FINAL REPORT
Project Year 3 (2006-2007)

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

Grant No. EPA X-97137901

Prepared by:

Rubenstein School of Environment and Natural Resources
and the
Gund Institute for Ecological Economics
The University of Vermont
Burlington, VT 05405-0088

Contributors

William B. Bowden
Alan McIntosh
Joel Nipper
John Todd
Alexey Voinov
Alexander Hackman
Barton Kirk
Helena Vladich
Evan Fitzgerald

8 December 2008

Table of Contents

1 Introduction

The project goal, objectives, and rationale are described in detail in the original work plan (Bowden et al. 2003) and in the PY1-2 (2003-2005) project status report (Bowden et al. 2006). This is a continuing project in which we have focused our research efforts on stormwater management issues that are the consequence of rapid development in and around 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 Zoning and 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, we were able 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 four 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 demonstration projects to test ideas and designs generated by 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 has 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. Progress on these initiatives was reported in our PY1-2 final project report (Bowden et al. 2006). In the following sections we provide a final report on our PY3 activities. Some initiatives will continue and will be summarized in a PY4 final report, expected in 2010.

2 The Study Area

The study area is described in detail in the PY1-2 report (Bowden et al. 2006). This project focused on a number of stormwater-impaired streams in the towns of Burlington and South Burlington, Vermont, and in particular, the Potash Brook watershed in South Burlington, Vermont. Potash Brook is a 1,827 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 1). Population has increased rapidly in South Burlington over the last 50 years and

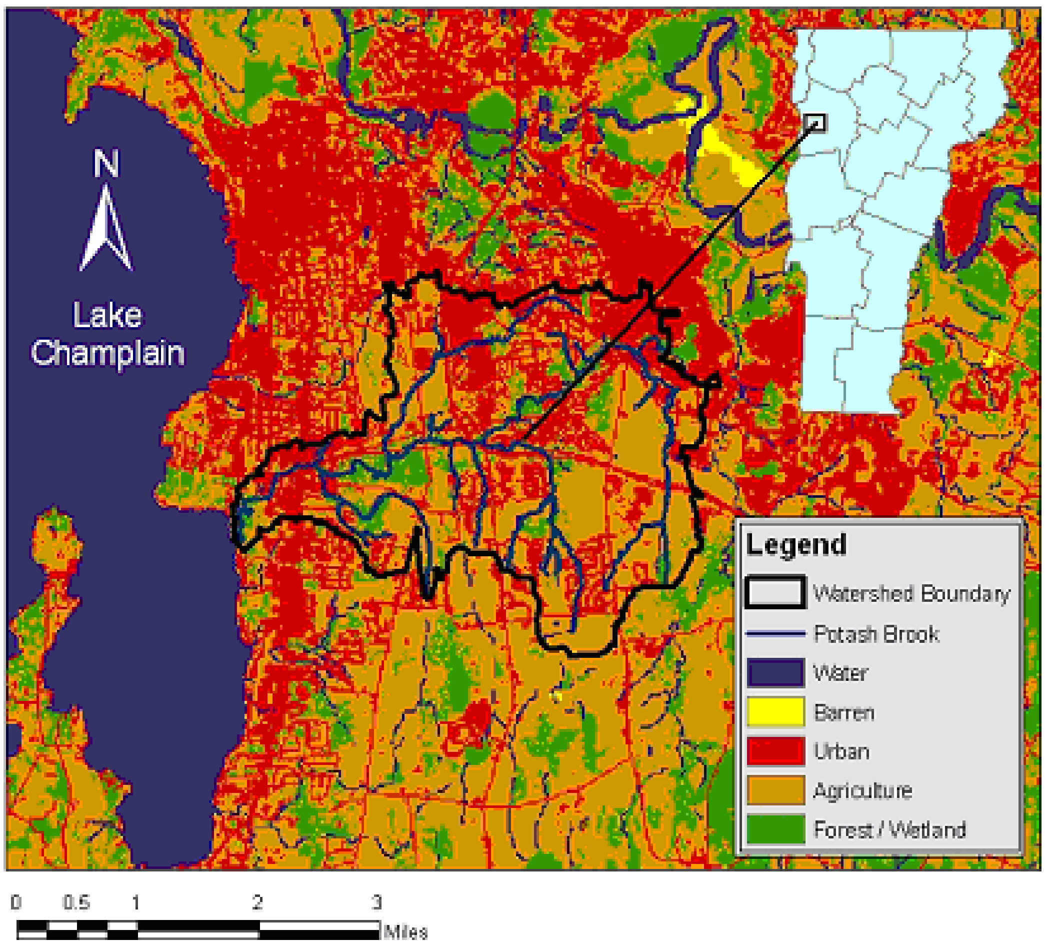

Figure 1. Land use and land cover of Potash Brook watershed (data from VCGI 2006).

this population growth has been accompanied by a significant expansion in development in Potash Brook. Lower portions of Potash Brook have been listed as "impaired by stormwater" by the Vermont Agency of Natural Resources on the USEPA's "303d" list since 1992. Recently a stormwater TMDL for Potash Brook (Vermont Department of Environmental Conservation, 2006) was accepted by the USEPA. However, as of this report the state has not issued permit framework for the TMDL.

Much of the effort associated with this project has focused on two adjacent neighborhoods: Butler Farms and Oak Creek Village. 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 (Figure 2). 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

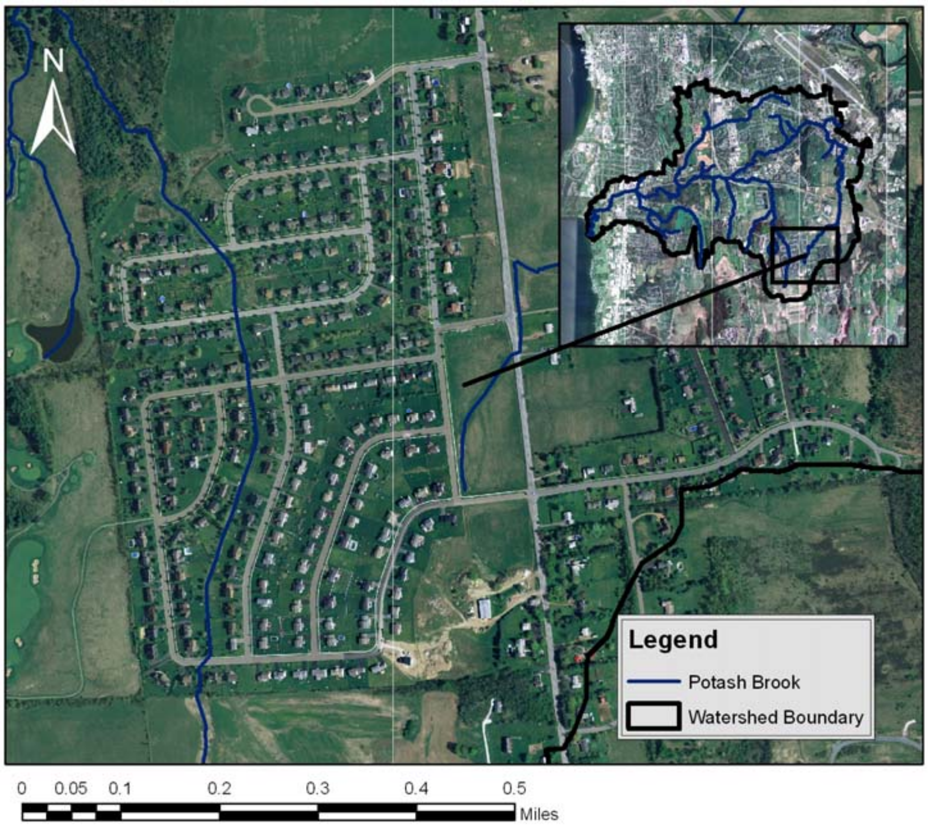

Figure 2. Aerial imagery of the Butler Farms (bottom half) and Oak Creek Village (top half) neighborhoods with an inset map of the Potash Brook watershed (data from UVM SAL 2007).

as late as 2004; however, throughout 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, Potash Brook in particular 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.

3 Project Accomplishments

3.1 RAN-55 Stormwater BMP Evaluation Tool

During PY3 we completed work on a simple modeling tool that we developed for use by non-technical stakeholders. The model is based on the widely-used TR-55 runoff model (NRCS, 1986) and for that reason we named our model RAN-55. The RAN-55 model is considerably simpler than the TR-55 model. We designed RAN-55 to simulate only a few, common, stormwater BMPs (rain barrels, rain gardens, and a wet detention pond), in a common scenario (a 10 acre parcel), with only two soil types (hydroclasses A and D). Users are allowed to subdivide the 10 acre parcel into lot sizes that they specify with development dimensions (i.e., house footprints and driveway, road, and sidewalk widths) that they specify. This provides a nearly endless number of development permutations that allow users to explore common characteristics of neighborhoods and then see – immediately – the effects of their development decisions. The model produces flow hydrographs as does TR-55 and for identical specifications the two models produce identical outputs. In addition, the RAN-55 model tracks the number and type of BMPs installed and applies standard costs to each BMP (which can be altered by the user if desired), so that the “cost and benefit” of the development scenario can be compared.

The model was implemented in STELLA, a widely used modeling program that provides an easy to use graphical user interface (GUI) (http://www.iseesystems.com). Demonstration copies of STELLA can be downloaded from the company website so that the RAN-55 model can be run for free (though the output can not be saved in the free downloadable version). Additional information about the model is provided in Appendix 1, which is also posted on the RAN program website on the “Library” page.

In addition to the RAN-55 tool, we published an article in *Stormwater* magazine about the incremental power contained in excess stormwater runoff. We purposely chose to publish this article in a trade journal rather than a peer-reviewed science journal because we wanted broad exposure to developers, engineers, and planners. The article was prompted by concerns that stakeholders (and the general public) might misunderstand the flow duration curve (FDC) concept that is at the heart of the new approach to stormwater runoff management in Vermont (Foley and Bowden 2005 and 2006). In particular, the differences in target flows ($Q_{0.3}$ or 1-day flow) for impaired and unimpaired streams do not appear to be large on logarithmic FDC graphs. Stakeholder might wonder, therefore, how these apparently “small” differences could generate the damage that we observe in urban streams. We used a widely accepted approach to calculate the incremental power contained in the *additional* runoff in stormwater from an impaired watershed compared to the expected runoff from an unimpaired watershed. We then related this excess power to the power that would be consumed by a typical bulldozer and found that the excess stormwater power in a 0.5 mile reach of stream was equivalent to the power consumed by a bulldozer in full operation over a period of 14 h. The point we made was that it is no wonder that our urban steams are physically degraded by stormwater runoff when the power unleashed by this runoff is equivalent to bulldozer operating continuously within the stream channel for nearly 2 working days, year after year.

The approach that we used here might be criticized on several grounds. However, the qualitative result conforms with general observation and makes a sobering point in a way that should appeal to the general public. It is well known that stormwater runoff creates a disequilibrium that destabilizes streams leading to sometimes massive erosion. The technical reasons why that this occurs can be lost on the general public and our paper – which we purposely published in a trade magazine rather than a scientific journal – helps illustrate these dynamics in terms to which most people can relate.

