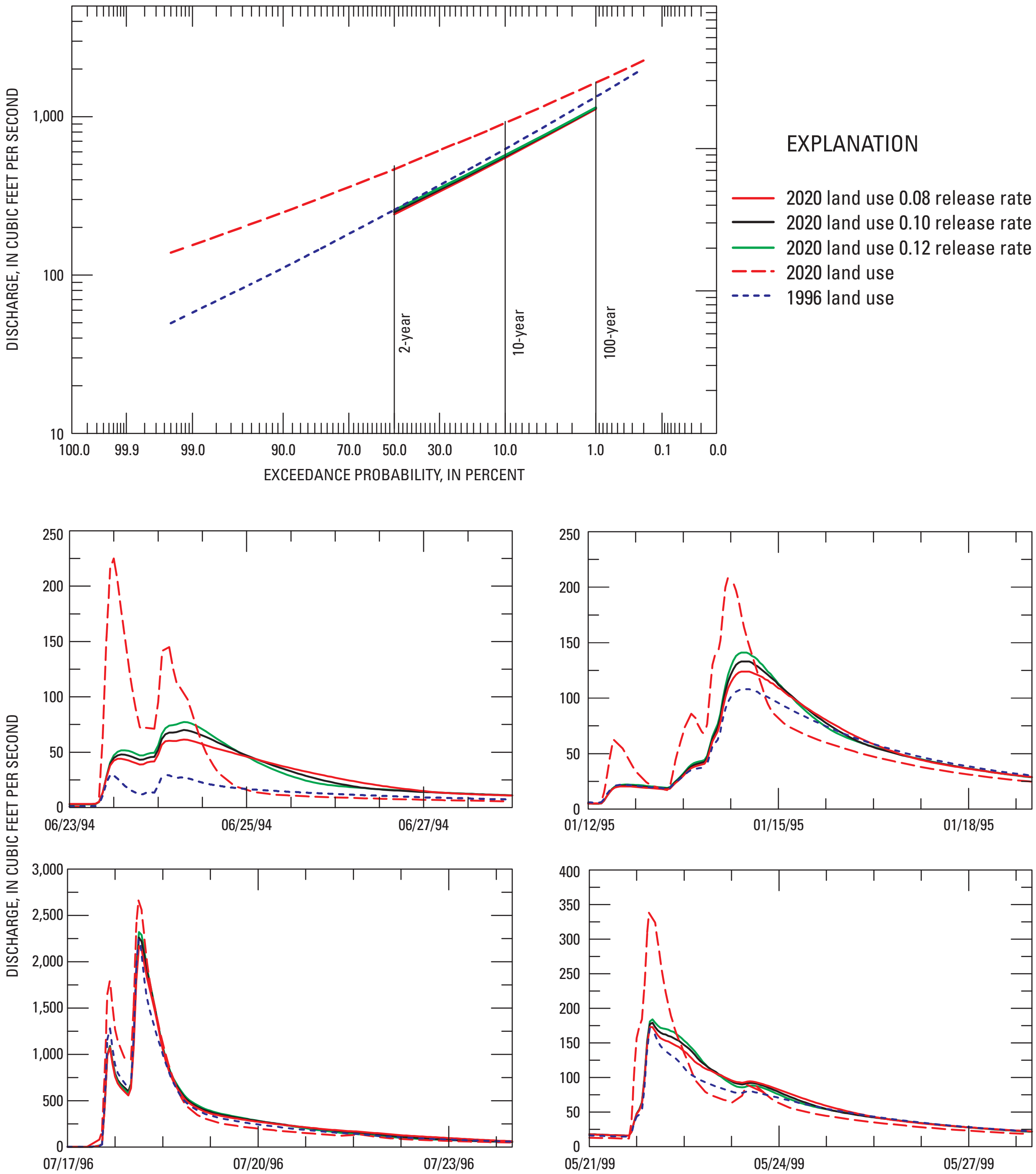

Figure 14. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek at Route 47 downstream from the junction with Elburn Run (subbasin 220), Kane County, Illinois.

