USGS
science for a changing world

Hydrologic and hydraulic analyses to assess the effects of temporal land-use development and flood mitigation scenarios in the Silver Creek watershed in Illinois

Charlie Cigrand
Physical Scientist
U.S. Geological Survey, Central Midwest Water Science Center

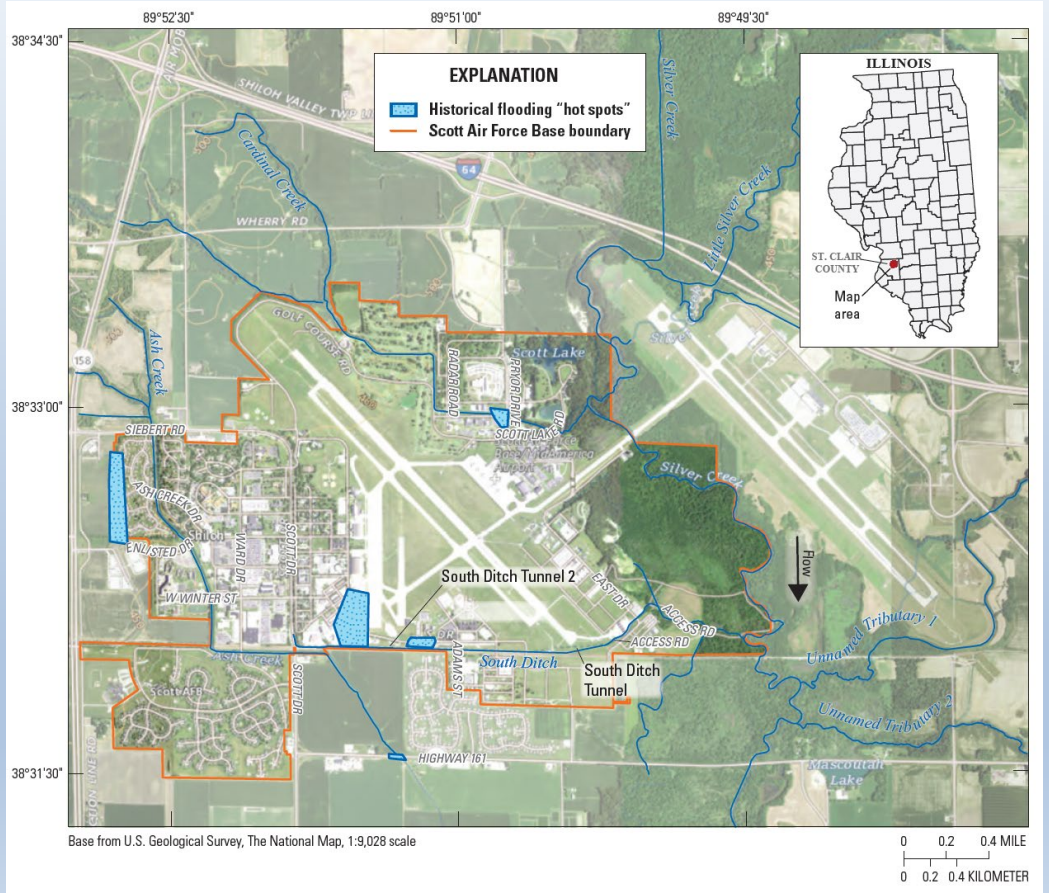
U.S. Department of the Interior
U.S. Geological Survey

Scott Air Force Base located within the Silver Creek Watershed

Scott Air Force Base (Scott AFB)

- Located in western Illinois and immediately east of the St. Louis metropolitan area
- Reoccurring flood events have caused significant damage to infrastructure while also disrupting ground transportation as roads become inundated
- Flooding sources include Silver Creek and tributaries consisting of Ash Creek, Cardinal Creek, and South Ditch
- Increases in land-use development within the Silver Creek watershed has potentially increased precipitation runoff in the area during the past 30 years





USGS

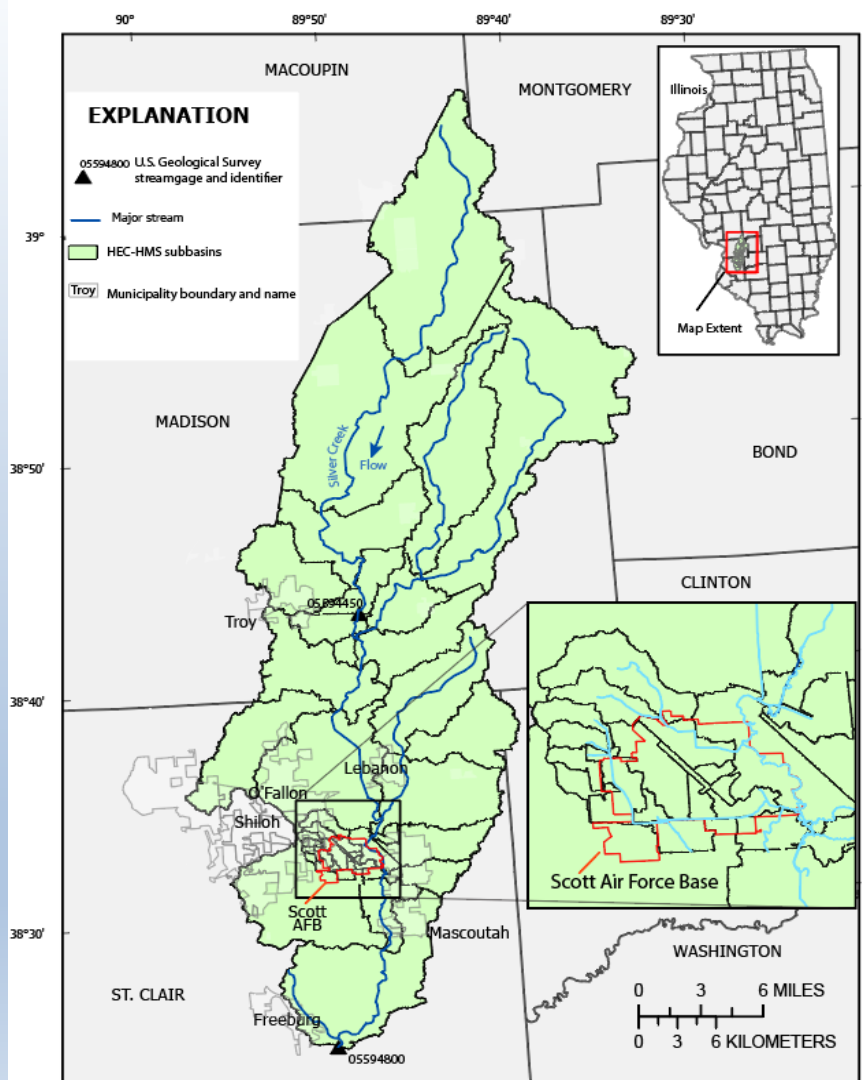
Hydrologic Model Development

Hydrologic Engineering Center –Hydrologic Modeling System (HEC-HMS)

Subbasins developed for two scales

- Silver Creek assessment at a watershed scale
- Smaller subbasins near Scott AFB for hydraulic model boundary conditions

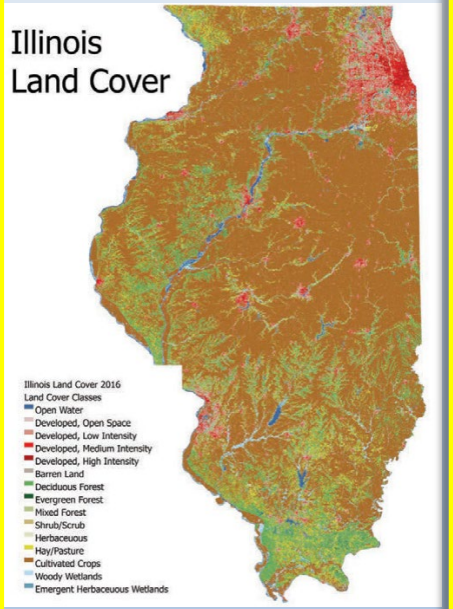
Subbasins range from 0.26 to 59 square miles and totaled 464 square miles



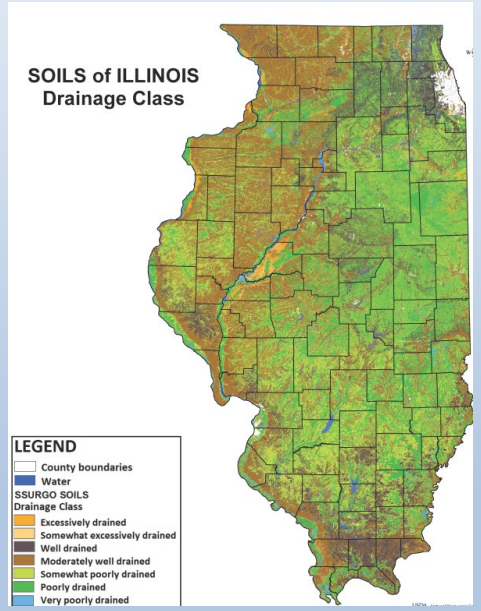
USGS

Hydrologic Model Inputs

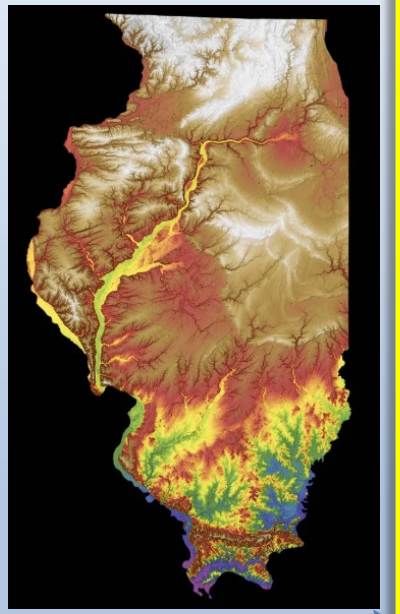
Land cover



Soil properties



Terrain model



Precipitation



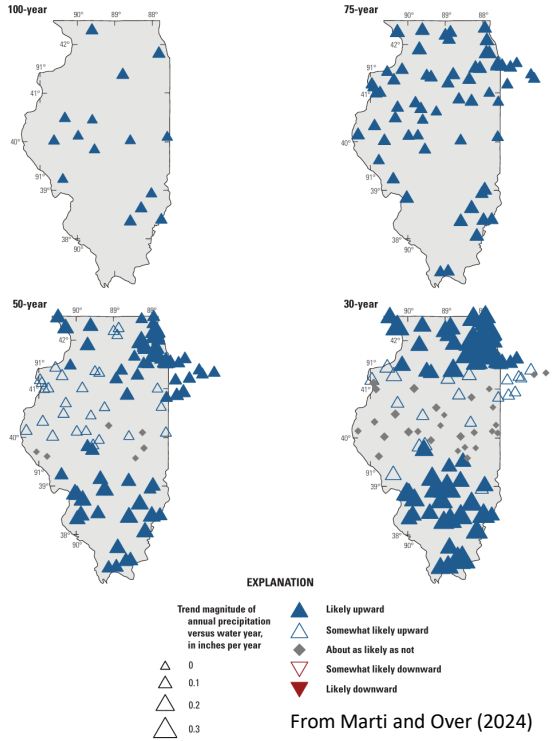
Can vary with time

USGS

The magnitude of annual precipitation are likely trending upward in southwest Illinois