3.2 Life cycle Assessments and Costs of Stormwater BMPs

Initial progress on this objective was reported in the PY1-2 report (Bowden et al. 2006). Since the last report initial work on this objective has been completed leading to one M.Sc. thesis (Kirk 2006) and one paper at the 2006 SETAC North America conference (Kirk et al. 2006).

Best management practice (BMP) treatment performance is usually defined in terms of net removal rates of criteria pollutants. However the direct impacts of construction, the indirect impacts of embodied materials and energy, the fate of pollutants captured, and changes in performance of BMPs over the life of the system, are typically ignored. Life cycle assessment (LCA) is a general method to systematically evaluate the long-term, indirect, and cumulative non-monetary impacts of human activities, by accounting for all of the materials and energy consumed and substances emitted to air, water, and soil, from the initial extraction of raw materials needed through the decommissioning and disposal of the system at the end of its life. An LCA approach provides a more complete quantification of the net or total environmental benefit of employing specific stormwater BMPs or general policies. The purpose of this effort was to compare four conventional and low-impact designs (LID) under evaluation at the University of New Hampshire’s BMP performance verification Stormwater Center (UNH-SC).

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 to conduct an LCA comparison of stormwater BMPs, through a partnership with the University of Vermont’s Redesigning the American Neighborhood (RAN) Program. 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.

3.2.1 General Approach

The life cycle assessment concept encompasses several variant methods designed for a variety of decision-making situations and in its attempt to be holistic, the calculation procedure often becomes complex, greatly increasing the chance of wrong or misleading results (Baumann and Tillman 2004). In response to such issues, the International Standards Organization (ISO) established a standardized LCA method beginning in 1996. The ISO 14040 series standards 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 and evaluated 4 of the 12 treatment units or TU (Table 2) in the UNH-SC facility.

Table 1. The 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 without LCIA)

Table 2. Stormwater BMP treatment units installed at the UNH Stormwater Center used in this study.

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

Each TU 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 the results reported here, the functional unit is 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.

The life cycle impacts calculated from this functional unit are limited by boundaries set in both the inventory analysis and impact assessment phases. Temporally, the systems were assumed to be in operation for 30 years, over which the impacts of construction were annualized (without discounting). Spatially, all operations occurring within the Stormwater Center's watershed (e.g. construction and treatment) were modeled using site and process specific data whenever possible and all operations occurring outside the watershed boundary (e.g. production of fuels and materials) were modeled using U.S. national average data. For transportation of equipment, personnel, and materials to the site, the distances used were site-specific, but the emissions per unit distance were based on U.S. national averages. Likewise for construction equipment the equipment hours, flywheel power, and loading factors were site-specific, but the emissions per (operating flywheel) kW-hour were based on U.S. national averages. The boundaries of the technical-economic system considered in this paper were defined as, "cradle to grave" plus the impacts of the stormwater treatment processes – including all activities related to construction, production of materials, transport of materials, and the effluent discharged from the stormwater TUs. This analysis did not include activities associated with the maintenance and repair of each TU over its life cycle or the costs of decommissioning the system at the end of its useful life. Other technical boundary assumptions included the exclusion of all physical components and activities that would be identical amongst the alternatives, most notably the influent and effluent piping. Lastly, the spatial boundaries for the impact assessment phase were established for the continental U.S., thus the characterization of the life cycle inventory into environmental and human health impacts was also based on U.S. national averages.

3.2.2 BMP Life Cycle Inventory

The bulk of work for any life cycle assessment is the development of the life cycle inventory in which the quantities of material and energy resources and emissions flowing across the previously defined technical-economic system boundary are calculated. This is generally conceptualized in a material flow diagram (Figure 3) and quantified through material flow analysis (MFA). The MFA is typically conducted through a series of process and product calculations, often based on either monetary budgets or cost models.

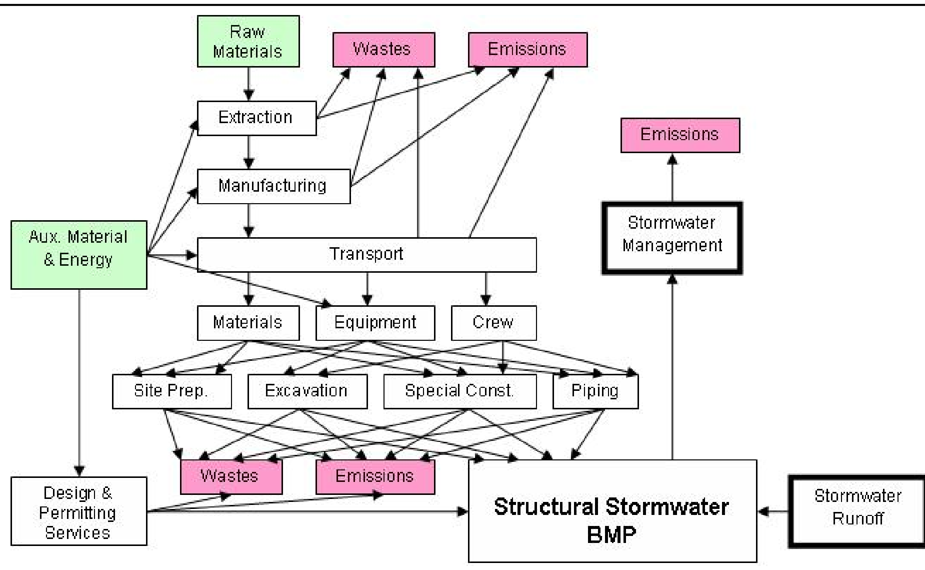

Figure 3. Simplified material flow analysis for a structural stormwater BMP, including consideration of treatment performance.

The foundation for the construction of LCIs of each TU was built from the original monetary construction budget and design documents adjusted for as-built changes. Each budget line item was translated into *RS Means* unit costs from which construction activity productivity data could be obtained (RSMeans 2005). The emissions and fuel consumption of construction equipment activities were calculated using the US EPA's 2005 release of the NONROAD emissions inventorying model and the loading factors and fuel consumption rates catalogued in the Caterpillar Performance Handbook (CAT 2004, USEPA 2005). Emissions and resource consumption of off-site activities such as material production and design services were calculated using Carnegie Mellon University's Environmental Input-Output Life Cycle Assessment Model (EIO-LCA) through a tiered-hybrid life cycle calculation procedure (Suh and Huppes 2005, GDI 2006). Emissions and fuel consumption factors for on-road transportation were obtained from the 2003 release of the US EPA's MOBILE 6.2 emissions inventorying model (USEPA 2003).

The TU operation inventory was calculated independently of the construction inventory and was more empirically derived. The operational inventory was defined by the total annual discharge of ten pollutants monitored by the UNH-SC staff. Each total annual discharge was estimated using the Simple method ($L = R*C*A$, where L represents the annual pollutant load) (CWP 2003). The pollution concentration, C, was based on the median annual event mean concentrations measured for each pollutant from each unit during twelve events from September 8^{th}, 2004 to August 13^{th}, 2005. The annual runoff, R, was calculated using the annual normal precipitation for Durham, NH; a factor of 0.9, representing the fraction of rainfall events generating runoff; and a runoff coefficient of 0.83 for 100% parking lot surface. The area, A, representing the functional unit, is given as 0.4 ha.

3.2.3 Impact Assessment

To characterize the inventory of each BMP, a predefined impact assessment method developed by the US EPA's National Risk Management Research Laboratory was used. The 2006 version of the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) classifies the impacts of 960 chemical emissions into nine impact categories. Each category does not represent an actual damage caused by the emission, but rather its potential to cause damages (Bare et al. 2003). The nine impact potentials include global warming, acidification, eutrophication, human health – cancer, human health – non-cancer, human health – criteria air pollutants, ecotoxicity, smog formation, and ozone depletion. Eight of the nine impacts are expressed as equivalents of a particular chemical emission. For example, emissions causing global warming potential are calculated as kilograms of CO_2-equivalents. The magnitude of effect of each emission in the inventory on each impact potential is determined by a characterization factor relating to the impact category unit (e.g. kg CO_2-e). The characterized results are then normalized with respect to U.S. conditions by dividing by the U.S. national per capita contribution to each impact category (Lippiatt 2002). In an attempt to value and compare the cumulative impacts appropriately, the normalized impacts were weighted using qualitative valuations established by the U.S. EPA's Science Advisory Board and quantified in accordance with the method applied by the Building for Environmental and Economic Sustainability (BEES) LCA tool (Lippiatt 2002). Additionally, the impacts of fossil fuel depletion have been characterized, normalized, and weighted according to BEES (Lippiatt 2002).

3.2.4 Results

The 30 year cumulative impacts of the four BMPs as characterized by TRACI are listed in Table 3, and represent aggregations of the largest and most damaging flows of substances recorded into and out of the technical-economic system, i.e. to and from the environment.

The results in Figure 4 are annualized (total results divided by the 30 year life span) and normalized using U.S. per capita normalization data to indicate the relative magnitude of each impact. The relative importance of each impact is then indicated in Figure 5, where the annualized and normalized results have been weighted according to values assigned by the U.S. EPA Science Advisory Board. The cumulative values in Figure 5 also represent a total or net "score" for each BMP. However, because performance is so often defined by just the effluent performance it is helpful to separate the construction or "cradle to grave" impacts from the TU effluent impacts (Figure 6).

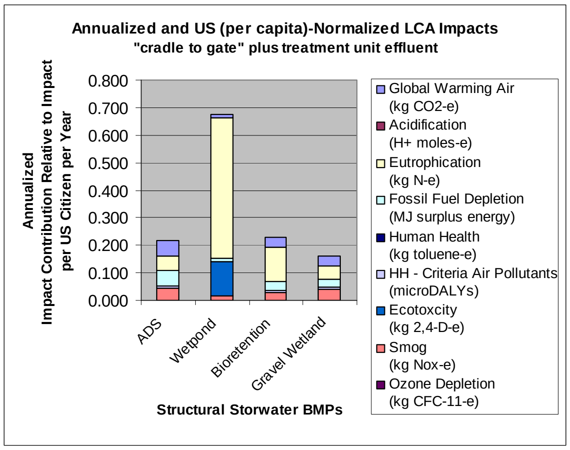

Figure 4. Stormwater TU impacts normalized by U.S. population.

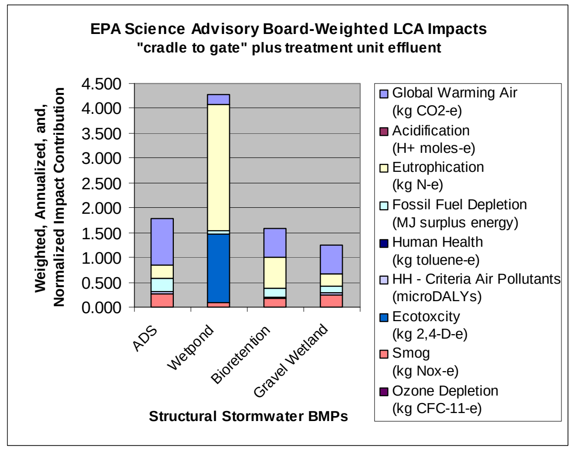

Figure 5. Stormwater TU impacts normalized by U.S. population and weighted based on EPA Science Advisory Board qualitative valuations.

