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Increase of Flood Risk due to Urbanisation: A Canadian Example

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Abstract. There has been increasing concern among the government officials who deal with emergency preparedness and natural disasters that increasing urbanisation is enhancing the risk from river flooding in urban areas. This study concerns such a risk for the City of London in the province of Ontario in Canada. It has been shown that between 1974 and 2000 there has been a considerably elevated risk from floods due to heavy urbanisation in the watershed of the Upper Thames River, of which the City of London is a part. Databases were prepared making use of satellite remote sensing technology on landuse classification and this information was integrated with meteorological and hydrological data records and analysed to obtain a quantitative estimate of the potential risk from river floods to London.

Key words: flood risk, remote sensing, urbanisation, flood management, Thames river watershed

1. Introduction

The goal of the study is to show that progressive urbanization increases considerably the risk of flooding using the City of London, Ontario, Canada as an example (Figure 1). The Upper Thames River Watershed (UTRW), shown in Figure 2, is at present experiencing net population migration trends that are quite similar to a very large metropolitan area, namely the City of Toronto, which is already facing increased risk of flooding due to urbanization. This study illustrates the process of establishing a relationship between an impervious area and river flows making use of remote sensing techniques and simultaneously analyzing the relevant meteorological and hydrological data. Results of this study have a direct application in the formulation of policies on land use planning and future balancing of urbanization through conservation means. Once the influence of urbanization on river flows is quantified, it will be possible to predict

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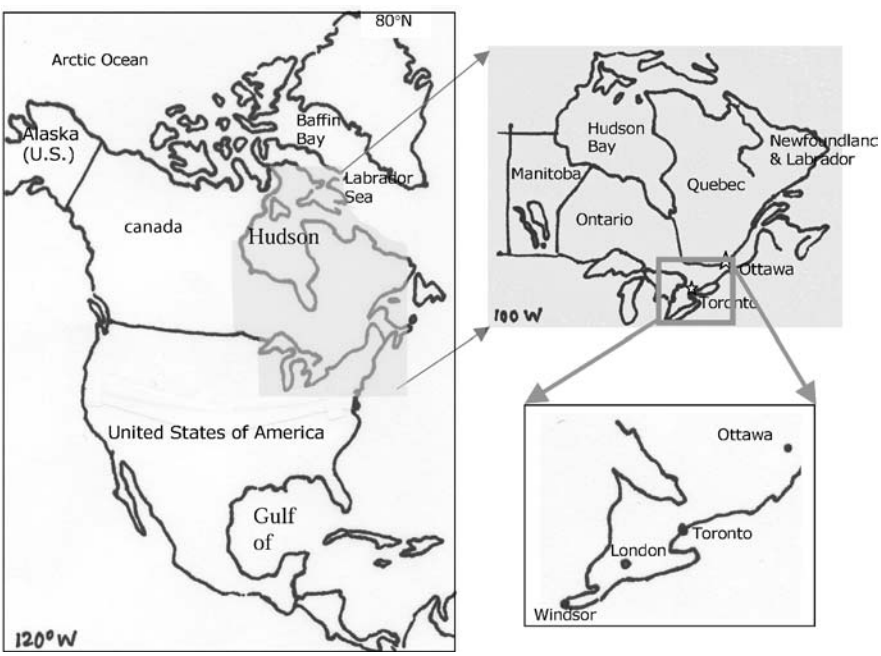

Figure 1. North America and the City of London in the province of Ontario in Canada (source: http://go.hrw.com/atlas/).

the future trends of flooding so that measures can be taken to cope up with increasing demand for residential and commercial areas without risking the increased intensity and extent of storm water in rainy periods.

The City of London was first settled in the early 1800s and at present it has a population of over 330,000. There were repeated flooding events from the very beginning and a catastrophic flood happened in July 1883 that killed 17 people. This led to a formal plan of a dyking system northwest of the forks of the Thames River, this dyke system now being referred to as the West London Dyke System (WLDS). In the early 1900s the dykes were reinforced, extended and raised in elevation for at least the second time. These elevated dykes were in place before the April 1937 flood that over topped the reinforcements and caused severe flooding. In the 1947 flood, some over topping of the dyke on the north branch section required evacuations, although flooding was not nearly as severe as in 1937.

At present, there are seven dyked areas in the City of London. The WLDS do provide some limited protection to a significant number of structures in the city. Behind the WLDS 1200 structures are protected at present to the 1937 flood level. The construction of flood control dams in the watershed after the formation of the conservation authority in 1947