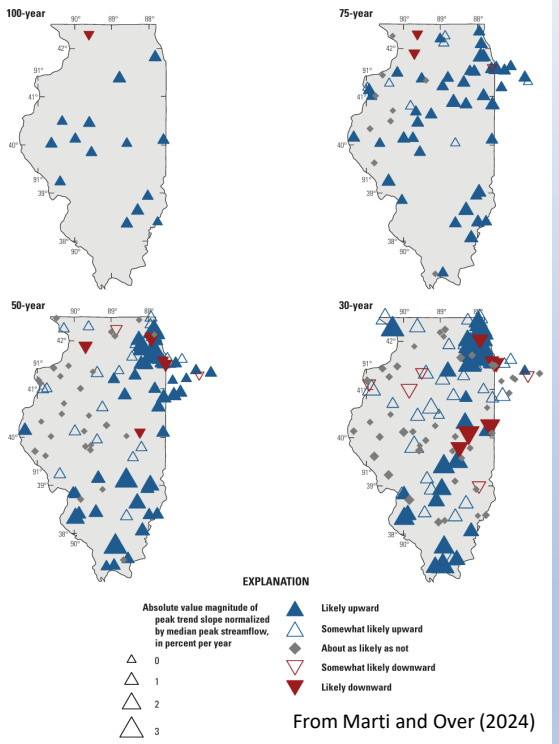
- The magnitude of annual precipitation are likely trending upward in southwest Illinois
- Notable increases in extreme precipitation events
- Both USGS streamgages on Silver Creek (near Troy and Freeburg, Illinois) have exhibited likely upward trends in peak streamflows for the 30- and 50-year trend periods

Likelihoods and magnitudes of trends in annual precipitation in study basins in Illinois for certain trend periods



From Marti and Over (2024)

Likelihoods and magnitudes of monotonic trends in peak streamflow magnitude for certain trend periods



From Marti and Over (2024)

Marti, M.K., and Over, T.M., 2024, Peak streamflow trends in Illinois and their relation to changes in climate, water years 1921–2020, chap. B *of* Ryberg, K.R., comp., Peak streamflow trends and their relation to changes in climate in Illinois, Iowa, Michigan, Minnesota, Missouri, Montana, North Dakota, South Dakota, and Wisconsin: U.S. Geological Survey Scientific Investigations Report 2023–5064, 58 p., https://doi.org/10.3133/sir20235064B.

USGS

Study Objectives

Develop a hydrologic model to assess hydrologic changes in the Silver Creek watershed under changing land-uses

- **Current Conditions** uses 2019 National Land Cover Database (NLCD) and was used for model calibration
- **Historical Conditions** using the 1992 NLCD
- **Future Conditions** uses the 2019 NLCD with the addition of local municipal comprehensive plans
- **Future Conditions+** incorporated projected 2050 precipitation frequency estimates

Hydrologic model analyses included determining:

- Percentage change in peak streamflow
- Change in the timing of the peak streamflow
- Change in total runoff volumes
    - To account for differences in subbasin drainage areas, cumulative event runoff volumes were normalized to subbasin drainage area to indicate relative change to subbasin runoff yields in acre-feet per square mile of drainage area

USGS

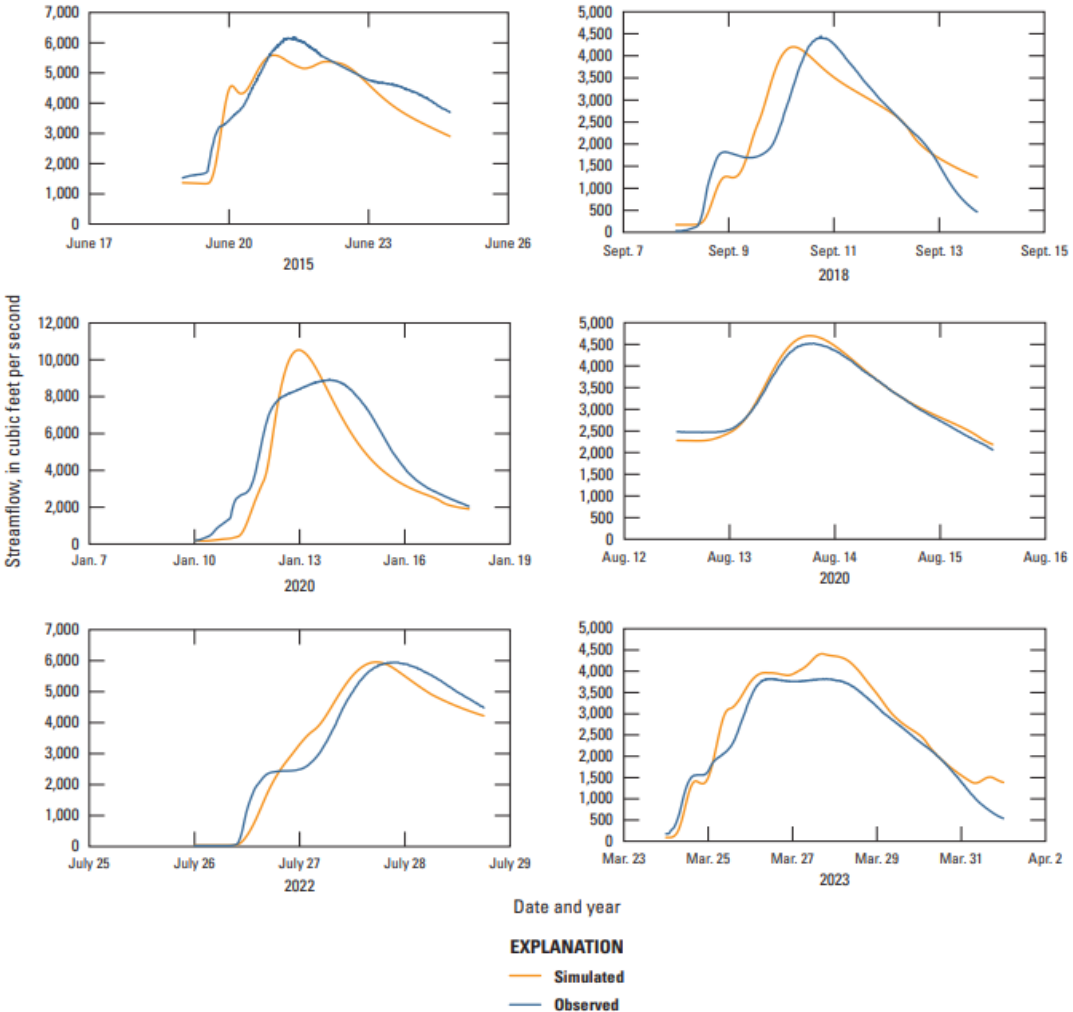
Model Calibration and Validation

Calibrated the model to observed events using data from two USGS streamgages: Silver Creek near Troy, IL (USGS station 05594400) and Silver Creek near Freeburg, IL (USGS station 05594800)



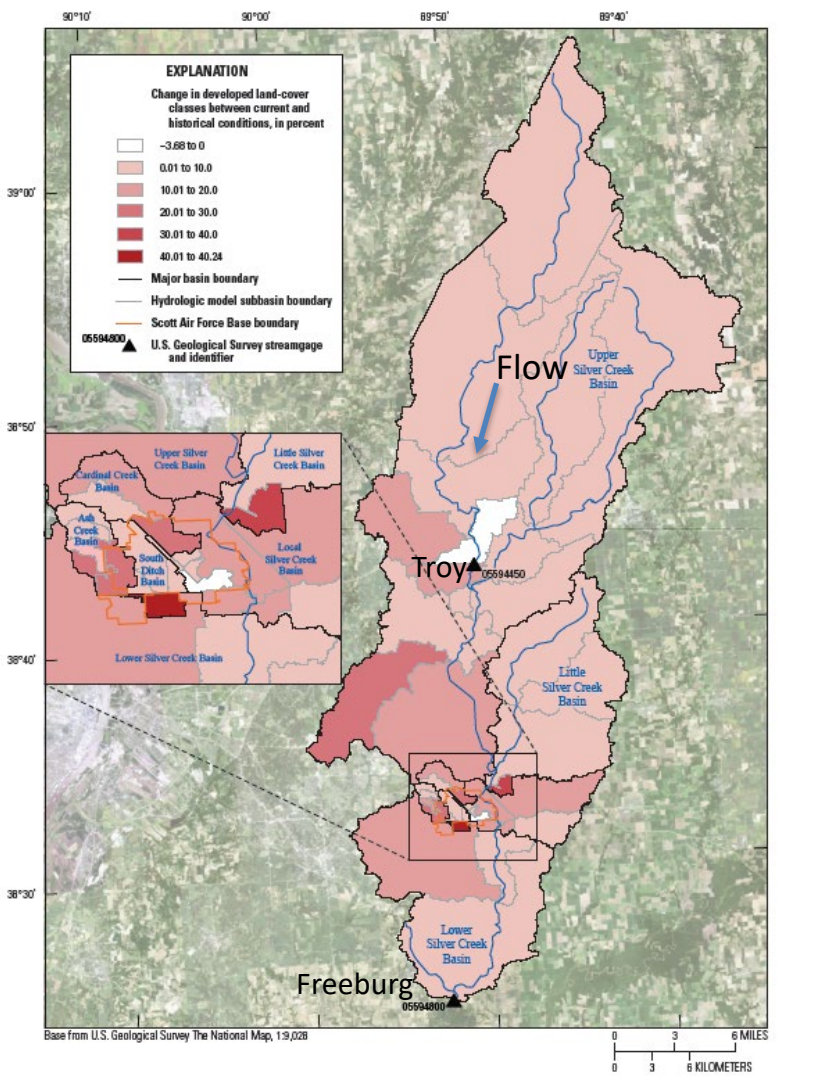
USGS streamgage on Silver Creek near Troy, IL

Simulated and observed streamflow hydrographs from selected calibration high-flow events at Silver Creek at Troy, Illinois (USGS station 05594400).



