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Conservation management practices: Success story of the Hog Creek and Sturgeon River watersheds, Ontario, Canada

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Abstract: The soil erosion from agricultural watersheds can be reduced by implementation of conservation management practices. In this study, the effectiveness of most popular agricultural best management practices (BMPs) for reducing sediment loads within Hog Creek and Sturgeon River watersheds in Ontario was investigated using measurement of the shift in the sediment rating curves from pre-BMP (1989 to 1993) to post-BMP (2004 to 2008) implementation periods. The data from the water quality monitoring program for the Hog Creek and the Sturgeon River watersheds over this decade of extensive conservation management program implementation showed significant reductions in the sediment loads of 49% for Hog Creek and 41% for the Sturgeon River. The results showed that the most widely adopted BMPs that greatly influenced the overall removal in sediment loads were stream bank fencing, no-till farming, and vegetative buffer strips. Overall, the outcome of the study recommends these promising practices to protect and improve receiving water quality. The practical novel technique presented in this study for quantification of the overall long-term water quality benefits of conservation management practices can be an integral part of an adaptive strategy for a watershed-scale BMP implementation program.

Key words: best management practices—conservation—management—sediment rating curve—Severn Sound—water quality

Clean water is essential for the health of watersheds and the rivers and lakes to which they contribute (Ritter and Shirmohammadi 2001). Ontario has almost one-third of Canada's population and thus its water resources need to be protected and managed in a safe and sustainable manner. Nonpoint source pollution and downstream flooding from agricultural watersheds can be controlled by implementing best management practices (BMPs) at strategic locations (Hernandez and Uddameri 2015; Tuppad et al. 2010a; Lam et al. 2011; Qi and Altinakar 2011a,b; Lemke et al. 2011; Giri et al. 2012; Sommerlot et al. 2013; Artita et al. 2013; Lizotte et al. 2014; Yang et al. 2014; Trenouth and Gharabaghi 2015). Soil erosion from agricultural watersheds can be reduced by adoption of sediment control practices, such as conservation tillage, crop rotation, vegetative filter strips, terraces, and grassed waterways (Baker et al. 2006; Zhou et al. 2009). There is a general lack of information on the location of hot spots on the watershed where BMPs application would prove to be most effective or how much of a benefit will accrue as a result of the implementation of a given practice at a given place in the watershed (Mostaghimi et al. 1997; Bracmort et al. 2004; Nietch et al. 2005; Prokopy et al. 2008; Arabi et al. 2007; Karamouz et al. 2010; Yang et al. 2012; Grady et al. 2013; Jang et al. 2013; Giri et al. 2014; Sattar and Gharabaghi 2015). The effectiveness of practices and optimization of their implementation is important to reduce the costs (Easton et al. 2008; Daroub et al. 2009; Bumbudsanpharoke et al. 2009; Chaubey et al. 2010; Giri et al. 2014; Atieh et al. 2015; Liu et al. 2015b; Brooks et al. 2015). The economic benefits and costs of the adoption of BMPs have been evaluated by several researchers (Maringanti et al. 2011; Yuan et al. 2002; Wu et al. 2006; Smith et al. 2007; Tuppad et al. 2010b; Lee et al. 2010; Gassman et al. 2010; Jang et al. 2013; Jeffrey et al. 2014; Perry-Hill and L. Prokopy 2014; Alemayehu et al. 2014; Kurkalova et al. 2015).

Performance evaluation of BMPs on watershed scale can be done via monitoring and/or modeling. Monitoring is always a better and preferred option, but it is an expensive and time-consuming method and yields only site-specific results for a given set of climatic conditions. Models can be used to evaluate the impacts of BMPs on water quality under scenarios that would be difficult, if not impossible, to study experimentally (Bracmort et al. 2006; Lin et al. 2009; O'Connor and Rossi 2009; Yang et al. 2009a; Busteed et al. 2009; Gazendam et al. 2009; Daggupati et al. 2011; Yang et al. 2012; Dechmi and Skhiri 2013; Liu et al. 2015b).

Inamdarm and Naumov (2006) estimated sediment yields of the Buffalo River watershed using the Soil and Water Assesment Tool (SWAT) model. They found that Cazenovia Creek had the highest contribution of total sediment yield to the Buffalo River watershed due to steeper slopes. Smith et al. (2015) examined several conservation practices, including single and combined, which were simulated at the field scale using the Agricultural Policy/Environmental eXtender (APEX) model. They found cover crops and forage to be the most effective single conservation practices.

In 1987, the International Joint Commission (IJC), an organization that has members from both Canada and the United States, listed Severn Sound and other areas along the Great Lakes with degraded water quality as Areas of Concern (AOC). The actions to restore a healthy environment for the community involve the development of

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a Remedial Action Plan (RAP) administered by the Severn Sound Environmental Association (SSEA 1993). The RAP provided the opportunity to upgrade the sewage treatment plants and implement extensive conservation management programs to improve the water quality within the region. The most commonly utilized BMPs included streambank fencing; increased forest cover; riparian buffers; upgraded manure storage facilities; milk house wash water treatment, nutrient management plans; runoff diversion systems and windbreaks/shelterbelts; and cropland protection practices, such as crop rotation, cover crops, conservation tillage, and no tillage (SSEA 2002). In 2003, after the SSEA reached its goal of improving the water quality and restoring wildlife habitat in Severn Sound, the IJC delisted the Severn Sound watershed as an AOC.

The main objective of this study was to analyze and document the success story of the implementation of extensive conservation management practices within Hog Creek and Sturgeon River watersheds, which resulted in significant improvements in regional water quality. This study also highlights opportunities for further water quality improvements through implementation of additional conservation management practices.

