Journal of Environmental Management 76 (2005) 35–45

Journal of Environmental Management

www.elsevier.com/locate/jenvman

Forecasting land use change and its environmental impact at a watershed scale

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Received 12 March 2004; revised 12 October 2004; accepted 4 January 2005

Abstract

Urban expansion is a major driving force altering local and regional hydrology and increasing non-point source (NPS) pollution. To explore these environmental consequences of urbanization, land use change was forecast, and long-term runoff and NPS pollution were assessed in the Muskegon River watershed, located on the eastern coast of Lake Michigan. A land use change model, LTM, and a web-based environmental impact model, L-THIA, were used in this study. The outcomes indicated the watershed would likely be subjected to impacts from urbanization on runoff and some types of NPS pollution. Urbanization will slightly or considerably increase runoff volume, depending on the development rate, slightly increase nutrient losses in runoff, but significantly increase losses of oil and grease and certain heavy metals in runoff. The spatial variation of urbanization and its impact were also evaluated at the subwatershed scale and showed subwatersheds along the coast of the lake and close to cities would have runoff and nitrogen impact. The results of this study have significant implications for urban planning and decision making in an effort to protect and remediate water and habitat quality of Muskegon Lake, which is one of Lake Michigan's Areas of Concern (AOC), and the techniques described here can be used in other areas.

Keywords: Urbanization; Hydrologic modeling; Runoff; Non-point source pollution; GIS; Forecasting

1. Introduction

The geographic extent of urban development worldwide has undergone tremendous change in the last 50 years. Virtually every urban area in the United States has expanded substantially in land area in recent decades (USEPA, 2001). The changes of land use patterns certainly provide many social and economic benefits. However, they also come at a cost to the natural environment. One of the major direct environmental impacts of development is the degradation of water resources and water quality (USEPA, 2001). Conversion of agricultural, forest, grass, and wetlands to urban areas usually comes with a vast increase in impervious surface, which can alter the natural hydrologic condition within a watershed. It is well understood that the outcome of this alteration is typically reflected in increases in the volume and rate of surface runoff and decreases in ground water recharge and base flow (Carter, 1961; Andersen, 1970; Lazaro, 1990; Moscrip and Montgomery, 1997), which eventually lead to larger and more frequent incidents of local flooding (Field et al., 1982; Hall, 1984), reduced residential and municipal water supplies, and decreased base flow into stream channels during dry weather (Harbor, 1994). Other impacts associated with change of discharge behavior due to urbanization include increased lake and wetlands water levels (Calder et al., 1995; Schueler and Holland, 2000), modified watershed water balance (Fohrer et al., 2001), and increased erosion of river channel beds and banks (Doyle et al., 2000).

The conversion from pervious to impervious surfaces can also degrade the quality of the storm water runoff. Monitoring and modeling studies have shown consistently that urban pollutant loads increase with watershed imperviousness (Schueler, 1995). Impervious surfaces collect pollutants either dissolved in runoff or associated with sediment, such as nutrients, heavy metals, sediment, oil and grease, pesticides, and fecal coliform bacteria. These pollutants are washed off

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0301-4797/$ - see front matter
doi:10.1016/j.jenvman.2005.01.006

and delivered to aquatic systems by storms (Schueler, 1995; Gove et al., 2001).

The Muskegon River watershed is one of Lake Michigan's eastern coastal watersheds. The Muskegon River flows through Muskegon Lake before eventually entering Lake Michigan. Due to the degradation of lake water quality and its impairment of water use, Muskegon Lake and the immediate drainage area, the Muskegon watershed, have been identified as one of the Areas of Concern (AOC) in the Lake Michigan area by the Lake Michigan Lakewide Management Plan (LaMP) (USEPA, 2000). LaMP was developed by the United States and Canada, in consultation with state and provincial governments, for open waters and Remedial Action Plans (RAP) for AOC. Research efforts presented in LaMP have discovered contaminants that result in the degradation of Muskegon Lake for beneficial uses through the media of water and sediment. Nitrogen, phosphorus and oil and grease are identified as major water pollutants in localized areas. Heavy metals were identified as both major water and sediment contaminants. The potential major urban NPS of these pollutants include fertilizer and animal waste for nutrients, roads and paints for heavy metals, and motor oil for oil and grease. It is of great importance to identify pollution sources and predict their future status in an effort to restore the water quality and eliminate use impairments of Muskegon Lake as a part of an integrated RAP of Lake Michigan.

The objectives of this paper are to:

(i) present past and future land use changes in the Muskegon watershed predicted by a land use change model,
(ii) forecast and assess the impact of the predicted land use changes on long-term runoff and NPS pollution using an environmental impact analysis model,
(iii) identify subwatersheds that are potentially most vulnerable to the impact of urbanization,
(iv) discuss the implications of the results for decision making and long-term urban planning.

2. Methods

2.1. Study area description

The Muskegon River watershed, located on the east side of Lake Michigan in north-central Michigan, covers an area of approximately 7032 km^2. The river begins as 'Big Creek' at Houghton and Higgins Lakes, approximately 352 km (219 miles) from its mouth at Muskegon Lake to Lake Michigan. The Muskegon River is the second longest river in Michigan. The Muskegon River watershed spans all or part of nine counties and nine cities and towns (Fig. 1). The dominant land uses are forest and agricultural, while urban occupies a small portion of the entire watershed area. A more detailed description of the land use distributions in the Muskegon watershed will be presented in Section 3.