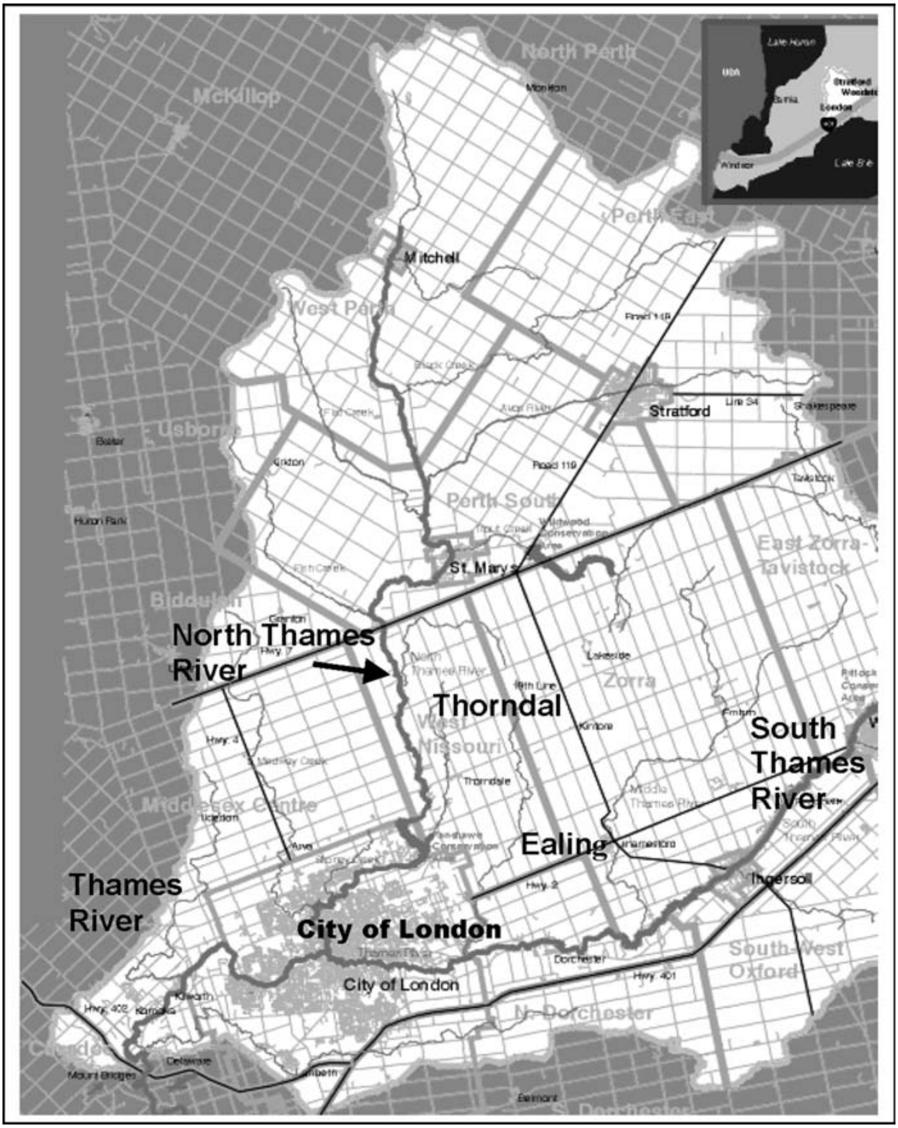

Figure 2. Upper Thames River Watershed.

has provided considerable additional protection for London and the dyked areas. During 1983 to 1987 the dykes were again reinforced and this reinforcement prevented flooding eight times since that times including winter 1997 and summer 2000. Without these upstream flood control works, the flooding in 2000 may have over-topped the dyke on the north branch just as it did in 1937.

The Thames River Watershed is 5825 km^2 in area and the length along the river is given in three parts: South Thames 86 km, North Thames

77 km, and Thames River 187 km. The highest elevation of the drainage basin is 420 m above sea level and the total watershed has a population of 532,000 (1995 Census). The next section provides more details about this watershed. The primary goal of the study is to quantify the flood risk to the City of London (Ontario, Canada) due to ever increasing urbanisation and also taking into account controlled measured such as dykes.

2. Upper Thames River Watershed

The Upper Thames River Watershed is the second largest in southwestern Ontario in Canada. The total area of this watershed is 3482 km^2 and falls within central meridian of 81 W, Zone 17 (satellite remote sensing) and length of drainage basin is 200 km covering the north and south branches of the Thames River (UTRCA, 2001). The watershed is mainly rural except for the larger urban centers of London, Stratford and Woodstock and has a population of over 400,000. The industrial sector within the watershed is based around automotive assembly and supply, aggregate extraction for the construction industry, and agricultural based industries. Agriculture is the main component of the landscape with approximately 3600 farms, including over 2000 livestock operations. The Thames River is much more responsive to climate changes than the larger Great Lakes area (UTRCA, 1994). Precipitation, or lack of it, can quickly cause conditions to change in the Thames River watershed. For example, stream flows were greatly reduced in the Thames River watershed in 1998 and 1999 causing many watercourses to dry up completely. The rate of runoff into the two branches of Thames River is too high (based on observations) and floods may occur at any time of the year, but it is the floods which occur during the spring break-up that are most frequent and most severe. The impervious clay soils, the high gradient of the riverbed, and the steep lateral slopes of the tributaries increase the rate of runoff (UTRCA publication, 1955). There are 20 sub-watersheds, 26 hydrologic observation stations, managed by Environment Canada, in the Upper Thames River watershed, out of which about 10 observation stations are on or near the Thames River. Hydrologic measurements at Thorndale (upstream inlet point) and Byron (downstream outlet point) have been used in this study.

The north branch of Thames River is regulated by Fanshaw dam (since 1952), which is located north of the City of London and downstream of Thorndale. Thorndale hydrologic measurement station records unregulated inflow into Fanshaw reservoir. Therefore, river flows at Thorndale are being used for analyzing the observed river flow time series. On the south branch of Thames River Pittock reservoir (since 1965) does not affect the flows at Ealing (Figure 2) observation station because it is quite far upstream from London. Byron measurement station, which is located south of London where the flow is measured and used in this study, can be considered the outlet point for the entire watershed. Though, total precipitation time series are available at London, Stratford and Woodstock meteorological stations managed by Environment Canada, only the time series of total precipitation at London has been used for the analysis purpose in this study because the effect of urbanization in London is the main focus here.

3. Methodology Used in this Study

This study has the following five components listed below;

- Land use classification of satellite imagery
- Remote sensing data analysis
- Hydrologic data analysis
- Integration of remote sensing images and hydrologic data analysis

Details of each of the above listed components are given in the following sections. However, it is useful to state here that a proper assessment of the increasing flood risk to the City of London from rapid urbanisation cannot be properly assessed without integration and analysis of landuse data (obtained mainly through remote sensing) combined with the hydrologic data analysis.

