MODELING METHODS TO EVALUATE LOW IMPACT DEVELOPMENT

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PROJECT SUMMARY

Project Description

This study developed a modeling framework for the representation, evaluation, and reporting the effectiveness of low impact development practices (LIDPs) using the curve number technology. This framework was developed within the Long-Term Hydrologic Impact Assessment Low Impact Development (L-THIA-LID) tool, a simple rainfall-runoff model to support decision-making in planning, regulatory, and research for a wide adoption of LIDPs. Using the L-THIA-LID model with the proposed framework and Geographic Information System (GIS), the study assessed hydrologic and water quality benefits of LIDPs in the Fox River-Frontal Green Bay Watershed (Fox River Watershed, Lake Michigan), and in the Ottawa River-Frontal Lake Erie Watershed in the Maumee River Watershed, Lake Erie). The sizes of the two watersheds are respectively 77 km^2 and 56 km^2 with the land uses shown in Tables 1 and 2. Five land use and planning scenarios incorporating rain barrels and porous pavement were evaluated. These scenarios consist of the existing condition (base line), 25% and 50% rain barrel adoption (25% and 50% of roofs in the watersheds are connected to rain barrel), and 25% and 50% porous pavement adoption (25% and 50% of roads and streets in the watersheds are designed with porous pavement). It should be recalled that the Maumee and Fox River watersheds are listed as priority watersheds by the U.S. Environmental Protection Agency (USEPA) for the Great Lakes Restoration Initiative.

Results of the study indicate that LID strategies have the potential to provide substantial benefits for stormwater quality retrofits in existing urban areas. The implementation of various levels of LIDPs shows varying runoff and pollutant loading reduction by the selected practices. The study reveals that retention of at least 8% and 7% for runoff, and 5% and 4% for pollutant loading to the Fox River and Maumee River, respectively, could be achieved with the use of rain barrels and porous pavement in the Fox River-Frontal Green Bay and Ottawa River-Frontal Lake Erie watersheds. The application of these results should be used with caution as these provide theoretical impacts of "what if" developments with and without LID design approaches. These are preliminary results of a larger study for the evaluation of the beneficial uses of LIDPs at watershed scales. The on-going activities take into account specific characteristics of the two watersheds through calibration and validation of model parameters with observed data, indicating that the final results may vary from the planning approach exhibited in these preliminary results.

Table 1. Land use characteristics in the Fox River-Frontal Green Bay watershed

Land use category	Area (ha)	Percent of total area
Water	995.2	13
Low density residential	492.9	6

High density residential	1766.3	23
Commercial/Industrial	1646.6	21
Roads/Streets	512.1	7
Bare soil	3.4	0
Forest	278.6	4
Grass/Pasture	732.0	10
Agricultural	1275.7	17
Total	7702.9	100

Table 2. Land use characteristics in the Ottawa River-Frontal Lake Erie watershed

Land use category	Area (ha)	Percent of total area
Water	198.1	3
Low density residential	752.7	13
High density residential	2018.5	36
Commercial/Industrial	2003.1	35
Roads/Streets	609.6	11
Forest	101.6	2
Grass/Pasture	1.4	0
Agricultural	0.1	0
Total	5685.1	100

Theoretical Framework

The framework presented in this study is an attempt to standardize modeling of LIDPs using the NRCS CN method, design considerations, performance measures, and readily available data. The procedure consists of four steps: (1) representation of LIDPs; (2) consideration of design guidelines; (3) computation of effective runoff; and (4) reporting the results. The proposed modeling approach is described in more detail in Ahiablame et al. (2012; Accepted for publication).

- Representation of LIDPs
  The curve number (CN) is a key parameter common to all LIDPs in the L-THIA-LID model. The effects of LIDPs such as porous pavement, permeable patio, rain barrel/cistern, grass swale, bioretention systems, green roof, and open wooded space, were characterized by CN values suggested by Sample et al. (2001) in accordance to runoff mitigation capacity of these practices. The alteration of CN values within the L-THIA model is a common approach. Previously, Lim et al. (2006) replaced default CN values to improve runoff and pollutant estimation for their study area.
- Consideration of design guidelines
  The effectiveness of LIDPs depends on the size of the practice with respect to the contributing area (watershed). These sizing requirements are published by design guidelines. Modeling efforts should take into account these sizing recommendations in regard to the site of interest.
- Computation of Effective Runoff

Runoff in the watershed is calculated using the distributed CN approach (Peters, 2010) to account for variations in runoff generation across land uses.

- Computation of LID Effectiveness Index
  The LIDP effectiveness index (EI_{LID}) describes the percent reduction in runoff and pollutant loads with the use of LIDPs for a study area.

