URBANIZING WATERSHEDS AND CHANGING RIVER FLOOD DYNAMICS: IMPLICATIONS FOR URBAN WETLAND RESTORATION

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Abstract. Urbanization alters river hydrology, morphology, water quality, and habitat and ecology. Most of these associated changes are due to an increase in impervious surface cover (ISC) throughout the watershed. But the spatial location of urban areas within the watershed also greatly influences river hydrology. As river hydrology changes, functions and structure of riverine wetlands associated with the hydrology may be impacted. In order to increase the long-term success of wetland restoration attempts within an urbanizing environment, it is necessary to quantify potential impacts to the wetlands as hydrology continues to change. This study investigated the effects of increased ISC on stream hydrology between 1972 and 1995 for a sub-watershed located north of Dallas, Texas. Moving window and FRAGSTATS analyses calculated the degree and location of ISC throughout the basin, and U.S. Geologic Survey stream-gauge data were analyzed to determine changes in steam hydrology between the 2 time periods. Average ISC for the watershed increased from 2 to 11% between 1972 and 1995, but highest cover (50–80%) occurred along the southern and eastern borders. Annual river flooding frequency and duration doubled between 1972 and 1995, and flooding velocity increased from 31.4 to 35.4 m3/sec. Wetland restoration attempts within the watershed should address the potential for future hydrologic changes as ISC continues to increase.

Key words: urbanization; impervious surface cover; wetlands; wetland restoration; hydrologic regime

INTRODUCTION

The process of urbanization impacts streams in many ways that include alterations to hydrology, morphology, water quality, and habitat and ecology (Schueler 1992). Changes to these stream attributes are caused by an increase of impervious surface cover (ISC) associated

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with the process of urbanization. With increasing ISC, soil water infiltration decreases, which increases surface runoff. The degree of urban surface runoff is typically proportional to the amount of ISC. For example, as ISC reaches 10–20% within a catchment basin, runoff increases twofold; 35–50% ISC causes a threefold increase in runoff; and 75–100% ISC increases surface runoff more than fivefold over forested regions (Arnold and Gibbons 1996).

The increased runoff associated with urbanization affects stream hydrology in many ways. The time lag between the center of the precipitation event to the center of the peak flow discharge decreases as urbanization increases (Espey et al. 1965). Stream velocity and the associated erosive forces increase, as do the magnitude and frequency of flooding events (Schueler 1992).

Although the degree of urbanization, as measured by the percent cover of impervious surface cover, is one of the most important factors determining stream hydrography, the location of urbanization within the watershed also plays an important role. Sheeder et al. (2002) found dual urban and rural hydrograph peaks based on the degree and spatial location of urbanization within the watershed. The first peak is a result of drainage from the urban area followed closely by drainage from the rural area. Although not addressed in the article, flood duration may increase as a result of the two flooding peaks occurring consecutively. Hirsch et al. (1990) theorize that if lower reaches of a basin become urbanized with little development in the upper basin, water from the lower urban portion could drain before the arrival of water from the upper portion, thus decreasing flooding magnitude but increasing duration.

The effects of urbanization on stream hydrology can have serious implications for the long-term sustainability and health of riverine wetlands. Riverine wetlands are those located within floodplains of rivers and streams. As hydrology is the most important determinant of wetland structure and function (Mitsch and Gosselink 2000), and because the hydroperiod of riverine wetlands are inextricably connected with the flooding regime of the associated river, an altered hydroperiod caused by urbanization may significantly alter wetland structure and function that had developed under pre-urban conditions.

Not only is the changing hydrology an important consideration for potential impacts on urban wetlands, but this has important implications for urban wetland restoration attempts as well. Most wetland restoration failures have been attributed to a failure to restore a proper hydrologic regime (Kunz et al. 1988, Kusler 1990, Mitsch and Gosselink 2000, Stolt et al. 2000).