Materials and Methods

Description of the Study Area for Hog Creek and Sturgeon River. The gross drainage area for Hog Creek is 65.2 km^2 (25.17 mi^2) and the geographic location at the outlet is approximately 44°43′33″ N latitude 79°46′44″ W longitude (figure 1). Hog Creek flows north from Oro-Medonte Township to Tay Township and outlets into Hog Bay. The creek has shaped a shallow channel in the flat-floored clay valley; the clay flats are of glaciolacustrine origin (Singer et al. 2002). Hog Creek is fed by springs along the valley sides, which feed into 15 first-order tributaries and many second and third-order tributaries (Singer et al. 2002).

The sides of the valleys are composed mainly of till with some stratified sand and gravel, which originated from ice movement during the last glacial retreat (Singer et al. 2002). Using the Local Minimum Method associated with the Ontario Flow Assessment Tool (OFAT), Hog Creek has an average base flow Index (BFI) of 0.44 (ratio of average base flow to average stream flow), indicating that groundwater is a regular contributor to the stream flow (Neff et al. 2005). The prominent land use in the Hog Creek watershed for the past 50+ years is agriculture and woodlots. However, small cottages occupy the reinforced banks near the outlet (SSEA 2002), with the majority of land use across the watershed under hay system followed by idle lands and pasture.

The Sturgeon River flows north from a hilly plateau near Hillsdale to Tay Township and outlets into Sturgeon Bay (figure 1). The gross drainage area for the Sturgeon River is 103 km^2 (39.77 mi^2) with a geographic location at the outlet of 44°43′49″ N latitude 79°43′11″ W longitude. The headwaters are located in Springwater Township and Oro-Medonte Township. The river is located on the flat floor of a steep valley that was created during the last glacial retreat. This created many ice-contact deposits of glaciofluvial and glaciolacustrine origin (Singer et al. 2002). These deposits consist of fine to coarse-grained sand, gravelly sand, and gravel with minor amounts of silt, clay, and till (Singer et al. 2002). The Sturgeon River has a large influence of groundwater base flow, which feeds into its ten first-order tributaries and a few second-order tributaries (Singer et al. 2002). The influence of groundwater helps to dilute total phosphorous (P) and chloride concentrations within the river (SSEA 2002). Similar to the Hog Creek watershed, the prominent land use for the past 50 years in the Sturgeon River watershed is agriculture and preserved forests with the majority of hay followed by idle lands and pasture.

Land Use in the Study Areas. It is necessary to take into account both the land use and the land cover pattern simultaneously in the study of the impacts of land use on the water quality (Houlahan and Findlay 2004). Key influencing factors changing the watershed and leading to more runoff plus erosion are the changes in land cover and land management practices (Bai 2010). Agricultural practices, including tillage, fertilization, and residue management, can affect surface runoff, soil erosion, and nutrient cycling. These processes, in turn, may affect water quality (Mueller-Warrant et al. 2012). However, table 1 presents land use for Hog Creek and Sturgeon River watersheds using census data for the pre-BMP versus post-BMP periods. The land use change in these watersheds over the study period has been negligible (slight increase in row crops and slight decrease in hay/pasture). Row crops typically have higher sediment loads per unit area compared to hay/pasture land cover.

Climate Change in the Study Area. Climate change is another possible factor that can affect the water quality of an area with time. Therefore, some studies were reviewed regarding changes due to climate. However, several studies, including Aber et al. (1995), Zhang et al. (2000), Whitfield and Cannon (2000), Van Liew et al. (2013), and most recently Asnaashari et al. (2015), analyzed historic records as well as projected future data to predict rate of change in precipitation and found that it is very slow and gradual in southern Ontario. They found a gradual "change per decade" of 1% increase in total precipitation, 2% increase in rainfall, 6.7% decrease in snowfall, 2.3% increase in potential evapotranspiration, 5% increase in streamflow during winter months, and 2.5% decrease in streamflow during the summer months over the study period. All of these percentage changes are per decade; therefore, during the two decades of the study period we could expect little change (less than 5%) in the sediment loads due to climate change and can safely assume that the bulk of the removal in sediment load was due to the BMP implementation.

Streamflow Monitoring Program. Historical stream flow data was provided by the Water Survey of Canada (WSC), which used a Stevens Type A-35 Water Level Recorder for the monitoring stations at Hog Creek (WSC Station ID 02ED017) and Sturgeon River (WSC Station ID 02ED018). The WSC still maintains the station at Hog Creek, but discontinued the station in the Sturgeon River on July 28, 1998. For the period between July 16, 2007, and October 31, 2008, two HOBO Level Loggers (Onset Computers, Massachusetts, United States) were installed in the existing WSC stilling well at the Sturgeon River to collect atmospheric and water pressure. The data collected by the HOBO Level Loggers was converted to water level data, which was calibrated using a staff gauge installed underneath the bridge directly upstream from the WSC stilling well on Rosemount Road. To convert water level data to flow data, the latest WSC stage-discharge curve for the Sturgeon River was updated using stream gauging via a Valemont electromagnetic flow sensor.

