Quantifying Urban Land Use and Runoff Changes Through Service-Learning Hydrology Projects

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ABSTRACT

We have used land use change, driven by development of the University of Vermont campus and recent student occupancy of surrounding neighborhoods in Burlington, Vermont, as an opportunity for service learning and for teaching fundamental hydrologic and geologic skills in two undergraduate Geology courses. Two students, from a *Geomorphology* class, used historical maps and aerial photographs of the University campus to document the dramatic increase in impermeable surfaces on campus from 4% of the land area in 1869 to 42% in 1999. In *Geohydrology*, student teams used aerial photographs, field mapping, and door-to-door surveys to document green space losses of 40 to 50% over the past 20 years in neighborhoods inhabited predominantly by students, despite zoning controls enacted in 1973. Students used simple hydrologic calculations to demonstrate that this unregulated change in land use increased both the volume and peak flow of stormwater runoff. Senior research projects have also made field and demographic studies of individual neighborhoods and examined the percent of land use change. In each of these studies, students worked closely with City and University staff and presented results at local forums, professional national meetings, and on the World Wide Web. These service-learning projects have received positive feedback from the students, city officials, and community members.

INTRODUCTION

The University of Vermont (UVM) is located in Burlington, Vermont, a moderate-sized (population 39,000 in 2000) college town situated on and above the shores of Lake Champlain (Figure 1). Burlington is often considered a desirable place to live because of its "Green" reputation and its family friendly environment (e.g. Steere, 1995). However, in recent years, some neighborhoods close to the UVM campus have experienced a significant change in character and land use as students have moved off campus and into the community. In this paper, we present several closely related service-learning projects in which students quantify the hydrologic impact of these land use changes, specifically the conversion of permeable green space to impermeable parking lots and buildings.

SERVICE-LEARNING PROJECTS

Undergraduate 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 (National Service-Learning Clearinghouse, 2002; Ward, 1999). At UVM, we use service learning as part of the sophomore/junior level Geomorphology class (Persico et al., 2000), the junior/senior level Geohydrology class (Gran et al., 1999; Clapp et al., 1996), and as part of senior research projects. Of these, independent senior research projects provide the greatest opportunity for in depth service learning in the hydrological sciences. Senior research has included quantifying land use change in Burlington neighborhoods (e.g. Kurfis and Bierman, 2002; Kurfis et al., 2001) and surveying campus groundwater wells (University of Vermont Geology Department, 2002a).

BURLINGTON SETTING AND RECENT LAND USE HISTORY

Burlington, underlain primarily by glacial and post-glacial sediment including till, lacustrine and marine silt, and deltaic sand, 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 that impervious surfaces may not cover more than 35% of each lot for many of the neighborhoods near the University where students live. The code is designed to leave 65% of each lot as open space where precipitation can infiltrate rather than runoff.

Between 1963 and 1973, UVM doubled its enrollment, adding more than 3000 students without concomitant expansion of dormitory space. This action forced many students to live off campus catalyzing the transformation of single- and multi-family housing units into student apartments. On average, student housing has four more cars per parcel (six) than family housing (two; Kurfis and Bierman, 2002), so this transformation increased the number of needed parking spaces. Since most houses currently occupied by students were built as single-family homes or duplexes, there is usually insufficient driveway space for additional cars. Tenants and their landlords have responded to the imbalance between the number of available parking spaces and the

