Best Management Practices for Water Quality Improvement in Central New York; A Review

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Richard C. Smardon
State University of New York College of Environmental Science and Forestry

Best Management Practices for Water Quality Improvement in Central New York:

A Review

Environmental Finance Center
Syracuse University

ESF
State University of New York
College of Environmental Science and Forestry

Reported by Fred Owusu-Ansah, Ph.D.
Environmental Science - Water Resource Management & Wetland Policy
State University of New York College of Environmental Science and Forestry

Under the supervision of Richard C. Smardon PhD SUNY Distinguished Service Professor,
Environmental Studies SUNY/ESF
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Introduction

The concept of Best Management Practices (BMPs) has been widely used in the international scientific and engineering literature, and variously defined by different researchers and institutions. For instance, BMPs are seen as a means of protecting the aquatic environment from pollution, achieved either by adopting 'clean' procedures or by providing structures to prevent or treat pollution (Hornferr *et al.*, 1994). From another perspective, the US Environmental Protection Agency (USEPA) defines BMPs as suites of measures and practices for which there are specific design criteria and published performance statistics (USEPA Guidance Document, 1995). According to Villarreal and Semadeni-Davies (2004) BMPs can include policy changes and educational programs; the choice of a particular BMP depends upon available space, land use, public perceptions, funding, and intended function.

Over the years, the use of BMPs for water quality improvement have been advocated in the Central New York. One outcome is the development of Project Watershed CNY. Under this cooperative agreement initiative, two major projects: (1) Monitoring Effectiveness of Agricultural BMPs in Maintenance of Water Quality in the Skaneateles Watershed (R.D. Briggs, PI), and (2) A Monitoring Plan for Harbor Brook Subsurface Flow Constructed Wetland - A CSO Water Treatment Demonstration Project (R.C. Smardon, PI) have been initiated. As part of this program, two Ph.D. students were contracted during summer 2009 (May-July) to investigate and document information on the effectiveness of rural and urban BMPs within central New York.

This report, therefore, is prepared as part of Project Watershed CNY and in accordance with The Research Foundation of the State University of New York College of Environmental Science and Forestry (SUNY-ESF) summer contract of May 23, 2009. It provides an overview of some of the of past and present BMP monitoring and assessment studies including a summary of research findings from the two major projects conducted by both SUNY-ESF professors Dr. Russell Briggs (Forest Soils) and Dr. Richard Smardon (Wetland Policy) within Central New York. An attempt has also been made to include in this report a review of BMPs in other cold climate regions, mainly in the United States and a few cases in Europe, for the purpose of: (a) comparing the performance and suitability of various BMPs under different cold climate conditions, and (b) providing recommendations of which BMPs could be useful for water quality improvement in the Onondaga Creek Watershed Program. Finally, this report also brings into view some considerations that might affect the efficiency of specific BMPs under cold climate conditions.

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Acronym Index

AEM | Agricultural Environmental Management

ALK-T | Total Alkalinity

AnnAGNPS | a modeling tool to evaluate the effect of management decisions impacting water, sediment and chemical loadings within a watershed system.

ASCE | American Society of Civil Engineers

BMP | Best Management Practices

BOD | biochemical oxygen demand

CCE | Cornell Cooperative Extension

COD | chemical oxygen demand

CSO | combined sewer overflow

DRP | dissolved reactive phosphorus

ESCP | Erosion & Sediment Control Plan

HDPE | high density polyethylene

HRT | hydraulic resident time

MANOVA | multivariate analysis of variance

NYSDEC | New York State Department of Environmental Conservation

OCSWCD | Onondaga County Soil and Water Conservation District

OGFC | open graded friction course

SLWAP | Skaneateles Lake Watershed Agricultural Program

SSO | sanitary sewer overflow

SUNY – ESF | State University of New York College of Environmental Science and Forestry

SWAT | Soil and Water Assessment Tool

TKN | total kjeldahl nitrogen

TP | total phosphorus

TSS | total suspended solids

USEPA | US Environmental Protection Agency

VSB | vegetated submerged bed

WASCoB | water and sediment control basin

Research Approach

Two research approaches were adopted in this report: (1) a systematic literature review approach, and (2) personal informal interview/communication. For the research-oriented literature review, relevant published documents were analyzed. Materials used in the report include academic articles, scientific papers and engineering reports obtained mainly from web resources. Some literature was also obtained from Dr. Smardon. Databases of some public institutions (including SUNY-ESF, USEPA, New York State Department of Environmental Conservation (NYSDEC), Toronto Region Conservation Authority, etc.) were searched. Some private organizations' websites (including ASCE Publications) were also visited. Additional articles were identified by following up on references and publication lists of certain online publishers (such as Elsevier, Wiley InterScience, SpringerLink, etc.). Some of these articles and reports have been summarized and organized into the present report structure. Additionally, discussions were held with individuals with professional expertise and involvement in source-control measures (including those affiliated with the Syracuse Center of Excellence, NYSDEC, Onondaga Environmental Institute Onondaga County Soil & Water Conservation District, Cornell Cooperative Extension of Onondaga County, and SUNY-ESF).

BMPs listed in this research, therefore, include those practices, programs, and initiatives deemed effective either by expert opinion and professional judgment (based on first impressions, field experiences, and observations) or by experiment and assessment studies. Some updated literature is provided by Dr. Smardon.