The greatest change in development from 1992 to 2019 occurred in the lower third of the watershed

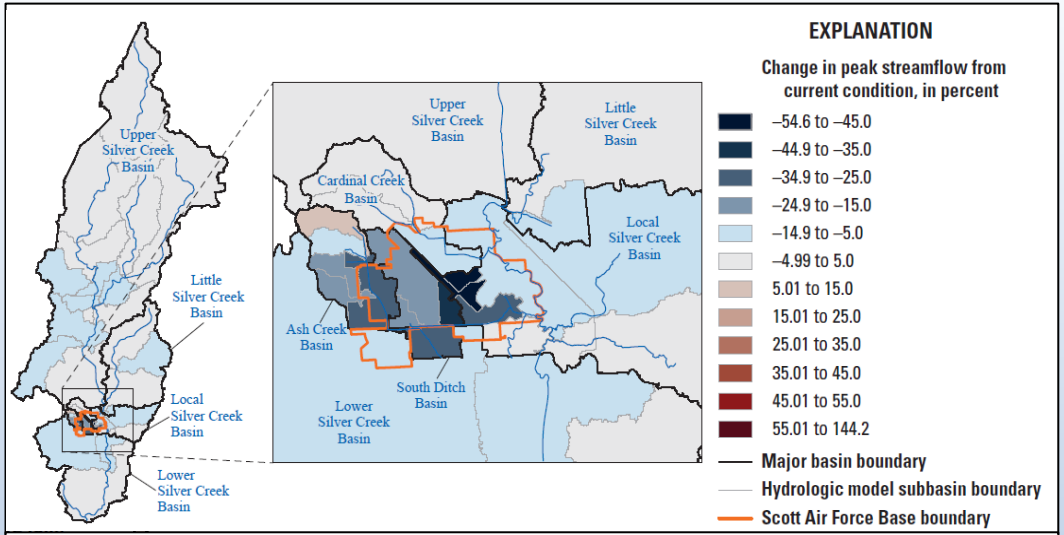
- Generally, change <5% (darker the color the greater the change)
- Overall change in development from -3.6 to 40%
- The inset shows subbasins located near the Scott AFB area and are subbasins with some of the highest change in development

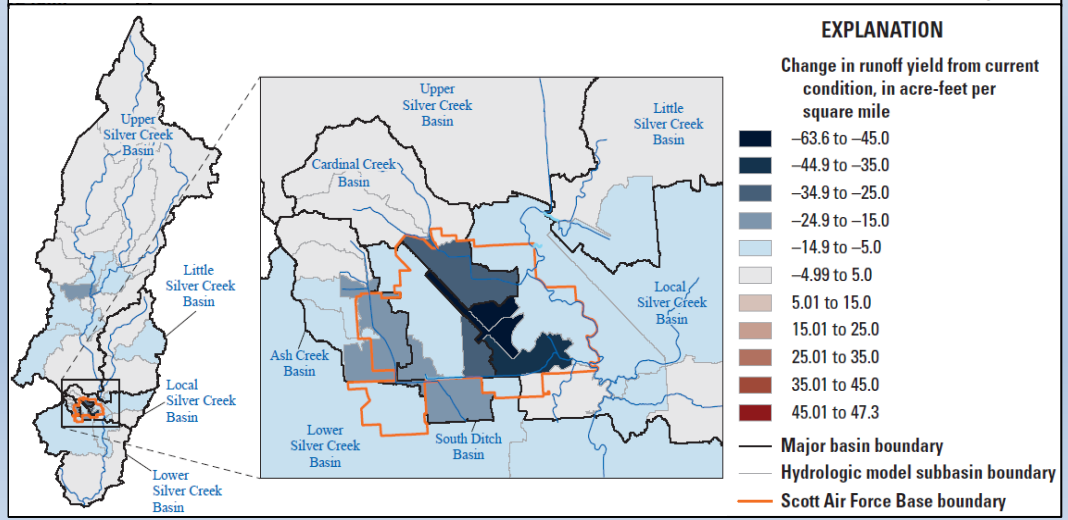


USGS

Percent change in peak streamflow and runoff yield between Historical and Current land cover

- Model results for a 2-year recurrence interval 24-hour duration event (3.7 in.)
- Most subbasins <5% change in peak streamflows including the upper areas of the watershed
- Largest change in the lower watershed near Scott AFB with decreases to peak streamflows and runoff yields up to 54% and 63 acre-ft/mi², respectively

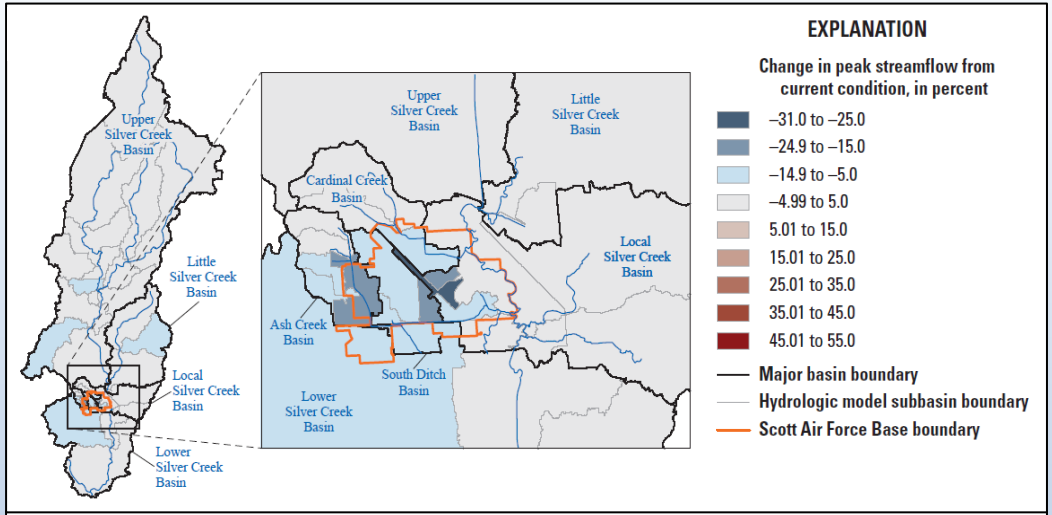


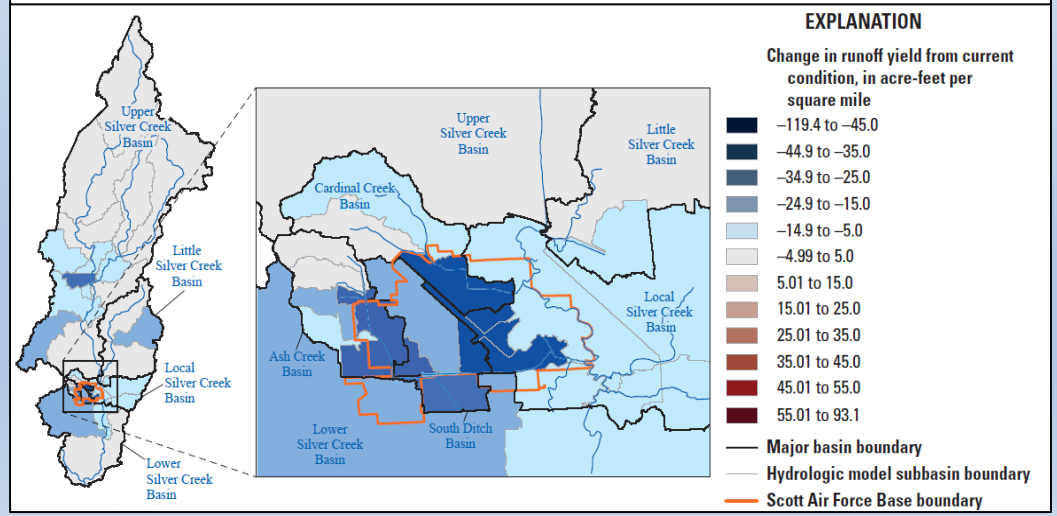


USGS

Percent change in peak streamflow and runoff yield between Historical and Current land cover

- Model results for a 100-yr recurrence interval 24-hr duration event (8.0 in.)
- More subbasins with <5% change than the 2-yr recurrence interval event
- Largest change in the lower watershed near Scott AFB with decreases to peak streamflows and runoff yields up to 30% and 119 acre-ft/mi², respectively

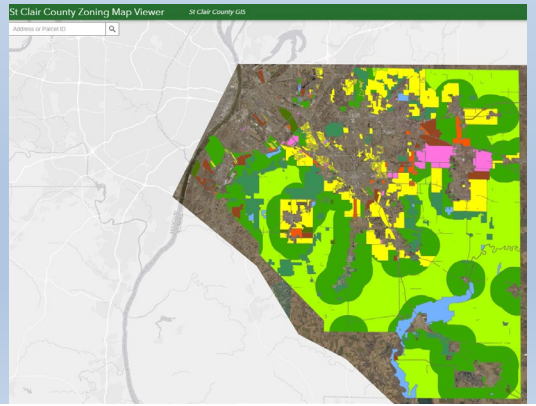




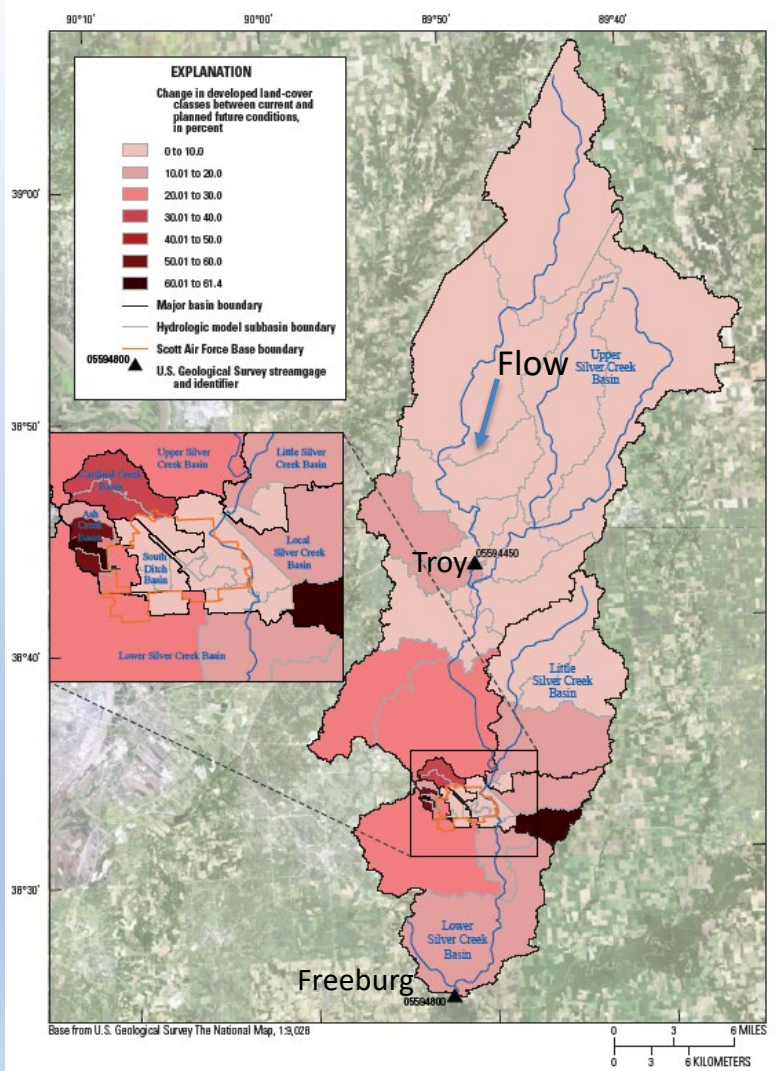
USGS

The greatest projected change in the basin from 2019 into the future is projected to occur in the lower third of the watershed