2.2. Modeling land use change

A land use change model, the Land Transformation Model (LTM) (Pijanowski et al., 2002a,b), is employed to project the land use change in this study. The LTM model is designed to forecast land use change over large regions. It relies on GIS, artificial neural network routines (ANNs), remote sensing and customized geospatial tools. The driving variables include a variety of social, political and environmental factors, such as distance to transportation, proximity to amenities (such as rivers, lakes, and recreational site), density of surrounding agriculture, exclusive zones, and population growth. Information derived from an historical analysis of land use change is used to conduct forecast studies. The model is a desk top computer application, and it mainly follows four sequential steps: (1) processing/coding of data to create spatial layers of predictor variables; (2) applying spatial rules that relate predictor variables to land use transitions for each location in an area; the resultant layers contain input variables values in grid format; (3) integrating all input grids using one of the three techniques, including multi-criteria evaluation, ANNs, and logistic regression; and (4) temporally scaling the amount of transitions in the study area in order to create a time series of possible future land uses. Detailed descriptions of the LTM can be found elsewhere (Pijanowski et al., 2000, 2002a). The LTM model has been applied and validated in a variety of locations around the world to help understand what factors are most important to land use changes and to simulate land use change in the past, present and future (Pijanowski et al., 2000, 2002a,b). It also offers the ability to link changes in land use to ecological process models, such as groundwater flow and solute transport (Boutt et al., 2001) and forest cover change (Brown et al., 2000, 2001).

Land use changes of the nine coastal watersheds located along the eastern shores of the Lake Michigan were simulated using the LTM model. This article contains representative results for only one of the watersheds, the Muskegon watershed. The data used and parameterizations for model operation have been documented by Pijanowski et al. (2002b). Therefore, only a brief description is presented in this paper.

The land use data for 1978 were obtained from the Michigan Resource Information System (MiRIS) land use database, which was derived from 1:24,000 aerial photographs. This database contains land use/cover to Anderson level III (Anderson et al., 1976) for areas larger than 2.5 acres (1.01 ha). A GIS layer with 100×100 m (1 ha) grid cells was created based on the land use data in 1978 and served as the base data layer to the LTM for predicting present and future land uses in the Muskegon watershed. The driving variables, including distance to transportation, proximity to amenities, exclusionary zone, and population

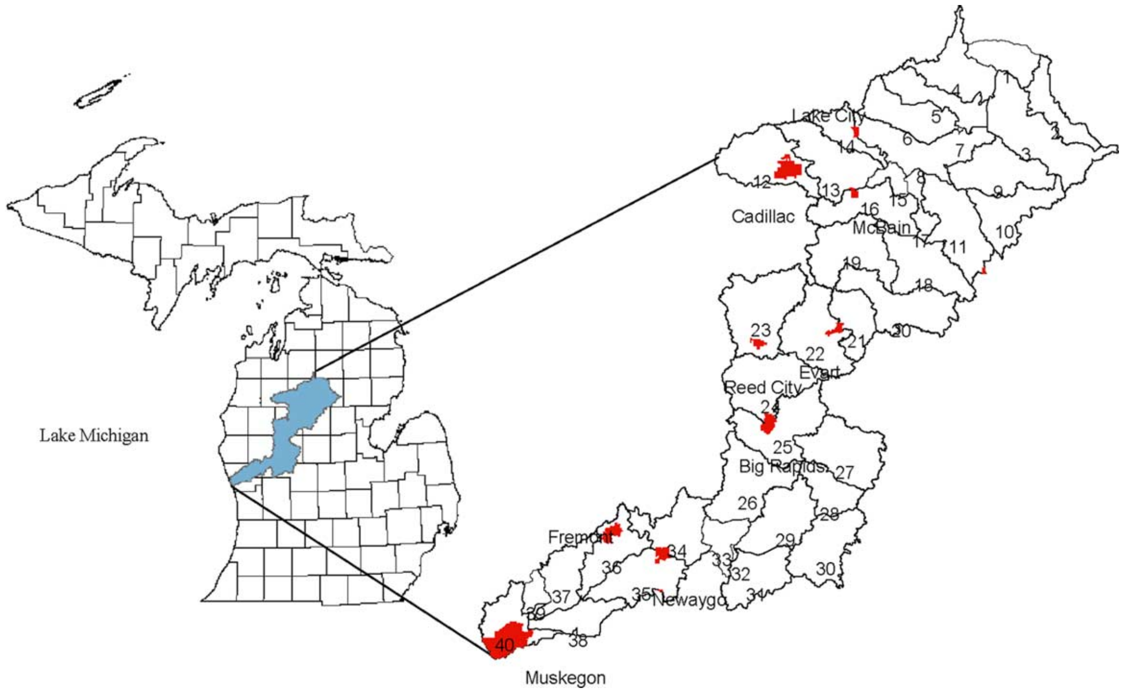

Fig. 1. The Muskegon River watershed. The location of the watershed in Michigan is shown on the left. The subwatersheds, cities, and towns inside the study area are shown on the right.

forecasts, were developed and input to neural network parameterization. Public areas are excluded from possible development by the model. The model was executed for the following two scenarios differentiated by using a different urban expansion index, which is defined as a ratio of the percentage increase of urban areas and the percentage increase of urban populations over the same time intervals in the LTM.

(i) Non-sprawl growth: an urban expansion index of 2.3 was used in this scenario. This value is taken from a study by the Planning and Zoning Center (Rusk, 1999), Lansing, Michigan. It was the lowest urban expansion index found in Michigan.
(ii) Sprawl growth: an urban expansion index of 8.76 was used in this scenario. This value was derived from an analysis of 17 counties for a 17-year period (1978–1995) (Pijanowski et al., 2002b).

Using 1978 as a baseline, the LTM forecasted the land uses to 1995 in non-sprawl condition and 2020 and 2040 in both non-sprawl and sprawl conditions for the entire watershed. The forecasted land use classes are a mix of Anderson levels I and III with urban land use predicted to level I.