For example, restoration projects resulting in wetlands becoming too wet for bottomland species may limit above ground production, while those resulting in dry conditions may not support obligate wetland species (Niswander and Mitsch 1995). Wetland restoration attempts within urbanizing watersheds need to consider the changing hydrology in order to ensure hydrologic levels suitable for optimal wetland production. Hydrologic conditions at the time of restoration may be very different from those some years down the road as urbanization within the watershed continues to increase. It is, therefore, imperative to quantify the degree and location of urbanization within the watershed with the associated hydrologic alterations over time, and be able to predict future hydrologic impacts based on past and present land-use changes.

A bottomland hardwood forest restoration project is currently being undertaken in Dallas County, Texas. As urbanization within the watershed has increased, river hydrologic regimes have been altered. Because the potential for continued urbanization exists, it is necessary to quantify past land use change to predict impacts of future land use changes on the restored wetland. The objectives of this study were to (1) determine the location and degree of urbanization within the East Fork Trinity watershed before and during urbanization and relate it to hydrologic changes of Rowlett Creek, which is located within the watershed, and (2) given the degree of urbanization and hydrologic alteration, determine necessary steps to take to ensure the long-term success of restored wetlands within the watershed.

METHODS

Study area

The East Fork Trinity watershed is located north of Dallas, Texas, in Dallas and Collin counties and was delineated by the US Environmental Protection Agency (2002). A sub-watershed within the East Fork Trinity watershed was derived from a digital elevation model with 30-m resolution to limit the watershed to include only the hydrologic area of interest directly influenced by urbanization. The extent of this watershed is 374 km^2.

The climate of the region includes mild winters and hot summers averaging 9º and 29ºC, respectively. Average annual precipitation is 94 cm, which occurs throughout the year but peaks slightly during the spring (NOAA 2003). The Dallas metropolitan area has experienced rapid urban growth, as much as 400% since 1970 (Knauss 2001).

Image preparation and analysis

Aerial photographs from 1972 were used for pre-urban analyses. DOQQs from 1995 with 1-m resolution were downloaded from the Texas Natural Resources Information System website (TNRIS 2003) for use of comparison to the 1972 photos. It became apparent that time would limit the amount of the watershed that could be analyzed for this study. Consequently, a sub-watershed was then chosen based on its small size (31 km^2) and close proximity to the U.S. Geologic Survey (USGS) stream-gauge station used for the hydrologic analyses.

Land cover types for the grids created from the photos and DOQQs were classified using unsupervised classification in ERDAS IMAGINE 8.6 (ERDAS IMAGINE 2002). The resulting 50 classes were then manually combined into 5 classes based on visual estimates from the photos and DOQQs. These cover classes included woody, herbaceous, bare ground, impervious surface, and water. The classification was still not entirely accurate as much of the actual water and herbaceous cover were classified as woody. These areas were subsequently manually delineated and appropriately reclassified.

The amount of cover of each class was determined for the entire sub-watershed in ArcView (ESRI 1998), but because spatial location of urbanization within a watershed is also important in determining hydrologic changes over time, a moving window approach was used in combination with FRAGSTATS v. 3 (McGarigal and Marks 1995) to determine patch attributes at a finer scale. Patch attributes calculated included cover, number of patches, mean patch size, and edge density.

Moving windows with a 356-m radius were systematically shifted in 178-m steps across the classified grids. At least 50% of each window needed to include data from within the sub-watershed in order to be included in the analyses. An ArcView script was then used to perform the FRAGSTATS metrics in all moving windows.

Hydrologic analyses

To compare hydrologic changes over time, stream-gauge data for Rowlett Creek were downloaded from the USGS website (NWISWeb Data for USA 2003). Analysis of the data included 5-year intervals centered on the 2 dates for which aerial photos and DOQQs were available, 1972 and 1995, respectively. Annual flooding frequency and duration were calculated for 2 flooding heights, 28 and 89 cm above base flow elevations. The average duration of a single flooding event was calculated by dividing the total annual flood duration by the number of annual floods. Average flooding magnitude (m^3/sec) of floods greater than 28 cm was also calculated for each of the time periods.