- Most of the watershed area is <10%
- Percent change ranged from <10 to 61%

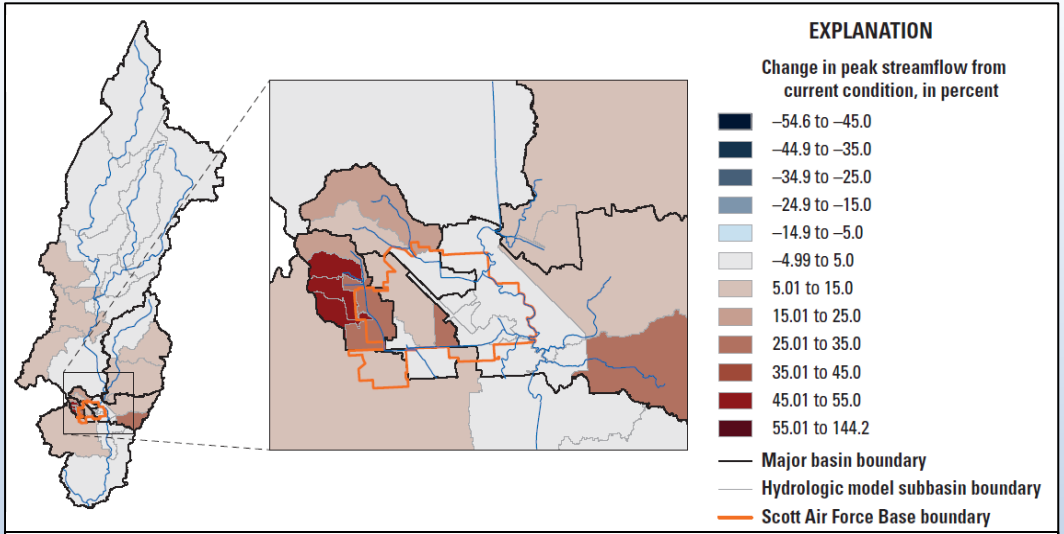


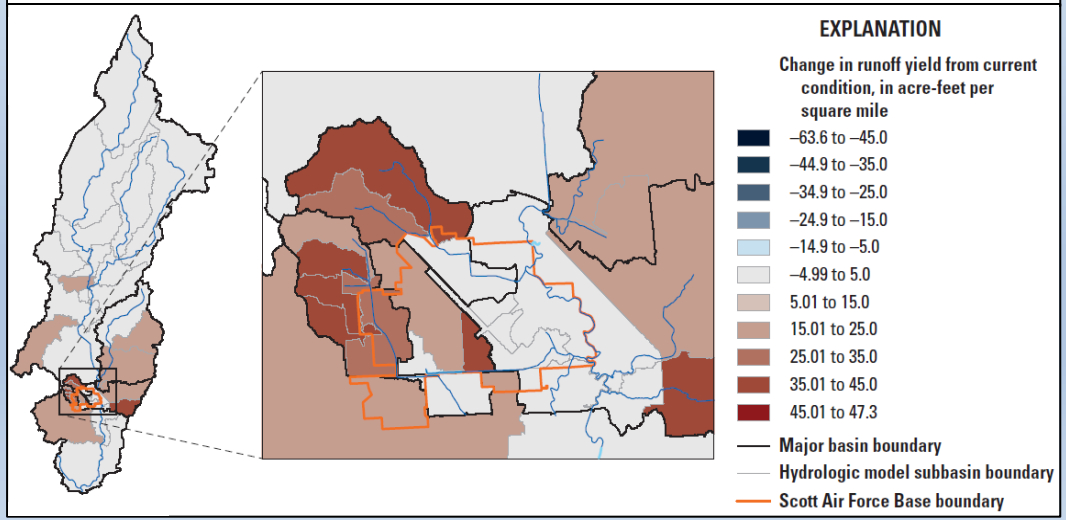
Example of comprehensive plan for St. Clair County, Illinois



Percent change in peak streamflow and runoff yield between Future and Current land cover

- Model results for a 2-yr recurrence interval 24-hr duration event (3.7 in.)
- Most subbasins <5% change in peak streamflows including the upper areas of the watershed
- Largest change in the lower watershed near Scott AFB with increases to peak streamflows and runoff yields of up to 120% and 47 acre-ft/mi², respectively

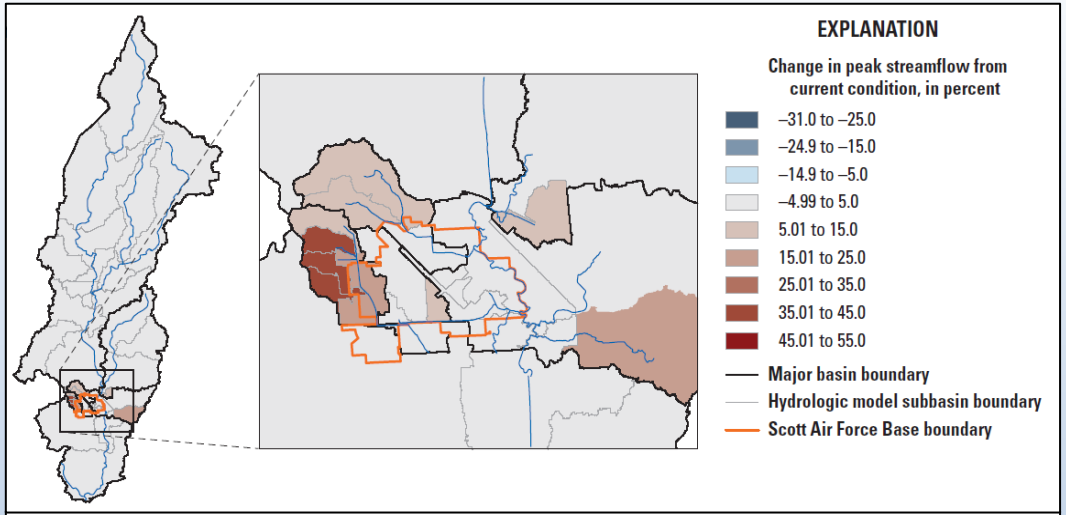


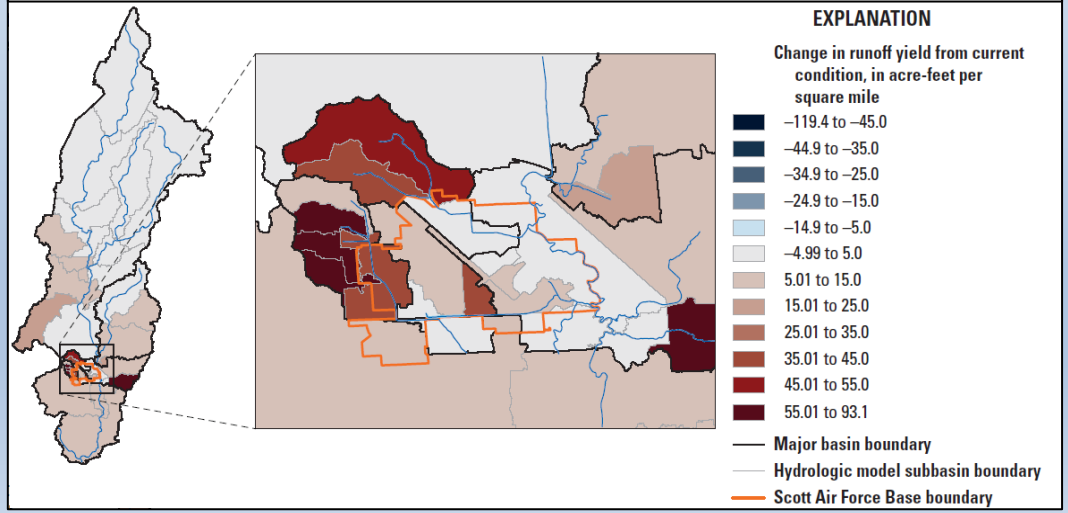


USGS

Percent change in peak streamflow and runoff yield between Future and Current land cover

- Model results for a 100-yr recurrence interval 24-hr duration event (8.0 in.)
- More subbasins with <5% change than the 2-yr recurrence interval event
- Largest change in the lower watershed near Scott AFB with increases to peak streamflows and runoff yields of up to -41% and 73 acre-ft/mi², respectively



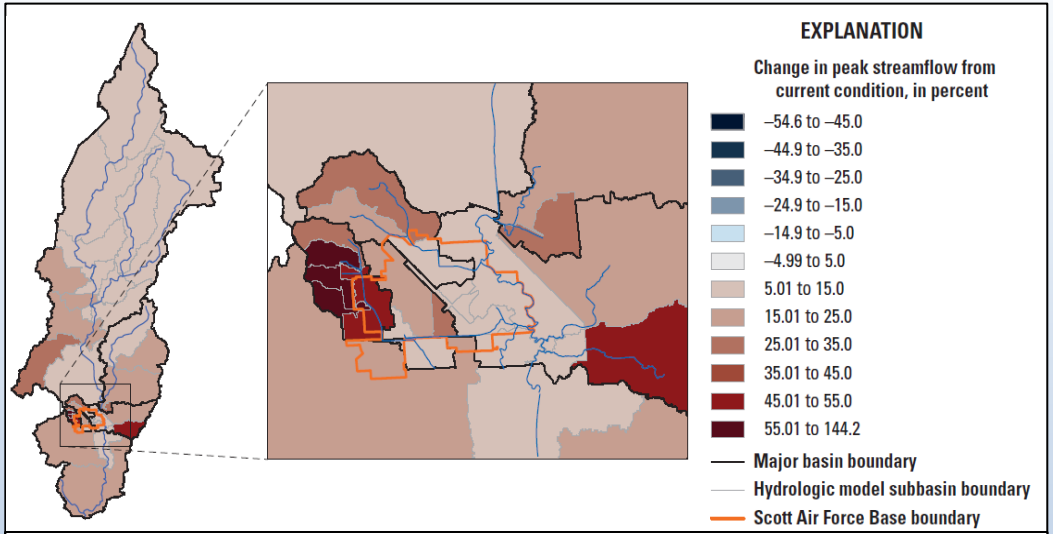


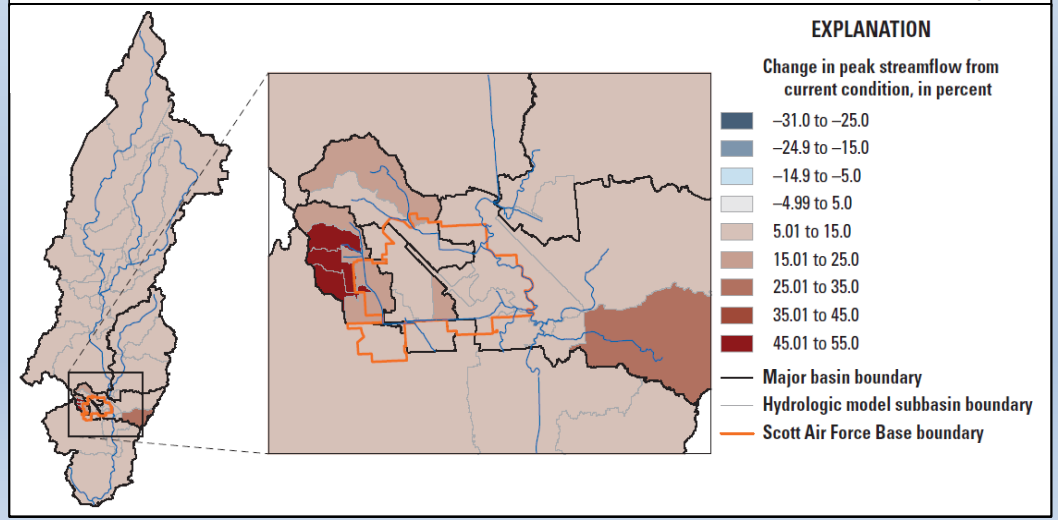
USGS

Percent change in peak streamflow and runoff yield for Future land cover + projected Precipitation