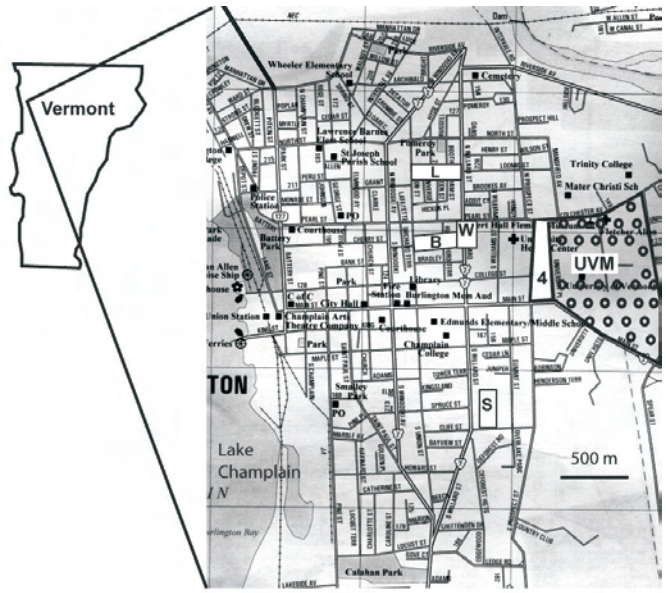


Figure 1. Map of Burlington, Vermont, showing location of the university, the student neighborhoods, and the control neighborhoods (S) that were studied. The number 4 represents location of Figure 4. B = Buell Street, W = Willard Street, L = Loomis Street, S = Summit Ridge.

number of vehicles 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 during the spring snowmelt, the new compacted parking area 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). *Parking creep*, the slow, steady conversion of permeable green space to impermeable parking areas, is ubiquitous in many Burlington neighborhoods.

There are important and interesting social and hydrologic issues that relate to parking creep, land-use change, and green space loss. Owner-occupant residents are concerned that parking cars on lawns lowers the quality of life and property values. Hydrologists are interested in how the change in land use relates to the overflow of storm sewers during high intensity precipitation events, and in the quantity and quality of urban storm-water runoff that enters Lake Champlain. Educators have an interest in developing projects that integrate science and public policy, and which allow students to apply what they know in their own neighborhoods.

PROJECT STRUCTURES AND METHODS

This paper introduces several service-learning projects that we have implemented at UVM. These projects give students experience collecting and analyzing data while working in the community and in university classrooms. 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. Door-to-door surveys and document searches provide students with an opportunity to interact as professionals with community members and university staff. Each project discussed in this paper concluded with a formal write up and a public presentation.

Independent Student Research - At UVM, two students performed year-long senior research projects related to green space conversion. Kurfis studied the land use of 190 parcels in a mixed rental/ owner-occupied neighborhood, determined ownership and building condition with surveys, and concluded that rental units drove land use change (Kurfis and Bierman, 2002). Owner occupied units remained largely unchanged in the 20-year period covered by his study. His project provided the impetus for the urban hydrology service learning unit in our Geohydrology course. Melillo became interested in land use change and hydrology after doing the Geohydrology unit. He mapped fewer parcels (n = 55) but searched zoning records to determine the legality of land use change (Mellilo, 2002). Senior research that has just begun includes working with the city to establish scientifically based remediation protocols for parking-compacted soils as well as quantifying the pollutant load that is washed off of parking spaces.

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 historical maps, aerial photographs, and campus planning documents, each of which cover different time frames. 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 (Figure 3A). 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. These agreements state that the University campus will strive to lose no more of its remaining greenspace.

Doing quantitative historical analysis of campus green space loss is not straightforward. Because early maps show only buildings and not footpaths (Figures 4A and 4B), the students needed to correct for this bias. They did so by calculating ratios between pathway areas and building areas for the years during which aerial photographs and detailed maps were available (1969, 1978, and 1996). These ratios were remarkably constant (1.6 to 1.8) supporting their method and the notion that the human instinct to walk between buildings by the shortest possible path across the grass has not changed over at least the past half century.

Geohydrology Class Project - Neighborhood change over time. For the last month of the spring semester, the Geohydrology class studied urban hydrology. Teams of two students each determined the amount and distribution of green space loss on a city block assigned to them and used these data to model hydrologic response. 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. During the next