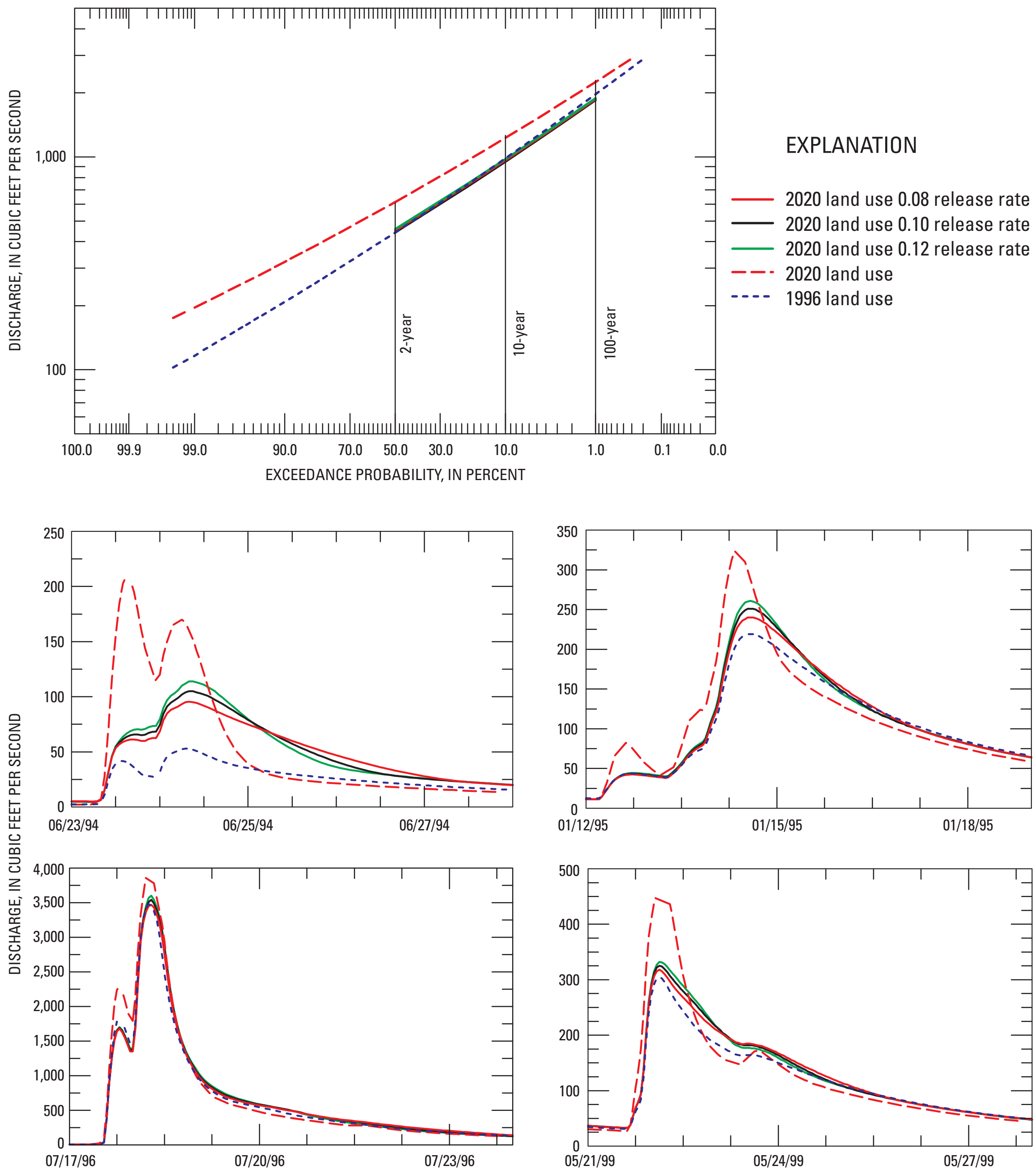

Figure 15. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek at Route 47 downstream from the junction with Seavey Road Run (subbasin 230), Kane County, Illinois.

