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Watershed Impact Analysis: Effects of Urbanization on the Cottonwood Creek, CA Watershed

Sacramento & San Joaquin River Basins Comprehensive Study

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14. ABSTRACT

During the Sacramento and San Joaquin River Basins Comprehensive Study, it became apparent that there was interest in quantifying the effect of changed land use on the hydrology of a watershed. The U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) was tasked to study the impact that future land use changes had on stream flows. This work was performed to compliment the Sacramento and San Joaquin River Basins Comprehensive Study performed by the Sacramento District (CESPK).

The impact of urbanization on the hydrologic response of watersheds was evaluated using the HEC's Hydrologic Modeling System (HEC-HMS). HEC-HMS provides a variety of options for simulating precipitation-runoff processes. Hydrologic models previously developed by HEC for the Comprehensive Study were used to study hypothetical land use changes resulting from watershed urbanization. Numerous build-out scenarios for the Cottonwood Creek watershed were modeled by varying the amount of impervious surface in the watershed. The increased impervious surface area would limit the amount of infiltration. Stream-flow hydrographs were computed from several rainfall events for each hypothetical land use change. Peak flow and runoff volume were used to quantify the hydrologic impact of urbanization to the watershed.

Results were consistent with hydrologic principles and modeling assumptions. Increased impervious area leads to a decrease in area available for initial and constant losses; thereby increasing the quantity of flow. Further, the general trend of a decreased affect for the extreme probability events supports the concept that for large rainfall volumes, initial and constant losses will have less impact because their losses are not substantial compared to the precipitation volume.

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Comprehensive Study

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Watershed Impact Analysis: Effects of Urbanization on the Cottonwood Creek, CA Watershed

Sacramento and San Joaquin River Basins Comprehensive Study

Introduction

Purpose

During the Sacramento and San Joaquin River Basins Comprehensive Study's F3 conference, held in October 2000, it became apparent that there was interest in quantifying the effect of changed land use on the hydrology of a watershed. As an outcome of that meeting, the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) was tasked to study the impact that future land use changes had on stream flows. This work was performed to compliment the ongoing Sacramento and San Joaquin River Basin's Comprehensive Study performed by the Sacramento District.

Intuitively, it was thought that land use change represented by an increase in impervious area, similar to what might be expected from increased urbanization, would noticeably increase the peak flows and volumes for the more frequent events but not for the extreme probability events. For the less frequent events, the volume of rainfall would be significantly large to overwhelm loss mechanisms such as infiltration regardless of the pervious surfaces. However, stakeholders from the Comprehensive Study wanted the effects of urbanization quantified.

Procedure

The impact of urbanization on the hydrologic response of watersheds was evaluated using HEC's Hydrologic Modeling System (HEC-HMS). HEC-HMS provides a variety of options for simulating precipitation-runoff processes. Hydrologic models previously developed by HEC for the Comprehensive Study were used to study hypothetical land use changes resulting from watershed urbanization. Numerous build-out scenarios for the Cottonwood Creek watershed were modeled by varying the amount of impervious surface in the watershed. The increased impervious surface area would limit the amount of infiltration. Stream-flow hydrographs were computed from several rainfall events for each hypothetical land use change. Peak flow and runoff volume were used to quantify the hydrologic impact of urbanization to the watershed.

Assumptions

It was assumed that the effect of urbanization on the watershed would not impact the timing of peak flows. That is to say, it was assumed that stormwater management practices associated with land use development such as regional detention facilities would incorporate measures to mitigate against decreased times of concentration. While this assumption addresses the effect of overland flow issues, it does not consider changes to peak timing associated with channel routing. The effects to flow routing were beyond the scope of this work and were not directly addressed. However, it was also assumed that the natural channels and their floodplains would not be altered. Therefore, the routing criteria would not be significantly changed. In addition, as noted above, it was assumed that for low frequency events the peak flows would not be greatly affected; therefore, consideration of new routing parameters would not be required.

Cottonwood Creek

The Cottonwood Creek study area consists of 945 square miles in the northwest portion of the Sacramento River Watershed. Its confluence with the Sacramento River is near Cottonwood, CA (Figure 1). The Cottonwood Creek basin was intended to be a demonstration watershed. There are no known plans to urbanize the watershed to the degree proposed in this study. Rather this study is intended to represent a generic basin that would be experiencing increased urbanization and to study the impacts on the basin hydrology. The Cottonwood Creek watershed was selected for this study primary because (1) the watershed is unregulated, so assumptions about reservoir operations would not impact the study; (2) calibrated rainfall-runoff models existed for the basin for two rainfall events; (3) sufficient initial and constant loss rates were used in the calibrated hydrology models, so that the impact of increased impervious areas on runoff could be demonstrated; and (4) adequate rainfall and snowmelt runoff data was available for the events considered.