Figures 3, 4, and 5 respectively show the Landsat images for the UTRW on the following three dates: July 7, 1974; July 23, 1990; October 30, 2000. It can be seen quite clearly from the images that the urbanisation is taking place at a rapid rate. Table I lists the landuse classification results for the three images shown in Figures 3, 4, and 5.

As it is clear from the values given in the table, tremendous urban development has taken place over three decades amounting to 22.25% urban region in 2000 as compared to only 10.07% in 1974. Because landuse varies in any given year we have combined woods, row cops and legume grasses, small grains or grass and fallow land into one unit. It can be seen that the maximum change is for urbanisation. There is also a very significant difference in the percentage of row crops and legume grasses and small grains or grasses. Fallow land percentage is varying due to the different time of image acquisition of LANDSAT 5 and 7. Also, homestead percentage drops from 3.14% in 1974 to 1.86% in 2000. The difference in water availability over three decades can be noticed as well (Table I).

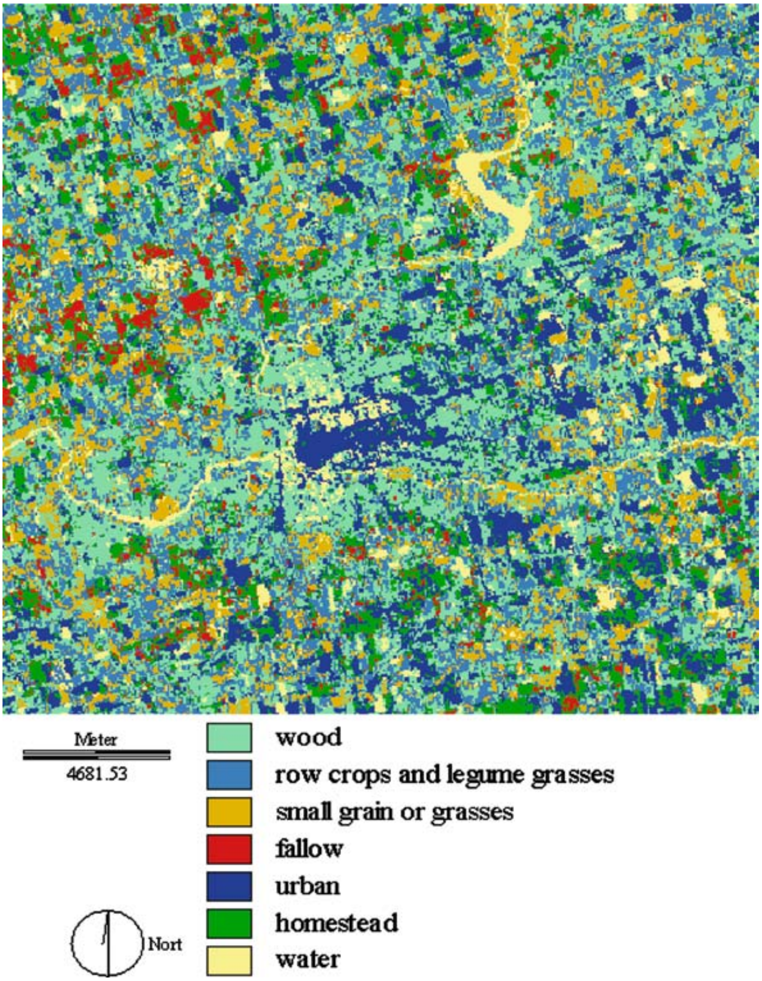

Figure 3. LANDSAT 1 Imagery of July 1974 classified for land use.

4. Land Use Classification of Satellite Imageries

Reflections measured by satellite sensors depend on the local characteristics of the earth's surface, which should be found out in order to extract information from the image data. Theoretically, a single spectral band of a remote sensing image should be enough to carry out classification; however, multi-spectral band classification gives much better results. Using image processing software satellite images of different time period for the same area were processed and analysed. To do so, first of all, *signatures*, which are statistical characterizations of each information (land use) class, were created. There are three main classification techniques, namely, the

