Nonpoint Education for Municipal Officials
Impervious Surface Research

Final Report

John C. Clausen, Glenn Warner, Dan Civco, and Mark Hood
University of Connecticut
Department of Natural Resources Management and Engineering

May 28, 2003

Table of Contents

Funded in part by the CT DEP through a US EPA nonpoint source grant under Section 319 Clean Water Act.

Introduction

The purpose of this project was to relate the percentage of impervious area to water quality. This objective emerged out of knowledge that water bodies in Connecticut, such as Long Island Sound, are impaired due to nonpoint source pollution, and that urban areas contribute to that pollution (US EPA, 2002). Planners and managers are looking for ways to reduce this pollution. Understanding the relationship between imperviousness and water quality would allow for informed land use management decisions.

It is known that urbanization increases the volume, duration and intensity of urban stormwater runoff (Booth and Jackson, 1997; Leopold 1968). Such flow increases might be expected to adversely impact water quality as well since many nonpoint water quality constituents are positively correlated with flow.

There have been several projects that relate either biotic stream characteristics or stream integrity to % imperviousness. Scheuler (1994) related % imperviousness to macroinvetebrate metrics. May et al. (1997) relate %total impervious area (TIA) to large woody debris, index of biotic integrity (IBI) score, and riparian buffer widths. Finkenbine et al. (2000) relate %TIA to characteristics of stream beds in British Columbia.

Numerous studies have related water quality to the percentage of land use or land cover in a watershed. Over 25 years ago Omernik (1976) showed that stream concentrations of inorganic nitrogen ($r= 0.82$) and orthophosphorus ($r= 0.70$) increased with an increase in combined percent of urban plus agricultural land use in watersheds. Since then, several studies have collaborated this finding. A study of the Etowah River catchment in North Central Georgia found concentrations of specific conductance ($r^2=0.48$), total suspended solids (TSS) ($r^2=0.28$), nitrate/nitrite nitrogen (NO_3/NO_2-N) ($r^2=0.24$), ammonium nitrogen (NH_4-N) ($r^2=0.16$) and soluble reactive phosphorous ($r^2=0.24$) to be positively correlated ($p<0.05$) with percent urban land cover (Roy et. al 2003).

Much attention has been devoted to the use of imperviousness thresholds in the literature. Research into the impact of urbanization on the biotic (Wang et al. 1997, Roy et al. 2003, Finkenbine et al. 2000; May et al., 1997), and physical (Wang et al. 1997, Booth and Reinelt 1993, Booth and Jackson 1997, Bledsoe and Watson 2001) integrity of streams has suggested that stream degradation occurs between 10%-20% imperviousness (Scheuler, 1994). However, a recent literature review concludes that a single threshold value is difficult to recommend (Brabec et al., 2002). Their summary suggests that thresholds have ranged from 4 to 12 % for fish populations, 8-15 % for macroinvertebrates, and 4 to 50 % for abiotic measurements such as water quality and habitat.

Herlihy et al. (1998) used multiple regression between stream chemistry and five land use classes (forests, agriculture, urban, wetland, and barren) to examine 368 streams in the mid-Atlantic United States. Significant ($p=0.05$) regressions existed for nitrate ($r^2= 0.39$ total phosphorus ($r^2= 0.31$), chloride ($r^2= 0.48$), base cations (Ca, Mg, Na, K)($r^2= 0.40$), and acid neutralizing capacity (r^2= 0.30). Herlihy et al. (1998) suggest that chloride, which reaches streams from numerous anthropogenic sources including road salting and fertilizer use could be a good indicator of human disturbance in a watershed.

One study found a negative correlation between event mean concentrations of total nitrogen (r= -0.200) and percent impervious area (Brezonik and Stadelmann, 2001). This study in Minnesota compiled data from 15 studies for 68 watersheds. The reasons for this deviation from other studies were not given, but Brezonik and Stadelmann (2001) noted that many factors contribute to runoff concentrations.

.

Urbanization has been determined to be a large anthropogenic source of nitrogen in receiving waters of the northeastern U.S.(Boyer et al. 2002). In a study of 16 catchments Boyer et al. (2002) found that total nitrogen input has a strong positive correlation (r^2= 0.96) (y=103x + 713) with percent of urbanized plus percent of agricultural land.

Recent works, especially those summarized in the literature review by Brabec et al. (2002), suggest that % imperviousness should be related to the water quality of Connecticut streams. However, no such comparison has been made. In fact, at the beginning of this study knowledge of the % impervious by watershed was not yet available.

Methods

Several potential sources of Connecticut water quality data were examined for use in this study. These sources include the U.S. Geological Survey (USGS), the Regional Water Authority and the Bridgeport Hydraulic Company. Metropolitan District Commission data were not considered appropriate as it applies to reservoirs. Water quality data were compiled for the water years 1994-1999. These water years bracket the 1997 land use/land cover source data. Following further examination, the USGS data was found to have the desirable characteristics for study. Fifteen basins were selected (Table 1, Figure 1). These watersheds were originally chosen because they were the smaller watersheds with gaging stations in Connecticut, did not have major reservoirs, and had relatively long periods of record.

For each basin, an average of the mean annual concentration was calculated for 1994-1999. The water quality variables used were those that might be expected to be related to urban stormwater runoff and included total residue, total nitrogen, total phosphorus, Chloride, and fecal coliform bacteria.

Land use and land cover data were obtained from Civco and Hurd (1999). The original source of this information was satellite imagery dated April 28, 1994, May 8, 1995, August 28, 1995, and September 6, 1995. Cell size for the classification was 100 ft by 100 ft. There were 28 land use and land cover classes developed. For this study the urban classification included the following classes: commercial & industrial & pavement (1), commercial & residential (2), rural residential (3), turf & tree complex (4), and turf & grass (5). The agricultural classification included the classes: pasture & hay & grass (6), pasture & hay/cropland (7), pasture & hay/exposed soil (8), exposed soil/cropland (9), exposed soil (10), shade-grown tobacco (11).

Percent impervious surface was determined from methods described in Flanagan and Civco (2001) and Civco et al. (2002). The ERDAS Imagine SubPixel Classifier was applied to Landsat TM and ETM+ data. The SubPixel Classifier is a supervised classifier that enables the detection of whole or fractional pixel compositions. The minimum detectable threshold was 20 percent with increments of 10 percent (*i.e.*, 20to 30%, 30 to 40%, . . . , 90 to 100). The procedures used in the impervious surface mapping were augmented to include a water mask, to eliminate the possible confusion with dark impervious surfaces.

