ANNUAL REPORT
Project Years 1 and 2 (2003-2005)

Redesigning the American Neighborhood: Cost Effectiveness of Interventions in Stormwater Management at Different Scales

Grant No. X 98187601

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27 November 2006

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1. Project Background

In undeveloped environments rain usually falls on dense vegetation in woods or meadows. The plants absorb the impact of the water, part of which is then filtered through soils before reaching groundwater below, and eventually, receiving waters such as streams and ponds. This natural process is relatively slow compared to the hydrodynamics in developed environments, where overland flow over impervious areas prevails. In contrast, when rain falls on traditionally-developed areas, a variety of engineered systems collect, concentrate, and then abruptly discharge the stormwater into local receiving waters. The hydrologic cycle is, to a large degree, accelerated and the rainwater accumulates contaminants, including suspended sediments, heavy metals, hydrocarbons, and pathogens that may impair the uses of the receiving waters (Burns et al. 2005, Paul and Meyer 2001, Walsh et al. 2005).

A common response to these impairments is to construct centralized engineered facilities to treat the stormwater. This strategy has associated short-term economic costs and benefits that are relatively easy to quantify (Hartigan 1986). However, there are also long-term ecological, and especially social, costs and benefits that are often not as easy to quantify (Lieb and Carline 2000). In the case of centrally-located detention ponds, for example, the economic costs for construction can easily be compared to the benefits gained in protection of downstream values in receiving waters (Braden and Johnston 2004). Similarly, the short-term environmental benefits are well known (e.g. contaminant settling and discharge reduction) (Wakelin et al. 2003). However, some costs (e.g. lack of protection of upstream receiving waters, failure to protect against some impairments, like pathogens) are harder to assess. Furthermore, the social benefits of this option are rarely explored. For example, is a detention basin really the best option, or is it just the easiest one to implement either operationally or from a social perspective (e.g. it avoids a ‘not in my backyard’ response)?

Alternatively, one might consider intervening to reduce stormwater impairments of receiving waters by managing the immediate sources of the impairments. For example, water collected on roofs of buildings could be filtered through constructed wetlands (Birch et al. 2004, Carleton et al. 2000), or parking lot runoff might be directed through a series of swales set between the parking lot and a receiving water body (Rushton 2001). Green roofs are another eco-technology adapted for large flat-top buildings (Hoffman 2006, Lazzarin et al. 2005). Here the building is planted with low maintenance roof top gardens that absorb moisture, filter the rainwater, and release it more slowly into the surrounding environment. The roof-top garden has the secondary benefits of reducing heating and cooling loads within the building and reducing the atmospheric heating impact of the building on local climate. Additionally, on the personal level, it is possible to address behaviors adversely contributing to the watershed quality, such as improper lawn fertilization, composting practices, pesticide and herbicide application, and disposal of household and consumer products such as cleaners and automotive fluids (Barr and Gilg 2006, Homburg and Stolberg 2006).

There is no single, all-encompassing, centralized solution for stormwater management in developed watersheds. Rather, each watershed has numerous potential points of intervention. Intervention can occur at several different levels, including the household, farmstead, city block, mall, industrial park, and roadway. Using a diverse palette of ideas, technologies, engineering approaches, and organisms, it is possible to change each of these components of medium density neighborhoods to lessen and manage stormwater impacts. Furthermore, while we can't “engineer” people to behave differently, we can include homeowners, developers, and other stakeholders in participatory processes that create economic and non-economic incentives to move in the right direction. There is overwhelming evidence that this process of *shared learning* is probably the most critical element to ensure long-term acceptance and success in any watershed-level management effort (e.g., Blumenthal and Jannink 2000, Costanza et al. 2002, Goma et al. 2001, Mendoza and Prabhu 2000, van den Belt, 2004).

The fundamental philosophy of ecological design is to substitute ecosystem services and information, mostly from the natural world, for costly hardware and "hard" engineering. Implementation of low-impact, ecologically-designed, stormwater management practices is relatively easy in the case of new construction if incentives or willingness exists to use them. It is a much greater challenge to retrofit existing, traditionally constructed developments to a low-impact, ecologically-designed standard. **The goal of this multi-year project was to develop approaches to identify practicable low-impact stormwater management alternatives in existing suburban environments through a combination of monitoring, research, engagement, and demonstration projects.** The purpose of this effort was to enable stakeholders, regulators, and researchers to collectively visualize alternative futures and to optimize a mix of stormwater management interventions at various scales to best balance environmental and social, as well as economic, criteria.

2. Project Objectives

We focused our research efforts on stormwater management issues that are the consequence of rapid development in South Burlington, Vermont. South Burlington is representative of towns throughout northern New England where 'sprawl' either has impaired or threatens to impair the quality of surface waters. Staff in the South Burlington Planning Office have sought innovative alternatives to traditional stormwater management technologies and have been proactive in identifying potential points of intervention and sources of funding for selected implementation projects. Thus, there were excellent opportunities to leverage the project research funds with South Burlington project implementation funds to collaborate in *research by management* experiments, particularly in the Potash Brook watershed, a focal point for recent stormwater management controversies.

We focused on the following working objectives:

> *Objective #1 - Assessment:* Develop a framework to assess opportunities for intervention in adaptive stormwater management at various spatial scales and apply this framework to the Potash Brook case study.
>
> *Objective #2 - Evaluation:* Compare the costs and benefits of the alternatives identified for the case study in Objective #1 and consider potential market-based incentives that could facilitate implementation of the identified alternatives.
>
> *Objective #3 - Participation:* Involve community stakeholders in the development and evaluation of Objectives #1 and #2 through 'town or neighborhood meetings' that rely on whole-watershed visualization tools and multi-criteria decision aids to promote shared learning among the project participants.

Objective #4 - Implementation: Initiate a demonstration project that can be used as a focal point to test ideas and designs generated by Objectives #1-3.

3. Original Research Rationale

Objective #1 (Assessment) focused on opportunities for intervention in stormwater management at different spatial scales and levels of community involvement. To meet this objective we proposed to develop a framework to assess how and where to use various types of intervention in a whole-watershed context. For Objective #2 (Evaluation) we proposed to compare the costs and benefits of these selected approaches from an ecological economics perspective. Objectives #1 and #2 were intimately linked to Objective #3 (Participation). Our fundamental premise was that success in both the Assessment (Objective #1) and Evaluation (Objective #2) components of this project would depend critically on Participation (Objective #3) by community stakeholders. These stakeholders included homeowners, developers, resource managers, and policy makers. A wide variety of tools exist to foster shared learning among stakeholders and project participants. We proposed to establish 'town or neighborhood meetings' at the onset of this project to guide both the Assessment and Evaluation components. As part of this effort we proposed to employ a general approach called 'participatory modeling' in which a number of watershed and landscape simulation tools are used as a means to facilitate discussion among stakeholders and project participants about the likely outcomes of various future management scenarios.

As a key part of this project we proposed to initiate the first phase of a longer-term demonstration project focused on "redesigning the American neighborhood" for more effective and holistic stormwater management (Objective #4 – Implementation). It is important to note two fundamental aspects of this objective. First, Objective #4 was *not* focused on proving the technical feasibility of *a particular* stormwater management technology. Rather, it was focused on development of a participatory process leading to effective stormwater management that might include a broad array of technologies or approaches and that had the *a priori* backing of the involved stakeholders. Second, for the purposes of our project, "effective" stormwater management meant more than simple attenuation of peak flows or reduction in contaminant levels. These are clearly essential metrics for success. However, other metrics - including enhancement of community well-being, improvements in ecosystem health, and profitability of economic developments - were also deemed to be important. The demonstration project proposed in Objective #4 was designed to provide a 'laboratory' for us to test the framework developed in Objectives #1-3.

Each of these objectives is intimately linked with the others and, in fact, we found it useful to regularly revisit all four objectives as this project progressed. By definition, "participation" (Objective #3) is governed by the willingness of the stakeholders to be involved. This is not a process that can be rushed nor held to a rigid schedule. Nevertheless, in the first two years of this project we were able to complete several critical tasks relevant to our primary objectives. In particular, we initiated the participatory process, refined our visualization tools, established preliminary feedback from the stakeholders, completed the background environmental assessments and provided feedback to a variety of stakeholder groups. In the following sections we review these accomplishments in greater detail.

4. Study Area

This project focused on a number of stormwater-impaired streams in the towns of Burlington and South Burlington, Vermont (Fig. 1). Much of our research focused on development in the Potash Brook watershed in South Burlington, Vermont. Potash Brook is a 2,145 ha watershed that drains directly into Lake Champlain. Land cover and land use in the watershed are mixed: 25% commercial/industrial, 35% residential, 30% agricultural, 10% open space (Pease 1997, Nelson and Nealon 2003, Figure 2). Population has increased rapidly in South Burlington over the last 50 years (Figure 3) and this population growth has been accompanied by a significant expansion in development in Potash Brook (Figure 4). Lower portions of Potash Brook have been listed as "impaired by stormwater" by the Vermont Agency of Natural Resources on the US/EPA's "303.d" list since 1992.

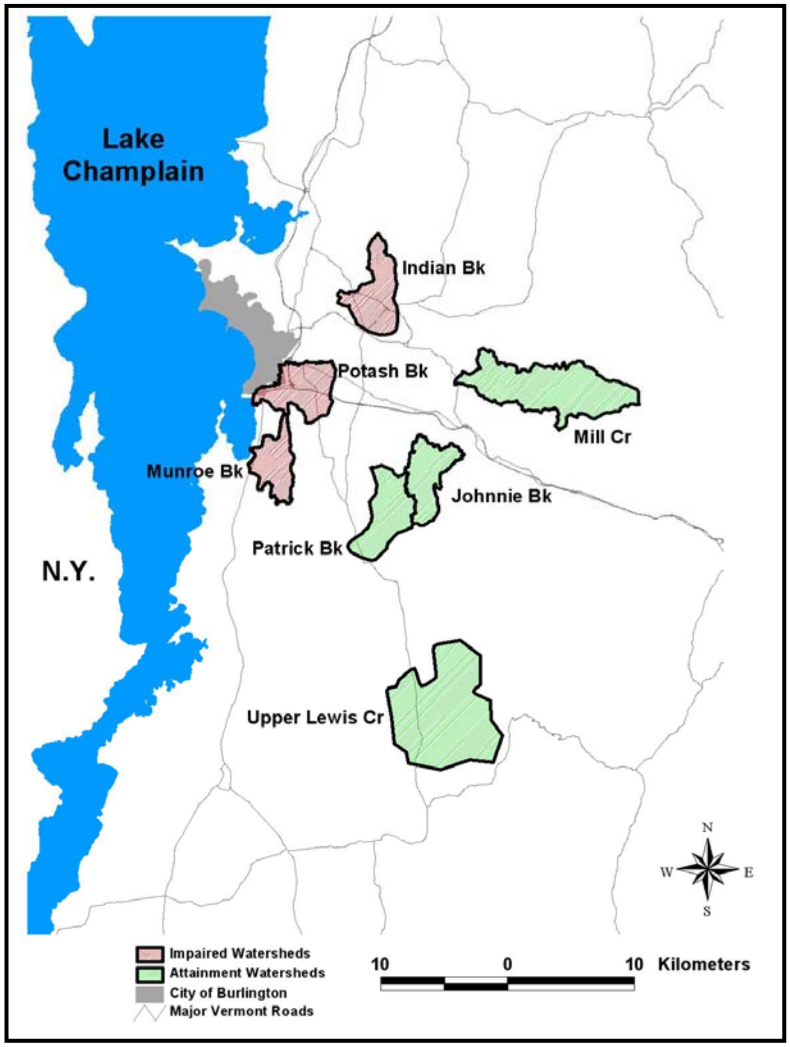


Figure 1: Map of study watersheds in Vermont.

Much of the effort associated with this project was focused on two adjacent neighborhoods: Butler Farms and Oak Creek Village (Figure 7). The neighborhoods collectively total about 65 ha and have 253 houses that are roughly evenly distributed over the developed area in ~0.1 ha lot sizes. These neighborhoods were selected for several reasons. First, the developments are typical of the construction methods and neighborhood design implemented over the last 30 years and before the current interest in low-impact design approaches. The neighborhoods were permitted by separate developers with construction beginning first in Oak Creek Village in 1988 and two years later in Butler Farms. Construction continued as late as 2004, however through out the entire construction history only minimal consideration was given to stormwater management. Second, a small tributary to Potash Brook runs through the middle of the neighborhood and provided the opportunity to measure direct inputs to and outputs from the neighborhoods. Finally, these neighborhoods were selected for study because the stormwater management issues faced by the residents were particularly problematic. Before the study began, residents were generally unaware that they were responsible for the stormwater discharge permits for the neighborhoods. Furthermore, they had no homeowners' association or similar neighborhood-wide mechanism for communication or decision making. Therefore, even the simplest procedures to arrive at a consensus regarding stormwater management did not exist. Thus, these neighborhoods were in effect a worst-case scenario for retrofitting stormwater management in an existing development.

This general area is representative of rapidly urbanizing areas in Vermont and the Northeast and is a good subject for study for several reasons. For example, it has been the focus of earlier studies that provide valuable background data for this project (Nelson and Nealon 2003). In addition, the research funds from this project could be leveraged with operational funds secured by the City of South Burlington to manage stormwater issues in the catchment. This leverage provided the potential for valuable synergies among researchers, resources managers, and community stakeholders. Finally, a good working relationship already existed among the potential project participants at the University of Vermont, in the South Burlington Planning Office, and within the Potash Brook community.

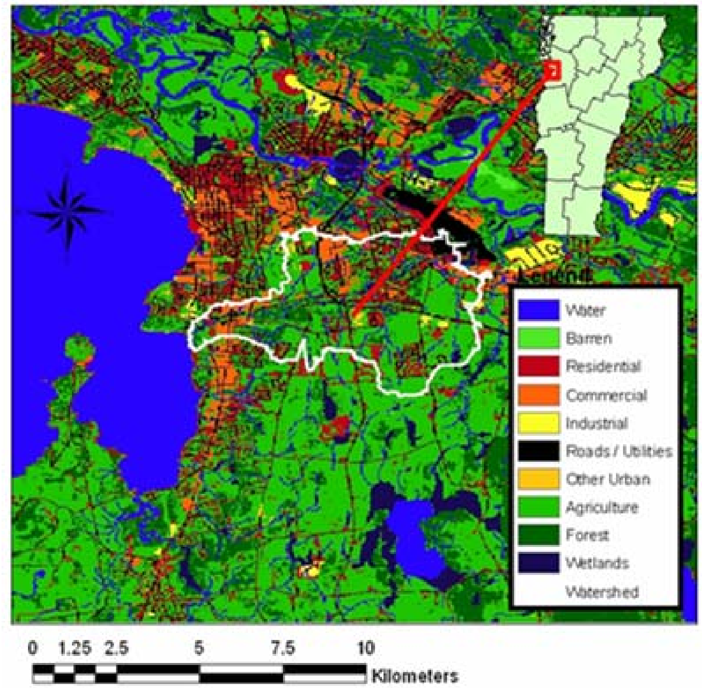


Figure 2. Land use and land cover of Potash Brook watershed (data from VCGI 2006).

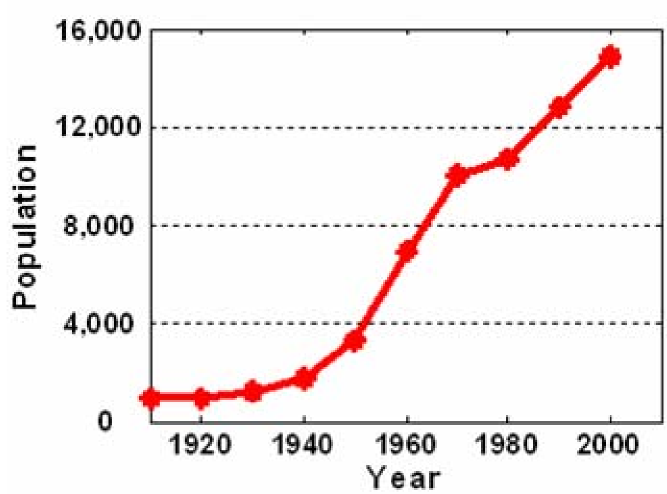


Figure 3. Population of South Burlington (data from UVM 2006).

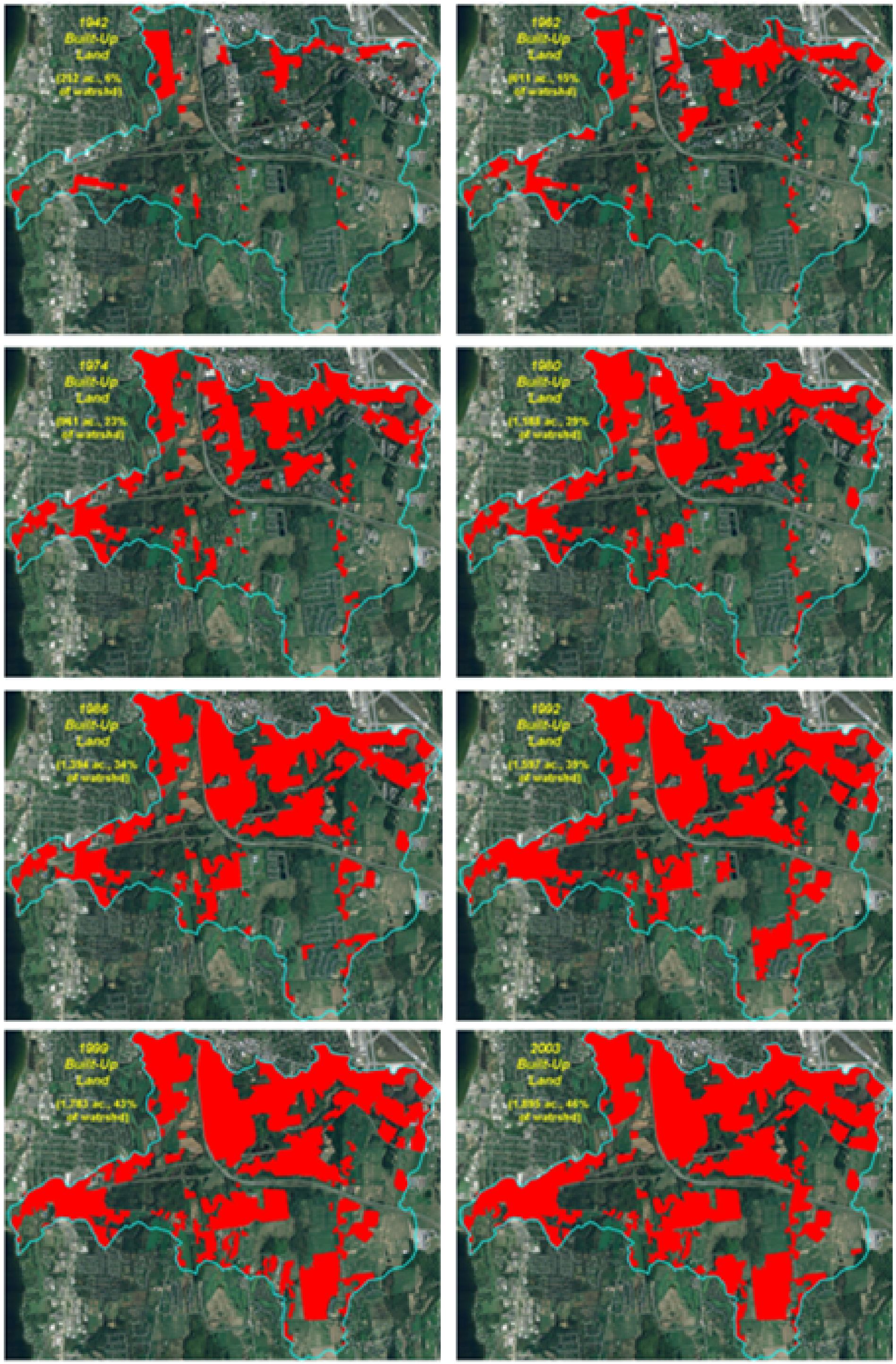


Figure 4. Build out of Potash Brook shown in red for 1942 (a), 1962 (b), 1974 (c), 1980 (d), 1986 (e), 1992 (f), 1999 (g), and 2003 (h) (Godfrey 2003).