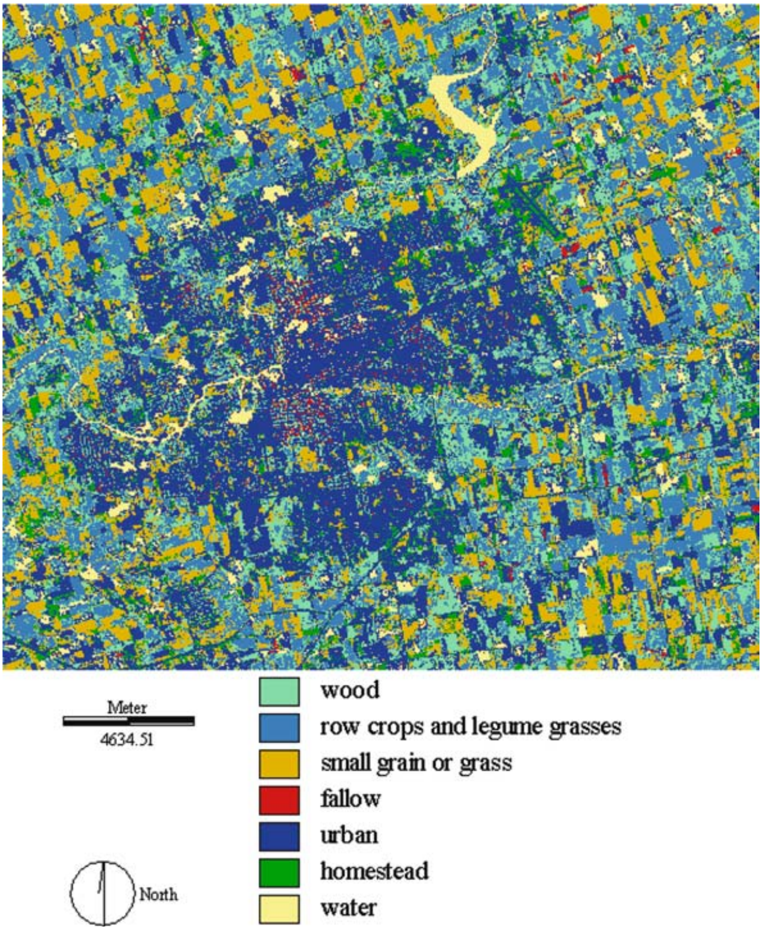

Figure 4. LANDSAT 5 Imagery of July 1990 classified for land use.

Parallelepiped procedure (included only for pedagogic reasons), Minimum Distance procedure (should be used when there are concerns about the quality of signatures) and Maximum Likelihood method (should be used when signatures are known to be strong). In this study it the third procedure that has been used. A brief description of the Maximum Likelihood method is give below;

The Maximum Likelihood method is based on Bayesian probability theory (ERDAS, 1991). It uses the mean and variance/covariance of signatures to estimate the posterior probability that a pixel belongs to each class. Maximum Likelihood procedure accounts for intercorrelation between bands; therefore, the information about the covariance between bands as well as their inherent variance is included thus producing elliptical zone of characterization of the signature. In fact, it calculates the

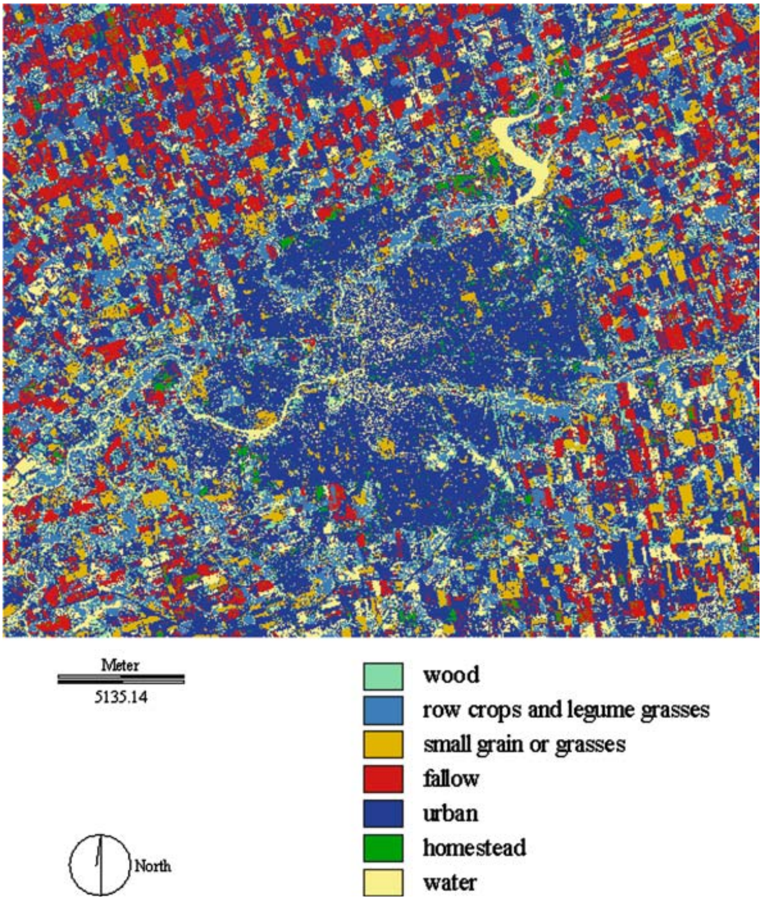

Figure 5. LANDSAT 7 Imagery of October 2000 classified for land use.

Table I. Landuse classification corresponding to the three images shown in Figures 3, 4, and 5.

Land use classes	July 7, 1974	July 23, 1990	October 30, 2000
Landuse changes in any year	83.14	78.41	73.16
Urban	10.07	16.72	22.25
Homestead	3.14	2.05	1.86
Water	3.65	2.82	2.73

The numbers shown are percentages. Because landuse varies in any given year we have combined woods, row cops and legume grasses, small grains or grass and fallow land into one unit. It can be seen that the maximum change is for urbanisation.

posterior probability of belonging to each class, where the probability is highest at the mean position of the class and falls off in an elliptical pattern away from the mean (Eastman, 2001). Mathematically, the procedure can be explained as (Gorte, 2000):

Let there be a set of N classes $C_1, \ldots, C_N$ and C_i is assigned as 'most likely' class to any feature vector x in an image. The most likely class label C_i for a given feature vector x is the one with the highest posterior probability $P\,(C_i|x)$. Each $P\,(C_i|x)$, $i \in [1, \ldots, N]$, is calculated, and the class C_i with the highest value is selected. The calculation of $P\,(C_i|x)$ is usually based on Bayes formula:

$$P(x|C_i) = \frac{P(x|C_i)P(C_i)}{P(x)} \tag{1}$$

where $P\,(x|C_i)$ – class probability density; $P(C_i)$ – prior probability and $P(x)$ – feature probability density (class-independent).

