RRB-87-43

This paper will be presented at UNESCO Symposium on Hydrological Processes and Water Management in Urban Areas Duisburg, FRG, April, 1988 and the contents are subject to change.

This copy is to provide information prior to publication.

EFFECTS OF URBANIZATION ON WATER RESOURCES IN THE WATERFORD RIVER BASIN

by
W. Ullah[1], J. Marsalek[2],
T. Hennigar[3] and T.L. Pollock[4]

[1]Newfoundland Dept. of Environment
St.John's, Nfld., Canada
[2]National Water Research Institute
River Research Branch
Burlington, Ontario, Canada
[3]WP&M Branch, Environment Canada
Dartmouth, N.S., Canada
[4]Water Quality Branch
Environment Canada
Moncton, N.B., Canada

August, 1987
NWRI Contribution #87-111

MANAGEMENT PERSPECTIVE

Urbanization of the Waterford River Basin has contributed to increased incidence of flooding and water pollution in the basin. To evaluate the impact of future urban development on water resources in the basin, a special hydrologic study of the basin has been undertaken. Study results indicate that, owing to special climatic and physiographic features of the basin, future urbanization will not significantly increase the volume of runoff, but will increase its peak flows. Such flow increases are caused by increased speed of runoff and can be effectively controlled by proper planning of drainage and land use. Low-density drainage systems delay runoff and thereby reduce runoff peaks and improve runoff quality which may be fairly impaired during the early stages of runoff. Therefore, the anticipated adverse impacts of urbanization on water resources in the Waterford River Basin can be avoided by proper planning of future development. The report should be of interest to planners, designers and managers dealing with urban water resources.

PERSPECTIVE-GESTION

L'urbanisation du bassin de la rivière Waterford a augmenté la fréquence des inondations et la pollution de l'eau dans le bassin. Pour analyser les répercussions des futurs projets d'aménagement urbain sur les ressources en eau du bassin, on a entrepris une étude hydrologique spéciale du bassin. Selon les résultats de l'étude, l'urbanisation future, grâce à certaines caractéristiques climatiques spéciales et à certains traits principaux de la structure du bassin, ne fera pas considérablement augmenter le volume des eaux de ruissellement, mais provoquera une augmentation de ses pointes de débit. Ces augmentations du débit sont attribuables à une augmentation de la vitesse du ruissellement et peuvent être efficacement contrôlées grâce à une planification appropriée du drainage et de l'utilisation des terres. Les systèmes de drainage à faible densité retardent le ruissellement et, par conséquent, réduisent les pointes de débit et améliorent la qualité des eaux de ruissellement qui peut se détériorer passablement au début des périodes de ruissellement. Par conséquent, on peut éviter les répercussions défavorables de l'urbanisation sur les ressources en eau du bassin de la rivière Waterford en planifiant convenablement l'aménagement futur. Le rapport devrait intéresser les urbanistes, les ingénieurs et les administrateurs qui travaillent dans le domaine des ressources en eau urbaines.

EFFECTS OF URBANIZATION ON WATER RESOURCES IN THE WATERFORD RIVER BASIN

W. Ullah
Newfoundland Dept. of Environment, St.John's, Nfld., Canada
J. Marsalek
National Water Research Inst., Burlington, Ontario, Canada
T. Hennigar
WP&M Branch, Environment Canada, Dartmouth, N.S., Canada
T.L. Pollock
Water Qual. Branch, Environment Canada, Moncton, N.B., Canada

Abstract

Continuing urbanization of the Waterford River Basin will not significantly increase the volume of runoff, but will increase the peak flows, by about 25%. Although urban development has increased pollution in the river during the early stages of runoff, the only real concern has been caused by high bacteria counts preventing body-contact recreation in the river. Runoff quantity and quality in fully urbanized sewered catchments have been effectively controlled by maintaining low effective imperviousness and low density of sewer inlets. Groundwater in the basin has been barely affected by progressing urbanization except for elevated levels of sodium chloride originating from road salting operations.