Preliminary Findings

The results reported here are based on model runs in an uncalibrated mode to assist decision-makers with "what if" scenarios as would be the case in many studies. Five land use and planning scenarios with rain barrels and porous pavement were evaluated using twenty years of data (from 1991-2010) in the two watersheds. The five scenarios consist of the existing land use condition in the watershed (S1), 25% of the roof tops were assumed connected to rain barrels or cisterns (S2), 50% of the roof tops were assumed connected to rain barrels or cisterns (S3), 25% of the roads were assumed designed with porous pavements (S4), and 50% of the roads were assumed designed with porous pavements (S5). S1 was used as the base line to which the other scenarios were compared (Table 3). The EI_{LID} is a metric that describes the percent reduction in runoff and pollutant loading with the application of LIDPs as shown in Table 3.

Results show that runoff was reduced by 8% in the two watersheds when 25% of the roofs were connected to rain barrels or cisterns. Pollutant loads were also reduced with reductions in runoff which is directly proportional to percent increase of LIDPs. This study shows that reduction in runoff is greatly influenced by reduction in impervious surfaces. Overall connecting 50% of the roofs to rain barrels or cisterns led to higher reduction than the other scenarios. Application to 50% of porous pavement to the roads in the watersheds (S5) resulted in a stormwater control level comparable to that to connecting 25 percent of the roofs to rain barrels or cisterns (S3). This is a significant finding for planners as rain barrels are relatively inexpensive and affordable compared to porous pavement.

Results from this study provide theoretical impacts of the developments with and without LID design approaches. The present framework can be adopted in other models using the NRCS-CN method to represent LID practices, to obtain information about the effectiveness of these practices and support the development of decision making tools for water resources planning and management. Modeling LIDPs following guidelines is needed for their wide applicability, sharing and distribution of modeling results to a wider community, or comparing results across models and studies.

Table 3. Estimated runoff, total SS, phosphorus, and nitrate loads for the base line scenario (S1) in the two Great Lakes Watersheds

	Runoff (m^3/ha)	Total SS (kg/ha)	Phosphorus(kg/ha)	Nitrate (kg/ha)
Fox River-Frontal Green Bay	1122	31.0	0.1	2.6
Ottawa River-Frontal Lake Erie	2334	71.6	0.2	5.0

Table 4. Percent reduction in runoff and pollutant loads in two Great Lakes Watersheds

	Runoff	Total SS	Phosphorus	Nitrate
Fox River-Frontal Green Bay watershed				
S2	8	8	7	9
S3	16	15	14	18
S4	5	4	4	6
S5	10	9	7	11
Ottawa River-Frontal Lake Erie watershed				
S2	8	7	8	9
S3	16	15	15	19
S4	5	4	4	6
S5	9	8	8	12

Current and Future Activities

This project is a part of a larger study to enhance the L-THIA-LID model in order to evaluate the beneficial uses of LID practices at watershed scales. The L-THIA-LID is being enhanced with the representation of a series of LIDPs within the model and base flow estimation capability. This will allow evaluation of LID choices on stream flow (not only on runoff). This will also encourage a wider use of the L-THIA-LID model in many states and regions. Currently the model is being calibrated in the two study watersheds described herein to account for specific site conditions and to validate model parameters with observed data. For future work, field experimental work and in-depth assessment with monitoring data would be required to determine the strengths and the deficiencies of the predictive capabilities of the model.

Impacts

The product of this project is the enhanced L-THIA-LID model that could be useful to IISG's local decision makers. The L-THIA-LID is being expanded with capabilities to estimate base flow, pollutants loads and concentrations in base flow, and flow process associated with long term 95th percentile event as discussed in the provisions of Section 438 of the Energy Independence and Security Act (Silva, 2009). The LIDPs represented in the model are increasingly used, and it is expected that this study will support and inform a wide spectrum of planning, regulatory, research, and engineering efforts.

The methods developed in the present work can be adopted in other models using the NRCS-CN method or similar underlying equations to represent LIDPs, obtain information about the effectiveness of these practices, and support the development of decision making tools for water resources planning and management. However, representation of LID choices for stormwater control should be carefully evaluated with optimization techniques as the performance of the LIDPs will likely vary with the needs and the history of the site of interest, reducing the accuracy of default CN values in the model.

Financial support from the Illinois-Indiana Sea Grant was instrumental in the L-THIA-LID enhancement and advancement of the dissertation project. The grant allowed the application of the L-THIA-LID model to the two watersheds to explore the impacts of LID practice adoption.