The accuracy of the percent impervious surface estimates has been determined by comparison with planimetric data. These results indicate that the method produces estimates of percent imperviousness very close to those provided by the validation planimetric data.

Simple linear regression was used to relate either % impervious or land use/land cover to water quality concentrations. Regressions were tested for significance using the analysis of variance of regression with the JMP version 5 software (SAS Institute, Inc. 2002).

Results

Mean stream concentrations for the 15 monitored basins were generally found to be positively related to the % Urban land use (Table 2, Figures 2-16). These relationships existed despite the presence of WWTPs in most of the watersheds. This relationship between % Urban land use and water quality is not surprising. As long ago as 1975 Omernik (1976) reported that % urban land use was related to concentrations of nitrogen and phosphorus. The Still River in Brookfield had higher concentrations of total residue, total N, Cl, and fecal coliform than might be expected based on the % Urban land use in the watershed. Also, the Still River watershed does not have any wastewater treatment plants (WWTP) in the watershed.

When the % agriculture land use was added to the % urban land use, the relationships between stream concentrations and land use/land cover generally improved (Table 2, Figures 2-16) for total nitrogen, total phosphorus, and fecal coliform concentrations. These relationships were not improved for total residue and Cl concentrations. The Still River remained an outlier in this comparison.

The relationship between % Urban land use and % Impervious was significant (Figure 17). The Still R. had a larger % Impervious value than expected based on the % Urban land use. Perhaps the % Urban value is in error. Since % Imperious is highly related to % Urban land use, significant relationships between stream concentrations and % Impervious would be expected. The % Impervious in a watershed was significantly related to all water quality characteristics examined (Table 2, Figures 2-16). The results further suggest that no effect on the concentrations (i.e. y=0) occurs at 4 % Impervious for total N, total P, and fecal coliform concentrations. This threshold ignores natural background concentrations. Exceptions occurred for total residue and Cl concentrations where positive intercepts were observed (Figures 4 and 13).

Conclusions

The quality of streamflow for 15 streams in Connecticut was found to be significantly related to the % imperviousness, the % urban land cover, and the % urban + % agriculture land cover. These relationships exist despite the presence of WWTPs in most watersheds. This finding suggests that management of nonpoint source pollution will be difficult in urban watersheds. Practices are needed that can compensate for the direct impact of imperviousness. Unfortunately, there are no large watersheds in Connecticut where such practices are in wide use today.

Acknowledgements

The authors wish to acknowledge significant contributions by University of Connecticut graduate students, John Guszkowski and John Christian, both who compiled data sets and obtained geographic information system data. Laurie Giannotti provided valuable assistance in guiding this project. Support for this project by Stan Zaremba at the Connecticut Department of Environmental Protection was central to the project's success.

References

Bledsoe, B.P., Watson, C.C., 2001. Effects of urbanization on channel instability, Journal of the American Water Resources Association, 37 (2): 255-270.

Booth, D.B., Jackson, R.C., 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Association, 33 (5): 1077-1090.

Booth, D.B., Reinelt, L.E., 1993. Consequences of urbanization on aquatic systems- measured effects, degradation thresholds, and corrective strategies. Watersheds '93, Conference sponsored by the U.S. Environmental Protection Agency, Alexandria, Virginia, March 21-24, pp. 545-550.

Boyer, E.W., Goodale, C.L., Jaworsk, N.A., Howarth, R.W., 2002. Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA Biogeochemistry, 57 (1): 137-169.

Brabec, E., S. Schulte, and P. L. Richards. 2002. Impervious surfaces and water quality: A review of current literature and its implications for watershed planning. J. of Planning Literature 16(4):499-514.

Brezonik, P., Stadelmann T., 2001. Analysis and predictive models of stormwater runoff volumes, loads and pollutant concentrations from watersheds in the twin cites metropolitan area, Minnesota, USA. Water Research, 36 1743-1757.

Civco, D. L. and J. D. Hurd. 1999. A hierarchical approach to land use and land cover mapping using multiple image types. Proceeding of the1999 ASPRS Annual Convention, Portland, OR. Pp. 687-698.

Civco, D.L., J.D. Hurd, E. H. Wilson, C. L. Arnold, and S. Prisloe. 2002 Quantifying and describing urbanizing landscapes in the Northeast United States. Photogrammetric Engineering and Remote Sensing 68(10)1083-1090.

Finkenbine, J. K., Atwater, J.W., Mavinic, D.S., 2000. Stream health after urbanization, Journal of the American Water Resources Association, 36 (5): 1149-1160.

Flanagan, M. and D.L. Civco. 2001. Subpixel impervious surface mapping. Proc. 2001 ASPRS Annual Convention. St. Louis, MO.

Herlihy, A.T., Stoddard, J.L., Johnson, C.B., 1998. The relationship between stream chemistry and watershed land cover data in the mid Atlantic region, US, Water Air and Soil Pollution, 105 (1-2): 377-386.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, E. B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound lowland ecoregion. Watershed Protection Techniques 2(4):483-494.

Leopold, L. B. 1968. Hydrology for urban land planning – A guidebook on the hydrologic effects of urban land use. Geological Survey Circular 554.

Omernik, J. M. 1976. The influence of land use on stream nutrient levels. EPA 600/3-76-014. U. S. Environmental Protection Agency, Washington D.C.

Roy, H.A, Rosemond, D.A., Paul, J. M., Leign, D. S., Wallace, B. J., 2003. Stream macroinvertebrate response to catchment urbanization (Georgia, USA), Freshwater Biology, 48, 329-346.

SAS Institute, Inc. 2002. JMP Version 5. Statistics and Graphics Guide. Cary, NC 27513.

Schueler, T., 1994. The Importance of Imperviousness. Watershed Protection Techniques 1(3):100-111.

U.S. Environmental Protection Agency. 2002. National Water Quality Inventory. 2000 Report. EPA-841-R-02-001. Office of Water, Washington, D.C. 20460.

Wang, L., Lyons, P., Gatti, R., 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams, Fisheries, 22 (6): 6-12.

Table 1. Summary of Connecticut watersheds studied.