The disadvantages of *minimum distance* method are that it does not consider class variability. For example, if an urban land cover class is made up of pixels with a high variance, which may tend to be farther from the mean of the signature, *minimum distance* classification method might improperly classify outlying urban pixels. Inversely, a class with less variance, like water, may tend to get overclassified because the pixels that belong to the class are usually spectrally closer to their mean than those of other classes (ERDAS, 1991). *Parallelepiped* method's problem is that the pixels falling in overlapping parallelepipeds or that fall outside any parallelepipeds are not taken care of properly. Also, since parallelepipeds have corners, pixels falling in them may be classified which are actually quite far, spectrally, from the mean of the signature. Advantage of *maximum likelihood* method is that it takes the variability of classes into account by using the covariance matrix (ERDAS, 1991). Therefore, Maximum Likelihood supervised classification technique was chosen to apply to the images used in this case study to classify them in seven land use category, such as, woods, row crops and legume grasses, small grain or grasses, fallow land, urban/city, homestead and open water bodies. These land use classes coincide with the Upper Thames River Conservation Authority (UTRCA) land use classes according to UTRCA's 1983 land use map (UTRCA publication, 1983).

5. Remote Sensing Data Analysis

Three imagery of LANDSAT satellites covering the Upper Thames River watershed were acquired over the time period of 1974 to 2000. Though LANDSAT-1 was launched in 1972, no clear (cloud-free) image could be found for the study area before 1974. Within the constraints, three images that are included in this study are LANDSAT-1 MSS (Multi Spectral Scanner) of July 7, 1974, LANDSAT-5 TM of July 23, 1990, and LANDSAT-7 ETM^+ (Enhanced Thematic Mapper) of October 30, 2000. To be able to see the details in satellite imagery more clearly, while MSS image of LANDSAT-1 was converted into colour composite of bands 2 (0.6–0.7 μm), 3 (0.7–0.8 μm) and 4 (0.8–1.1 μm), LANDSAT-5 image was converted into colour composite of bands 3 (0.63–0.69 μm), band 4 (0.76–0.9 μm) and band 5 (1.55–1.75 μm) and ETM image of LANDSAT-7 was converted into a colour composite of bands 3 (0.63–0.69 μm), 4 (0.76–0.9 μm) and 5 (1.55–1.75 μm). Spectral resolution of LANDSAT-1 MSS image is 80 m and that of LANDSAT-5 TM and 7 ETM image is 30 m. Therefore, the different land use classes are more clearly visible in LANDSAT-5 and 7 images compared to LANDSAT-1 image.

Results of *Maximum Likelihood* supervised classification carried out on LANDSAT-1, 5 and 7 images are given in Figures 3, 4 and 5. Details of land use classes and their corresponding areas are given in Table I.

6. Hydrologic Data Analysis

One hydrologic data measurement station, which would represent the inlet and another hydrologic data measurement station, which would represent the outlet of the study area, were chosen for daily river flows time series acquisition. Similarly, another representative meteorological measurements station was chosen for daily total precipitation (rainfall + snow) time series. All the three time series (two river flows series and one total precipitation time series) were plotted together to get the peak flows pattern as well as the time to peak at inlet and outlet points of the study area. Also, the difference in peak flows at inlet and outlet stations would give an idea of the affect of the urbanization because the inlet station is at the upstream of the major city and outlet station is located just outside the city at the downstream.

Land use/cover classification results would illustrate the changes in land use over three decades. In particular increased urban area would imply increased impervious region and reduced time to peak as well as reduction in infiltration. Integrating the analysed hydrologic and meteorological data and classification findings would indicate the effect of urbanization on river channel flows.

Observed total precipitation (rainfall and snowfall) and river discharge measurements were plotted to illustrate the actual changing trend of peak flows during the years 1970 to 1997. Hydrologic observation station, Thorndale is located upstream of London and hydrologic observation station, Byron is located south of London at the outlet of UTRW (Figure 2).

The differences in peak flows between Thorndale and Byron, when plotted (Figure 6), show a mixed pattern over the years.

Figures 7–15 are plots of observed flows at Thorndale and Byron and total precipitation at London plotted together to have an understanding of the flow response to total precipitation occurred during each particular year. 1970 hydrographs at Byron and Thorndale, in Figure 7, plotted against total precipitation indicate a peak flow of about 300 m^3/s for a total precipitation of about 400 mm. As demonstrated in Figure 8, in 1976 a total precipitation of the order of 300 mm to 500 mm brought high flows of 660 m^3/s at Byron thus resulting in high peak flow difference between Thorndale and Byron, which means that the high peak flow difference was due to high total precipitation that year. In 1983 (Figure 9) the peak flow difference between Byron and Thorndale is due to the low total precipitation. However, the precipitation increased from the middle towards the

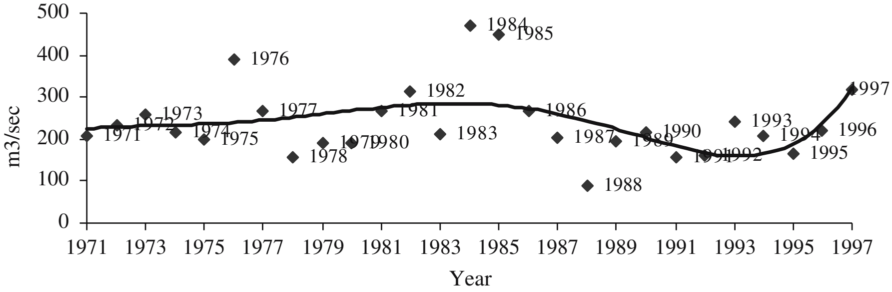

Figure 6. Plot of differences in observed peak flows at Thorndale and Byron.

