2006

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Krause, Tony Dean; Stansbury, John S.; Dvorak, Bruce I.; and Admiraal, David M., "Stormwater Best Management Practices Assessment for the City of Lincoln, Nebraska" (2006). *Civil Engineering Faculty Publications*. 120.
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Stormwater Best Management Practices Assessment for the City of Lincoln, Nebraska

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Abstract

The objective of this research was to assess BMP performance and implementation in Lincoln, Nebraska. In order to accomplish this objective, four tasks were established: sampling of stormwater runoff at eight sites located upstream of Holmes Lake, inspecting BMPs at construction sites in Lincoln, sampling and analysis of soil phosphorus levels in the Holmes Lake watershed, and conducting discussions with professionals involved with stormwater management in Lincoln. Based on the information collected during these tasks, several recommendations regarding the BMP assessment process are made including: recommendations for sampling site selection, an inexpensive flow monitoring method, and a rapid construction site BMP assessment protocol.

Introduction

In response to the 1987 Clean Water Act amendments, states and municipalities have developed programs to address non-point source pollutants in stormwater under the existing NPDES program. Stormwater management is accomplished through the use of best management practices (BMPs). Assessment of BMPs is a necessary process in the development of more effective programs aimed at controlling non-point source pollution in stormwater drainage. This paper summarizes the BMP assessment process for the City of Lincoln, Nebraska in 2004 and 2005. The aim of this paper is to show the methods used for runoff sampling, construction site inspections, soil phosphorus evaluation, and professional discussions in the assessment.

Methods: Runoff Sampling

Site Selection

Runoff was collected and analyzed from eight sampling sites in the Holmes Lake watershed for ten runoff events. This sampling provided data that was used to calculate annual loadings of pollutants in the Holmes Lake watershed. One common method of sampling used for BMP assessment is to collect samples directly upstream and downstream of a specific BMP. This type of sampling provides information regarding the effectiveness of a specific BMP application. However, BMP effectiveness is highly dependent on proper installation and operation and is, therefore, variable; thus this type of sampling is only moderately useful in assessment of an overall BMP program.

Instead, it was decided to sample downstream of suites of BMPs serving a particular land use (e.g. residential, construction). This allowed investigation of pollutant loading to water bodies while still allowing investigation of different land uses and suites of BMP applications. This led to selection of subwatersheds of less than a half square mile. The evaluated land uses include residential areas, commercial areas, residential construction areas, and one site that was in transition from an agricultural to a commercial area.

All sites were selected upstream of Holmes Lake because Holmes Lake is a 303d listed impaired water body, and because it put all the sampling sites in a relatively close area. Since grab sampling techniques were used, it was necessary that sampling sites be close enough that travel time between sites be minimized.

Since flow data was necessary for compositing of samples, it was decided to sample at sites where a relationship between the flow depth and the flow rate could be established. This led to areas where either critical flow was established or where uniform flow was approximated. Although there are other techniques to measure flow, the use of critical and normal flow calculations is the least expensive, and is adequate for estimating stormwater flow rates.

Sampling

Manual sampling was used to collect samples. The sampling protocol developed was similar to that outlined by Burton and Pitt (2002). Dipper samplers were used to collect samples according to ASTM D5358-93. Additionally, biological sampling was conducted in accordance with ASTM Standards on Environmental Sampling. This method of grab sampling used an extended pole with a mounted collection cup (dipper sampling). A team of four to six samplers was mobilized from a group of approximately twelve samplers during each sampling event. Typically this team would be split into two groups, each collecting samples from four of the eight sites. Samples were collected from each site approximately every forty-five minutes throughout the runoff events.

During sampling, depth measurements were taken, and pH and temperature were tested in the field. Following sampling events, samples were preserved and transferred to cold storage.

Precipitation Measurements

Precipitation data was collected with a 0.0254 cm tipping bucket recording rain gage placed near the center of the sampling sites. The rain gage recorded precipitation data as 15-minute totals. A secondary source of data was through the High Plains Regional Climate Center (HPRCC). The nearest rain gauge maintained by the HPRCC was located approximately 0.8 km from the sampling sites. HPRCC precipitation data was used to estimate the rainfall before the primary gauge was turned on, and when the primary gage did not function properly.