USGS Basin	Station No.	Basin No.	Town	Area (ha)	Urban (%)	Agriculture (%)	Impervious (%)	WWTP No.
Burlington Brook	01188000	4311	Burlington, CT	1,062	6.35	10.57	6.18	0
Farmington River	01188090	4300	Unionville, CT	97,902	11.63	8.05	7.97	2
French River	01125100	3300	Grosvenordale, CT	26,159	12.87	7.79	6.76	1
Hockanum River	01192500	4500	East Hartford, CT	19,011	43.43	11.33	19.66	1
Naugatuck River	01208049	6900	Waterville, CT	35,224	24.03	6	15.72	2
Norwalk River	01209710	7300	Winnipauk, CT	8,547	37.18	3.93	18.06	3
Pequabuck River	01189030	4315	Farmington, CT	14,815	36.49	11.21	18.53	4
Quinnebaug River	01124000	3700	Quinebaug, CT	40,145	9.31	12.39	7.52	3
Quinnipiac River	01196222	5200	Meriden, CT	18,026	45.05	11.1	21.09	2
Salmon River	01193500	4700	East Hampton, CT	25,900	3.09	4.27	3.17	0
Saugatuck River	01208990	7200	Redding, CT	5,439	18.15	4.59	7.73	0
Shepaug River	01203000	6700	Roxbury, CT	34,188	4.24	16.45	3.62	1
Shetucket River	01122610	3800	South Windham, CT	105,672	11.74	11.82	8.15	1
Still River	01201487	6600	Brookfield Center, CT	16,136	13.42	6.68	20.81	0
Willimantic River	01119375	3100	Merrow, CT	24,346	10.6	7.95	7.69	1

Table 2. Significance of simple linear regressions for percent impervious surface.

	% Urban			% Urban + % Agriculture			% Impervious		
Variable	F-ratio	p>F	R^2	F-ratio	p>F	R^2	F-ratio	p>F	R^2
Total Residue	11.323	0.005	0.466	9.387	0.009	0.419	37.340	<0.001	0.742
Total Nitrogen	7.564	0.016	0.368	8.297	0.013	0.390	28.435	<0.001	0.686
Total Phosphorus	16.502	0.001	0.559	21.549	<0.001	0.624	14.416	0.002	0.526
Dissolved Chloride	7.799	0.015	0.375	5.379	0.037	0.293	38.816	<0.001	0.749
Fecal Coliform	8.798	0.011	0.404	9.531	0.009	0.423	25.402	<0.001	0.662

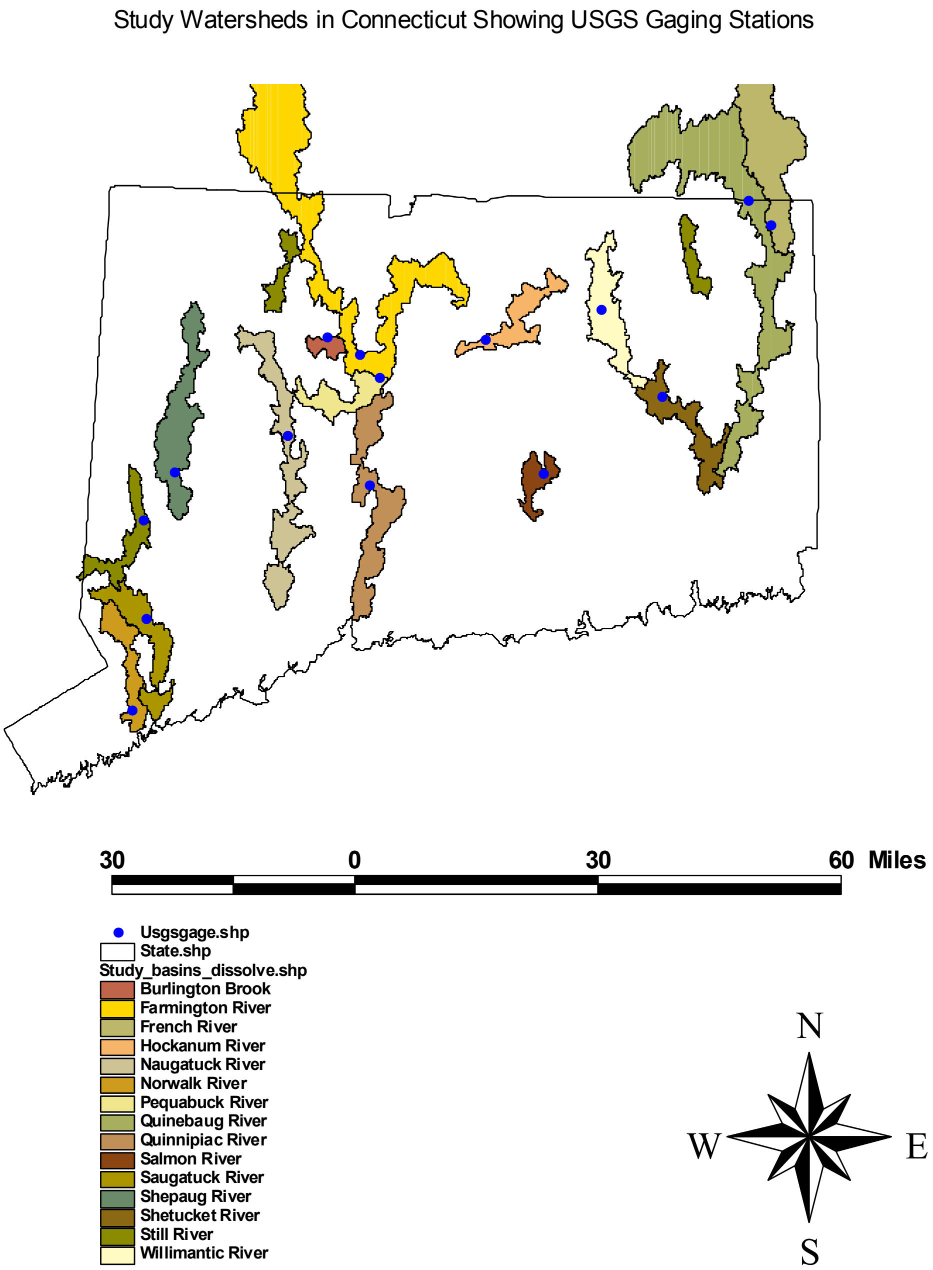

Figure 1. Map of Connecticut showing 15 study watersheds and gaging stations.