Research Findings

I. STUDIES & DOCUMENTED LITERATURE ON BMPS WITHIN THE BORDERS OF CENTRAL NEW YORK

Very little documented literature evaluating the effectiveness of BMPs for water quality improvement within the borders of Central New York was found during the period under review (May-July, 2009). BMPs found in Central New York include the following practices:

(a) collective nutrient management practices
(b) buffer strips
(c) subsurface flow constructed wetlands
(d) using alkalinity as a tracer in combined sewer overflows (CSOs)
(e) using a combination of green-roofs, Flexi-Pave and rain barrels
(f) green infrastructure cost assessment study
(g) vegetated submerged bed (VSB)
(h) exclusive fencing
(i) manure storage
(j) a combination of rock-lined outlets and grassed waterway
(k) water deflectors
(l) CleanSweepNY program
(m) Skaneateles Lake Watershed rules & regulations on erosion control
(n) composting toilets
(o) static pile carcass composting
(p) Agricultural Environmental Management (AEM) Award
(q) the district's equipment rental program
(r) stormwater management practices.

1. Collective Nutrient Management Practices

Dr. Russell Briggs and a team of students have monitored the effectiveness of agricultural BMPs in maintenance of water quality in the Skaneateles Watershed. Major aspects of this work involved:

(1) monitoring bacterial and nutrient levels associated with agricultural activities within the Grout Brook, Bear Swamp Stream, Shotwell Creek, and Harold Brook sub-watersheds sub-watershed (several of the major tributaries emptying into the southern end of Skaneateles Lake)
(2) using two watershed models (AnnAGNPS, SWAT) to model water quality. Over the years (2005-2009), this research has focused on:
  (a) stream water sampling (including macro invertebrate sampling, determining the abundance of all aquatic insect in agricultural and forested stream, and conducting simple biotic index studies)

(b) laboratory and statistical analysis (for soil solution, tile drainage solution, milk house waste, turbidity, total suspended sediments, soluble reactive phosphate, total nitrogen and phosphate, nitrate, ammonium, orthophosphate PO_4, total coliform and E. coli bacteria, dissolved oxygen, total suspended sediments, pH, etc)

(c) a general assessment of the effectiveness of BMPs for water quality improvement.

No particular BMPs were evaluated by this research. However, the general effectiveness of agricultural BMPs designed and implemented within the watershed (to prevent farm sources of nitrogen and phosphorous from entering surface waters) was monitored and found to be influenced by a combination of variables, such as soil drainage, soil texture, and the extent of grassed, forested, or riparian buffers separating site of application of nitrogen and phosphorous from surface water. Nutrient enrichment and vegetation removal practices associated with agricultural land use were shown to influence stream ecology.

2. Buffer Strips

Young and Briggs (2008) studied buffer strips within Onondaga County, New York, comparing phosphorus concentrations in soil and subsurface water among cropland and riparian buffers. The buffers strips consisted of grass buffers (predominantly reed canary grass), grass-willow buffers (*Salix discolor*; variety S365), and riparian forest buffers (Timothy and orchard grass). Their findings revealed that buffer strips reduced soil solution and shallow ground water dissolved reactive phosphorus (DRP) concentrations relative to paired cropland plots. Their impact on particulate and organic phosphorous in ground water was less clear.

Young and Briggs (2007) found that in studies performed along portions of Spafford Creek and Onondaga Creek soil drainage affected nitrate removal within riparian buffers. Well-drained or moderately well-drained soil types present in riparian buffers were not as effective at nitrate removal as poorly drained and very-poorly drained soils (Young and Briggs 2007). Young and Briggs (2005) also found that nitrate nitrogen (NO3-N) and ammonium nitrogen (NH4-N) concentrations in ground water differed by land use type:

- Forested buffers had the lowest average NO_3–N, the highest NH_4–N
- Cropland soils (with appreciable NO_3–N in ground water adjoining riparian buffers on outwash deposits) were ineffective at reducing NO_3–N; and
- Consistent NO_3–N reductions occurred between cropland and buffers where ground water flowed from moderately well and well drained cropland to poorly-drained riparian buffer soils.

3. Surface Flow Wetland for Agricultural Waste Treatment

A restored drained wetland could provide removal of nonpoint source nitrogen (N) from animal feeding operations (AFO) runoff as an equivalent to a constructed wetland (Pasi 2011). Johnson and Smardon (2011) address the N removal efficiency of the drained and restored Long Acres Wetland (LAW) in Chenango County NY. This research modeled the constructed wetland equivalents, and the relationship of the five denitrifying variables of bacterial population size, bacteria-pollutant contact, N cycle continuity, kinetics and bacteria-pollutant contact time to rate their relative influence on N removal. Although Johnson and Smardon (2011) found restoration improved percent of total nitrogen removed (%TNR) from 90.9% to 94.6%, analysis of variance (ANOVA) of the actual drained versus actual restored %TNR datasets indicated no statistical difference, indicating that the actual restored wetland was not operating at its theoretical efficiency. Subsequent ANOVA of the denitrifying variables' previous post-restoration data sets indicated that restoration had favorably influenced all denitrifying variable except bacteria-pollutant contact. Results suggest lack of mixing was the limiting factor negating all other enhanced variables potential treatment contributions. Nevertheless, the actual drained wetland significantly removed N, indicating that the drained wetlands maybe removing considerable N from polluted runnoff.

