Effects of Climate Change on the Hydrologic and Hydraulic Response of the Caulks Creek Basin, Wildwood, Missouri

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Extended Abstract

The City of Wildwood, Missouri (MO), has identified fluvial erosion along Caulks Creek as a management priority due to potential effects of channel erosion on stormwater and transportation infrastructure as well as residential, recreational, and commercial property (Figure 1). Erosion along Caulks Creek has been a concern since the City's incorporation in 1995 (Bricker, 2019). More recently, the City of Wildwood has documented concerns regarding stream erosion from over 50 local residents (D. Rahn, Assistant City Engineer, written commun., May 2021) and identified specific locations along Caulks Creek (Hammer, 2020a, b; City of Wildwood, 2020). Planning for future management of Caulks Creek could be helped by understanding the potential effects of climate change on the stream. The U.S. Geological Survey (USGS), in cooperation with the City of Wildwood, has therefore undertaken a study to examine the response of Caulks Creek to design storms that represent current and predicted climate scenarios for years 2050 and 2099 using a combination of hydrologic and two-dimensional (2D) hydraulic simulations. The simulations were used to quantify the peak, volume, and timing of the flow response and the resulting distribution of velocity, shear stress, and stream power throughout Caulks Creek.

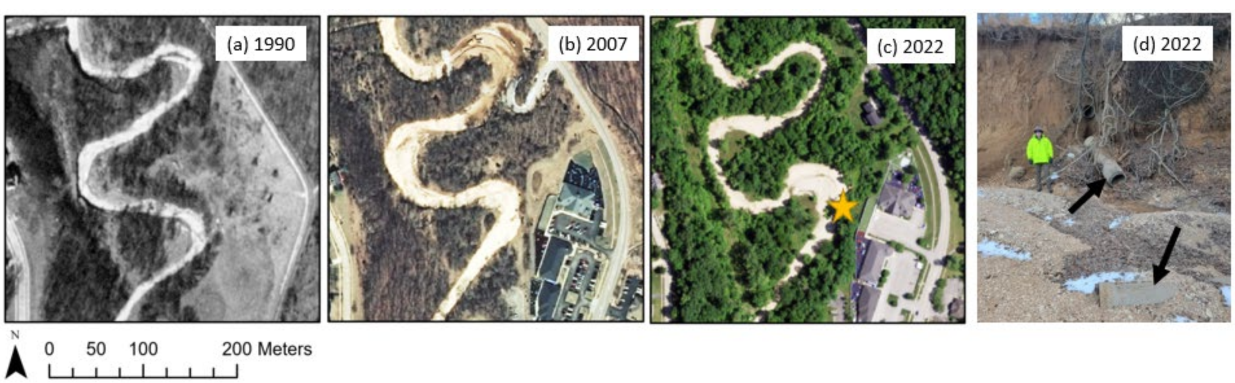

Figure 1. (a-c) Digital aerial orthophotographs of Caulks Creek showing lateral migration and channel width adjustments from 1990 to 2022 (Imagery from U.S. Geological Survey Earth Resources Observation and Science Center archive; flow is from bottom to top). In the 2007 image, the northeast cut bank is being laid back and covered with rip-rap to prevent further erosion toward a road. (d) Sections of a stormwater runoff pipe (indicated with black

arrows) have collapsed into the channel as the bank is eroded at the location of the gold star in the 2022 aerial image (Photograph by Jessica LeRoy, U.S. Geological Survey).

The Caulks Creek basin (Figure 2) is in western St. Louis County along the edge of the Ozark Plateau. The drainage area of Caulks Creek is 17.1 square miles (mi^2) at USGS streamgage 06935830 (Caulks Creek at Chesterfield, MO) and 19.3 mi^2 at its confluence with Bonhomme Creek (USGS, 2019). At the USGS streamgage Caulks Creek at Chesterfield, MO (06935830), the mean annual flow was 23 cubic feet per second (cfs) for water years 1997 to 2015 (Granato and others, 2017). A water year is the period from October 1 to September 30 and is designated by the year in which it ends; for example, water year 2015 was from October 1, 2014, to September 30, 2015. Annual peak flows at USGS 06935830 range from 1,120 to 7,940 cfs for the period of record (water years 1972 to 1979 and 1997 to 2022; USGS, 2023). Prior to development, the Caulks Creek basin was characterized by steep, forested slopes with relief on the order of 150 feet (ft) (Hammer, 2020a). A wave of suburban development occurred in the 1990's and by 2001, nearly 19% of the Caulks Creek basin was covered with impervious surfaces (USGS, 2019). Stream incision and widening followed development in the Caulks Creek basin—in some reaches an increase in channel cross-sectional area from 40–100 square feet (ft^2) to more than 800 ft^2 has been observed (Hammer, 2020a).