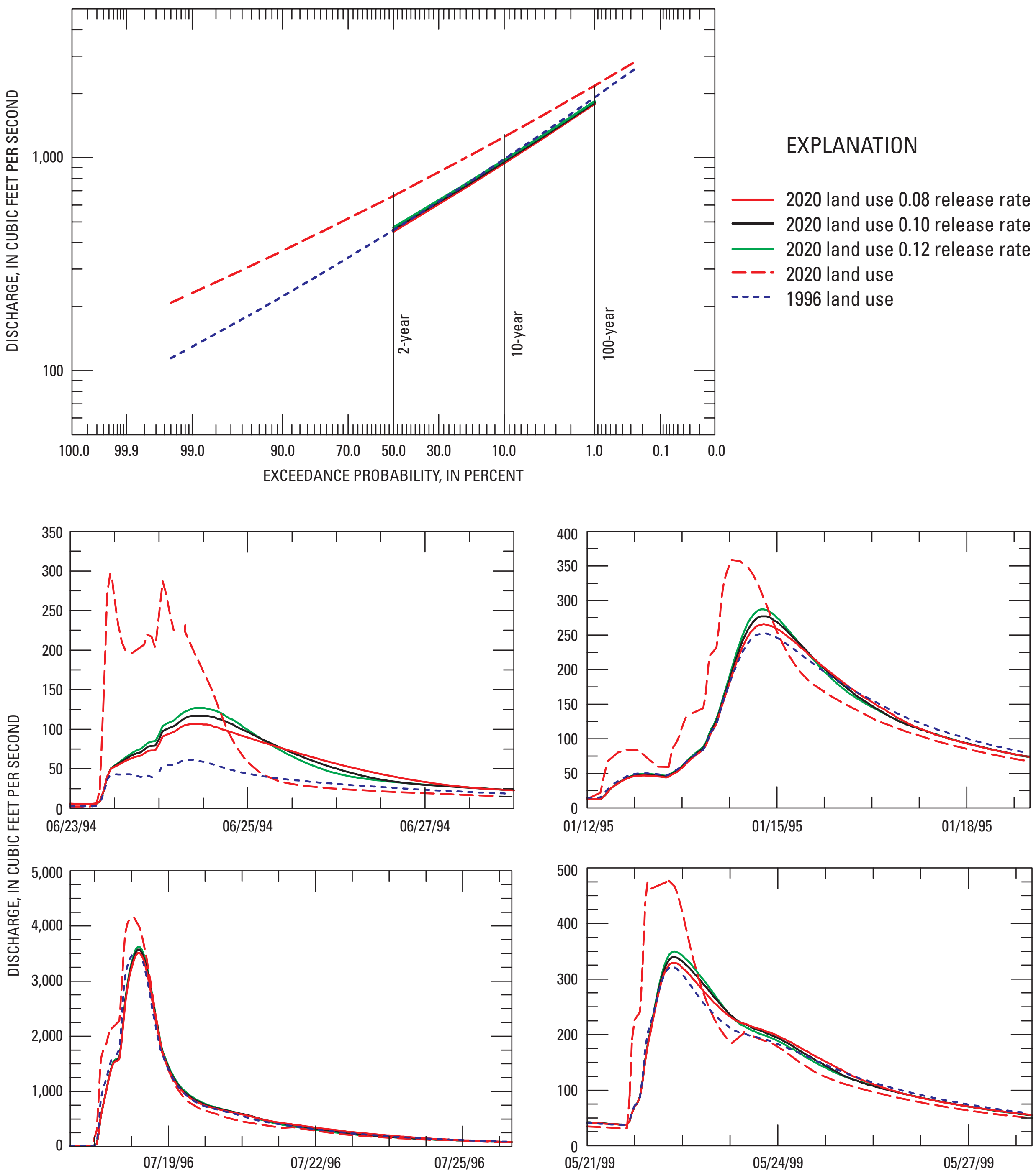

Figure 16. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek near the Village of Sugar Grove (subbasin 236), Kane County, Illinois.

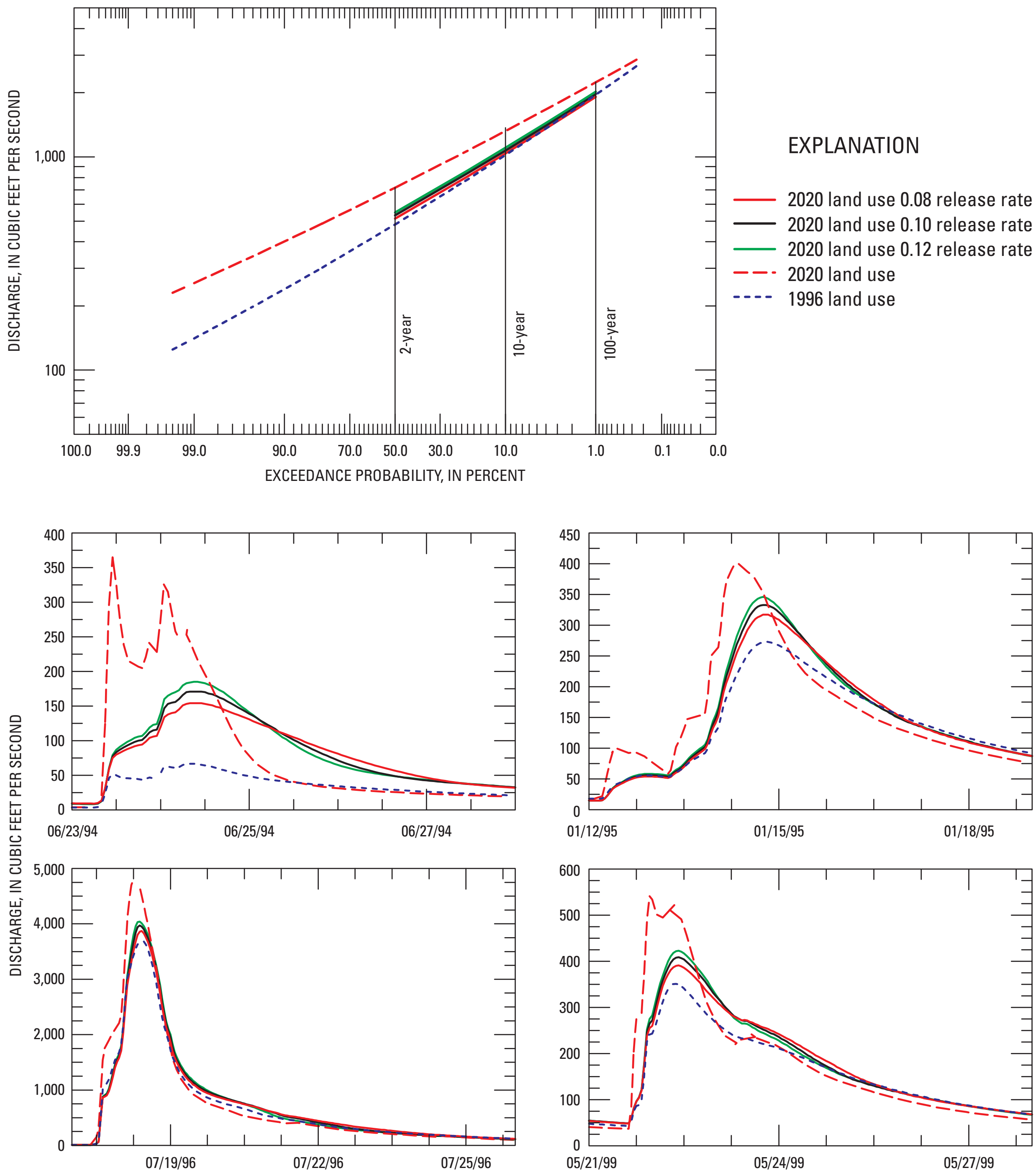

Figure 17. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek upstream from the junction with Lake Run (subbasin 240), Kane County, Illinois.