4. Combined Sewer Overflow (CSO) Treatment Wetlands

Dr. Smardon and his students have been working on a combined sewer overflow (CSO) water treatment demonstration project at Syracuse's Harbor Brook Wetlands. Through this project, a subsurface flow constructed wetland has been proposed for CSO water treatment from CSO 18. Studies conducted on this demonstration project concentrated on

(a) investigating the fluctuation nature of water quality in both sanitary sewer overflow (SSO) and CSO - also involves studies on factor analysis of potential properties of storm events
(b) laboratory analysis of: fecal coliform, biochemical oxygen demand over a five-day period (BOD_5), total suspended solids (TSS), total phosphorus (TP), total kjeldahl nitrogen (TKN), chemical oxygen demand (COD), alkalinity (ALK) and pH
(c) using statistical methods to determine whether CSO 18 has a significant impact on water quality
(d) developing a nutrient removal design model.

Some of the findings of this demonstration project include the following:

- BOD_5 in the Harbor Brook stream was found to be very low (below

2 mg/L) with insignificant fluctuations, however, the SSO sewage recorded a much higher BOD_5 concentration with significant time fluctuations. BOD_5 in the SSO was estimated to be relatively higher in June and September, but lower in August. This could be attributed to changes in human activities associated with different months of the year in that area.

- During the year under investigation, TSS fluctuated with time in both the SSO and the Harbor Brook. Still, TSS concentration in SSO sewage was much higher than that of the stream. In July, TSS concentration in the sewage reached its lowest point, while TSS in the stream peaked during that same month. TSS in the SSO was relatively higher in the months of June and September, while TSS in the stream was relatively lower in these months.
- Variations in TKN were observed in both SSO and Harbor Brook. TKN concentration was relatively higher in June, but lower in September. Concentration of TKN in the SSO sewage varied significantly and was much higher than that of the stream
- TP concentration in the SSO sewage was comparatively higher in the months of June, September and October. During the rest of the year, however, TP levels remained fairly steady. Although TP was relatively low in Harbor Brook, the highest peak was recorded in July.
- There was no significant change in the levels of total alkalinity (ALK-T) in both SSO sewage and the Harbor Brook. ALK-T in the Harbor Brook was fairly constant with a concentration of 270mg/L. However, ALK-T in the sewage was slightly higher in July and August.
- Fecal coliforms in SSO sewage fluctuated greatly throughout the year under investigation. Two peak levels were registered: the highest recorded in October and the other peak in September. Fecal coliforms counts were virtually non-existent for the Harbor Brook, and water quality was observed to be relatively clean.
- A pH value of 7.7 was estimated for the Harbor Brook stream, which remained fairly constant throughout the year under investigation. However, in the case of the SSO sewage, slight variations occurred with the highest pH value (7.7) recorded in August and the lowest (7.4) in the months of June and September.
- With the exception of pH, statistical analysis revealed significant differences between the SSO and Harbor Brook water for all the parameters mentioned above.
- A multivariate analysis of variance (MANOVA) of storm events (with the use of SAS statistical software) also revealed that CSO overflows had a significant impact on Harbor Brook water quality.
- From the calculation of hydraulic resident time (HRT), an attempt was

made to design the subsurface flow treatment wetland as an attached growth biological reactor using first order plug flow model.

- Field experimentation also demonstrated that both prairie cordgrass and sweet grass could grow very well in the proposed constructed wetland. Woolgrass bulrush and common cattail would not survive without a favorable fine gravel bed media. There is still regulatory uncertainty as to how to address constructed CSO treatment wetlands in both North America and Europe(Levy et al 2014).

Dr. Smardon and his team investigated the use of alkalinity as a tracer to estimate the ratios of sewage in CSO overflows in Syracuse. After discovering that the total alkalinity in the sewage of CSO 18 and the Harbor Brook is relatively conservative and does not show heavy fluctuations with time, the researchers used total alkalinity as a tracer to estimate the ratios of sewage in CSO 18. This research suggested that the use of alkalinity to estimate CSO sewage ratios is a convenient and cost effective method that could be adapted to facilitate small, community-based treatment wetlands for treating CSO runoff (Wu et al 2012).

5. A Combination of Green Roofs, Flexi-Pave and Rain Barrels

Local residents reactions to Green Infrastructure (GI)implementation in the near west side was judged to be positive regardless of negative aspects and income level (Barnhill and Smardon 2012).

Syracuse University established the "Near Westside Initiative" in Onondaga County to educate and support property owners on the use of a combination of practices to reduce stormwater runoff and flooding. These practices include green roofs, Flexi-Pave, and rain barrels. Expert opinion (based on field observations and first impressions) indicates this combination of practices is promising for urban stormwater management; however, educating and convincing property owners to undertake such practices requires both human and financial resources.

When choosing a specific rain barrel design, consider the following characteristics of the barrel in terms of the use and application you would use one for: functional overflow, conveneience of spigot, quality construction, potential areas for leaks, removable lid, and a secure screen.

6. Green Infrastructure Cost Assessment Study

Professor Emanual Carter and a team of student in the Department of Landscape Architecture at SUNY–ESF, carried out a preliminary green infrastructure cost assessment study with Home Headquarters Near Westside Initiative. The researchers assessed runoff reduction credit, size of practice, minimum cost and maximum cost of some selected BMPs in the interest of achieving stormwater reduction goals. BMPs under investigation included: cisterns, grass pavers, porous concrete, porous asphalt, rain gardens, interlock pavers, stormwater planters, and green roofs. The information obtained, however, did not detail which of these practices are most effective for water quality improvement purposes.