PRESENTATIONS AND PUBLICATIONS

Ahiablame, L., Engel, B., Chaubey, I. Application of a modeling approach to evaluate low impact development practices in two Great Lakes watersheds. (In preparation).

Ahiablame, L., Engel, B., Chaubey, I. (2012). Effectiveness of Low Impact Development Practices: Highlights of the Current Knowledge and Suggestions for Future Research. Submitted (pending revision).

Ahiablame, L., Engel, B., Chaubey, I. (2012). Representation and Evaluation of Low Impact Development Practices with L-THIA-LID: An Example for Planning. *Environment and Pollution*, Accepted.

Ahiablame, L., Engel, B., Chaubey, I. (2011). A Modeling Framework to Evaluate Low Impact Development Practices. Presented at The Ohio Stormwater Conference, Columbus, Ohio, May 12-13.

REFERENCES

Lim, K.J., Engel. B.A., Tang, Z., Muthukrishnan, S., Choi, J., Kim, K. (2006). Effects of calibration on L-THIA GIS runoff and pollutant estimation. *Journal of Environmental Management*, 78, (1), 35-43.

Peters, E.G. (2010) Improving the practice of modeling urban hydrology. Stormwater, *The Journal of Surface Water Quality Professionals*. [Online] Available: http://www.stormh2o.com/march-april-2010/improving-practice-modeling.aspx (May 10, 2011).

Sample, D.J., Heaney, J.P., Wright, L.T., Koustas, R. (2001). Geographic information systems, decision support systems, and urban storm-water management. *Journal of Water Resources Planning and Management*. 127(3), 155-161.

Silva, P. S. (2009).*Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*.EPA-841-B-09-0001.U.S. Environmental Protection Agency, Washington, D.C.