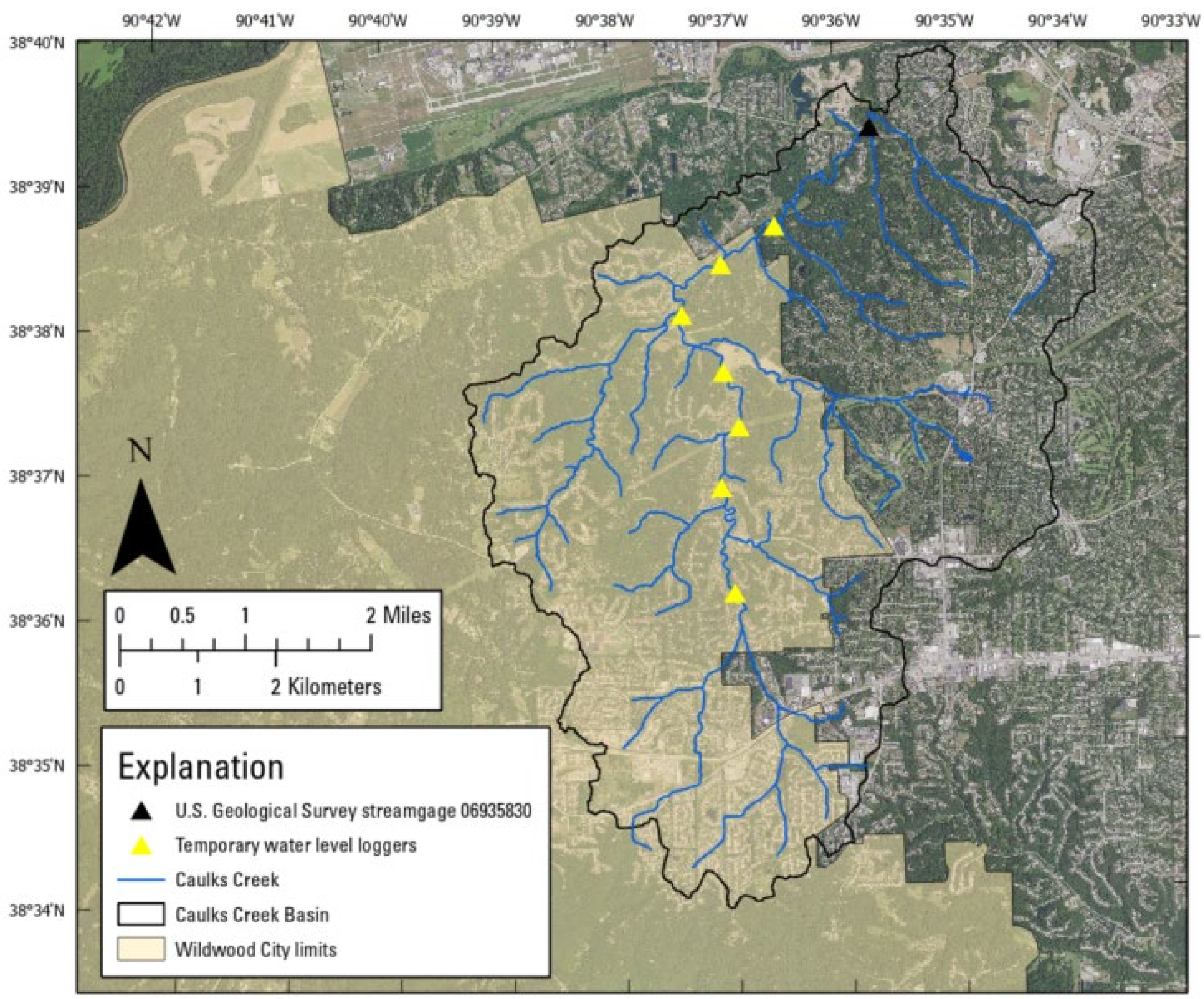

Figure 2. Study area map, flow in Caulks Creek is from bottom to top (2020 digital aerial orthophotograph from the U.S. Department of Agriculture National Agriculture Imagery Program).