Water Quality Monitoring Program. Water quality data collected in this study

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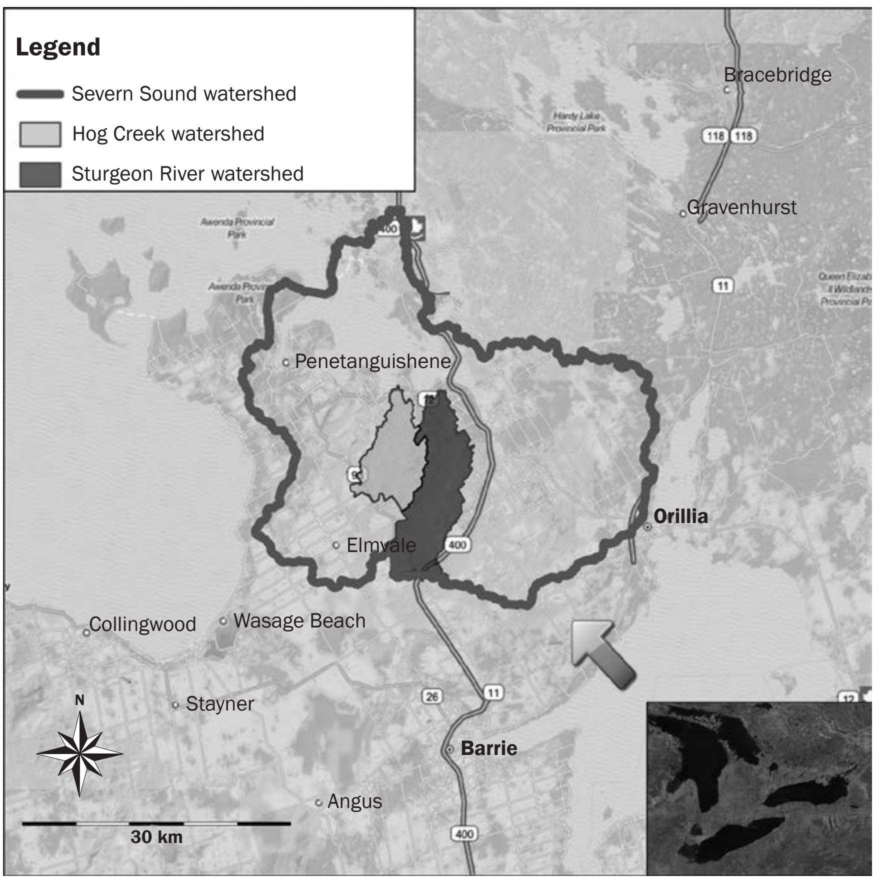
Table 1
Land use comparison using census data for pre-best management practices (BMP) versus post-BMP period.

	Row crops (km^2)			Hay/pasture (km^2)			Total area of farms (km^2)		
County	1996	2001	Change (%)	1996	2001	Change (%)	1996	2001	Change (%)
Springwater	195	207	5.5	35	26	–32.0	269	278	3.2
Oro-Medonte	140	159	11.5	48	44	–7.9	250	255	1.9
Tiny	51	57	11.0	15	14	–8.0	91	90	–1.5
Tay	27	24	–11.4	11	11	1.1	53	48	–10.4
Total	415	448	7.4	110	97	–13.6	665	672	1.1

Figure 1
Severn Sound watersheds (SSEA 2010).



utilized both an instantaneous sampler (open bottle sampler) and isokinetic sampler (DH-48) to compare both techniques. Samples were taken during or within 24 hours of a rain event. The instantaneous sampler used in the field investigation was a standard 0.5 L (16.9 oz) open sample bottle used by the Ministry of the Environment for the Provincial Water Quality Monitoring Program in Ontario. The isokinetic sampler used for this study was the DH-48, which is a rod-suspended sampler that has an aluminum casting that partially encloses a 0.5 L rigid plastic sample container. Samples were analyzed at the University of Guelph's Environmental and Water Laboratories according to the US Environmental Protection Agency (USEPA) standard outlined in technical document 160.2 (Guo 2008). Samples were filtered through 0.45 µm cellulose fiber filters, and residual fines were washed onto the filter paper from the pump apparatus with distilled water. Filtered samples were oven dried for one hour at 105°C (221°F) and reweighed on an analytical balance according to the USEPA standard outlined in technical document 160.2 (Guo 2008).

Best Management Practices Sediment Removal Efficiency. Based on a comprehensive list of conservation management practices found in the Canada–Ontario Farm Stewardship program, a detailed review of the literature was examined from both composite and individual literature sources. The BMPs were reviewed for their effectiveness for reducing loads of pollutants commonly found in freshwater streams.

The findings of all the literature were synthesized into simple tables for easy comparison and future application. Table 2 shows the results of the BMP literature review and summarizes the known sediment removal efficiency for 25 types of BMPs found to improve water quality.

The results from the literature review (table 2) show that a higher mean or median value for each BMP represents greater ability to reduce sediment, while a lower mean or median value indicates that the BMP is less effective at reducing a particular pollutant.

Development of Sediment Rating Curves. Sediment rating curves are empirical relations between water discharge (independent variable) and sediment concentration or sediment load (dependent variable). Sediment rating curves can be created for instantaneous, daily, monthly, seasonal, annual, or event-based data and are often developed from logarithmically transformed data. The sediment rating curve is thus expressed as a linear or nonlinear power function based upon the stream's characteristics (Equation 1; Glysson 1987):

$$Q_s = a\, Q_w^{\,b}, \qquad (1)$$

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Table 2
Published best management practices (BMP) sediment removal efficiency mean (median).

