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Quantifying Land use and Urban Runoff Change Through Service-Learning Hydrology Projects

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Abstract

We have used landuse change, driven by development of our University campus and recent student occupancy of surrounding neighborhoods, as an opportunity for service learning and for teaching fundamental hydrologic and geologic skills in two undergraduate Geology courses. In Geomorphology, two students documented, using historical maps and aerial photographs, the dramatic increase in impermeable surface, from 4% to 42%, over the past 130 years. In Geohydrology, student teams used aerial photographs, field mapping, and door-to-door surveys to document green space losses in student neighborhoods over the past 20 years; such losses ranged from 40 to 50%, despite zoning controls enacted in 1973. Students used simple hydrologic calculations to demonstrate that this unregulated change in landuse increased both the volume and peak flow of stormwater runoff. Individual senior research projects have also made field and demographic studies of individual neighborhoods and examined the effect of landuse change on infiltration rates. In all of these studies, students worked closely with City and University staff and presented their results in a variety of public forums including local and national meetings and the world wide web.

Introduction

Undergraduate hydrogeology projects provide excellent opportunities for student and faculty involvement with public issues and for hands-on service learning that requires students to interact with community members while collecting data. In the junior/senior level Geohydrology class at the University of Vermont (UVM), service-learning projects are the culmination of each semester; projects include mapping groundwater wells for towns (Clapp et al., 1996), collecting snowpack water-equivalent data (Gran et al., 1999), evaluating slope stability for proposed developments, and surveying campus groundwater wells (http://geology.uvm.edu/geowww/morphwww/wellfield/Project/wellindex.html). In the sophomore/junior level Geomorphology class, students do semester-long research projects, some of which have hydrologic and service learning components. Independent senior research projects provide additional opportunities for hydrologically oriented, service-learning.

In this paper, we present several closely related service-learning projects in which students quantify the hydrologic impact of land use changes, specifically the conversion of permeable green space to impermeable parking lots and buildings. These projects give students experience collecting and analyzing data while working in the community, rather than in university classrooms. To successfully complete their assignments, students learn and apply traditional geologic and hydrologic techniques, including aerial photograph interpretation, field mapping, mathematical modeling of runoff, and simple statistical compilation and analysis. Students, as they gain experience collecting data using door-to-door surveys and document searches, learn to interact as professionals with community members and university staff. The projects we describe are appropriate for use in college-level Hydrology, Geomorphology, and Environmental Geology classes as well as for senior research.

Project Setting and Problem Definition

Burlington, Vermont, is a moderate-sized (population of 39,000 in year 2000) college town situated on and above the shores of Lake Champlain. The town is underlain primarily by glacial and immediately post-glacial sediment including till, lacustrine and marine silt, and deltaic sand; there are few rock outcrops. Burlington began urbanizing in the mid- to late-1800s; most urban neighborhoods were built out by 1930 and are served by storm sewers. Zoning codes (passed in 1973) mandate a maximum of 35% lot coverage for many of the neighborhoods near the University where students live. The code, if followed, leaves 65% of each lot as open space where precipitation can infiltrate rather than runoff.

During the last 30 years, growing enrollment at UVM, without concurrent expansion of dormitory space, forced many students to live off campus catalyzing the transformation of single- and multi-family housing units into student apartments. With more students and fewer families living in each building, there are more cars per house (Kurfis and Bierman, 2002). Because most houses occupied by students were built for single families or as duplexes, there is usually driveway space for only several cars. Tenants and their landlords have responded to imbalance between parking spaces and the number of vehicles associated with a residence by slowly creating more parking at the expense of green space, usually without the required zoning permits or City approval.

Conversion from green space to parking usually occurs in a slow but predictable sequence (Kurfis and Bierman, 2002). First, drivers park their vehicles on green space (Figure 2a). Then, usually after the spring snowmelt, the new parking area, the soil under which has been compacted, becomes muddy (Figure 2b). Landlords, then dump gravel on the mud (Figure 2c) formalizing the parking space. Finally, after a period of months to years, the gravel parking space is paved (Figure 2d). Termed *parking creep*, such conversion of permeable green space to impermeable parking areas is ubiquitous in Burlington neighborhoods inhabited by students. The loss of green space is not limited to the Burlington neighborhoods. The UVM campus has also experienced significant green space loss over the last 130 years from the construction of buildings, parking lots, and sidewalks (Persico et al., 2000).

