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CONTINUOUS SIMULATION OF CHANGES IN STREAMFLOW DUE TO URBANIZATION

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MANAGEMENT PERSPECTIVE

Adverse effects of urbanization on water resources are widely recognized by water managers. Such problems and their prediction for future land use scenarios need to be properly addressed in water management planning. For this purpose, a special methodology was developed and demonstrated in a joint federal/provincial study of the Waterford River Basin located near St. John's, Newfoundland. This methodology is based on the use of continuous simulation of the basin response to the future development scenarios. In these simulations, the continuous simulation model, HSPF, developed by the U.S. Environmental Protection Agency, was successfully used to predict the changes in streamflow caused by the progressing urbanization. Although the impact of future urbanization on high flows in the basin could have been predicted by means of simpler models, the model employed offers additional advantages including simulation of low flows and water quality aspects. The same approach can be applied in other urbanizing basins and the methodology presented should be of interest to water resource researchers and managers alike.

ANALYSE DE GESTION

Les effets nocifs de l'urbanisation sur les ressources en eau sont largement reconnus par les gestionnaires des eaux. On doit en tenir compte et les prévoir dans la planification de gestion des eaux, en ce qui a trait notamment à l'utilisation future des terres. À cette fin, une méthode spéciale a été mise point et testée dans le cadre d'une étude fédérale-provinciale conjointe du bassin de la rivière Waterford, près de St. John's, à Terre-Neuve. Cette méthode consiste à simuler continuellement la réaction du bassin aux divers scénarios de mise en valeur. Le modèle de simulation continue, le HSPF, mis au point par le U.S. Environmental Protection Agency, a été utilisé avec succès pour prévoir les changements du débit causés par l'urbanisation croissante. Les effets de l'urbanisation future sur les débits élevés dans le bassin auraient pu être analysés à l'aide de modèles simplifiés, mais le modèle utilisé offre des avantages supplémentaires; il permet notamment de simuler des débits faibles et de recueillir des données sur la qualité de l'eau. La même approche peut être appliquée à d'autres bassins en voie d'urbanisation de sorte que la méthode décrite devrait intéresser à la fois les chercheurs et les gestionnaires des ressources en eau.

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ABSTRACT

Continuing urbanization is adversely affecting water resources in urbanizing river basins by disturbing flow regimes and downgrading water quality. Such effects have been observed and studied in the Waterford River Basin near St.John's, Newfoundland. The effects of future urbanization on flows in the Waterford River have been studied using both single-event and continuous simulation models. In continuous simulation, reported here, the model developed by the U.S. Environmental Protection Agency has been used and calibrated, with good-to-very-good results, against the available precipitation/ streamflow records. The calibrated HSPF model was used to simulate streamflows for several hypothetical land development scenarios. Such simulations indicated that the projected future development will not increase significantly the seasonal or annual streamflow volumes, because of the high conversion of precipitation into streamflow under the existing basin conditions. However, some increases in peak flows and incidence of flooding have been indicated by the simulations. If the basin impervious areas are doubled, the highest peak flows in the basin would increase by about 25%. It was recommended to use the calibrated HSPF model, expanded for water quality simulation modules, in the future management of water resources in the basin.

RÉSUMÉ

Dans les bassins fluviaux qui connaissent une urbanisation continue, on constate des effets néfastes sur les ressources en eau, soit la perturbation des régimes d'écoulement et la diminution de la qualité de l'eau. Nous avons observé et étudié de tels effets dans le bassin de la rivière Waterford près de St. John's, à Terre-Neuve. Pour étudier les effets de l'urbanisation sur l'écoulement de la rivière Waterford, nous nous sommes servis d'un modèle de phénomène unique et d'un modèle de simulation continue. En ce qui concerne la simulation continue, qui nous intéresse ici, nous avons utilisé le modèle HSPF de l'Environmental Protection Agency des É.-U., que nous avons étalonné avec des résultats bons à trés bons grâce aux relevés disponibles sur les précipitations et sur l'écoulement. Le modèle étalonné a servi à simuler l'écoulement pour plusieurs scénarios, hypothétiques, d'aménagement des terres. Selon les simulations, les projets d'aménagement n'entraîent pas d'augmentation marquée des volumes saissonniers et annuel de l'écoulement, et ce, en raison du rapport de conversion élevé des précipitations à l'écoulement pour les conditions actuelles du bassin. Nous avons remarqué toutefois une certaine augmentation de l'ecoulement maximal et des épisodes de crue. Pour un doublement de la surface imperméable du bassin, on obtient une augmentation de l'écoulement maximal absolu de 25 %. Nous recommandons que soit utilisé le modèle HSPF étalonné, et doté de modules de simulation de la qualité de l'eau, dans la gestion future des ressources en eau, dans ledit bassin.