BMP	Sediment removal efficiency mean (median)	Source material
No-tillage	92 (85)	*Merriman et al. 2009; *Dinnes 2004; *DPRA Inc. 1989; *Yagow et al. 2002; Bryant et al. 2008; *Cook 1999; *Schnepf and Cox 2006.
Diversion channels/runoff control	83 (68)	*SERA 17 2009; *Cook 1999; *Merriman et al. 2009; *Dinnes 2004; *DPRA Inc. 1989; *Pennsylvania State University 1992; *Yagow et al. 2002; *Ghebremichael and Watzin 2008.
Wetland habitat restoration	80 (80)	*SEPA 2010; *Merriman et al. 2009; *Dinnes 2004; *Yagow et al. 2002.
Sediment control basins	76 (75)	Boyer 2006; *Cook 1999; *DEPRA Inc. 1989; *Yagow et al. 2002; *SEPA 2010.
Vegetative buffer strips	74 (69)	*Cook 1999; *SERA 17 2009; *Schnepf and Cox 2006; Mikkelsen and Gilliam 1995; Daniels and Gilliam 1996; Patty et al. 1997; Robinson et al. 1996; Heathwaite 1998; *SWCS 2008; *Merriman et al. 2009; *Dinnes 2004; *SEPA 2010; *Ghebremichael and Watzin 2008; *Gitau et al. 2005; Boyer 2006; *Wenger 1999; *Melcher and Skagen 2005.
Relocation of livestock	70 (70)	*Dinnes 2004; Lugbill 1990; Meals 2001 *SEPA 2010.
Ditch bank/gully stabilization	70 (59)	*Merriman et al. 2009; *Cook 1999; *DPRA Inc. 1989; *SEPA 2010; *SWCS 2008; *Yagow et al. 2002.
Terraces	65 (61)	*SERA 17 2009; *Merriman et al. 2009; *DPRA Inc. 1989; *SEPA 2010.
Wastewater treatment	64 (64)	*SEPA 2010.
Conservation tillage	55 (56)	*SERA 17 2009; *Cook 1999; *SWCS 2008; *Merriman et al. 2009; *Dinnes 2004; *DPRA Inc. 1989; *Yagow et al. 2002; Bryant et al. 2008; *Ghebremichael and Watzin 2008; *Gitau et al. 2005.
Streambank fencing	40 (47)	*Schnepf and Cox 2006; *Cook 1999; *SWCS 2008; *Merriman et al. 2009.
Alternative water source	39 (49)	*Schnepf and Cox 2006; *SWCS 2008.
Cover crops	35 (44)	*Merriman et al. 2009; *Dinnes 2004; *Yagow et al. 2002; *SEPA 2010; *SWCS 2008; *Schnepf and Cox 2006.
Reforestation	14 (27)	*Merriman et al. 2009; SWCS 2008.
Improved manure spreading	10 (10)	*Merriman et al. 2009; *Dinnes 2004.

Notes: Not all of the data used in this table are from Ontario studies. N/A = Not applicable.
*Indicate sources that included synthesis, evaluation, or reporting of multiple studies or documents.

where Q_s is suspended sediment discharge (t d^{-1}), Q_w is water discharge (m^3 s^{-1}), a is scaling factor, and b is exponent.

The sediment rating curve is often developed for sites with long-term record of stream flow measurements. One common use of sediment rating curves is to generate power equations to estimate unknown daily sediment loads between sampling intervals and determine monthly or annual sediment loads (Livesey 1975). Figure 2 presents a sample of a few sediment rating curves for Ontario watersheds. Sediment rating curves for Hog Creek and Sturgeon River were created using measured stream flow and sediment data. These data sets were used by combining stream flow with sediment concentration to calculate the total sediment load for the sample. Sediment rating curves for the instantaneous and isokinetic sampler were evaluated separately to analyze the periods before and after BMPs were implemented. Monthly sediment rating curves were also derived from daily values from the power equations for all of the combined data for each period. The equation from the line of best fit was used to compute daily sediment load and the average of each month was used to create an average monthly value.

Hydrologic Model Development. The main limitation of the new technique for the assessment of the overall long-term water quality benefits of conservation management practices is the required streamflow and water quality monitoring data from pre- to post-BMP periods to determine the shift in the sediment rating curves. For watersheds with limited monitoring data, it is common practice to develop and calibrate/validate a watershed-scale water quality model (e.g., SWAT, AGricultural Non-Point Source Pollution [AGNPS], Hydrological Simulation Program–Fortran [HSPF], or Canadian Nutrient and Water Evaluation Tool [CANWET]) to fill-in monitoring data gaps (if necessary) and validate the observed trends using simulated data. In this study we have selected CANWET model, as it is a Canadian model that is easier to setup due to compatibility with Canadian data sets (Das et al. 2008; Rudra et al. 2010; Singh et al. 2012; Ahmed et al. 2013; Chapi et al. 2014; Liu et al. 2015a).

The CANWET model is an empirical semidistributed model for surface water and solid-phase sediment and nutrient loadings, which means it combines multiple land use/cover scenarios (Greenland 2007). Input parameters used to calculate watershed hydrology and erosion are area-weighted calculations created by clipping the land use, soils, and topography geographical information system (GIS) layers. CANWET model predicts a continuous streamflow using the daily weather data based on the water balance

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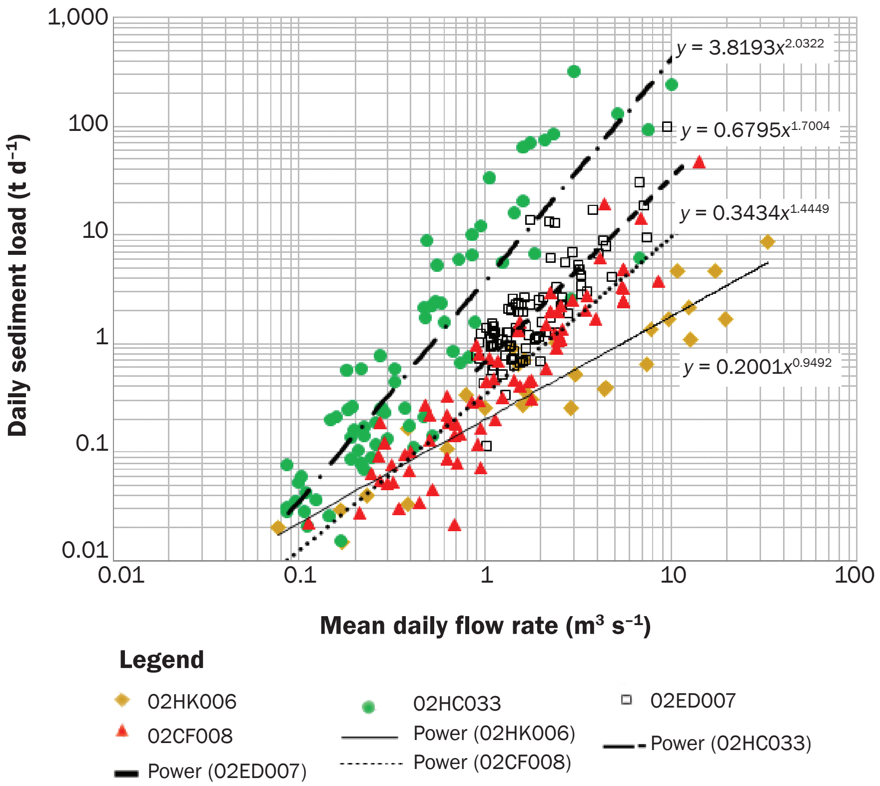
Figure 2
Sample sediment rating curves for Ontario watersheds.



calculations. The surface runoff is calculated using SCS curve number approach.