RESULTS

Image analyses

Percent cover values of each cover class were calculated for the entire sub-watershed for 1972 and 1995 (Table 1). Percent woody cover almost doubled between years from 9 to 17%. Because it was difficult to distinguish between bare ground and ISC during the classification procedure, these 2 cover classes are listed both separately and combined. ISC alone increased over fivefold between years from 2 to 11%, while combining bare ground and ISC resulted in a little under double the cover in 1995 compared to 1972 (8 to 15%).

Table 1. Percent cover of different land-cover classes summarized for the entire sub-watershed in 1972 and 1995.

	1972	1995
Woody	9%	17%
Herbaceous	81%	67%
Bare ground + ISC	8%	15%
Bare ground	6%	4%
ISC	2%	11%
Water	0.8%	1.2%

Results of FRAGSTATS analyses showed differing changes in cover for different areas of the sub-watershed between years. Percent woody cover as well as the size and numbers of woody patches have increased over much of the sub-watershed (Fig. 1). Edge density also increased between years (Fig. 1d). The most pronounced increases in numbers and cover of woody patches in 1995 were centered around areas where patch number and cover were highest in 1972.

An increase in ISC between years was mainly restricted to a few scattered areas throughout the sub-watershed (Fig. 2). ISC cover was highest in 1995 along the southern and eastern edges of the basin (Fig. 2a). These areas are located close to the mouth of the basin. The number of ISC patches increased between years, but the mean patch size decreased (fig. 2b, c). These results, in combination with high edge densities of 3000/ha (Fig. 2d), indicate that ISC increased but became more fragmented between years.

Hydrologic analyses

Because urbanization has a greater effect on smaller floods (Hirsch et al. 1990), analyses of flooding frequency and duration were separated into small floods (28 cm) and larger floods (89 cm). Despite this separation, both annual flooding frequency and duration of Rowlett Creek doubled between years for both heights (Table 2).

Table 2. Average annual flooding frequency and duration for small and larger floods for 2 time periods. The data represent 5-yr averages centered on 1972 and 1995.

	Frequency (#/yr)		Duration (days/yr)	
	1972	1995	1972	1995
Small floods (28 cm)	9.6	18.4	15.8	31.6
Larger floods (89 cm)	4.6	8.8	6	11.4

Disregarding flooding height, the average duration for a single flooding event increased from 40 hrs to 42hrs between 1972 and 1995. The average flood velocity remained the same between the 2 time periods (Fig. 3), but when extreme low and high floods were discounted flood velocities increased from 31.4 to 35.4 m^3/sec.