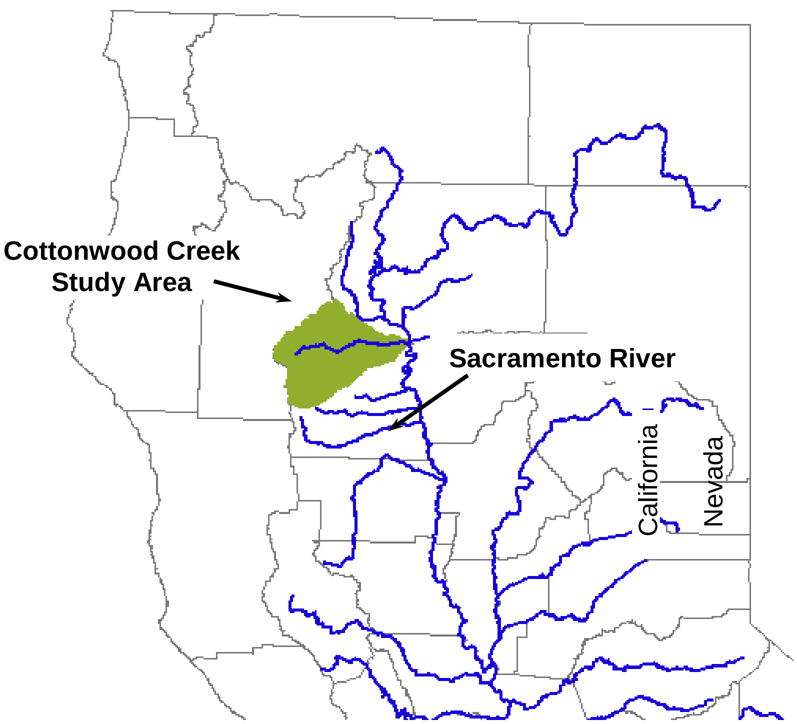

Figure 1. Location of Cottonwood Creek watershed.

Calibrated hydrology models using the March 1995 and January 1997 precipitation events were used. These models were calibrated as part of HEC's hydrologic modeling for the Sacramento and San Joaquin River Basins Comprehensive Study (HEC, 2001). Calibration of the events was performed using observed hydrographs recorded at the Cottonwood, CA gage operated by the USGS (gage 113760000). Calibrated hydrographs for the 1995 and 1997 are shown in Figure 2 and Figure 3, respectively. The 1995 and 1997 events were identified as the 20 percent chance exceedence and 12.5 percent chance exceedence events, respectively. (Sacramento District, 2000).

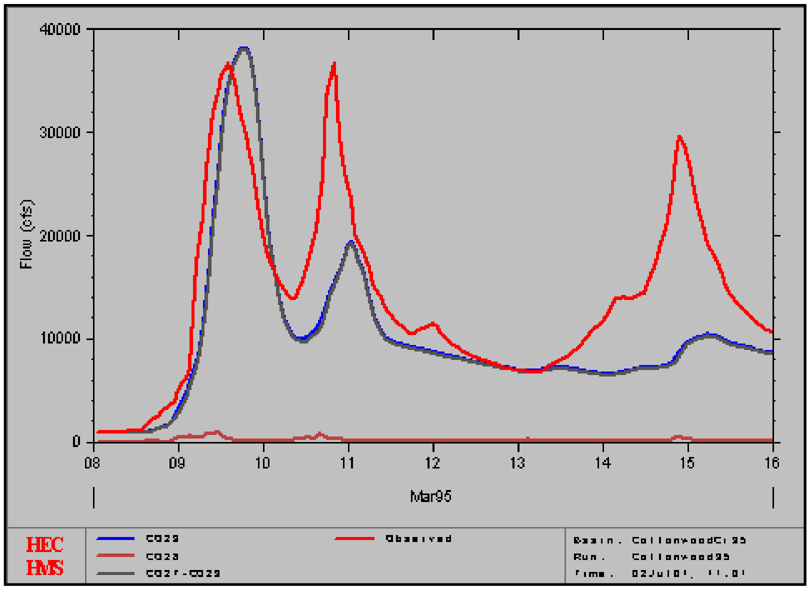

Figure 2. Calibration for Cottonwood Creek: 1995 event.

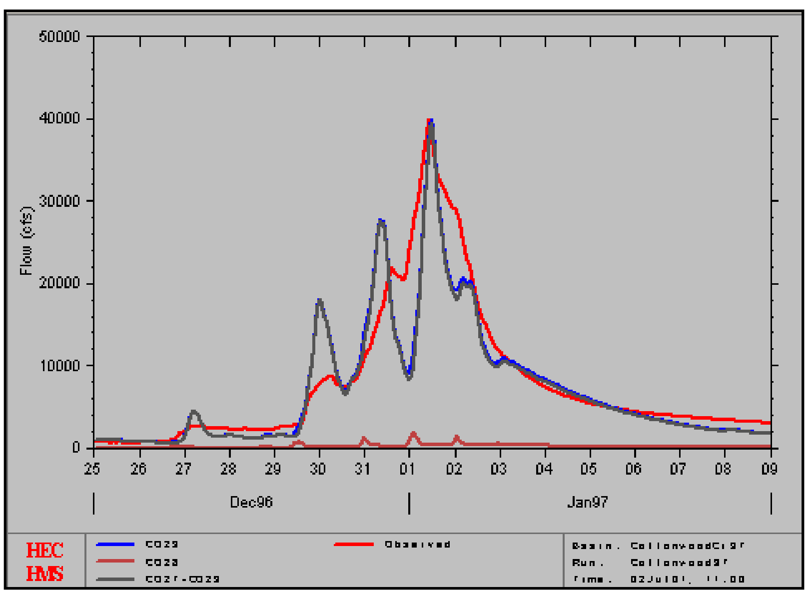

Figure 3. Calibration for Cottonwood Creek: 1997 event.