5. Project Accomplishments

5.1 The RAN Toolbox

Our initial efforts were oriented toward developing a decision support knowledge base that would allow end-users to quickly identify potential sites and methods for stormwater intervention. We are aware that substantial information on stormwater treatment practices exists elsewhere (e.g. Center for Watershed Protection, Burton and Pitt 2002). However, we found it necessary to organize this information in a way that allowed end-users to logically and efficiently identify alternatives that will address their own particular interests and issues. This was largely a 'desk top' organizational effort that fed directly into Objectives #2 (Evaluation) and #3 (Participation).

The toolbox we developed includes a mix of basic stormwater knowledge, specific information about the study area, and helpful decision-making aids, delivered via a web interface (http://www.uvm.edu/~ran). In response to stakeholder interest, we developed a section on "Stormwater Basics" which provides a primer on what stormwater is and how it is generated. We also provided an extensive review of stormwater best management practices (BMPs) with performance and cost data wherever possible. In addition to this general information we provided or developed specific information about the Butler Farms and Oak Creek Village neighborhoods, including a "Virtual Tour" section and a variety of basic maps and aerial imagery. The Toolbox includes a RAN project "Library" in which we have posted emerging products from the project, a "Links" page that includes an extensive list of other sites that we think may be of interest to stakeholders, and direct links to our project data. The Toolbox is not a static or closed resource; we have continued to develop and expand this resource as new information and needs have arisen.

5.2 Communications With Stakeholders

A fundamental premise of the RAN program is that acceptable and effective solutions to stormwater management problems in existing neighborhoods require inputs from a broad base of stakeholders, including the affected residents. As a complement to our efforts to communicate with non-technical, resident stakeholders, we conducted a baseline survey of residents in the Butler Farms and Oak Creek Village neighborhoods to assess their understanding of stormwater dynamics, concerns about stormwater impacts, and expectations about stormwater management alternatives. We used the results of this baseline survey as one means to initiate a dialogue with the resident stakeholders.

5.2.1 Establishing a baseline

Shortly after the RAN program began, we conducted a survey of residents in the Butler Farms and Oak Creek Village neighborhoods to collect baseline data regarding several aspects of their attitudes about the environment in general and understanding of stormwater management in particular. The goals of this survey were:

1. to understand how people perceive the stormwater issues and determine what they know about stormwater related problems;

2. to collect information about the behavior patterns and daily practices related to stormwater in the neighborhood; and,

3. to evaluate the overall level of environmental awareness and willingness to act and/or change in the neighborhood.

The survey and summary results are included in Appendix 10.1 and are posted on the RAN website. We received 99 completed surveys from 200 distributed for a ~50% return. The stakeholders who returned surveys are well-educated and reported a high level of concern about the environment. However, a high educational level and concern for the environment does not necessarily translate into more benign stormwater related practices (Figure 5). Most (95%) of the residents did not expect flooding to be a problem when they purchased their properties, even though the soil type (clay) and topography (flat) suggest the risk of flooding is high. As it turns out, local flooding has been an important problem for some homeowners and has tended to dominate broader concerns about stormwater impacts; e.g. on local streams or on Lake Champlain. They are more willing to adopt certain "good" stormwater practices rather than contribute their time and money to solve the problems (Figure 6). The majority of respondents expected large-scale engineering solutions to solve their problems, rather than small-scale interventions, and expected the city or state to take responsibility for the costs associated with these engineered solutions. Most residents did not realize or understand their responsibilities with respect to stormwater management.

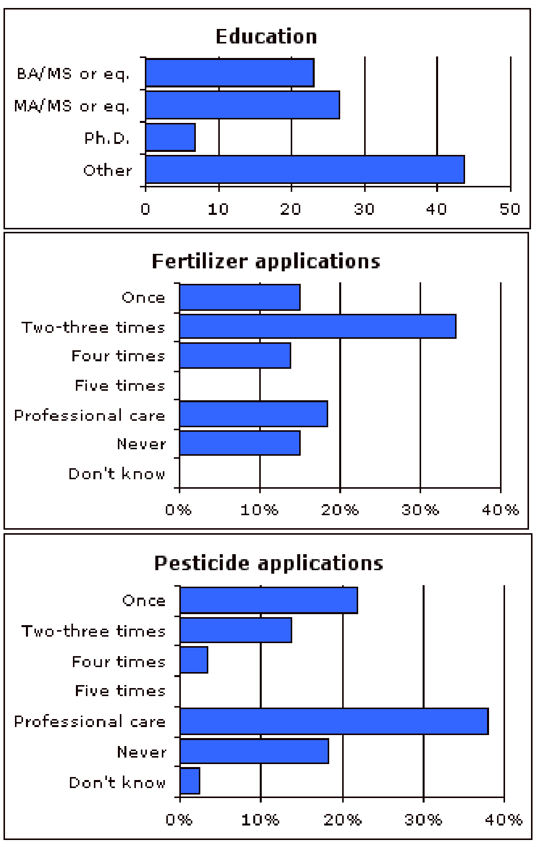


Figure 5. More than 50% of residents have a college degree or more. Yet, they tend to use quite high rates of fertilizer and pesticide applications.

The results of this survey were presented to the resident stakeholders at a meeting in April 2004. This meeting was our first extensive outreach to the whole community and provided the basis for a wider working group, which has been our liaison for future work on the project.

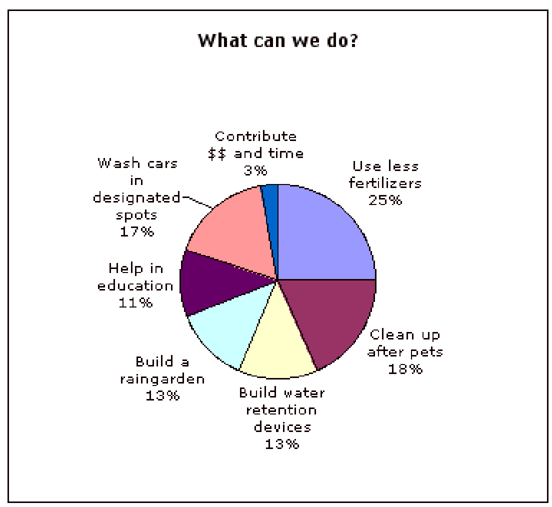


Figure 6. Residents are willing to adopt a mix of practices to improve stormwater quality. However they are rarely interested in contributing time and money for this cause.

5.2.2 Opening a dialogue

As our efforts to develop the RAN toolbox progressed, and in light of the resident survey results, we began to engage the Butler Farms and Oak Creek neighborhoods in a discussion about stormwater management strategies. Our intention was to facilitate a discussion about strategies for stormwater management at several different scales (e.g., individual homes, clusters of homes, entire neighborhoods). In preparation for these discussions we gathered information about the effects and costs of various BMPs to help citizens make decisions about their choices and priorities. Through a process of 'shared learning' we expected to identify an approach or approaches to stormwater management that would be effective environmentally and acceptable financially to all parties.

The process that we proposed in this project differed substantially from a typical research approach in which the objective might be to test the effectiveness of a particular technology or technologies. Instead, we proposed to engage the stakeholders in a process that could have any number of ultimate end points that could not be identified *a priori*. This approach is not new. Indeed, previous experience and a growing body of literature show that this "shared learning" approach is an effective way to achieve consensus – or at least a robust decision – in complex and contentious issues (Bowden et al. 2004, USEPA 2005).

We have utilized a number of different approaches to communicate with stakeholders in this project. While we rely on our RAN website to be a dynamic and evolving resource for stakeholders to explore, we recognize that websites are not necessarily the preferred or best means to engage stakeholders. For this reason we have organized a number of other outreach activities. Early in 2004 we initiated a series of evening meetings in the South Burlington Town Offices in which we discussed residents' concerns and knowledge about stormwater management. In addition to these evening dialogues, we organized Saturday morning Stormwater Field Days in September 2004 and 2006 in which we engaged resident homeowners to discuss emerging findings and activities related to RAN. We also used the opportunity to engage children in a better understanding of the value of stream ecosystems.

5.3 Impact Evaluation

There is a critical need for community stakeholders and local regulators to be able to identify potential opportunities for stormwater management and to compare the relative costs/benefits of these interventions against criteria that incorporate ecological/ecosystem and social/community considerations as well as traditional economic criteria. The same intervention in different settings may yield different levels of benefit or incur different costs. During the first two project years we began to explore two ways to satisfy this need through development of life cycle assessments of BMPs and through development of system modeling tools.

5.3.1 Life Cycle Assessment

The environmental life cycle assessment (LCA) method has been used to address questions regarding the long-term, indirect, and cumulative non-monetary impacts of human actions. In the broadest sense, the life cycle is considered from "cradle to grave," meaning the direct and indirect provisions of raw materials, manufacturing, and transportation; use, maintenance, and reuse; and finally decommissioning or disposal. The environmental impacts include materials and energy used and releases of substances to the air, water, and soil. In the evaluation of projects with direct environmental priorities such as water treatment, LCA may be used to prevent or reduce unanticipated "problem shifting" or the substitution of an environmental problem in one medium or location to another medium or location. For this reason LCA has the potential to provide an appropriate foundation for conducting a holistic assessment of stormwater treatment systems which considers "up-stream" as well as downstream impacts.

Late in 2004 the University of Vermont RAN program initiated a partnership with the University of New Hampshire's Stormwater Center (UNH/SC) to develop LCAs for several popular stormwater BMPs. The UNH/SC currently operates and monitors twelve structural stormwater BMPs in parallel. The direct comparability of the systems combined with the Center's detailed monitoring and construction records presented an ideal opportunity for conducting LCAs of stormwater BMPs. The on-going product of this partnership is a comparative economic life cycle cost analysis and environmental life cycle assessment of the conventional, low-impact development, and pre-manufactured designs in operation at the UNH/SC.

The life cycle assessment concept encompasses several different methods originally designed for a variety of decision-making situations. In an attempt to be holistic, the calculation procedure often becomes complex, greatly increasing the chance of wrong or misleading results (Bauman and Tillman 2004). In response to such issues, the International Standards Organization established a standardized LCA method beginning in 1996. The ISO 14040 series standards (ISO 1997) outline the major procedural steps of LCA most commonly followed for comparisons of process and product alternatives and documentation of industry-wide "eco-profiles." The RAN/SC Life Cycle Study adheres to the ISO framework described in Table 1.

Table 1. Life Cycle Assessment Framework (ISO 1997).

ISO Life Cycle Assessment Framework	
1. Goal and Scope Definition	Establish objectives; methods; temporal, spatial, and technical system boundaries; functional unit and criteria (impact categories); map all relevant human and natural material and energy flows.
2. Life Cycle Inventory (LCI)	Catalogue all resources used and emissions for each process, product, or activity. Process flow and/or input/output modeling may be necessary to calculate material and energy flows.
3. Life Cycle Impact Assessment (LCIA)	Determine the environmental consequences. Classify the inventory into pre-defined impact categories and characterize the magnitude of each element's contribution to the impact categories. (Further aggregation, normalization, and valuation is optional)
4. Interpretation	Determine the dominance, sensitivity, and uncertainty of results. (Interpretation can be conducted with or without LCIA)

The LCA procedure begins with the definition of the goal and scope, establishment of the functional unit (the unit used for comparisons, e.g., 100 m^2 of roof for an LCA of roofing materials), system boundaries, and the extent and method of calculation to achieve the information necessary for decision-making. The goal of this partnership between the UVM/RAN and UNH/SC efforts was to provide an initial assessment of four of the twelve treatment units in the UNH/SC installation (Table 2).

These treatment units were chosen because they are directly comparable. Each system was designed to manage and treat runoff from 0.4 ha (1 acre) of parking lot and to meet equivalent performance criteria, including treatment of the water quality volume, detention of the channel protection volume, and attenuating the 0.9, 1, and 10-year storm to pre-development conditions. The similar design basis provides the foundation for the life cycle functional unit. For this study, the functional unit was defined as the management and treatment of stormwater runoff from 0.4 ha (1 acre) of impervious surface for one year, with reference to the New York State stormwater design criteria, precipitation characteristics of Durham, NH, and the runoff pollutant characteristics of the University of New Hampshire's West Edge Parking Lot.

This project was initiated in the 2004 project year (year 2) and is continuing.

Table 2. Stormwater BMPs included in the comparison.

BMP General Descriptions					
Treatment Unit	Unit Type	Design Source	Areal Dimensions	Volumes	Treatment Function
ADS Water Quality and Infiltration Device	Manufactured Device	Advanced Drainage Systems (ADS)	A1: 1.5 m x 6.1 m A2: 6.1 m x 12.2 m	Treatment: 92 m^3	A1: Physical A2: Physical - Chemical
Retention Pond (Wet Pond)	Conventional	New York State Stormwater Design Manual	14.0 m x 21.3 m (approx.)	Forebay: 23 m^3 Perm. Pool: 92 m^3	Physical - Settling
Bioretention	Low Impact Design	New York State Stormwater Design Manual	Filter Bed: 20.4 m x 10.7 m Top Width: 21.6 m x 14.0 m	Forebay: 23 m^3 Filter: 92 m^3	Physical - Chemical and Biological
Gravel Wetland	Low Impact Design	Custom	Filter Beds (2): 4.6 m x 9.8 m Top Width (2): 11.3 m x 17.1 m	Forebay: 23 m^3 Wetland: 92 m^3	Physical - Chemical and Biological

5.3.2 Modeling frameworks

Our second proposed approach was to develop a modeling framework to help the project participants (researchers and stakeholders) visualize and evaluate the costs and benefits associated with different management practices. The purpose of this integrated assessment tool was to compare alternative approaches to achieve user-specified stormwater treatment outcomes (e.g. reduced nutrient or pollutant loads, reduced sediment transport, improved fish habitat). As a first step in this initiative, we began to gather existing data resources that would underpin development of this tool. These resources included, for example, GIS base maps of watershed boundaries, topography, soil data, streams, groundwater levels, roads, and hydrology.

However, several unanticipated developments arose which caused us to delay and ultimately refocus this effort. One of the first and most important impediments to the development of this initiative is that we expected stakeholder interest which did not materialize. Mediated modeling has been found to be an extremely valuable approach to shared learning among stakeholders who have widely divergent points of view (van den Belt 2004). However, a fundamental premise underlying this approach is that the stakeholders involved in the issue accept that mediated modeling is a useful approach and agree to engage in the process. At least initially we found no such interest among the resident stakeholders in the Butler Farms and Oak Creek Village neighborhoods.

Second, we had also proposed to explore a variety of different ways to engage stakeholders in a dialogue about stormwater management options that include low-impact or ecologically engineered solutions. These options include, for example, a variety of means to facilitate social learning, tax incentives, regulation, etc. However, late in 2004 it became clear that the town of South Burlington was poised to initiate a Stormwater Utility (SBSU 2006), the first of its kind in Vermont. This utility created a unique incentive that obviated other approaches; i.e., given the development of the utility, proposing competing alterative approaches did not make sense.

Finally, late in 2004 we became aware that the Vermont Agency of Natural Resources (ANR) Stormwater Section had contracted with Tetra Tech Inc. to expand and adapt their Best Management Practice Decision Support System (BMPDSS) for Vermont stormwater discharge permits. The approach we originally proposed in the RAN Work Plan was in direct competition, at least conceptually, with Tetra Tech's BMPDSS approach. Again, we thought it would be counterproductive to introduce a competing alternative approach.

Rather than develop an alternative modeling framework, we began to consider how the new Stormwater Utility could offer new opportunities to engage the resident stakeholders in a dialog about stormwater management. In addition, we offered to partner with ANR and Tetra Tech in the development of the BMPDSS approach. For example, the RAN project had developed some of the only empirical stream discharge data available for stormwater-impaired streams in Chittenden County. These data sets were utilized by Tetra Tech for some of the early calibrations of the P-8 model that formed a basis for what has become the BMPDSS. In addition, we have offered to collaborate with ANR and Tetra Tech on computational approaches to optimize choices among alternative BMPs within the DSS. This important collaboration is still in progress and provides an important link between the RAN program, ANR, and stakeholder interests in stormwater management.

5.4 Demonstration and Implementation

Objectives #1-3 in the first two years of this project focused on development of tools that could be applied directly to Potash Brook in South Burlington, Vermont, but that would be relevant to other urbanizing watersheds in New England. The various approaches that we evaluated were intended to help communities identify ways to manage stormwater over the long-term. There remained, however, a need to demonstrate that these tools would be effective and produce the desired outcomes. To do this, we proposed to establish a 'demonstration project' focused on a particular stormwater management issue that is relevant both locally and regionally.

Through consultation with local regulatory stakeholders, we identified that the Butler Farms and Oak Creek Village subdivisions in South Burlington, Vermont (Figure 7) provided a useful opportunity for this purpose. These adjacent subdivisions of over 250 homes on about 65 hectares are representative of so-called 'cookie cutter' neighborhoods that typify urban sprawl. Tributary 7 of Potash Brook arises in agricultural land above the Butler Farms and Oak Creek subdivisions, flows through the middle of the developments, and then emerges onto conservation land managed by the City of South Burlington. The stream within the Butler Farms and Oak Creek developments has been highly degraded and is deeply incised. There was, therefore, an opportunity to employ restoration strategies specifically targeted at abating stormwater impacts, improving the water quality of the stream, and enhancing community well-being associated with having this stream in the neighborhood landscape. Furthermore, plans exist to subdivide and develop the agricultural land above the existing Butler Farms and Oak Creek subdivisions and so an opportunity exists to work with the developer to design stormwater management features into the new development from the inception.

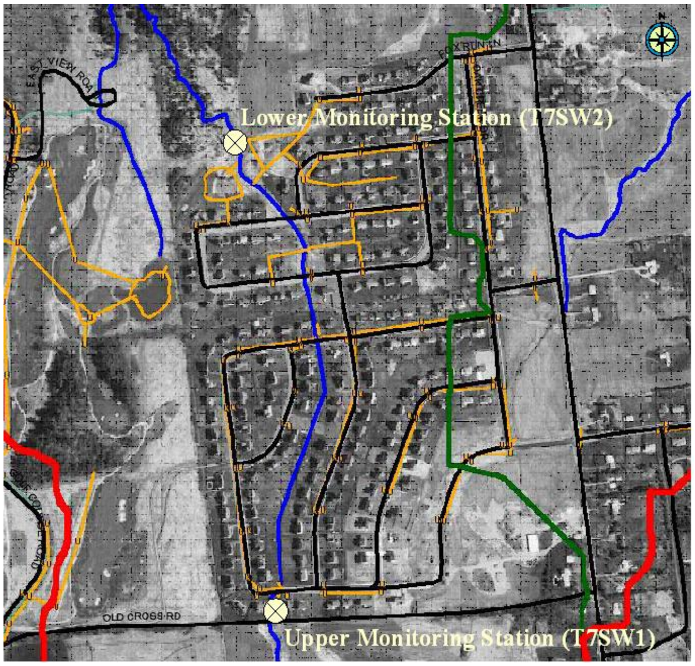


Figure 7. Butler Farms and Oak Creek Village.