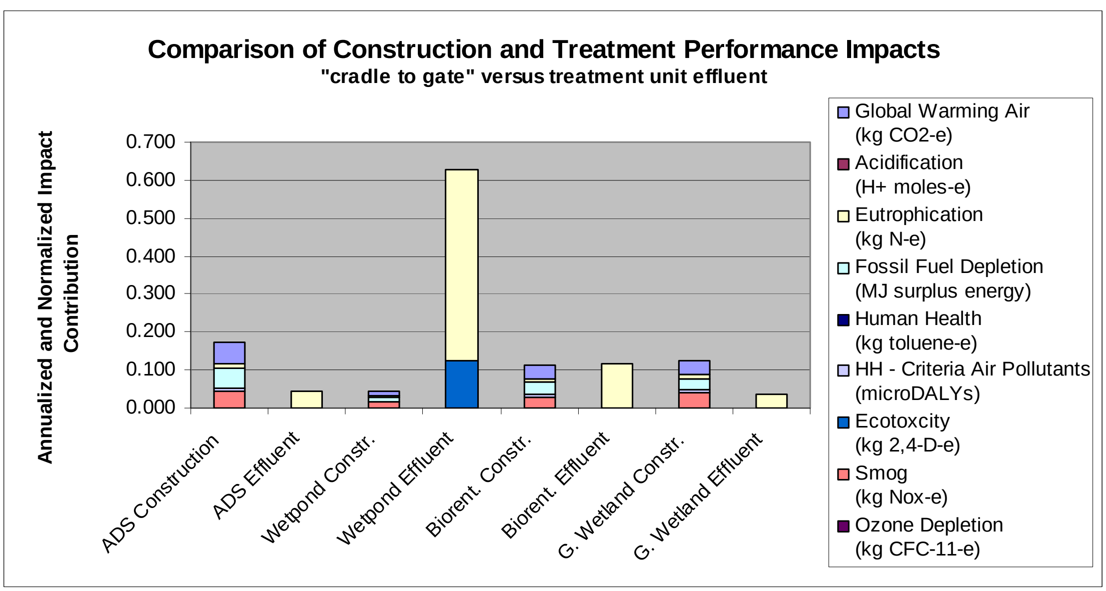

Figure 6. Impacts for included TUs based on construction versus effluent, by impact category.

Table 3. Characterized structural stormwater BMP Life Cycle Impacts. "Cradle to grave" and treatment effluent impacts over 30 year life cycle for a 0.4 ha (1 acre) parking lot.

Impact Categories	*Global Warming*	*Acid.*	*Eutrophication*	*Fossil Fuel Depletion*	*Human Health*	*HH-Criteria Air Pollutants*	*Ecotoxicity*	*Smog*	*Ozone Depletion*
Units	*kg CO2-e*	*H+ moles-e*	*kg N-e*	*MJ surplus energy*	*Kg Toluene-e*	*microDALYs*	*kg 2,4 D-e*	*kg NOx-e*	*kg CFC 11-e*
ADS	44900	9940	30.8	58500	1160	3.70	0.0775	203	0
Wetpond	9520	2930	292	12300	1480	1.54	306	67.0	0
Bioretention	27700	6450	71.5	37600	1330	2.97	0.0840	134	0
Gravel Wetland	27500	8100	27.9	30600	1420	4.23	0.0810	181	0

3.2.5 Discussion

There are numerous assumptions associated with any LCA, which can lead to subjectivity and error. For this reason it is useful to first review the raw impact assessment results (Table 3) prior to normalization and weighting to determine if any two or more alternatives in comparison have lower or higher emissions and resource consumption across all categories ranking them as unequivocally better or worse under those criteria. Unfortunately, there are no clear distinctions and tradeoffs between impacts are unavoidable if a choice between alternatives is made. For such tradeoffs the normalization and weighting of impact categories can be helpful.

The normalized results indicate that the magnitude of annual eutrophication impact of the wetpond is nearly half of the eutrophication impacts per capita, while the cumulative impacts of the other alternatives are significantly less. As these results are weighted and the cumulative results are compared, the wetpond remains by far the poorest performer, but there is a slight shift in the ranking of the others. While the ADS unit appeared to perform slightly better than the bioretention unit in the normalization results, the high importance placed on global climate change by the Science Advisory Board caused the weighted cumulative score to increase slightly above that of the bioretention unit. The higher global climate change score is due largely to the carbon dioxide emissions associated with plastic pipe manufacturing, upon which the ADS unit depends heavily. In both the normalized and weighted results the wetpond stands out as having the highest net environmental impact. In addition, although an apparent ranking among the net impacts of the other three alternatives is visible, their results are too close to determine an undoubtedly lowest net performer without further analysis of the uncertainty of results.

What may be more useful are the results in Figure 6, which disaggregate the normalized results into contributions of construction and effluent. These results indicate that the wetpond actually has somewhat fewer "embodied" impacts resulting from construction than the other alternatives, but its poorer treatment performance causes relatively poor overall net performance. It is also interesting to note that, while the effluent impacts of the gravel wetland and the ADS unit are similar, there is a high degree of variation (nearly 1.4 times) in the construction impacts with respect to the cumulative effluent impacts, which suggests that it is important to determine and compare the impacts of construction in addition to effluent quality.

These results should be useful to decision makers interested in achieving broader water quality, environmental, or sustainability goals than those typically outlined in stormwater guidelines. These results may also be of interest to those responsible for environmental quality over large regions, watersheds, or airsheds, particularly those that are heavily urbanized. However, any decision maker considering the results of this study must recognize the limitations of the LCA method, the goal and scope defined within the study, the TRACI impact assessment characterization, and the weighting values used. The most notable of these limitations are the exclusion of impacts associated with pollutants not measured, the exclusion of maintenance and decommissioning impacts, the lack of characterization factors for total suspended solids (TSS) and total petroleum hydrocarbons (TPH) emitted to water, and the subjectivity of impact valuation.

3.2.6 Conclusions

In comparison to the current and traditional measures of stormwater BMP performance, the life cycle assessment method, as applied in this paper, broadens the scope of BMP impact assessment. The LCA approach integrates spatial, temporal, and technical aspects of BMP performance and provides useful insight into the cumulative, direct, indirect, and long-term non-monetary impacts of structural stormwater BMPs. For designers, decision-makers, and agencies committed to achieving environmental quality and sustainability goals, these findings could result in a considerable broadening of the definition of performance used to evaluate BMPs for design, planning, and regulation. However, there are still some limitations in this analysis that should be considered. In particular, the impacts such as erosion during construction, water consumption, and the final disposition of retained pollutant were not measured and should be considered. Characterization of TSS and TPH should be added and impact category weights for different groups of stormwater decision-makers should be determined. Nevertheless, the LCA approach holds substantial promise as way to assess the real, long-term impacts of different BMP alternatives.

3.3 Integrated GIS tool: Micro Stormwater Drainage Density Index

During PY3 Helena Vladich completed initial development of a tool that integrates LiDAR (Light Detection and Ranging) remote sensing data into a GIS to predict fine-scale runoff flow paths in developed areas. The GIS tool can be used to calculate a spatially distributed micro-level stormwater drainage density (MSDD) index that can be used to identify areas where water tends to collect and that would be natural candidates for low-impact design (LID) stormwater BMP options. The prototype tool was developed using the BF/OCV neighborhoods as the study area.

3.3.1 General Approach

As part of other regionally-funded projects, LiDAR point data were collected for Chittenden County, Vermont by EarthData International in January 2005 with an ALS40 sensor at 3 meter post spacing. Interpolation tools from ArcGIS 9.2 were used to derive a fine-scale surface digital elevation model (DEM). ArcGIS 9.2 hydrologic modeling capabilities were subsequently used to delineate watersheds, sub-watersheds and associated drainage networks. The minimum sub-watershed size that can be delineated is only limited by the resolution of the LiDAR data (3 m). Data for the existing stream hydrologic network, roads, houses, land use, engineered catchments pipeline network and inlet points were obtained from the Vermont Center for Geographic Information (VCGI http://www.vcgi.org/).

3.3.2 Specific Steps

Development of the MSDD index proceeded in a series of steps. First, source areas and areas of opportunity for BMPs were identified. LiDAR data offers extremely precise terrain analysis as compared to coarser resolution DEM data. Results of this analysis showed the modeled water drainage network to follow the stormwater pipelines, street curves, and even depressions along property lines. With these data it wass possible to identify the main stream channel (Fig. 7) as well as smaller stormwater drainage pathways (Fig. 8).

Figure 7. The main stream calculated using LiDAR data.

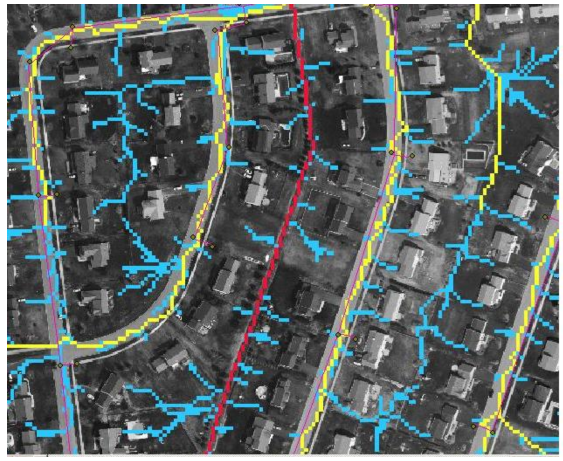

Figure 8. Micro Stormwater Drainage Network calculated using LiDAR data.

Using this approach we identified a series of sub-watershed areas in the neighborhoods where different BMP approaches could be used (Fig. 9):

- A,B,C – are areas that require coordination at the municipal level because these areas extend beyond the management boundaries of the neighborhoods (e.g., the National Golf Course and Marceau Farms)..

- D,E,F - are areas where mid-scale BMPs and small-scale dispersed BMPs are appropriate because the areas are entirely confined to the neighborhood and are places were the MSDD indicates water naturally collects after storms.

- G, H - are two areas that appear to have been artificially connected to the neighborhood drainage area during the process of development and regrading. They add significant amounts of stormwater runoff to the neighborhood and make it more difficult for the residents to comply with the Vermont stormwater regulations. Restoring the natural topographic drainage could reduce stormwater hydrologic loadings within the neighborhood.

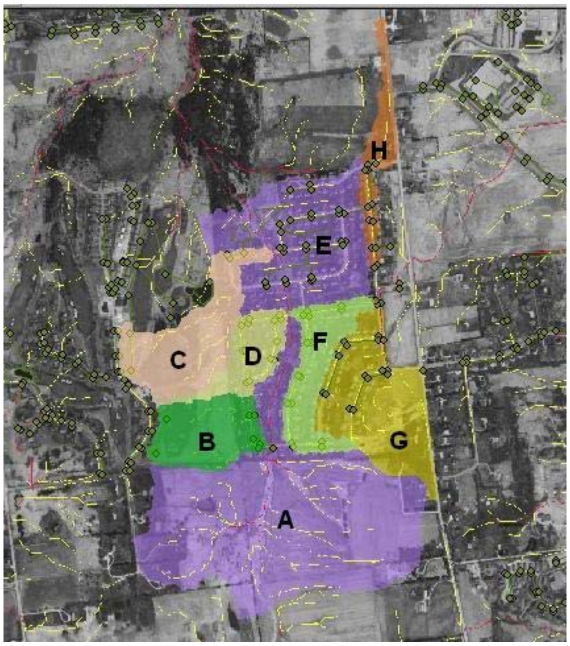

Figure 9. Source areas and areas of opportunity. Delineated sub-watersheds based on the LiDAR data.