The HMS basin model for Cottonwood Creek (Figure 4) was comprised of fourteen subbasins ranging in size from 29.8 to 135.6 square miles. Calibrated initial and constant losses differed for the 1995 and 1997 events. They differed because the computed hydrographs were calibrated by adjusting the loss and routing parameters so that the computed runoff volumes and peak flows matched those observed at the Cottonwood Creek gage. For the 1995 event, initial and constant losses were 0.8 inches and 0.08 inches per hour, respectively. For the 1997 event, initial and constant losses were 1.0 inch and 0.05 inches per hour, respectively. Because the vast majority of the watershed is undeveloped and forested, the percent impervious area was chosen to be zero percent for both events.

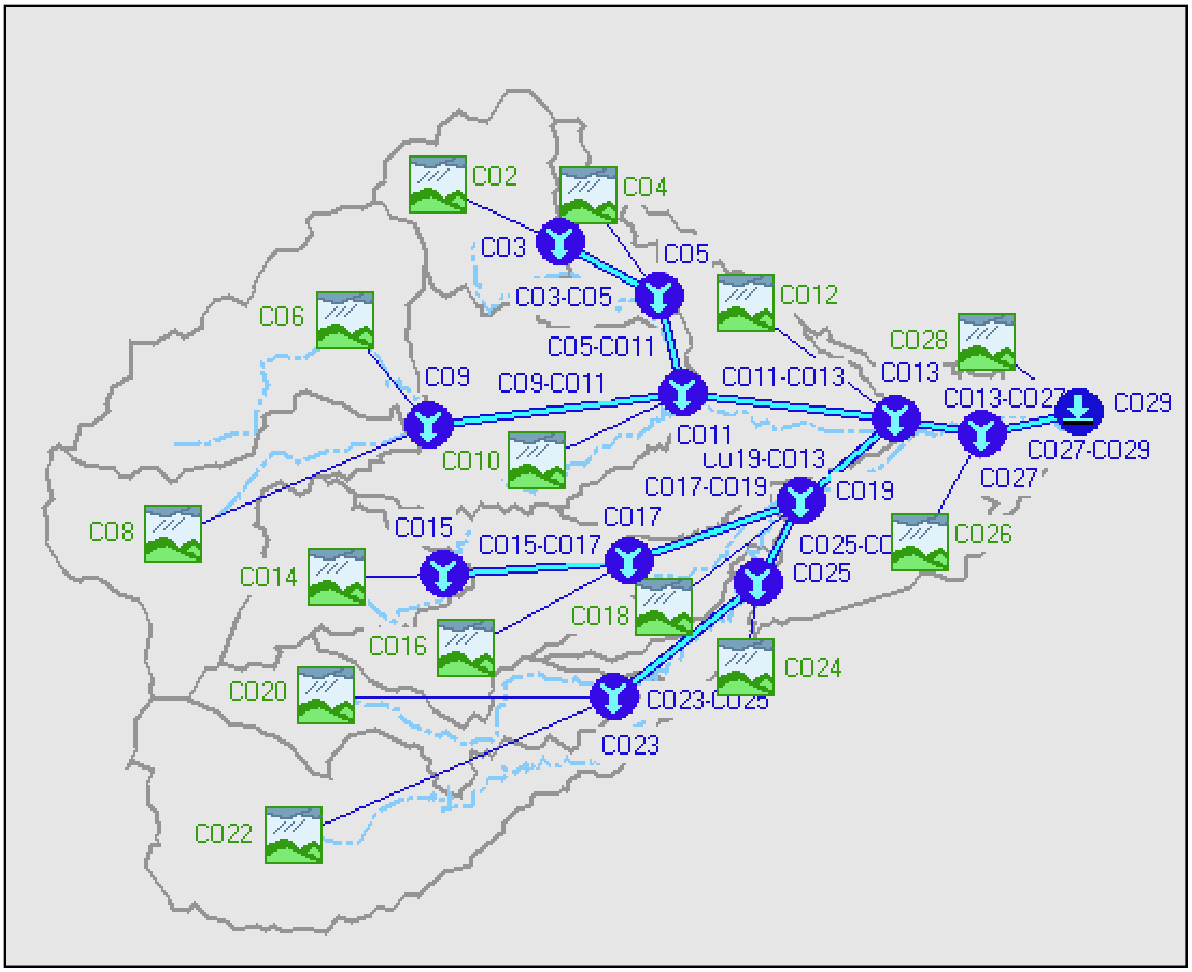

Figure 4. HMS model setup for Cottonwood Creek.

Procedure

Hydrologic modeling for the Cottonwood Creek watershed was performed using HEC-HMS to simulate hypothetical land use development. The effect of urbanization was modeled by varying the percentage of imperviousness and the amount of impervious area in the watershed. Twenty-seven different land use scenarios were then run with three different rainfall events. Runoff hydrographs were computed for each scenario and the peak flow and volume were identified at the watershed outlet.

Watershed Definition

The 945 square mile watershed was separated into three distinct regions: lower, middle, and upper (Figure 5). An attempt was made to make three equal-area regions by organizing and combining the fourteen subbasins from the existing hydrologic models; however, the outcome resulted in 269 square miles (29 percent) in the lower region, 346 square miles (36 percent) in the middle region, and 330 square miles (35 percent) in the upper region. The watershed was broken up into separate regions to model the spatial distribution of urbanization throughout the watershed (i.e., would it make a difference if the urbanization occurred in the lower, middle, or upper portion of the watershed).