Two other aspects of the Butler Farms and Oak Creek Village neighborhoods are noteworthy and have important influences on the motivations for stormwater management in these neighborhoods. First, the permits regulating stormwater discharges in both neighborhoods expired many years ago and the original stormwater structures in the neighborhoods are substandard and currently virtually non-functional. Pressures by the state to renew all expired stormwater discharge permits mean that the residents in the neighborhoods are faced with financial and procedural challenges to address their stormwater management problems. The required upgrades to obtain the necessary discharge permits will be expensive and so the best choice among alternatives is of considerable concern to the residents. Secondly, these neighborhoods are notable in not having homeowners associations or any other means for making community decisions. Thus, even the process for choosing among alternatives is unclear. The RAN program, in partnership with the Town of South Burlington, has been very active in trying to help the resident stakeholders address these challenges.

We recognized that in helping the residents of Butler Farms and Oak Creek Village to evaluate alternative stormwater management designs, there was a unique opportunity to quantify how low-impact design alternatives help key stormwater management issues; e.g., reduction of peak flow, sediment movement, and phosphorus load. Although we could not be sure which stormwater management alternatives the residents would ultimately choose, we felt it was critical to obtain a baseline assessment of conditions in the neighborhoods before any new infrastructure was installed, for comparison to post-installation conditions. To do this we proposed two complementary initiatives. The first initiative was a straightforward monitoring effort, and the second initiative focused on two fundamentally important processes or functions in stream ecosystems: whole-stream metabolism and nutrient spiraling.

5.4.1 Quantitative impacts of typical neighborhood development: baseline monitoring

By the end of the second project year, environmental assessment activities were completed in the Butler Farms and Oak Creek Village neighborhoods. The condition of Tributary 7, as it runs through the study neighborhoods, was evaluated through the combination of surveys, flow monitoring, and storm event sampling. The purpose of these activities was to provide a ‘snap-shot’ in time of the existing physical and biological conditions, collect data on stream water quality during storm-events, and evaluate rainfall and stream flow characteristics.

Monitoring stations were established on Tributary 7 in 2004 at points above and below the study neighborhoods. We reasoned that changes observed in the stream between the two stations could be attributed to the neighborhood itself in terms of land cover and use. At each monitoring site, we constructed a cross-sectional control area to provide a stable area for probe mounting and measurements. We installed ISCO 6712c automatic stormwater samplers and pressure transducers at each site (Figure 8). The pressure transducers measured water level at the two locations in 5-minute intervals; the data were logged on the ISCO unit. We translated the water level data to flow (per standard USGS methods) using rating curves we developed (r^2 values of 0.99 for the upper station, and 0.97 for the lower station) for each site from a series of hydrologic profile events. The ISCO units were programmed to collect flow-weighted composite stream water samples during storm events for eventual laboratory analysis. In addition to the flow monitoring and storm-event sampling, we also collected and analyzed benthic macroinvertebrates to evaluate the current biological condition of the stream using VT DEC protocols. We also surveyed the geomorphic and habitat conditions using VT DEC methods. These activities have all been described in detail in project Work Plans. The results of these efforts are summarized in the following sections.

Figure 8a. Upper Monitoring Station (T7SW1).

Figure 8b. Lower Monitoring Station (T7SW2).

5.4.1.1 Basic surface water hydrology

Following construction of the monitoring stations in 2004, we performed nearly continuous measurement of water level in Tributary 7. Data were collected in 5-minute intervals from July 2004 to November 2004, and from April 2005 to November 2005. Winter monitoring was not performed due to ice and equipment limitations. In total, we recorded 345 and 343 days of flow data for the upper and lower monitoring stations, respectively. The mean daily stream flow for both monitoring stations over time is presented below in Figure 9. Highest flow periods occurred during the summer of 2004 and late fall of 2005.

The stream flow record for Tributary 7 may also be viewed as flow duration curves (FDCs) (Figure 10). FDCs indicate the percentage of time represented by the recorded data during which specified discharges are equaled or exceeded (USGS 1963).

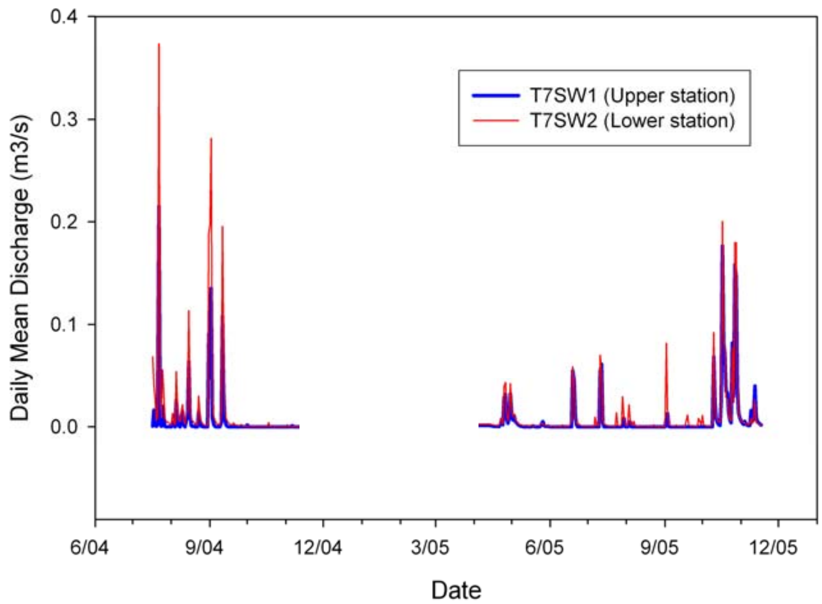


Figure 9. Flow Monitoring at Tributary 7 (Potash Brook).

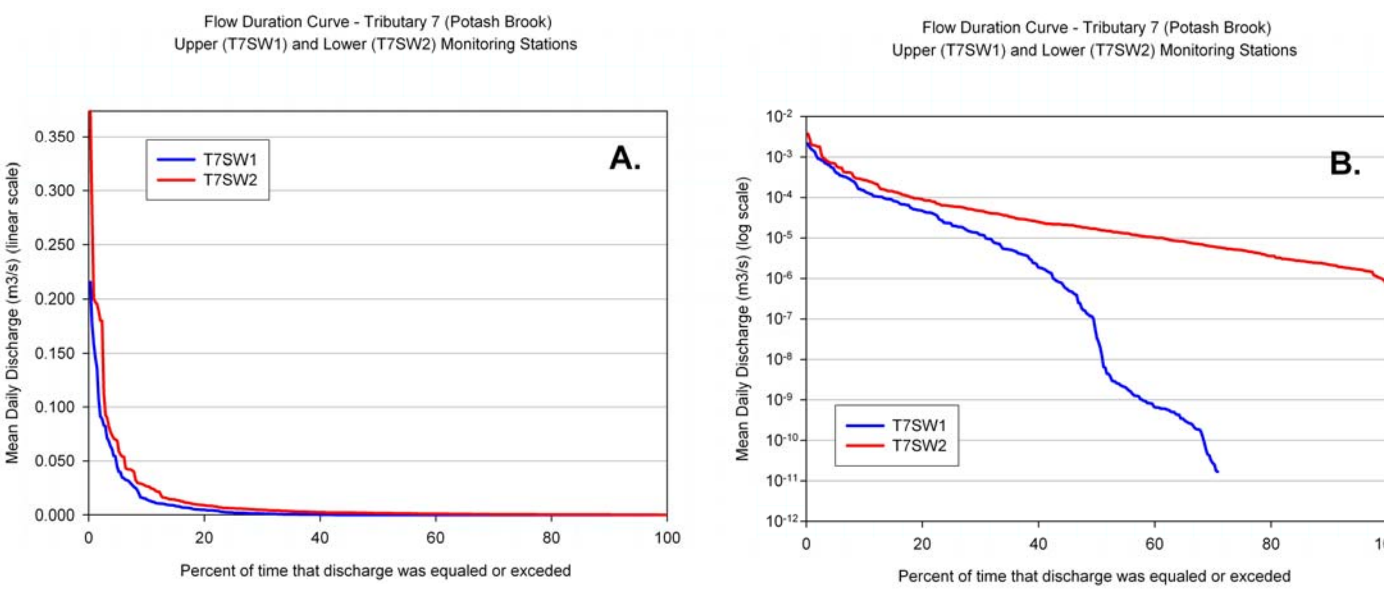


Figure 10. Flow Duration Curves for the upper and lower stations

In Figure 10, Panel A provides the FDCs for the upper and lower stations plotted on a linear y-axis. Plotted in this way there appears to be little difference between the upper and lower monitoring stations. However, when the y-axis (mean daily discharge) is converted to a logarithmic scale, the differences in the FDCs become apparent Note that in Panel B, the curve for the upper station ends at an x-axis value of approximately 68%, indicating that the flow was only present for this percentage of time monitored. In other words, we recorded zero (0) flow at the upper monitoring station 32% of time during our monitoring.

Stream flow data for Tributary 7 were analyzed to provide basic descriptive statistics for the 2004 and 2005 monitoring periods (Table 3). As noted above, data were collected in the field at 5-minute intervals and then aggregated to both hourly and daily periods.

Table 3. Descriptive statistics of stream flow at the upper and lower stations.

Descriptive Statistics	Upper Station (T7SW1)	Lower Station (T7SW2)
5-minute (field) data		
• N	98705	97887
• Min/Max Discharge (m3/s)	0.00 / 1.43	0.000 / 1.53
• Mean Discharge (m3/s)	0.01	0.01
• Standard Deviation	0.04	0. 05
• Standard Error	0. 00	0. 00
• Variance	0.00	0.00
1-hour (aggregated) data		
• N	8227	6278
• Min/Max Discharge (m3/s)	0.00 / 1.26	0.00 / 1.46
• Mean Discharge (m3/s)	0.01	0.01
• Standard Deviation	0.03	0.05
• Standard Error	0.00	0.00
• Variance	0.00	0.00
Daily (aggregated) data		
• N	345	343
• Min/Max Discharge (m3/s)	0.00 / 0.22	0.00 / 0.37
• Mean Discharge (m3/s)	0.01	0.01
• Standard Deviation	0.02	0.04
• Standard Error	0.00	0.00
• Variance	0.00	0.00

As noted in Figure 9 above, during the 2004 and 2005 monitoring periods the upper end of Tributary 7 (T7SW1) in the study neighborhoods was intermittent or ephemeral. Water did not flow continuously at that location and was characterized by prolonged dry periods. During 2004-2005 the lower monitoring point on Tributary 7 (T7SW2) flowed continuously. One likely explanation for this difference is simply the increase in upstream watershed size at the lower station. One should expect a larger, continuously flowing (perennial) stream for larger drainage basins in the Northeast. However, it is also possible that residential development of the small watershed has altered the "natural" flow characteristics of the stream in several important ways. For example, water leaking from underground pipes could provide a constant supply of base flow, moving upstream the point at which normal transition from ephemeral to perennial might exist. Furthermore, runoff from impervious surfaces in the neighborhood is rapidly collected during storm events and transported directly to the stream via drainage infrastructure, fundamentally changing the magnitude, timing, and duration of the stream's flow regime.

The stage and flow monitoring from 2004 to 2005 at Tributary 7 provide a good baseline for future comparison. These data can be analyzed further to explore individual storm hydrographs or might used in watershed modeling efforts. By combining the stream flow and storm-event sampling data (discussed below), it is possible to develop estimates for total mass of pollutants (sediment, excess nutrients, and metals) transported during individual storm events. As noted above, the 5-minute field data have also been aggregated to 1-hour and daily mean values for future reference. All of these files are available on the RAN project website.

5.4.1.2 Storm event water quality sampling

Urbanization not only affects the flow regime of a watershed, it also influences the chemistry of runoff (and groundwater), and ultimately concentrations of pollutants in stream water. We were also interested in how the stream chemistry would differ above and below the study neighborhoods during storm events. We used ISCO 6712c automated samplers, installed at the upper and lower monitoring stations, to collect samples throughout storm events in 2004 and 2005. Sampling was triggered by water level, and continued throughout the storm hydrograph based upon flow. Flow-weighted, composite samples were thus collected for storm events, as described in the project Work Plan and reports. As such, the analytical result for each parameter represents the event mean concentration (EMC) for the entire storm event. Our intention was to analyze the stream chemistry during 4-5 storm events per year, including all seasons if possible. Samples collected in the field were laboratory analyzed for common constituents of concern including sediment, nutrients, bacteria, and heavy metals. Laboratory methodologies have been previously described.

In 2004, we collected composite samples that spanned entire storm events (using the ISCO samplers) for 5 and 6 storms at the upper and lower stations, respectively. Samples could not be collected from the upper station during some storms due to no flow conditions. No samples could be collected during the late fall of 2004 due to a lack of storm events of sufficient size to result in elevated flow conditions. In 2005, we collected 6 and 10 rounds of additional storm event composite samples from the upper and lower sites, respectively. As was the case in 2004, samples from the upper station could not be collected during storm events due to no flow conditions. In 2005, duplicate samples were collected from both monitoring stations on two occasions for quality assurance purposes. There was good agreement for all analysis, and these results were averaged to provide a single set of results for each station on those dates. In total, the number of storm events sampled via flow-weighted composite sampling (and used in the final statistics described below) was 11 for the upper station and 16 for the lower station.

Composite stormwater samples were analyzed for pH (method 150.1), conductivity (120.1), total suspended solids (TSS)(160.2), total phosphorus (TP)(365.1), total Kjeldahl nitrogen (TKN - organic nitrogen plus ammonium)(351.3), nitrate-nitrite (inorganic nitrogen)(300*IC*), and heavy metals including cadmium, lead, mercury, nickel, and zinc (methods 200.7, 3113b, and 245.1). Laboratory methods and standard operating procedures for these analyses are provided in the project Work Plan. We calculated total nitrogen (TN) by adding together the inorganic and organic nitrogen components from the above-referenced analyses. We originally planned to analyze all composite storm samples for *E. coli* as well. However, the first several rounds of results were all above the maximum colony density discernable by our analytical laboratory. Given our sampling strategy, one likely explanation for the *E. coli* issues was the inability to preserve samples in a manner consistent with laboratory requirements. Thus, we elected to cease the bacteria analyses for the composite storm sampling. All results for cadmium, mercury, and nickel were below the laboratory detection limits, and are not presented in Table 4. Where reported data were below the detection limits, we substituted a value of one-half of the detection limit for statistical analyses.

Paired *t*-tests were performed on the composite storm-event sampling data (Table 4) to explore differences in the EMCs between the upper and lower stations. For this analysis, we included data from storm events during which samples were obtained from both monitoring stations (n = 11). We excluded sampling data for those storms during which no flow was present at the upper monitoring station. Descriptive statistics are provided below, with significant differences from the *t-test*s noted as well.

Table 4. Storm-event composite sampling results for TSS, conductivity, pH, and heavy metals.

Monitoring Site	Statistic	TSS (mg/L)	Conductivity (µS/cm)	pH (units)	Lead (mg/L)	Zinc (mg/L)
T7SW1 (Upper Site)	Mean	31.4	225.3	7.68	0.001	0.016
	N	11	11	11	4	4
	Std. Error of Mean	8.1	20.9	0.07	0.000	0.006
	Minimum	4.0	125	7.27	0.001	0.010
	Maximum	94.0	353	8.01	0.002	0.033
	Median	24.5	229.0	7.66	0.001	0.010
T7SW2 (Lower Site)	Mean	***62.3	***355.6	***7.96	0.001	0.016
	N	11	11	11	4	4
	Std. Error of Mean	8.7	31.1	.05	0.000	0.003
	Minimum	29.0	195.0	7.59	0.001	0.010
	Maximum	113.0	548.0	8.23	0.001	0.023
	Median	60.0	372.0	7.94	0.001	0.016

Note: Paired *t-test* indicates significant difference between mean values (***p ≤ 0.01, **p ≤ 0.05, or *p ≤ 0.10).

Total suspended solids (TSS), conductivity, and pH all increased significantly during storm events as Tributary 7 flowed through the study neighborhoods. These findings are consistent with our observations of the stream during storms. During elevated flow periods, we generally observed stream water at the upper station to be clear, while stream water at the downstream monitoring station (T7SW2) was often turbid and grey in color. There are several potential explanations for the increase in suspended sediment in the water column during storms, including wash-off from impervious surfaces within the neighborhood, stream bank erosion, and re-suspension of fine clay present in the stream bottom. During our physical surveys of the stream, we noted numerous areas of fine, gray-colored sediment covering the stream bottom. These observations suggest that re-suspension of fine grained bottom sediments may be a major source of downstream sediment transport.

Concentrations of lead and zinc were low to non-detectable at both stations. These concentrations are 5 to 6 times lower than the national median values, suggesting that these metals are not an important concern in the study neighborhoods.

There was considerable variability in measured nutrient concentrations at both monitoring stations during storm-event sampling (Table 5). Mean TP concentrations were slightly lower below the study neighborhood (T7SW2) than above it (T7SW1), but the difference was not significant. Nitrite (NO_2^-) concentrations were four times higher at the lower station than at the upper station. However, nitrite is a small component of total nitrogen and this difference was not significant. Nitrate, TKN and TN concentrations were all slightly lower at the lower station, but not significantly.

Table 5. Storm-event composite sampling results for nutrients.

Monitoring Site	Statistic	Total P (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	TKN-N (mg/L)	Total N (mg/L)
T7SW1 (Upper Site)	Mean	0.22	0.01	1.14	1.33	2.48
	N	11	11	11	11	11
	Std. Error of Mean	0.04	0.00	0.69	0.15	0.80
	Minimum	0.06	0.01	0.01	0.71	0.76
	Maximum	0.41	0.06	7.37	1.93	9.29
	Median	0.19	0.01	0.09	1.29	1.59
T7SW2 (Lower Site)	Mean	0.19	0.04	0.84	1.02	1.90
	N	11	11	11	11	11
	Std. Error of Mean	0.02	0.02	0.24	0.15	0.27
	Minimum	0.09	0.01	0.20	0.04	0.80
	Maximum	0.29	0.20	3.12	1.90	4.14
	Median	0.18	0.01	0.62	1.01	1.52

Note: Paired *t*-test indicates significant difference between mean values (***p ≤ 0.01, **p ≤ 0.05, or *p ≤ 0.10).

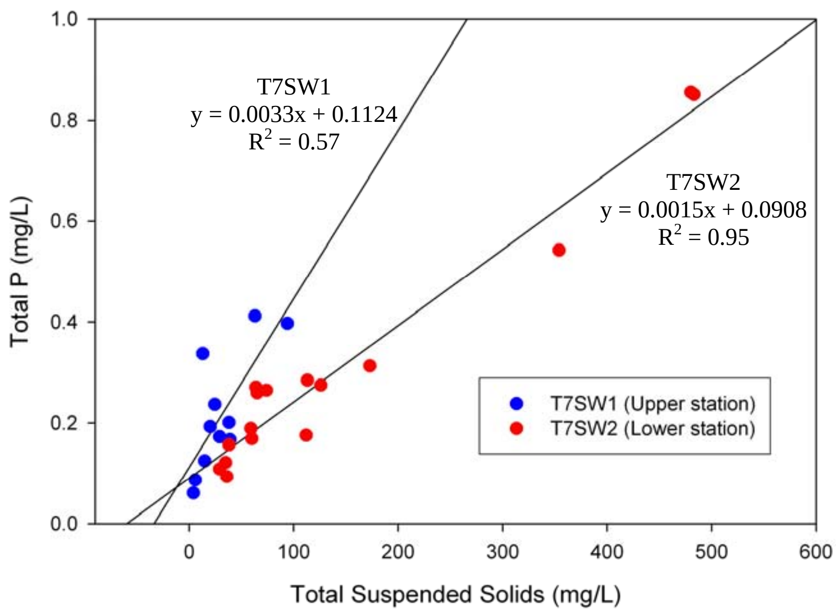


Figure 11. Relationship between TSS and TP concentrations at the upper and lower stations.