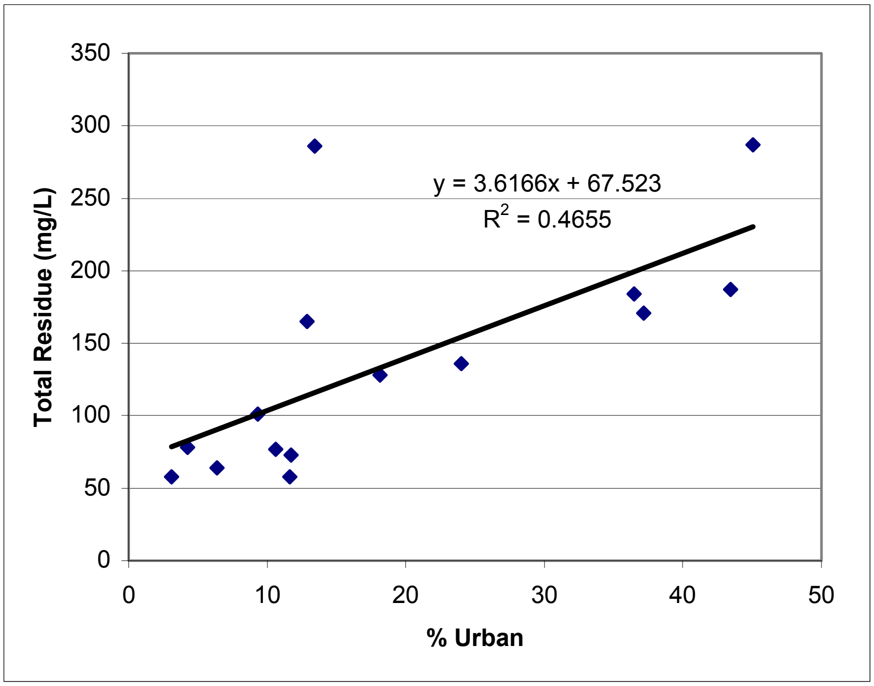

Figure 2. Total residue stream concentrations as a function of % urban land cover in Connecticut.

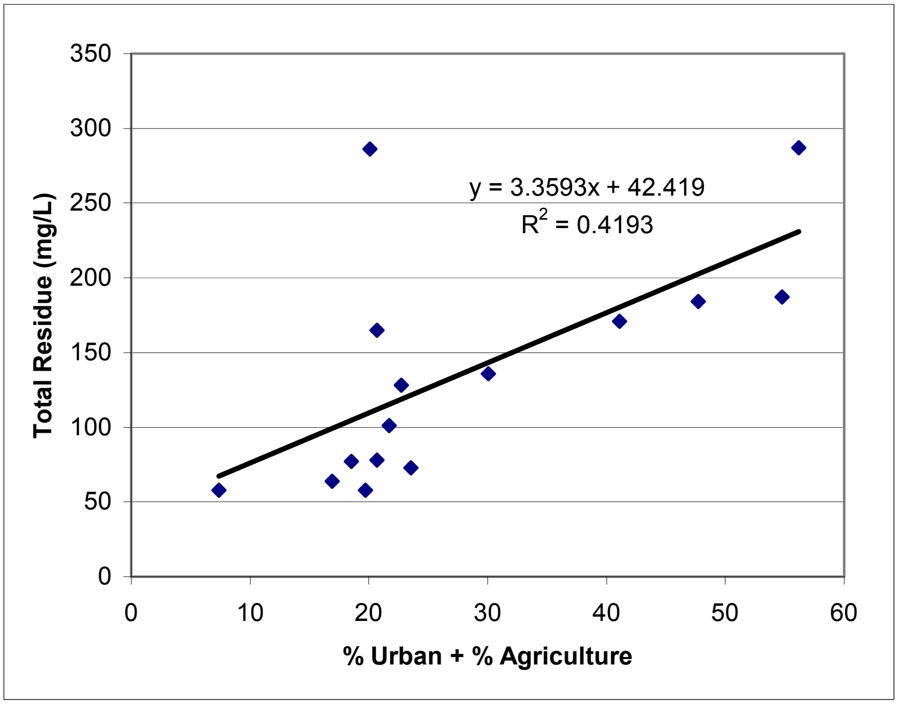

Figure 3. Total residue stream concentrations as a function of % urban + % agriculture land cover in Connecticut.

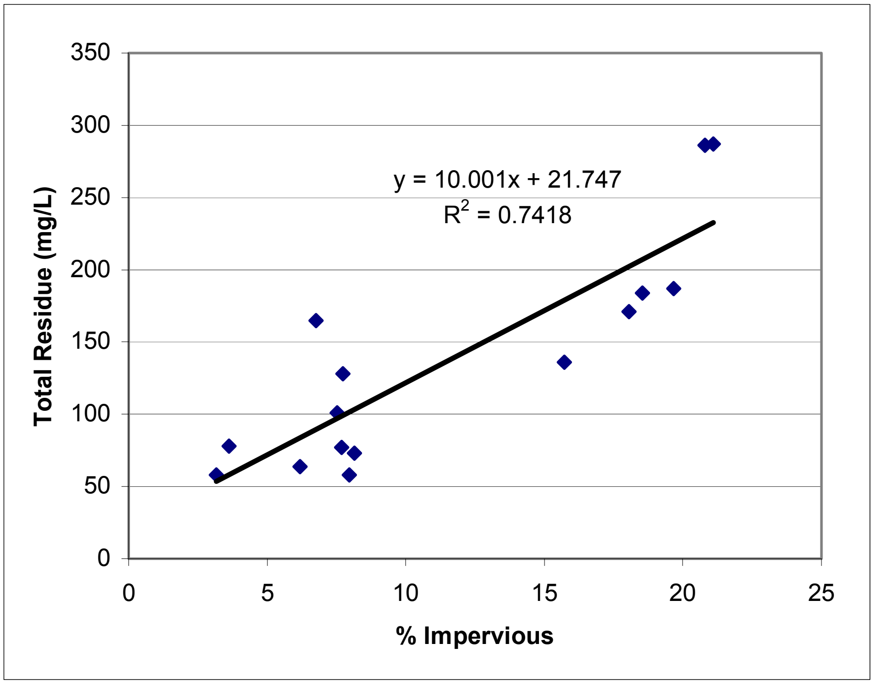

Figure 4. Total residue stream concentrations as a function of % impervious surface in Connecticut.