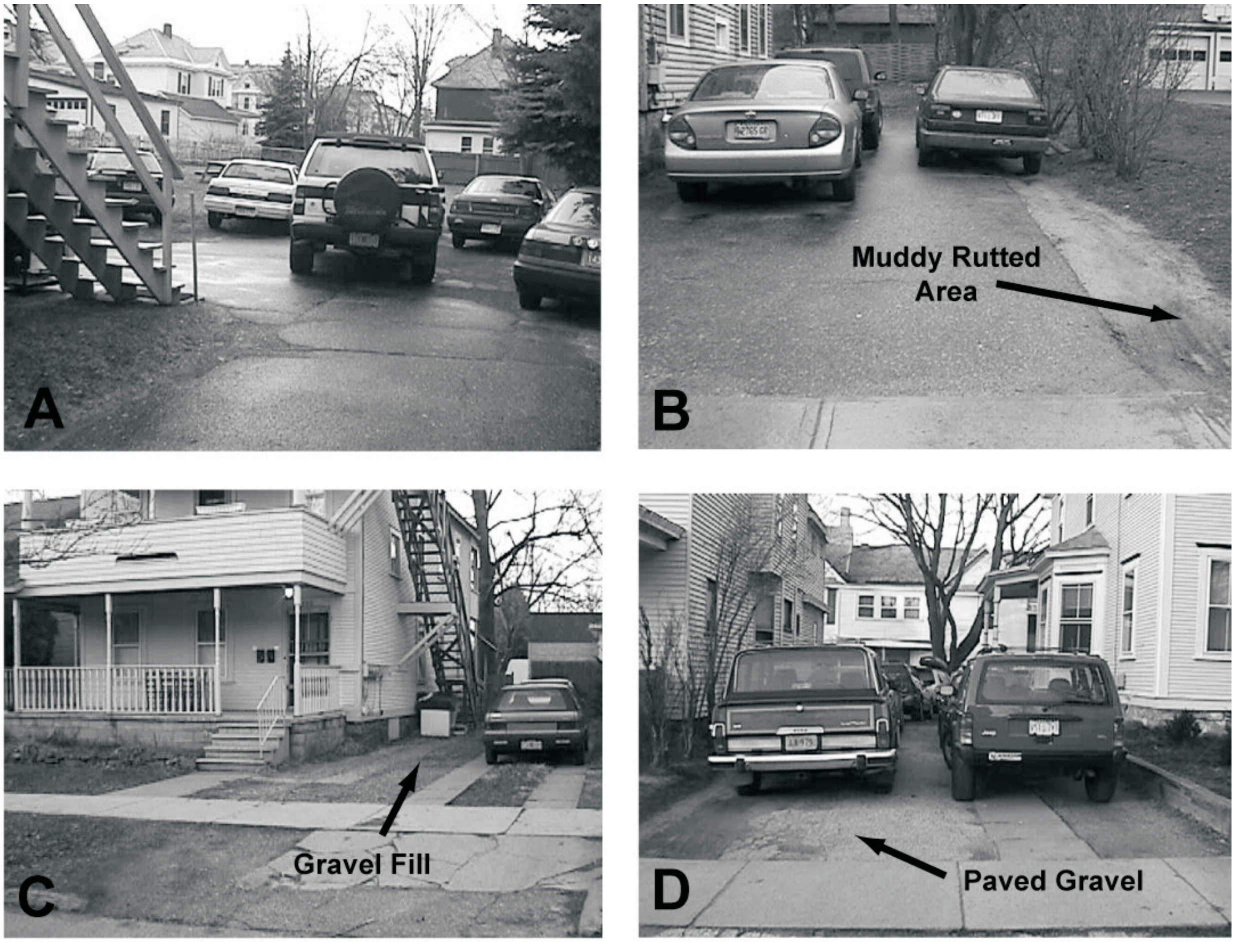
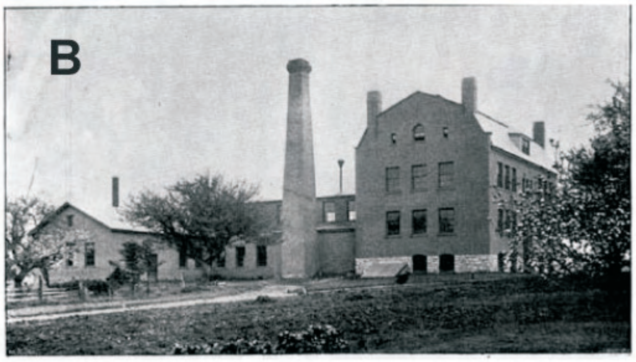


Figure 2. Sequence of photographs that demonstrate parking creep process. A. More people live in a housing unit than the parking can accommodate. Tenants park on the lawn or they crowd into parking spaces, extending the driveway. Four of the five cars pictured are wholly or partially parked on the lawn. B. Ruts in greenspace become muddy causing tenants to complain to owner (right of driveway). C. Owner fills ruts with gravel, making parking space semi-formal (next to house). D. Owner paves gravel filled ruts, which then become formal paved parking. Over the course of the sequence, infiltration rate drops and runoff increases.