There was a strong linear relationship between TSS and TP (Figure 11). The relationship between TSS and TP at the lower station (T7SW2, R^2=0.95, p<0.001) was stronger that the same relationship at the upper station (T7SW1; R^2=0.57, p=0.007); however, both of these relationships were statistically significant. The difference in the slope of the line describing the TSS to TP relationship at the upper and lower stations is notable. The upper station has a steeper slope, indicating that small increases in TSS resulted in a more pronounced increase in TP than at the lower station. The difference in slope between the upper and lower stations could be the result of dilution by suspended sediments with lower associated TP or alternatively to loss of TP relative to suspended sediments. We cannot distinguish between these scenarios with the current data. In general, efforts to reduce downstream sediment transport could have the dual benefit of also reducing downstream phosphorus export, which is a main concern in the Potash Brook watershed.

It is also informative to examine the sediment and nutrient data in terms of total loads, which were calculated by multiplying the measured EMCs by the volume of water associated with the event. These data represent the total mass of sediment or nutrients moving downstream at the monitoring location during a given storm. Table 6 presents mean storm loads at both monitoring stations, with standard errors provided in parentheses. We performed paired *t*-tests on these values to explore whether differences in mean values were statistically significant. For these statistical analyses, we included all sampling rounds (n=15). If no flow was observed at the upper station, then the loading was zero by definition.

Table 6: Mean Storm-Event Loads (+/- 1 S.E.)

Parameter	**Upper Station (T7SW1)**	**Lower Station (T7SW2)**
Water (m^3)	4579 (1419)	***7087 (2343)
TSS (kg)	185 (70)	***447 (138)
Total Nitrogen (kg)	12.99 (6.21)	12.83 (3.89)
Nitrate (kg)	7.22 (4.91)	***6.25 (2.55)
Nitrite (kg)	0.08 (0.04)	0.36 (0.22)
TKN (kg)	5.69 (1.80)	*6.22 (2.24)
Total Phosphorus (kg)	1.04 (0.32)	***1.43 (0.47)

Note: Paired *t*-test indicates significant difference between mean values (***p ≤ 0.01, **p ≤ 0.05, or *p ≤ 0.10).

On average, sediment loads more than doubled as a result of an ~35% increase in hydrologic loading between the monitoring stations (an additional ~2,508 m^3 of water). While nitrite and TKN increased slightly between the monitoring stations, nitrate decreased significantly. As a result, total nitrogen decreased, but negligibly. Total phosphorus loading increased significantly between the monitoring stations.

Comparisons of mean concentrations and loadings for nitrate are strongly influenced by two high nitrate concentration values at the upper station in 2005, as shown in Figure 12. As noted in the 2005 status report, both of these events occurred after prolonged no-flow periods, during which nitrate may have accumulated within the system, before being flushed out by the storm flow. Removal of these two nitrate readings at the upper station in 2005 substantially increases the difference in mean values between the upper and lower stations. Aside from these values, almost every reading was higher at the lower station. Examination of the median nitrate value from Table 5 is also telling. The median value for nitrate at the lower station (0.62 mg/L) was more than seven times that of the upper monitoring station (0.09 mg/L). Thus, there is some evidence that nitrate concentrations increased as Tributary 7 moved through the study neighborhoods.

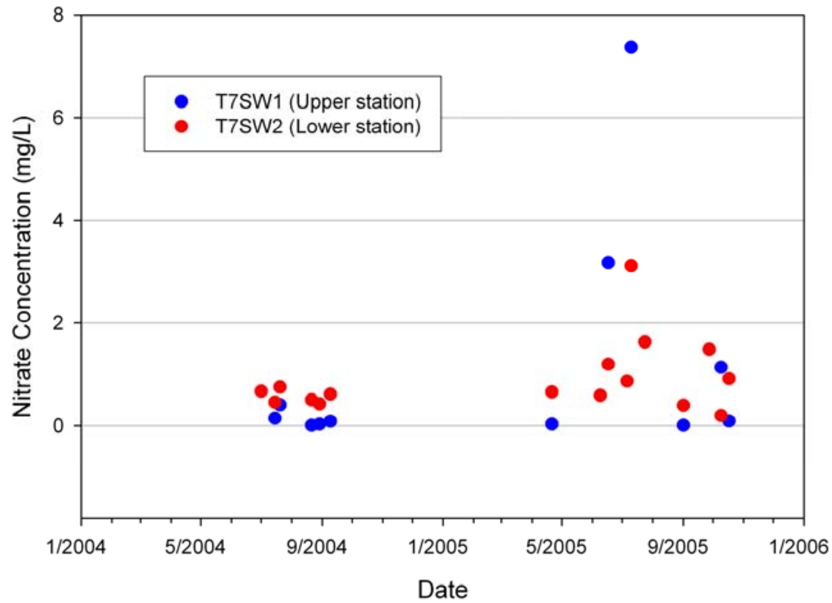


Figure 12. Storm-event nitrate (NO_3^-) concentrations at the upper and lower stations.

The nitrite load exiting the neighborhoods was greater than the load entering in stream flow. Nitrite is an unstable intermediary form of nitrogen formed during the nitrification and denitrification processes (Novotny 2003). Based upon our sampling, we were unable to determine if nitrification or denitrification was responsible for the presence of nitrite. Furthermore, we were unable to determine if the elevated nitrite levels below the neighborhoods were the result of in-stream production or runoff from the neighborhoods during storm events.

5.4.1.3 Comparison to national data

We compared the storm-event sampling results with national and/or regional averages provided in the Vermont ANR Stormwater Manual (VT ANR 2002) which provides a list of national median concentrations for common constituents found in stormwater. In Figures 13-15, below, median values are shown as a line within the boxes, boxes indicate the 25th and 75th percentiles of the data, and whiskers indicate the 5th and 95th percentiles.

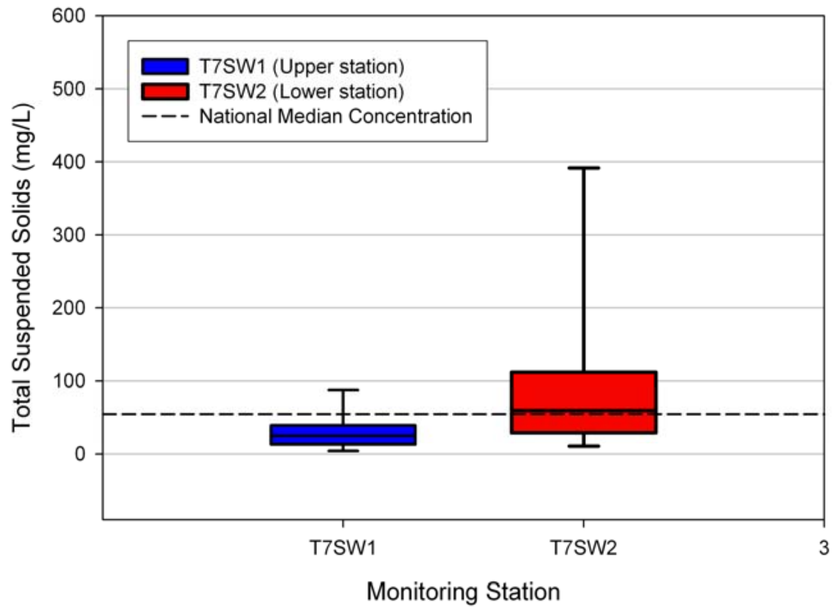


Figure 13. Storm-event TSS concentrations vs. the national median value.

The median value for our TSS sampling at the upper station was below the national median concentration. At the lower station, the median TSS value was just above the national value. It is noteworthy that many storm events resulted in TSS concentrations above the national median value, particularly at the lower monitoring station located below the study neighborhoods. Efforts to reduce downstream sediment transport should be a focal point of any new stormwater management activities in this area.

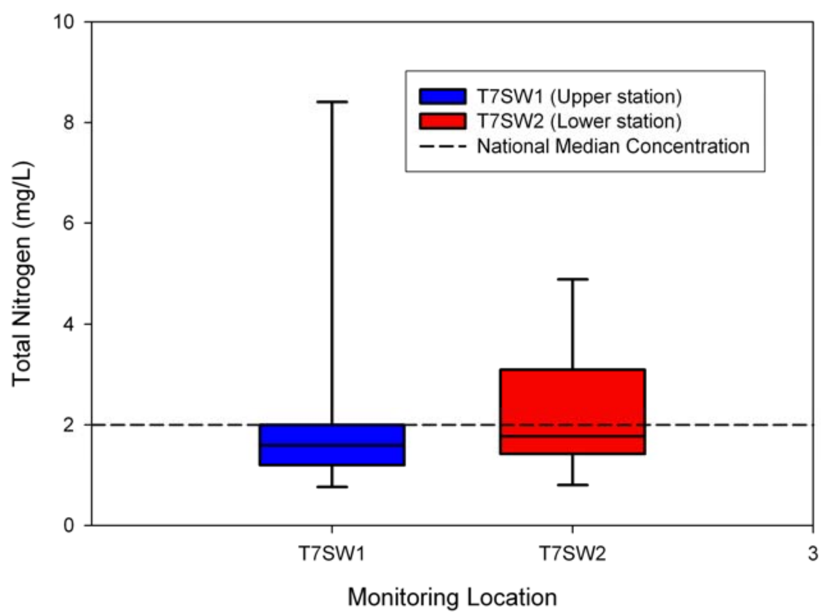


Figure 14. Storm-event TN concentrations vs. the national median value.

Median TN values at both stations were below the national median concentration. The length of the whiskers for the T7SW1 (Upper station) plot reflects the considerable variability in the sampling results, as discussed above. In addition, TN concentrations at the lower station were above the national median value during many storms.

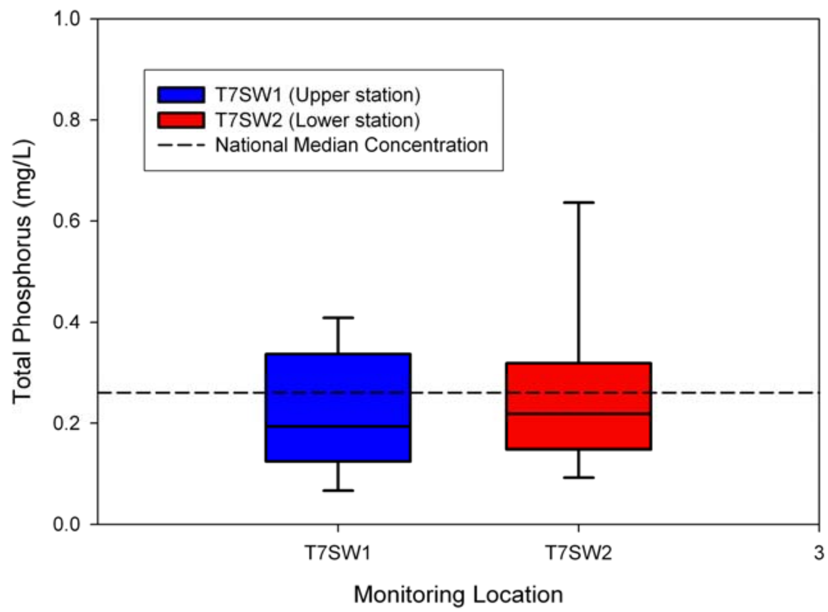


Figure 15. Storm-event TP concentrations vs. the national median value.

Median TP concentrations during storm events at both Tributary 7 monitoring sites were below the national median value. However, several storm events produced concentrations above this national value, with elevated levels closely linked to TSS. As noted above, efforts to reduce sediment transport may have the dual-benefit of reducing TP export.

5.4.1.4 Geomorphology and habitat

The physical condition of Tributary 7 was evaluated during the summer of 2005 using the Rapid Habitat and Rapid Geomorphic Assessments (RHA and RGA) described in the Vermont ANR Stream Geomorphic Assessment Protocols (www.vtwaterquality.org). The stream within the study neighborhoods has been subject to channel alteration (i.e. dredging) and is characterized by relatively homogenous features and substrate conditions. Fine sediment deposits are common throughout the reach, and several areas of significant erosion were identified. In many areas, the riparian buffer vegetation has been completely removed and residential landscaping and lawns are maintained to the edge of the stream. Piles of yard waste were noted in several areas directly in the stream channel. A significant amount of in-stream vegetation is present through the tributary, including wetland-type species (e.g. cattails) and aquatic grasses. The stream is degraded and incised in many areas. The RHA and RGA evaluations include the assignment of a score rating the condition of the study reach. Based upon our surveys, Tributary 7 in the study neighborhoods was assigned a RHA score of ‘poor’ and an RGA score of ‘fair’. Additional data describing the physical condition of Tributary 7 is provided in section 5.4.2.

5.4.1.5 Biological condition

The biological condition of Tributary 7 has been evaluated through an assessment of the benthic macroinvertebrate community. Benthic macroinvertebrate surveys are commonly used to assess stream condition by describing the biological community structure present within a stream segment. In fact, the recently released Wadeable Streams Assessment by the USEPA (USEPA 2006) focuses on benthic macroinvertebrates as an indicator of ecological 'health' because of their capacity to integrate the effects of stressors over time. Aquatic insect communities are affected by changes in physical conditions, water chemistry, and other biological factors within a stream ecosystem. Different insects are more affected than others, and over time the composition of a macroinvertebrate community will reflect the biological, physical, and chemical characteristics of a stream.

Suitable riffle habitat was identified just below the study neighborhoods, and field sampling was completed in the fall of 2004. We used the methods documented in VT DEC Field Methods Manual (VT DEC 2003) to collect and process the aquatic macroinvertebrate samples. Laboratory sorting of the samples and identification of the organisms (to Genus) took place in early 2005.

As anticipated, the benthic macroinvertebrate community in Tributary 7 was characterized by a low diversity and a high percentage of pollution-tolerant species. These findings indicate an 'impaired' status, which is consistent with the assessments performed in other urbanizing watersheds as part of the functional assessment study (section 5.4.2).

5.4.1.6 Summary of baseline conditions

The existing condition of Tributary 7 in the Butler Farms and Oak Creek Village study neighborhoods was evaluated using a variety of monitoring and assessment techniques. Detailed data sets describing flow conditions, as well as storm-event stream chemistry, have been developed for 2004 and 2005. Within the study neighborhoods, the stream changes from ephemeral to perennial and the transition point may be affected by historical and current land uses. During monitored storm events, the concentration of TSS, as well as conductivity and pH levels, were significantly higher below the neighborhoods. Nitrogen and phosphorus concentrations were also higher below the neighborhood, but these results exhibited substantial variability. Total nitrogen and phosphorus levels were often higher than the national median storm-event concentration. Phosphorus levels were closely tied to TSS in the water column, illustrating the need to consider sediment reduction strategies in future stormwater and stream management efforts. The existing biological community of the stream reflected the poor physical condition of the stream. In many parts of the study reach, excessive sedimentation has created conditions favoring wetland-type vegetation.

5.4.2 Functional assessment for stormwater impacted streams

Traditional bioassessment methods rely on integrated measures of community *structure*. Alternatively, *functional* bioassessments provide integrated measures of processing behavior in stream systems. These different approaches to stream bioassessment are complementary and provide important information about both the structure and function of stream ecosystems.

In our initial Work Plan we proposed to employ two simple and widely-used functional bioassessment methods. The first is whole-stream metabolism (WSM). This method (Marzolf et al. 1994, Bott 1996, Young and Huryn 1998, Westlake 1974) is based on a simple oxygen budget for a stream reach and provides an integrated estimate of whole stream respiration, net photosynthesis, and gross photosynthesis. These processes are critical to the overall function and health of stream ecosystems and relate directly to the processing of nutrients and pollutants in streams. A detailed description of the WSM field procedures was provided in the project Work Plan.

The second functional bioassessment method we proposed to employ was an assessment of nutrient uptake length (S_w). This method (Stream Solute Workshop 1990, D'Angelo et al. 1993, Webster and Ehrman 1996) provides an estimate of the average length of time a solute molecule (nutrient or pollutant) remains in solution before it is taken up, adsorbed, or exchanged in the stream system. Thus, it is a metric of the rapidity with which a compound is cycled in a stream ecosystem, a concept that is referred to as 'spiraling'. Excessively short or long uptake lengths (S_w) are indicative of systems that may be under stress or out of balance. We proposed to focus on key forms of nitrogen (ammonium and nitrate) and - especially - phosphorus, which help explain how runoff from land affects eutrophication in Lake Champlain. A detailed description of this general approach was provided in the project Work Plan.

In 2004 and 2005, we used structural and functional assessment methods to study a set of seven stream reaches near Burlington, Vermont. Streams in this area have been a focal point for stormwater controversy for several years. Three of these streams are considered "impaired" by the State of Vermont (303d listed) for general impacts associated with "urban runoff". Four of the reaches are considered to be in "attainment" condition pursuant to state biological monitoring. Study reaches (80m – 175m) were established in each stream trying to match for upstream watershed area, stream size and type, substrate, and canopy cover, with attention also to accessibility and landowner permission. At the bottom of each study reach, we constructed and maintained monitoring stations consisting of equipment to measure and record water level, temperature, dissolved oxygen, specific conductivity, and sunlight (PAR). We also performed regular surveys and experiments to evaluate stream conditions over time. Field work included more than 280 site visits and calibration checks, 79 hydrologic discharge profiles (producing 13 hydrologic rating curves), 88 sound surveys (to evaluate reaeration at the feature scale), 15 cross-sectional characterization surveys (physical measurements at 5-meter intervals along entire reach), 6 benthic macroinvertebrate surveys with laboratory identification to genus, 6 surveys of geomorphic and habitat conditions, 9 basic algae surveys, 2 slug tests using a conservative tracer, and 17 full-day, solute injection experiments.

Since the scope of this work was expanded in 2004 (from limited monitoring of a single stream to continuous monitoring of seven streams), we have pursued several key objectives. We used the Vermont bioassessment methods (which are based on biological community structure) and surveys of geomorphic/habitat condition to confirm the status of the streams. In addition, we examined the feasibility of using functional (ecosystem process-based) methods to assess impairment in difficult urban settings. We used both approaches to compare "impaired" urban streams to those of less-impaired (and typically more rural) counterparts. We have completed or made good progress on all of these objectives.

By the end of the second project year, we completed assessments of the benthic macroinvertebrate community structure and the geomorphic/habitat condition that confirmed the ANR classifications as 'impaired' or 'attainment' condition. The results for the assessments at Tributary 7 are also provided in this section for comparison purposes (Figure 16, Figure 17).

The benthic macroinvertebrate samples that were collected in the fall of 2004 were sorted and identified in early 2005. Sampling and analysis was performed according to VT DEC protocols, described in detail in the project Work Plan. Several of the metrics used in the VT DEC protocols to describe the biological condition are presented below. In general, the 'impaired' streams are characterized by lower species richness, fewer environmentally sensitive species, and more pollutant tolerant species. These findings are consistent with the prior VT DEC findings. Note that the results from Tributary 7 (Potash Brook) in the Butler Farms and Oak Creek study neighborhoods are consistent with the other urban stormwater-impaired streams in our study.