2.3. Modeling the impact of land use change

The Long-Term Hydrologic Impact Assessment (L-THIA) model (Harbor, 1994; Bhaduri et al., 2000) was employed to estimate the impact of land use change on surface runoff and NPS pollution. The core of the model is based on the Curve Number (CN) method (NRCS, 1986), a widely applied technique for estimating the change in discharge behavior as a watershed undergoes urbanization. Pollutant loading rates are combined with runoff estimates to quantify NPS pollutants. The L-THIA model requires only readily available data including hydrologic soil group, land use, and long-term climate data to assess the relative hydrological and NPS pollution impacts of past, present, and alternate future land management decisions for a specific watershed or subwatershed (Bhaduri et al., 2001; Grove et al., 2001). The L-THIA model provides assessment on the long-term average impact, rather than impact resulting from a particular storm or year. A detailed description about the model structure and approach can be found in Harbor (1994) and Pandey et al. (2000). The L-THIA model is freely accessible in web-based and downloadable GIS versions at http://www.ecn.purdue.edu/runoff/lthianew/

The L-THIA model is being used by land use planners, consultants, water resource managers, and decision makers. It has been also utilized and validated in many efforts for assessing hydrologic and NPS impacts of historical land use change (Bhaduri et al., 1997, 2001; Minner et al., 1998; Grove et al., 2001; Kim et al., 2002) or land use development plans (McClintock et al., 1995; Muthukrishnan, 2002).

The web version of the L-THIA model was used to estimate the runoff and NPS pollutants for 1995, 2020 and 2040 land uses. It requires input data for rainfall, land use and hydrologic soil group combinations in the Muskegon watershed. A rainfall database in L-THIA provides rainfall based on the state and county where a watershed is located. Hydrologic soil groups were derived from a USDA STATSGO (USDA, 1996) soil map. A land use reclassification was needed to map land use classes from the LTM land uses to the L-THIA land uses. The land use classes of L-THIA include agricultural, grass/pasture, forest, water/wetlands, and urban presented as commercial, industrial, High Density (HD) residential and Low Density (LD) residential. The land use classes predicted by the LTM are a mix of Anderson level I (urban) and level III as stated earlier. Thus, the only difficulty in the reclassification process is to map the single urban land use in LTM to multiple suburban classes in L-THIA. To solve this problem, the area distributions between urban subclasses relative to 1978 were assumed unchanged. In other words, the urban subclass distributions of the predicted urban areas in 1995, 2020 and 2040 were assumed to be the same as those in 1978. The distributions of urban areas in these predicted years, therefore, were derived from level III land uses in 1978 for the entire watershed. The areas of all land use and soil combinations were then calculated to use in L-THIA for estimating average annual runoff volume and NPS pollutant losses for the entire watershed. The indicator NPS pollutants to be assessed were selected based on the major water and sediment pollutants identified in LaMP (USEPA, 2000) and are: nutrients (nitrogen, phosphorus), heavy metals (lead, copper, chromium, nickel), and oil and grease.

To explore the spatial variation of urbanization and its impact, further studies were conducted at the subwatershed level. The entire Muskegon watershed was divided into 40 subwatersheds defined using USGS 14 digit hydrologic unit areas. The assessment of the impact on runoff and NPS pollution was conducted for 1978 and 2040 with two development rates: constant and sprawl. The same assumption as for the entire watershed was made for each subwatershed to map the single urban class to multiple suburban classes. The average annual runoff depth and NPS pollutant losses were estimated for each subwatershed.

3. Results and analysis

3.1. Analysis of land use change in the entire watershed

Land use change can have significant effects on runoff volume and consequently NPS pollution. To quantitatively reveal this effect for the entire watershed, an evaluation of land use change is presented first. In 1978, the dominant land use was forest, covering more than half of the watershed (53.2%); agricultural ranked second (23.0%); and urban was the least portion with 4.2%. The remaining areas were shared by grass/pasture (9.9%) and water/wetlands (9.7%). The land use distributions are predicted to undergo changes driven by urban development and expansions as shown in Fig. 2. The urban proportion of the total watershed area is predicted to increase from 4.2 to 7.1% in the non-sprawl scenario and 11.5% in the sprawl scenario from 1978 to 2040. The gains in urban areas result in losses in all non-urban land uses as depicted in Fig. 3. Forested areas will have the largest area losses (up to 3.7% in 2040 sprawl) in all projection years, while water/wetland will have the smallest area losses (up to 0.6% in 2040 sprawl).

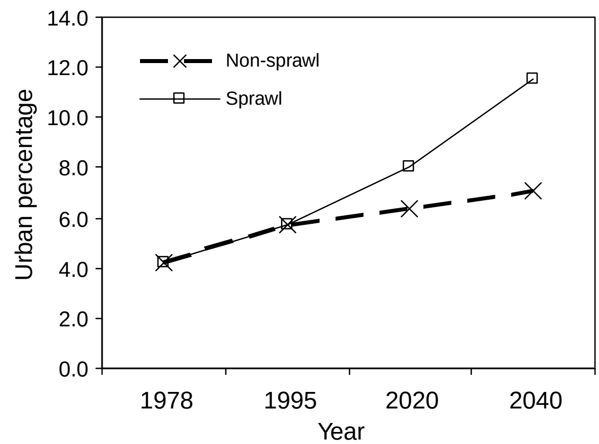

Fig. 2. The urban proportions of the entire watershed in non-sprawl and sprawl scenarios over the modeling time frame.