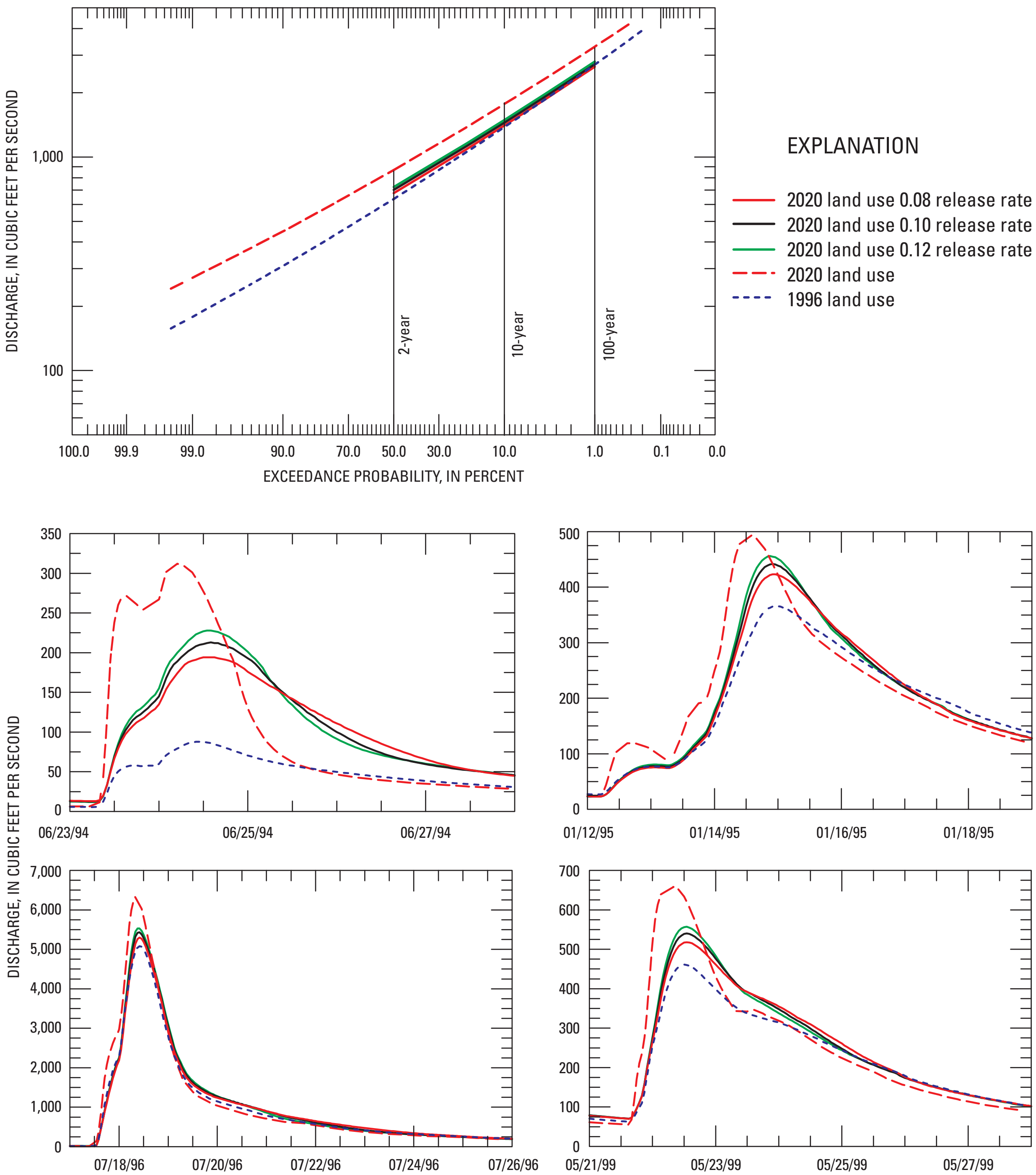

Figure 18. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek upstream from the junction with East Run (subbasin 250), Kane County, Illinois.