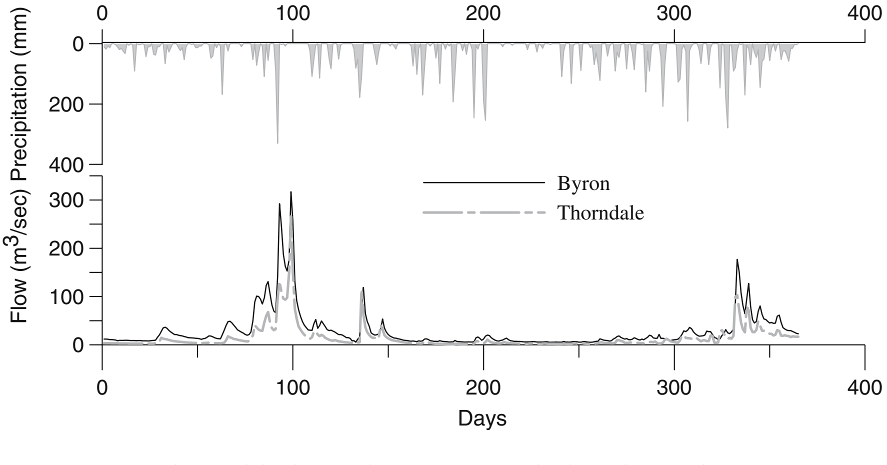

Figure 7. 1970 observed hydrographs at Byron and Thorndale and total recipitation at London, Ontario.

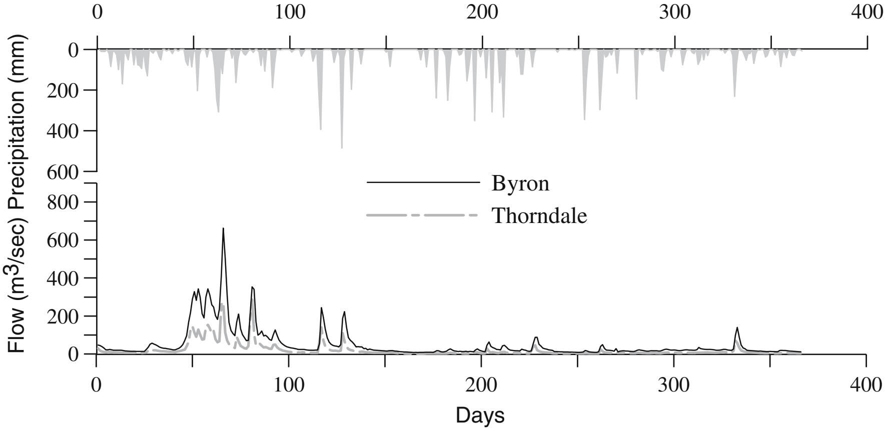

Figure 8. 1976 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

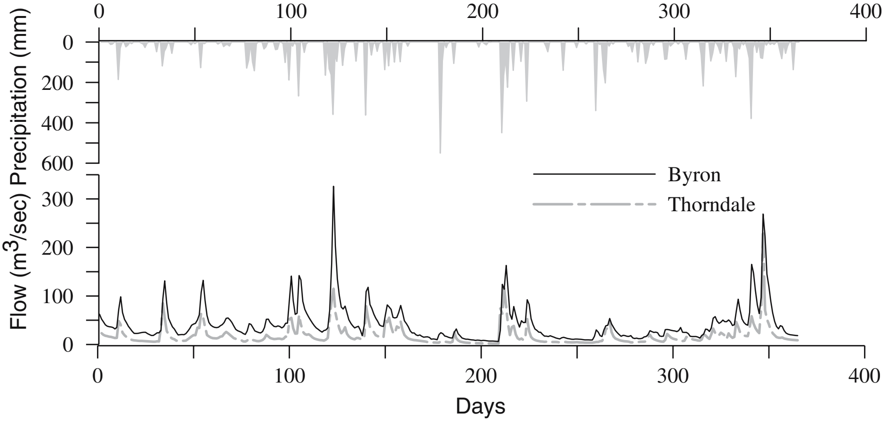

Figure 9. 1983 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

end of the year bringing the flows at the beginning of 1984 to another high (Figure 10). Similar pattern of precipitation can be seen in 1985 (Figure 11) flows, which is the result of over 400 mm of continuous precipitation between the 50th and 100th day of the year. The peak flow differences are very low in 1988 (Figure 12). January 1993 precipitation brought an instant high peak of more than 700 m^3/s (Figure 13). In the 1995 (Figure 14) five peaks were observed even though the total precipitation had been of the order of 200 mm to 400 mm.

In 1997 (Figure 15), too, despite the total precipitation being as low as below 200 mm during the beginning of the year there are instant high flows of more than 800 m^3/s at that time.