The second step in this process was to develop and apply the MSDD index. The LiDAR data resolution was sufficiently fine to calculate flow paths at the scale of individual houses and lawns (Fig. 10). The micro flow paths converge at a high density in various locations indicating areas that could be considered for LID/BMP installations. The GIS form of the MSDD index provides a medium that can be easily understood by non-technical stakeholders, planners, and developers. The threshold for this index was calculated on a basis of the LiDAR minimum resolution, the average parcel size, average imperviousness for the area, and recommendations for typical private rain garden sizes suggested by, for example, the Wisconsin Department of Natural Resources (http://clean-water.uwex.edu/pubs/pdf/home.rgmanual.pdf). The index correlates well with the stakeholder survey/assessment reported on in the PY1-2 report (Bowden et al. 2006), which produced a map of 'areas of concern' based on residents' observations, e.g., poorly drained standing water along property lines or scattered microdepressions. The MSDD index quantifies and provides a means to easily visualize the density of micro-level stormwater drainage pathways. To further simplify the visual presentation, the drainage density was classified into a spatial index (the MSDD index, Fig. 11). The large oblong area in the center left of Figs. 10 and 11 is from Area E in Fig. 9 and indicates a location that might be suitable for a mid-size BMP.

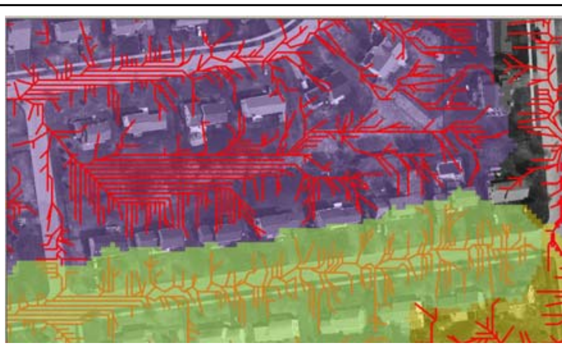

Figure 10. Micro stormwater drainage pathways from Area E in Fig.9.

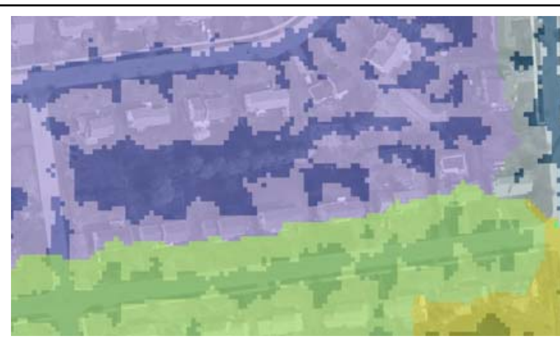

Figure 11. Spatial representation of reclassified MSDD index – the density of micro storm water drainage network.

3.3.3 Impact Assessments

The final step was to estimate required BMP sizes for each of the delineated areas. This required an estimate of the impervious area within the delineated sub-watersheds and an estimate of the volume of water (and if necessary, the mass of contaminants, e.g., sediment) to be intercepted by the BMPs. High resolution 2.4m Quick Bird imagery and 0.15m Metropolitan Planning Organization near infrared (MPO NIR) images were used to identify impervious area by calculating the Normalized Difference Vegetation Index using methods describe by Morrissey (2004). A comparison of impervious surfaces identified using this approach agreed well with orthophotographs of the same area (Fig. 12). Quick Bird imagery is much less expensive than MPO NIR imagery and was found to provide an estimate that was at least as good.

Using the impervious surface area derived as explained above (13.7% of the total 3.263 acres or 0.447 acres) the water quality protection volume (WQv) recommended for this area by the Vermont Stormwater Manual (2004) would be 0.042 acre-feet or about 1847 cubic feet of runoff. The channel protection volume (CPv) for the 1 year/24 h storm is 2.1 inches of rain (Chittenden County, Table 1.2 in the Vermont Stormwater Manual, 2002). For this same area this storm generates 0.33 acre-feet or 13,269 cubic feet of runoff according to the calculations in Section 1.3 of the Vermont Stormwater Manual. To contain this volume in a BMP in which the average water level rises only 1 ft would require a device of about 120 feet x 120 feet or 50 feet x 287 feet. A device of this size would service ~12-14 homes, as depicted in Fig. 13.

Figure 12. Impervious surfaces outlined based on the 2.44m multi-spectral Quick Bird image (red line) versus NDVI on the basis of 15cm MPO NIR image.

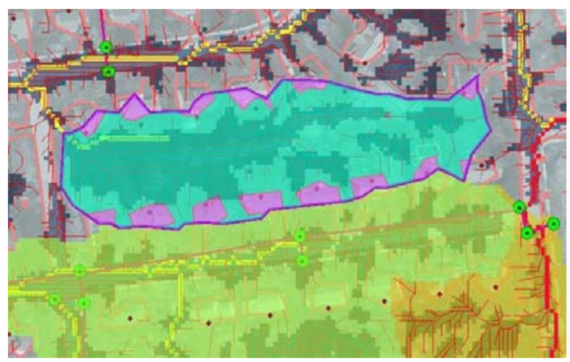

Figure 13. Overlay showing the area of impervious cover that would be treated by a mid-sized BMP installed at this location in sub-watershed E, Fig. 9.

3.3.4 Conclusions

The approach that has been developed here is generic and could be applied anywhere that LiDAR and Quick Bird data are available. It is reasonably economical and could be used in the early stages of site or area planning to help stakeholders visualize where stormwater management will be required in a development and an initial estimate of the size of BMP that will be required. Further engineering will be required, of course, to provide the detailed design specifications for construction. However, this approach could serve the needs of both technical and non-technical stakeholders and could facilitate communication among them.

3.4 Cost/Benefit Evaluation Tool

In our PY1-2 and PY3 Work Plans we proposed to develop and refine an integrated stormwater BMP optimization and cost/benefit evaluation tool. However, as reported in your PY1-2 final report (Bowden et al. 2006) we concluded that this initiative had been largely obviated by the BMP/DSS initiative that ANR has contracted Tetra Tech, Inc. to produce. Although we were initially asked to collaborate, this was developed by Tetra Tech and delivered to the state independent of this project.

3.5 Background Monitoring of Impaired Streams

3.5.1 Tributary 7 Background Monitoring

This output was completed and reported in the PY1-2 status report (Bowden et al. 2006). As proposed, we did evaluate whether or not to continue the Tributary 7 monitoring over the 2006 field season and to seek support from the City of South Burlington and/or the State of Vermont to continue this monitoring in the future. We decided not to monitor in 2006 but initiated a new and more extensive monitoring initiative as part of our the final PY3 and on-going PY4 work, in anticipation that construction on stormwater BMPs might begin in the BF/OCV neighborhoods in the near future. In addition, we initiated a separate but related initiative to monitor the performance of the new Englesby Brook (lower) BMP near Flynn Avenue, as a collaborative effort with the USGS.

3.5.2 Tributary 7 Expanded Monitoring

In anticipation of stormwater treatment practice construction in the BF/OCV neighborhoods new and expanded in-stream sampling equipment was redeployed in 2007. The installations and sampling approach above and below the neighborhood were consistent with the monitoring work reported in PY1-2 (Bowden et al. 2006). As a component of Joel Nipper's PhD research we sought to expand sampling within the neighborhood for several reasons. First, while our background monitoring had quantified changes in pollutant loads carried by the stream as it passed through the neighborhood, the specific sources of these pollutants remained un-quantified. Second, the stormwater treatment practices under consideration for the neighborhood ranged from a single large detention pond, to a distributed array of swales, porous pavement, and other LID installations. Pre- and post-treatment data on these types of installations in real world conditions are not widely available and would be useful both for assessing their effectiveness on site and for evaluating their applicability at other sites.

For the expanded sampling the City of South Burlington purchased two additional pressure transducers and automated water samplers for use in the neighborhood. In the summer of 2007 we installed this equipment inside two separate sewershed outfalls discharging directly into Tributary 7, with a combined drainage of more than half of the Butler Farms neighborhood. A series of difficulties in operating the equipment within low-gradient storm drain outfalls resulted in little useful data being collected from these installations in 2007. In-stream sampling above and below the neighborhoods was successful however. In 2008 we moved the equipment to two of the neighborhood's smaller sewersheds, also discharging directly into Tributary 7, where the outfall configurations were more favorable (Figure 14). These sewersheds were selected in consultation with the City of South Burlington and the project engineer and were chosen in part because it was thought to be likely that LID BMPs would be constructed in the sewersheds for these outfalls. Sampling at these outfalls began in July 2008 and is ongoing.

Figure 14. Instrumented sewersheds (outlined in red) and storm drain lines (yellow) within the BF/OCV neighborhoods.

Preliminary hydrologic data from the instrumented sewersheds are shown in Figure 15 with the corresponding hyetograph and in-stream discharge measurements. The high level of impervious cover within the sewersheds (37% and 47%), relative to the entire Tributary 7 drainage area (12%), results in noticeably flashier discharge responses from the outfalls. Storm event water quality sampling began in August 2008 and will be reported on in the PY4 report.

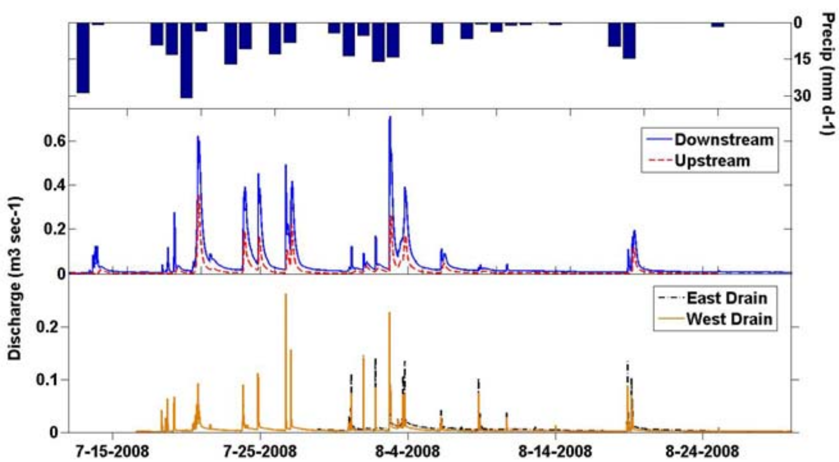

Figure 15. Precipitation, in stream discharge, and sewershed discharge for a seven week period.

Due to longer than anticipated formulation of the Vermont State stormwater permitting process it now appears unlikely that construction of stormwater treatment practices will be mandated within the neighborhood before 2010. Since voluntary installation is also not likely we refocused our experiment design quantify the relative importance of sediment and solute wash-off from drained impervious areas and in-stream resuspension relative to total watershed loads. The BF/OCV study area is ideally suited to separate these different sources of sediment and solutes. We plan to continue this monitoring as a primary part of the PY4 initiative and will report complete results from this initiative in the PY4 final report.