The model uses the universal soil loss equation (USLE; Wischmeier and Smith 1965) for soil erosion calculation. Evapotranspiration is determined by the Hamon method (1961), using daily weather data and land use cover factor. The model computes the daily water balance for both unsaturated and saturated zones. The infiltration is simply calculated as the precipitation minus surface runoff and evapotranspiration. CANWET model is also a lumped model for lateral groundwater discharge and dissolved-phase nutrient loadings. Surface loadings of runoff, sediment, and solid-phase nutrients are generated for each source area and aggregated to determine watershed totals.

Lateral groundwater discharge and dissolved phase loadings are lumped for the entire watershed. There is no internal spatial routing routine as water quality loads from each land use layer are aggregated to present a total watershed load; although, this functionality has been added with later versions. Output results are presented daily for streamflow, whereas results for hydrology, erosion, and sediment/nutrient loads are produced on a monthly basis. CANWET model was calibrated/validated for both pre- and post-BMP periods (1989 to 1993 and 2004 to 2008). For this reason the first three years of each BMP period were selected for calibration (1989 to 1991 and 2004 to 2006). The remaining two years of data for each BMP period were served as validation periods (1992 to 1993 and 2007 to 2008).

Results and Discussion

Sediment Loads Removal Efficiency. The overall sediment loads removal efficiency for BMPs applied within the Hog Creek and Sturgeon River watersheds are presented in table 3. The BMP removal efficiency were applied to the study watersheds utilizing the data from the literature (table 3) to both the Hog Creek and Sturgeon River. The results are compared for two periods of before (1989 to 1993) and after (2004 to 2008) BMPs implementation. It is evident that stream bank fencing was widely applied and thus greatly influenced the overall removal in sediment loads (table 3).

Stream bank fencing was applied to control sediment load to many of the streams that intersected with agricultural lands containing livestock, thus producing an estimated overall sediment removal efficiency of 28.4% for Hog Creek and 28.8% for the Sturgeon River. The vegetative buffer strips were found to be the second effective BMP followed by ditch bank/gully stabilization for Hog Creek. For Sturgeon River, ditch bank/gully stabilization was the second best practice followed by vegetative buffer strips for sediment load. No-tillage has the highest sediment removal efficiency (92%), although this was not widely applied from pre-BMP to post-BMP period due to technical challenged that it posed for the growers and thus the overall sediment removal contribution due to this BMP in this period was just 5%.

Sediment Rating Curves. The sediment rating curves for both Hog Creek and Sturgeon River watersheds are presented in figures 3 and 4. The amplitude (scaling factor) from the sediment rating curve using the power equation was greatly reduced during the post-BMPs period (2004 to 2008) when compared with the pre-BMP period (1989 to 1993).

Canadian Nutrient and Water Evaluation Tool Simulation Results—Monthly Sediment Load Simulations. CANWET model was calibrated and validated to adequately simulate sediment loads. The simulation results of monthly sediment loads during the calibration and validation periods are presented in figures 5 through 8.

In general, the results indicate a close agreement between the observed and simulated sediment loads during both calibration and validation periods in Hog Creek and Sturgeon River watersheds. However, the model underestimated the sediment loads during the March and April snowmelt events of the year 1990 in both Hog Creek and Sturgeon River watersheds. The streamflow under-prediction by the model can be attributed to error in precipitation data. The performance of the model to simulate stream flow for the calibration and validation periods was further examined by using statistical criteria. The statistical indices for the comparison of monthly observed and simulated flows are presented in tables 4 and 5.

Based on the statistics, the model accurately represents the sediment loads for both watersheds and for both BMP periods. The model performed better for the post-BMP

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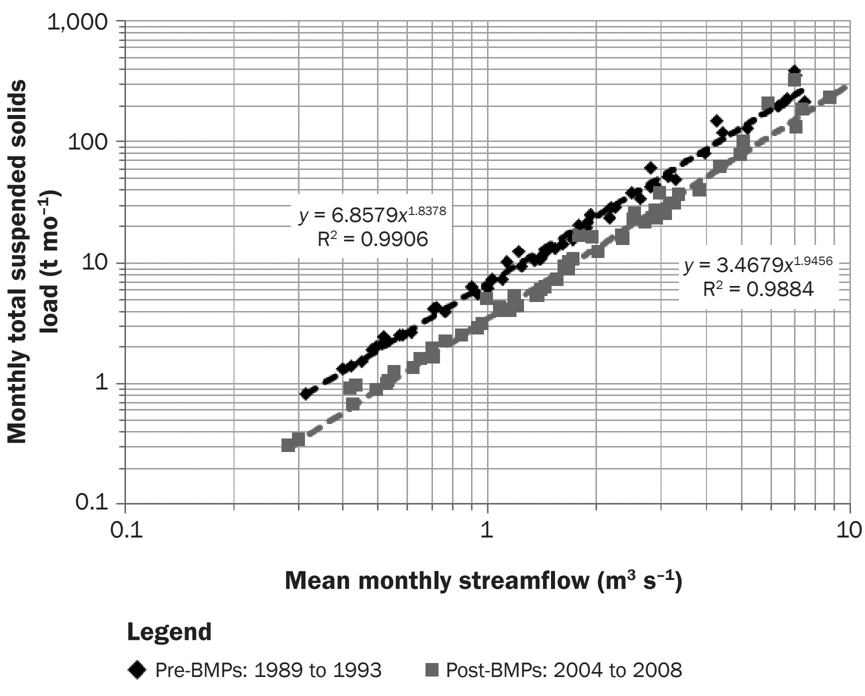
Table 3
Overall sediment load removal efficiency for best management practices (BMPs) applied within the Hog Creek and Sturgeon River watersheds from pre-BMP (1989 to 1993) to post-BMP (2004 to 2008) period.