- 2-yr recurrence interval cumulative rainfall increased from 3.7 to 4.0 in. while the 100-yr increased from 8.0 to 8.9 in.
- All subbasins >5% change in peak streamflows with the increase in rainfall
- 2- and 100-yr recurrence interval events with projected precipitation had subbasin peak streamflows increase up to 144% and 52%, respectively

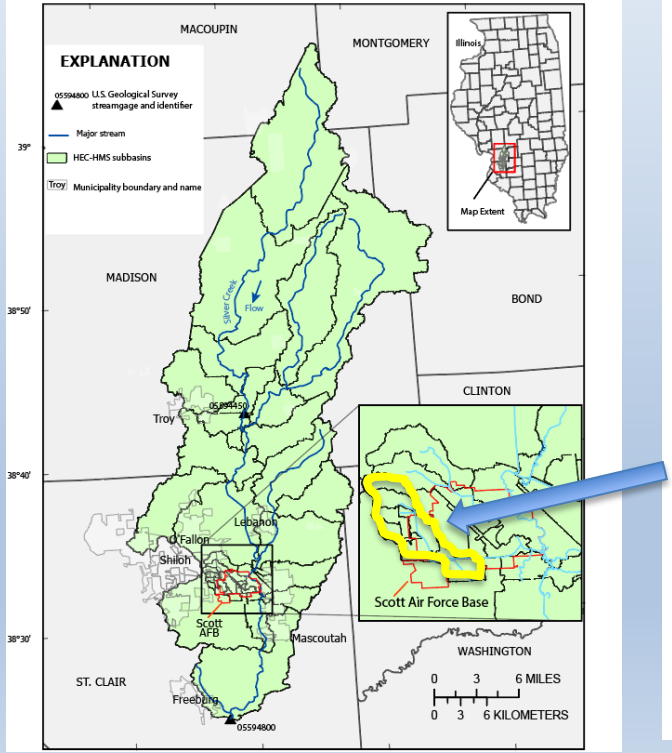
USGS

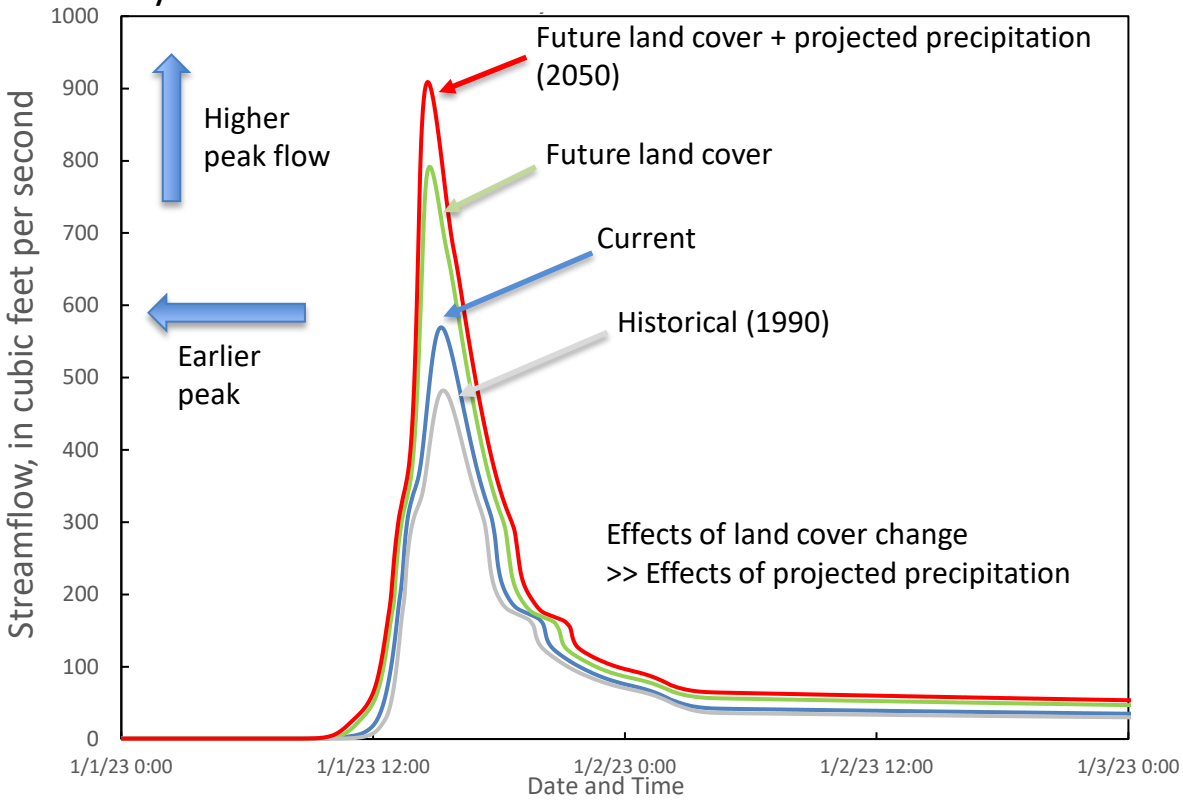




Compare Historical, Current, and Future 10-yr recurrence interval events for two example subbasins

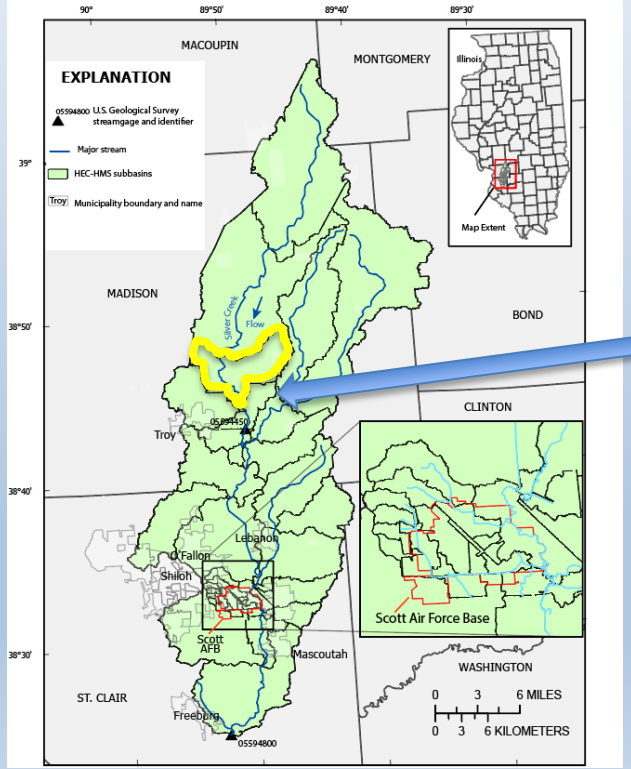
Ash Creek subbasin (tributary of Silver Creek near Scott AFB)

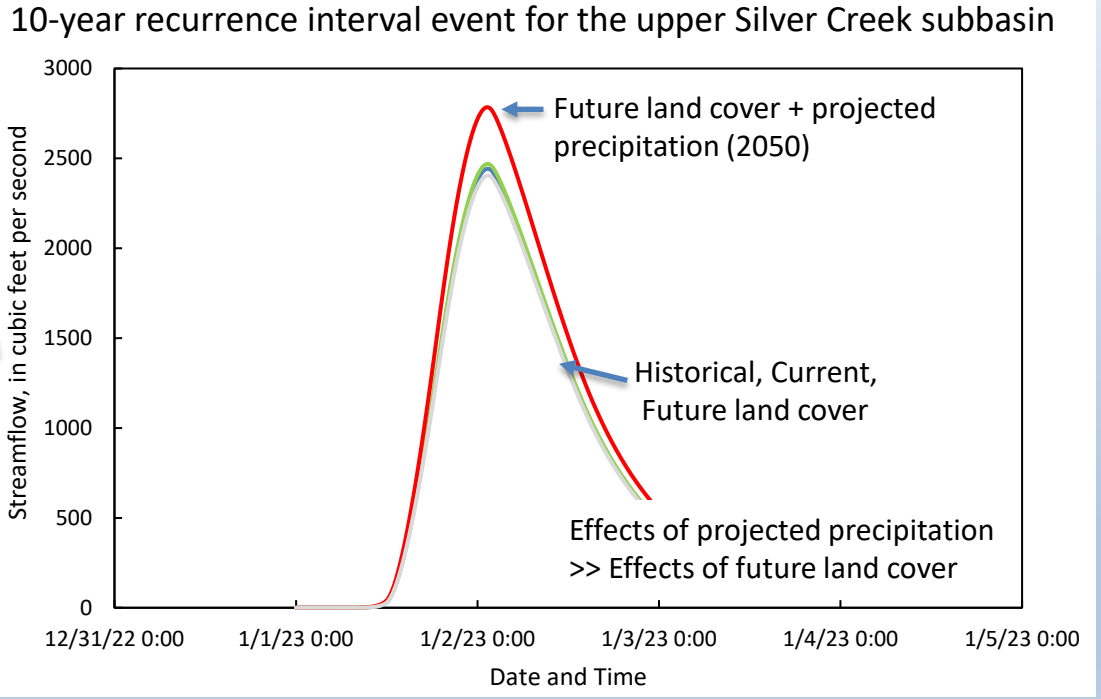




Compare Historical, Current, and Future 10-yr recurrence interval events for two example subbasins

Upper Silver Creek subbasin





Study Objectives

Develop a hydraulic model to assess the effects of added detention storage on/near Scott AFB under:

- **Current conditions** with and without added detention storage
- **Future conditions+** with and without added detention storage