3.5.3 Englesby Brook BMP Effectiveness Monitoring

Englesby Brook has long been a focal point of stormwater research and management primarily because it is one of the most urbanized small catchments in Chittenden County and partly because it intersects several different jurisdictions (UVM, Burlington, South Burlington). Englesby Brook was the first urban watershed to be instrumented by USGS to monitor discharge, nutrients, and sediments. Beginning in 2006 Breck Bowden (UVM/RAN) and Jamie Shanley (USGS) began to discuss shared interests in potential impacts of stormwater treatment practices in the Englesby Brook watershed. In particular, USGS was interested in mercury dynamics in urban areas and how a large detention pond constructed in the Englesby Brook watershed in 2005 might affect the generation methyl mercury. The RAN program interest in innovative BMP performance, Life Cycle Analysis, and stormwater dynamics in general made the Englesby Brook watershed an especially interesting opportunity for collaboration. In the spring of 2007 discharge gauging equipment, automatic water samplers, and turbidity and conductivity probes were installed at the inlets and outlets of the lower Englesby Brook storm water detention pond (Figure 16). The inlet sampling provides storm event wash-off sampling for a 110 acre mixed residential commercial sewershed and comparison with the outlet allows us to quantify the effectiveness of this BMP for nutrient and sediment removal.

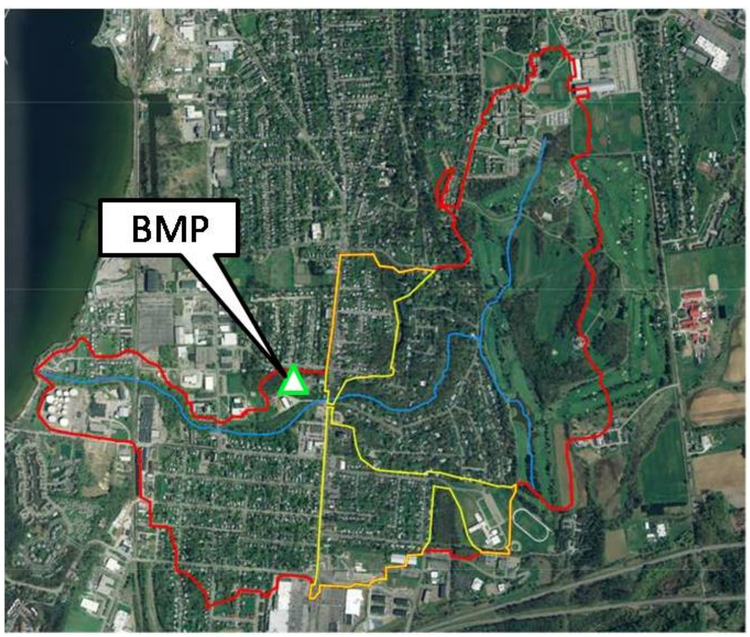

Figure 16. Englesby Brook watershed (red) showing the location of the stormwater detention pond and the areas treated by the BMP (yellow).

Flow weighted composite samples are collected during storm events, with periodic baseflow samples collected throughout the year. Samples are analyzed for total nitrogen and total phosphorus by the Vermont ANR Water Quality Lab in Waterbury, VT. An additional pair of autosamplers were also installed at the inlet and outlet to collect discrete suspended sediment concentration samples across a range of flow conditions. These data are being used with the continuous turbidity record to establish sediment rating curves for the inlet and outlet. Data collection and rating curve development are ongoing. Joel Nipper (UVM/RAN) has primary responsibility for operation of the Englesby Brook BMP monitoring system and the data from this initiative will form one portion of his PhD work.

Preliminary results from the inlet and outlet sampling show that total nitrogen and total phosphorus loads have been significantly reduced over the sampled events. Loading data from sixteen events are summarized in Figure 17. During the sampled events we measured a mean total nitrogen reduction of 47%. The total phosphorus analyses showed a mean reduction of 81% across the sampled events. In contrast to nitrogen, phosphorus has no important gaseous export mechanisms and so we assume that most of the retained phosphorus is in the sediments and vegetation. Turbidity and nutrient sampling at this site are expected to continue through September 2009. Through this time our efforts will be focused on sampling additional storms across a range of seasonal and antecedent conditions and on sampling the spring runoff event at the site. We plan to also sample the accumulated sediment when the forebay of this BMP is dredged in 2009 and will use this data with the storm load data to assess the long term performance dynamics of the BMP. Further results and outcomes from this initiative will be reported on in PY4 final report.

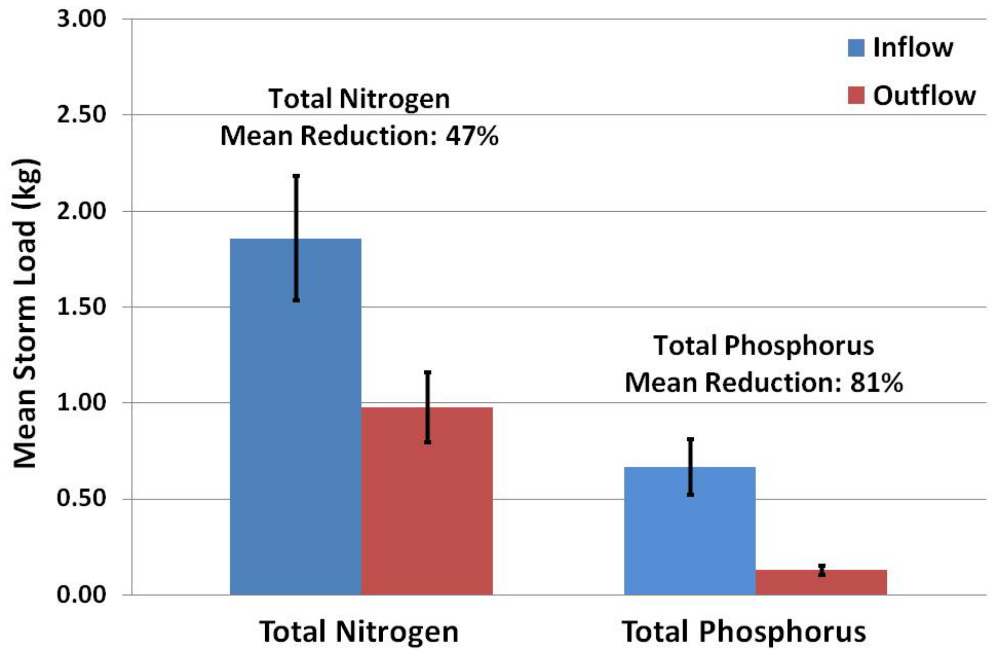

Figure 17. Reductions in total nitrogen and total phosphorus loads through the BMP for sixteen events.

3.6 Functional Assessments of 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, gross photosynthesis, and net metabolism. These processes are critical to the overall function and health of stream ecosystems and relate directly to the processing of organic matter, 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. The macroinvertebrate and geomorphic data were reported in our PY1-2 final report (Bowden et al. 2006). This initiative was the primary focus of Alex Hackman's M.Sc. thesis research. Alex presented his findings at the August 2006 meeting of the North American Benthological Society, in Anchorage, Alaska and ultimately defended his this thesis in the spring of 2008. A manuscript based on this results has been completely drafted and will be submitted for publication shortly.

3.6.1 Whole-Stream Metabolism

The "urban stream syndrome" (Paul & Meyer, 2001, Meyer et al, 2005, Walsh et al, 2005) describes a well-studied and consistent pattern of biological, chemical, and physical degradation to lotic systems. However, the impact of urbanization on key ecological processes (e.g. rates of whole-stream primary production and respiration) is still unclear, despite increasing calls to include these integrated measures in holistic assessments of stream health (Bunn et al, 1999, Walsh et al, 2005).

We studied reaches (100-200m) with similar characteristics (e.g., canopy cover, substrate, riffle-pool form) in 7 streams over a 2-year period (Table 4). Three of the streams are located in suburban watersheds and were listed as impaired for "urban runoff" on Vermont's "303d" report to the USEPA. The other 4 streams were located in more rural watersheds and were considered in "attainment" condition per state monitoring which relies exclusively on biocriteria (see previous report, Bowden et al. 2006). We used the open-system, single-station approach (Odum, 1956, Bott, 1996, Mulholland et al. 2001) to estimate daily rates of gross ecosystem production (GEP), ecosystem respiration (ER), net daily metabolism (NDM), and the ratio of primary production to respiration (P/R).

Table 4. Characteristics of the streams used in this study.

Stream	Status	Order	W.S. Area (km^2)	Slope (%)	Depth (m)	Width (m)	Temp. (°C)	D.O. ($mg\ L^{-1}$)	SpCond ($uS\ cm^{-1}$)	PAR (uE)	Q ($L\ s^{-1}$)	kO2 (day^{-1})
INDI	I	3rd	19.5	0.84	0.19	3.89	14.15	10.17	571	258	159	38.28
MUNR	I	3rd	13.9	1.82	0.19	2.20	15.81	9.50	596	229	71	66.08
POTA	I	3rd	18.1	1.18	0.19	4.47	17.43	9.47	1217	276	125	62.05
JOHN	A	3rd	9.5	1.66	0.16	3.34	12.58	10.18	151	246	66	64.26
PATR	A	3rd	16.2	1.81	0.23	2.47	11.83	10.60	243	178	66	48.65
MILL	A	4th	41.9	1.20	0.30	5.47	16.34	9.53	155	252	222	59.54
LEWI	A	3rd	18.3	0.25	0.25	6.52	19.64	8.88	165	357	408	14.52

The streams we used in this study were Indian Brook in Essex (INDI), Munroe Brook in Shelburne (MUNR), Potash Brook in South Burlington (POTA), Johnnie Brook in Richmond (JOHN), Patrick Brook in Hinesburg (PATR), Mill Creek in Jericho (MILL), and Lewis Creek in Starksboro (LEWI). Slope was surveyed in the field. Depth and width were mean values from measurements of reach cross-sections at 5-meter intervals, and at hydrologic profile locations. Temperature, dissolved oxygen (DO), specific conductivity (SpCond), photosynthetically active radiation (PAR), discharge (Q), and reaeration coefficient (kO2) were mean values only for the days on which WSM was measured. Temperature, DO, and specific conductivity were measured in a well-mixed area in the thalweg using a YSI 600XLM sonde. DO was verified/recalibrated using a roving WTW oxi 315i meter. Stream gages were constructed to monitor stage with a Global Water GL15 pressure transducer and hydrologic surveys were performed using a Marsh McBirney Flo-mate 2000 to develop rating curves each year. PAR was measured with ONSET sensors and HOBO microstation loggers. All data were collected in 5-minute intervals, cleaned, and aggregated to hourly means. Reaeration coefficients (kO2) were estimated using the energy dissipation model (Tsivoglou & Neal, 1976) and adjusted with changing discharge conditions (Bott, 1996).