7. Vegetated Submerged Bed (VSB)

In the Village of Minoa (located east of Syracuse in Central New York,), a vegetated submerged bed (VSB) constructed wetland system to treat primary effluent to secondary effluent standards was established (EPA Manual 2000). The residential community, researchers at Clarkson University and some New York State agencies (including NYSDEC and the USEPA) initiated a research and technology transfer project to monitor the performance of the Minoa VSB under three operational systems: conventional parallel operation, series-flow, sequential fill-and-drain operation, and alternating parallel fill-and-drain/series-flow operation. Under the conventional parallel operation, the VSB's Total Suspended Solids (TSS) and (biological oxygen demand) BOD_5 removal performance was reasonably good; however, TKN and TP removal was quite poor. Further investigation revealed that cells planted with *Phragmites* removed more COD, TKN, and TP than cells planted with *Scirpus*. Under the sequential fill-and-drain operation, the VSB's BOD_5 removal was significantly better. No significant improvement was recorded for TKN and TP removal. According to the EPA Manual, one of the most important improvements under this operation was the reduction in the hydrogen sulfide odor that had plagued the system during the conventional operation period. Under the alternating parallel fill-and-drain/series-flow operation, BOD_5 and TSS removal performance remained effective since 1997 and the system also demonstrated a significant increase in nitrogen removal.

8. Exclusive Fencing

Onondaga County Soil and Water Conservation District (OCSWCD) revealed that exclusive fencing is a recommended BMP for individual farmers who own and operate pasture-based farms in the Skaneateles Lake Watershed. Practiced in the town of Spafford, exclusive fencing is aimed at preventing multi-species grazing animals (including market lambs and pigs) from having contact with water bodies. This reduces bacterial load associated with animal waste in watercourses within the watershed.

9. Manure Storage

Manure storage is another practice in use in the Skaneateles Lake Watershed. This practice facilitates pathogen management by handling and controlling manure. A manure storage facility with a pump and loading pipe can store manure silage leachate and milk house wastewater for up to six months during the winter months. Farmers following this practice incorporate the nutrients at the correct rates during times of the year when crops can use them. Pathogen and nutrient management are top priorities of the Skaneateles Lake Watershed Agricultural Program (SLWAP). As such, this practice creates a healthier environment for livestock and has the potential to reduce pathogens and nutrient runoff from farmstead and crop fields to nearby waterways.

10. A Combination of Rock-lined Outlets and Grassed Waterways

Another soil management practice emphasized under the SLWAP is the use of rock-lined outlets and grassed waterways. Skaneateles, NY carried out a project where various roadside locations where erosion has occurred were stabilized using geo-textile fabric as lining with riprap laid over so that there were stable runoff outlets for field runoff.In another development, a waterway that had been filled with sediment and vegetation was cleared, graded, and seeded to create a grassed waterway (a.k.a vegetated filter system). This practice prevents road drainage from flowing across the fields and bringing sediment, nutrients, and pesticides into Skaneateles Lake.

11. Water Deflectors

Water deflectors divert surface water and reduce erosion on unpaved roads. Comprised of standard-grade rubber (made from used conveyor belts) sandwiched between two treated wooden planks (2" x 6"), water deflectors are being installed on unpaved access roads under the SLWAP. According the OCSWCD, additional practices aimed at stabilizing roads, managing surface water, and reducing road erosion within the Skaneateles Watershed include: water boxes, broad-based dips, and box and pole culverts.

12. CleanSweepNY Program

A program called *CleanSweepNY* was initiated in Onondaga County during the week of November 2, 2009. This program targets certain materials that can pose human health risks upon exposure and significant hazard to water resources.

The program provides the safe, economical collection and disposal of unwanted or unusable pesticides, school chemicals, elementary mercury, and mercury containing devices such as thermometers. It also targets the collection and recycling of high-density polyethylene (HDPE #2) plastic pesticide containers from agricultural and certain non-agricultural entities.

13. Skaneateles Lake Watershed Rules and Regulations on Erosion Control

Since eroding construction sites are a leading cause of water quality problems in New York State, special rules and regulations (particularly for homeowners, builders, and contractors) have been put in place to preserve Skaneateles Lake's water quality. Requirements include: (a) building projects that need local building permits, other land disturbance permits, or shoreline permits which require the applicant to submit copies to the City of Syracuse Water Department; (b) where the project is located in an "environmentally sensitive" area that will disturb 5000 sq. ft. or more of land, an Erosion/Stormwater Control Plan (ESCP) is required. The new rules and regulations (adopted in September 2004 and amended in July 2005) also cover other areas of concern including: sediment generation and control; seepage, sludge and human excreta; wastewater treatment systems; agriculture; pesticide and herbicide use; solid waste; road salt storage/application; snow disposal; petroleum storage and the handling of dangerous materials.

14. Composting Toilets

Human waste management in the Skaneateles Lake Watershed has turned towards composting toilets and other alternative technologies instead of septic systems, which have remained the sanitary solutions of choice since the 1930s. Composting toilets take advantage of the natural processes of decomposition to break down the by-products of human digestion into a safe, stable, humus-like end product that can be used as a soil amendment. As no water is used, no water is polluted, thus obviating the potential for human waste to combine with potable water and require treatment. The waste becomes a resource, eliminating the need to dispose of or transport anything to the sewage treatment plant.