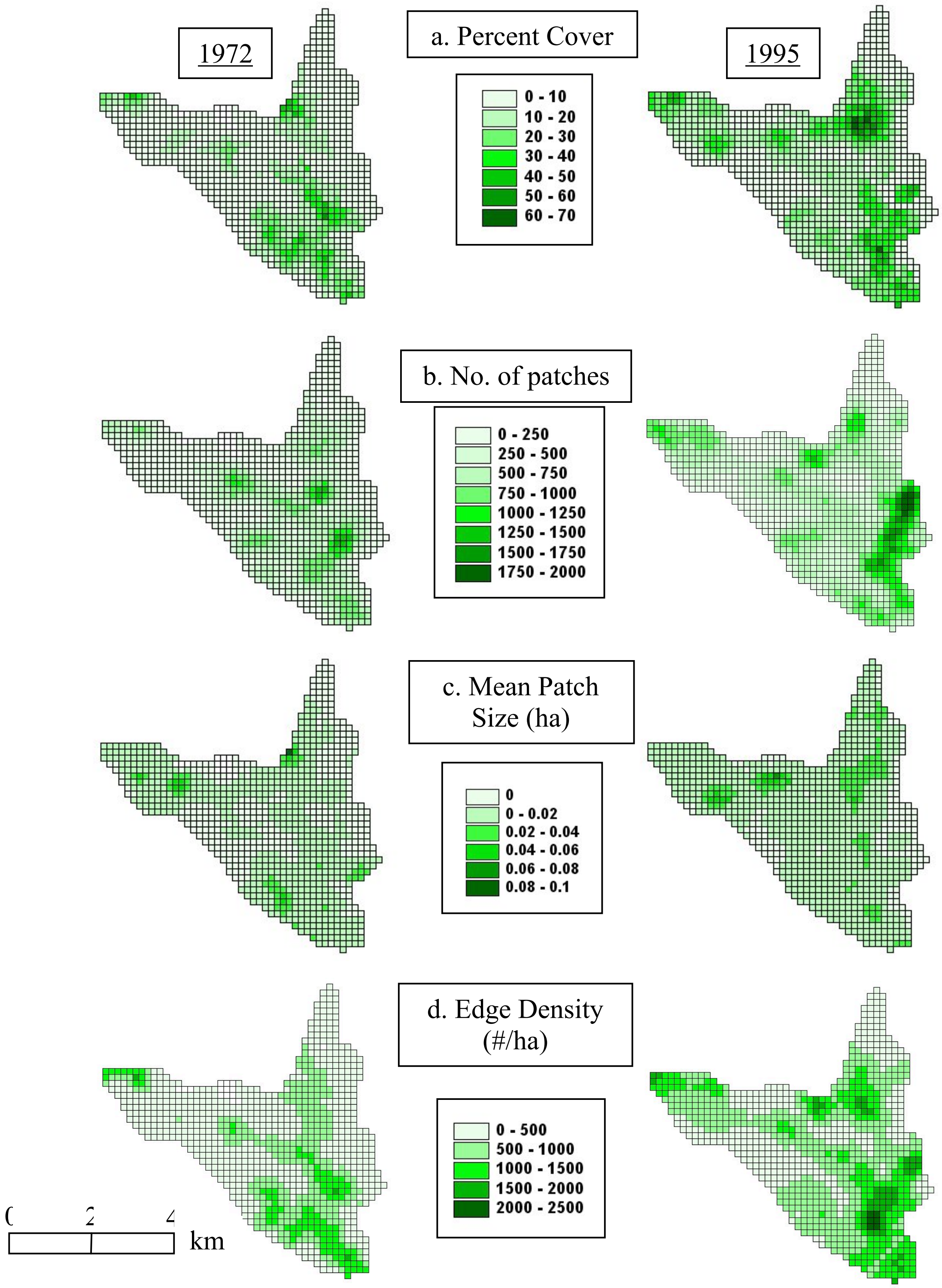

Figure 1. Results of FRAGSTATS analyses for woody cover within the sub-watershed performed on grids generated from moving window analyses. Figures in the left column refer to 1972 and those in the right to 1995. (a) Percent cover, (b) number of patches, (c) mean patch size, and (d) edge density.