Flow Estimation

Where possible, flows were estimated using critical flow hydraulic relationships (e.g., weir equations). Where critical flow conditions did not occur, uniform flow relationships were used. In all cases, depth was measured at intervals throughout the runoff event. The depth measurements were used to estimate flow using the appropriate relationships. These depth-based flows were used to calibrate hydrologic models of the watersheds, which were used to develop hydrographs for the sampled runoff events. Runoff hydrographs were developed for each sampling site using the Soil Conservation Service (SCS) method, applying lagged 15-minute unit hydrographs. A similar hydrologic method was described by Dent et al. (2001) for flow measurement of wet weather flows.

Sample Compositing

There are two typical methods of sample compositing: flow-weighted or time-weighted compositing. In flow-weighted compositing, the time interval between sub-samples is held constant, and the volume of each sub-sample in the composited sample is proportional to the flow at the time the sub-sample is taken. With time-weighted sampling, the sampler must monitor the flow through time, calculating the total amount of runoff passing the sampling point, and sub-samples of equal volumes are taken after a preset amount of runoff passes the sampling point (ISCO, 2001). Flow measurements were not available until after each sampling event, and constant time intervals were not maintained through sampling. Therefore, a modified version of the flow-weighted compositing process was used. After flow rates were determined as a function of time, aliquots were taken from each discrete sub-sample and combined proportionally to the volume of water they represented in the composite sample.

Chemical/Biological Analysis

Samples were tested for pH and temperature in the field. Laboratory sampling included total suspended solids (TSS) Standard Methods (Clescerl et al., 2004) 209c, nitrates (NO_3) EPA Method 353.2, total Kjeldahl nitrogen (TKN) EPA Method 351.3, reactive phosphorus (PO_4) EPA Method 365.2, total phosphorus (TP) EPA Method 365.2, and hexane extractable material (HEM) EPA Method 1664A-SPE. Biological analysis included fecal Streptococcus (FS) EPA Method IIID.2, total Streptococcus (TS) Standard Methods 9223-QT, fecal Coliform (FC) Standard Methods 9223-QT, and total Coliform (TC) Standard Methods 9223-QT.

Data Analysis

Event loadings were calculated by multiplying the event mean concentrations by the total runoff volume. Annual loadings were calculated using the USEPA simple method which applies a runoff concentration over the entire watershed (Schuler, 1987). These loadings were compared with loadings reported by other agencies (LPRD, 2003), the loadings expected based on the 1983 NURP report (USEPA, 1983), and the TMDL established for Holmes Lake (NDEQ, 2003).

Comparisons of the loadings per unit area from different land uses were also made. For example, construction activities typically generate elevated sediment loads. By analyzing the loads from areas with construction activities and comparing them to loads from developed areas, an assessment of construction site controls was made.

Methods: Construction Site Inspections

Rationale

Construction site visits were conducted to assess the level and quality of BMP implementation on construction sites in Lincoln. Two sets of site visits were conducted, with the first series of visits occurring in September of 2004, and the second in April and May of 2005. Each site was visited one time. The objective was not to evaluate any specific site through time but rather to evaluate implementation of construction site BMPs on a city-wide basis. Sites were selected from recently submitted and approved Storm Water Pollution Prevention Permits (SWPPP) permits.

Development of Metric for Assessment

In order to look objectively at construction site BMPs, a simple metric tool was developed. The metric developed was based on the "OhioEPA Construction Site Inspection Checklist" (OhioEPA, 2003). The metric included evaluation of five BMP categories: stabilization, sediment tracking control, ponds, linear controls, and inlet protection. The evaluated categories of BMPs are similar to the list of the five common BMP types discussed by Lee (2000). Non-sediment controls were not assessed as that would involve investigating spill prevention and control plans in the SWPPP permits. Wind erosion controls were not assessed as typical applications are temporary. The metric provided a simple measure of the BMPs that were present at the site and an assessment of their condition at the time of the visit. The metric was not used to compare BMPs at a site

Figure 1: Metric for the Assessment of Sediment Tracking Practices

with the SWPPP plans. Use of the metric did require a basic knowledge of construction site BMP types, their function, and their minimum requirements.

Figure 1 shows the metric developed to assess sediment tracking controls. Similar metrics were developed for each of the five BMP categories. A score of zero indicates the complete lack of controls; a score of one-half indicates controls in place but not functional at the time of the visit; a score of one indicates a proper application; and a score of not applicable indicates the BMP was deemed not necessary.

Methods: Soil Phosphorus Evaluation

Because phosphorus loadings are responsible for the impairment of Holmes Lake, an investigation into the potential need for additional BMPs to limit phosphorus loadings was conducted. Ten to twenty soil samples were collected from each of ten sites in the Holmes Lake watershed, representing seven residential lawns, and three open areas. Soil samples were taken using a soil probe from the top 15 cm of soil. One composite sample was created for each of the ten sites. Samples were tested for organic matter (Walkley Black), phosphorus (Weak Bray, Strong Bray, Bicarbonate), and pH. Tests were conducted in accordance with NCR013 recommendations.