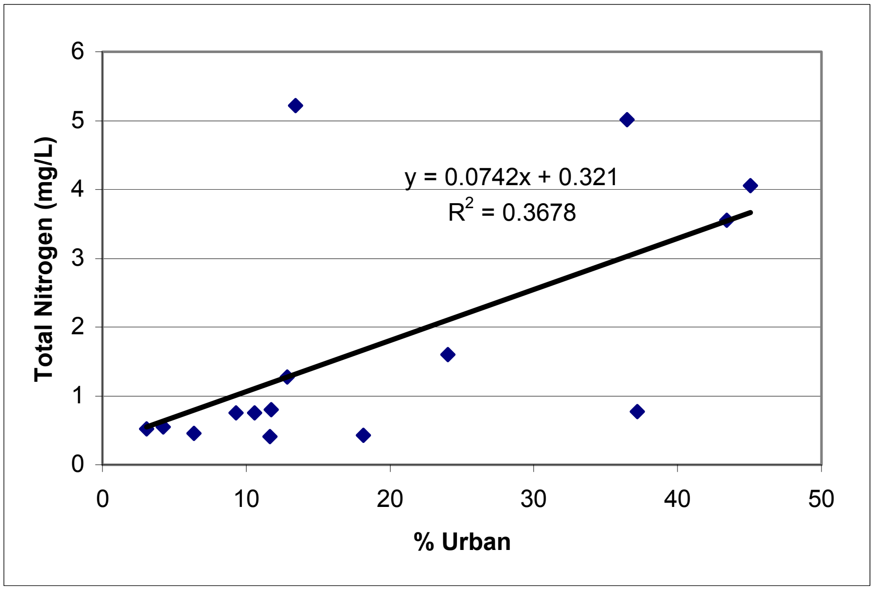

Figure 5. Total nitrogen concentrations as a function of % urban land cover in Connecticut.

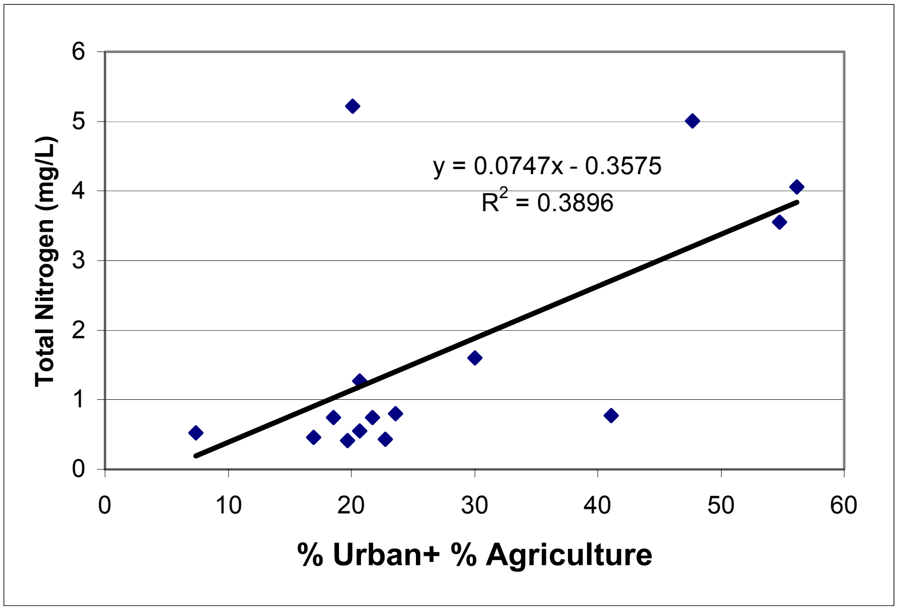

Figure 6. Total nitrogen stream concentrations as a function of % urban + % agriculture land cover in Connecticut.

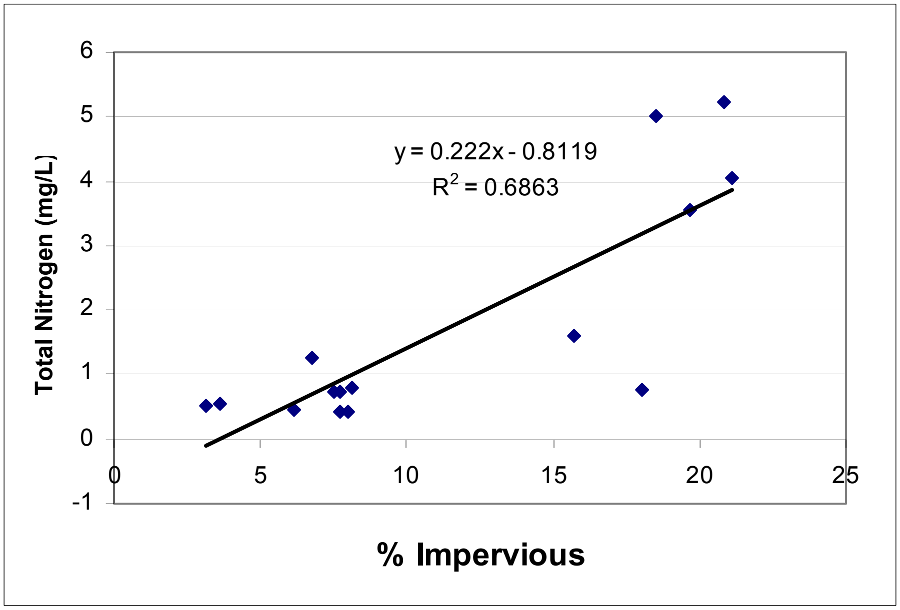

Figure 7. Total nitrogen stream concentrations as a function of % impervious surface in Connecticut.

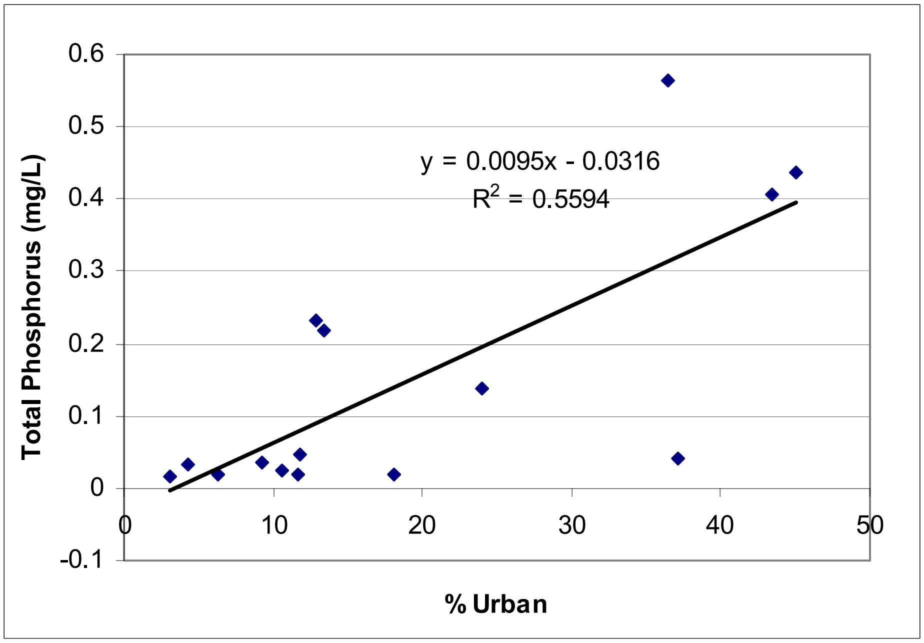

Figure 8. Total phosphorus stream concentrations as a function of % urban land cover in Connecticut.