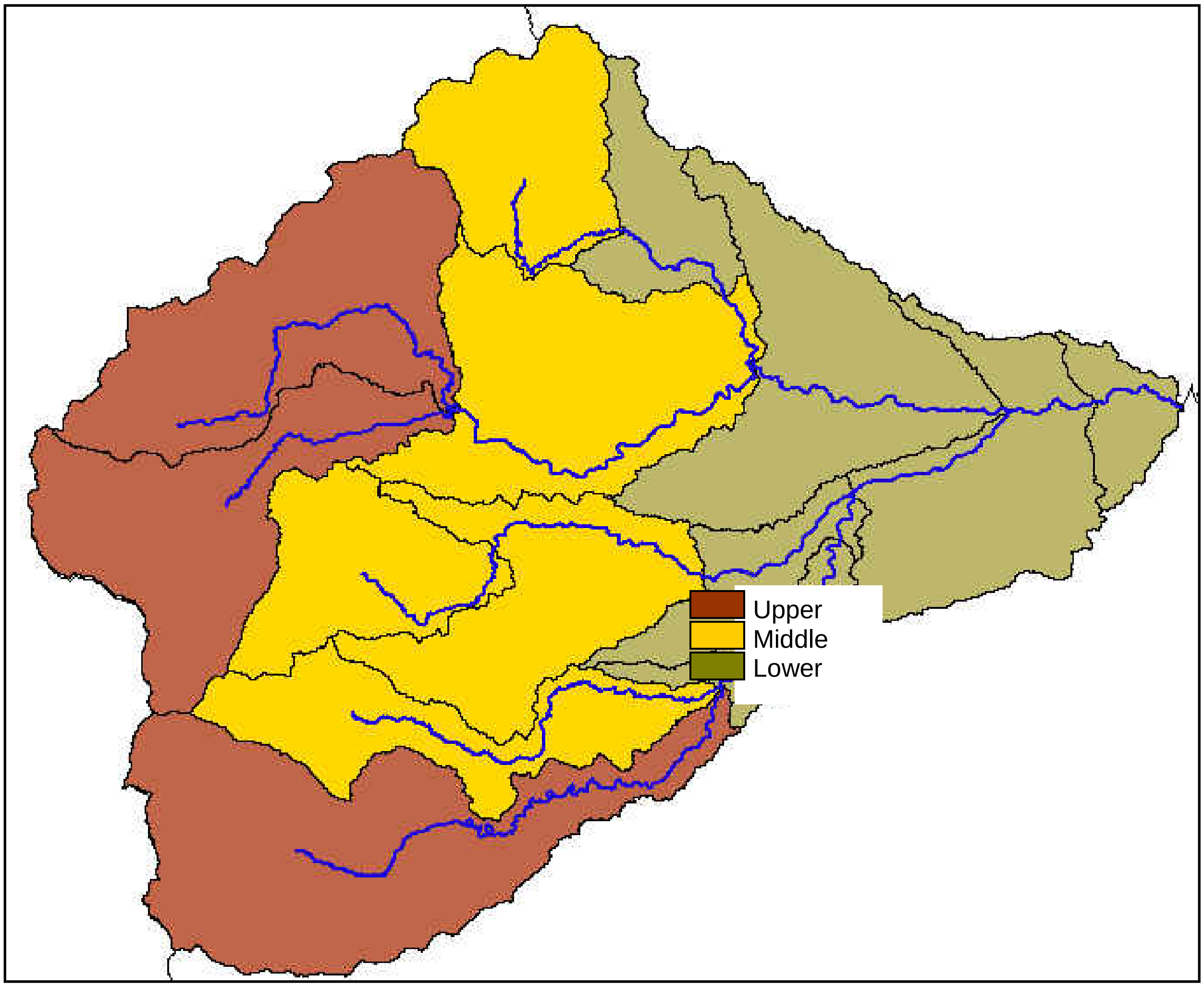

Figure 5. Cottonwood Creek separated into three separate regions; lower, middle, and upper.

Percent Imperviousness

Urbanization of the watershed was modeled in two ways. First, by varying the percent of imperviousness on a region by region basis and second, by increasing the area impacted by the urbanization for each region. Percent imperviousness values used were 10 percent, 25 percent, and 50 percent. These values are sited values for average percent impervious area for urbanization of small watersheds (Soil Conservation Service, 1986). The 10 percent imperviousness was used to model residential homes on larger lots (two acres), while the 25 percent imperviousness was used to model residences with a smaller lot size (half acre). High density build-out conditions were modeled using 50 percent imperviousness area for residences built on small lots (1/8 –1/4 acre) with community parks, natural areas, and commercial areas incorporated into the land use conditions.

The percent imperviousness values were then incrementally applied to each region in one-third increments. Therefore, for each region (lower, middle, and upper) 10 percent, 25 percent, and 50 percent imperviousness values were applied to one-third, two-thirds, and three-thirds of each region to provide a range of land use development scenarios.

Table 1. Percent imperviousness values used for urbanization.

Impervious Area[1]	Urbanization	Description
10%	Low	Residential homes on 2+ acre lots
25%	High	Residential homes on 1/2 acre lots
50%	Very High	High density residential homes on 1/8 to 1/4 acre lots with parks, natural areas and commercial areas

[1]Values adapted from TR-55

Precipitation

Three precipitation events were considered for this study. Precipitation in the form of gridded records were applied to the study area based on the March 1995 event, January 1997 event, and a hypothetical event that was double the 1997 event. These rainfall events produced a peak flow that correspond to the approximate 20 percent, 12.5 percent, and 1 percent chance events, according to published data (Sacramento District, 2000).