15. Static Pile Carcass Composting

Static pile carcass composting is a BMP recommended for managing livestock mortalities within and around the Skaneateles Lake Watershed. This practice requires a well-drained site, at least 200 feet from watercourses, sinkholes, seasonal seeps or other landscape features that indicate hydrological sensitivity. The animal carcass should be covered with dry, high-carbon material, old silage, sawdust, or dry stall bedding for up four to six months for complete degradation. Site cleanliness is vital to deter scavengers, control odors, and maintain good neighbor relations.

16. The District's Equipment Rental Program

The OCSWCD purchased three different conservation implements (including: *12' AerWay; Great Plains 1006 Compact Drill; and JD 1750 Conservation Planter*) for use on farms in the Skaneateles Lake Watershed and Onondaga County. The program's goal is to promote conservation tillage, better manure management, no-till seed establishment for pastures and buffers, and cover crops.

17. Agricultural Environmental Management (AEM) Award

AEM is a voluntary, incentive-based program that helps farmers make common sense, cost-effective, and science-based decisions to help meet business objectives, while protecting and conserving the state's natural resources. Under this program farmers work with local AEM resource professionals to develop comprehensive farm plans using a tiered process. The first farm to receive this award within Onondaga County, Trinder Farm (located at the headwaters of the Upper Tioughnioga River, in the town of Fabius) has been focusing on environmentally sound practices. They installed strip cropping and zone tillage, implemented soil and nutrient management plans with help and support from the OCSWCD, and reduced soil erosion, among others (OCSWCD, 2009). Other practices implemented under this program within Onondaga County include: silage leachate collection and treatment, water and sediment control basin (WASCoB) for soil management, barnyard runoff management system, milk house waste collection and treatment system, manure handling system, fencing/laneway, tillage, subsurface drainage system, terraces, agricultural waste systems, and pasture management system.
These practices (8-17), helped and supported by OCSWCD, are all aimed at reducing agricultural nonpoint source pollution throughout Onondaga County. Although assessment studies have not specifically evaluated the effectiveness of each of these practices for water quality improvement purposes, a source from the office of OCSWCD revealed that BMPs implemented through the SLWAP will prevent approximately 19,525 pounds of phosphorus per year from entering the Skaneateles Lake.

18. Stormwater Management Practices

According to the office of the NYSDEC, different stormwater management practices have been put in place at over 500 different locations within Onondaga County; however, none of these have been monitored or evaluated for their effectiveness.

II. STUDIES & DOCUMENTED LITERATURE ON BMPS IN OTHER COLD CLIMATE REGIONS

Table 1 gives a brief descriptive account of some of the BMPs evaluated for their effectiveness for storm water management and water quality improvement purposes in other cold regions, mostly within the United States, but also in other parts of the world.

Table 1. Descriptive Analysis of BMPs and their Effectiveness for Water Quality Improvement in Cold Climate Regions

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
1. Micropool Extended Detention Pond	- Constructed stormwater pond/ retention basin - Designed as structural stormwater management practice (SMP) to meet water quality treatment goals	- New York State
2. Wet Pond	- As in 1 above	a. New York State b. Alaska
3. Wet Extended Detention Pond	- As in 1 above	- New York State
4. Multiple Pond System	- As in 1 above	- New York State

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- Improves water quality - Good for the removal of phosphorus, nitrogen, metals (cadmium, copper, lead, zinc), pathogens (coliform, E.coli, and streptococci)	- Might cause habitat degradation; do not locate it within the stream channel - Provides channel protection - Offers overbank flood protection - Enhances extreme flood protection - Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/ or redundant treatment methods (combinations of pool, extended detention and marsh) - See web link (chapter 6) for cold climate design considerations	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/ chemical/29072.html)
a.As in 1 above a. Wet-pond sedimentation basins can remove as much as 80% of total suspended solids in influents	a. As in 1 above b. Should not be used on trout waters (evidence suggests this practice can increase stream temperatures) - But less efficient in reducing runoff turbidity caused by fine particles	a. NYSDEC (2008) (Accessed from http://www.dec.ny.gov/ chemical/29072.html) b. Jokela, J. B (1999)
- As in 1 above	- As in 1 and 2a, b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/ chemical/29072.html)
- As in 1 above	- As in 1 and 2a, b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/ chemical/29072.html)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
5. Pocket Pond	- As in 1 above	- New York State
6. Shallow Wetland	- Constructed stormwater wetland that create shallow marsh areas to treat urban stormwater	- New York State
7. Extended Detention Shallow Wetland	- As in 6 above	- New York State
8. Pond/Wetland System	- As in 6 above	- New York State
9. Pocket Wetland	- As in 6 above	- New York State
10. Subsurface gravel wetland	- Filtration system	- New Hampshire