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INTRODUCTION

In response to the concerns about the adverse effects of urbanization on water resources in the Waterford River Basin (Newfoundland Environment, 1978), a five-year federal-provincial study, referred to as the Waterford River Basin Urban Hydrology Study, was conducted from 1980 to 1985. The main study objectives were to examine the processes causing changes in the hydrologic regime of the Waterford River, to establish a modelling capability for simulating such changes, to develop solutions to specific water management problems in the studied basin, and to develop guidelines for implementation of similar solutions elsewhere in Newfoundland. The study has been successfully completed and its results are discussed elsewhere (Ullah et al., 1988). The paper that follows deals with one of the study components, continuous simulation of streamflow in the Waterford River Basin and the use of such simulations for investigating the impact of future urban development in the basin.

STUDY AREA

An upper part of the Waterford River Basin, located near St. John's, Newfoundland, measuring 53 km^2, was selected as the study area. The main stream in the basin is the Waterford River, which flows northeasterly over a distance of about 14 kilometres and discharges into St. John's Harbour. Its main tributary, South Brook, flows through the undeveloped part of the basin and discharges into the Waterford River just upstream of the hydrometric station at Kilbride.

The land use in the basin was reported by Jones (1986) as follows: forest - 33%, unproductive land - 29%, urban areas - 19%, agricultural areas - 11%, and transitional land use - 8%. The approximate population of the study area is about 30,000 persons. The impervious area in the basin was estimated at 2.65 km^2. The basin geology and soil characteristics indicate that precipitation and snowmelt are largely converted into runoff with little loss by infiltration into the ground (Batterson, 1984; King, 1984).

The climate in the study area is moderated by the sea. The average annual precipitation of 1514 mm/year is distributed, on the average, over 207 days in a year. The evapotranspiration in the basin is rather low, less than 300 mm/annually (Ng and Marsalek, 1987). High streamflows occur in the spring, as a result of the combined effect of rainfall and snowmelt, or in late fall. Low flows occur in summer or winter months. The extreme flows observed in the Waterford River at Kilbride, from 1974 to 1984, were 0.15 m^3/s and 66.1 m^3/s, respectively.

STUDY APPROACH

One of the important trends noted in recent urban developments is the acceleration of the urbanization process induced by technological changes coupled with socio-economic demands. Fast expansion of urban developments in the study area was of concern and, consequently, it was desirable to evaluate the impact of anticipated future land use changes on the hydrological regime of the Waterford River. Recognizing the short duration of the study, it was unlikely that changes in the river regime could be observed during the study period. Consequently, the general strategy was to establish calibrated models of the river response and to use such models to predict regime changes arising from future land use changes. For this purpose, two models were used, an event model, HYMO, and a continuous simulation model, Hydrologic Simulation Program - Fortran (HSPF) (U.S. Environmental Protection Agency, 1980). When selecting these models, it was recognized that for analysis of flow peaks the event model might be sufficient. However, the continuous simulation HSPF model offers additional advantages, because it can simulate both high and low flows, and can be easily expanded to water quality simulations in the future and serve for integrated water management in the basin.

A three-year data base, established during the Waterford River Basin Study (Ullah et al., 1988), was sufficient to support only the quantity modules of HSPF and could be used to calibrate the model. The calibrated model was then applied to three hypothetical future land use scenarios assuming various increases in the basin imperviousness (Ng and Marsalek, 1987). Such scenarios cover a wide range of conditions which could possibly materialize during the periods of economic expansion. The results of such investigations follow.