		Hog Creek			Sturgeon River		
BMP	BMP sediment removal efficiency (%)	BMPs applied pre-BMP period (1989 to 1993; %)	BMPs applied post-BMP period (2004 to 2008; %)	Overall sediment load removal from pre to post (%)*	BMPs applied pre-BMP period (1989 to 1993; %)	BMPs applied post-BMP period (2004 to 2008; %)	Overall sediment load removal from pre to post (%)*
Cover crops	33	10	11	0.3	10	11	0.3
Stream bank fencing	40	20	91	28.4	20	92	28.8
Reforestation	14	N/A	7	1	N/A	5	0.7
Vegetative buffer strips	74	N/A	11	8.1	N/A	8	5.9
Ditch bank / gully stabilization	70	11	20	6.3	11	20	6.3
No-tillage	92	7	12	4.6	7	12	4.6
Conservation tillage	55	11	19	4.4	11	19	4.4
Total				53.2			51.1

*Calculated by (increase in BMPs applied from pre- to post-BMP Period) × (BMP sediment removal efficiency) for Hog Creek and Sturgeon River.

Figure 3
Sediment rating curves for Hog Creek for the pre-best management practice (BMP) and the post-BMP periods.



period for both watersheds for sediment. The statistical coefficients show that the model performed slightly better in the calibration period than in the validation period.

Summary and Conclusions

This study presents a novel method for quantification of the overall long-term water quality benefits of conservation management practices (i.e., reduction in sediment loads) within a watershed by quantifying the shift in the sediment rating curves from pre-BMP to post-BMP implementation periods. Watershed modeling was also performed for the pre- and post-BMP periods using CANWET model. The models performed well when compared both statistically and graphically with observed data. The average monthly simulated results had almost the same overall sediment reduction efficiency as calculated using the shift in sediment rating curves. However, it is much faster and easier to calculate the overall long-term water quality benefits of conservation management practices using the proposed new method compared to the time-consuming and advanced experience required for proper watershed-scale water quality modeling using SWAT, AGNPS, HSPF, or CANWET models (Das et al. 2008; Rudra et al. 2010; Singh et al. 2012; Ahmed et al. 2013; Chapi et al. 2014; Liu et al. 2015a).

However, the main limitation of the new technique for the assessment of the overall long-term water quality benefits of conservation management practices is the required streamflow and water quality monitoring

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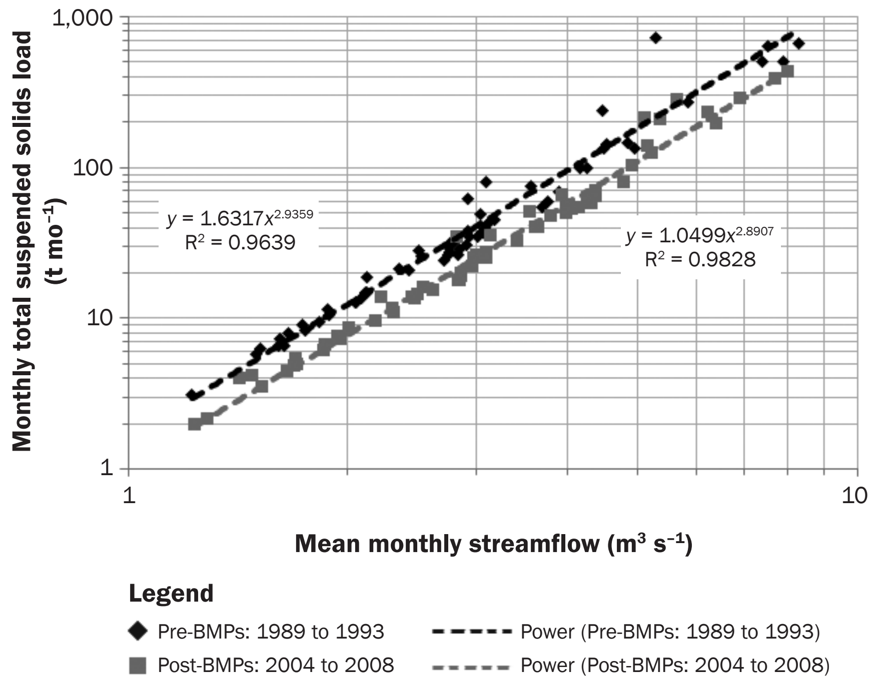
Figure 4
Sediment rating curves for Sturgeon River for the pre-best management practice (BMP) and the post-BMP periods.



data from pre- to post-BMP periods to determine the shift in the sediment rating curves. Minimum two years of continuous daily streamflow monitoring and at least 30 water quality grab sampling during a wide range of flow rates is needed for each of the pre- and the post-BMP periods to develop reliable sediment rating curves. For ungauged watersheds with limited monitoring data, watershed-scale water quality modeling (using SWAT, AGNPS, HSPF, or CANWET) can be used to fill-in data gaps.

Since both the land use and climate had changed negligibly from pre-BMP to post-BMP periods, it was concluded that more than 40% reduction in the sediment loads in these two watersheds was the direct result of (and solely due to) the implementation of the numerous BMPs by local residents, growers, and the SSEA, and thus the amount of sediment loads entering the receiving waters and for the Severn Sound region to become delisted as an AOC on the Great Lakes.

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Figure 5
Hog Creek monthly sediment load (a) calibration and (b) validation for pre-best management practice (BMP) period (1989 to 1993).