Category	Description
Building Footprint	Buildings, porches, garages, and other outbuildings. This unit is generally an orthogonal polygon that appears to have a vertical aspect. This unit often appears to have a slanted top or peaked appearance. Areas represented by buildings may be an overestimate due to shadowing and or distortion.
Sidewalk	Paved walkways. Usually a rectilinear polygon that parallels streets or intersects streets or other sidewalks at or near right angles. This unit usually appears bright white, generally straight, and does not appear to have a vertical aspect.
Formal Parking	Well defined parking areas and driveways. This unit has linear or curvilinear polygons with distinct well-defined edges. This unit ranges in tone from a very light gray to a very dark gray.
Informal Parking	Poorly defined parking areas, driveways, or automobile traffic on what was formerly greenspace. Polygons have ill defined boundaries often blending into adjacent units. This unit has no distinct shape criteria, but is generally longer than it is wide.
Greenspace	Vegetation including grasses, trees, and shrubs. Areas that have a tufted appearance with some minimal but detectable vertical aspect in the tufts. These areas appear to be less smooth than parking areas, sidewalks, and building footprints. This unit often has well-rounded vertical developments interpreted as trees and shrubs.

Table 1. Orthophotograph Mapping Categories and Descriptions



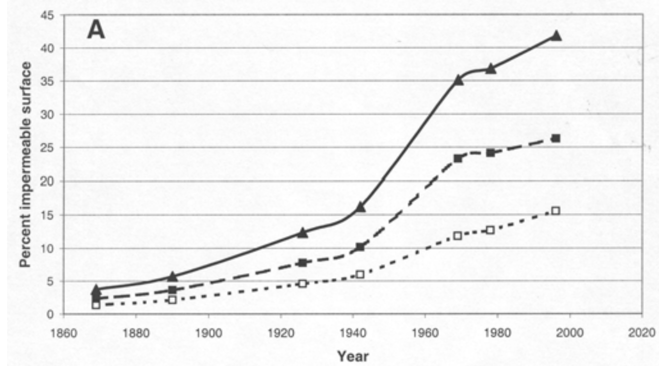


Figure 3. The UVM campus has experienced loss of greenspace. A. Graph of percent impermeable surface of campus over time. Most conversion of greenspace to impermeable surfaces occurred between the 1940s and the 1980s. Solid line is total impermeable surface. Middle line (large dashed) is impermeable surface other than buildings (walkways, parking lots, roads, etc.). Bottom line (small dashed) is building coverage. B. Historic photograph of Perkins Geology Hall on the UVM campus, c. 1900. C. Photograph taken in 2000 of Perkins Hall from similar location. Notice how there is almost no greenspace left near the building.

three weeks, the students mostly worked on their own, with the exception of classes on statistical analyses and on runoff modeling. The students mapped in pairs, conducted door-to-door surveys, modeled runoff and peak discharge, performed simple statistical analyses, and prepared a poster for public presentation (Figure 5). The instructors were available to answer questions in the field and in the lab during normal class time and during additionally scheduled days.

Class, field, and lab activities - We chose specific streets of Burlington for each student pair to map. Most streets were heavily impacted by parking creep and dominated by student rentals; one street served as a control where all homes were owner occupied (Figure 1). To acquire baseline data, students mapped their street digitally using scans of the 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 land uses (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 diffuse boundaries and were harder to delineate. Students calculated green space as the difference of the sum of the four mapped units from total lot area. Students used a graphics program with polygon and layering capabilities (such as Adobe Illustrator or Canvas) to make overlay maps of their field areas and to calculate the area of each mapping unit (Figure 6). Alternatively, the students could use ArcView; however, if the students are unfamiliar with the software, the time to project completion could significantly increase.

The students repeated the mapping exercise using 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 evaluation of property conditions and conducted door-to-door surveys (Figure 7).

Analysis and modeling - After quantifying the area represented by each land use unit on both the 1978 and 1999 aerial photographs, students calculated the hydrologic response to measured changes. To show the effect of land use change since European settlement, the students calculated the runoff volume and peak discharge from pristine forest land (representative of pre-settlement up to 1780), the runoff from agriculture and pasture land (representative of pre-development, about 1820), and the runoff from the land use they documented using the 1978 and 1999 aerial photos. The students calculated runoff for a 10-year return storm of 6-hour duration. We used meteorological data appropriate for Burlington, Vermont. For those working elsewhere regionalized data for storms of different return periods and durations can be inferred from maps in Dunne and Leopold (1978).