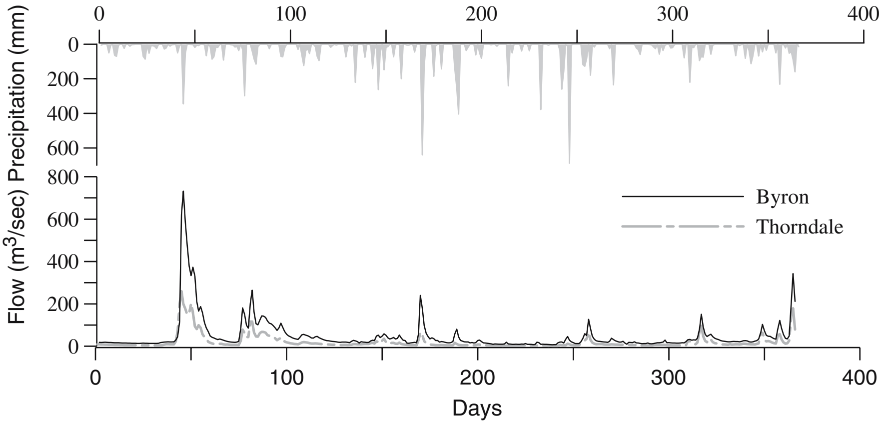

Figure 10. 1984 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

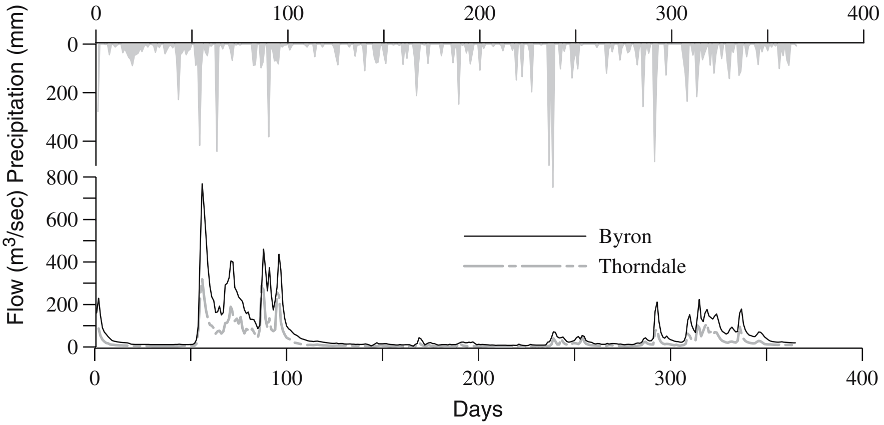

Figure 11. 1985 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

7. Integration of Remote Sensing Images and Hydrologic Data Analysis

The remote sensing images, when classified for land use classes (woods, row crop and legume grasses, small grain or grass, fallow land, urban/city, homestead and water), give an indication that there has been major increase in urban sprawl over past three decades. Because landuse varies in any given year we have combined woods, row cops and legume grasses, small grains or grass and fallow land into one unit, namely landuse changes in any year. It is clear from Table I that this landuse change has

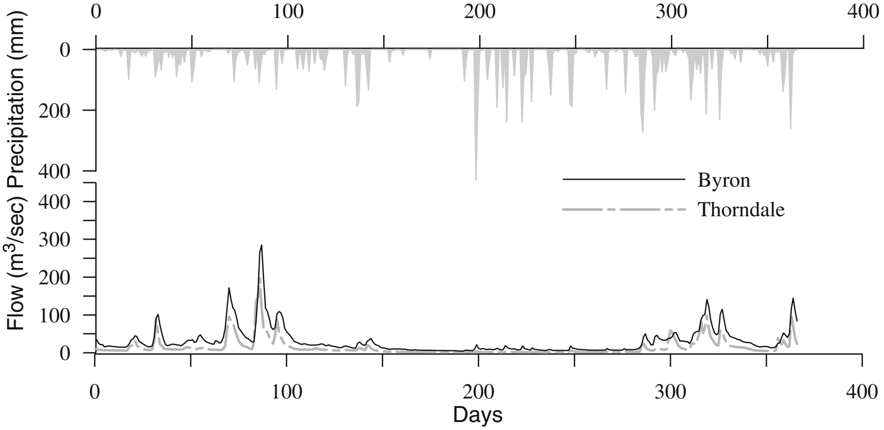

Figure 12. 1988 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

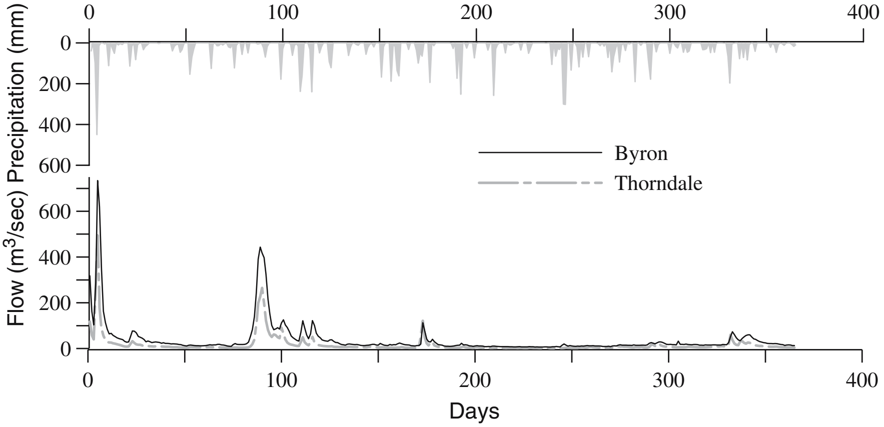

Figure 13. 1993 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

dropped by 10% over a period of two and a half decade. Looking at the hydrologic data, it can be seen that whereas, in 1970 (Figure 8) a total precipitation of nearly 400 mm resulted in 350 m^3/s of peak flow, in 1997 (Figure 14) about 200 mm of total precipitation brought about more than 800 m^3/s of river flows at Byron (outlet point of UTRW). Similar trend can be seen in other years too, except for the fact that 1988 and 1989 were dry years according to UTRCA report (http://www.thamesriver.on.ca). So, it can be inferred that increase in impervious area enhances the river flows considerably.