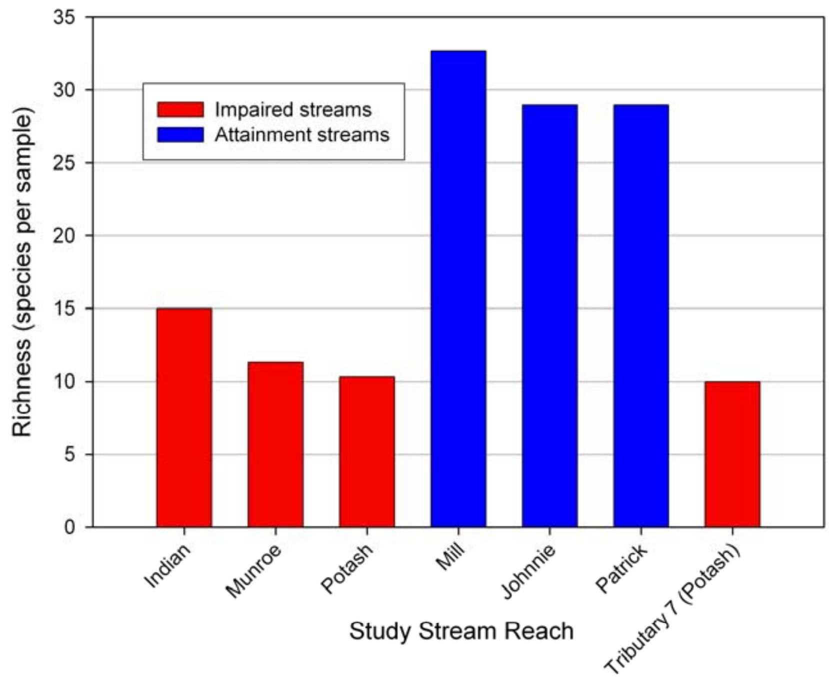


Figure 16. Benthic macroinvertebrate species richness at RAN monitoring sites.

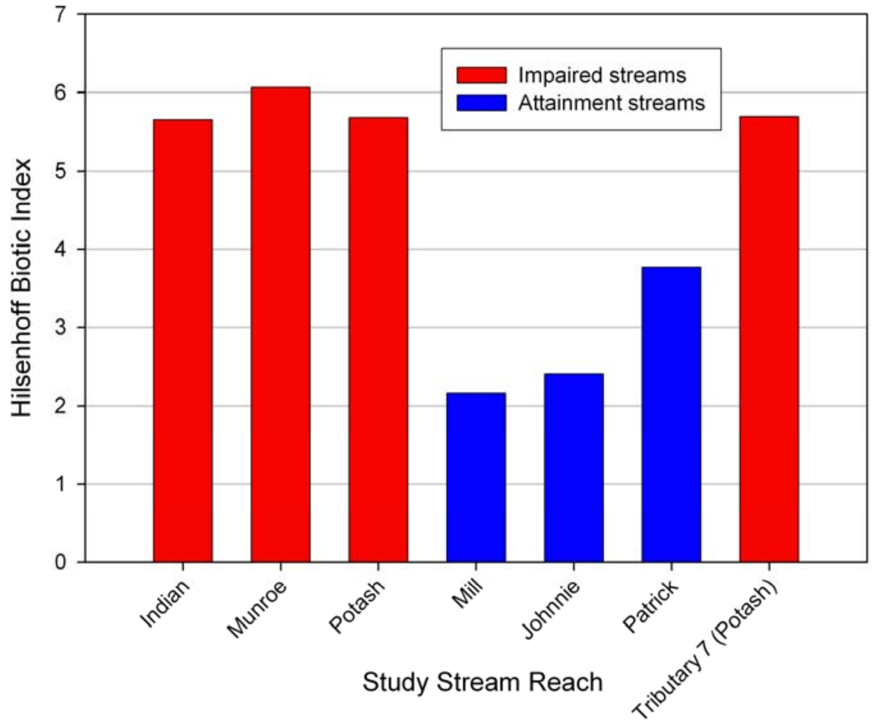


Figure 17– Hilsenhoff Biotic Index at RAN monitoring sites (The Hilsenhoff Biotic Index (0-10) is a measure of the macroinvertebrate assemblage tolerance toward nutrient enrichment).

The physical assessment of all study locations was completed in 2005 using Phases I and II of the Vermont DEC Stream Geomorphic Assessment Protocols. A majority of this work was conducted under a joint University of Vermont - DEC initiative to assess the geomorphic condition of all stormwater impaired streams in Chittenden County. This is a new collaboration that began in early 2005 as a direct offspring from prior RAN activities and interaction with state personnel.

Habitat and geomorphic ratings varied across the study sites (Table 7). The overall 'health' of the reaches, as determined from the Rapid Habitat and Rapid Geomorphic Assessments (RHA/RGA), indicates differences between the 'impaired' and 'attainment' condition streams.

Table 7 - Rapid Habitat and Geomorphic Assessment Results

Stream	Habitat Rating	Habitat Condition	Geomorphic Rating	Geomorphic Condition
Potash	0.54	Fair	0.45	Fair
Munroe	0.48	Fair	0.48	Fair
Indian	0.64	Fair	0.58	Fair
Patrick**	0.82	Good	0.45	Fair
Johnnie	0.72	Good	0.69	Good
Mill	0.80	Good	0.79	Good
Lewis*		Reference	0.91	Reference
Tributary 7 (Potash)	0.34	Poor	0.39	Fair

* Data from VT DEC (2004).

** Data from 2004 RHA/RGA survey for Patrick Brook was not a part of the above-referenced UVM-DEC effort.

The WSM functional assessment work was fully operational beginning in mid-summer 2004 and continued through late fall of the same year. We resumed measurements from late spring to late fall 2005. Data reduction, variable construction, and initial analyses are continuing and will be reported in the PY3 final report. The nutrient spiraling length (S_w) work was supposed to be repeated seasonally in 2004 and 2005. However, flow conditions were routinely too high in 2004 to obtain useful results; high flows dilute the injection stock, suppress biotic activity, and yield uninteresting results (i.e., uncharacteristically long spiraling lengths). We completed several runs in 2005. However an initial assessment of the data indicated it was of questionable value due to further high-flow conditions in 2005 and due to analytical problems we encountered (see Appendix 10.3.3). Results from these experiments will be reported in the PY3 final report.

6. Summary of Deliverables and Achievements

The first two years of this project were devoted to development of the background and basic framework for stormwater management in the study areas. The following specific deliverables were associated with this effort:

- <u>Project Web Site</u>: A project web site was developed to serve as a tool for project coordination and public outreach. The web site includes a project description, maps of the watershed and study area, a calendar of all meetings, agendas, links to relevant sites of local and national interest, personal profiles of those involved, and other pertinent information. It continues to be updated to continually inform and engage the stakeholder community. COMPLETED.

- <u>Project Brochures</u>: A tri-fold brochure was produced to describe and illustrate the project and research in a manner that is accessible to the general public. This brochure was produced for and distributed at the first project Field Day. COMPLETED.

- Additional Public Outreach: Non-technical, 'lay-persons' meetings and a Field Day were held to summarize the status of the project for the communities and stakeholders of the Potash Brook watershed. At these meetings we described our framework for addressing watershed issues and solicited community input. COMPLETED.

- Status Reports: A mid-year status report was produced in year 1 to document the progress to that date. An annual progress report was produced at the end of the first year to document our progress and experience as of that time. COMPLETED.

- Eco-technology selection: Beginning in year 2 the project team began to work more closely with residents of the Butler Farms and Oak Creek neighborhoods, the original developer, and staff from the Town of South Burlington and the Vermont Agency of Natural Resources, to identify low-impact eco-technologies to manage suburban stormwater runoff from this test neighborhood at scales that ranged from individual homes, to clusters of homes to entire subdivisions. COMPLETED.

- Eco-technology implementation: Once a set of low-impact eco-technologies were identified, we began to work with the Town of South Burlington, the state of Vermont, and the USEPA to identify resources that could be used to implement the selected technologies. ON-GOING.

- Stormwater event sampling in Tributary 7: We completed a series of seasonal event samples documenting the dynamics of stormwater runoff from the Butler Farms and Oak Creek neighborhoods as they are currently configured. COMPLETED.

- Functional assessments of paired stream reaches: We continued a set of functional assessments of 3 stormwater impaired and 3 'attainment' stream reaches. ON-GOING.

- Public outreach: We regularly updated our web site and liaised with local media (newspaper and radio) to widely disseminate our findings. ON-GOING.

- Annual project report: This document.

7. Overall Conclusions and Recommendations For Future Work

Vermont has become a focal point for stormwater issues in the region, if not nationally. Traditional approaches to stormwater management have not worked well enough in this area, leading to litigation. It is widely recognized that creative research is needed to underpin and/or develop alternative approaches for stormwater management. The key feature of this project is our focus on a *range of stormwater management interventions* that include individual behavioral modifications and ecologically-based technologies, as well as traditional engineered approaches. A second feature of our project is the focus on including *long-term social and ecological considerations*, rather than short-term economic cost/benefit analyses, in the evaluation of our scenarios for action. A third key feature of our project is our focus on *stakeholder participation* in developing our action plan. Vermont in general – and Chittenden County in particular – have established reputations as being among the most ecologically concerned and active communities in the United States. Thus, we thought there is a high likelihood that we would be able to secure stakeholder participation in the project and, ultimately, application of the products that arise from this project. Certainly, there will be divergent opinions regarding the best plans for action. However, this diversity of opinion will provide valuable input to the project.

During the first two years of this project we initiated or completed several important objectives in this multi-year research program. One of the most important of our objectives was to establish a flexible toolbox that could be used to convey information to stakeholders and serve as an archive for project information and data. The RAN website and embedded toolbox were established within year two. We completed a survey of the resident stakeholders' knowledge and attitudes regarding stormwater management and reported a summary of the results to the community. We began to gather background technical data about the Butler Farms and Oak Creek Village sites and began to share these data with resident and technical stakeholders. We also began to gather important new baseline data on the condition of Tributary 7 (which drains the Butler Farms and Oak Creek Village neighborhoods) and initiated functional assessments of six different streams, including Potash Brook, into which Tributary 7 drains. We initiated a partnership with the University of New Hampshire Stormwater Research Center to complete a Life Cycle Assessment of several common stormwater best management practices. And we have worked closely with a variety of stakeholders – from homeowners, to city managers, to state regulators, to research scientists – to explore innovative ways to manage stormwater runoff from existing developments. This included a major involvement in the Vermont Water Resources Board Stormwater Docket, which was concluded in 2004 and that lead – through the RAN program – to collaborations with the Vermont Agency of Natural Resources on several related stormwater management research initiatives.

Many of the efforts initiated in project years 1 and 2 are still in progress and have lead to new initiatives that define our current activities. In year 3 we completed the Life Cycle Assessment initiated in year 2. We also completed the functional assessment initiative. We continued to facilitate discussions with the Butler Farms and Oak Creek Village residents and continued to develop the RAN website and toolbox. New features added to the toolbox include a simple modeling tool based on the widely-used TR-55 rainfall-runoff model (which we called RAN-55) that allows non-technical users to explore how development intensity affects peak discharge from design rain events. In addition, we conducted, summarized, and posted the results from a survey of residents' observations of unusual hydrologic conditions (e.g., flooding, icing) in the neighborhoods. These results were posted as a spatially-explicit map. Finally, we facilitated the establishment of a Stormwater Study Group that represents a new, pro-active stage in organization of the Butler Farms and Oak Creek Village residents to address their community stormwater management concerns. We will summarize progress on these initiatives in our project year 3 annual report.

8. Acknowledgements

We acknowledge the strong and continuing involvement of J.B. Hinds, Director of Zoning and Planning for the Town of South Burlington, without whom this project would be immeasurably more difficult. We acknowledge D. Ross from the University of Vermont Soil Testing Laboratory for assistance with analytical trials. We thank B. Alafat and E. Perkins, Program Managers, U.S. Environmental Protection Agency Region 1, for their guidance and patience over the course of this project period. We deeply appreciate the time devoted by residents of the Butler Farms and Oak Creek Village neighborhoods to participate in this project and the continuing interest they have shown to address these complex issues. Finally, we are indebted to Senator Jim Jeffords and his staff for bringing attention to the environmental problems caused by unmanaged stormwater runoff from urban and suburban development to Vermont's streams and lakes, including Lake Champlain. This project was funded by Grant No. X 98187601 from the U.S. Environmental Protection Agency. The data, conclusions, and opinions expressed in this report are those of the authors and not the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

9. Literature cited

Barr, S., and A. Gilg. 2006. Sustainable lifestyles: Framing environmental action in and around the home. Geoforum 37: 906–920.

Bauman, H., and A. Tillman. 2004. The Hitchhiker's Guide to LCA. Studentlitteratur Publishers, Sweden.

Birch, G.F., C. Matthai, M. Fazeli, and J.Y. Suh. 2004. Efficiency of a constructed wetland in removing contaminants from stormwater. Wetlands 24(2): 459-466.

Blumenthal, D., and J.L. Jannink, 2000. A classification of collaborative management methods. Conservation Ecology 4(2): 13-20.

Bott, T. 1996. Primary production and community respiration. Chapter 25 *in* R. Hauer, and G. Lambertti (editors). Methods in Stream Ecology. Academic Press, New York.

Bowden, W.B., A. Fenemor, and N. Deans. 2004. Integrated water and catchment research for the public good: The Motueka River-Tasman Bay Initiative, New Zealand. International Journal of Water Resources Development 20(3): 311-323.

Braden, J.B., and D.M. Johnston. 2004. Downstream economic benefits from storm-water management. Journal of Water Resources Planning and Management 130(6): 498-505.

Burns, D., T. Vitvar, J. McDonnell, J. Hassett, J. Duncan, and C. Kendall. 2005. Effects of suburban development on runoff generation in the Croton River basin, New York, USA. Journal of Hydrology 311: 266–281.

Burton, G.A. and R.E. Pitt. 2002. Stormwater effects handbook: A toolbox for watershed managers, scientists, and engineers. Lewis Publishers, New York.

Carleton, J.N., T.J. Grizzard, A.N. Godrej, H.E. Post, L. Lampe, amd P.P. Kenel. 2000. Performance of a constructed wetlands in treating urban stormwater runoff . Water Environment Research 72(3): 295-304.

Center for Watershed Projection, CWP. 2003. Impacts of Impervious Cover on Aquatic Systems. Monograph No. 1. Elicott City, Maryland.

Costanza, R., A. Voinov, R. Boumans, T. Maxwell, F. Villa, H. Voinov, and L. Wainger. 2002. Integrated ecological economic modeling of the Patuxent River watershed, Maryland. Ecological Monographs 72 (2): 203-231.

D'Angelo, D.J., J. R. Webster, S. V. Gregory, and J. L. Meyer. 1993. Transient storage in Appalachian and Cascade Mountain streams as related to hydraulic characteristics. Journal of the North American Benthological Society 12(3): 223-235.

Godfrey, R. 2003. Impervious cover build out of Potash Brook watershed. Available at: www.uvm.edu/~ran/ran/toolbox/stormwater/index.php.

Goma, H.C., K. Rahim, G. Nangendo, J. Riley, and A. Stein, 2001. Participatory studies for agro-ecosystem evaluation. Agriculture, Ecosystems & Environment. 87(2): 179-190.

Hartigan, J. P. 1986. Regional BMP master plans. In *Urban Runoff Quality—Impact and Quality Enhancement Technology*, 351-365. Reston, Va.: ASCE Conference Proceedings.

Hoffman, L. 2006. Combating combined sewer flow: Green roof stormwater modeling. Biocycle: 38-40.

Homburg, A., and A. Stolberg. 2006. Explaining pro-environmental behavior with a cognitive theory of stress. Journal of Environmental Psychology 26(1): 1-14.

International Standards Organization, ISO. 1997. ISO 14040: Life Cycle Assessment. Geneva, Switzerland: International Organization for Standardization.

Lazzarin, R.M., F. Castellotti, and F. Busato. 2005. Experimental measurements and numerical modelling of a green roof. Energy and Buildings 37(12): 1260-1267.

Lieb, D.A., and R.F. Carline. 2000. Effects of urban runoff from a detention pond on water quality, temperature and caged *Gammarus minus* (Say) (Amphipoda) in a headwater stream. Hydrobiologia 441: 107–116.

Marzolf, E.R., P. J. Mulholland, and A. D. Steinman. 1994. Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole-stream metabolism in small streams. Canadian Journal of Fisheries.and Aquatic.Science. 51: 1591-1599.

Mendoza, G.A. and R. Prabhu. 2000. Development of a methodology for selecting criteria and indicators of sustainable forest management: A case study on participatory assessment. Environmental Management 26(6): 659-673.

Nelson, J.A. and M.M. Nealon. 2003. Potash Brook watershed restoration plan, South Burlington, Vermont. Final report. Pioneer Environmental Associates, LLC. Middlebury, Vermont. January 27, 2003.

Novotny, V. 2003. Water quality: diffuse pollution and watershed management. 2nd edition. John Wiley and Sons, New York.

Paul, M.J., and J.L. Meyer. 2001. Streams in the Urban Landscape. Annual Review of Ecological Systems 32: 333–365.

Pease, J. 1997. Potash Brook stormwater management evaluation. Vermont Department of Environmental Conservation. Agency of Natural Resources. Waterbury, Vermont.

Rushton, B.T. 2001. Low-impact parking lot design reduces runoff and pollutant loads. Journal of Water Resources Planning and Management 127(3): 172-179.

South Burlington Stormwater Utility, SBSU. 2006. South Burlington Stormwater Utility website. Available at www.south-burlington.com/stormwater/.

Stream Solute Workshop. 1990. Concepts and methods for assessing solute dynamics in stream ecosystems. Journal of the North American Benthological Society 9(2): 95-119.

United States Environmental Protection Agency, US EPA. 2006. Draft Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams (EPA 841-B-06-002). Washington, D.C.

United States Environmental Protection Agency, US EPA. 2005. Top Ten Watershed Lessons Learned (EPA840-F-97-001). Washington, D.C.

United States Geological Survey, USGS. 1963. Water Supply Paper 1542-A: Flow-Duration Curves. Manual of Hydrology: Part 2. Low-Flow Techniques. Washington, D.C.

University of Vermont, UVM. 2006. 2002 Land Cover/Land Use Dataset for Vermont. UVM Spatial Analysis Lab, Burlington, VT.

van den Belt, M., 2004. Mediated Modeling: A System Dynamics Approach to Environmental Consensus Building. Island Press, Washington, D.C.

Vermont Agency of Natural Resources, VT ANR. 2002. Stormwater management manual. Volumes I and II. Montpelier, VT.

Vermont Agency of Natural Resources, VT ANR. 2003. Stream Geomorphic Assessment Protocol Handbooks. Waterbury, VT.

Vermont Center for Geographic Information, VCGI. 2006. Vermont County Population Data 1840 to 2000.VCGI. Burlington, VT

Vermont Department of Environmental Conservation, VT DEC. 2003. Methods for Determining Aquatic Life Use Status in Selected Wadeable Streams Pursuant to Applicable Water Quality Management Objectives and Criteria for Aquatic Biota Found in Vermont Water Quality Standards (VWQS) Chapter 3 '3-01, as Well as Those Specified in 3-02(A1 and B3), 3-03(A1 and B3), and 3-04(A1 and B4:a-d). Waterbury, VT.

Vermont Department of Environmental Conservation, VT DEC. 2004. Stream Geomorphic Assessment of Lewis Creek. Waterbury, VT.