The urban land use is composed of commercial, grass/pasture, high density (HD) residential, industrial, and low density (LD) residential. As the dominant urban uses, LD residential and industrial made up 85% of the total urban area (Fig. 4). This distribution was derived from land use data in 1978, but was applied to all projection years as well. Although urban is a small portion of the watershed (less than 10% by 2040 for sprawl development), it showed a significant increasing trend compared to 1978 (Fig. 5). The areas of urban use in 1978 and percent changes in the 3 predicted years are tabulated (Table 1). The urban areas will increase 35% by 1995 and this increase will double by the year 2040 assuming constant urbanization rates. In contrast, assuming sprawl ratios, urban increases will exceed 170% by the year 2040. The LD residential and industrial land uses were identified as having the highest increases. HD residential had the lowest increases, which range from

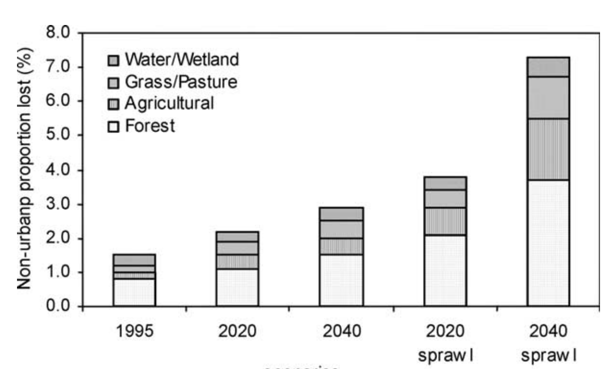

Fig. 3. The non-urban land use proportion lost for the entire watershed in non-sprawl and sprawl scenarios over the modeling time frame.

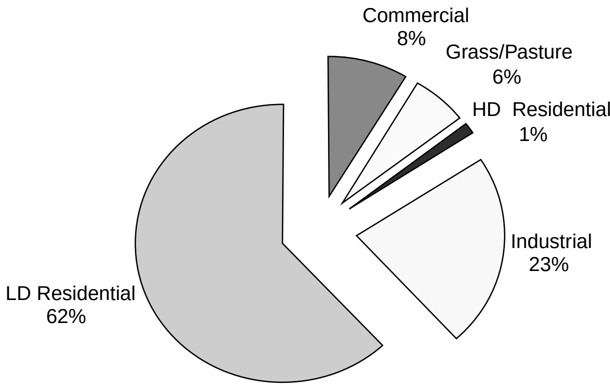

Fig. 4. Urban land use distribution for 1978. These urban distributions were assumed in estimating runoff and NPS pollution in 1995, 2020, 2040, 2020 sprawl and 2040 sprawl.

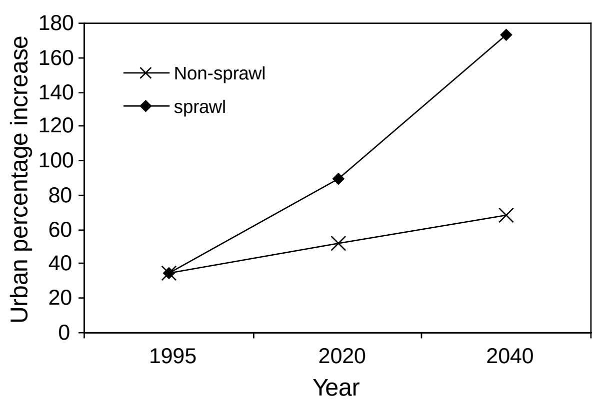

Fig. 5. Percentage increases of urban areas relative to 1978.

0.4 to 0.7 times the increases of LD residential and industrial.

3.2. Assessment of runoff and NPS pollution for the entire watershed

The amounts of annual average runoff and indicator NPS pollutants, nutrients, heavy metals, and oil and grease, are presented for 1978 (Table 2). The percent increases of the total average runoff volume and NPS pollutants from the whole watershed are depicted in Fig. 6. Due to the conversion of non-urban to impervious urban uses with higher runoff potential, runoff and all NPS pollutants are estimated to increase but in varied extents. Runoff volumes increased 5% with non-sprawl development rates and 12% with sprawl development rates by 2040. This increase modified the distribution of the total runoff, in which urban contributions go up from about 10% in 1978 to 17 and 25% in 2040 with non-sprawl and sprawl scenarios, respectively.

Estimated nitrogen and phosphorus losses increase less than 3% in about 60 years (1978–2040) in spite of the sprawl development rate. This is the result from the losses of agricultural land which has higher nutrient contribution potential than urban land uses.

The impact of urbanization on heavy metal losses for the Muskegon watershed differed with the types of heavy metals. Nickel losses were estimated to have the highest increase with overall increases of more than 70 and 186% by 2040 for constant and sprawl development rates, respectively. The increases of lead and copper losses are about 0.3 and 0.1 times the nickel losses for all projections, respectively. Chromium losses had the least change compared to the other heavy metals with a 6% increase by 2040 with sprawl development. Losses of oil and grease are contributed only by urban areas. Non-urban areas, such as agricultural, forest, and grass/pasture areas, are not potential sources of oil and grease. So the increase of oil and grease is proportional to the increase of urban areas. The overall amounts were almost equal to percentage increases of the urban areas shown in Fig. 3. In 2040, the loss of oil and grease in the sprawl scenario will be double compared to the non-sprawl scenario.

3.3. Spatial variation of the urbanization and its impacts

Urbanization rarely occurs homogeneously across an entire watershed. This spatial variability of the development, as well as land use and soils, therefore results in the spatial variability of runoff and NPS impacts. The impacts of urbanization on long-term average annual runoff and indicator NPS pollutants have been assessed for the whole Muskegon River watershed, as the area weighted average response of all subwatersheds. To explore the spatial variation of urbanization and its impact and identify subwatersheds vulnerable to the impact of urbanization, further studies were conducted at the subwatershed level. The assessment for the entire watershed shows that urbanization has similar impacts on nitrogen and

Table 1
The areas of urban subclasses in 1978 and their percentage changes relative to 1978

Land use	1978 (km^2)	Percent change relative to 1978				
		1995	2020	2040	2020 sprawl	2040 sprawl
Commercial	25.1	27.3	43.1	59	78.5	158.1
Grass/pasture	18	33.4	50	66.6	87.1	170.6
HD residential	3.5	15.4	30	44.1	61.8	134
Industrial	66.8	37.5	54.5	71.7	92.7	178.8
LD residential	182.6	35.6	52.4	69.3	90.1	175
Total urban	296	35	51.7	68.5	89.2	173.7