APPENDIX

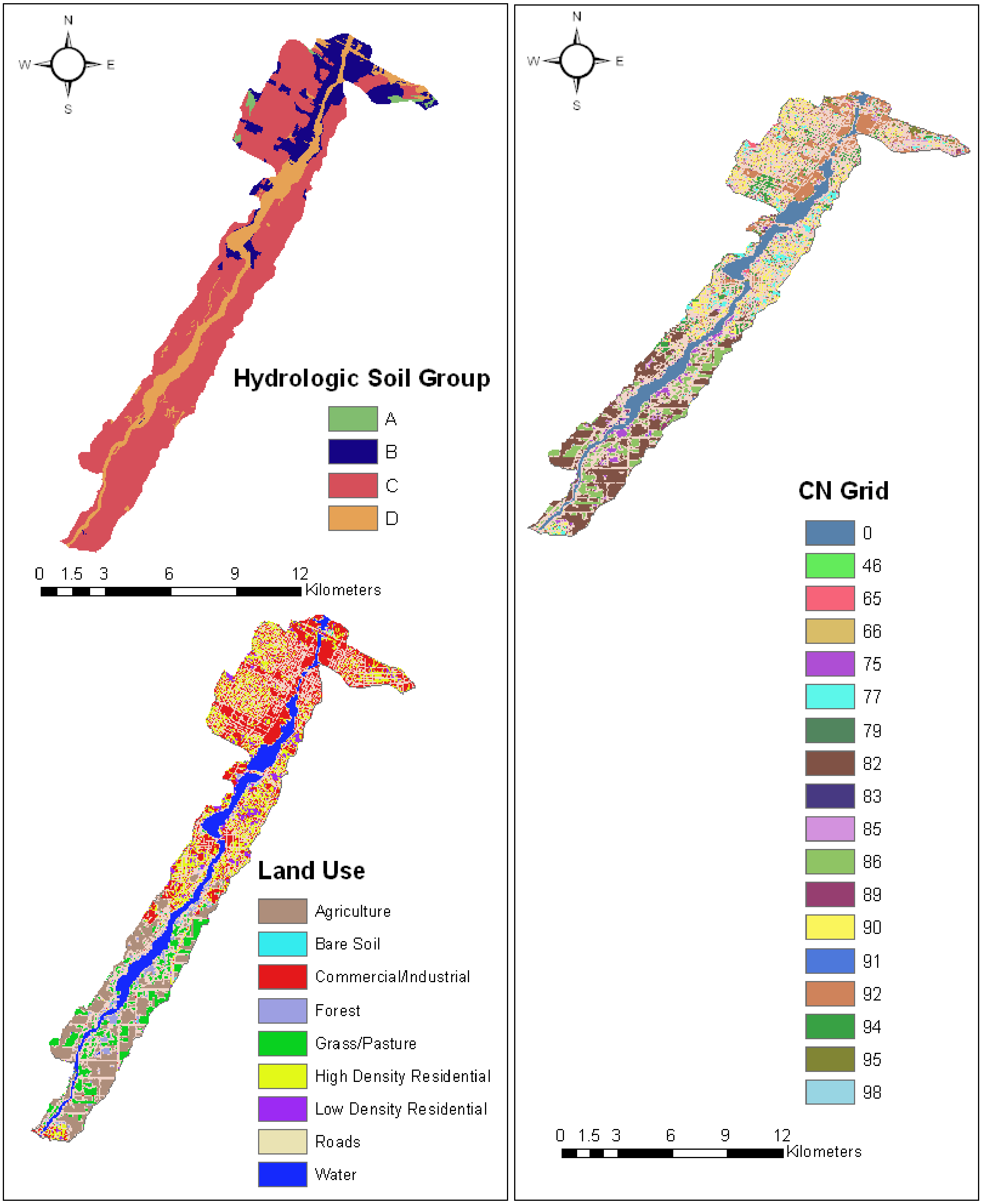

Figure 1: Soil, land use, and CN classification in the Fox River-Frontal Green Bay watershed (Wisconsin) based on 2001 NLCD.

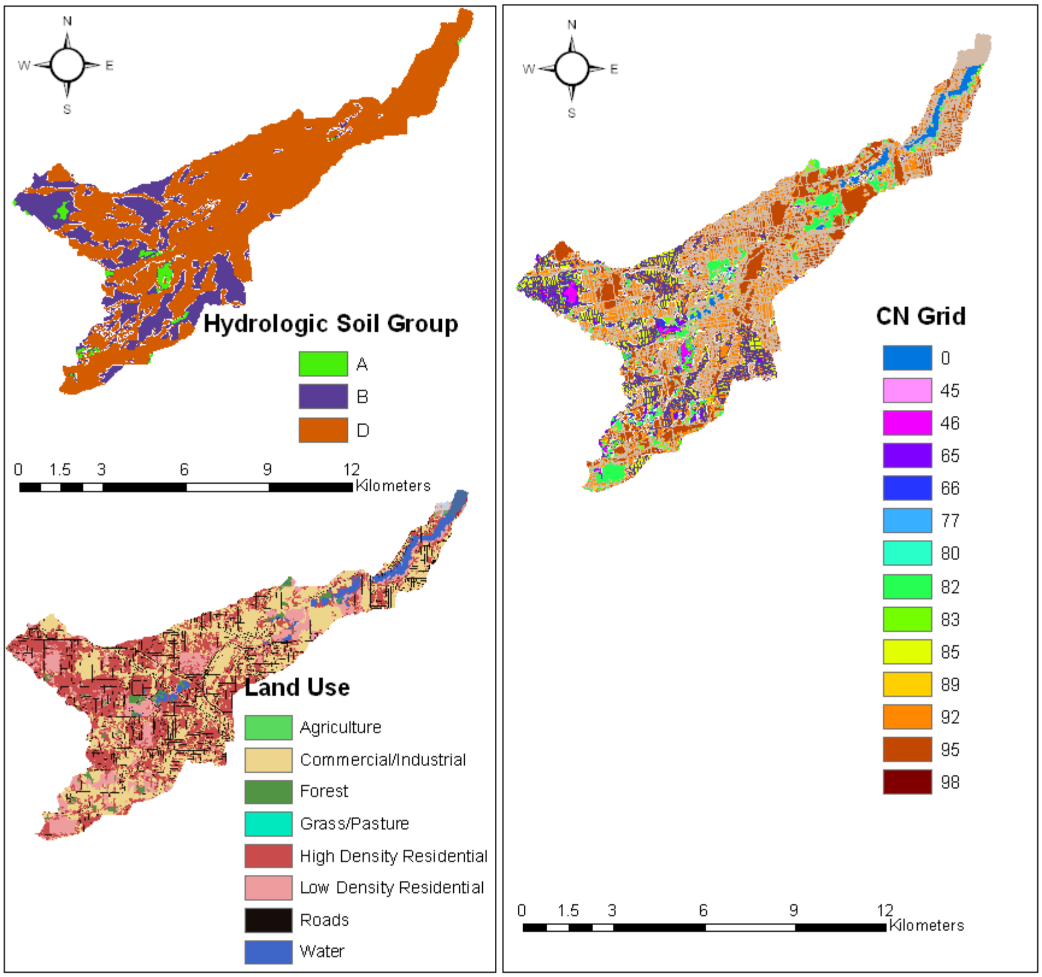

Figure 2: Soil, land use, and CN classification in the Ottawa River-Frontal Lake Erie (Ohio) based on the 2001 NLCD.