Wakelin, S.C., P. Elefsiniotis, and D.G. Wareham. 2003. Assessment of stormwater retention basin water quality in Winnipeg, Canada. Water Quality Research Journal of Canada 38(3): 433-450.

Walsh, C.J., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman, and R.P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3): 706–723.

Webster, J.R. and T.P. Ehrman. Solute dynamics. 1996. Chapter 8 *in* R. Hauer and G. Lambertti (editors). Methods in Stream Ecology. Academic Press, New York.

Westlake, D.F. 1974. Measurements on non-isolated natural communities. Chapter 3 *in* R.A. Vollenwieder (editor). Primary Production in Aquatic Environments, IBP Handbook 12. Blackwell Scientific Publications, Oxford.

Young, R.G. and A.D. Huryn. 1998. Comment on: Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole -stream metabolism in small streams. Canadian Journal of Fisheries and Aquatic Science 55: 1784-1785.

10. Appendices

10.1 Resident Survey of Butler Farms and Oak Creek Village

In March-April 2004 a survey of residents living in the Butler Farms and Oak Creek Village neighborhoods was completed. The survey was developed with three goals in mind:

1. to understand how people perceive the stormwater issues and determine what they know about stormwater related problems;
2. to collect information about the behavior patterns and daily practices related to stormwater in the neighborhood; and
3. to evaluate the overall level of environmental awareness and willingness to act and/or change in the neighborhood.

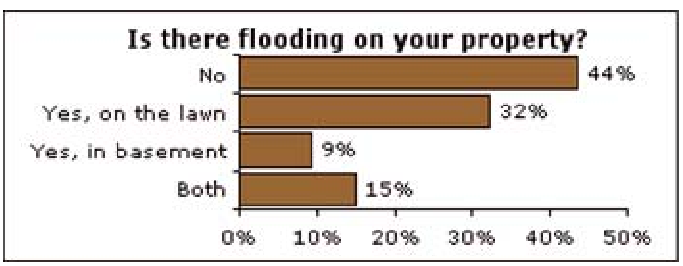
We have discussed the questions in the survey with a sub-set of residents who volunteered to help us with this project. This stakeholder group helped us revise some of the survey questions so they would be understood better by the surveyed residents. In addition, the neighborhood group volunteered to help us distribute the survey. We all agreed that if this was regarded as a neighbor-to-neighbor activity, the return rates might be higher than if this was regarded as a UVM or town activity only. We received 99 completed surveys out of 200 circulated for an ~50% return.

The survey questions and final results are provided below:

Stormwater in your Neighborhood
Preliminary Results of the Stakeholder Survey

General Statistics:	
Total Forms Submitted	87
Total Damage from Flooding	$14,850
Average Damage from Flooding	$170
Max Damage from Flooding	$4,000
Expected a problem	5%
Have flood insurance	5%

1.



2. Have you incurred any property damage or losses because of flooding?

☐ No - 78% ☐ Yes - 17%

(Approximately how much was the total damage? $$ 170 . How many times? 19 times)

3. Did you expect flooding to be a problem when you were purchasing the property?

☐ Yes - 5% ☐ No - 95%

4. Did you purchase flood insurance?

☐ Yes - 5% ☐ No - 80% ☐ Was not offered, or not available - 9% ☐ Don't know

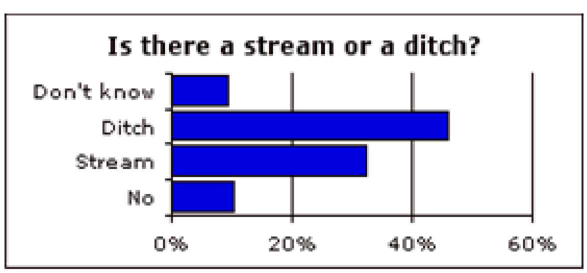
5. Do you have a basement drain?

☐ Yes - 24% ☐ No - 56% ☐ Don't know - 17%

6. Where does the water from your roof drain go?

☐ Drains into my lawn - 69%
☐ Drains onto a paved area - 6%
☐ Drains into a pipe to the waterway - 2%
☐ All the above - 21%
☐ Don't know

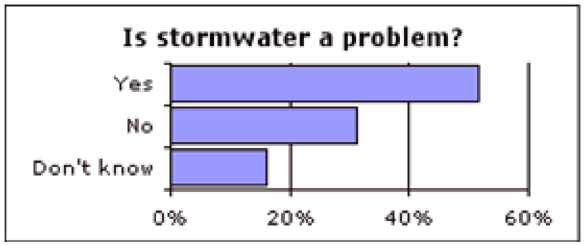
7.



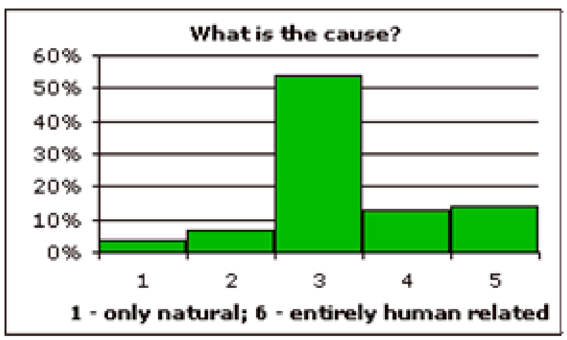
8. If "YES" how far away is it from your property?

- Right next to it - 29%
- On the average 7 houses away - 22%
- On the average 163 feet away - 17%
- Don't know - 16%

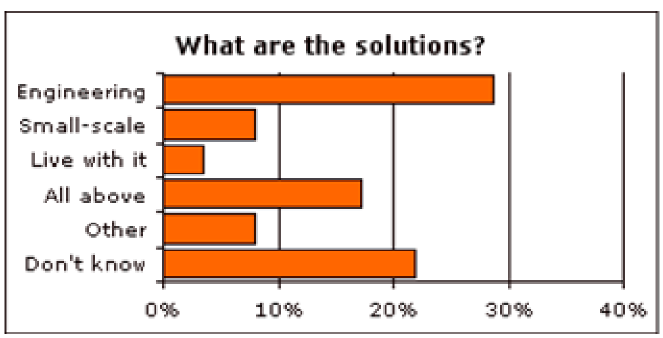
9.



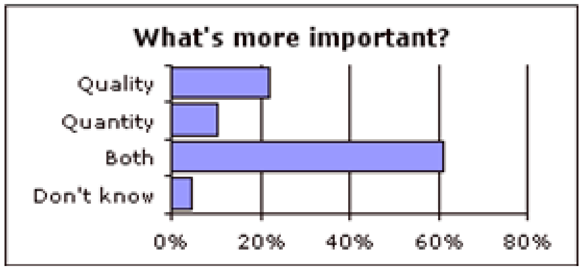
10.



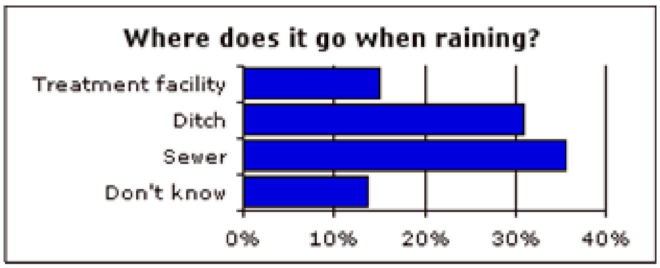
11. What do you think is the best way to prevent flooding in your neighborhood?



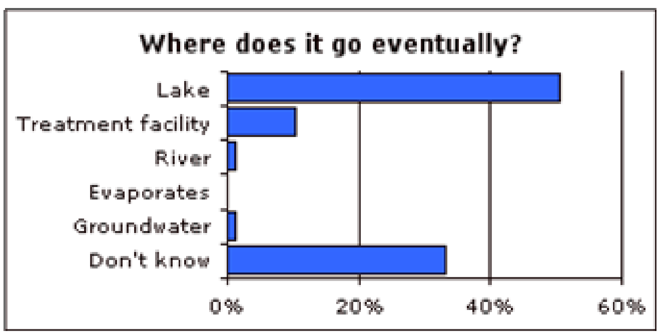
12. When we talk about stormwater management, what do you think is more important?



13. When it rains in your neighborhood where does most of the water runoff go?



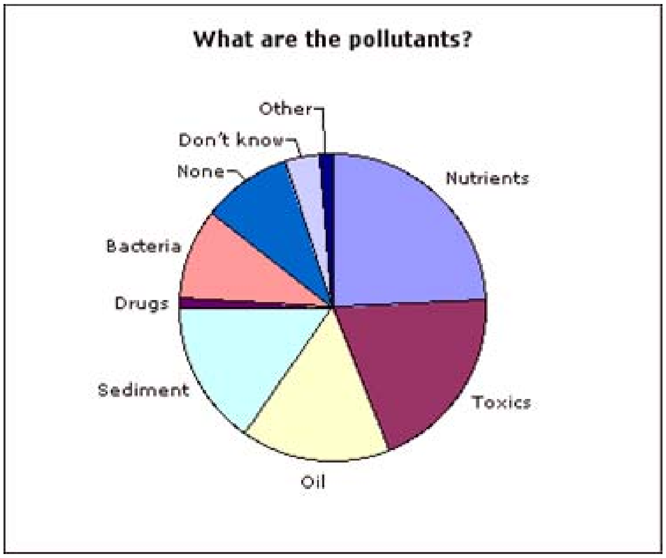
14. The water collected from your neighborhood eventually goes to...



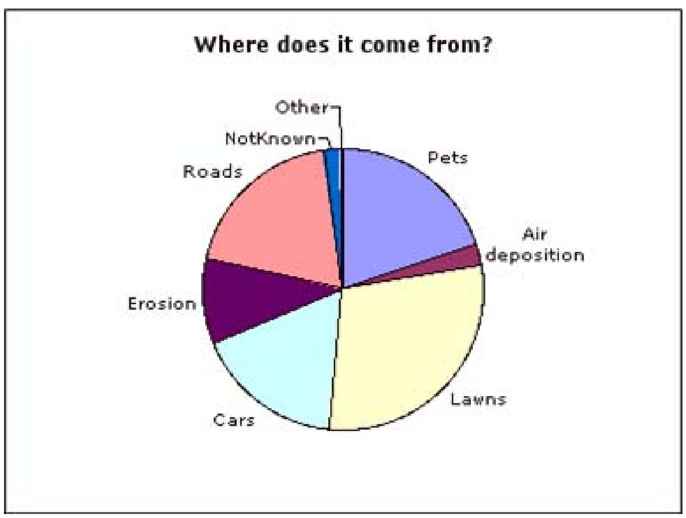
15. As stormwater moves through your neighborhood its quality will...

☐ ...improve - 0% ☐ ...get worse - 64% ☐ ...stay the same - 11% ☐ Don't know - 21%

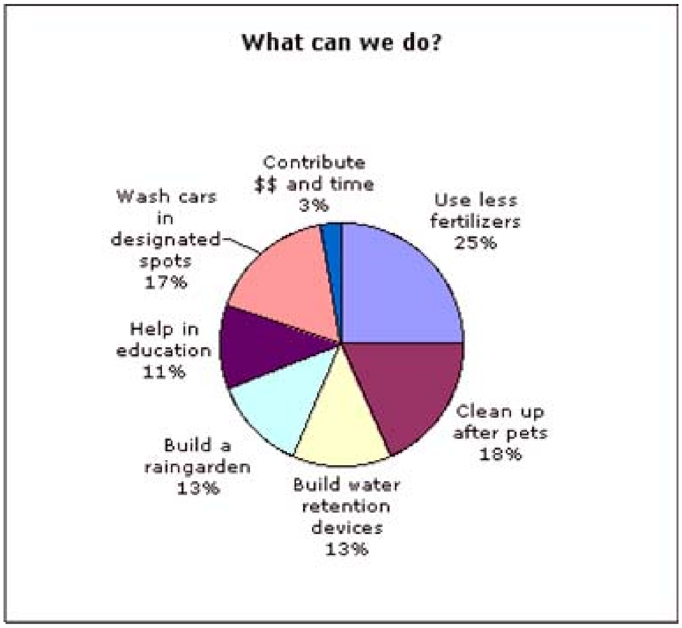
16. What types of pollutants does your neighborhood contribute to stormwater? (You may click more than one)



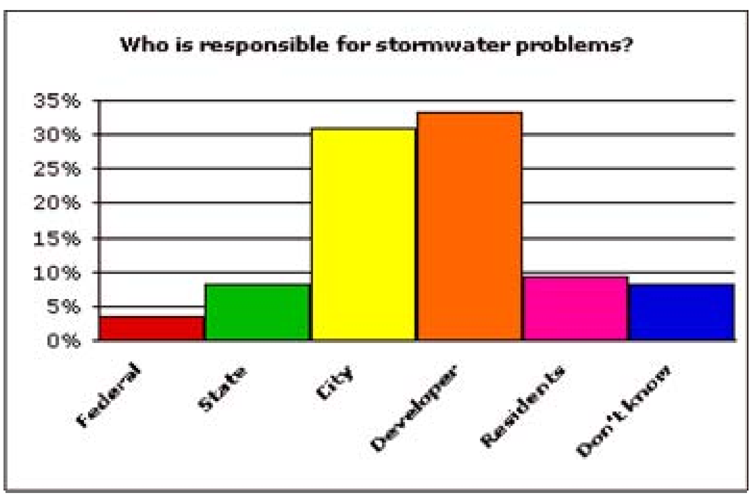
17. What are the main sources of stormwater pollutants in your neighborhood? (You may click more than one)



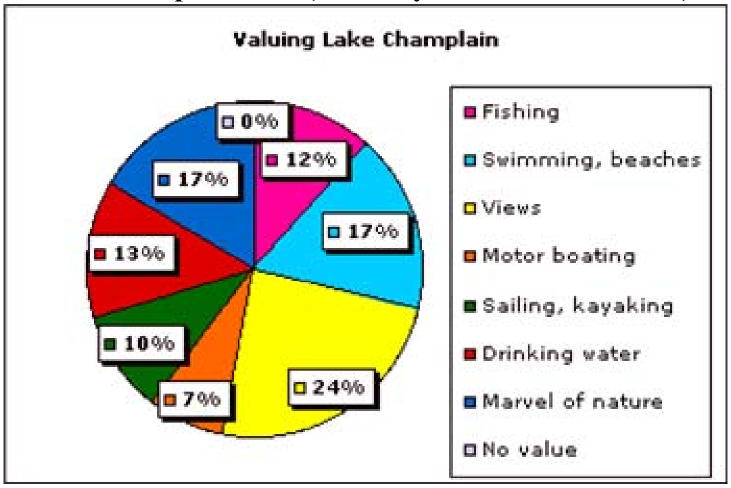
18. If you think that stormwater quality is a problem in your neighborhood, what would you be willing to do to fix the problem? (You may click more than one)



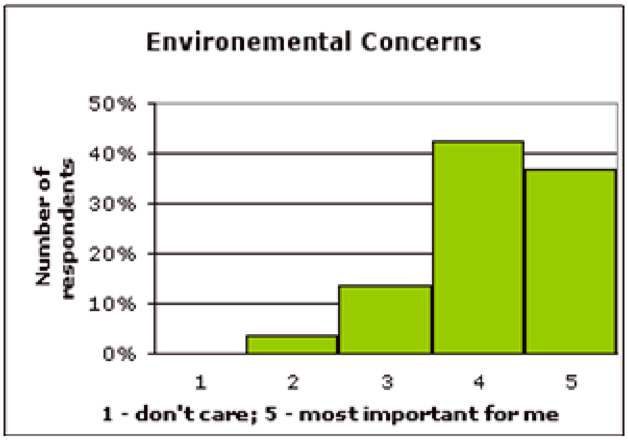
19. If stormwater is a problem in your neighborhood, who do you think has primary responsibility for fixing the problem?



20. What do you value Lake Champlain for? (You may click more than one)

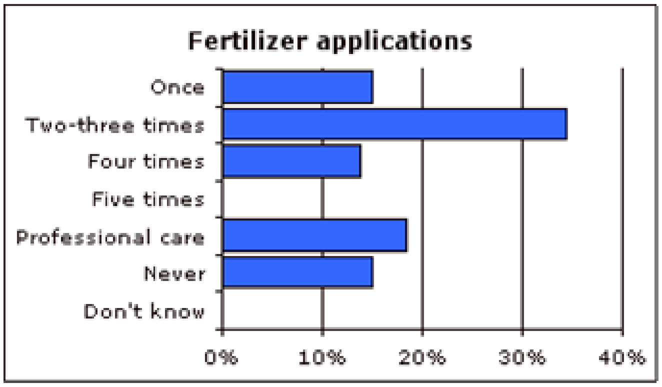


21. How important are environmental issues to you on a scale from 1 (do not care at all) to 5 (this is the most important issue for today)?

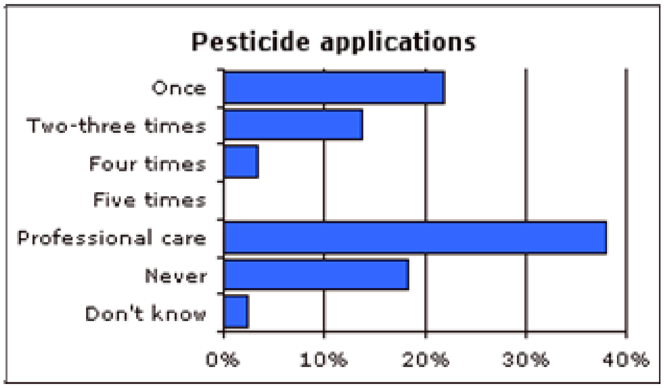


22. Finally a few questions about your household behavioral patterns:

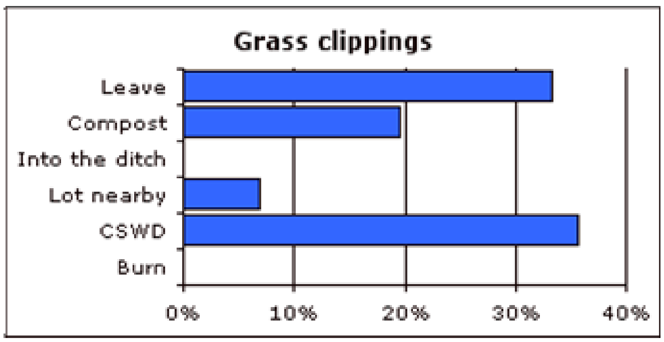
a. During the growing season, how often do you use lawn fertilizers?



b. During the growing season, how often do you use pesticides/herbicides?



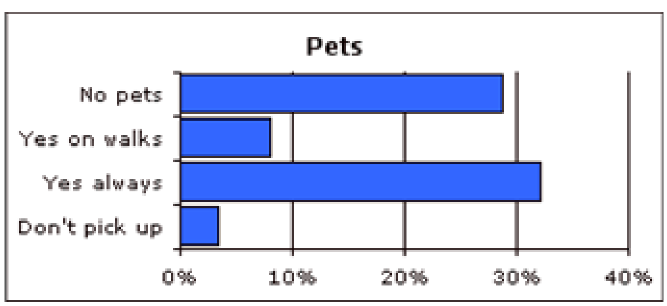
c. Where do you dispose of your yard waste and grass clippings?



d. Have you ever had a soil test done on your soil?