RESULTS AND DISCUSSION

Special physiographic and climatic features of the basin lead to a very high conversion of precipitation into streamflow, in the order of 80-90%. Although such values are unusual compared to the typical examples given in hydrologic handbooks, they are common in many river basins of Newfoundland (Ullah et al., 1988). For the Waterford River Basin data, the average conversion of precipitation into streamflow was 82% (Ng and Marsalek, 1987). Using these data, the HSPF model was calibrated for the annual balance, seasonal balances, and individual event peak flows. The results of such calibrations were rated as good-to-very-good, using the existing calibration criteria. The annual observed and simulated balances were matched within a few percent, the calibrated monthly values were within ±15%, and the hydrograph peak flows, for flows larger than 6 m^3/s, were within ±5% of the observed values (Ng and Marsalek, 1987).

Following this calibration, the HSPF model was applied to three hypothetical land use scenarios assuming increases in the catchment imperviousness by 50, 100 and 200%. It was noted that the streamflow volume increased just by one percent even for the greatest increase in the basin imperviousness.

Urbanization generally increases surface runoff and streamflow discharges as a result of two processes - increased volume and speed of runoff. Increased runoff volumes are caused by reduced rainfall abstractions resulting from an increased imperviousness of the urbanized basin. Increased speed of runoff is caused by reduced times of concentration resulting from faster hydraulic transport in the urbanized parts of the basin. The simulated data indicate that there are practically no changes in the simulated streamflow volumes as a result of increased imperviousness. This follows from the very high conversion of precipitation into streamflow in the basin, which is given by basin geology and climate. Consequently, any future increases in river discharges can be caused only by increased speed of runoff (reduced times of concentration).

Typical peak flow changes simulated for three future land use scenarios are plotted in Fig. 1

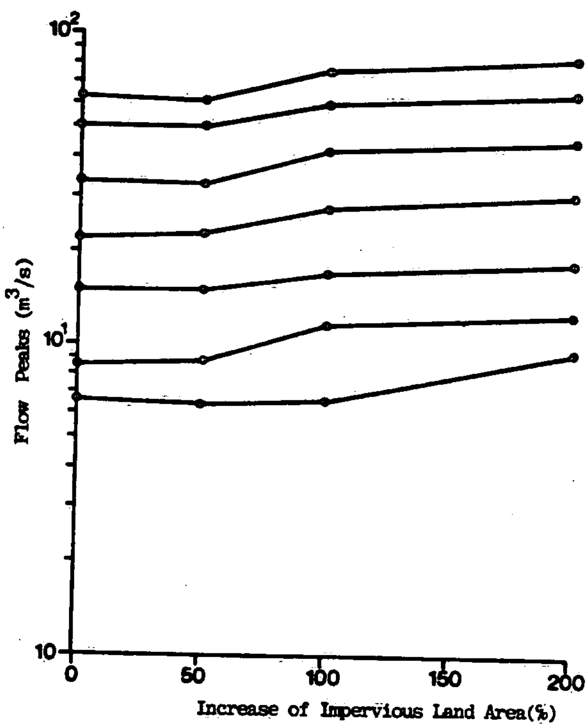

Fig. 1 Waterford River Peak Discharges Simulated for Hypothetical Future Land Use Scenarios

When examining the changes in peak flows shown in Fig. 1, some increases in peaks are observed for imperviousness increases equal to or greater than 100%. Thus, increased speed of runoff leads to some increases in the postdevelopment flows. It appears that for prediction of the effects of urbanization on flow regimes, the existing models are well suited to detect any changes in streamflow volumes, which may be translated into higher flows. The changes caused by faster runoff are more difficult to evaluate, because they depend on detailed characteristics of postdevelopment land use, including the extent of impervious areas, the percentages of such areas directly connected to sewers, drainage density, etc. Such characteristics cannot be easily predicted, because of changing land use patterns and improved management of stormwater in new developments.

SUMMARY

The HSPF model was successfully used to predict the changes in streamflow caused by progressing urbanization. The results obtained somewhat depart from the conventional views and show a limited sensitivity of the Waterford River Basin streamflow to future development, which is caused by the unique geological and climatological features of the basin. Such features result in high conversion of precipitation into streamflow under the existing conditions with limited urbanization. Progressing urbanization will not increase significantly the volumes of streamflow but will cause some moderate increases in peak flows because of more efficient hydraulic transport in newly developed areas. The detection of such trends would not justify, on its own, the use of the HSPF model which has high requirements in terms of data and computer support. The main benefits of using this model comprise its capability to simulate both high and low flows, and the possibility of a future expansion to include simulations of water quality.

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