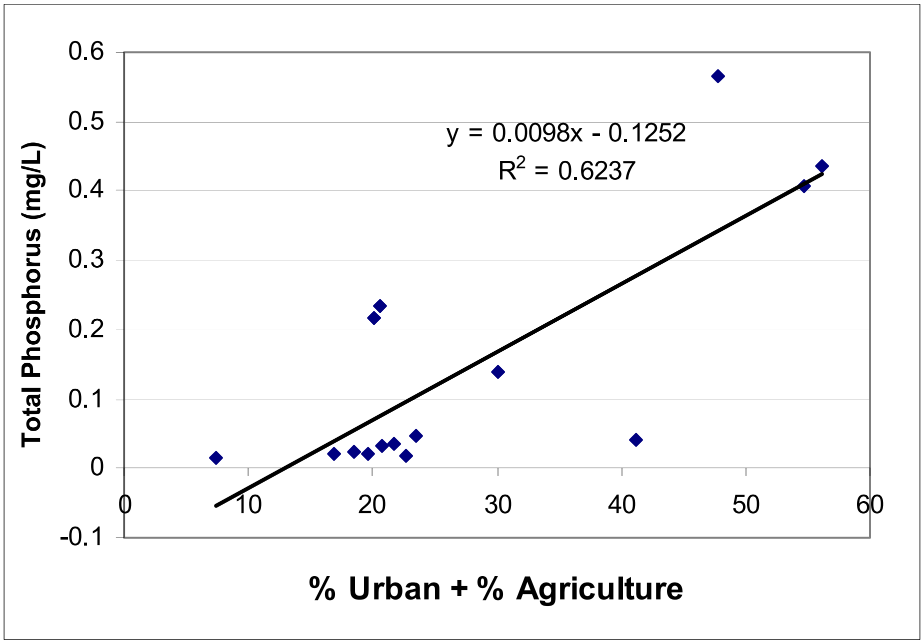

Figure 9. Total phosphorus stream concentrations as a function of % urban + % agriculture land cover in Connecticut.

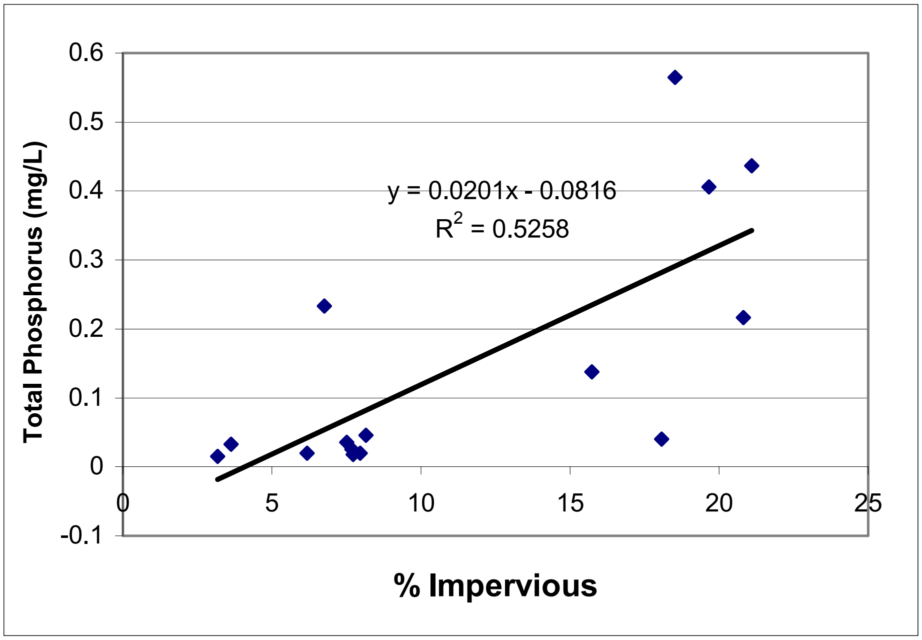

Figure 10. Total phosphorus stream concentrations as a function of % impervious surface in Connecticut.

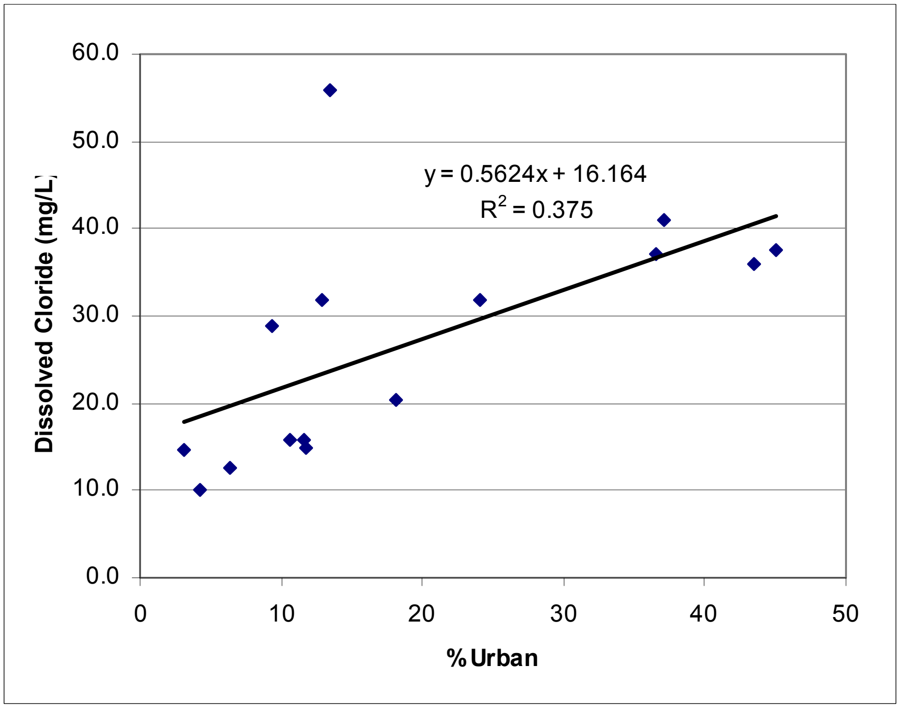

Figure 11. Dissolved chloride concentrations as a function of % urban land cover in Connecticut.