Yes - 14% No - 77% Don't know - 6%

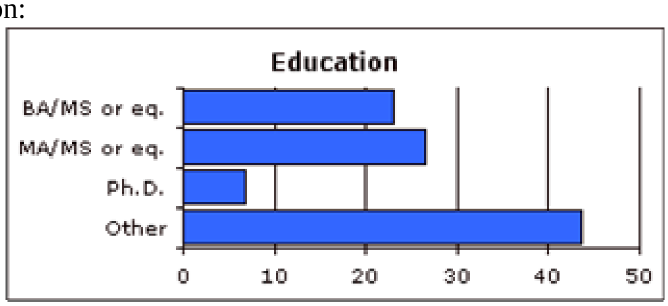
e. Do you normally pick up waste after your pet?



23. Comments (any other suggestions, recommendations, concerns):

"Our neighborhood seems to care a lot about lawn appearances. Some form of education would be needed to address the lawn appearance issue with options that do not pollute the environment."
"We need a pesticide ban townwide. Need a more global parameter. At individual level we do not see results of cumulative impact, therefore we do not care"
"Residents should only have one cat or dog that evacuates outside, and they should clean up the feces. Licensing fees should be increased to $75 and the proceeds to fund enforcement efforts to warn and then heavily fine violators who do not pick up feces. This is disgusting and an environmental disaster. Also some composting and organic gardening - see gardensalive.com"
"Too much pet waste in development. Should advise pet owners of risks, consequences (i.e. e-coli and children). I would impose fines on those who do not pick up after pets."
"The big problem in our neighborhood is the storm sewer that runs under Mill Pond lane. It is obvious from the stench that at least one house on the street has a house-sewer line that runs off into the storm sewer. This storm sewer drains into Potash Brook! The town has done preliminary investigation but has shelved the matter."
"Pet droppings are a huge problem throughout the area and should be addressed."
"Make sure concentrate on septic leaking into the lake. Upgrade our sewer system. Need more marketing + public service announcements on what we can do."
"First concern is adequacy of the drainage ditch in Butler Farms. Its large volume in spring thaw has caused it to block adequete flow of water from my house's foundation drainage system, causing flooding in the basement. Concerned that proposed development of Marceaus/Larkin land south of Butler Farms will negatively impact the ability of current drainage to handle incresed volume of water caused by development. Since new houses /driveways/ streets will hinder ability of soil to absorb water, thus increasing the volume that goes to ditch."
"Mostly people either leave dog waste or pick it up in plastic bags and throw the bags off the rec path."
"As city approved the current system for runoff, they should play a major role in solving the problem. Home buyers should not be required to understand civil engineering when they buy their homes in city approved developments. Obviously the developer should also play a major role in the solution as well."

Highest level of education:



Do you own this house - 100%

For how long have you been living in this house? 7.7 years

The longest time lived - 17 years

Did you build it? Yes - 26 No

Do you plan to come to the community meeting on April 14th? Yes - 17

Is there anything special in the perceptions of the people living directly on the stream?
ANSWER: In most cases nothing special
Some Comparisons

All neighborhood

General Statistics:

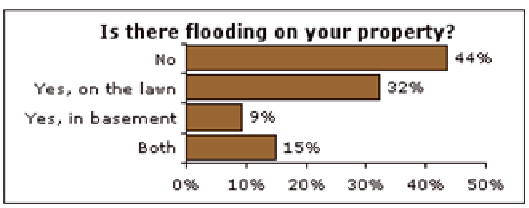
Total Forms Submitted	87
Total Damage from Flooding	$14,850
Average Damage from Flooding	$170
Max Damage from Flooding	$4,000
Expected a problem	5%
Have flood insurance	5%

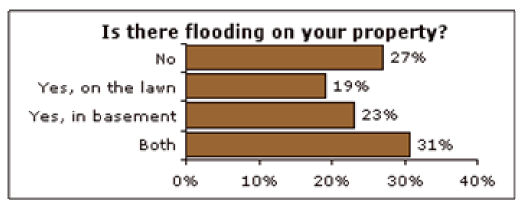
Right next to the stream

General Statistics:

Total Forms Submitted	26
Total Damage from Flooding	$8400
Average Damage from Flooding	$323
Max Damage from Flooding	$4,000
Expected a problem	0%
Have flood insurance	4%

1.



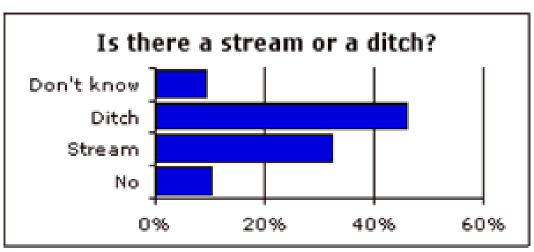


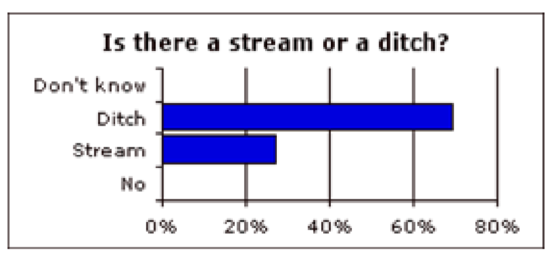
2. Have you incurred any property damage or losses because of flooding?

No - 78% Yes - 17%

No - 73% Yes - 27%

7.





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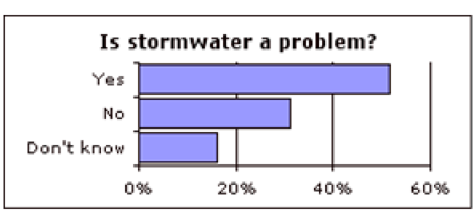

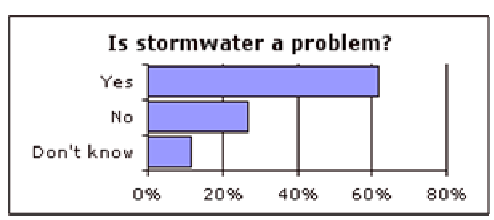

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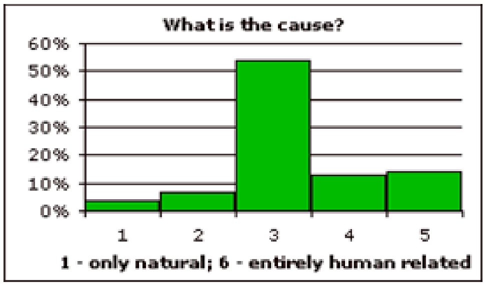
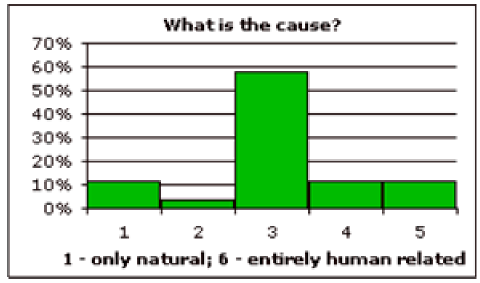
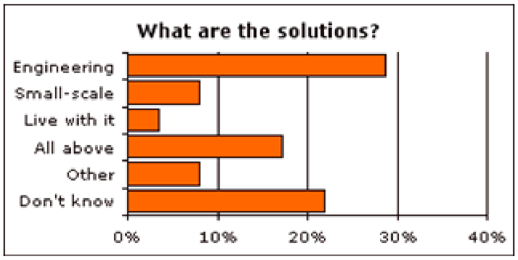
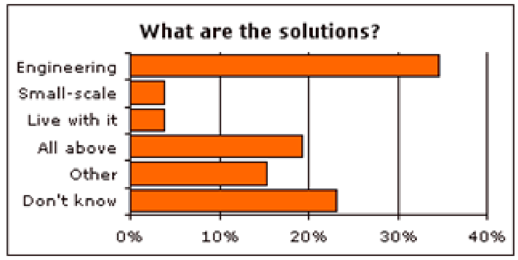


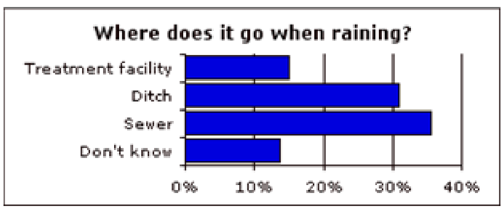


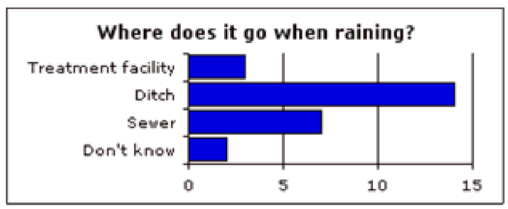
11. What do you think is the best way to prevent flooding in your neighborhood?



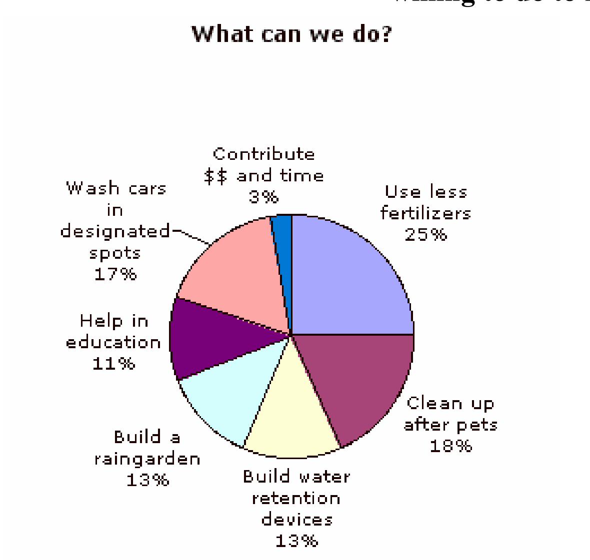


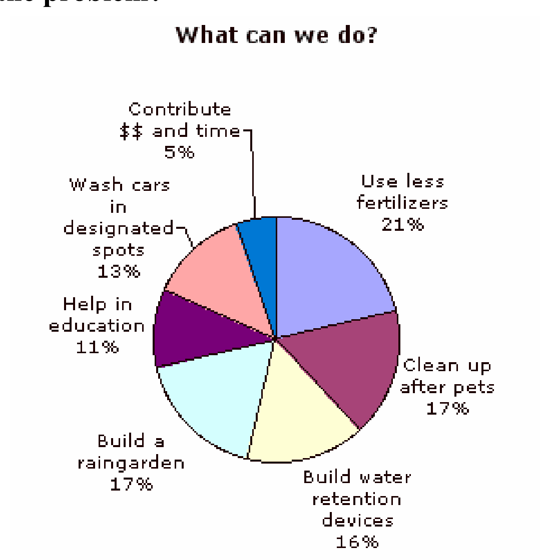
13. When it rains in your neighborhood where does most of the water runoff go?



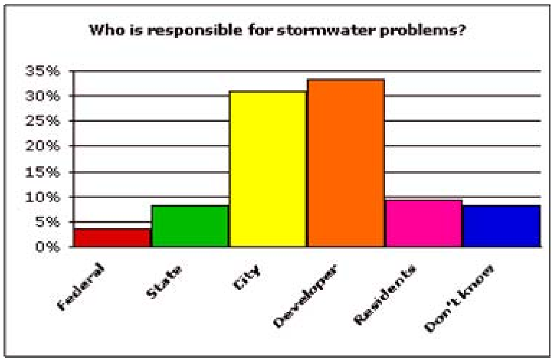


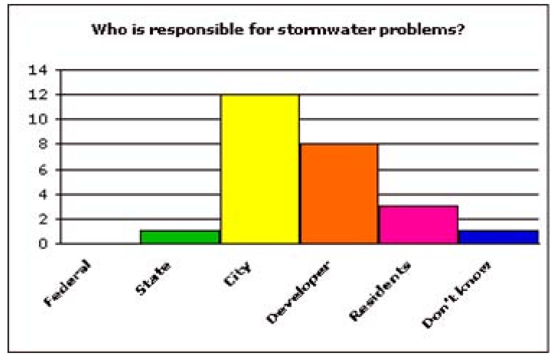
18. If you think that stormwater quality is a problem in your neighborhood, what would you be willing to do to fix the problem?



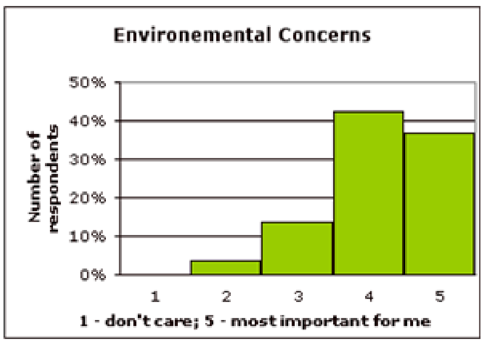


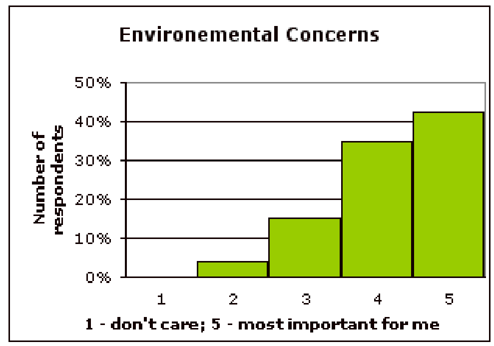
19. If stormwater is a problem in your neighborhood, who do you think has primary responsibility for fixing the problem?



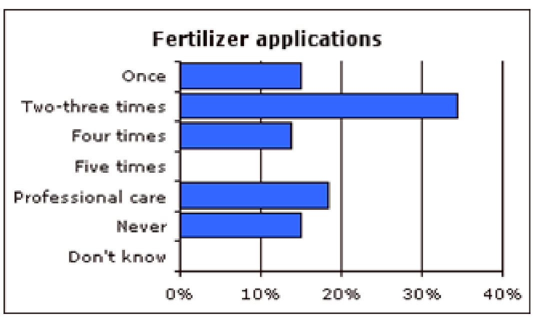


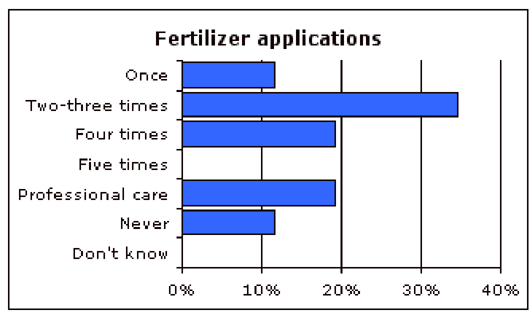
21. How important are environmental issues to you?



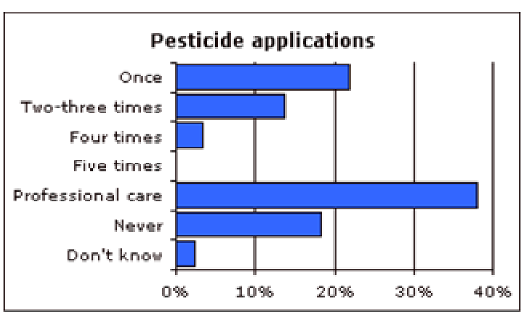


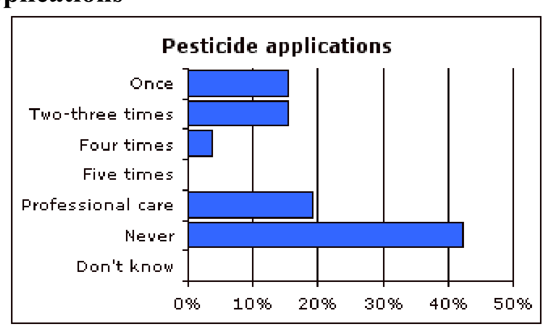
22a. Fertilizer applications





22b. Pesticide applications





10.2 Field Sampling Procedures

10.2.1 Storm event sampling

We originally proposed to establish stream flow monitoring and sampling stations at three locations, above and below the development and below conservation land further downstream from the nieghborhoods. We subsequently dropped the last (most downstream) station because of substantial tributary inputs from another development. Initially we proposed to install temporary weirs at each site. As noted above, however, we found that installations of weirs was not feasible due to the low slope in this area. Instead we opted for a modified open-channel flow procedure to monitor discharge consisting of a cross-sectional control area and continuous stage monitoring. We related stage height to discharge with rating curves developed using standard USGS stream profiling protocols (http://water.usgs.gov/pubs/twri/, Book 3, Section A, Chapters A6-A8 and A10) and then we monitored stage height behind the weirs continuously with high-resolution pressure transducers.

We obtained stormwater samples for representative storms in the summer and fall seasons of 2004 and in late spring, summer, and fall of 2005. We established a minimum antecedent "dry-period" of five days between sampled storm events to ensure that we captured representative concentrations of stormwater constituents. Samples were taken at both sites with an ISCO autosampler programmed to trigger at flow events larger than a minimum flow threshold specific to the two sampling sites and adjusted seasonally, based on prevailing flow conditions. Once triggered the autosamplers were programmed to sample in a flow-proportional mode. Cumulative rather than discrete samples were obtained for each sampled storm. For this study we were most interested in among-storm loadings rather than within-storm dynamics (e.g., washoff). Immediately following a storm event the autosamplers were checked and, if they had triggered, samples were removed and the units re-launched.

Samples were analyzed by Severn-Trent Laboratory as described below.

10.2.2 Whole stream metabolism (WSM)

The WSM approach is based on the same principles as 'light-dark' incubation methods used to assess photosynthesis and respiration in closed bottles, except that the method must also account for oxygen exchange between open channels and the atmosphere. WSM is calculated from a detailed budget of oxygen input, output and exchange over a specified stream reach, using either a dual-station or a single-station methodology. In this study we employed a single-station methodology, which requires less equipment. Dissolved oxygen can be measured continuously and reliably with commercially-available, oxygen-specific probes and meters connected to dedicated dataloggers (e.g., WTW probes and meters connected to Campbell Scientific dataloggers or integrated systems such as YSI and Hydrolab). Based on best available instruments, the stream reach must usually be at least 100 m long to be able to accurately measure changes in dissolved oxygen over the reach (or zone of influence in the single station method). For most accurate measurements of dissolved oxygen there must be a minimum velocity of water past the probe sensor and the water depth must be sufficient to fully immerse the sensing unit. Both criteria can normally be achieved in the middle of the stream channel, especially near the heads of stream riffles. Preliminary investigations of our proposed stream reaches indicate that we can meet these criteria, with the possible exception of low-flow periods in the upper-most boundary (agricultural to subdivision transition). If there is insufficient flow in a stream reach, then WSM is negligible, by definition.

Temperature-compensated dissolved oxygen probes (YSI model 600 XLM sondes with model 6562 dissolved oxygen probes) were used for this purpose and calibrated as per the manufacturer's specifications. These systems had on-board data logging and storage capabilities and also measured electrical conductivity. At each location we will also measured and recorded light intensity (Onset model M003 PAR sensors and HOBO microstation data loggers)

Dissolved oxygen sensors are subject to slow "drift" as the membranes age and become clogged. Consequently, we monitored DO sensor regularly (weekly) and replaced the membranes when they differed significantly from a known standard reading in the field. Calibrations in the field were accomplished using a separate, portable dissolved oxygen sensor and meter system (WTW model Oxi 340i) that was calibrated in the laboratory. The sole purpose of this meter was for field calibration; it was not used to continuously collect data and thus was not subject to drift. When field units drifted beyond an acceptable limit (0.5 mg/L) between field calibrations, we noted the intervening data were "suspect". Given the nearly continuous probe deployment, calibration was subject to error from a variety of sources, including biofilm or black fly larvae buildup on the sensor membrane and debris dams accumulated on the sondes. For the metabolism calculations, all "suspect" data sets were eliminated, and only those data sets with minimal drift (less than 0.5 mg/L) were used Minor drift and constant offsets between dissolved oxygen sensors were corrected mathematically before the data were analyzed. The final corrected data were analyzed using well-established methods for WSM (Marzolf et al. 1994, Bott 1996, Young and Huryn 1998, Westlake 1974) to calculate net daily metabolism, which was then used to infer community respiration and gross primary production.