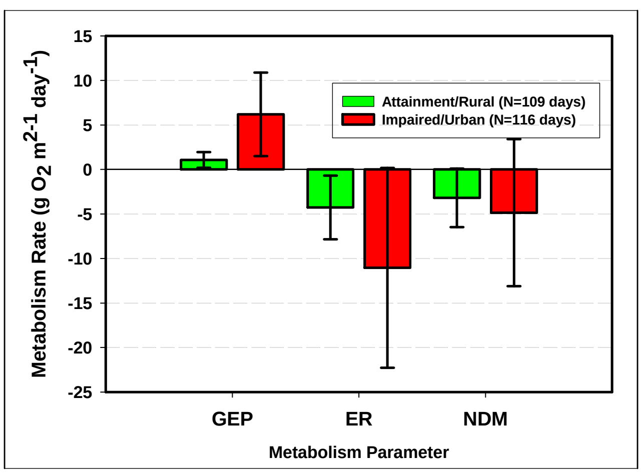

Figure 18. Mean daily metabolic rates. Gross ecosystem production (GEP), ecosystem respiration (ER), and net daily metabolism (NDM) are pooled for attainment/rural and impaired/urban study streams ($\pm$1 SD).

Comparison of mean daily metabolism values (ANOVA) indicates that urban streams differed significantly (overall and across seasons) from their rural counterparts in Vermont (Figure 18 and Table 5). While prior research has not identified systematic metabolic differences in urban streams (Meyer et al. 2005), our findings are consistent with other aspects of the urban stream syndrome - such as increased algal biomass (Taylor et al. 2004) - which should translate into higher in-stream production rates.

Table 5. Mean daily metabolism values by season. (*p <= 0.05; **p<=0.01; ***p<=0.001. GEP, ER, and NDM values are g O2 m^{-2} day^{-1}.)

Variable	Stream Status	All N (A) = 109 days N (I) = 116 days	Spring N (A) = 18 days N (I) = 21 days	Summer N (A) = 53 days N (I) = 62 days	Fall N (A) = 38 days N (I) = 34 days
GEP	Attainment/Rural (A)	1.08	1.60	1.24	0.61
	Impaired/Urban (I)	6.20***	6.63***	7.98***	2.57***
ER	Attainment/Rural (A)	-4.26	-3.81	-5.94	-2.14
	Impaired/Urban (I)	-11.05***	-15.17**	-13.15***	-4.50***
NDM	Attainment/Rural (A)	-3.19	-2.21	-4.70	-1.54
	Impaired/Urban (I)	-4.85*	-8.54*	-5.16	-1.93
P/R	Attainment/Rural (A)	0.37	0.42	0.34	0.37
	Impaired/Urban (I)	0.69***	0.56	0.79***	0.59**

3.6.2 Solute Injection Experiments

In total, we performed 28 solute injection experiments (SIEs) on 16 days, to evaluate nutrient uptake rates in stormwater impaired and attainment stream reaches. Experiments were performed in three rounds (fall 2004, spring 2005, and summer 2005) in an attempt to observe seasonal differences. Samples were analyzed as detailed in our original Work Plan, by Endyne, Inc. (Williston, VT). However, after observing some discrepancies in the data (high variability and many non-detections) we ran many samples in parallel at the UVM Plant and Soil Science Lab (Burlington).

The results for these experiments were variable. In the fall 2004 rounds we prepared separate analyses base on results from the two laboratories because of substantial disagreements in reported concentrations. In the spring 2005, we averaged both readings from the UVM lab and used confirmatory analyses from Endyne on a case by case basis. The summer 2005 analysis was more straightforward, after switching back entirely to Endyne and getting much cleaner results.

For each experiment we calculated a standard suite of metrics from the literature. These include measures of uptake length (S_w), uptake velocity (V_f), and gross uptake per unit stream area (U). We also developed a new metric following the approach used by Bott et al (2006) who reported whole-stream metabolism and gross nutrient uptake per unit stream length for a series of streams in the mid-Atlantic Piedmont region. Bott el al. (2006) argue that metabolism estimates based on area (i.e. O_2 production per m^2) overstate the importance of metabolism in small, narrow streams compared to large, wide streams where there is more overall area and therefore more potential for nutrient processing per unit length of stream.

The results from the spring 2005 SIE runs illustrate the trends that were found (Table 6). In general, the uptake lengths were longer and the four uptake rate estimates were lower in the attainment reaches than in the impaired reaches. This was true for all three measured nutrients (NH_3, NO_3, and PO_4). However, the variance in these estimates was high and there was often significant variation among the concentrations reported by the two labs (Endyne and UVM). We concluded that there is weak but likely evidence that nutrient processing in general was accelerated in the impaired streams, where we often also observed substantial growth of filamentous green algae.

Table 6. Results from spring 2005 solute injection experiments (nd = no data).

Nutrient	Reach Status	Metric	Uptake Rate (k_c) (1/m)	Uptake Length (S_w) (m)	Uptake Velocity (V_f) (mm min^{-1})	Area-Specific Uptake Rate (*U*) (ug m^{-2} min^{-1})	Length-Specific Uptake Rate (ug m^{-1} min^{-1})
NH3	Attainment	Mean	-0.0063	331	3	30	193
		SE	0.0046	239	2	21	165
	Impaired	Mean	-0.0107	167	16	195	778
		SE	0.0045	94	7	51	275
NO3	Attainment	Mean	~0	>1000	very low	very low	very low
		SE	nd	nd	nd	nd	nd
	Impaired	Mean	-0.0015	852	2	1321	5883
		SE	0.0004	310	1	667	2956
PO4	Attainment	Mean	-0.0025	410	2	1	3
		SE	0.0005	78	0	1	2
	Impaired	Mean	-0.0093	125	14	94	380
		SE	0.0027	30	5	70	306

3.7 Stormwater Eco-Park Design Concept

In our Work Plan for PY3 we proposed to provide a preliminary designs for a stormwater "eco-park" that would provide opportunities for recreation and greenspace during fair weather but would serve as a stormwater treatment facility during storm events. We proposed to use a workshop (charrette or atelier) format that would extensively involve key stakeholders. We approached the City of South Burlington regarding one site (Dorset Park area) and the University of Vermont for another site (Horticulture Farm). In both cases we were discouraged from even initiating a design process for these sites due to community political tensions over the best uses for these sites. These tensions had little or nothing to do with stormwater management. This was a discouraging development but illustrates some of the real and difficult problems in working with vested stakeholders within a "research" framework.

As an alternative, we engaged in two distinct design initiative to explore how stormwater eco-parks could be implemented in the BF/OCV neighborhood and in a potential new waterfront park in downtown Burlington, VT. These design processes and outputs are described below.

3.7.1 Residential Stormwater Eco-Park

A team of four University of Vermont students, mentored by Professor John Todd, used ecological problem solving to create a design for a wetland park to help treat stormwater runoff from the south east section of the Butler Farms neighborhood. Rather than focusing solely on treating a predetermined storm volume, their planning focused on creating a stormwater treatment wetland that provides wildlife habitat, recreational open space, educational opportunities, and aesthetic value. A schematic of the proposed wetland design is presented in Figure 19.

Figure 19. Location and design for a "front door" wetland natural area park in the eight-acre field adjacent to the BF/OCV neighborhoods.

The wetland was designed to have two sediment forebays to treat incoming stormwater from the two discrete stormwater outfalls. The students designed zones of perpetually wet, regularly inundated, seasonally or occasionally inundated, and upland vegetation to help stabilize soil, remove pollutants, remove excess water through transpiration, and shield the park from traffic noise. The diversity of vegetation was intended to maximize both stormwater treatment capacity and wildlife habitat. Additional proposed components of the wetland eco-park included a boardwalk, an observation tower, and outdoor sculptures to encourage educational engagement and a broader sense of community among residents.

The design results were presented to the BF/OCV community during a SWG meeting in 2008. The designs generally received good reviews. However, uptake of this (or any other stormwater management schemes) is effectively on hold until issues surrounding the Vermont stormwater permit process for impaired watersheds can be resolved.

3.7.2 Urban Stormwater Eco-Park

The second site for a proposed storm water eco-park was adjacent to the ECHO Aquarium and Lake Science Center at the Leahy Center on the Burlington waterfront. The site is currently occupied by a small unpaved parking lot serving ECHO, an undeveloped strip of land adjacent to the railroad tracks, and a small grassed park and the Navy Memorial that is also a part of the Leahy Center. The area to be treated by the proposed stormwater eco-park is a 23 acre drainage of highly developed downtown Burlington that currently discharges directly into Burlington Bay via a single outfall at the end of College Street. This site was thought to be particularly well suited for a stormwater eco-park with a strong educational component due to the high foot traffic it would receive as a result of its proximity to ECHO and the waterfront location. An aerial view of site in its current form and with the proposed eco-park are presented in Figure 20.

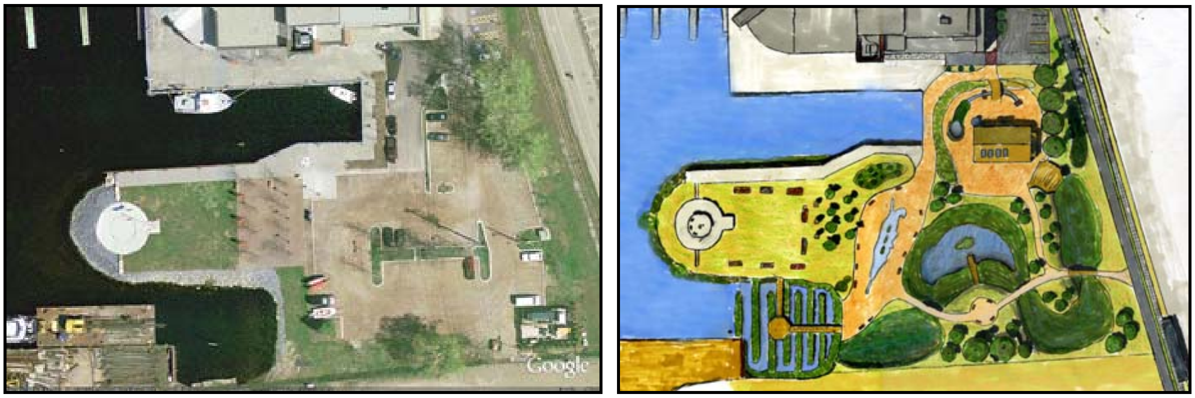

Figure 20. Aerial view of proposed stormwater eco-park location (left) and schematic overview of wetland and eco-park design (right).

The central feature of the storm water eco-park was a constructed wetland sized to treat Vermont's water quality protection volume for the contributing area. Due to the high visibility of the site a number of other features were included in the design to add to the educational and recreational value. Across the wetland's outlet into Lake Champlain a series of elevated walkways were proposed to allow visitors to explore the wetland from above. To highlight the usefulness of LID technologies a vortex separator at the inlet and porous pavement walkways throughout were proposed in the design. Together, the use of walkways and explanatory signage would allow visitors to learn about the both the effects of untreated stormwater on the lake and applicability of LID technologies in stormwater mitigation.