The hypothetical event was constructed to create a less frequent rainfall event so that HEC could evaluate the hydrologic impact for a larger rainfall. As noted in the introduction, it was assumed that an increase in impervious surface would have a greater impact for the more frequent events than for the less frequent events. With the 1995 and 1997 events representing the 20 percent and 12.5 percent chance events, a less frequent event had to be developed. Therefore, arbitrarily doubling the 1997 rainfall led to an outflow hydrograph comparable to a 1 percent chance exceedence event if the 1997 event model parameters were used.

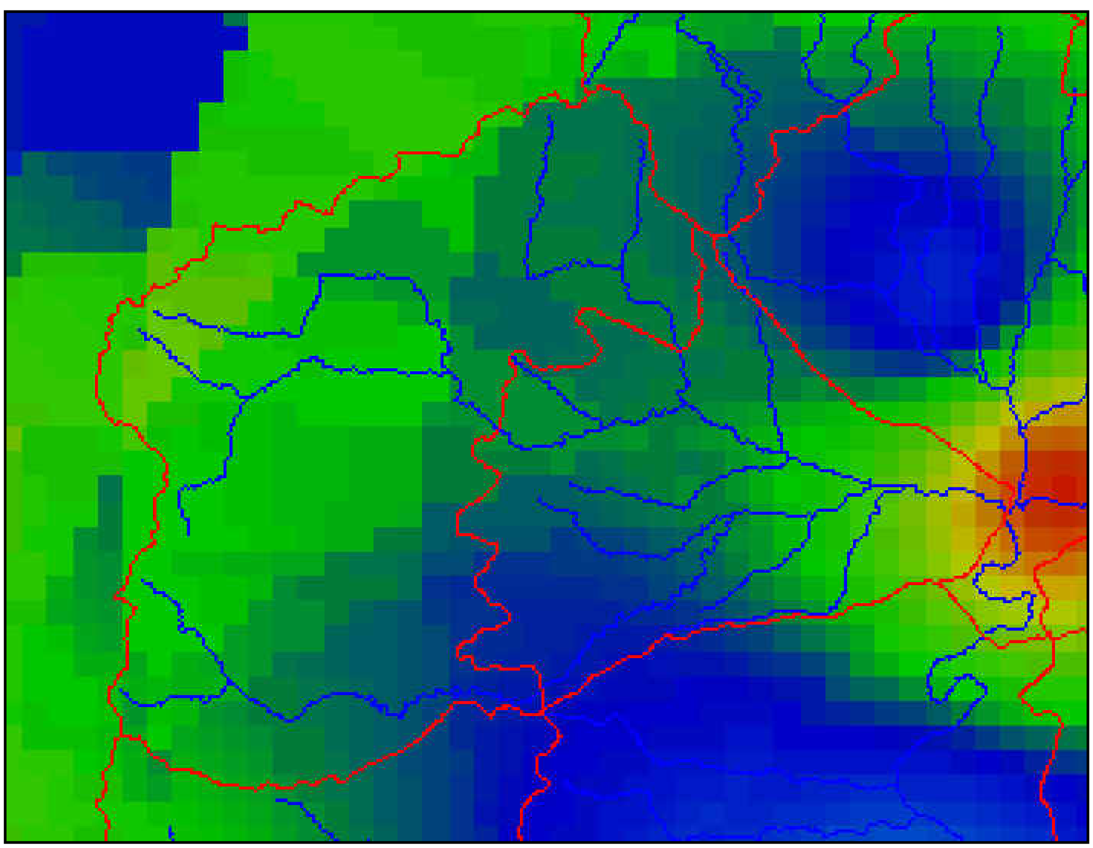

Figure 6. Example rainfall distribution for the Cottonwood Creek watershed.

Results

As anticipated, an increase in land use development, as represented by increased impervious area, resulted in an increase in peak flow and runoff volume from the watershed for all precipitation events. Peak flows were not affected as significantly as the runoff volumes. The effect of urbanization on the watershed had the greatest impact on higher frequency events and the greatest impact was observed from changes to the middle region.

The greatest hydrologic response was consistently computed when changing the percent impervious area in the middle region. Several factors may have led to this response. These include: region area, rainfall intensity, and coincident hydrographs. The middle region was slightly larger than the upper region and significantly larger than the lower region. Rainfall intensity varied between events throughout the study area. Lastly, the timing of the increased hydrographs from the middle region may have combined with the others in the watershed to develop a larger peak. Further study of the individual watershed characteristics would be necessary to determine the importance of each of these factors. The purpose of this preliminary study was not to answer why an increase in runoff would occur, rather it was to answer whether it occurred or not.

March 1995 Event

The March 1995 event was considered to be a 20 percent chance exceedence event. This was the smallest event modeled, and yet the affect of urbanization had the greatest impact on the hydrologic response. Peak flows (Figure 7) were increased 22 percent while volumes (Figure 8) increased by 36 percent when 50 percent imperviousness was applied across the entire middle region of the watershed.