Table 2
Annual average runoff volumes and the amounts of NPS pollutants generated from urban and non-urban areas of the entire study area in 1978

Runoff and pollutants	Urban	Non-urban	Total
Total runoff volume (10^6 m^3)	21.2	181.0	202.2
Nitrogen (kg)	104,322	1,221,671	1,325,993
Phosphorus (kg)	17,569	337,690	355,259
Chromium (kg)	291	3677	3968
Copper (kg)	606	1851	2457
Nickel (kg)	444	6	450
Lead (kg)	582	1123	1705
Oil and grease (kg)	190,323	0	190,323

phosphorus and the most significant impact on nickel among the heavy metal group. Therefore, nitrogen and nickel, as representatives of the nutrient and heavy metal groups, were selected for the impact analysis on NPS pollutants at the subwatershed scale.

The majority of the subwatersheds account for 1–4% of the total area. Subwatersheds 3 and 23 are the biggest with each making up 5% of the total area. Subwatersheds 7 and 32 are ignored in the following discussions as their areas are less than 0.1% of the totals.

The urban proportion in each subwatershed differs. In 1978, the entire watershed was composed of 4.2% urban, which is an area weighted average of all subwatersheds. Most subwatersheds contain less than the average urban land use proportion. However, three subwatersheds (38, 39, and 40) which the Muskegon River flows through before finally entering Lake Michigan, each contain more than 10% urban (Fig. 7). Among them, subwatershed 40 was the most urbanized area with 36% urban. Urban development in each watershed appeared at varied paces. By 2040 with both non-sprawl and sprawl scenarios, subwatersheds located in the middle north of the watershed (subwatersheds 4, 5, 6, 9, 15, 16, and 17) will experience very slow urban expansion

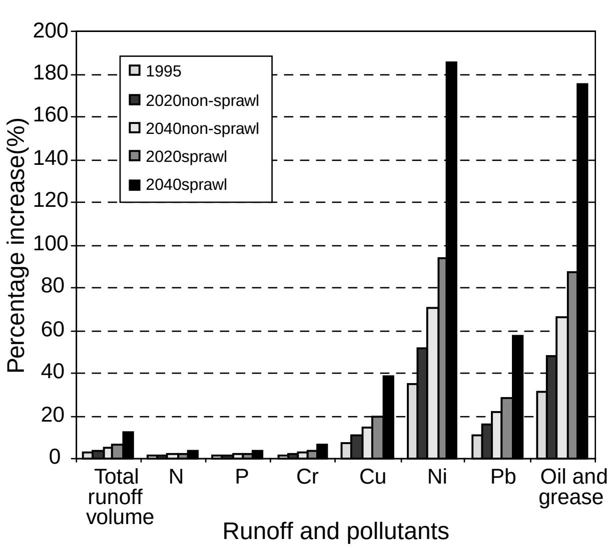

Fig. 6. Percentage increases of runoff and NPS pollutants of the entire watershed in 1995, 2020, 2040, 2020 sprawl, and 2040 sprawl scenarios.

with less than 0.5% increases each in their urban proportions. In the middle part of the watershed, most subwatersheds will increase their urban proportions from less that 5% to between 5 and 10% for the non-sprawl scenario and 11–20% for the sprawl scenario in 2040. The number of subwatersheds with urban proportions equal to or over 10%, but less than 50%, increased from three in 1978 to eight for the non-sprawl scenario and 15 for the sprawl scenario in 2040. These watersheds are close to Lake Michigan (subwatersheds 31, 35, 36, 37, 38, and 39) and the cities Cadillac (subwatershed 12) and Lake City (subwatershed 14). By 2040, only one subwatershed has urban proportions equal to 50% for the non-sprawl scenario, but three subwatersheds exceed this level for the sprawl scenario. Subwatershed 40 would contain the greatest proportion of urban use which is 50 and 66% for non-sprwal and sprawl scenarios, respectively, because of the sprawl development of Muskegon.

Figs. 8 and 9 illustrate the percentage increases of runoff depth, nitrogen and nickel in 2040 compared to 1978 at the subwatershed scale. For normal (i.e. non-sprawl) development rate, more than half of the subwatersheds have less than 5% runoff increases. These subwatersheds are mainly located in the middle north and southwest portions of the watershed in Mussaukee and Newaygo Counties. Subwatersheds close to Lake Michigan, such as 38, 39, and 40, have more than 10% increases. Seventeen out of 40 watersheds have more than average nitrogen increases (<3%). Among them, subwatersheds 1, 3, 10, and 40 increased more than 15%. Urbanization increased nickel losses in each watershed significantly. Ten watersheds doubled their nickel losses. The highest increase appeared in subwatershed 26 with about a 150% increase as the urban proportion increased significantly in this subwatershed. For the sprawl scenario, the percentage increases of runoff and nickel are more than the increases for normal development rate as expected, however, nitrogen decreased in some watersheds (subwatershed 34, 36) due to the reduction of agriculture in these areas. The subwatersheds close to the lake have more than 25 and 20% runoff and nitrogen increases, respectively. About half of all the subwatersheds double or triple their nickel losses. The maximum increase in nickel is as high as seven times in subwatershed 37.

