Mapping land use change in Massachusetts watersheds with increasing peak flows

Introduction
Imperviousness, the presence of impermeable surfaces over a landscape, has been proven to affect water quality and quantity in several ways. Imperviousness contributes to decreased groundwater levels by diverting precipitation to storm water treatment facilities rather than allowing recharge. Impervious cover may also increase the "flashiness", or the degree to which precipitation runs off surfaces into a stream, creating higher peak flows during storm events. Impervious cover negatively affects water quality by washing surface pollutants directly into stream systems during storm events, degrading channel stability and creating habitat for aquatic biota.

This project built upon the master's thesis work of Tufts Civil and Environmental Engineering alumnus Meghan Walters. Walters determined that peak flows are rising in some Massachusetts watersheds. One possible cause of this increase in peak flows may be the subsequent increase of impervious cover. The use of spatial analysis permits examination of land use change over a physical area and through time. This project used ArcGIS to spatially investigate trends in development of impervious cover in watersheds with increasing peak flows.

Methods
This analysis used Walters’ study to compare the watersheds with the highest increase in peak flows to those with the lowest increase in peak flows. Table 1 displays the watersheds, gauge identification numbers, the slope, and corresponding p-values for each gauge, and the period of flow record. The top five gauges in this table showed change in peak stream flow. The watersheds in which these gauges are sited are termed change watersheds. The degree to which change occurred is depicted in the “Slope” column. The bottom five gauges in Table 1 (in italics) showed almost no change in peak stream flow as depicted by their low slope values. The watersheds in which these gauges are sited are termed no change watersheds. Note that the Nashua watershed contains both slope and no slope gauges. Nashua is a change watershed and a no change watershed and because the ArcGIS data layers used for this analysis were not complex enough to analyze mixed change/no change watersheds, Nashua was removed from the spatial analysis. Table 2 depicts the GIS data layers used, along with the source and year published for each layer.

Study watersheds

<table>
<thead>
<tr>
<th>Waterbody</th>
<th>Decade</th>
<th>Change</th>
<th>No Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nashua</td>
<td>1940 - 1949</td>
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<td>1.00</td>
</tr>
<tr>
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<td>Nashua</td>
<td>1960 - 1969</td>
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</tr>
<tr>
<td>Nashua</td>
<td>1970 - 1979</td>
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</tr>
<tr>
<td>Nashua</td>
<td>1980 - 1989</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Nashua</td>
<td>1990 - 1999</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Analysis Step 1
The units built ArcGIS layer (Table 2) shows the number of units built per decade per block group as reported by US Census respondents. This layer was presumed to serve as a surrogate for land use change and, therefore, change in impervious cover over time. Change in units built between 1940 and 1999 was calculated for the change watersheds as one group and for no change watersheds as a second group. This calculation was also made individually for the watershed which exhibited the most change in peak stream flow (Concord) and for the watershed which exhibited the least change in peak stream flow (Nepsonset).

Analysis Step 2
The land use layer from MassGIS shows land use for the years 1971, 1985, and 1999. This layer contains 21 categories for land use which are depicted in Table 3. The values for percent impervious cover for each land use category were given in a report for a hydrological modeling system created by Compton et al. at the University of Massachusetts, Amherst. The report did not give percent impervious values for the last two categories, woody perennial and recreation - displayed in Table 3 in italics. These categories were not used for this analysis.

Graph 2 depicts the change in units built per acre per decade for the watershed with the highest increase in peak stream flow (Concord) and the watershed with the least increase in peak stream flow (Nepsonset). Although the rate of units built per acre in Nepsonset watershed is decreasing, there are consistently more units built per acre per decade in Nepsonset watershed than in Concord watershed.

Analysis Step 2

Using the land use layer (Table 2), change in impervious cover was estimated for the study watersheds for the years 1971, 1985, and 1999. Because water quality degradation begins when land use reaches 10 percent imperviousness, the change in highly pervious land use (land use with less than 10 percent impervious cover) was analyzed. Table 4 displays the change in number of acres of highly pervious cover as well as percent change of highly pervious cover for each of the study watersheds.

Results

Analysis Step 1
Units built per decade per US Census block group was used to estimate change in impervious cover. Graph 1 depicts the change in units built per acre. At the end of 1939 there was an average of 73 housing units per acre in change watersheds and an average of 1.58 housing units per acre in no change watersheds. In change watersheds, 008 housing units were built per acre per year on average. In no change watersheds, 02 housing units were built per acre per year on average. Based the data in this layer, watersheds which experienced increases in peak flows had less development over the 60-year period than watersheds in which peak flows remained unchanged.

Graph 2: Change in housing units

No change watersheds: Change in housing units

Conclusions

Based on Meghan Walters’ research, peak flow volumes are changing in some Massachusetts watersheds. One possible explanation of this phenomenon is that development and an increase in impervious cover is causing rainwater to run directly into streams rather than infiltrating. This theory was tested using GIS data sets in ArcGIS. While some of the watersheds which exhibited changes in peak flows also showed increase in impervious cover, watersheds with no change in peak flows also showed change in impervious cover. Using spatial analysis, this research did not find conclusive evidence that impervious cover increased peak flows in the study watersheds. However, because neither of the land use data sets were created for this type of study, further research should be conducted using aerial photographs intended for analysis of impervious cover.

Cartography: Kendall Webster
Urban and Environmental Policy and Planning
5/2/2010