There are several important and interesting issues, both social and hydrologic, that relate to parking creep, land-use change, and green space loss. Owner-occupants, as long-term residents, are concerned that parking cars on lawns demonstrates a lack of investment in and concern for the neighborhood, thus lowering the quality of life and property values. As hydrologists, we are interested in how the change in land use relates to the overflow of storm sewers during high intensity precipitation events and the quantity and quality of urban storm-water runoff that enters Lake Champlain. As educators, we are interested in developing projects that integrate science and public policy, projects that allow students to apply what they know to the neighborhoods in which they live.

Project Structures and Methods

Projects in both the Geomorphology and Geohydrology classes have formal but different structures that can be examined in detail by consulting the respective class web sites (accessible from http://geology.uvm.edu/morphwww/urbanhydro). Independent senior research projects include both field and lab components. All projects discussed in this paper conclude with a formal write up and a public presentation.

Geomorphology Team Research Project – Campus change over time

The University of Vermont was founded in 1791 and has been expanding ever since. The history of the campus is well-documented by a variety of sources, each of which covers different time frames including historical maps, aerial photographs, and campus planning documents. As their semester-long geomorphology project, two students (Persico and Bosley) used these sources to document the loss of campus green space and the expansion of impermeable surfaces over time (Figures 3A, 3B, and 3C). Such impermeable surfaces include buildings, sidewalks, parking lots, and the network of heavily compacted footpaths that traverse the campus. The campus data show a decrease in green space over time. Loss of green space accelerated in the 1940s and appears to have slowed in recent years, most likely in response to land use agreements between the City of Burlington and the University.

Doing such historical analysis is not straightforward. Because early maps show only buildings and not foot paths (Figures 4A and 4B), the students needed to correct for this bias. They did so by calculating ratios between building areas and pathway areas for the years during which aerial photographs were available (19XX, 19XX and 19XX); these ratios were remarkably constant (y to z) lending support to their method. This ratio correction presumes that the human instinct to walk between buildings by the shortest possible path across the grass has not changed over the past century.

Geohydrology Class Project --Neighborhood change over time

For the last month of the spring semester, the Geohydrology class studied urban hydrology in teams of two. We began the project with a neighborhood walk-through, led by the director of code enforcement for the City of Burlington. We followed with class exercises in air-photo-based mapping and spread-sheet based runoff modeling. During a three-week period, students mapped in pairs and we scheduled days when the faculty were available to answer questions in the field and lab. The goal of the project was to determine the amount and distribution of green space loss in city neighborhoods and to use those data to model hydrologic response.

Class, field, and lab activities -- We chose specific streets of Burlington for each student pair to map. Most chosen streets were heavily impacted by parking creep and dominated by student rentals; one street served as a control where all homes were owner occupied. To acquire baseline data, students mapped their street using 1978 low-level, high-resolution aerial photographs taken by the State of Vermont (1:1250). We provided the students with five mapping units based on different landuse properties (Table 1). Building footprints, sidewalks, and formal parking were fairly easy to delineate and all were considered impermeable. Informal parking areas, created by cars repeatedly parking on lawns, had boundaries that were more diffuse and thus harder to delineate. Green space was calculated by difference. Students used Canvas 5.0 to make overlay maps of their field areas and to calculate the area of each mapping unit (Figure 5A and 5B).

The students repeated this mapping using more recent, 1999 aerial photographs (1:5000). We had the teams field check the 1999 data for several reasons. Since the 1999 photos were less detailed than those from 1978, field checking provided quality control and allowed for the most current analysis of land-use change. While field checking their data, students conducted a standardized property evaluation of property condition (form available from geology.uvm.edu/landuse) and door-to-door surveys. Students asked occupants simple questions such as: How many people live in the building? How many housing units are in the building? Does the owner live in the building?