To determine the volume of runoff, students used the *curve number* approach, an empirical method that requires characterization of soil and land use characteristics (U.S. Soil Conservation Service, 1972). Curve numbers provide the average percentage of rainfall that runs off for a given rainfall amount. Higher curve numbers are associated with more impermeable surfaces and higher runoff volumes. For example, paved driveways have a curve number of 98; almost all rainfall becomes runoff. Conversely, woodland soils have a lower curve number (55), which corresponds to a low runoff volume. The students used the areas of the mapped units to determine a weighted average curve number. Common weighted average curve numbers for the areas the students mapped were between 80 and 90. For example, in a storm during which 2.5 inches of precipitation fell (10-year, 6-hour storm), 0.9 inches of runoff would result. Curve number graphs can be found

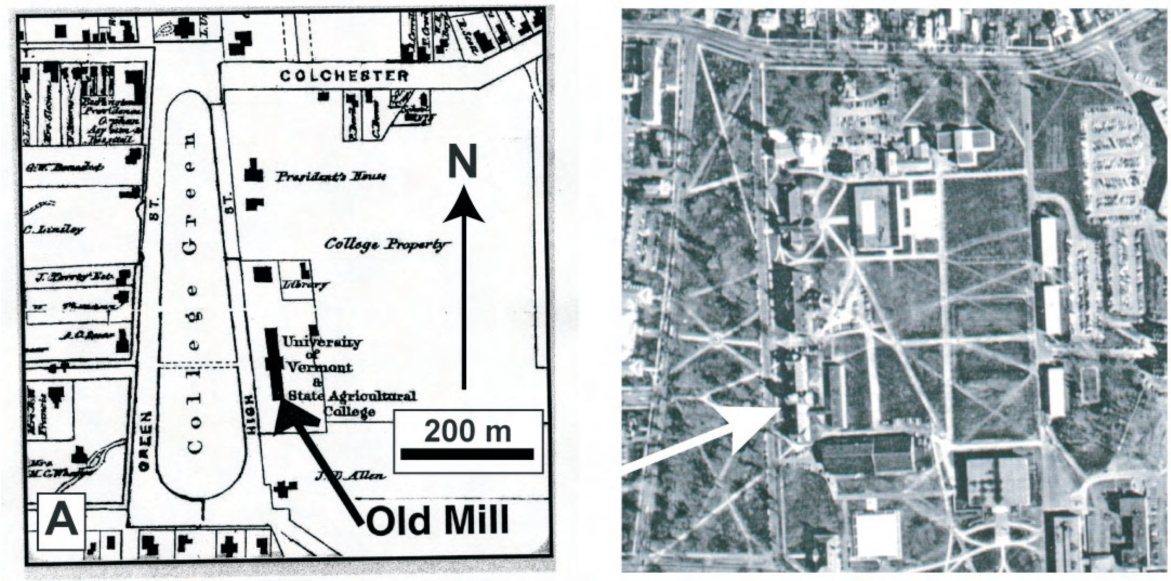


Figure 4. Diagrams showing loss of greenspace on campus. A. 1869 map of UVM campus. B. 1969 aerial photograph of same area of UVM main campus. Scales are approximately the same. Note the loss of greenspace by extensive construction and the numerous walkways.

Street	Location	Percent Greenspace loss Since 1978	Current Percent Impervious Cover
Buell	South side	43	76
Buell	North side	46	78
Loomis	South side	47	83
Loomis	North side	48	81
Willard	Both sides	39	75
Summit	Both sides	2	24

Table 2. UVM 2001 Hydrology Class data on land use change. On Buell, Loomis, and Willard Streets alone, 2.2 acres of greenspace is now pavement.

in most introductory hydrology textbooks, such as Dunne and Leopold (1978).