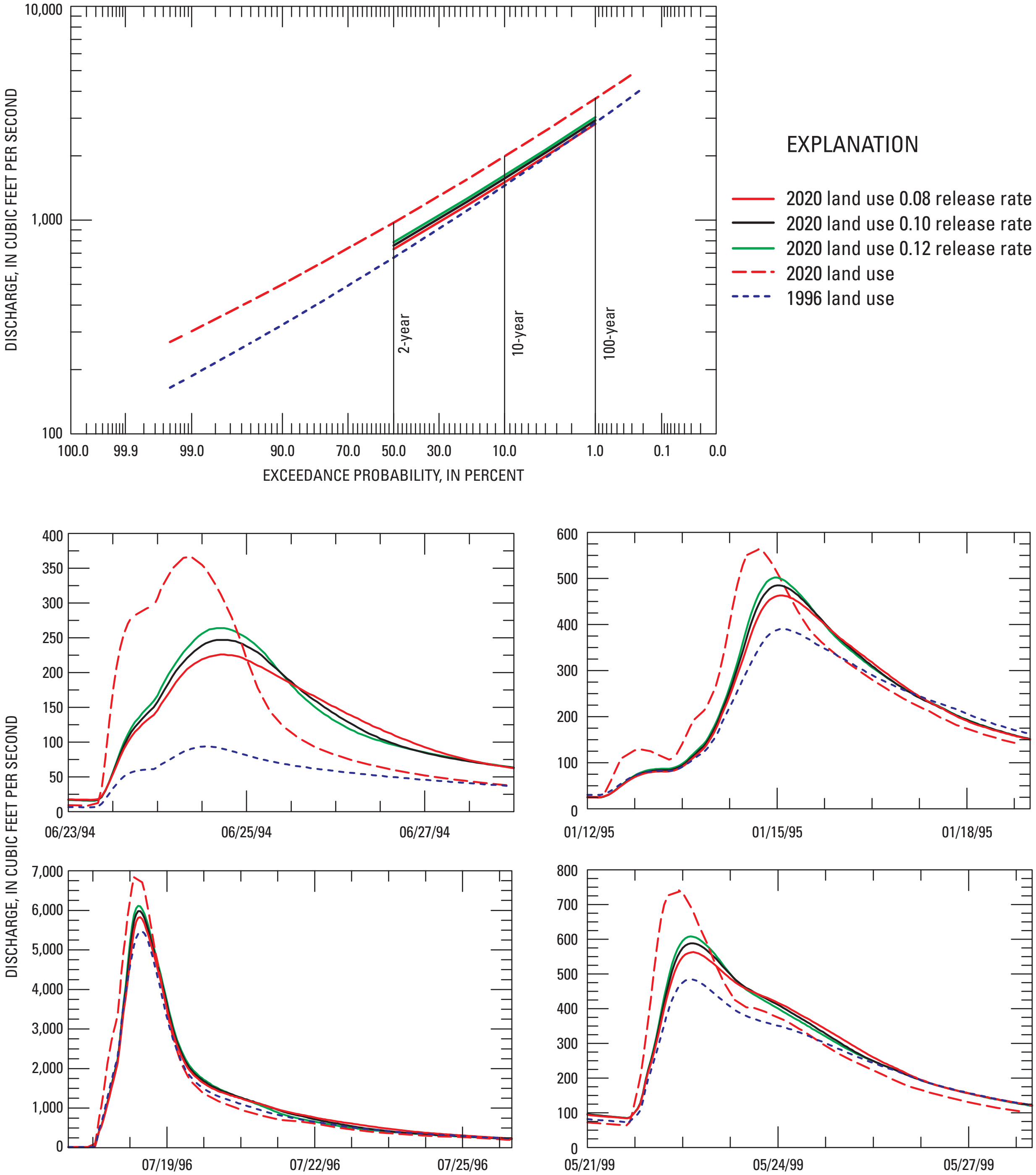

Figure 19. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek downstream from the junction with East Run (subbasin 260), Kane County, Illinois.

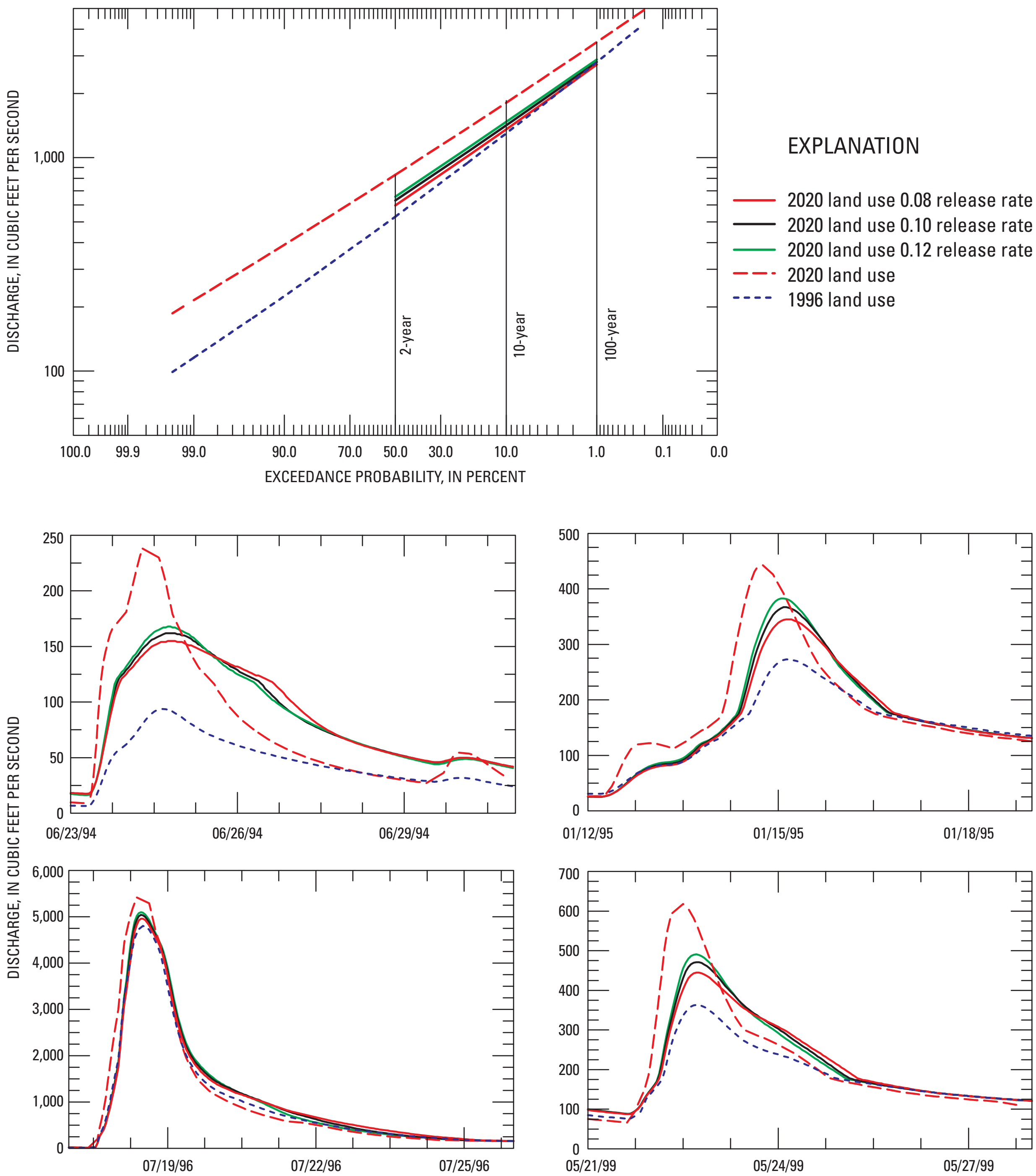

Figure 20. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek upstream from the junction with Aurora Chain-of-Lakes (subbasin 265), Kane County, Illinois.