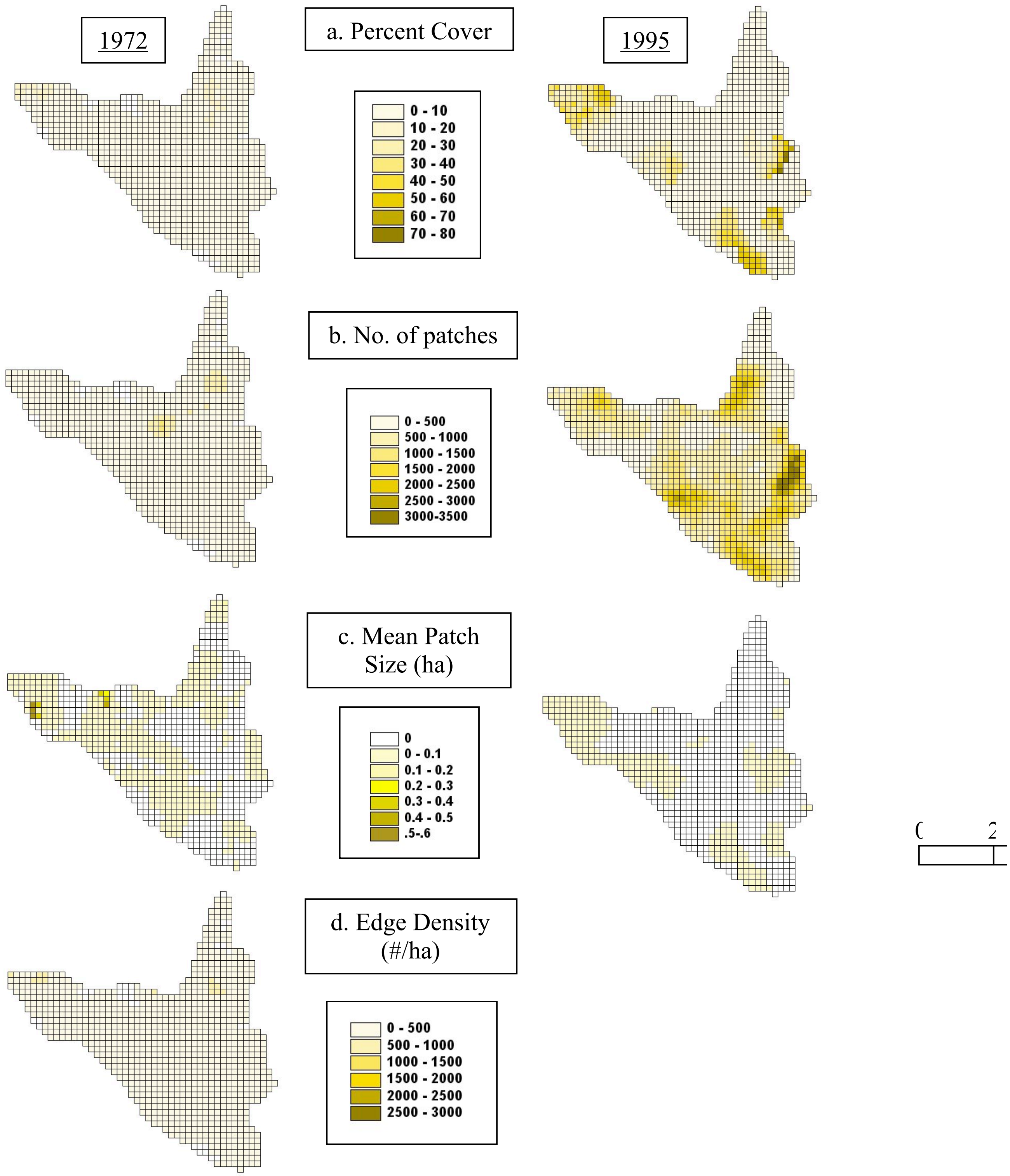

Figure 2. Results of FRAGSTATS analyses for ISC within the sub-watershed performed on grids generated from moving window analyses. Figures in the left column refer to 1972 and those in the right to 1995. (a) Percent cover, (b) number of patches, (c) mean patch size, and (d) edge density.

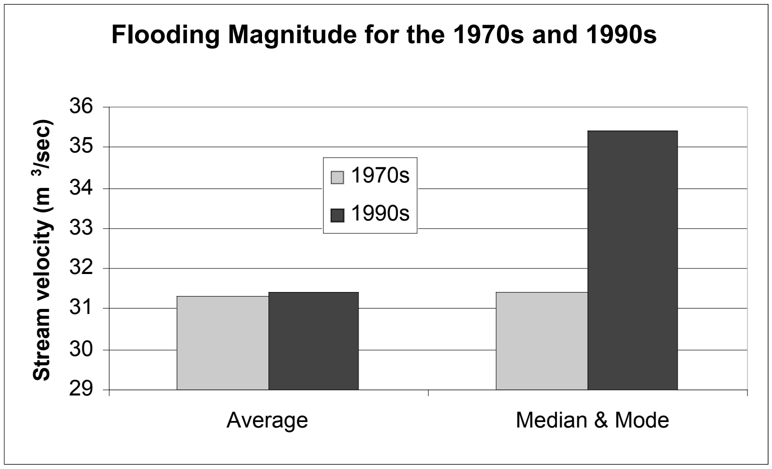

Figure 3. Average, median, and mode flooding magnitude for the 5-yr periods from 1970 to 1974 and 1993 to 1997.