Determining the effect of land use change on the peak intensity of urban runoff was another important goal of the project. Students used the *rational runoff method* to estimate peak discharge for their mapping areas as land use changed. The rational runoff method is a 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 for small basins. The method assumes that rainfall of uniform intensity covers the entire drainage basin. The peak 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 of C can be obtained from Dunne and Leopold (1978) and the U.S. Soil Conservation Service (1972) for 5 to 10 year storms; values of C should be adjusted upward for larger storms (Rantz, 1971).

In order to relate the land use 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, the property condition, or the property ownership, and the conversion of green space into parking. 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.

Results - Maps depicting land use change, the hydrologic calculations, and the statistical analyses shocked most students. Between 1978 and 1999, 39% to 48% of green space was lost in the mapped areas occupied heavily by students, while only 2% green space was lost in the 100% owner-occupied control

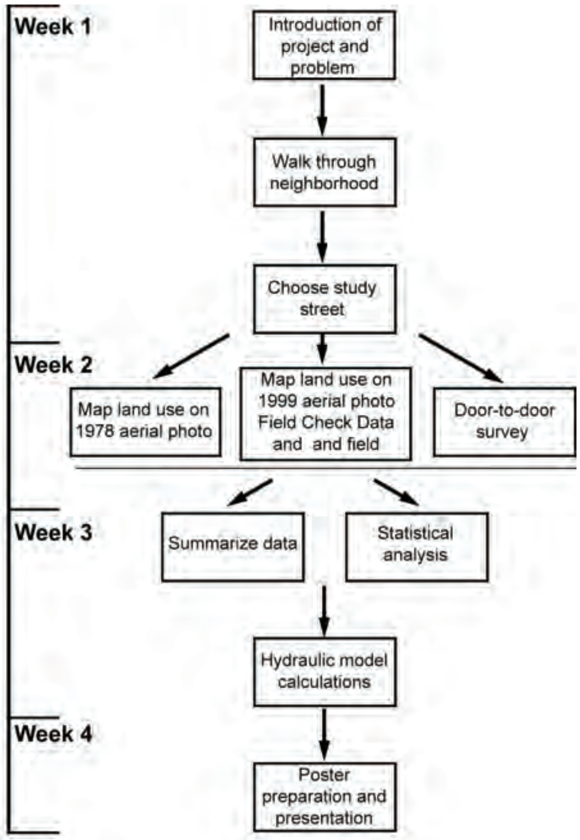


Figure 5. Flow chart showing the service-learning process for the Geohydrology project from start to finish. Many of the student-performed activities such as mapping, door-to-door surveys, and field checking can be completed in any order.

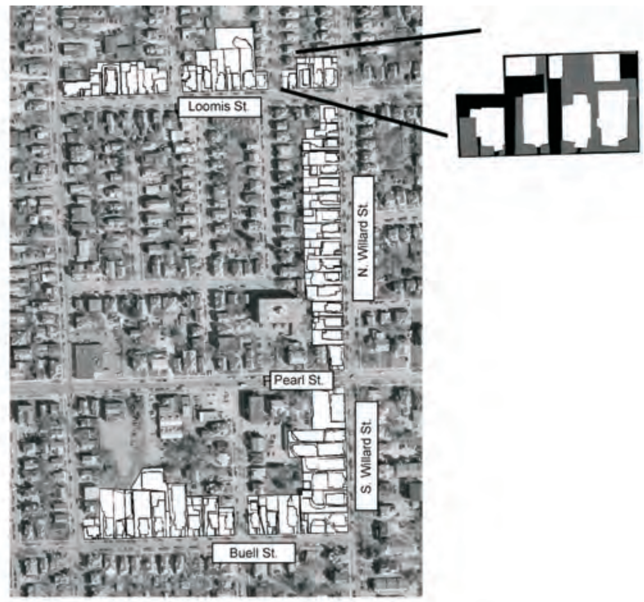


Figure 6. Land use overly map of 1999 aerial photograph. Each polygon is coded to a different land use described in Table 1. Students used their coverage maps to quantify the percentage of each land use category. They used these percentages to develop weighted curve numbers. Blowup of Loomis St.: Black = Sidewalks, formal, and informal parking, White = Buildings, Stippled = Greenspace.

neighborhood (Table 2). The total impervious cover for these impacted blocks ranges from 75% to 83%, much higher than the 35% maximum lot coverage allowed by city ordinance. 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 over the 21-year period. This is equivalent to paving 1/3 of the College Green (Figure 4A), a measure that students and townspeople alike can readily comprehend.