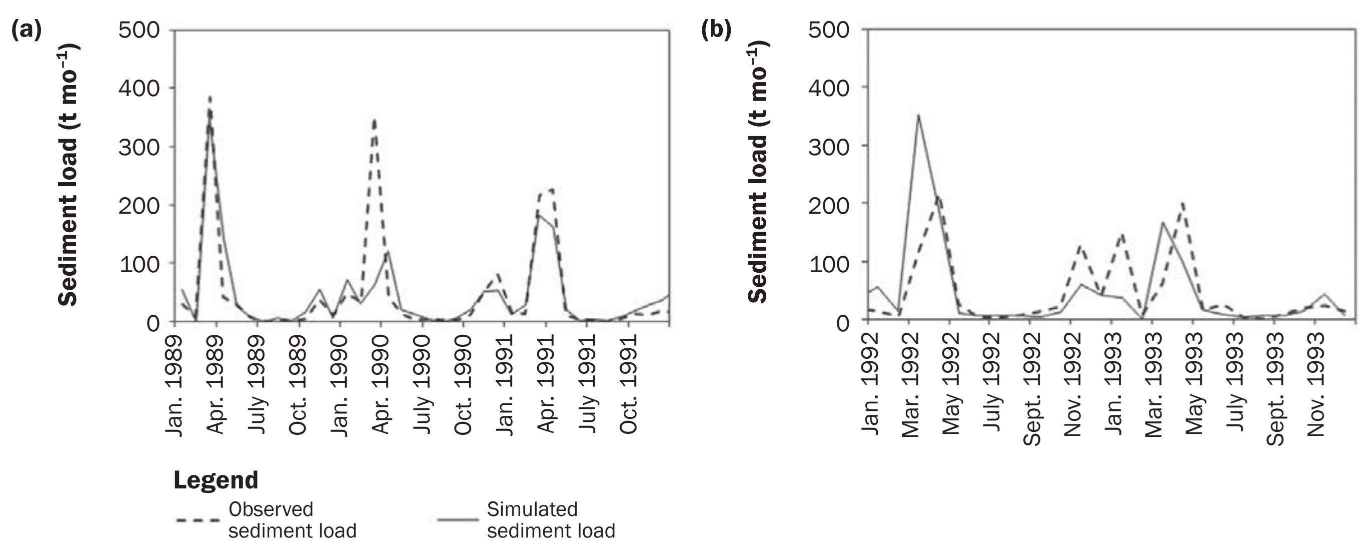

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Figure 6
Hog Creek monthly sediment load (a) calibration and (b) validation for post-best management practice (BMP) period (2004 to 2008).

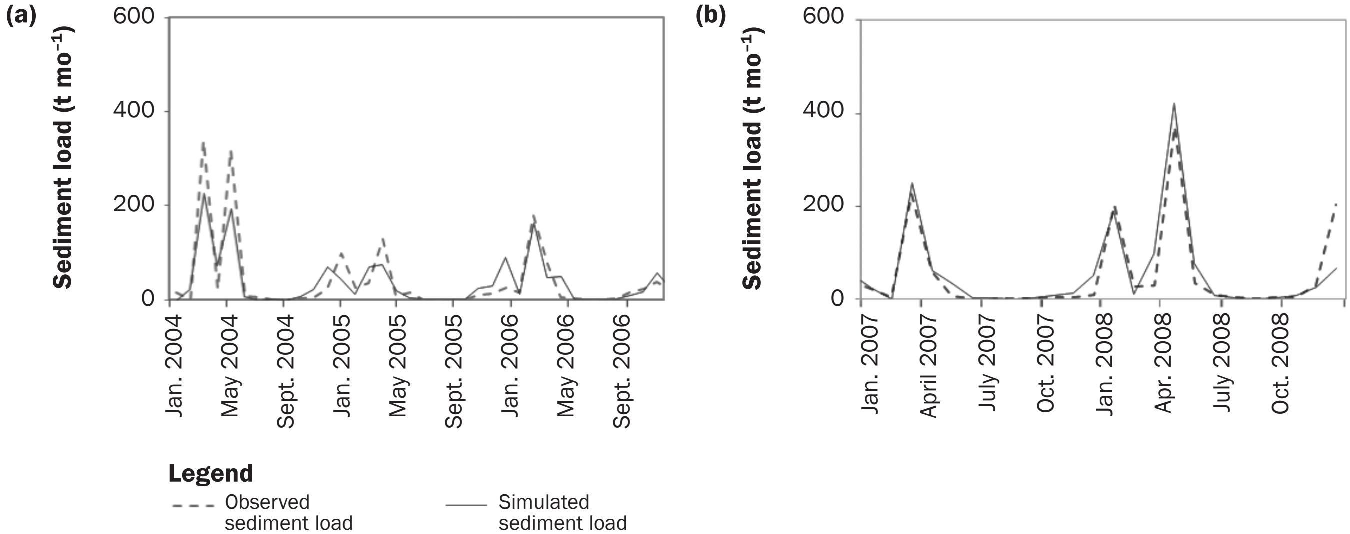

Figure 7
Sturgeon River monthly sediment load (a) calibration and (b) validation for pre-best management practice (BMP) period (1989 to 1993).