4. Discussion

Urban land use was forecast using two development rates for the Muskegon River watershed in Michigan. The non-sprawl scenario used the most historically conservative urban to population expansion ratio with a value of 2.3, while the sprawl scenario used a statewide average value, 8.7. With non-sprawl development, the entire watershed was estimated at 6.4 and 8.0% urban in the years 2020 and 2040, respectively. With sprawl development, the entire watershed will be composed of 7.1 and 11.5% urban land

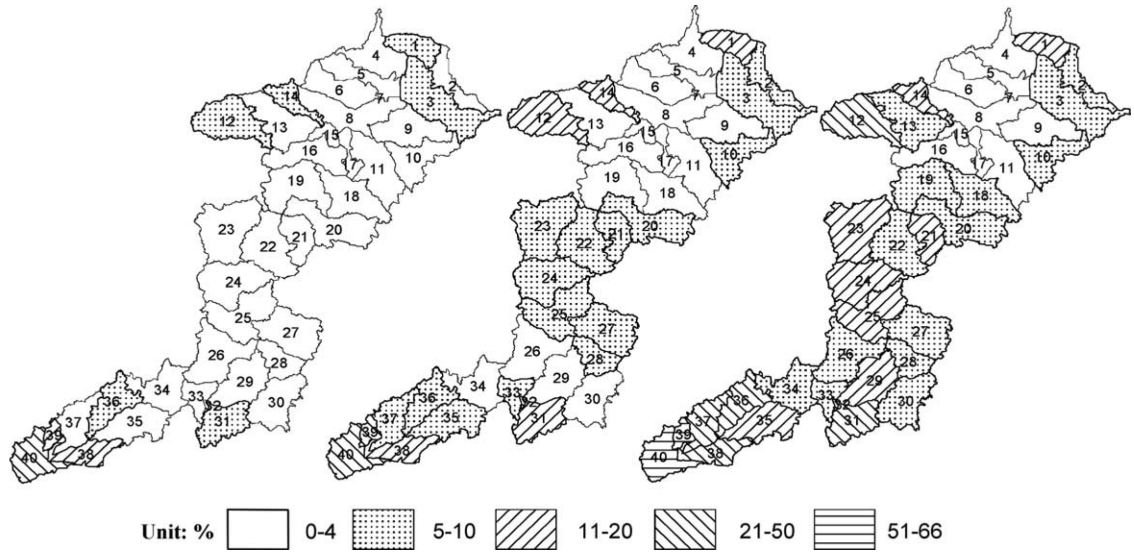

Fig. 7. Urban proportions in each subwatershed in 1978 (left), non-sprawl scenario in 2040 (middle), and sprawl scenario in 2040 (right).

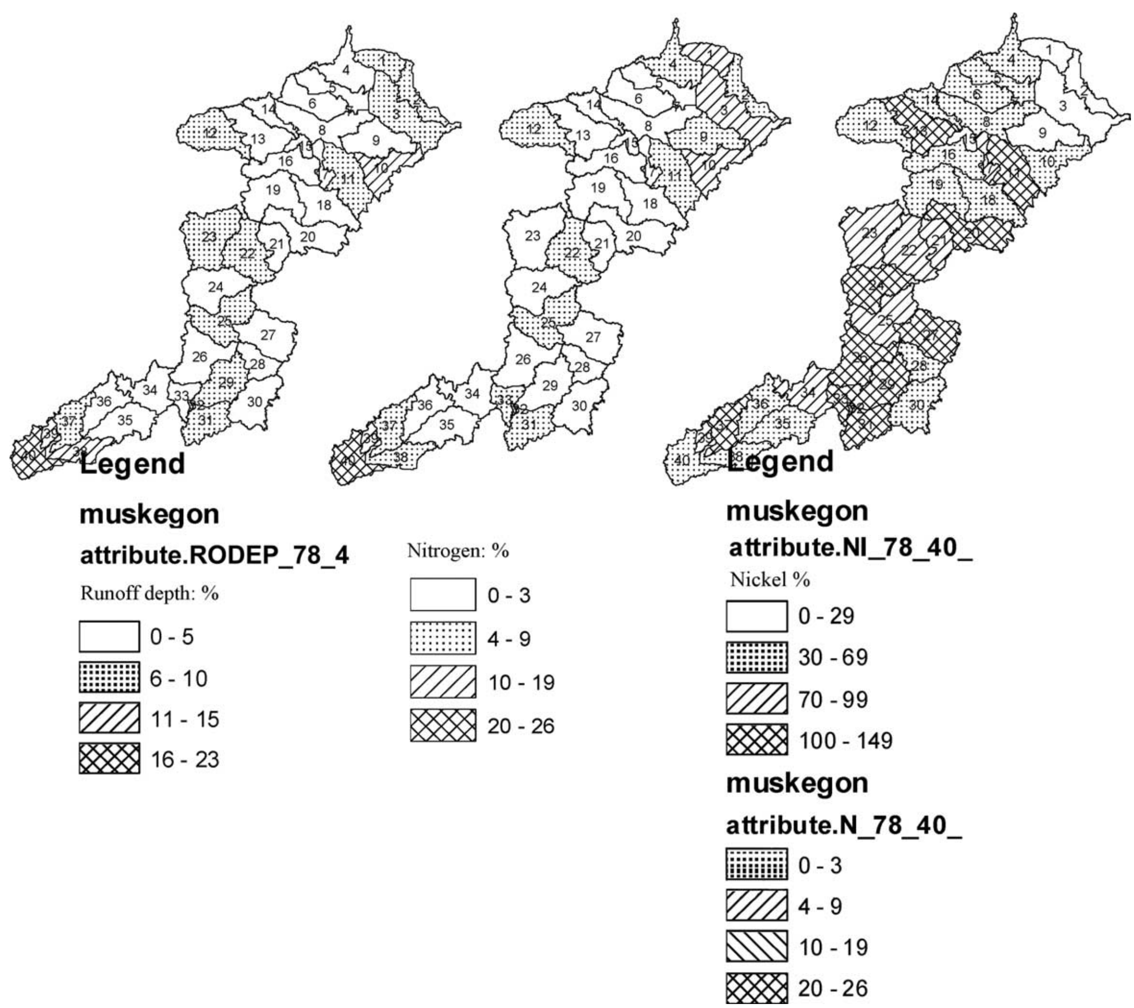

Fig. 8. The percentage increases of average annual runoff depth (left), nitrogen (middle) and nickel (right) in 2040 under constant development relative to 1978. The watershed averages are 5, 3 and 70%, respectively.