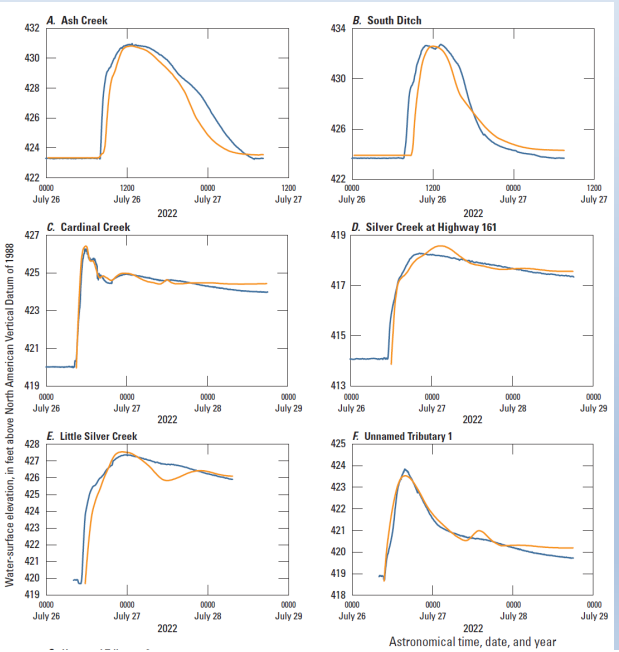
Hydraulic model analyses included:

- Use the HEC-HMS model outputs for boundary conditions in the hydraulic model event simulations
- Assessment of flood prone areas. Why is it flooding there? Terrain? Source of the localized flooding?
- Locate potential areas for detention storage

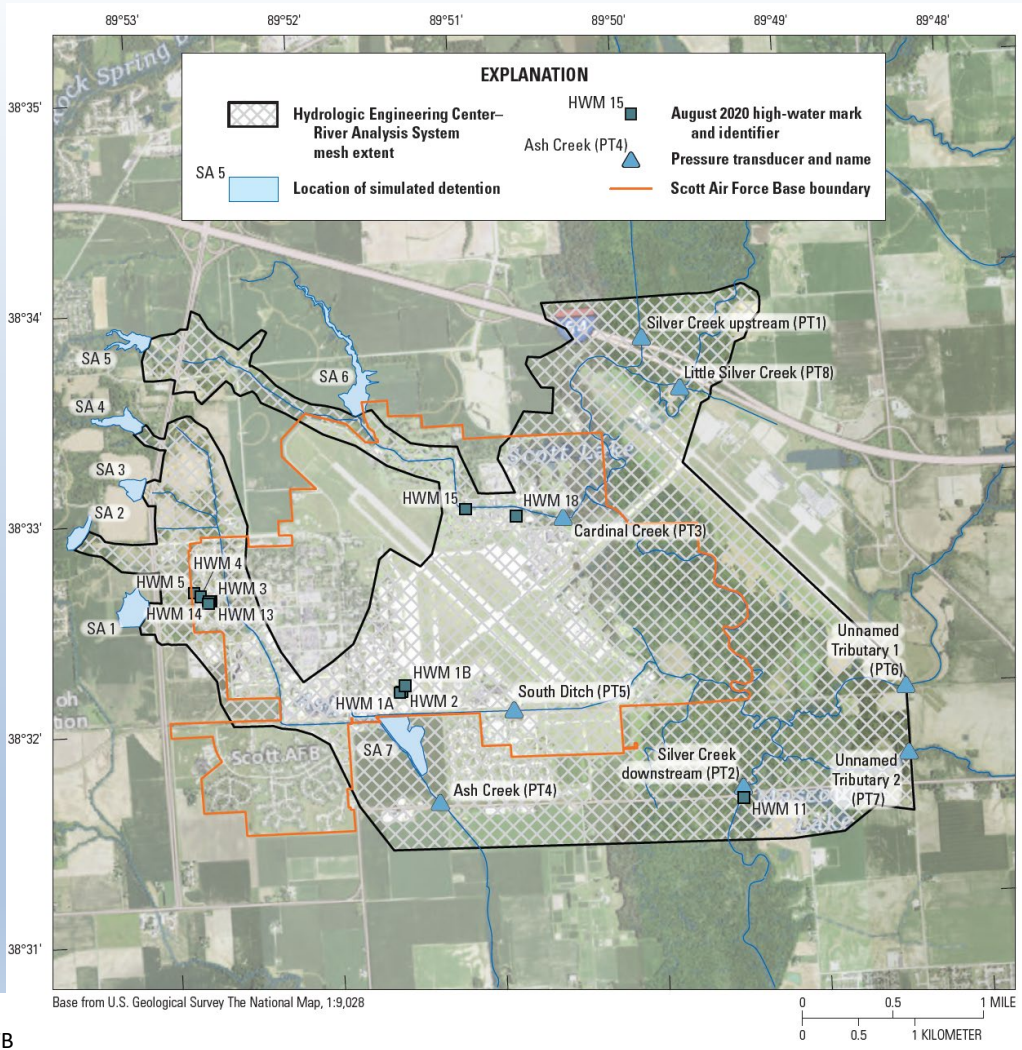
USGS

Hydraulic model development

- Hydrologic Engineering Center–River Analysis System (HEC-RAS) 2D model
- Used to simulate stage, streamflow, and flooding extents associated with Silver Creek and tributaries near Scott AFB
- Model calibrated to surveyed high-water marks and stage sensors deployed in the streams

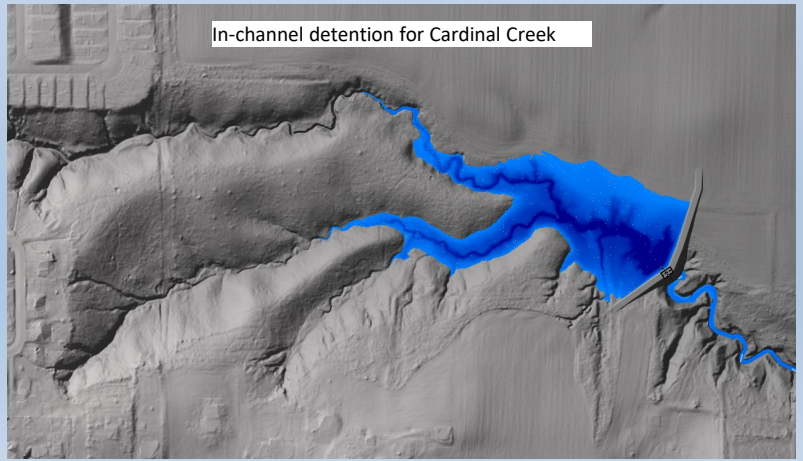


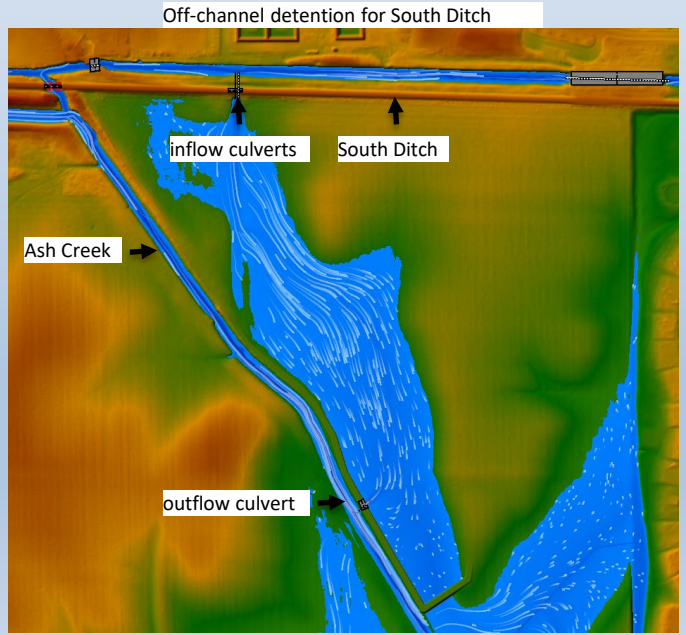
Simulated and observed stage hydrographs from selected calibration events at PT sensors deployed in and around Scott AFB



Detention Structures in the Model

- Detention consisted of six in-channel detention structures near the headwaters of Ash Creek, Cardinal Creek, and associated tributaries; one off-channel detention structure for South Ditch
- Conceptual in design and utilizes existing terrain with storage behind an earthen dam/berm
- Detention storage ranged from 23 to 50 acre-feet and drainage areas ranged from 0.26 to 1.44 square miles
- Simulated dam/berm height and outlet culvert size to have the capacity to contain a 24-hr duration rainfall event with a 25-yr recurrence interval