Analysis and modeling -- After quantifying the area represented by each map unit on both the 1978 and 1999 aerial photographs, students calculated the hydrologic response to measured changes using simple curve number and rational runoff approaches. To show the affect of landuse change since European settlement, the students modeled the runoff volume and peak discharge from pristine forest land (presettlement up to 1780), runoff from agriculture and pasture land (predevelopment, about 1820), and runoff from the land use they documented using the 1978 and 1999 aerial photos. To quantify the affect of changes in land use on runoff, the students calculated runoff from a 10-year return storm of 6 hour duration. We used meteorological data appropriate for Burlington, Vermont but data for most cities can be obtained from the weather service; regionalized data can be inferred from maps in Dunne and Leopold (1978).

To determine the volume of runoff, we used the *curve number* approach, an empirical method that requires characterization of soil and land use characteristics (U.S. Soil Conservation Service, 1972). Well-drained forest soils have the lowest curve number, which corresponds to the lowest runoff volume per unit volume of precipitation (Table 2). Using graphs of curve numbers plotted as storm runoff vs. rainfall, students calculated the volume of runoff for different time periods and land uses using by area weighting averages for different land-use categories (Figure 6). The curve number graphs can be found in most introductory hydrology text books, such as Dunne and Leopold (1978).

One goal of the project is to determine the affect of landuse change on the peak intensity of urban runoff. We had the students use the *rational runoff method* to estimate the peak discharge for their mapping areas as land use changed. The rational runoff method is widely accepted method for the design of storm sewers (Dunne and Leopold, 1978). Such a calculation, when compared to the engineering specifications (if available), would quantify the storm intensity required to fill the sewer system.

Calculation of the peak discharge is straightforward. The method assumes that uniform intensity rainfall covers the entire drainage basin. After the whole drainage basin is contributing to the discharge (time of concentration), streamflow discharge is a fixed proportion of the rainfall intensity. The peak discharge is calculated using:

$$Q_{pk} = 0.278CIA \qquad (1)$$

Where Q_{pk} is discharge ($m^3\ sec^{-1}$), C is the rational runoff coefficient, I is rainfall intensity ($mm\ hr^{-1}$), and A is drainage area (km^2). Values for C were determined for 5 to 10 year storms for urban conditions by the American Society of Civil Engineers (Table 3). To use these values for larger storms they should be adjusted upward (Rantz, 1971).

In order to relate the landuse changes to the lifestyle of people living in homes and apartments, the students reduced the door-to-door survey data and performed statistical analyses. For example, students investigated whether there was a relationship between the number of occupants in a property, property condition, and property ownership, and the conversion of green space into parking; there was. Since statistical knowledge was not a prerequisite for the Geohydrology class, we led the class through simple statistical analyses such as using averages and regressions to show which parameters were associated with the loss of green space.

Student's Results -- Maps depicting land use change, the hydrologic calculations, and the statistical analyses shocked most students. Between 1978 to 1999, 39% and 48% of green space was lost in the mapped areas occupied by students; no green space was lost in the 100% owner-occupied control neighborhood (Table 2). The total impervious cover for these impacted blocks ranges from 75% to 83%. Most of the green space loss occurred when lawns were converted into informal and formal parking areas. In only 6 city blocks, 2.2 acres of lawn were converted into parking spaces.

The results of the hydrologic calculations were similarly impressive. Consider a 2 acre area that was 60% greenspace, 40% impermeable in 1978. When the land was mostly forest or pasture, the 10-year storm generated 41 m^3 of runoff over the mapped area. However, after development to 1978 levels, same storm generated 185 m^3 of runoff. By converting half the greenspace to parking from 1978 to 1999, runoff increased to 308 m^3, an increase of 66%. The results of the peak discharge calculations parallel those for runoff volumes. Peak discharges off of the mapped areas increased by 33% in 21 years. Within the last 10 years, there are reports of storm sewer overflows from the lower elevations in Burlington Such observations support model results suggesting decreased infiltration and increased runoff due to land use changes.