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- As in 1 above	- As in 1 above - Direction of hotspot runoff to this design should be avoided	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- Improves water quality - Good for the removal of phosphorus, nitrogen and pathogens (coliform, streptococci, E.coli) - Not so good (fair) for the removal of metals (cadmium, copper, lead, and zinc)	- As in 2a & b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 6 above	- As in 2a & b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 6 above	- As in 2a & b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 6 above	- As in 2a & b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html; date 06/01/09)
- As in 6 above	- As in 2a & b above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html; date 06/01/09)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
11. Infiltration Trench	- Stormwater infiltration practice - Designed to capture and temporarily store water quality volume	- New York State
12. Infiltration Basin	- As in 11 above	- New York State
13. Dry Well	- As in 11 above	- New York State
14. Surface Sand Filter	- Stormwater filtering system of practice (Multi-chamber structural design) to treat stormwater runoff through filtration, using a sediment forebay, a primary filter media and an under drain collection system	a. New York State b. New Hampshire
15. Underground Sand Filter	- As in 14 above	- New York State

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- Improves water quality - Good for removal of phosphorus; nitrogen; metals (cadmium, copper, lead, and zinc); and pathogens - coliform, E.coli, streptococci	- Infiltration practices alone cannot meet detention and channel protection requirements, except on sites where the soil infiltration rate is greater than 5.0 in/hr. - Not good for: channel protection, overbank flood protection, and extreme flood protection	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 11 above	- As in 11 above - Extended detention storage may be provided above an infiltration basin. - Extraordinary care should be taken to ensure long-term infiltration rates are achieved through performance bonds, post construction inspection, and long-term maintenance.	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 11 above	- As in 11 and 12 above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
a. Improves water quality a. Good for the removal of phosphorus, nitrogen, metals (cadmium, copper, lead, zinc). b. Fair for pathogen removal including, coliform, E. Coli, and streptococci	a. Not good for: channel protection, overbank flood protection, and extreme flood protection b. High level of functionality during winter observed	a. NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html) b. Roseen et al., (2009)
- As in 14 above	- As in 14 above	- NYSDEC (2008) (Accessed from http://www.dec.ny. gov/chemical/29072.html)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
16. Perimeter Sand Filter	- As in 14 above	- New York State
17. Organic Filter	- As in 14 above	- New York State
18. Bioretention / rain gardens	- Stormwater filtering practice - shallow stormwater basin or landscaped area, - Utilizes engineered soils and vegetation to capture and treat runoff	a. New York State b. Trondheim, Norway c. Maryland d. Connecticut

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- As in 14 above	- As in 14 above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 14 above	- As in 14 above	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
a. As in 14 above b. Metal retention was good in both April and August (90% mass reduction of zinc, 82% mass reduction of lead and 72% mass reduction of copper). c. Removed over 95% of Cu, Pb and Zn. However, variation in pollutant retention recorded at different locations: 15-16% for nitrite + nitrate–nitrogen (NO_3–N); 52-67% for total Kjeldahl–nitrogen (TKN); 65-87% for total phosphorous; 49-59% for TN; 43-97% for Cu; 70-95% for Pb and 64-95% for Zn. d. 26% total Kjeldahl–nitrogen (TKN) retention; 82% ammonia–nitrogen (NH_3–N) retention; and 67% nitrite + nitrate–nitrogen (NO_3–N) retention were recorded	a. As in 14 above a. This practice is often located in parking lot islands, and can also be used to treat residential areas b. Peak flow reduction was 13% in April versus 26% in August b. Total volume reduction was 13% in April versus 25% in August b. Bioretention functions well through the winter months: no seasonal differences in retention time or lag time were found c. Bioretention and pervious pavements continued to infiltrate even with frost in the ground. d. When planted with shrubs, perennials, or trees, and covered with shredded hardwood bark mulch: decreased surface runoff, increased groundwater recharge, and pollutant treatment.	a. NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html) b. Muthanna, et al., (2007) c. Dietz (2007) See link for paper http://www.springerlink.com/content/nq10685n4112/?p=c-c88b050bfb240fc9772d-b30e4aa22ac&pi=12 c. Dietz (2007) d. Dietz (2007); Dietz and Clausen (2006)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
As in 18 above (Bioretention /rain gardens)	- As in 18 above	- New Hampshire
19. Dry Swale	- Constructed vegetated open channels - Designed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means	a. New York State b. New Hampshire
20. Wet Swale	- As in 19 above	- New York State
21. Street Tree/Tree filter	- Filtration system	- New Hampshire

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- 96% total suspended solids retention; 27% nitrite + nitrate–nitrogen (NO_3–N) retention; and 99% Zn retention were recorded		- Roseen et al., (2006)
a. Improves water quality a. Good for the removal of phosphorus, metals (cadmium, copper, lead, and zinc) a. Fair for nitrogen removal a. Poor for pathogens removal: coliform, streptococci, E.coli	a. Primarily applicable for land uses such as roads, highways, residential development, and pervious areas a. Not good for channel protection, overbank flood protection and extreme flood protection b. Pronounced decline in performance of stone-lined swale observed due to snow and ice coverage: performance declined for total suspended solids from 80% in summer to 8% in winter; for vegetated swales, performance declined from 68% in summer to 13% in winter (other contaminants under investigation included: hydrocarbons-diesel; dissolve inorganic nitrogen - nitrate, nitrite and ammonia; total phosphorus; and total zinc)	a. NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html) b. Roseen et al., (2009)
- As in 19 above	- Should be restricted in residential areas because of the potential for stagnant water and other nuisance odors - Not good for channel protection, overbank flood protection and extreme flood protection	- NYSDEC (2008) (Accessed from http://www.dec.ny.gov/chemical/29072.html)
- As in 19 above	- High level of functionality during winter observed	- Roseen et al., (2009)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
22. Porous Asphalt System	- Filtration system	- New Hampshire
23. Sediment on basin and Wetland Complex	- Sedimentation basin discharge with constructed wetland to augment stormwater discharge treatment	- Alaska
24. Combination of green-roofs, open channels and detention ponds (dry and wet)	- Structural BMPs in series for stormwater management	- Sweden
25. Vegetated roof systems (Green roofs)	- Urban stormwater management	a. Oregon b. Michigan c. Wisconsin