DISCUSSION

The results of the FRAGSTATS analyses seem initially counterintuitive. Woody cover increased with an increase in number of patches and patch size, while ISC increased with increasing number of patches but decreasing patch size. One would expect that as urbanization increases, ISC patch size would also increase and woody cover would decrease. These results can be explained by 2 phenomena: (1) land that was used for agriculture had been cleared of woody cover, but the conversion to urban land allowed woody cover to increase, and (2) this doubling of woody cover would appear to fragment the ISC from an aerial photo or DOQ, thus creating smaller ISC patch sizes. Viewing the original 1972 aerial photos revealed very little woody cover in presumably newly developed urban areas. By 1995, the trees had grown to an extent that they covered housetops and streets, thereby fragmenting ISC. Analyses of patch attributes may have yielded more accurate results had the woody patches within ISC patches been discounted.

Spatial location of urban patches varied throughout the sub-watershed. This spatial complexity makes it difficult to directly relate the influence of spatial location of ISC to specific hydrologic variables. However, a clear relationship does exist between changes in the amount of ISC and changes to the hydrologic regime. In 1972, only 2% of the sub-watershed was covered by ISC. In 1995, ISC increased to 11%. By that time annual flooding frequency and duration had doubled, and average flooding magnitude and single flood duration also increased.

Although 11% ISC is not much of the total cover, Arnold and Gibbons (1996) state that ISC over 10% can cause volume of runoff to double over similar forested watersheds. With 84% of the sub-watershed still covered by woody and herbaceous vegetation, the potential for future urbanization is high. Although difficult to accurately predict, it is safe to say that if urbanization continues, future flooding frequency, duration, and magnitude will increase as ISC increases.

Increasing ISC tends to affect smaller floods to a greater extent than larger floods (Hirsch et al. 1990, Paul and Meyer 2001). Increased ISC doubled the frequency and duration of floods in Rowlett Creek without respect to flood size. However, large floods in this study were considered all those greater than 89 cm. Flooding heights of 89 cm may still have been too small to see differences in flood responses to increased ISC. Analyzing larger floods may reveal results consistent with other published studies.

The increased flooding frequency, duration, and magnitude associated with an increase in ISC has important implications for wetland restoration endeavors. Wetlands that develop under pre-urban conditions may become degraded with rapidly changing hydrologic conditions brought about by urbanization. When attempting to restore such wetlands, it is necessary to quantify the effect that past land-use changes have had to bring about current hydrologic conditions. It is then necessary to predict influences of future land-use changes on the future hydrologic regime. Steps must be taken during initial restoration efforts to establish sufficient plasticity within the system to allow for adaptation to future hydrologic variations, thus increasing the self-sustainability of the wetland. For example, sufficient microtopography could be created to produce a hydrologic gradient that would allow species colonization to fluctuate with fluctuating water tables (Barry et al. 1996). Also, species introduced to the site should include those that are tolerant of a wide range of hydrologic conditions, thus increasing the likelihood that species will be in place that can tolerate future conditions. And, although outside the realm of self-sustaining, variable water control structures could be incorporated to allow for manual manipulation of the hydrology.

CONCLUSIONS

Hydrologic restoration in an urbanizing environment presents a unique question: how can wetlands be restored given the fact that hydrology will continue to change? When attempting to restore wetlands within an urbanizing environment, it is necessary to determine changes in the degree and spatial location of urbanization over time. This study has shown that flooding frequency, duration, and magnitude increased as urbanization increased. It is important to note that these conclusions were based on analyses completed on a portion of the watershed. However, it is safe to say that as urbanization continues flooding dynamics will continue to change. Instead of fighting against them, allowing the system to respond to these changes, by creating hydrologic gradients, introducing species with wide environmental tolerances, and installing variable water control structures, will increase the probability of continued restoration success.

ACKNOWLEDGEMENTS

Special thanks are extended to Paikho Rho and Humberto Perotto for their assistance with software applications and advice on proper remote-sensing methodologies. Funding for this project was supported by the Department of Rangeland Ecology and Management, the City of Garland, Texas, and the Texas Water Resources Institute.

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