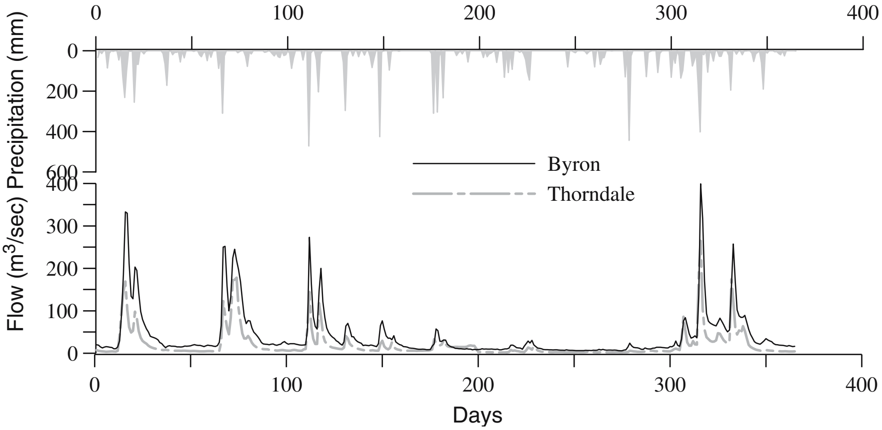

Figure 14. 1995 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

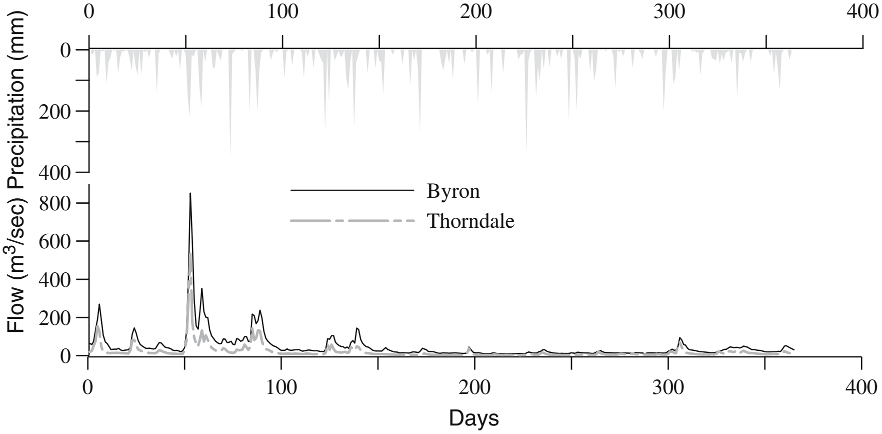

Figure 15. 1997 observed hydrographs at Byron and Thorndale and total precipitation at London, Ontario.

8. Discussion of Results

Results presented in Table I and Figures 3, 4, and 5 show that tremendous urban development has taken place in the watershed over three decades. Areas covered by woods came down in 1983 but rose again in the year 2000, probably due to the conservation measures taken by the provincial government and environmental groups after mid-70s (UTRCA, 1975). Cropping is a dynamic process, which keeps changing several times during the year and the timing of the three remote sensing images do not match, therefore the different landuse classes of woods, row crops & legume grasses, and small grains or grass, have been combined into one class, called ‘landuse changes in any year’. This landuse change has dropped from 83% in 1974 to 73% in the year 2000. Homestead percentage drops gradually over the decades, indicating that farmers have moved to towns indulging in other professions and selling their lands to developers. Surface water area appears to be decreasing over the years – from 3.65% in 1974 to 2.73% in 2000.

Considerable areas of woods have been cleared up for urban development in and around London city in UTRW and number of homestead have reduced considerably. Considering the awareness regarding conserving the forests that came into effect in late 70s (UTRCA, 1975), the rise in woods (dense forested area) is a positive sign, which conveys the message of successful implementation of UTRCA’s policies. Similarly, new policies can be brought into affect to balance the urban and industrial development as a measure to keep the direct runoff under control and hence mitigate the chances of occurrences of floods during high intensity storms.

9. Concluding Remarks

Over the last three decades urban development has taken place everywhere in general. From conservation point of view the planning for developments is vital. In Upper Thames River watershed drastic land use changes have taken place over three decades. Whether or not these changes affect the river flows (leading to possibility of floods) has been discussed in this report. The Upper Thames River watershed case study clearly demonstrates that urban area has increased to 22.25% of the total watershed area in the year 2000 compared to only 10.07% in 1974. According to natural hydrological phenomena, due to increased impervious area precipitation responds quickly reducing the time to peak and producing higher peakflows in the drainage channels. Figures 8–15 illustrate this phenomenon through the hydrographs plotted using observed hydrologic and meteorological time series. Quantity of available surface water appears to be reducing slightly over the decades (3.65% in 1974 to 2.73% in 2000). Forests are being cut down continuously at an alarming rate reducing the forest reserves to a mere 13.06% at present. With the help of remote sensing technology the Upper Thames River watershed could be studied efficiently in lesser time compared to conventional methods. To update the database on land use in the watershed, all we would need to do is acquire more recent satellite imagery and carry out the land use classification. The case study is an example of how remote sensing technology can help in understanding the development pattern in a region and its affect on the hydrology of the area so as to help the authorities in forming the conservation policies with respect to landuse.

Conventionally, flood emergency management, both public and private usually responds to crises rather than being concerned with the broader issues of vulnerability and its management (Shrubsole, 2001). Its time this culture changed a little so other alternatives for mitigation of flood damages, land slides and soil erosion, such as, planned land use, should be explored, proposed and implemented. The future is promising with the new generation of very high-resolution satellites, like, IKONOS, TSINGHUA and QUICKBIRD and many more coming future years. They will provide the daily high-resolution imaging of the world to track natural and human-made disasters.

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