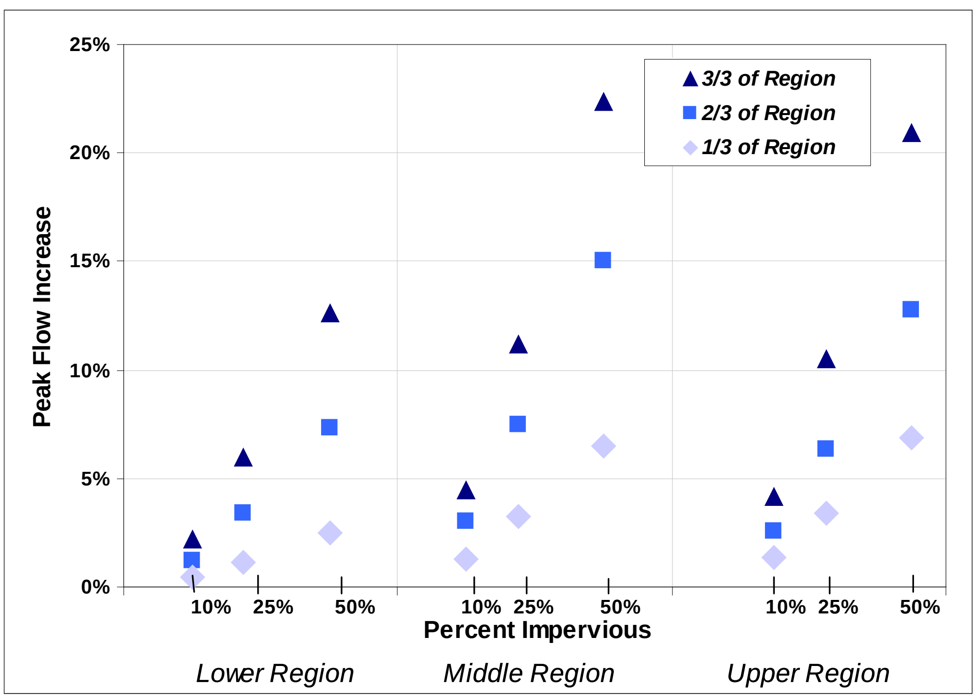

Figure 7. Effect of urbanization on peak flow: March 1995 event.

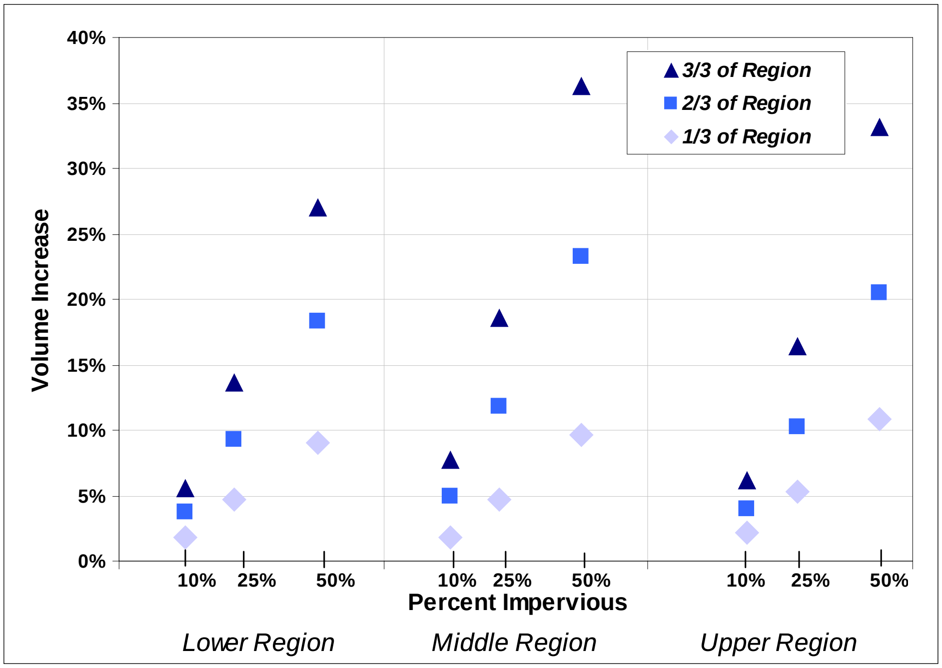

Figure 8. Effect of urbanization on volume: March 1995 event.

January 1997 Event

The January 1997 event was considered to be a 12.5 percent chance exceedence event. Peak flows (Figure 9) increased by 10 percent and volumes (Figure 10) increased by 25 percent when 50 percent imperviousness was applied across the entire middle region.