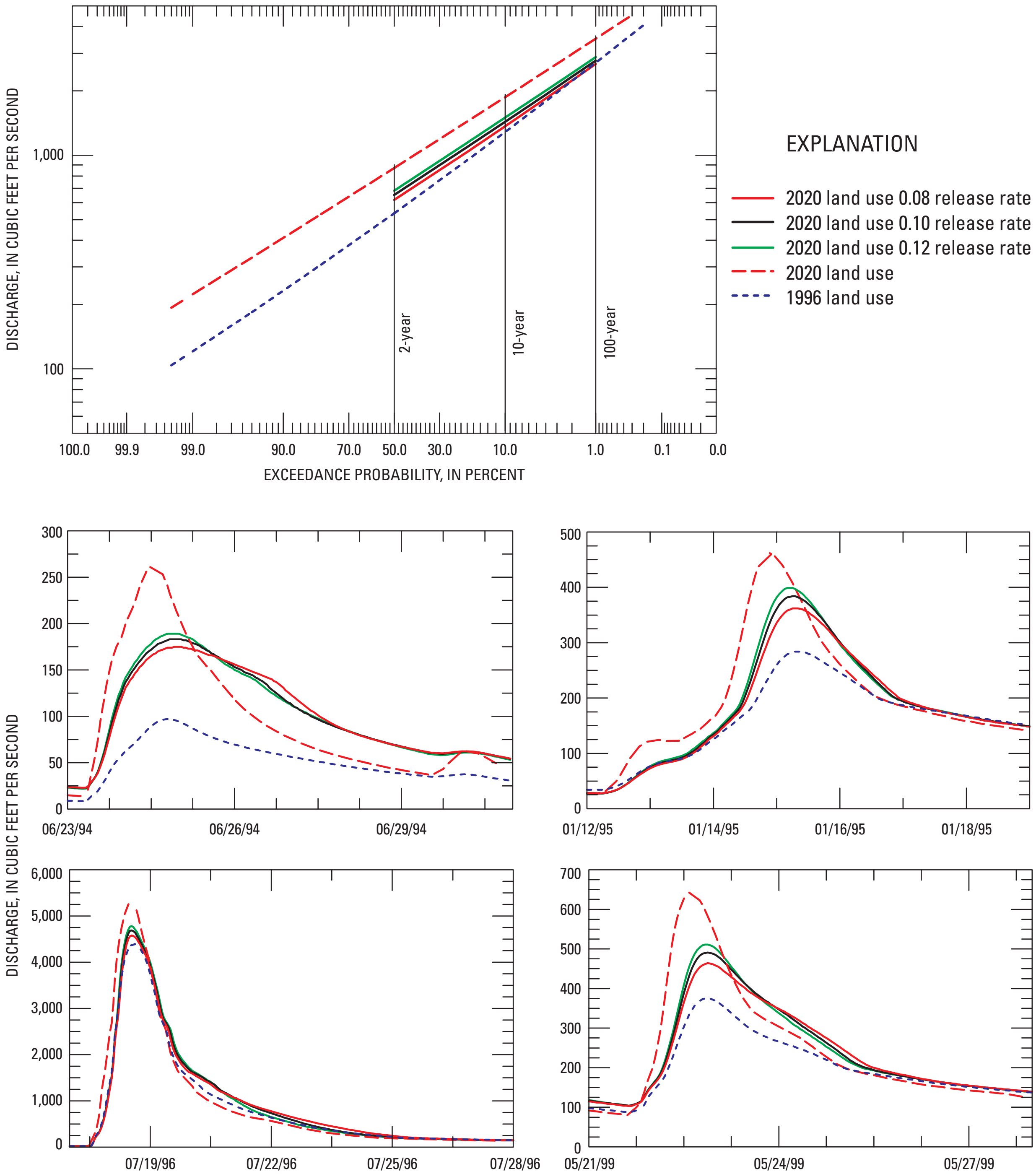

Figure 21. Comparison of flood frequencies and selected storm hydrographs simulated for 1996 and 2020 land uses and selected detention basin release rates on Blackberry Creek (subbasin 270), at the Kane and Kendall County, Illinois, line.

Summary and Conclusions

The Kane County Department of Environmental and Building Management (KCDEM) developed a stormwater ordinance for managing continuing growth and protecting natural resources in Kane County. The ordinance specifies that detention storage should be constructed in all new development areas in the county and that detention basins should have a release rate set at 0.1 cubic feet per second per acre of developed area (ft^3/s-acre) for controlling the 100-year flood. However, uncertainty remains about the extent of protection given by this release rate on the watershed scale. The U.S. Geological Survey (USGS), in cooperation with the KCDEM, undertook this study to determine the effect of detention basin release rates on flood flows for stormwater management in the Blackberry Creek watershed in Kane County.