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- As in 18 above	- High level of functionality during winter observed	- Roseen et al., (2009)
- As in 19 above	- Reduced turbidity	- Jokela, J. B (1999).
- As in 18 and 19 above	- Significant reduction in peak flows - Effective in retaining and detaining stormwater volumes - Increased time of concentration, and delayed storm peaks	- Villarreal, E. L. and Lars Bengtsson A. Semadeni-Davies (2004)
- Retained a large percentage of rainfall (63% on average) in a variety of climates	a. A common thread across bioretention, green roofs and grassed swales was found: the export of phosphorus; a. Cu concentrations in runoff exceeded acute water quality criteria of 9 µg l−1. Authors speculate Cu from treated wood used on the roof and the soil media itself. b. Total phosphorus (TP) concentrations ranged from 0.2 to 1 mg l−1 in runoff from a green roof b. Mean TP concentrations in green roof runoff ranged from 0.5 to more than 4 mg l−1; although the authors reported that the plots were fertilized; NO3–N concentrations over 20 mg l−1 in roof runoff were also reported c. TP concentrations in roof runoff from residential and commercial areas were 0.15 and 0.20 mg l−1, respectively	a. Dietz (2007) b. Dietz (2007); Hutchinson et al. (2003) b. Dietz (2007); Monterusso et al. (2004) c. Dietz (2007); Bannerman et al. (1993)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
26. Concrete Blocks or Grids	- Permeable pavements /precast concrete - Grid or block shaped with open voids to allow for stormwater infiltration	a. Virginia b. Renton, Washington c. Connecticut d. Toronto, Canada

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
a. High retention (>81%) for all metals (Cu, Pb, Zn) a. phosphorus and nitrogen fractions were inconsistently retained. b. Negligible surface runoff was noted, virtually all of the precipitation infiltrated; decreased in copper and zinc concentrations; Water quality improved. c. Runoff depth from the paver surface was 40% of precipitation depth - about 72% less than the runoff depth from a nearby asphalt driveway c. Concentrations of all pollutants measured (TSS, NO_3– N, NH_3–N, TKN, TP, Cu, Pb and Zn) were significantly lower in runoff d. No surface runoff occurred from the parking lot for 9 storm events, with a maximum intensity of 31 mm h–1	a. Three products under investigation/ monitoring: Monoslab®, Grasscrete®, and Turfstone® a. In some cases, ortho-phosphate (ortho PO_4–P) and NO_3–N were exported from the systems b. Two concrete products, under investigation: Turfstone® (turf infill) and UNI Eco-Stone® (gravel infill) c. Products under investigation/ monitoring: UNI Eco-Stone® c. Due to lower concentrations and runoff volumes, mass export for all of the pollutants was also lower than the asphalt driveways d. Products under investigation/ monitoring: Unilock® pavers	a. Dietz (2007); Day et al. (1981). b. Dietz (2007); Booth and Leavitt (1999); Brattebo and Booth (2003) c. Dietz (2007) d. Dietz (2007); Toronto and Region Conservation (2006)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
27. Plastic Grids	- Permeable pavements, mostly pervious with large spaces designed to be filled either with topsoil and planted with turf, or filled with a small diameter-shape crushed stone to encourage rapid infiltration	a. Renton, Washington b. Georgia
28. Pervious Asphalt	- Permeable asphalt, also termed open graded friction course (OGFC) - The OGFC material is typically put down over a coarse aggregate storage layer designed to rapidly infiltrate and store water.	- France
29. Combination of Pervious Asphalt and Swales	-As in 19, 20, and 28 above	- Sweden
30. Free Water Surface (FWS) Wetland	- Densely vegetated by a variety of plant species, has water depth on the order of 0.3 m.	- Varied locations

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
a. Virtually no surface runoff was reported; a. copper and zinc concentrations in infiltrate water below were significantly lower ($p=0.01$) than asphalt runoff concentrations b. Runoff was 93% less than runoff from an adjacent asphalt lot	a. Products under investigation/ monitoring: Grasspave® and Gravelpave® a. During a long duration storm, where 121 mm of rain fell, 4 mm of surface runoff was observed from the Grasspave® section b. Grassy Paver™ plastic grid parking lot filled with sand and planted with grass was under investigation	a. Dietz (2007); Booth and Leavitt (1999); Brattebo and Booth (2003) b. Dreelin et al. (2006).
- On the average, 96.7% of the storm water volume infiltrated in the soil below the reservoir structure		- Legret and Colandini (1999).
- Between 30% to 40% of precipitation ran off the site	- The swales were a confounding factor in this study	- Stenmark (1995)
- Has advantage for moderate to high biochemical oxygen demand (BOD_5), TSS, ammonia, Total nitrogen and phosphorus	- Contaminant removal performance differs by constituent - The use of winter storage enables FWS to be used in freezing conditions - Is more temperature sensitive for nitrogen species reduction than HSSF	- Kadlec (2009)