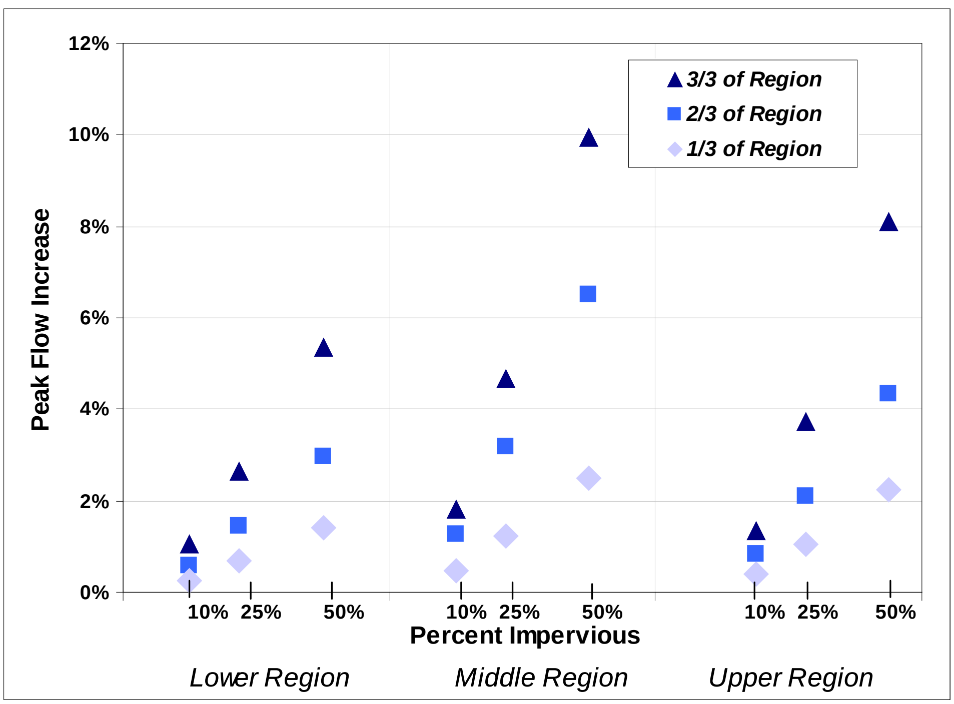

Figure 9. Effect of urbanization on peak flow: January 1997 event.

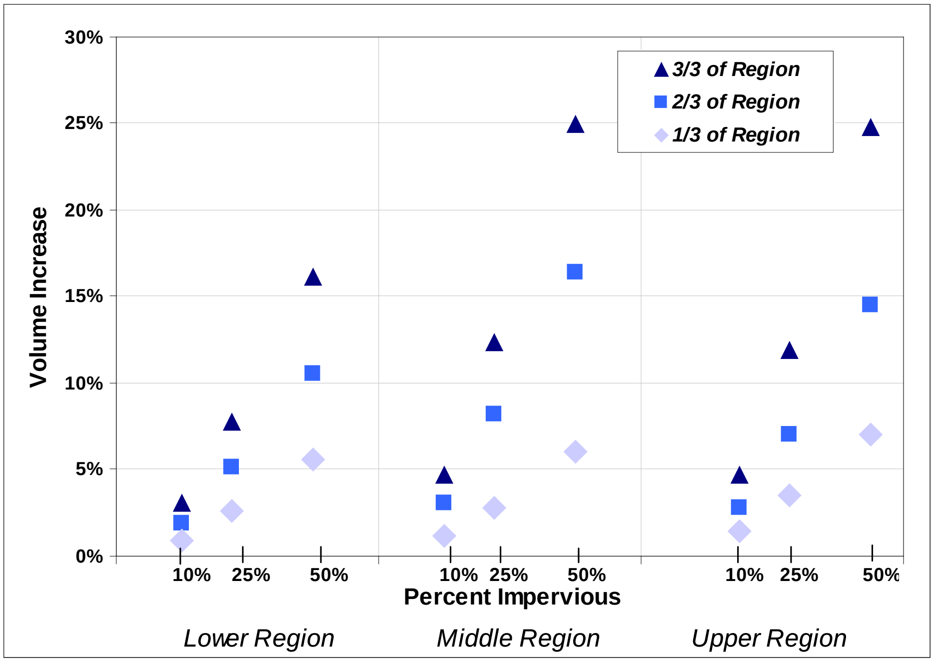

Figure 10. Effect of urbanization on volume: January 1997 event

Hypothetical Event

The hypothetical event was considered to be approximately a 1 percent chance exceedence event. The precipitation was derived from doubling the 1997 precipitation. As expected, the affect of urbanization on the hydrologic response on the watershed was the smallest for the hypothetical event with the increase to the peak flow (Figure 11) less than 4 percent and the increase to flow volume of 9 percent.

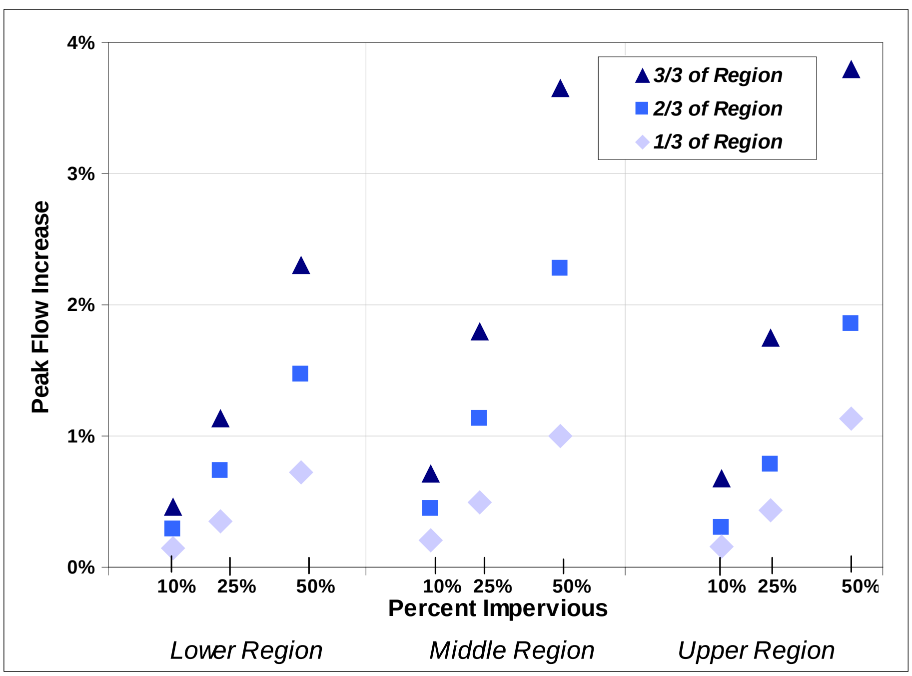

Figure 11. Effect of urbanization on peak flow: hypothetical event.