The effects of stormwater detention basins with specified release rates are examined on a watershed scale with a Hydrological Simulation Program-FORTRAN (HSPF) continuous-simulation model. The outlet structure of the simulated detention basins was an orifice and a weir, and procedures for estimating the detention basin storage with a given release rate and for implementation in the HSPF models were developed and described. To facilitate future detention modeling as a tool for watershed management, a chart relating impervious area in a watershed to detention volume is presented.

A case study of the Blackberry Creek watershed in Kane County, Illinois, a rapidly urbanizing area seeking to avoid future flood damages from increased urbanization, illustrates the effects of various detention basin release rates on peak flows and volumes and flood frequencies. A detention basin was simulated in each subbasin where urban development was projected to occur between 1996 and 2020. Simulated flows based on a 1996 land-use HSPF model were compared to those based on four projected 2020 land-use HSPF model scenarios: no detention, and detention basins with release rates of 0.08, 0.10, and 0.12 ft^3/s-acre, respectively.

Flood-frequency analyses and selected flood hydrograph plots showed the effect of increased urban development and implementation of detention basins with specific release rates in the watershed. Overall, the detention basin storm runoff hydrographs show reduction in flood peaks; however, the recession limbs were prolonged with higher discharge magnitudes. The release-rate effectiveness was evaluated by whether 100-year flood-peak discharge could be maintained at or below the 1996 land-use conditions.

The results of the simulations at 15 locations, which included the downstream ends of all major tributaries and strategic locations along the main stem, showed that a detention basin release rate of 0.10 ft^3/s-acre, in general, could maintain postdevelopment 100-year peak flows at a similar magnitude to that of 1996 land-use conditions. Although the release rate is designed to reduce the 100-year peak flow, reduction of the 2-year peak flow is also achieved for a smaller proportion of the peak. Results also showed that the 0.10 ft^3/s-acre release rate was less effective in watersheds with relatively high percentages of preexisting (1996) development than in watersheds with less preexisting development.

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The Kane County Department of Environmental and Building Management and the Illinois Department of Natural Resources–Office of Water Resources, in cooperation with the USGS–Illinois Water Science Center, conducted this investigation of stormwater management strategies for the Blackberry Creek watershed in Kane County. Darren Olson, of Christopher Burke Engineering, Ltd. (CBBEL), provided a detention basin sizing spreadsheet that was the basis of the detention basin spreadsheet developed in this study. Valuable input was received from the following technical reviewers: William Coon, USGS–New York Water Science Center; Karen Kosky, Kane County Department of Environmental and Building Management; Chad Ostheimer, USGS–Ohio Water Science Center; Loren Wobig, Illinois Department of Natural Resources–Office of Water Resources.

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Appendix 1

Appendix 1. Flood quantiles estimated for selected recurrence intervals based on Hydrological Simulation Program–FORTRAN analysis for the 1996 land uses, 2020 projected land uses without detention basins, and 2020 projected land uses with detention basins and release rates of 0.08, 0.10, and 0.12 cubic feet per second per acre at subbasins of the Blackberry Creek watershed in Kane County, Illinois.

[ft^3/s-acre, cubic foot per second per acre; tributaries shown on figure 2; Q_T, flood quantile at T-year recurrence interval, in cubic feet per second; presented Q_T are for 2, 10, 50, and 100 years]

Sub-basin number	1996 land use without detention basin				2020 projected land use without detention basin				2020 projected land use with detention basin and 0.08 ft^3/s-acre release rate				2020 projected land use with detention basin and 0.10 ft^3/s-acre release rate				2020 projected land use with detention basin and 0.12 ft^3/s-acre release rate			
	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}
Route 38 Branch																				
10	26	59	91	105	38	67	93	104	24	55	86	100	24	55	86	100	24	55	86	100
Elburn Run																				
22	54	104	145	162	110	152	187	201	36	72	107	121	36	72	107	121	36	72	107	121
21	107	277	478	576	284	476	657	738	81	196	336	408	83	200	342	414	85	203	347	420
20	151	411	728	886	350	633	916	1,047	127	319	559	682	131	325	566	690	135	330	573	697
Seavey Road Run																				
33	60	158	284	349	65	164	287	350	57	152	272	335	57	152	272	335	57	152	272	335
32	77	218	407	507	77	218	407	507	77	218	407	507	77	218	407	507	77	218	407	507
31	146	344	570	680	151	349	572	679	145	342	566	675	146	342	567	675	146	343	566	675
30	153	361	609	734	161	373	622	746	152	359	606	730	152	359	606	730	153	359	606	730
Prestbury Branch																				
41	12	36	71	90	40	98	168	203	4	10	20	26	4	10	20	26	4	10	20	26
40	14	32	54	66	30	62	93	108	22	37	51	56	24	41	57	63	25	44	61	68
Lake Run																				
57	74	205	373	460	74	204	373	460	74	204	373	460	74	204	373	460	74	204	373	460
56	10	40	95	129	12	42	97	132	9	32	72	98	9	32	72	98	9	32	72	98
55	24	76	158	206	25	79	160	206	22	68	140	182	22	68	140	182	22	68	141	182
54	101	283	521	647	103	284	521	645	100	277	508	629	100	277	509	630	100	277	509	631
53	17	38	54	60	22	38	51	56	14	35	54	62	14	35	54	62	14	35	54	62
52	288	678	1,095	1,288	296	681	1,082	1,266	275	656	1,065	1,255	277	658	1,067	1,257	278	659	1,068	1,257
51	305	663	1,009	1,160	320	673	1,006	1,150	298	650	995	1,147	300	651	998	1,151	301	653	1,000	1,154
50	236	525	845	999	287	584	894	1,038	225	495	798	945	226	497	800	947	228	500	804	951
East Run																				
64	93	209	328	382	171	297	421	478	60	133	208	243	60	133	208	243	60	133	208	243
63	115	285	481	576	321	546	751	841	73	165	273	327	74	169	278	332	76	172	283	337
62	65	157	274	335	222	367	505	567	44	89	138	162	48	95	148	173	51	102	158	185
61	61	144	249	303	213	363	510	576	70	131	195	225	78	148	222	257	86	165	248	288
60	39	89	151	182	124	258	407	480	59	114	173	201	64	129	200	234	69	141	223	262