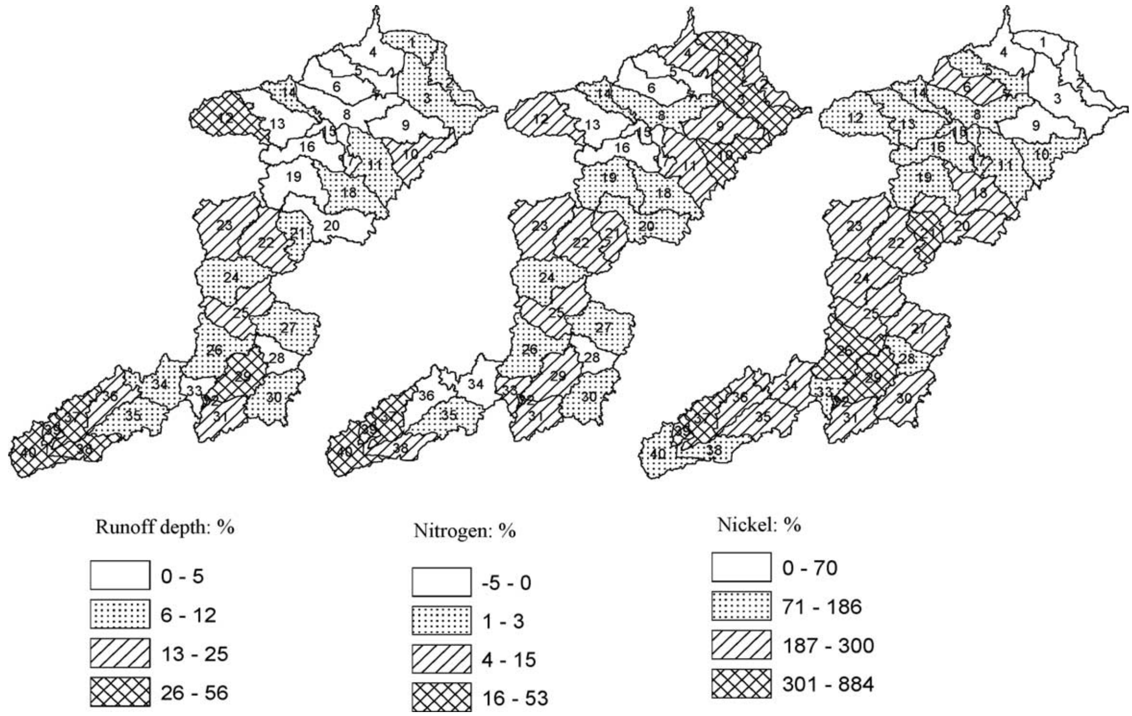

Fig. 9. The percentage increases of average annual runoff depth (left), nitrogen (middle) and nickel (right) in 2040 under sprawl development rate relative to 1978. The watershed averages are 12, 3 and 186%, respectively.

uses in 2020 and 2040, respectively. The increases in urban areas result in losses of non-urban land uses in varied amounts, including agricultural, forest, grass/pasture, and water/wetland. The loss of forest area is predicted to be the biggest.

The impacts of urbanization on runoff and NPS pollution for the entire watershed were assessed based on the predicted urbanization. From 1978 to 2040 for the non-sprawl scenario, urbanization will slightly increase runoff volume (5%) and nutrient (N and P) losses ($<2\%$), but significantly increases the losses of oil and grease ($>65\%$) and nickel ($>65\%$). Within the same time period for the sprawl scenario, urbanization would have a similar impact pattern but greater percentage increases. Runoff volume increases will be more pronounced (12%), nutrient loss increases will be insignificant (3%), and heavy metals and oil and grease losses will more than double compared to the non-sprawl scenario. In addition, the expansions of urban use will modify the distribution of the total runoff from the entire watershed. The runoff proportion from urban land use increased almost 1 and 1.5 times for the entire watershed under a non-sprawl and a sprawl scenario, respectively.

The spatial variability of the urban development, as well as its impact, was also evaluated at the subwatershed scale for the year 2040 for the non-sprawl and sprawl scenarios. The study showed that the middle northern portion of the watershed would experience slow urban development due to the presence of large national forests that would prevent development. Of the 40 subwatersheds in the study area, seven will contain 10% or more urban area in 2040 for non-sprawl development. This number doubled for the sprawl development. The growth will mainly occur in the subwatersheds along the coast of Lake Michigan and around cities. Subwatersheds 39 and 40 will be subjected to urbanization and will contain as much as 30 and 50% urban for non-sprawl development and more than 60% for sprawl development.

The percentage increases of runoff and NPS pollutants for the entire study area are the average responses at the subwatershed spatial scale. Most subwatersheds in the middle northern and southwest areas of the study area had less than average runoff percentage increases (5%) for both scenarios. The increases in the costal subwatersheds exceeded 10% for the non-sprawl scenario and 25% for the sprawl scenario. Although nitrogen will only slightly increase ($<2\%$ for non-sprawl and 3% for sprawl scenarios) in the entire study area, some watersheds, such as subwatersheds 1, 3, 10 and 40, could increase as much as 15 and 20% for non-sprawl and sprawl development, respectively. However, nitrogen losses decreased in certain subwatersheds, such as 36, as the reduction of agricultural areas occurred. Urbanization has significant impact on the nickel loading in the subwatershed level. For the non-sprawl scenario, 10 out of 40 subwatersheds double their nickel losses with the highest percentage increase (about 50%) appearing in subwatershed 26. For the sprawl scenario, half of the subwatersheds have double or triple nickel losses, with the highest percentage increase (884%) in subwatershed 37. The significant percentage increases of nickel losses can be explained as the substantial increases of urban proportion in subwatersheds. Urban is the predominant nickel contributor.