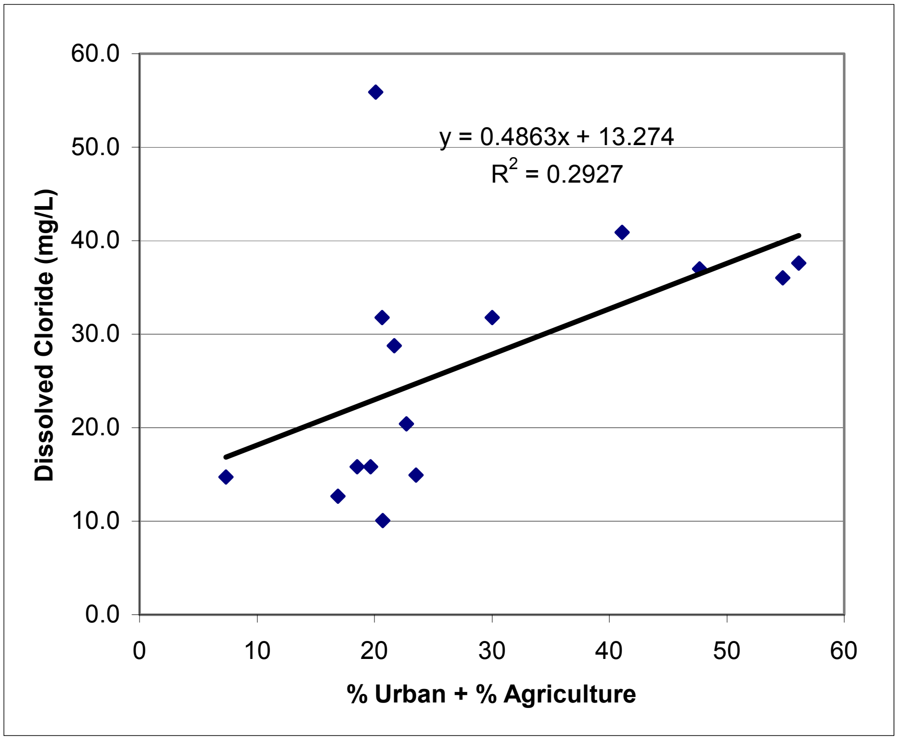

Figure 12. Dissolved chloride stream concentrations as a function of % urban + % agriculture land cover in Connecticut.

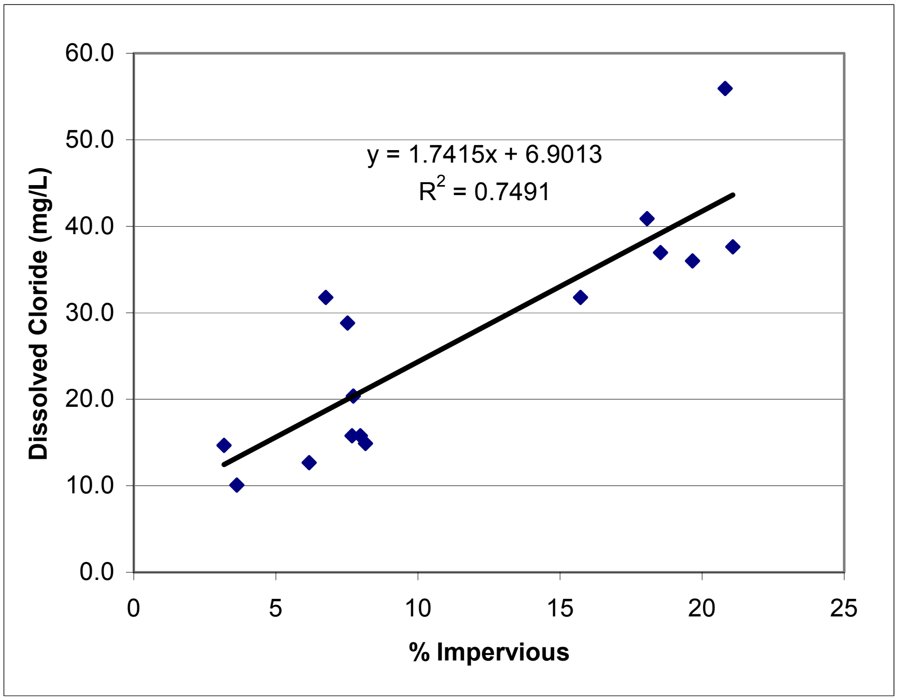

Figure 13. Dissolved chloride stream concentrations as a function of % impervious surface in Connecticut.

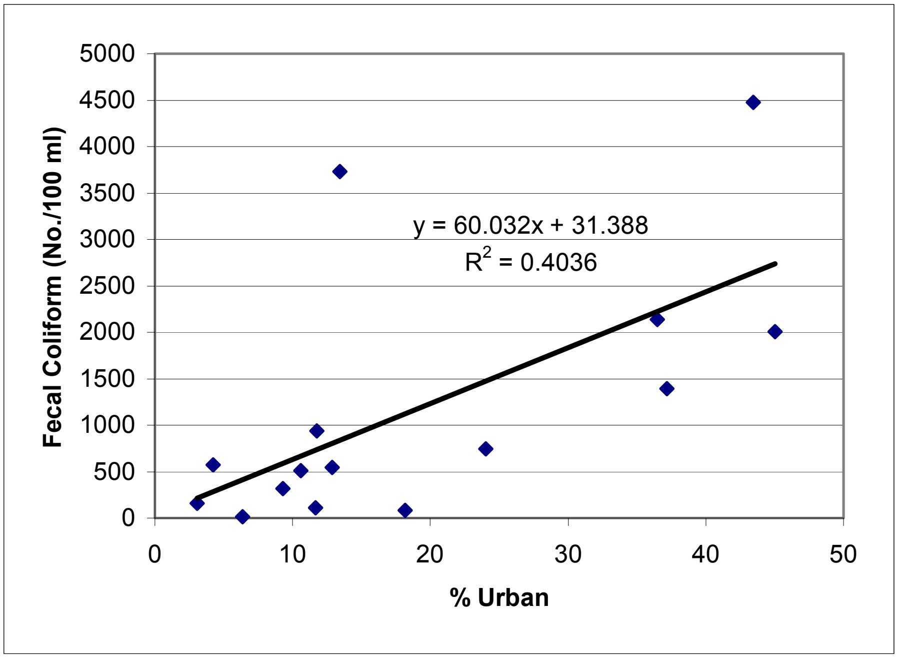

Figure 14. Fecal coliform bacteria stream abundance as a function of % urban land cover in Connecticut.