Appendix 1. Flood quantiles estimated for selected recurrence intervals based on Hydrological Simulation Program–FORTRAN analysis for the 1996 land uses, 2020 projected land uses without detention basins, and 2020 projected land uses with detention basins and release rates of 0.08, 0.10, and 0.12 cubic feet per second per acre at subbasins of the Blackberry Creek watershed in Kane County, Illinois. —Continued

[ft^3/s-acre, cubic foot per second per acre; tributaries shown on figure 2; Q_T, flood quantile at T-year recurrence interval, in cubic feet per second; presented Q_T are for 2, 10, 50, and 100 years]

Sub-basin number	1996 land use without detention basin				2020 projected land use without detention basin				2020 projected land use with detention basin and 0.08 ft^3/s-acre release rate				2020 projected land use with detention basin and 0.10 ft^3/s-acre release rate				2020 projected land use with detention basin and 0.12 ft^3/s-acre release rate			
	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_2	Q_{10}	Q_{50}	Q_{100}
Aurora Chain-of-Lakes																				
79	4	13	29	39	25	93	207	275	1	2	4	5	1	2	4	5	1	2	4	5
78	5	12	21	26	12	29	50	60	7	11	16	18	7	13	18	21	8	14	20	23
77	30	102	207	265	166	325	494	575	29	74	127	153	31	77	130	157	33	80	133	159
76	65	208	398	497	278	502	711	803	82	190	304	357	87	199	314	367	91	207	324	376
75	30	115	271	370	284	611	938	1,085	45	142	295	386	52	162	329	425	60	180	355	452
74	4	5	6	6	6	7	8	9	4	5	5	5	4	5	5	5	4	5	5	5
73	32	91	177	225	249	668	1,139	1,361	45	111	196	241	52	129	229	282	58	147	265	329
72	3	9	19	24	26	72	137	172	1	3	5	7	1	3	5	7	1	3	5	7
71	4	9	16	20	16	47	94	120	6	11	16	18	6	12	18	21	7	14	21	24
70	21	46	74	88	74	235	487	633	34	74	118	139	38	86	143	171	41	98	168	204
Blackberry Creek main stem																				
208	67	175	302	364	68	176	302	363	67	174	300	362	67	174	300	362	67	174	300	362
210	131	323	545	654	168	363	578	681	126	307	516	618	126	308	516	618	127	308	516	618
213	136	347	612	748	257	510	782	912	113	279	485	590	114	281	487	592	115	282	487	592
216	128	299	511	620	211	420	652	765	124	275	456	548	129	282	466	559	133	290	476	570
218	138	312	526	635	216	433	674	791	135	291	473	565	140	298	484	578	144	306	496	591
220	258	625	1,092	1,336	465	913	1,403	1,640	243	551	928	1,121	250	562	941	1,135	257	571	951	1,144
223	295	711	1,237	1,511	501	989	1,526	1,786	280	637	1,075	1,300	287	647	1,085	1,309	294	655	1,092	1,314
226	314	713	1,197	1,443	498	971	1,486	1,734	311	669	1,092	1,304	318	681	1,105	1,318	325	692	1,119	1,332
230	441	985	1,638	1,970	613	1,229	1,916	2,250	442	951	1,550	1,851	450	964	1,567	1,868	458	977	1,583	1,886
233	450	994	1,646	1,976	617	1,243	1,942	2,282	452	963	1,561	1,860	461	978	1,579	1,879	470	993	1,600	1,902
236	457	984	1,605	1,916	663	1,254	1,881	2,179	450	942	1,508	1,789	461	959	1,530	1,812	471	976	1,554	1,839
240	482	1,020	1,646	1,958	716	1,322	1,946	2,237	514	1,038	1,624	1,910	532	1,072	1,675	1,969	549	1,103	1,720	2,021
250	636	1,380	2,262	2,706	870	1,771	2,786	3,284	678	1,405	2,236	2,646	702	1,450	2,302	2,722	724	1,492	2,367	2,798
260	667	1,452	2,383	2,853	973	1,988	3,136	3,699	731	1,505	2,385	2,819	761	1,565	2,478	2,928	787	1,618	2,560	3,024
265	529	1,300	2,286	2,801	832	1,811	2,926	3,474	598	1,359	2,269	2,728	630	1,417	2,343	2,805	657	1,471	2,415	2,882
270	535	1,286	2,225	2,709	872	1,871	2,978	3,511	618	1,367	2,240	2,673	653	1,434	2,330	2,771	684	1,500	2,425	2,876

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