An existing Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model of the Caulks Creek Basin and an existing one-dimensional steady-state Hydrologic Engineering Center River Analysis System (HEC-RAS) model of Caulks Creek were provided by Wood Environment & Infrastructure Solutions, Inc., for use in this study. The furnished HEC-HMS model uses the Natural Resources Conservation Service curve number method for runoff estimation (USDOT, 2021), the Clark (1945) unit--hydrograph transformation method, and the Muskingum-Cunge method (Cunge, 1969) for routing. The HEC-HMS model terrain was updated to the 2017 USGS 3D Elevation Program 1-meter digital elevation model (USGS, 2022). The channel cross-sections in the reaches upstream from USGS 06935830 were also updated based on field surveys and recent aerial imagery. There are five reservoirs in the basin, which were updated with new measurements of reservoir outlet dimensions and elevations. Additionally, the HEC-RAS model was updated with field-surveyed channel bathymetry measurements and converted to a 2D unsteady model, with inflow boundary condition lines corresponding to the subbasin junctions in the HEC-HMS model.

The HEC-HMS and 2D unsteady HEC-RAS models were run iteratively for calibration and validation to make use of the superior streamflow routing in the hydraulic model. Calibration simulations for four historic storm events were run using gridded Multi-Radar Multi-Sensor data for precipitation inputs (Zhang and others, 2011). The simulated streamflow and water levels were compared to observations at USGS 06935830 and seven temporary water level loggers along the study reach (only available for events in 2022, Figure 2). During calibration, the time of concentration and storage coefficient values in the HEC-HMS model and the Manning's n value in the HEC-RAS model were manually adjusted. Three additional simulations were used to validate the selected parameters. The results of the calibration and the validation simulations were evaluated using the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) and the percentage bias (Gupta and others, 1999).

After calibration and validation, HEC-HMS and 2D unsteady HEC-RAS simulations were run for 30 design storms, each with a 6-hour duration, using curve number three (CNIII) values (wet antecedent response conditions). CNIII values were used for this set of simulations as this set represents a "worst-case" scenario in terms of the hydrologic response and potential fluvial erosion effects. Design storms for current climate conditions were obtained from the National Oceanographic and Atmospheric Administration (NOAA) Atlas 14 Frequency Estimates (NOAA, 2013) accessed via the Precipitation Frequency Data Server (NOAA, 2022). Predictions of future climate (years 2050 and 2099) were obtained from the U.S. Department of Transportation (USDOT) Coupled Model Intercomparison Project Climate Data Processing Tool for representative concentration pathways (RCP) 4.5 and 8.5 (USDOT, 2020). RCP 4.5 is considered an intermediate climate change scenario and RCP 8.5 is considered a "worst-case" climate change scenario. The predictions for years 2050 and 2099 indicate greater precipitation totals compared to current climate conditions for a given design storm. The 6-hour design storms modeled in this study included all combinations of recurrence intervals (annual exceedance probability in parentheses): 2-year (0.5), 5-year (0.2), 10-year (0.1), 25-year (0.04), 50-year (0.02), and 100-year (0.01); and climate scenarios: current climate, 2050-RCP 4.5, 2050-RCP 8.5, 2099-RCP 4.5, and 2099-RCP 8.5.

The results of the HEC-HMS and HEC-RAS simulations were examined to determine the potential effects of climate change on the peak discharges and the distributions of velocity, shear stress, and stream power throughout the stream. Particular focus will be given to known areas of concern identified by the City of Wildwood (Hammer, 2020a, b; City of Wildwood, 2020). A complementary study monitoring bank erosion in these areas of concern is ongoing. Ongoing work that is outside the scope of this presentation includes additional simulations with normal antecedent response conditions (curve number 2) as well as the effect of added detention/retention storage within the basin.

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