Best Management Practices	Description/Purpose	Location (where practiced/monitored)
31. Horizontal Subsurface Flow (HSSF) Wetlands	- Densely vegetated by a variety of plant species, utilizes a bed of soil or gravel as a substrate for growth of rooted wetland plants, has water depth on the order of 0.6 m.	- Varied locations
32. Horizontal Flow Wetland	- Retardation of water flow to allow biological activity and sedimentation	- Varied locations in UK and Denmark
33. Riparian buffers/ riparian zone/ buffer strip/filter strip/ vegetated filter strip	- Sustainable means of protecting aquatic ecosystems against anthropogenic inputs of nitrogen	

Effectiveness	Comments	Sources of Information/ Websites/ Contacts
- Effective for tertiary BOD_5 levels, nitrate and pathogens	- Economics do not favor the choice of HSSF - Less cold sensitive - Easier to insulate for winter operation	- Kadlec (2009)
- Very effective for the removal of BOD_5, suspended solids, bacterial and nitrate	- Phosphorus or ammonia removal requires specialized treatment	- Hiley (2003)
- Buffers of various vegetation types were equally effective at removing nitrogen - Buffers composed of herbaceous and forest /herbaceous vegetation was more effective when wider.	- Soil type, subsurface hydrology (e.g., soil saturation, groundwater flow paths), and subsurface biogeochemistry - organic carbon supply, nitrate inputs - are also important factors governing nitrogen removal in buffers - Wide buffers (.50 m) consistently removed significant portions of nitrogen entering a riparian zone than narrow buffers (0–25 m).	- Mayer et al., 2007

From Table 1 above, constructed wetlands and bioretention/rain gardens seem to be the most suitable management practices for water quality improvement in cold climate regions. Widely evaluated in different cold climate locations, reports indicate these practices are especially promising in urban areas. It is worth noting, however, that the selection of wetland type is vital. The use of aquatic plants in wetland construction might have a significant and active role in contributing to wastewater treatment. However, the introduction of certain plants could also constrain constructed wetland performance, especially under cold climatic conditions where growth could be restricted and the rate at which suspended solids are degraded could be very slow. Therefore, strong evidence must indicate that selected plants could perform better than other varieties before using them as a major component of a constructed wetland for water quality improvement.

Roseen *et al.*, (2009), conducted studies that involved the following contaminants: total suspended solids, hydrocarbons-diesel, dissolved inorganic nitrogen - nitrate, nitrite and ammonia, total phosphorus, and total zinc. The researchers concluded that vegetated system such as retention pond had the greatest seasonal decline in performance followed by bioretention. This suggests the level of functionality and performance of bioretention cannot be guaranteed to handle all water quality parameters throughout the year.

Again, from Table 1, it could be concluded that constructed wetlands are good for the removal of BOD_5, solids, nitrates, phosphorus, nitrogen and pathogens (coliform, streptococci, *E. coli*). However, they cannot be expected to remove ammonia and some metals (including cadmium, copper, lead, and zinc) during summer or winter due to extreme temperature; specialized media or conventional chemical means could be considered to enhance their treatment performance. Highly functional and less vulnerable to seasonal variation in water quality during winter, surface sand filter is more effective at the removal of phosphorus, nitrogen and metals (such as cadmium, copper, lead and zinc) and has good potential to augment or improve the treatment performance of constructed wetlands.

Findings from the demonstrated project conducted by Dr. Richard Smardon and students, suggest that subsurface flow constructed wetlands provide many direct and indirect opportunities for CSO management, hence the potential for water quality improvement in the Onondaga Creek Watershed. While mandating the use of subsurface flow constructed treatment wetlands for CSO pollution abatement could have some policy implications, its prospects in New York State look good.

Conclusions and Recommendations

Very little documented literature evaluating the effectiveness of BMPs for water quality improvement within the borders of Central New York was found during the period under review (May-July, 2009).

Research should examine the nature and functionality of the BMPs put in place in over 500 different locations in Onondaga County. These findings should lead to further progress in identifying the various practices and their effectiveness for water quality improvement within the borders of Central New York.

No one best management practice is efficient or adequate to encompass all water quality parameters. Instead, a combination of constructed wetland (*subsurface flow constructed wetland*) and surface sand filter is recommended for water quality improvement in the Onondaga Creek Watershed. If feasible, the ideal construction would be a well-aerated, multi-purpose and multi-stage subsurface flow complex, which combines the following three features: (a) vertical flow beds (to compensate for the mineralization of organic matter, nitrification, and phosphorus absorption); (b) horizontal flow beds (for denitrification purposes) and (c) free-water surface beds (to enhance the removal of nitrogen).

Finally, we wish to support the idea put forth by Roseen *et al.* (2009), that the development of effective BMPs, particularly under cold climate conditions should take the following into consideration:

- Increased runoff due to rain or snow events and limited ground infiltration capacity
- Frost-related snow impacts on system performance (reduced or no infiltration capacity, frozen filter media)
- Changes in roughness characteristics due to snow and ice cover
- Obstruction by freezing of piping or hydraulic control structures
- Chloride toxicity related to deicing particles
- Reduced particle settling velocities due to low temperature
- High viscosity
- High chloride content runoff
- Dormant vegetation/biological functions
- Hydraulic failure due to freezing or viscosity changes of the waste water and inadequate purification processes due to low temperatures
- Understanding the characteristics of heavy metal, organic and inorganic compounds is essential

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