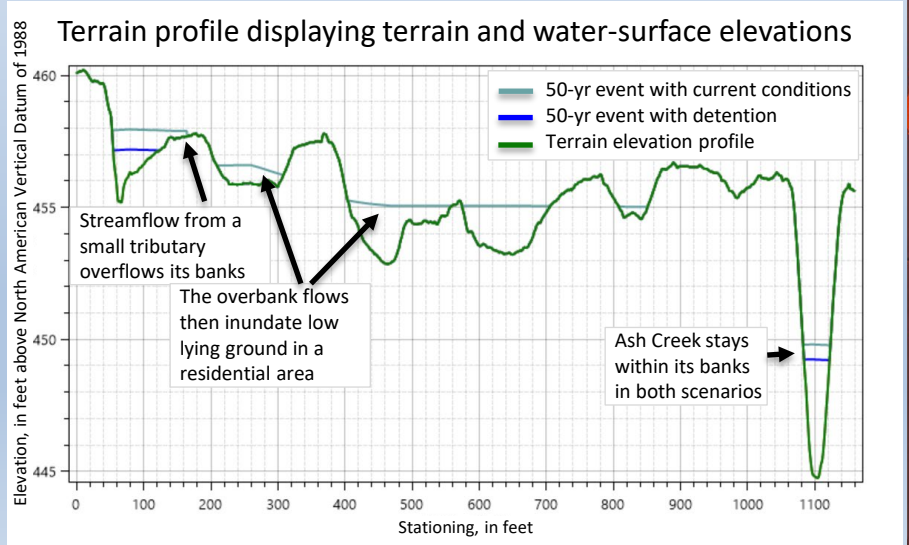


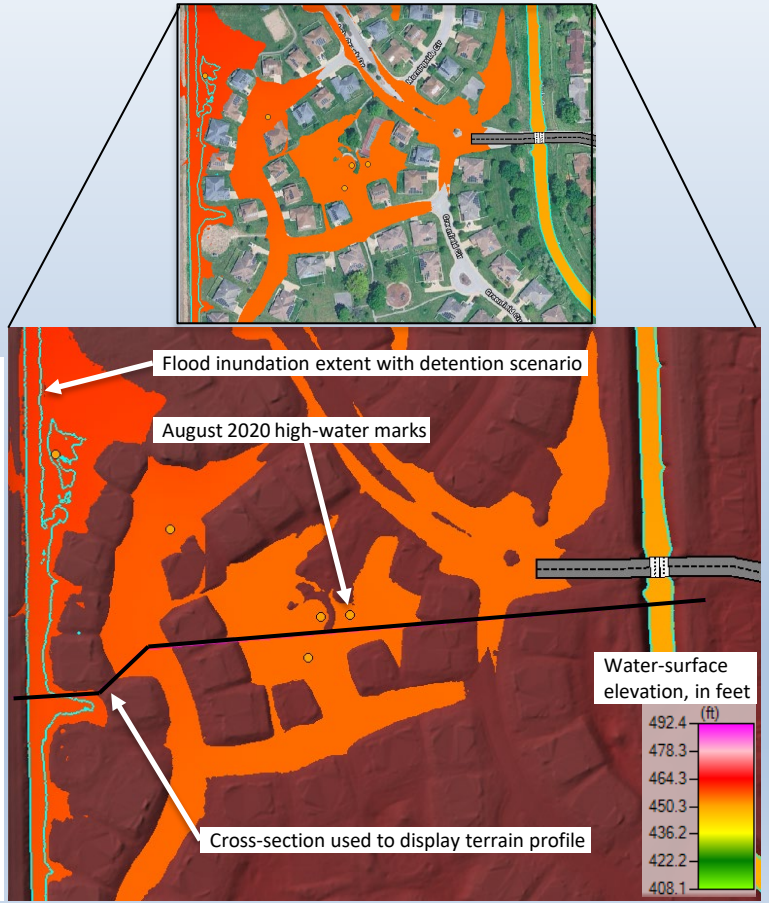


USGS

Flood inundation extent on Ash Creek for detention scenarios

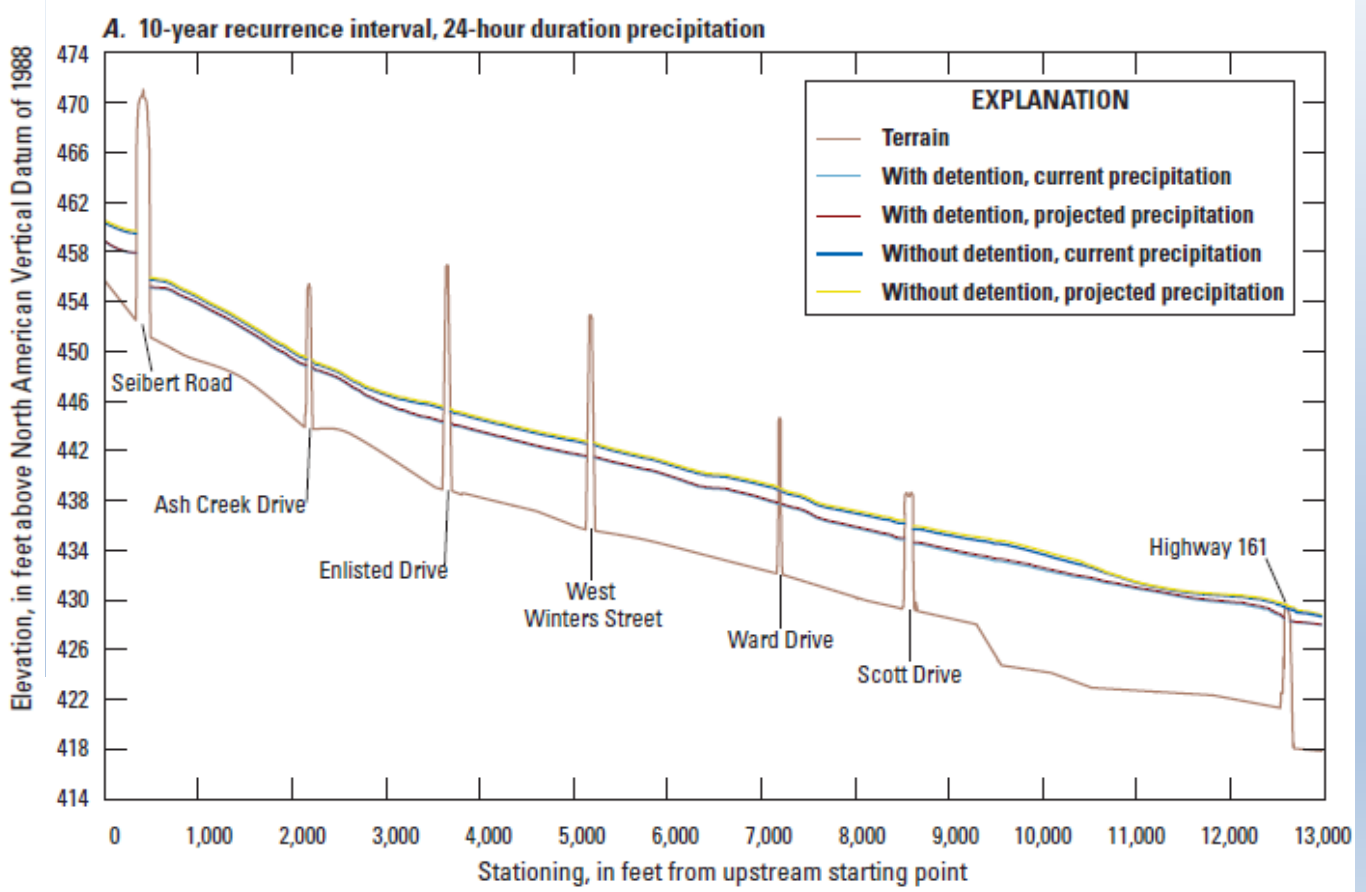
- Detention storage for the 50-year recurrence interval event can mitigate flooding near the Ash Creek Drive neighborhood
- With no detention, simulated flooding level were similar to the August 2020 flood event which inundated some homes
- Hydraulic model results demonstrate that the source of the flooding was not Ash Creek but from a smaller tributary channel





Water-surface profiles on Ash Creek for detention scenarios

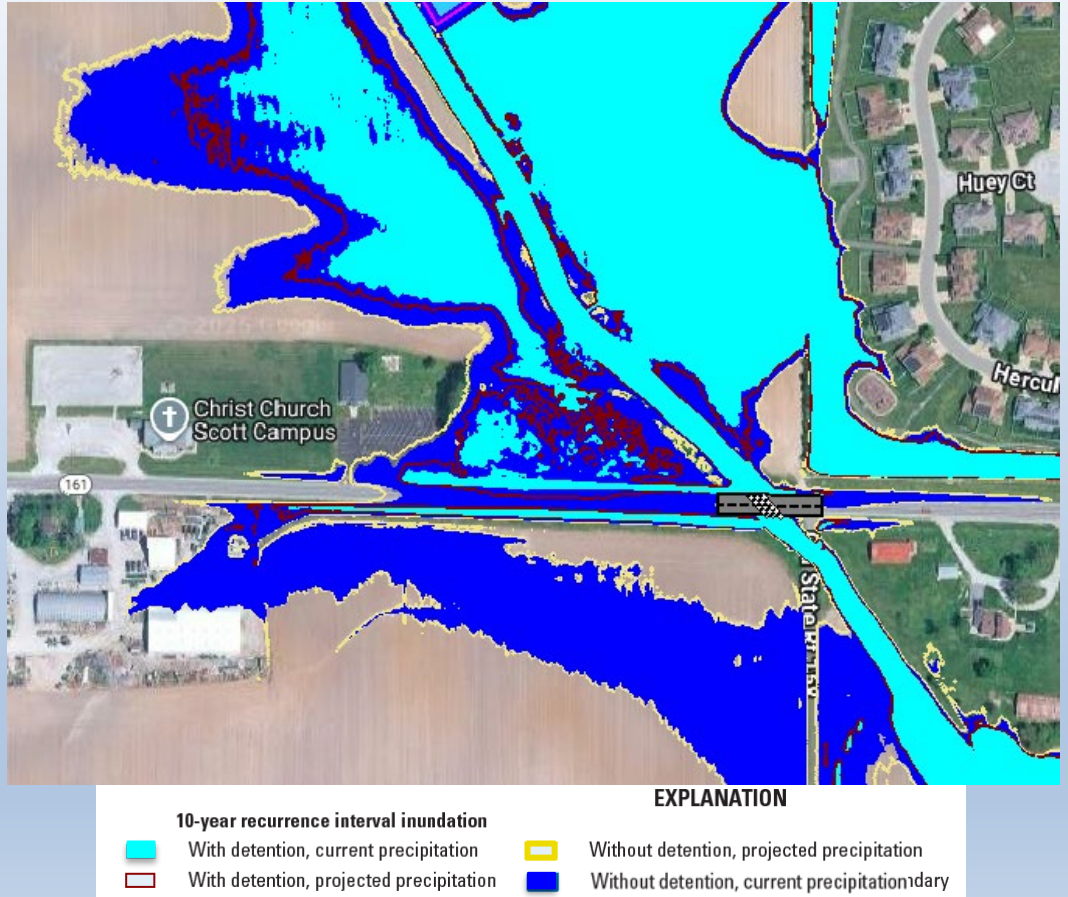
- 1 to 2-feet lower water-levels for Ash Creek from Seibert Road to Highway 161
- Highway 161 at Ash Creek is a flood prone area for this reach and serves as a major access route to Scott AFB