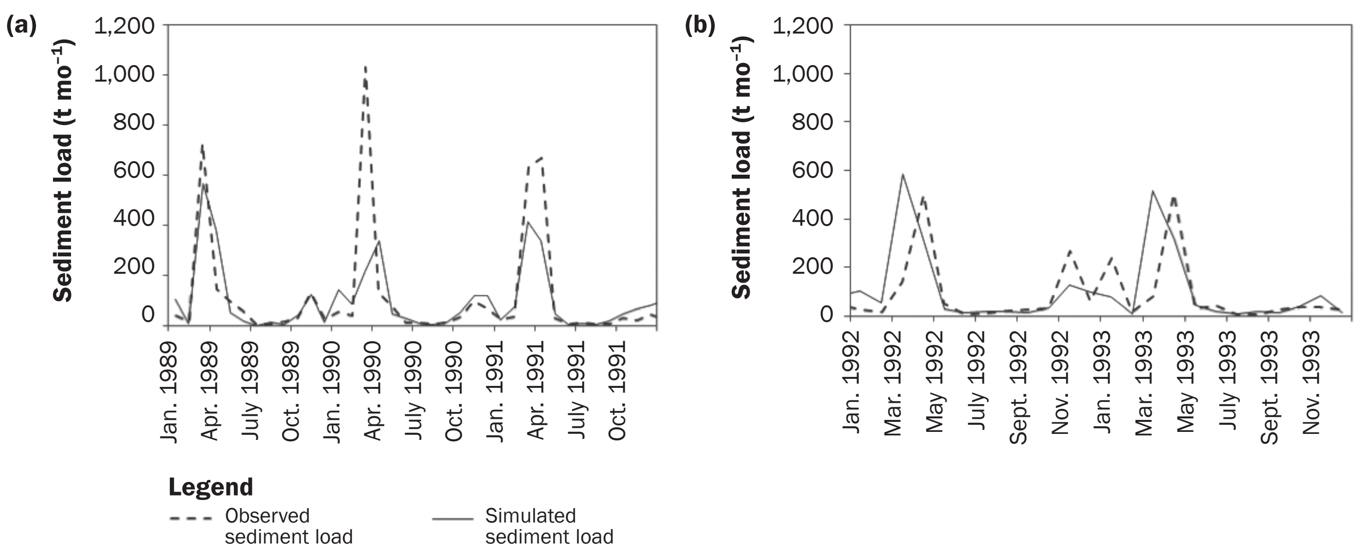

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Figure 8

Sturgeon River monthly sediment load (a) calibration and (b) validation for post-best management practice (BMP) period (2004 to 2008).

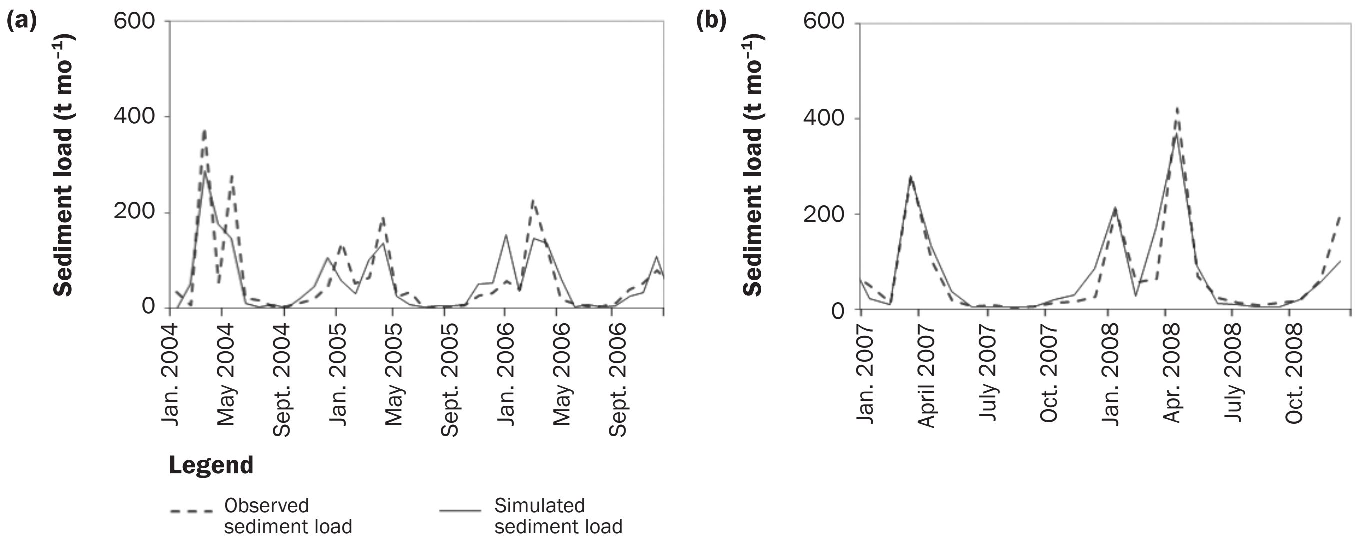

Table 4

Statistical coefficients or measures for model evaluation and their range of variability.

Coefficient or measure	Equation	Range
Coefficient of determination	$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right]^2$	0 to 1
Root mean square error	$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$	0 to ∞
Index of agreement (Willmout 1984)	$D = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(\lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}$	0 to 1

Note: n = number of observations. O_i and P_i = observed and predicted values at the time step i. $\bar{O}$ and $\bar{P}$ = mean of observed predicted values at the time step i.

Table 5

Canadian Nutrient and Water Evaluation Tool (CANWET) model statistics for monthly streamflow and sediment load.

		Streamflow (m^3 s^{-1})				Sediment load (t mo^{-1})			
		Pre-BMP		Post-BMP		Pre-BMP		Post-BMP	
Watershed	Statistical coefficient	Calibration	Validation	Calibration	Validation	Calibration	Validation	Calibration	Validation
Hog Creek	R^2	0.79	0.74	0.91	0.96	0.80	0.63	0.91	0.93
	RMSE	1.27	1.48	1.02	1.80	0.06	0.06	0.04	0.04
	D	0.88	0.98	0.95	0.98	0.87	0.76	0.91	0.96
Sturgeon River	R^2	0.70	0.71	0.73	0.87	0.74	0.53	0.83	0.93
	RMSE	1.54	1.45	1.45	2.12	0.16	0.15	0.05	0.04
	D	0.81	0.98	0.82	0.98	0.77	0.69	0.89	0.96

Notes: BMP = best management practices. RMSE = root mean square error. D = index of agreement. R^2 = coefficient of determination.

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