3.8 Communication and Outreach

3.8.1 Interactions with Key Stakeholders

In late spring 2005, RAN organized two public meetings for the Butler Farms/Oak Creek Village communities, with representatives from the City of South Burlington and Vermont Dept. of Environmental Conservation. The meetings followed the City's public announcement of the initiation of a municipal stormwater utility and were, in part, intended to inform residents of the purpose and conditions of the utility. The meetings also covered the nature, context, and history of general suburban stormwater issues and legal and financial concerns relating to the communities' expired stormwater permits. The spring meetings were characterized by intensive question and answer sessions. At times the discussions stumbled over legislative, legal, and financial issues at the state and city level that could not at the time be answered. In the interest of making progress, the RAN team attempted to redirect the meetings' energy and interest toward building the collective stakeholder knowledgebase. From discussions with this group the idea evolved to create a smaller investigative committee to work with RAN, the City, and outside experts to answer questions in further detail. These discussions also revealed a strong interest to map and catalogue residents' knowledge of stormwater problem areas. In response, the various partners formed a Stormwater Study Group in September 2005 (later called the Stormwater Working Group, SWG). This smaller group of volunteers from Butler Farms and Oak Creek Village met roughly monthly with RAN team members, City officials, and a professional engineer (Jack Myers, Stantec, Inc.) to tackle technical questions in an increasingly participatory and collaborative manner, while policy and financing issues continued to be discussed at the city and state levels. Most of the results summarized in earlier sections of this report were relayed to the SWG during these meetings and different draft designs for stormwater management options (discussed below) were presented.

3.8.2 Development of Stormwater Treatment Planning Alternatives

An important initiative related to this output was an ad hoc effort arose as a consequence of our interactions with the homeowners in the Stormwater Working Group (SWG). See the PY1-2 report (Bowden et al, 2006) for background details. In the course of working with the SWG, they requested information about alternative stormwater treatment designs ranging from a large detention pond (the "Super Pond" scenario) to more distributed LID installations. In addition to performance information, the SWG members also requested estimated costs and we worked closely with Jack Myers of Stantec, Inc. (formerly Dufresne-Henry, Inc.), a national consulting firm with a local office in South Burlington, to produce these numbers.

The treatment plans we developed in collaboration with the SWG represented different levels of "hard" versus "green" engineering and "centralized" versus "dispersed" treatment. Consultations with the project engineer, Jack Myers, began in 2005 and resulted two main treatment alternatives. The first proposed plan consisted of several relatively small treatment practices distributed throughout the neighborhood. The existing stormwater pond just downstream of the neighborhood would be retrofitted at or near its current size. Two additional small ponds would be constructed along the east side of the neighborhood, and existing swales behind and in between many of the lots would be converted into vegetated treatment systems. The average per household cost of this plan (Option 1) was estimated to be $4,320 (Table 7).

Table 7. Summary of areas treated, calculated sediment reductions, and estimated probable costs for Options 1 and 2.

Treatment Options Presented at Meetings	Opinion of Probable Cost	Lbs of TSS Removed	Acres of Impervious Area Treated	$'s Per Acre Treated	Impervious Area that is Public (%)	Public Cost	Private Cost	Per Household Cost
Option 1								
Option 1 Areas 18 & 15 (Pond in Common Area)	$1,027,000	4,361	10.8	$95,093	46%	$469,442	$557,558	
Area 1 (Micro Pool by Hinesburg Rd)	$231,000	1,284	3.2	$72,188	57%	$131,670	$99,330	
Area 2 (Retrofit Existing Pond)	$385,000	1,760	4.1	$93,902	42%	$161,700	$223,300	
Areas 3,9,10, & 12a (Convert Swales to Treatment System)	$426,000	1,184	3.1	$137,419	47%	$200,220	$225,780	
Total Option 1	**$2,069,000**	**8,589**	**21**	**$97,594**		**$963,032**	**$1,105,968**	**$4,320**
Option 2								
Treat all Areas both Developments (except Areas 1 and 19)	$2,098,000	12,220	30.02	$69,887	44%	$923,120	$1,174,880	
Area 1	$231,000	1,284	3.2	$72,188	57%	$131,670	$99,330	
Total Option 2	**$2,329,000**	**13,504**	**33.22**	**$70,108**		**$1,048,050**	**$1,280,950**	**$5,004**

The second proposed treatment plan (Option 2) consisted primarily of an enlargement of the existing wet detention pond downstream of the neighborhood. The pond capacity would be enlarged to a sufficient size to accommodate all areas of the neighborhood that could feasibly be routed to a structure in that location. The cost to do so was estimated to be $5,004 per household (Table 7). Figure 21 shows the spatial configuration of the treatment areas referenced in Table 7, with the areas treated in Option 2 shown in yellow.

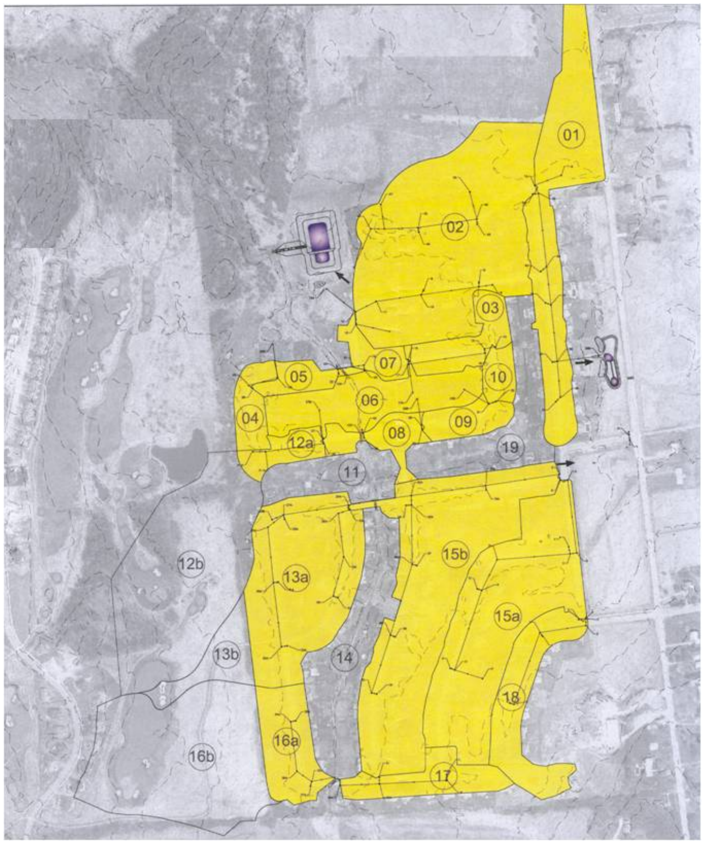

Figure 21. Delineated subareas of the BF/OCV neighborhoods. The areas in yellow are those treated by Option 2.

The smaller per household cost as a result of the more distributed approach to treatment suggest that additional cost savings may be achieved through a more comprehensive embrace of LID principles. To evaluate how those principles might be applied within the neighborhoods while meeting expected stormwater management targets we invited a group of experts who had practical experience in the design and implementation of residential LIDs to consult with our group in November 2007. The invited experts included Chris Mays and Steve Moddemeyer of Seattle Public Utilities, Steve Apfelbaum of Applied Ecological Services, Brian Carleton of Carleton Hart architects, and Jack Claussen of University of Connecticut. These experts met with the project engineer, members of the RAN team, and representatives of South Burlington Planning and Zoning, Stormwater Utility, and Public Works. The group participated in a site visit to the neighborhood, presented their ideas at a meeting of the City Planning Council, and participated in a working design session at the project engineer's office to draft locations and configurations of potential LID installations. These included narrowing streets, installation of new and retrofitting of existing vegetated swales, installation of porous pavement in place of asphalt, and several other location specific ideas.

The results of this design session were presented to the neighborhood residents, along with Options 1 and 2, at meeting in June 2008 to which all neighborhood residents were invited. The LID installations received a generally favorable reception from those in attendance. However, it became clear at this meeting that no action would be taken by the homeowners within the neighborhoods prior to finalization of the State's regulatory structure. We except, however, that the outcomes of this design process to be reconsidered when active stormwater treatment planning resumes for the neighborhood.

3.8.3 Other Outreach

In addition to our interactions with the SWG, we held one community Field Day (October 2006). In addition, we responded to inquiries from the press about our research program. These included televisions interviews with local Channels 3 (WCAX) and 5 (WPTZ) regarding the October Field Day, substantial contributions to a major series on stormwater published by the *Burlington Free Press* (Aug 2006), and a cover story on stormwater in the *Vermont Quarterly* (developed in 2006 but not published until Winter 2007).

We continued to develop the content and functionality of the RAN website. During the period of this report we focused most on the content of pages associated with the SWG. Another area of focus was the development of number of concise project component summaries or Fact Sheets. These allow us to communicate our progress in various areas to technical and nontechnical stakeholders, and are included in Appendix 4.Content in other parts of the web site will be updated in the coming year.

Finally, we submitted a manuscript to *Stormwater* magazine, describing the RAN project and early lessons learned. We intentionally utilized a trade magazine rather than a professional journal to spread word about our program of research to interest groups that we might not reach otherwise. This article was published in the May/June 2006 issue.

Acknowledgements

We acknowledge the strong and regular involvement of Juli Beth Hinds, Director of Zoning and Planning for the Town of South Burlington, without whom this project would be immeasurably more difficult. We acknowledge Don Ross from the University of Vermont Soil Testing Laboratory for assistance with analytical trials. We also acknowledge the contributions of John Myers of Stantec, Inc., to develop alternative stormwater management treatment options for consideration by the Stormwater Working Group. We thank Shari Halik for her assistance in producing the fact sheets that describe the key results of this research in terms that the public can understand. We thank Eric Perkins, Program Manager, U.S. Environmental Protection Agency Region 1, for his 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 former 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. EPA X-97137901 from the U.S. Environmental Protection Agency and was an extension of work previously funded by Grant No. X-97137901-0, also 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.

4 References

Baumann, H. and A.-M. Tillman. 2004. The hitch hiker's guide to LCA. Studentlitteratur Publishers, Sweden.

Bare, J. C., G. A. Norris, et al. 2003. TRACI - The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. Journal of Industrial Ecology 6(3-4): 49-78.

Bowden, W., A. McIntosh, J. Todd, R. Costanza, A. Voinov, A. Hackman, B. Kirk, H. Vladich, and T. White. 2003. Redesigning the American Neighborhood: Program Work Plan. Report to USEPA.

Bowden, W., A. McIntosh, J. Todd, R. Costanza, A. Voinov, A. Hackman, B. Kirk, H. Vladich, and T. White. 2006. Redesigning the American Neighborhood Annual Report: Project Years 1 and 2. Report to USEPA.

CAT. 2004. Caterpillar Performance Handbook. Peoria, IL, Caterpillar, Inc.

CWP. 2003. New York State Stormwater Management Design Manual. Center for Watershed Protection. Albany, NY, New York State Dept. of Environmental Conservation.

GDI. 2006. Economic Input-Output Life Cycle Assessment Model, Green Design Institute, Carnegie Mellon University.

Kirk, B. 2006. Suburban stormwater management: A life cycle approach. M. Sc. Thesis. Burlington, VT. University of Vermont, Rubenstein School of the Environment and Natural Resources.

Kirk, B., W. Bowden, J. Erickson, R. Roseen, J. Todd, and A. Voinov. 2005. Life cycle approaches to suburban and exurban stormwater management. In *SETAC North America 26th Annual Meeting*. 13 - 17 November 2005. Baltimore, Maryland.