1 Introduction

Ongoing urban development in the Waterford River Basin has adversely affected water resources in the basin through increased runoff, higher incidence of flooding, and deterioration of surface water quality. It is anticipated that further development of the basin will aggravate the condition of water resources, unless proper control measures are adopted. In response to concerns about the state of water resources in the Waterford River Basin, the Department of Environment of the Province of Newfoundland and Environment Canada initiated a joint 5-year study of the basin in 1980. The main study objectives were to evaluate the

INCIDENCE DE L'URBANISATION SUR LES RESSOURCES EN EAU DANS LE BASSIN DE LA RIVIÈRE WATERFORD

W. Ullah
Newfoundland Dept. of Environment, St. John, Nfld., Canada
J. Marsalek
Institut national de recherche sur les eaux, Burlington (Ontario), Canada
T. Hennigar
Planification et gestion des eaux, Environnement Canada, Dartmouth (N.-É.), Canada
T.L. Pollock
Direction de la qualité des eaux, Environnement Canada, Moncton (N.-B.), Canada

Résumé

L'urbanisation continue du bassin de la rivière Waterford ne fera pas considérablement augmenter le volume des eaux de ruissellement, mais provoquera une augmentation des pointes de débit d'environ 25 p. 100. L'aménagement urbain a accru la pollution de la rivière au début des périodes de ruissellement, mais les seules préoccupations réelles découlent du fait que le taux élevé de bactéries empêche la population de se baigner dans la rivière. On contrôle efficacement le volume et la qualité des eaux de ruissellement dans les bassins de drainage entièrement urbanisés en maintenant les bouches d'égout à un faible taux d'impermêabilité et à une faibe densité. Les eaux souterraines du bassin n'ont guère été altérées par l'urbanistion progressive, mais les taux de chlorure de sodium ont augmenté à la suite de l'application du sel de voirie.

effects of progressing urbanization on water resources in the study area and to investigate the means for controlling such effects.

2 Study area

The Waterford River Basin is located near St.John's, Newfoundland, Canada. Although the entire basin measures almost 77 km^2, the study area in the upper part of the basin measures only 53 km^2. Land use types and physical features of the study area include forests, agricultural, urban, and recreational areas, ponds, bogs, river channels, and gravel pits. More than 50% of the study area is still forested. Because of unfavourable soil conditions, trees are relatively small and only a small portion of land is suitable for agricultural purposes. The main stream in the basin, the Waterford River, flows northeasterly over a distance of about 14 kilometres and discharges into St. John's harbour. South Brook, flowing through the forested parts of the basin, is the largest tributary.

Batterson (1984) and King (1984) reported that all rocks in the Waterford River Basin are of late Precambrian age and generally are interbedded clastic sediments of slate-siltstones, sandstones, and conglomerates. About 90% of the field area is covered by a veneer of till which, together with the orientation of hills and rocky ridges parallel to the bedrock structures, suggests that rainwater and snowmelt will be largely converted into surface runoff with little infiltration into the groundwater system.

The soils in the study area have developed from the underlying rocks. Such soils are coarsely to moderately-coarsely textured, strongly to extremely acidic, and low in natural fertility. They are generally classified as the soils of the humoferric and ferro-humic podzol group. Although these soils exhibit rapid surface drainage, their internal drainage generally ranges from poor to very poor and this leads to fast hydrological response during rainfall or snowmelt.

The climate in the study area is moderated by the sea. Consequently, temperature variations are fairly limited and contribute to relatively mild winters and cool summers. The average daily maximum and minimum temperatures are 8.6°C and 1.0°C, respectively. Precipitation occurs on the average 207 days a year and the average annual precipitation is 1514 mm. High streamflows usually occur in the spring as a result of the combined effect of rainfall and snowmelt. Low flows usually occur from June to August, or during the winter months. From 1974 to 1984, the minimum and maximum instantaneous discharges observed at Kilbride were 0.15 m^3/s and 66.1 m^3/s, respectively.

The urbanized part of the basin, which represents about 20% of the total basin area, falls under the jurisdiction of the municipalities of Mount Pearl and Paradise, and the St. John's Metropolitan Board. The approximate populations of these municipalities, within the study area boundaries, are 21,500, 3,500 and 3,000, respectively. Expansions of the urban areas in the basin during the study period were much smaller than expected. Future urban development is expected mostly around Mount Pearl.

3 Study components

The study of the Waterford River Basin addressed a wide range of interrelated hydrological and water quality aspects which can be grouped into the two study components outlined below.