Recommended fertilizer application rate information was collected from literature (Rosen et al., 2004; Harms et al. 2004) and from the testing laboratory for each sample. Information on commercially available lawn fertilizer application rates was collected from Earl May. Most literature recommendations for fertilizer application are designed for optimal crop production or turf vigor rather than to avoid environmental impacts (Hoeft, 2001). However, "Soil Test Interpretations and Fertilizer Management for Lawns, Turf, Gardens, and Landscape Plants" from the University of Minnesota Extension does take into account environmental concerns (Rosen et al., 2004).

Methods: Stormwater Professional Discussions

Discussions were held with professionals involved with stormwater management in Lincoln. Participants included representatives from government agencies, engineers, contractors, developers, lawyers, and regulatory representatives. The objective of these discussions was to compile and evaluate comments and criticism on the existing stormwater management program from those involved.

Results and Conclusions: Runoff Sampling

The averages of the event mean concentrations from ten sampling events at each site are provided in Table 1. The samples were collected between August 2003 and June 2004. Sites were selected to represent different land uses. Sites D, E, F and G were located in a developed residential area. Site H was in a commercial construction area. Site I became inaccessible during sampling and results are not presented; Sites J and K were in a residential construction area.

Annual loads were estimated from the average event mean concentrations using the USEPA Simple method (Schuler, 1987). These loads were compared with other measured and calculated loadings reported in the Holmes Lake watershed and with the waste load allocations developed for the established TMDL.

Table 1: Average Event Mean Concentrations of Total Suspended Solids and Nutrients at Seven BMP Sampling Sites (mg/L).

Land Use	Developed Residential				Commercial Construction	Residential Construction	
Site	D	E	F	G	H	J	K
TSS	20	103	112	123	222	409	651
Nitrate	1.37	3.76	4	4.4	5.1	5.54	6.82
TKN	1.43	2.05	1.97	1.92	1.68	2.23	2.92
Reactive Phosphorus	0.4	0.38	0.51	0.49	0.2	0.33	0.52
Total Phosphorus	0.61	0.76	0.86	0.92	0.56	0.79	1.02

* Sites D and E represent retention basin effluent and influent respectively, sites J and K represent detention basin effluent and influent respectively

Figure 2 is a loading comparison (annual loads have been converted to annual yields by dividing by the subwatershed area). The figure compares (in general descending order) the existing loading reported in the TMDL report (established using EUTROMOD modeling), the loads calculated in this study, the loads expected using the USEPA simple method in connection with the results of the 1983 NURP report, the loading reported in the Community Based Watershed Management Plan (LPRD, 2003), and the waste load allocation (WLA) established by the TMDL.

Figure 2: Annual Yields of Total Phosphorus

Figure 3: Annual Yields of Total Suspended Solids

Figure 2 shows the measured loads are bracketed by measured/modeled loadings reported in other studies for Holmes Lake; it also shows the measured loads significantly exceed the established TMDL.

Figure 3 compares the loadings for total suspended solids. In this figure it is notable that three measured loads from this study exceed the reported recent loads (based on reservoir capacity loss studies). Holmes Lake has recently been dredged due to heavy loads of sediment that are believed to have been generated while much of the Holmes Lake watershed was under construction. Each of the three sites with elevated yields was under construction at the time of sampling. It is also notable that measured loads for this study are below the established TMDL for sediment in Holmes Lake.

During runoff sampling, data was collected from the inlets and outlets of a stormwater retention basin and a stormwater detention basin. The retention basin was located between Sites D and E (flowing from E to D); the removal efficiencies for this facility are presented in Figure 4. At this facility promising results were seen for removal of all pollutants except total phosphorus. This is unfortunate as phosphorus is the primary pollutant leading to impairment of Holmes Lake.

The detention basin was located between Sites J and K (flowing from K to J). The removal efficiencies for this facility are presented in Figure 5. At this facility, limited performance was seen. The lack of performance was likely due to the design of the structure. Early in the study a channel had developed between the inlet and outlet reducing overland flow. Later in the study a concrete liner was installed in the basin creating the same effect. An evaluation of peak flows was made at three sites where critical flow conditions were present. Peak flows were compared with pre-developed peak flows estimated using hydrology. A nearly 100% increase in peak flows was witnessed at all sites. The City of Lincoln requires matching of the peak flows for the 2, 5, and 10-year events. Although there was a ~100% increase in the peak flow during sampled events, all events sampled and compared were smaller than the 2-year event; thus the increase in

Figure 4: Performance of Retention Basin between Sites D and E

**Literature values were taken from the EPAs Menu of BMPs (USEPA, 2004)*

**Removal efficiencies based on reduction of calculated annual loads*

Figure 5: Performance of Detention Basin between Sites J and K

peak flows may be expected. Similar results were reported for smaller events via modeling efforts by Emerson et al. (2005).