Lippiatt, B. C. 2002. BEES 3.0 Building for Environmental and Economic Sustainability Technical Manual and User Guide, National Institute of Standards and Technology.

Meyer, J.L., M.J. Paul, and W.K. Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society 24(3): 602.

Morrissey, L. 2004. Personal communication.

Mulholland, P.J., et al. 2001. Inter-biome comparison of factors controlling stream metabolism. Freshwater Biology 46(11): 1503.

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.

Odum, H.T. 1956. Primary Production in Flowing Waters. Limnology and Oceanography 1(2): 102.

Paul, M.J., and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32: 333.

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

RSMeans. 2005. Site Work and Landscape. CostWorks 2005. RSMeans. Kingston, MA, Reed Construction Data.

Suh, S. and G. Huppes. 2005. Methods for Life Cycle Inventory of a Product. Journal of Cleaner Production 13(7).

Taylor, S.L., S.C. Roberts, C.J. Walsh, and B.E. Hatt. 2004. Catchment urbanization and increased benthic algal biomass in streams: linking mechanisms to management. Freshwater Biology 49: 835.

Tsivoglou, E.C. and L.A. Neal. 1976. Tracer Measurements of reaeration: III. Predicting the reaeration capacity of inland streams. Journal of the Water Pollution Control Federation 48(12): 2669.

University of Vermont, UVM. 2007. True color orthophotos: Chittenden County 2004. UVM Spatial Analysis Lab, Burlington, VT.

USDA NRCS. 1986. Urban hydrology for small watersheds: TR-55- User's Guide. Available at: http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-tr55.html.

USEPA. 2003. MOBILE6.2 - US EPA Mobile Source Emission Factor Model. O. o. T. a. A. Q. Assessment and Standards Division, U.S. Environmental Protection Agency.

USEPA. 2005. NONROAD2005 - US EPA Nonroad Emissions Model. O. o. T. a. A. Q. Assessment and Standards Division, U.S. Environmental Protection Agency.

Vermont Department of Environmental Conservation. 2002. Stormwater Manual. Volume 1. Agency of Natural Resources, Water Quality Division. Waterbury. Available at: http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf

Vermont Department of Environmental Conservation. 2006. Total maximum daily load to address biological impairment in Potash Brook (VT05-11) Chittenden County, Vermont. Agency of Natural Resources, Water Quality Division. Waterbury. Available at: http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_pot_tmdl_final_epa_submittal.pdf

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.

Appendix 1 - RAN-55 Stormwater BMP Evaluation Tool

Background: This model was originally developed by Evan Fitzgerald, a graduate student in the Rubenstein School, as part of Simulation Modeling (NR 285) class during spring semester 2005 taught by Alexey Voinov in UVM's Gund Institute for Ecological Economics. It has since evolved into a tool designed specifically for cost-benefit analysis of Stormwater Best Management Practices (BMP) and Low Impact Designs (LID) in Vermont. Since the model's original creation, various members of the RAN team have provided significant input into its development, and the model continues to evolve under the wing of the RAN project. In essence, the model is intended to bridge the gap of understanding between the scientists and engineers working intimately with stormwater problems and the homeowners, homebuilders, and planners directly impacted by these problems. By organizing a spectrum of calculations under one roof, the tool is capable of providing quick answers to important questions surrounding the stormwater in Vermont.

This tool is specific to Vermont because the calculations associated with compliance are based on the regulations found in Vermont Agency of Natural Resources Stormwater Management Manual (3^{rd} Edition - April 2002). Although specific to ANR's regulations, the model's analysis of rainfall-runoff for peak flow rates and BMP/LID cost-benefit can be used anywhere in the Northeast, as these data and calculations are applicable region-wide.

Model Components

Rainfall-Runoff Calculations: The standard rainfall-runoff relationships and equations used in NRCS TR-55 and TR-20 models have been written into the Stella model to produce near identical results to the NRCS models. These relationships include the Curve Number approach as well as the Type II mass rainfall curve used for the Northeast. A comparative analysis between TR-55 and Stella model results was performed for the time of concentration variable at the fixed scale of ten acres, and it was determined that the effect of not including this variable in the Stella model was negligible for peak flow rate calibration. Therefore, this normally sensitive variable has not been included in the current version of the model. It is possible that future versions of the model with greater or varying subdivision areas may need to incorporate this important variable.

Subdivision Data: The subdivision data interface has been designed to allow for the user to control the overall development layout and footprint of impervious surfaces. While the total area is fixed at 10 acres, various lot acreages can be selected for preferred build-out densities. Roadway, driveway, and sidewalk widths, as well as house footprints can also be adjusted by the user per LID specification. Impervious cover calculations associated with the hydrologic modeling and attainment of ANR's regulations will be automatically updated by the model per the user's selection of subdivision layout.

ANR Stormwater Regulations and Compliance: Calculations included in ANR's 2002 Stormwater Management Handbook have been incorporated into the model such that required treatment volumes are updated with each model run according to the input parameters chosen by the user. The Water Quality (WQv) and Channel Protection (CPv) Volumes are calculated separately but are summed in the interface.

Required Recharge Volume (Rev) is also calculated and is displayed separately from WQv and CPv. Peak flow rates for Predevelopment Conditions, Post-development Conditions without BMP mitigation, and Post-development Conditions with BMP mitigation are included in the hydrographs in the interface. Although required peak flow reduction for the 1 year storm event is inherent when CPv is met, peak flow reduction (as a percent) has also been included in the interface with respect to post-development peak flow without mitigation, as well as percent reduction from pre-development conditions.

BMP Selection and Cost Analysis: Three options for BMPs include: rain barrels; raingardens; and wet detention ponds. All BMP specifications for performance are described in brief in the interface, and a number of options for routing of water through one or more structures exists. These routing options, which include the specification of type of runoff collection system as well as routing rain barrel overflow into raingardens, are also described in brief in the interface. Cost ranges for each BMP have been included in the interface, but the model allows for user control of cost data if specific values are known. Lastly, costs associated with the stormwater collection system are automatically calculated in the model when the option of including this system is turned "ON". Collection system costs, at $28/linear foot, were calculated to be the costs above and beyond those associated with LID grassed swales, where:

Grassed Swales - $9
Curb/Gutter/Culvert - $37

Source: 1997 BMP Fact Sheet – Bay Area Stormwater Management Agencies Association (www.basmaa.org)

To operate this model

1. Download the PC or McIntosh trial version of the STELLA modeling software from here (or http://www.hps-inc.com/community/downloads/STELLA /STELLADemo.aspx). This trial version will allow you to operate the RAN-55 model, but you won't be able to save any output or changes to the model structure.
2. Open the RAN-55 program file (.STM) with the STELLA and follow the instructions above and embedded in the model.

For further information contacts:

Evan.Fitzgerald@uvm.edu
Breck.Bowden@uvm.edu or
Alexey.Voinov@uvm.edu

Appendix 2 - UVM Standard Operation Procedure for Nitrate and Ammonium

SOP 8: LACHAT Automated Flow-Injection Analysis Procedure for Low-level Nitrate and Ammonium Samples in Water

References:

- Lachat QuikChem Methods 10-107-062-2-A (Ammonium; 26 August 2003) and 10-107-04-1-J (Nitrate; 27 March 2001). Lachat Instruments / Hach Co. PO Box 389, Loveland, CO 80539-0389 USA.
- Ammonium: AHPA 4500-NH3 G
- Nitrate: AHPA 4500-NO3 F

Equipment:

1. Lachat QuikChem FIA+ 8000 Series Flow Injection Analyzer (Hach Co., Loveland, CO USA), equipped with interference filters at 660 nm (nitrate) and 540 nm (ammonium).

Reagents:

1. Distilled/de-ionized water (carrier)

NITRATE:

2. Ammonium chloride buffer (pH 8.5)
3. Sulfanilamide color reagent

AMMONIUM:

4. EDTA solution (6%, pH 7.0)
5. Sodium phosphate buffer
6. Salicylate-nitroprusside color reagent
7. Hypochlorite reagent

Procedure:

1. Prepare reagents as described in published methods, using distilled/de-ionized water.
2. Prepare calibration standards (six to eight values, 0.1 to 10 mg nitrate-N and ammonium-N per liter) from 1,000 mg per L stock solutions and distilled/de-ionized water. Calibration Blank is distilled/de-ionized water.
3. Prepare QC check samples (0.5, 1.0, and 5.0 mg nitrate-N and ammonium-N per liter) from 1,000 mg per L stock solutions (from a different manufacturer than those used for calibration standards) and distilled/de-ionized water.
4. Filter samples through a 0.45-µm membrane filter.
5. Calibrate instrument according to instrument method. Recalibrate if $R^2 < 0.999$.
6. Analyze QC check samples at beginning and end of run, and every ten samples. Recalibrate and re-run samples if value is greater than 15% different from expected value.

Appendix 3 - UVM Standard Operation Procedure for Phosphate

SOP 19: Spectrophotometer Analysis Procedure for Low-level Phosphate Samples in Water

References:

- Wolf, Ann, and Douglas Beegle. 1995. Recommended Soil Tests for Macronutrients: Phosphorus, Potassium, Calcium and Magnesium. Pp. 30-38 in Recommended Soil Testing Procedures for the Northeastern United States. 2nd Edition. Northeastern Regional Publication No. 493. NEC-67. Agricultural Experiment Stations of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia. Revised December 15, 1995.
- AHPA 4500-P D

Equipment:

1. Manual spectrophotometer, capable of reading absorbance at 660 nm.

Reagents:

1. Distilled/de-ionized water (carrier)
2. Ammonium molybdate solution
3. Stannous chloride / Hydrochloric acid solution

Procedure:

1. Prepare reagents as described in published methods, using distilled/de-ionized water.
2. Prepare calibration standards (0.05, 0.1, 0.2, 0.5, 1.0, 2.0 mg ortho-phosphate-P per liter) from 1,000 mg per L stock solution and distilled/de-ionized water. Calibration Blank is distilled/de-ionized water.
3. Prepare QC check samples (0.1, 0.5, and 1.0 mg ortho-phosphate-P per liter) from 1,000 mg per L stock solution (from a different manufacturer than that used for calibration standards) and distilled/de-ionized water.
4. Filter samples through a 0.45-µm membrane filter.
5. Measure 7 mL of each standard into test tubes.
6. Add 2 mL ammonium molybdate to each tube. Mix on vortex mixer.
7. Add 1 mL stannous chloride solution to each tube. Mix on vortex mixer.
8. Between 5 and 15 minutes after reagent addition, measure calibration standards at 660 nm. Re-calibrate if calibration curve $R^2 < 0.999$.
9. Repeat mixing and measurement procedure for QC check samples and unknown samples.
10. Analyze QC check samples at beginning and end of run, and every ten samples. Recalibrate and re-run samples if value is greater than 15% different from expected value.

Appendix 4 - RAN Fact Sheets

4.1 Stream Power and Erosion

4.2 Stormwater BMP Evaluator Tool

4.3 Biotic Metabolism of Streams

4.4 Remote Sensing & Spatial Analysis Tools

4.5 Life Cycles of BMPs

4.6 Burlington Stormwater Park Design

4.7 Suburban Stormwater Park Design