- Investigations of surface water in the basin

The assessment of the hydrologic characteristics of the Waterford River and the changes caused by urbanization was a major task of this study. Because the study period was not long enough to detect any regime changes in the observed flow records, it was necessary to investigate the river regime for current and future land use by means of computer modelling. In a related activity, flood risk maps were produced for simulated 20-year and 100-year floods. On a smaller scale, runoff from a fully urbanized and sewered test catchment was also studied.

Surface water quality was studied at a number of stations on the Waterford River, its tributaries, and in the urban test catchment. Such a program was designed to detect the effects of land use changes on water quality.

- Investigations of groundwater

The impact of urbanization on groundwater levels and bacteriological and chemical quality was also investigated using a network of observation wells.

4 Study results and discussion

The study results are presented and discussed according to individual components.

4.1 Surface waters

Streamflow changes in basins undergoing urbanization are hard to detect in short-period hydrometric records and, furthermore, such an analysis for current and past land use does not yield predictive capability for future land use. Consequently, streamflow changes in the Waterford River Basin were studied by means of hydrological modelling using field observations for model calibration. For this purpose, a continuous hydrologic model, the Hydrologic Simulation Program - Fortran (HSPF), was used by Ng and Marsalek (1987). The HSPF is a comprehensive model for predicting the watershed hydrological response and streamflow water quality. In the study described here, a limited computer support and lack of special input data restricted HSPF simulations to hydrological aspects only. In that case, the model employs meteorological input data, such as precipitation, air temperature, wind movement, solar radiation and evaporation, and physiographic data, such as land use and soil characteristics, to simulate hydrological processes that occur in the watershed.

Flows observed in the Waterford River were reproduced fairly well by means of HSPF model, which was calibrated for annual balance, monthly (seasonal) flows and event hydrographs, using hourly input data and simulation time steps. Good to very good agreement between the observed and simulated data was obtained for annual and monthly streamflows, and for low and peak hourly flows. The simulated and observed annual, monthly and event peak flows were within 3, 15 and 5%, respectively. The calibrated model was then applied to three hypothetical future land use scenarios representing increases in the basin imperviousness by 50, 100, and 200%. Although such increases in imperviousness increased the simulated annual and monthly streamflow volumes by less than 1%, the corresponding increase in simulated peak flows was much more significant. The doubling of imperviousness of the basin would result in increases of the largest observed peak flows by up to 25%. Such unexpected results are caused by the special topographic and geologic features and low evapotranspiration in the basin leading to high conversion of precipitation into streamflow, in the range of 80%. The increases in peak flows arise largely from an increased speed of runoff in developed areas. Such phenomena are difficult to properly simulate, because their simulation requires detailed information on drainage density, and connectivity and roughness of drainage elements in future developments. As more data become available, the reliability of simulation of flow changes will improve.

In a related activity, the 20- and 100-year open water flood profiles and flooded areas were determined by Environment Canada and Newfoundland Department of Environment (1986) using the HEC-II hydraulic model. The flows used in this work were determined by the HYMO model which is a relatively simple event model.

Investigations of runoff in a fully developed and sewered catchment in the study basin were reported on by Marsalek et al. (1985) and indicated low runoff peaks which were caused by a relatively low effective imperviousness (20%) of the catchment and by low density of sewer inlets. The effective imperviousness represented about one half of the total catchment imperviousness (38%) and was achieved by discharge of roof drainage and other drainage waters onto pervious areas. Low density of sewer inlets extended the runoff overland travel, thus increasing the time of concentration and reducing the runoff peaks. Observed runoff volumes and peak flows were well reproduced by common urban runoff models, such as ILLUDAS and SWMM. Typical differences between the observed and simulated flow peaks were smaller than 0.010 m^3/s.

To investigate anthropogenic influences on water quality in the study area, monitoring stations were established in both urbanized and rural parts of the basin and their chemical, bacteriological and biological data were compared. Such comparisons, reported by Arseneault et al. (1985), indicated that urban areas contributed bacteria and dissolved and suspended inorganic as well as organic matter to surface waters. Peak loadings of suspended solids as well as other turbidity causing agents, nitrate-nitrite, total nitrogen, total phosphorus and extractable metals were observed during the early stages of runoff.