The results of the hydrologic calculations were similarly impressive. When the land was mostly forest or pasture, using a 2-acre plot for comparison, the 10-year, 6-hour storm would generate 41 m^3 of runoff from a 2-acre plot. However, after development to 1978 levels (a conservative 60% greenspace and 40% impermeable coverage) the same storm would generate 185 m^3 of runoff. By converting half the greenspace in 1978 to parking areas in 1999, runoff increased to 308 m^3, an increase of 66%. The results of the peak discharge calculations parallel those for runoff volumes. Modeling suggests that peak discharges increased from 0.011 m^3 sec^{-1} to 0.016 m^3 sec^{-1} between 1978 and 1999, an increase of 45% in 21 years. Although we did not test water quality directly, higher runoff volumes and peak discharges decrease storm water quality (Tasker and Driver, 1988; Driver and Troutman, 1989). In addition to poorer water quality, there are eyewitness accounts from the lower elevations in Burlington of storm sewer overflows, which occurred during heavy rainstorms within the last 10 years. The storm sewer overflow observations support model results of 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. Mellilo's work showed over 75% of rental properties contained at least one student in a neighborhood adjacent to the University. Owner-occupied properties in this area show no significant increase in parking area over the 21 years between 1978 and 1999 (Kurfis and Bierman, 2002; data available from, University of Vermont Geology Department, 2002b).

The conversion of green space to parking is probably driven by economics. Apartments with off-street parking, whether in compliance with zoning or not, are desirable rental units. In non-owner occupied properties, the number of occupants and cars per parcel are higher and the property quality assessment is markedly lower than for owner-occupied properties (Kurfis and Bierman, 2002). The vacancy rate for Burlington is currently so low (0.24% for rentals; Community & Economic Development Office, 2002) that landlords can command high rents and have little incentive to maintain their properties.

Community Outreach - Students are required to 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. Other presentations are poster-based and done in the classroom. Some students have presented their work at national meetings of professional

UNIT SURVEY

Address ______________________ Owner Occupied (Y) (N) ______________________

Apartment # ______________________

____

# of cars associated with this apartment / unit ______________________

____

Occupancy ___________- # of Bedrooms ____________-

Average monthly cost of living per person in unit __________-

Primary occupation of residents in unit ___________________________-

Is there difficulty in finding a parking place?

Never Sometimes Often Usually Always

Do you or anyone who lives here, park on areas other than a paved driveway?

Never Sometimes Often Usually Always

Is there garbage/rubbish leftover that is not taken away ?

Never Sometimes Often Usually Always

Did you know that the City of Burlington has an ordinance governing parking on areas other than driveways?

YES NO

Have you ever contacted the City of Burlington about problems or issues in your unit or adjacent properties?

If so, who did you contact?____

Were you satisfied with the results? YES NO

Figure 7. Door-to-door survey used by students in assessing properties. Survey is easily understood by residents and can be completed rapidly.

organizations (Kurfis et al., 2001; Persico et al., 2000). 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 (Page, 2002). The data have also been 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. Many of the students lived in the mapped areas, some routinely parked their cars on lawns, and all were surprised by the results of the project. Most students became engaged in the project, and each team did a significant amount of work. The students prepared attractive, readable, and data-rich posters for the public presentation. After the public presentation, a majority of the students stayed to discuss the connection between the hydrologic and social changes in land use. As a group, they came up with a variety of ideas for preventing future green space loss and remediating areas already affected. Suggestions included building community-parking garages in areas that were already used as parking lots, turning the roofs of these garages into grassy public parks, increasing both the number and attractiveness of on-campus housing units, and increasing zoning enforcement.

CONCLUSIONS

Field-based, service-learning projects are useful for teach hydrology and to encourage student interaction with the community. Urban hydrology, particularly, connects scientific and social issues at a local level. Students respond enthusiastically to real-world applications that have implications for the society in which they live. The documented loss of residential green space 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 system, Lake Champlain into which some storm sewers empty, and the quality of life in Burlington neighborhoods. Service learning-hydrology projects such as this provide a forum for students, government agencies, and community members to interact with each other and for each to benefit from different aspects of the project (University of Vermont Geology Department, 2002c and 2002d).

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