Results and Conclusions: Construction Site Inspections

Figure 6 shows the site scores for all of the visited construction sites. It shows a relatively even distribution of scores.

Figure 6: Site Scores from Construction Site Inspections

Construction activities were divided into three categories: general construction, residential construction, and commercial/industrial construction.

Figure 7 shows the average score for each type of BMP for each category of construction. Notable points in this figure include the low scoring of stabilization practices in residential construction, and of inlet protection in commercial construction, as well as a generally low score for sediment tracking controls for all types of construction.

Figure 7: Average Scores for BMP Implementation by Types of Construction by Type of BMP

Results and Conclusions: Soil Phosphorus Evaluation

Table 2 summarizes the average results of soil phosphorus testing done in the Holmes Lake watershed and the resulting fertilizer application recommendations from Midwest Labs (MWL), The University of Minnesota Extension, and the University of Nebraska Extension. The MWL recommendations and the University of Nebraska recommendations are designed primarily to provide lush turf without consideration of environmental impacts. The University of Minnesota recommendations do consider environmental impacts. If these application rates are compared with commercially available fertilizer application rates (which are typically used without soil phosphorus testing) an excess of phosphorus application may occur. The Earl May lawn program, which provides 2.42 kg P₂O₅ /1000m²-yr without regard to soil phosphorus levels, was used to represent typical phosphorus application of commercially available fertilizer. To evaluate potential phosphorus loadings to Holmes Lake, it was assumed that 40% of the watershed area is fertilized (total watershed size = 15.5 km², fertilized watershed = 6.2 km²). Using the Earl May application rate, annual application of commercially available fertilizer exceeds recommendations (compared with the recommendations of the University of Minnesota Extension) by 9101 kg

P_2O_5 /yr across the watershed, which converts to a loading of phosphorus of 3975 kg/yr. This estimated application rate is comparable to those recommended by the UNExtension and MWL. Since these latter two recommendations were designed primarily to promote turf growth without consideration for environmental impact, it is likely that the current application rates are leading to degradation of aquatic systems.

Table 2: Average Soil Phosphorus Levels and Fertilizer Application Recommendations

Average Soil P Level (Weak Bray, or Bicarbonate when Applicable) (mg/kg)*	P_2O_5 Application Recommended by MWL (kg/1000m ²) **	P_2O_5 Application Recommended by UMExtension (kg/1000m ²) **	P_2O_5 Application Recommended by UNExtension (kg/1000m ²) **
35.8	2.44	0.73	2.25

* - Soil P level is mg of available phosphorus / kg of soil. Weak Bray results were used where soil pH < 7.7, Bicarbonate results were used where soil pH > 7.7

** - Phosphorus application expressed as P_2O_5 , phosphorus oxide

Results and Conclusions: Stormwater Professional Discussions

The following is a list of key composite comments brought up by interviewed stormwater management professionals.

- Developers of residential areas noted problems associated with controlling properties after they were sold to individual homeowners/builders.
- Grading contractors, who are often contracted for BMP installation, find maintenance a problem after they have graded and left a site.
- Post construction controls such as retention and detention facilities are often the property of homeowner associations. Many people commented on the inability of these associations to properly maintain these and other structures.
- Proper installation, inspection, and maintenance of construction site controls are critical. Given typical resources, proper inspection is difficult for the growing number of construction sites.

Final Conclusions

The methods used for BMP assessment provided insight into the stormwater management program in Lincoln, Nebraska.

- Selecting suites of BMPs in small watersheds instead of individual BMP applications allowed assessment of the performance of “typical” applications of the BMP program for specific land uses.
- Using sampling sites with either critical flow or uniform flow conditions allowed flow estimation that was inexpensive yet accurate enough to support sample compositing calculations.
- Construction site inspections which investigated the quality and existence of different BMP types without concern about regulatory compliance simplified the inspection process. The process used provided valuable insight into BMP application trends in Lincoln, Nebraska.

Acknowledgements

We would like to thank the City of Lincoln for its financial and technical support for this project.

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