Surveys and statistical analysis demonstrate that the conversion of greenspace to parking occurs mostly on rental properties occupied by students; owner-occupied properties show no significant increase in parking area over the 21 years between 1978 and 1999 (Kurfis and Bierman, 2002; data available from geology.uvm.edu/landuse). The conversion is driven by economics; apartments with off-street parking, whether in compliance with zoning or not, are desirable to rent and command premium rents. In mapping units where 100% of the houses are non-owner occupied, the number of occupants and cars per parcel are higher and the quality assessment of the properties are markedly lower than in the owner-occupied control street (Kurfis and Bierman, 2001). Such trends are probably due to the fact that students live in housing units for only one or two years and have little incentive to maintain the property.

Community outreach -- Our class and research structures mandate that students make a public presentation of their findings as part of their final report. Such presentations allow students, residents, and local government members to interact using hydrologic science projects as the basis for discussion on how to improve the quality of city and university life. Some of these presentations are oral and involve tools such as PowerPoint; others are poster-based and done in the classroom. Some students and their presentation have gone to national meetings of professional organizations (Persico et al., 2000; Kurfis et al., 2001). The data collected by students were of sufficient public interest that the local newspaper, *The Burlington Free Press,* covered the class project and the students' involvement in the community. Data we collected were presented to several neighborhood planning associations in Burlington, groups that provide citizen input to local government.

Student response to project -- The student feedback for this exercise was overwhelmingly positive. Most students became engaged in the project and all the teams did a significant amount of work and prepared well their posters for public presentation. Many of the students lived in the mapping areas, some routinely parked their cars on lawns, and all were surprised by the results of the project. After the public presentation, a majority of the students stayed to discuss the connection between the hydrologic and social changes in landuse; as a group they came up with a variety of ideas for preventing future green space loss and remediating areas already affected.

Independent Student Research

The land-use change projects reviewed in this paper can easily be adapted from class exercises to the individual student research projects. At UVM, two students have done full-year senior projects related to green space conversion. The first studied the land use of 190 parcels in a mixed rental/owner-occupied neighborhood, determined ownership and condition with surveys, and concluded that land use change was driven by rental units (Kurfis and Bierman, 2002). The second student mapped fewer parcels but searched zoning records and used sprinkling infiltrometers to measure directly the effect of lawn parking and gravel driveways on infiltration rates. Future senior research includes working with the City to establish scientifically-based remediation protocols for parking-compacted soils.

Conclusions

We demonstrate a field-based, service-learning project that is useful not only to teach hydrology but to get students intetacting with other community members. In particular, urban hydrology highlights the connection between scientific and social issues. The students responded enthusiastically to a real-world application that has implications for the society in which they live. The loss of residential green space that as a group they documented, has important hydrological and social implications for the City of Burlington. Conversion of green space to impervious surfaces increases the volume and peak discharge of storm runoff. Such changes in hydrology have adverse effects on the storm sewer capacity, water quality, the streams into which some storm sewers empty and quality of life in Burlington neighborhoods.

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Figure Captions

Figure 1. Map of Burlington, Vermont , showing location of the university and the student neighborhood that we studied.

Figure 2. Sequence of photographs that demonstrate the predictable parking creep process. A. More people live in a housing unit than the parking can accommodate. Tenants park on the lawn or they crowd into parking spaces, extending the driveway. B. Ruts in greenspace become muddy causing tenants to complain to owner. C. Owner fills ruts with gravel, making parking space semi-formal. D. Owner repaves driveway and gravel filled ruts become formal parking and paved.

Figure 3. The UVM campus has experianced similar loss of greenspace. A. Graph of percent impemeable surface of campus over time. Most conversion of greenspace to impermeable surfaces occurred between the 1940s and the 1960s. B. Historic photograph of Perkins Hall (the geology building) on the UVM campus c. 1900. C.

Photograph taken in 2000 of Perkins Hall from similar location. Notice how there is almost no more greenspace around the building.

Figure 4. Diagrams showing loss of greenspace on campus. A.   Locations of mapping areas in Burlington. The University of Vermont is located to the southwest of this area.

Figure 4. A. 1978 aerial photograph of ???Street. B. Example of student generated overlay map. From these overlay maps, the students calculated the areas of the different mappable units.

Figure 5. Example of curve number graphs.