However, these relatively high concentrations did not prevail long in the river. High flow velocities in the Waterford River did not permit accumulation of phosphorus or other nutrients and, therefore, excessive autotrophic productivity was not a problem in the basin, except in rare cases of extremely low discharge conditions at some sites.

In biological monitoring, Stirling and Clemens (1986) sampled the benthic invertebrates of the Waterford River System using artificial substrates with the objective of identifying indicator communities for water quality and assessing the deterioration of water quality in that system. Diverse communities, with a small number of individuals per species, were considered to indicate clean water, while sites with poor water quality seemed to support communities dominated by a few species with large numbers of individuals. It was observed that South Brook, the main tributary passing through the undeveloped part of the study basin, contained water of relatively good quality, while that of the Waterford River itself was only fair to poor. In the overall evaluation, surface waters in the study area were found to be of acceptable physical and chemical quality for the present water uses. There are, however, concerns about body-contact recreational use of the river, because of high bacteria counts in developed parts of the basin.

Runoff quality was also studied by Marsalek et al. (1985) in the fully sewered catchment. Although runoff showed typical signs of urban pollution arising from characteristic land use activities, such a pollution in the studied catchment was relatively limited because of low density of the development, low levels of urban activities within the catchment, and absence of industrial complexes in the immediate vicinity. Some concerns may be caused by the elevated concentrations of sodium chloride, zinc and lead.

4.2 Groundwater

Robinson and Gibb (1987) observed groundwater in a network of wells and reported that, in general, the groundwater levels in the basin were unlikely to be affected by progressing urbanization, because of high surface runoff rates and limited recharge rates even in undeveloped parts of the study basin. The data indicate that the only changes caused by urbanization will be those in the chemistry of groundwater and among those the most readily detectable was the increase in sodium and chloride concentrations caused by road salting operations. Such effects were particularly strong in the vicinity of salt storage depots. Nitrate concentrations observed in groundwater were very low and well below 10 mg/L which is the limit recommended for potable water. Highly fluctuating coliform and iron values did not allow detection of any trends.

5 Conclusions and summary

The climate and geology of the Waterford River Basin result in high conversion of precipitation into runoff and, consequently, future urban developments in the basin should not significantly increase streamflow volumes. Increases in peak flows will result from the increased speed of runoff in the expected developments and appear to be about 25%. Chemical, bacteriological and biological monitoring of surface waters in the basin indicate that urban developments substantially increase the levels of pollution during the early stages of runoff. The biological monitoring based on diversity and numbers of benthic invertebrates indicated fair to good water quality in the Waterford River. The only parameter causing real concern is bacteria whose elevated counts prohibit the use of the river for body-contact recreation. In fully urbanized and sewered catchments, low runoff peaks can be achieved by maintaining low effective imperviousness and low density of sewer inlets. The composition of stormwater appears to be acceptable mainly because of low level of urban activities and absence of industrial complexes. Groundwater in the basin is barely affected by progressing urbanization, except for elevated levels of sodium chloride originating from road-salting operations. In the overall evaluation, the adverse effects of future urbanization on water resources in the basin can be minimized provided that such developments progress in a well-planned manner.

6 References

Arseneault, R.A., T.L. Pollock, S. Ratnam, and D.Hansen 1985. Surface water quality study in the Waterford River Basin. Technical Report No. 4, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 91 pp.

Batterson, M.J. 1984. Surficial geology of the Waterford River Basin. Technical Report No. 1, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 29 pp.

Environment Canada and Newfoundland Department of Environment 1986. Flood study, Vol. 1 and 2. Technical Report No. 11, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 61 and 212 pp.

King, A.F. 1984. Geology of the Waterford River Basin. Technical Report No. 2, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 25 pp.

Marsalek, J., U. Panu, and H.Y.F. Ng 1985. Storm runoff study of Newtown urban catchment. Technical Report No. 5, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 122 pp.

Ng, H.Y.F. and J. Marsalek 1987. Streamflow modelling in the Waterford River Basin using the HSPF model. Technical Report No. 12, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 56 pp.

Robinson, J.W. and J.E. Gibb 1987. Groundwater study. Technical Report No. 6, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 80 pp.

Stirling, B. and T. Clemens 1986. Biological indicators of water quality in the Waterford River System. Technical Report No. 8, Urban Hydrology Study of the Waterford River Basin, Newfoundland Department of Environment, St. John's, Nfld., 157 pp.