One point that needs to be emphasized for the above discussion is that results are described as percentage change. A higher percentage increase in a subwatershed does not necessarily mean there were larger increases in mass lost than the other subwatersheds. For instance, although subwatershed 37 has the highest percentage increase (884%), its contribution to the total nickel losses of the entire watershed is only 5% in contrast to the highest contribution of 16% from subwatershed 40 with a percentage increase of 118%.

4.1. Limitations

To map the single urban class predicted by LTM to multiple suburban classes in L-THIA, the urban subclasses relative to 1978 were assumed unchanged in 1995, 2020, and 2040. This is one of the limitations of the study. It can be mitigated when the temporal change of urban distributions on subclasses are considered. One possible method to derive the temporal change of urban distributions on subclasses is from past temporal land use sequences if available. In order to eventually overcome the limitation, LTM is being expanded to be capable of forecasting to Anderson level III land use classes. Future research on the integration of LTM and LTHIA will identify land use classes appropriate for both models to eliminate mapping process.

L-THIA employs the event mean concentration method to estimate NPS pollution. These concentrations are site-specific. However, they are not available for the Muskegon watershed. Therefore, the predictive results were estimated based on the data of other comparable areas (Pandey et al., 2000).

It is important to calibrate a model and validate its results against field/real-world data to increase confidence in predicted results. In this study, temporally distributed land use, runoff and water quality data are needed to achieve this purpose. In reality, such ideal data sets are almost impossible to obtain. Therefore, the results could not be compared against field data to assess model performance.

One should also be aware that the prediction of NPS pollutants for the modeling time frame did not take into account changes in temporal values due to policy changes or technological evolution, which could be significant impact factors on NPS pollution. An example is the use of lead-free gasoline since the 1970s that has greatly reduced lead pollution. Similarly, if lead-free paints and hybrid automobiles become widespread in the future, the impact of lead and oil on the environment will be reduced. These factors can be incorporated with model prediction when necessary.

4.2. Decision making and land use planning implications

The water and habitat quality of Muskegon Lake has been degraded, because it has received direct discharges of industrial wastewater, municipal wastewater treatment plant effluent, combined sewer overflows, and urban runoff (USEPA, 2003). The Muskegon River watershed is one of its major pollution sources. The results of this study can provide useful information for the RAP being developed for Muskegon Lake. It can be used to raise decision maker's awareness of potential long-term impacts of urban sprawl so that policy can be developed that might mitigate or minimize negative impacts. The forecast urban development and its impact on runoff and NPS pollution from this study imply that the following issues may need to be considered by decision makers or urban planners:

(i) Rapid urban development in subwatersheds along costal watersheds and close to some cities, especially those located in the downstream portion of the river, is a greater threat to the lake water quality than that in other areas,
(ii) Total runoff increases and possible hydrologic impairment occurred in the entire watershed under sprawl development,
(iii) Oil and grease loss from urbanized areas and its potential contamination to Muskegon Lake, and eventually Lake Michigan, by urban runoff, are significant,
(iv) Heavy metal losses, such as nickel, increased significantly. This suggests intervention may be needed to control nickel increase,
(v) Significant runoff increases and losses of nutrients, heavy metals and oil and grease will occur in localized areas (subwatersheds).

Another implication for urban planning may be the need for smart growth in the study area. LD residential is identified as the dominant urban land use in the entire study area and would undergo the greatest increases in the future. This observation indicated that it is possibly the result of large lot zoning, a commonly used land use planning technique in the last two decades. The technique involves zoning land at very low densities to disperse impervious cover over large areas. This approach may be used to decrease impervious cover at the site or subwatershed level, but may have an adverse impact on regional or watershed imperviousness (CWP, 1998). To avoid this problem, smart growth which requires compact and environmentally friendly development is encouraged for future land use planning in the Muskegon River watershed.

5. Conclusion

Urban expansion is a major driving force altering local and regional hydrology and NPS pollution. The Muskegon River watershed, one of the eastern costal watersheds of Lake Michigan, has undergone urbanization in recent decades. To explore the environmental consequences of future land use changes, urbanization trend was forecasted and long-term runoff and NPS pollution were estimated.

The land use change model, LTM, was used to investigate the development rate and locations of urbanization by the years 2020 and 2040. The effect of predicted urbanization on long-term annual average runoff and NPS pollutants were assessed using a web-based environmental impact model L-THIA. The spatial variation of urbanization and its impact were also evaluated at the subwatershed scale.

Urbanization occurs in the entire Muskegon River watershed at varied rates. The greatest urban development rate will mainly occur in the coast of Lake Michigan and cities, such as Muskegon, Cadillac and Lake City. The study area is likely subject to impacts on runoff and some NPS pollution from urbanization. These impacts revealed the following: (i) For long-term annual average runoff, the impact can be limited or considerable, depending on the rate of urbanization of the entire watershed, but in all cases the impact is significant in costal subwatersheds. (ii) For nutrient losses, the impact is slight for the entire watershed. However, it would be pronounced in certain subwatersheds. (iii) For heavy metal losses, the impact varies with the heavy metal type. The increase of nickel losses is significant regardless of spatial scales. (iv) For oil and grease, the impact would have the same increasing rate as urbanization for any spatial scale.

This study also demonstrated that a land use change model together with an environmental impact assessment model, such as LTM and L-THIA, are capable of generating useful information about future urbanization and its possible environmental impact. It indicated the integration of a land use change model and environmental impact assessment model could be a potential future research direction. Such coupled models can be used as decision support systems to inform policy formulation. Scenarios of land-use change help to explore possible futures and their environmental impacts under a set of simple conditions.

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