10.2.3 Nutrient uptake length (S_w)

The determination of nutrient "spiraling" length (S_w) is based on changes in concentrations of reactive solutes (e.g., ammonium, nitrate, phosphate) in comparison to a conservative solute (e.g., bromide) during solute injection experiments (SIE). Changes in the reactive solutes can be related to transport and exchange processes by equations involving advection, dispersion, dilution (i.e. by groundwater), transient storage zones, and biotic and abiotic transformations. While both reactive and conservative solutes are subject to the hydraulic processes mentioned above, only the reactive components are modified by biotic and abiotic transformations. In most cases, changes in nitrate and ammonium are dominated by biotic processes; abiotic processes (exchange) can be important for phosphate. Each SIE was composed of two complementary runs – one involving nitrate and phosphate followed by one involving ammonium. Co-injecting ammonium with nitrate can stimulate nitrification which could affect the estimated nitrate spiraling length.

The SIE runs were done on the same reaches used for the WSM monitoring. Several days before running an SIE, grab samples were collected from the stream reach to determine nutrient background levels. The samples were analyzed for ammonium (NH_4^+), nitrate (NO_3^-), and phosphate (PO_4^{3-}). Two stock solutions – one consisting of nitrate and phosphate and the other consisting of ammonium – were created that would provide no more than a 10% enrichment over the background levels. Sodium bromide (NaBr) was added to this stock as a conservative tracer to correct for dilution by groundwater, which would otherwise be interpreted as uptake. Bromide is essentially non-existent in normal water samples from this area. The target concentrations for bromide were between 2-5 mg/L.

To conduct an SIE experiment, the combined stock solution was added continuously via a high-precision metering pump until a stable concentration was achieved at two downstream sampling locations that defined a reach of about 150 m. The most downstream sampling point coincided with the WSM monitoring point. The solute injection point was placed 10 to 20 stream widths upstream of the first sampling point to ensure adequate mixing. We used ion-specific electrodes (Br^- ISE) to monitor the bromide concentrations in the field. For the purposes of these experiments, it was unnecessary to confirm the precise concentration of bromide in the stream; it was sufficient to know that the concentrations indicated by the ISE probes were stable. Once a stable downstream concentration at both downstream locations was achieved for at least 1-hour, we conducted longitudinal sampling every 20 meters for ammonium, nitrate, and phosphate. In addition, we estimated bromide concentrations by moving the upstream ISE probe to each of the longitudinal sampling locations. Once the longitudinal sampling was completed, the experiment was terminated.

10.3 Analytical Methods

The samples collected from the storm-event sampling and the nutrient uptake length experiments were analyzed at Endyne Inc. and the Vermont Department of Public Health (DPH) laboratory, both located in Burlington, VT. Operating and quality assurance procedures for all analytical methodologies followed standard procedures that were provided in detail in the original Work Plans and that are on file at Endyne. Brief descriptions are provided below.

10.3.1 Storm event sample analysis

The composite samples prepared for the storm events were transported to Endyne Inc. for analysis of total suspended solids (TSS) by method 160.2, total phosphorus (TP) by method *365.1*, TKN by method 351.3, nitrate-nitrite by method *300IC*, heavy metals by methods *200.7*, *3113b*, and *245.1*, pH by method *150.1*, conductivity by method 120.1, and *E. coli* by method *9223B.*

10.3.2 Nutrient uptake length (S_w)

All samples generated by the solute injection experiment were immediately transported to Endyne for analysis of ammonium (NH_4^+) by method *350.1*, nitrate (NO_3^-) by method *300IC*, phosphate (PO_4^{3-}) by method 365.2, and bromide by method *300.0* (ion chromatography).

10.3.3 UVM/Endyne comparison

Memorandum

To: Dr. Breck Bowden, Co-Director, EPA/RAN Project

From: Alex Hackman, Research Assistant

Re: Analysis of Laboratory Results - Solute Injection Experiments

Date: May 18, 2005

The memorandum provides the results of statistical analyses that compare the performance of two laboratories involved in the *Redesigning the American Neighborhood* (RAN) project. This comparison was performed due to concerns over disagreement of results between the laboratories used to analyze stream water samples collected during solute injection experiments at our functional assessment sites last fall. The results presented below may justify contacting EPA to obtain formal approval to change laboratories for the future analyses.

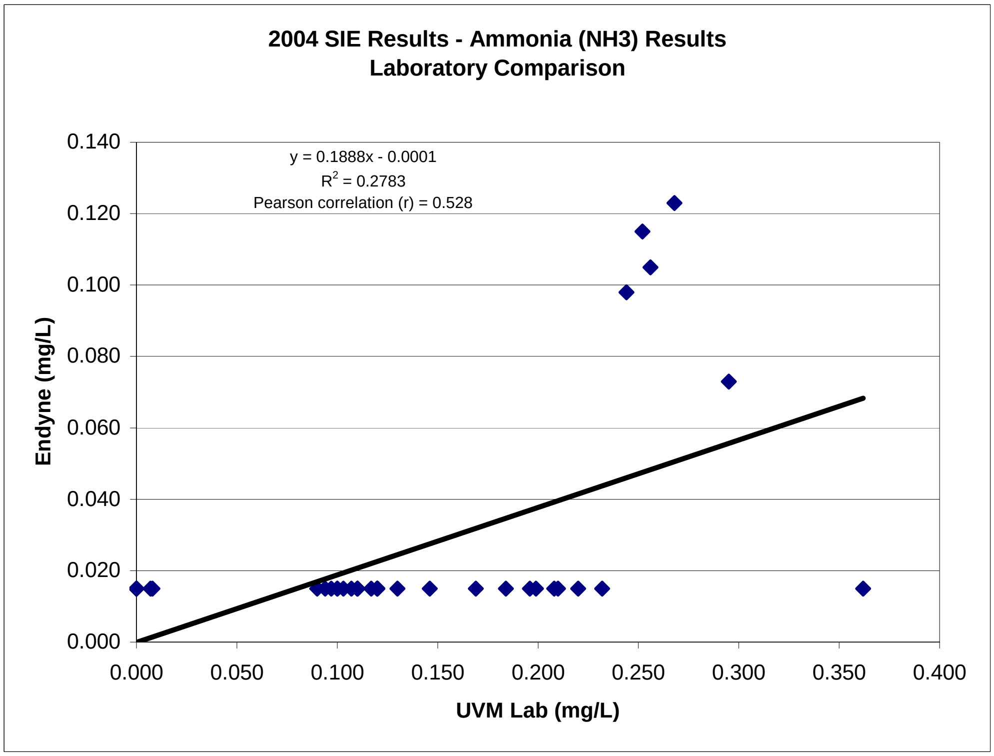
Background

Last fall, duplicate stream water samples were collected during solute injection experiments for laboratory analysis of nutrients (nitrate, ammonia, and phosphate) and a conservative tracer (bromide). On the basis of some previous analyses of samples, we were suspicious that results for low-level ammonium analyses (at least) were not accurate. Consequent, we send one set of samples to Endyne, Inc., (herein "Endyne") the EPA-certified laboratory identified in the RAN work plan and another duplicate set of samples was sent to the University of Vermont (UVM) Agricultural and Environmental Testing Laboratory (herein "UVM Lab"). The UVM Lab is not EPA-certified, but employs the same analytical procedures used by Endyne. Both samples were collected and preserved in accordance with the recommendations of the respective laboratories. The purpose of the duplicate analyses was to evaluate performance and accuracy, in light of substantial differences in analytical detection limits and costs. The results from both laboratories are presented below with scatter plots to assist in the visual interpretation of the results. Simple linear correlation and one-way ANOVA results are presented as well to provide a statistical basis for comparison of the Endyne and UVM Lab results.

Ammonia (NH_3)

A review of the literature on solute injection studies involving nitrogen indicates typical results for ammonium in the range of 0.005 to 0.030 mg/L. The Endyne detection limit for ammonia is 0.030 mg/L, which is therefore at the upper limit of most previous findings. Indeed, 86% (31 of 36) of the Endyne ammonia results came back below the detection limit. On the other hand, the UVM Lab returned no results below their detection limit of 0.005 mg/L. In order to perform a statistical analysis, a value of one-half the detection limit is used when a result is provided as "below detection limit". For example, a value of 0.015 mg/L is used for all Endyne results of <0.030 mg/L.

The Pearson correlation coefficient for the simple linear correlation of the laboratory results is 0.528, indicating a moderate level of association. However, if five of the Endyne results are removed (the *only* five above the detection limit), then the correlation value drops to zero. Results from a one-way ANOVA indicate a significant difference between mean laboratory values ($F=56.862$, $p\text{-value} \ll 0.05$).



ANOVA: Single Factor

SUMMARY

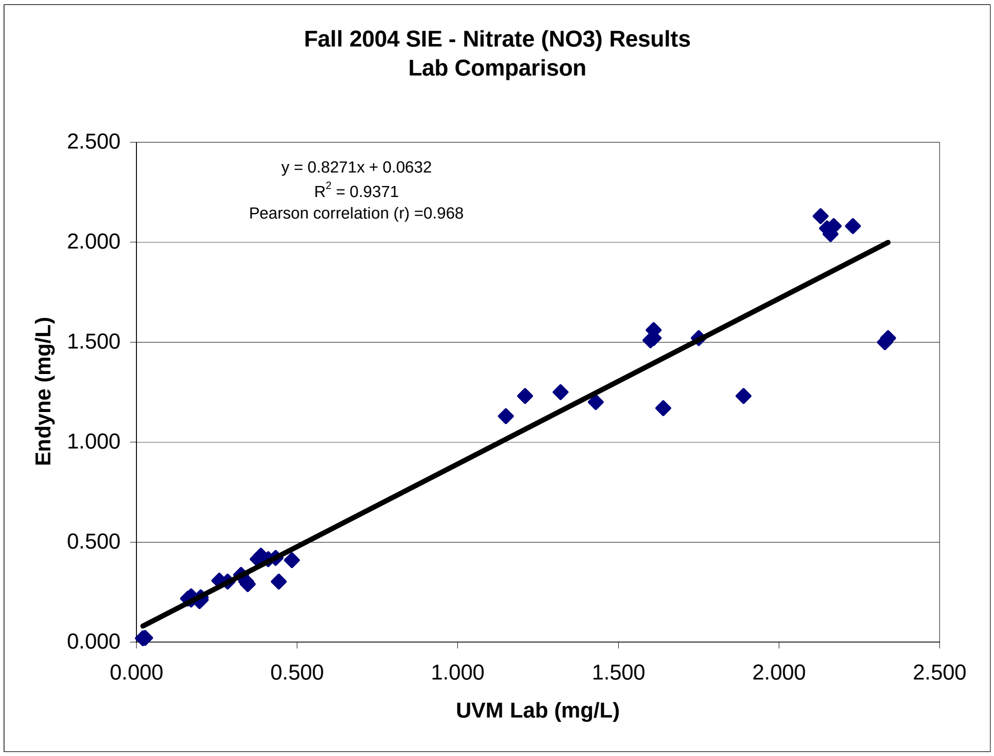
Groups	Count	Sum	Average	Variance
UVM Lab	36	5.204	0.145	0.008
Endyne	36	0.979	0.027	0.001

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.248	1	0.248	56.862	0.000	3.978
Within Groups	0.305	70	0.004			
Total	0.553	71				

Nitrate (NO_3)

Nitrate concentrations in the six study streams are much than ammonium concentrations, therefore detection limit issues were less of a problem. The Pearson correlation coefficient between the Endyne and UVM Lab results was 0.968, indicating a strong linear relationship. The intercept is not significantly different from 1 (though there is some variation in the data) nor is the intercept different from 0, as should be expected if the two labs returned identical results. The ANOVA results also indicate no significant difference between mean laboratory values (F=56.862, p-value<<0.05).



ANOVA: Single Factor

SUMMARY

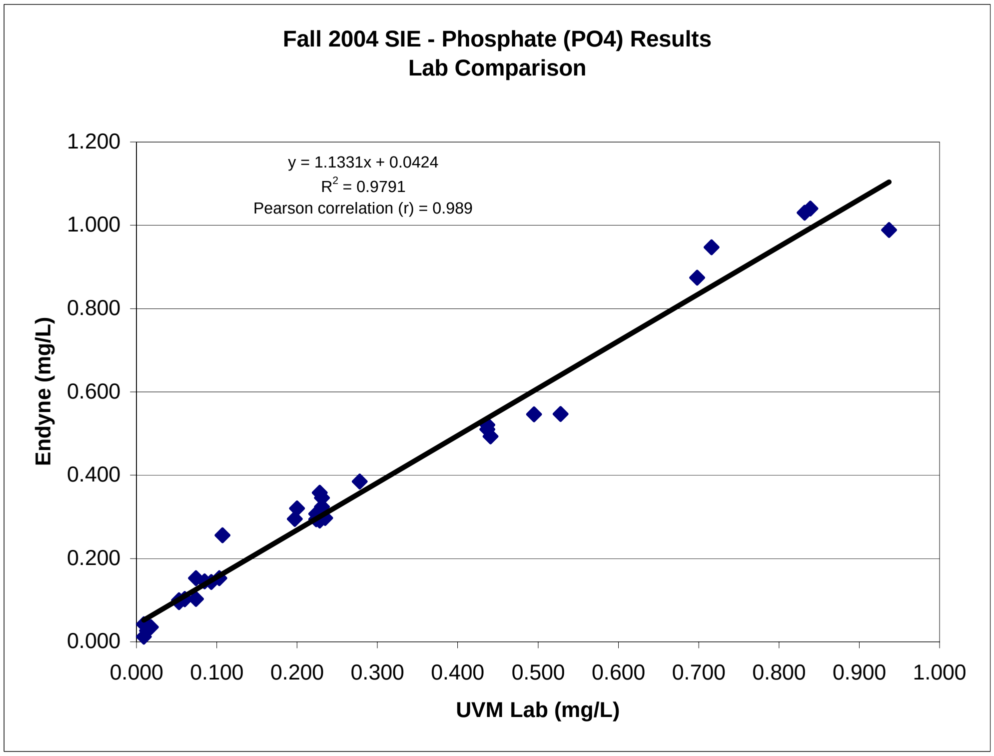
Groups	Count	Sum	Average	Variance
UVM Lab	36	35.952	0.999	0.683
Endyne	36	32.012	0.889	0.499

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.216	1	0.216	0.365	0.548	3.978
Within Groups	41.383	70	0.591			
Total	41.599	71				

Phosphate (PO_4)

The Endyne and UVM Lab results for phosphate were strongly related (Pearson correlation coefficient of 0.968). The slope of the regression line is essentially 1 and the intercept is 0, as should be expected if the two labs returned identical results. There was also no significant difference bewteen the mean values for the two groups based upon ANOVA analysis (F=0.365, p=0.548).



ANOVA: Single Factor

SUMMARY

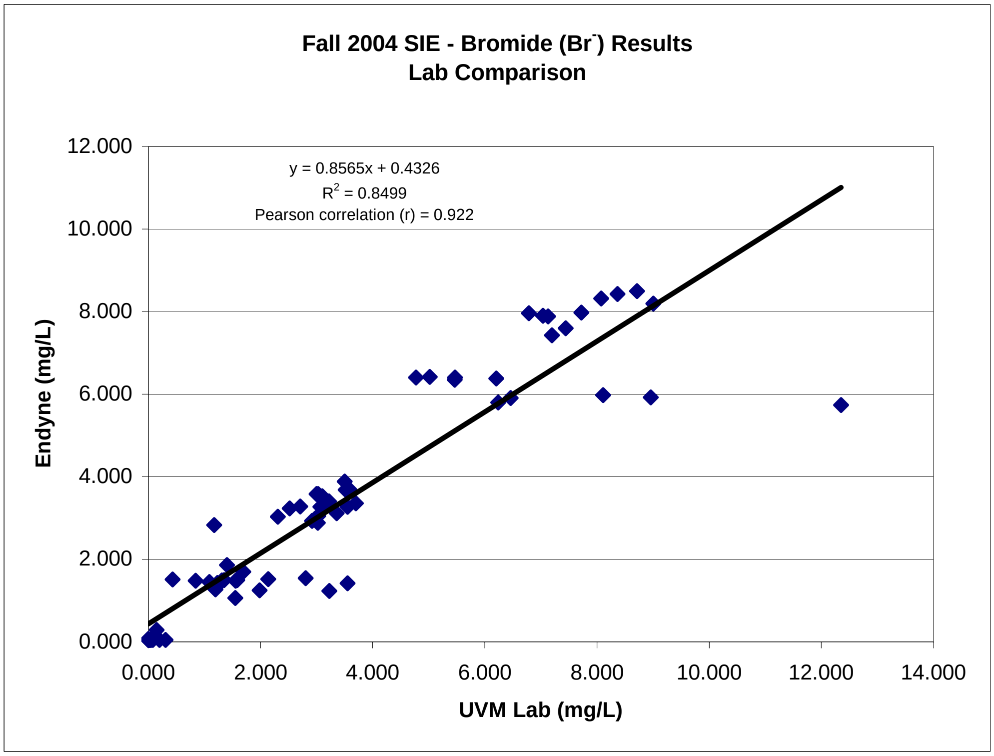
Groups	*Count*	*Sum*	*Average*	*Variance*
UVM Lab	36	9.474	0.263	0.070
Endyne	36	12.260	0.341	0.092

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.108	1	0.108	1.324	0.254	3.978
Within Groups	5.700	70	0.081			
Total	5.807	71				

Bromide (Br^-)

There were not significant differences between the bromide results returned by the two laboratories. The results are strongly associated (Pearson correlation coefficient = 0.922) using simple linear correlation. The slope of the regression line is not distinguishable from 1 nor is the intercept distinguishable from 0, as should be expected if the two labs returned identical results. An ANOVA indicates that there is no significant difference in the mean value for the bromide analysis between the two laboratories (F=0.012, p=0.913). It is notable, however, that there is substantial Within Groups variation in these bromide results. Simple examination of the data suggests that the UVM lab distinguished greater differences that reported by Endyne. This should not necessarily be interpreted as greater variation in the UVM data. Rather, it would appear that the UVM lab picked up real differences among samples that were not identified by the Endyne analyses.



ANOVA: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
UVM Lab Result	72	242.111	3.363	8.126		
Endyne Result	72	238.514	3.313	7.014		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.090	1	0.090	0.012	0.913	3.908
Within Groups	1074.938	142	7.570			
Total	1075.028	143				

Conclusions

The Endyne and UVM labs returned similar values for duplicate samples analyzed for nitrate and phosphate. However, the Endyne analyses for ammonia are not adequate for the solute injection experiments we have proposed to do as a part of this project (Objective 4). This is not entirely surprising because the Endyne lab detection limit is stated as 0.30 mg/L and most of the samples from these experiments are near or below this limit. The UVM lab has refined the standard ammonium method to achieve lower detection limits out of a need to process samples from more pristine environments. The bromide analyses from the two labs are similar, but there is substantial variation in the data that seems most associated with a lack of sensitivity in the Endyne data. The UVM data fit expected temporal trends in the solute injection data much better than the Endyne data.

Based on these results, we recommend that we have all future samples from the solute injection experiments analyzed by the UVM Lab. There are substantial, additional logistical and cost benefits in having all analyses for these experiments performed by the UVM Lab.