USGS

Flood inundation extent on Ash Creek for detention scenarios

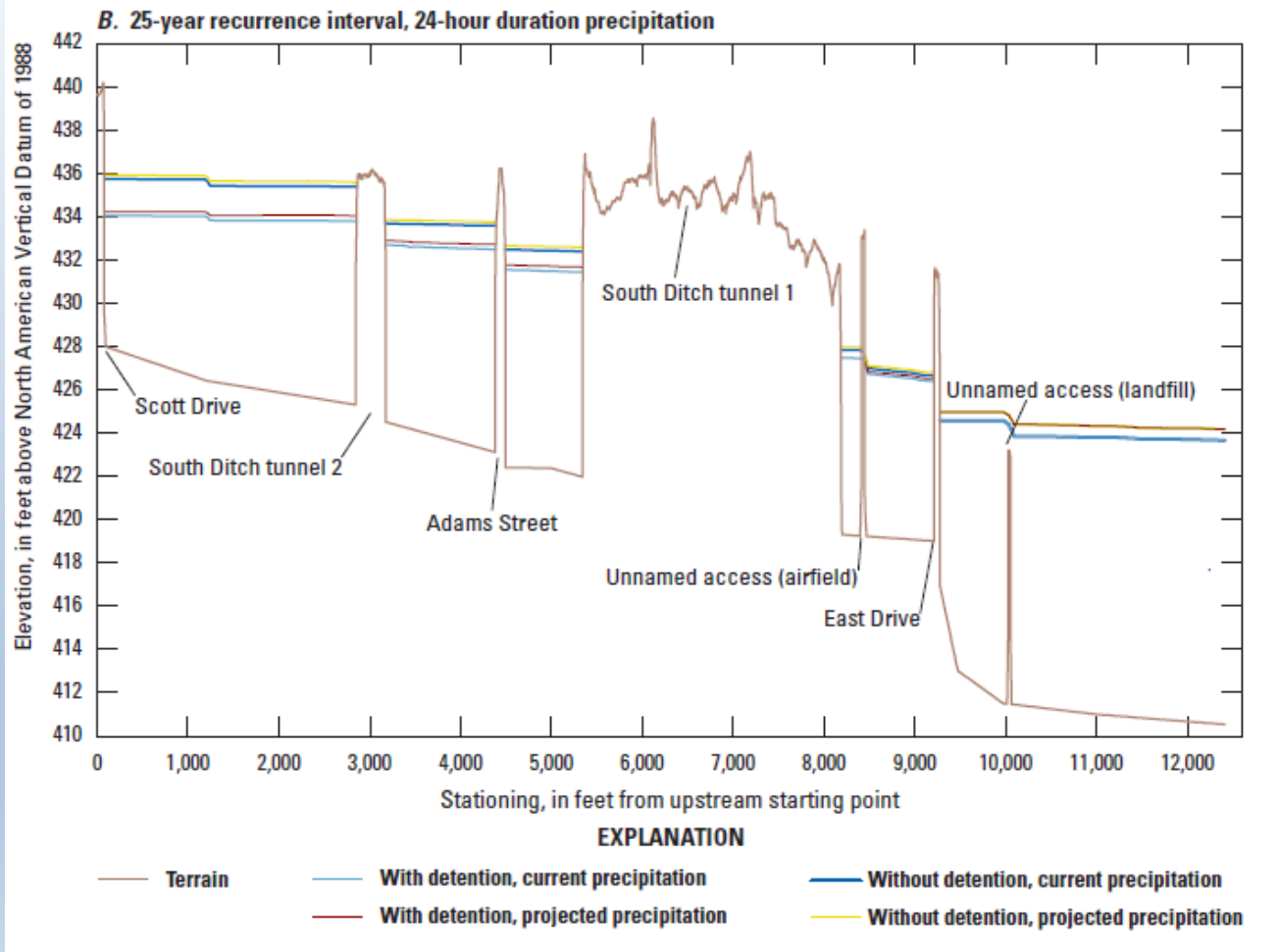
- Detention storage lowers flood inundation on local infrastructure and open areas
- Mitigates flood waters from overtopping Highway 161 for the 10-year precipitation event



USGS

Water-surface profiles on South Ditch for detention scenarios

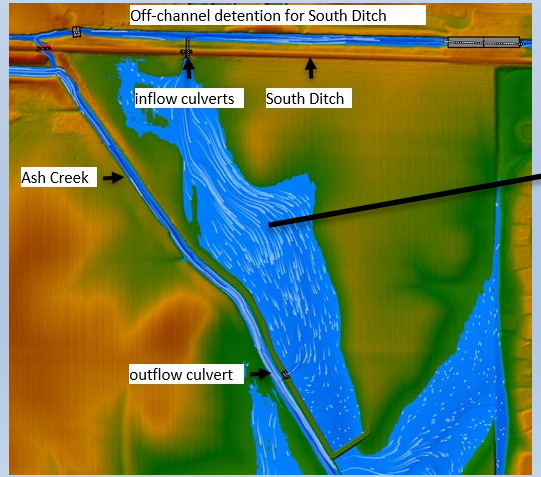
- 1 to 2-feet lower water-levels for South Ditch near Scott Drive and Adams Street with detention storage
- Less impact downstream from the South Ditch tunnel 1 (Silver Creek backwater and headloss through the structure)

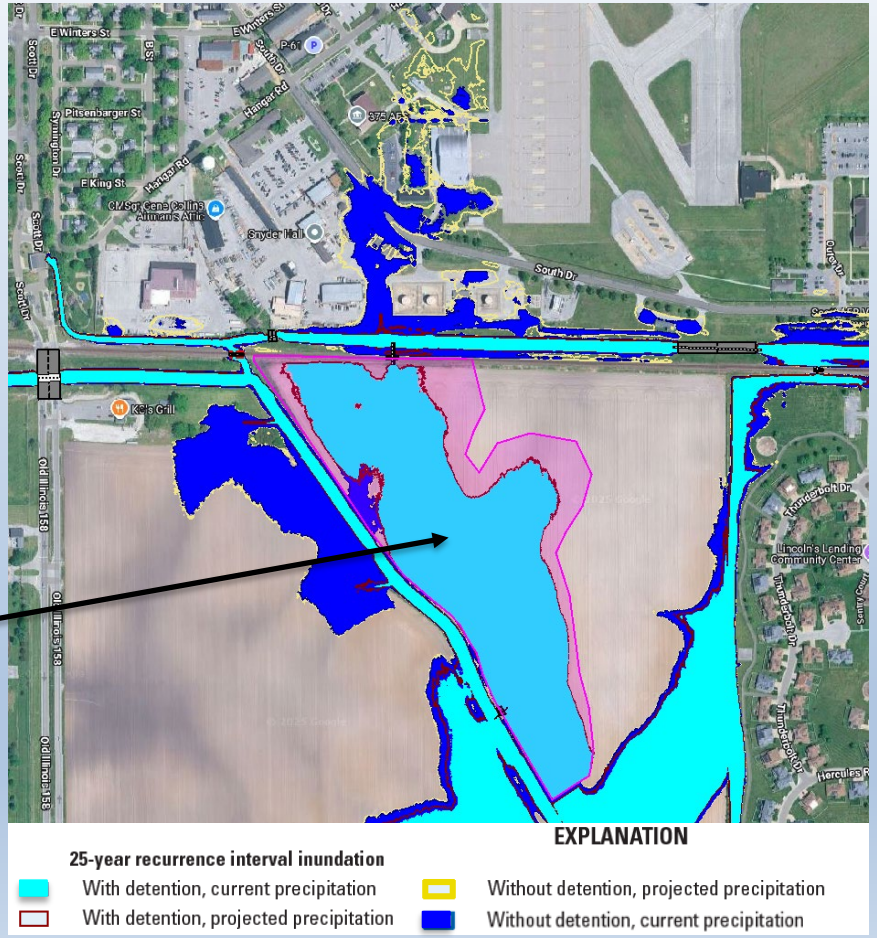


USGS

Flood inundation extent on Ash Creek and South Ditch for detention scenarios

- Detention storage can mitigate flood-inundation near South Drive and southwest of the airfield
- Detention structure for South Ditch is located on the field south of the Base

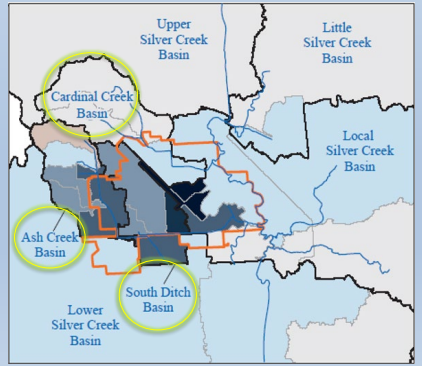


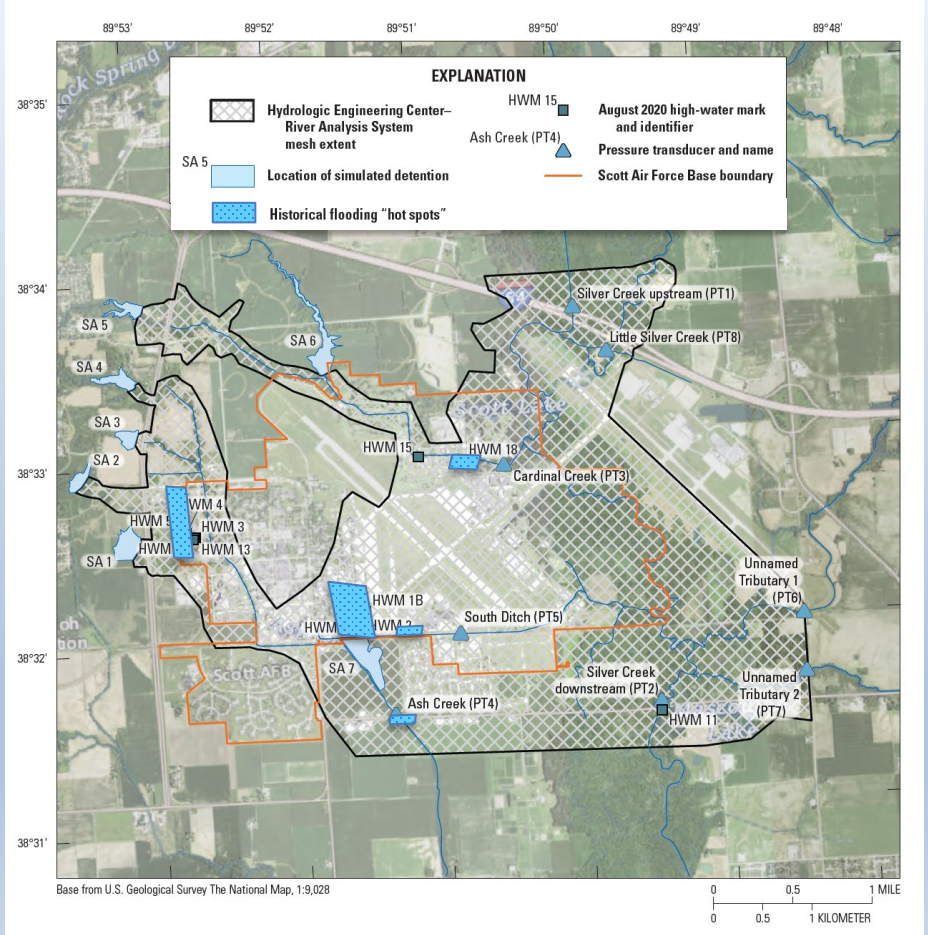


USGS

Flood inundation extent on Ash Creek and South Ditch for detention scenarios

- The effects of 7 detention structures were assessed at for 3 tributaries of Silver Creek that cause flooding on Scott AFB
- Model simulations demonstrated that flooding was mitigated at historical flooding “hot spots” for 10- and up to 50-yr recurrence interval events (depending on the location)
- The 3 tributaries include subbasins identified in the HEC-HMS model that signaled some of the largest changes in land cover and peak streamflow





USGS

Study Conclusions

Hydrologic model analysis

- Quantified changes in peak streamflows and runoff volumes from historical, current, and projected future conditions
- Identified potential areas (subbasins) with higher contributions to changes in hydrological conditions
- Simulated hydrological conditions with projected future land uses and precipitation that can be used for future watershed plans

Hydraulic model analysis

- Identified flood prone areas, what rainfall frequency events cause flooding to those areas, and the primary source of the flooding
- Assessed conceptual detention storage for flood mitigation:
  - Quantify the amount of storage needed for flood mitigation
  - Placement of detention structures in the existing terrain with current land use conditions
  - Simulating detention storage with a range of recurrence interval rainfall events to measure their effectiveness in flood mitigation

USGS