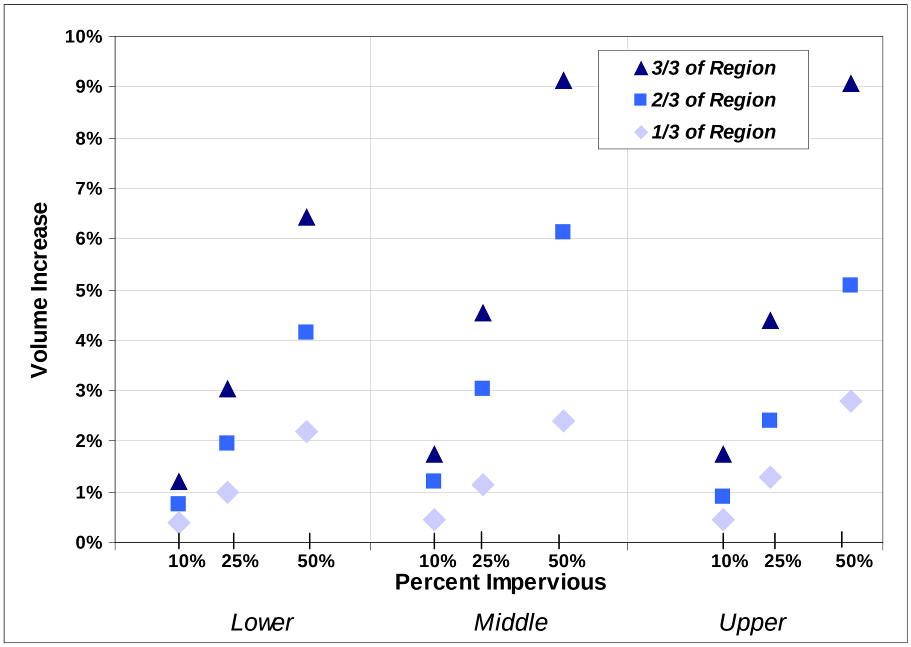

Figure 12. Effect of urbanization on volume: hypothetical event.

Conclusions

Modeling the effects of urbanization by increased impervious area and increased percentage of imperviousness resulted in increased peaks and volumes of flow from the Cottonwood Creek watershed. The maximum increase in peak flow and volume were calculated to be 34 percent and 22 percent, respectively, for the 1995 event. The maximum hydrologic response (Figure 13) was observed for the most frequent precipitation event with the general trend indicating a reduction in the affects of urbanization for the infrequent precipitation events.

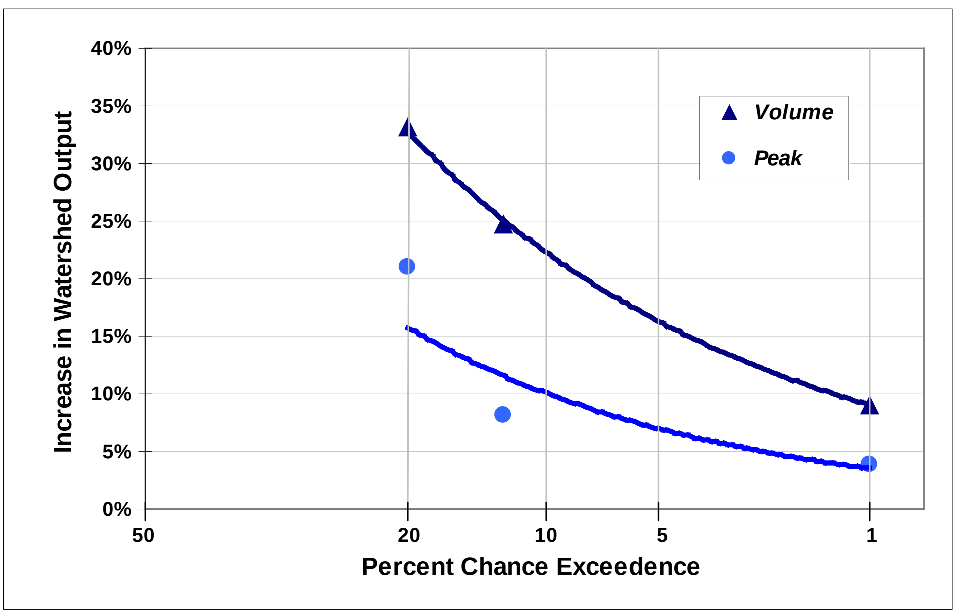

Figure 13. Impact to the hydrologic response of a watershed due to urbanization.

These results are consistent with hydrologic principles and modeling assumptions. Increased impervious area leads to a decrease in area available for initial and constant losses; thereby increasing the quantity of flow. Further, the general trend of a decreased affect for the extreme probability events supports the concept that for large rainfall volumes, initial and constant losses will have less impact because their losses are not substantial compared to the precipitation volume.

This study did not implement stormwater management practices to mitigate for localized increases in peak flows and volumes. Issues concerning combining of hydrographs and peak flows from decreased basin concentration times were also not addressed.

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TP-161 Corps Water Management System - Capabilities and Implementation Status
TP-162 Watershed Impact Analysis: Effects of Urbanization on the Cottonwood Creek, CA Watershed - Sacramento & San Joaquin River Basins Comprehensive Study