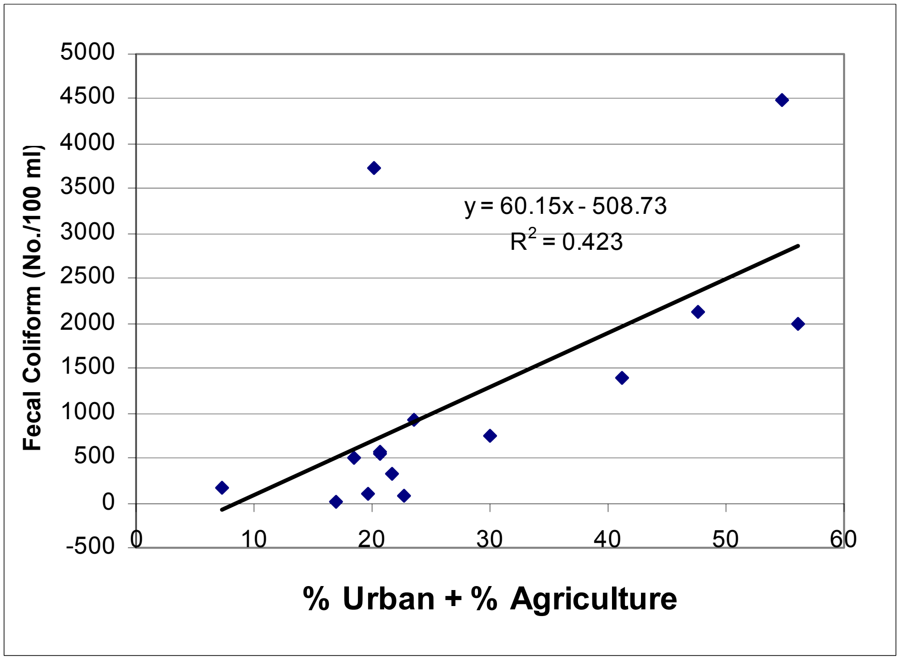

Figure 15. Fecal coliform bacteria stream abundance as a function of % urban + % agriculture land cover in Connecticut.

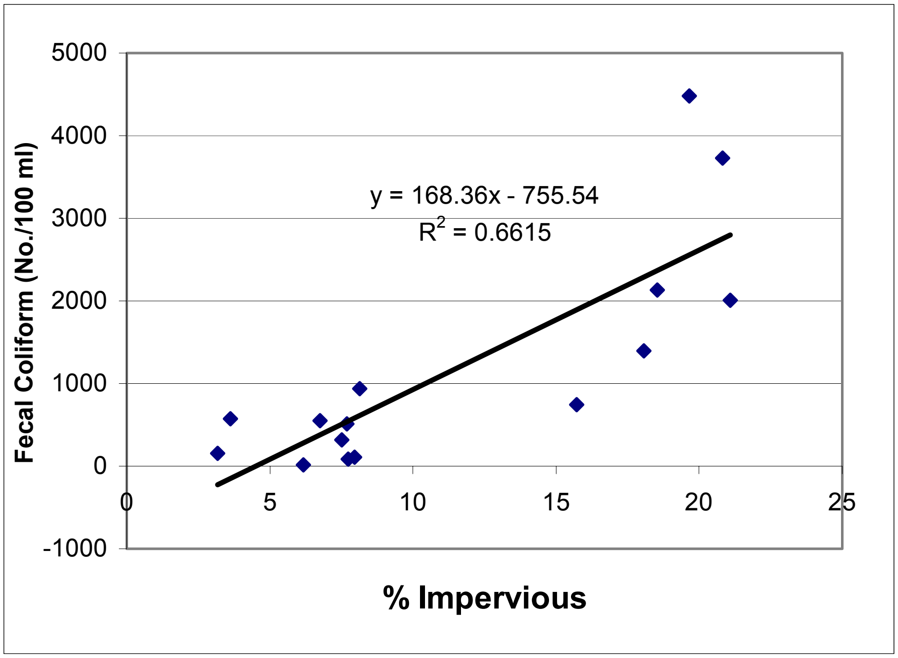

Figure 16. Fecal coliform stream abundance as a function of % impervious surface in Connecticut.

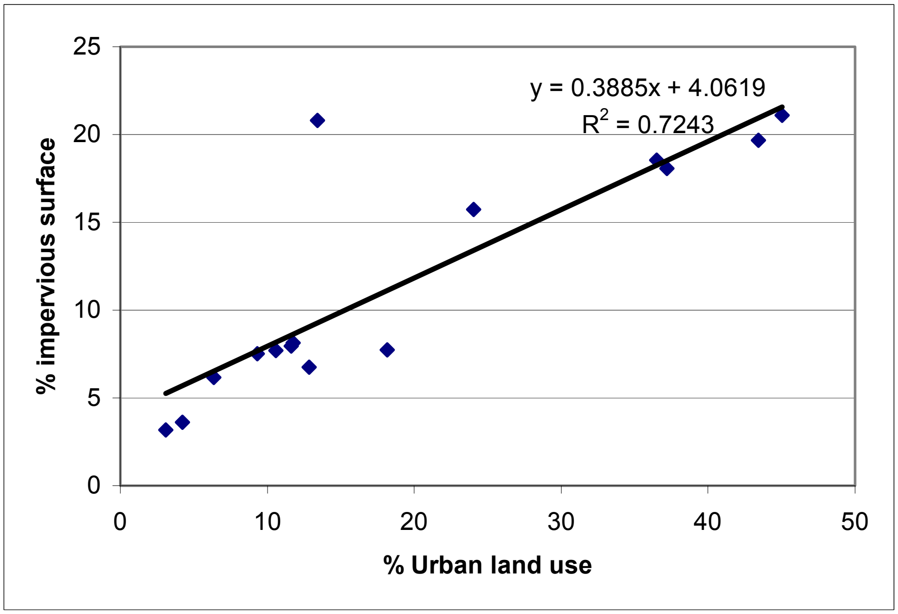

Figure 17. Percent impervious surface as a function of % urban land use for study watersheds in Connecticut.