The Assessment of the Impacts of Urban Development on Catchment Response Using The Winnipeg Airport Extension.

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THE ASSESSMENT OF THE IMPACTS OF URBAN DEVELOPMENT ON CATCHMENT RESPONSE USING THE WINNIPEG AIRPORT EXTENSION

BY

PAUL KANYAKATIKA SAKA

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

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ABSTRACT

Some of the problems encountered in assessing impacts of urbanization in ungauged urban watersheds are explained.

The effects of urbanization on catchment response are examined under various degrees of development using design storms developed from 34 years of data provided by Atmospheric Environment Services. The effects of urbanization are presented in form of growth factors which depict the ratios of urban runoff quantities to those of rural or existing conditions. The derived flood frequencies are also compared with those that were derived using recorded data for rural and urbanized watersheds.

Two approaches were considered. One consisted of using HEC-1, a general flood hydrograph model and the other approach was by utilizing the statistically derived models for assessing peak flow changes.

The results show an average maximum growth of 38 percent for the 2-year flood, 26 percent growth for the 5-year flood, 21 percent for the 10-year flood, 18 percent for the 25-year flood, 16 percent for the 50-year flood, and 14 percent for the 100-year flood above the rural floods.

The results of sensitivity analysis show that for drier basins where the infiltration loss rates are high, urbanization has more pronounced effects than for for wet basins where infiltration loss rates are low.

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Chapter I

INTRODUCTION

1.1 General

In our daily lives throughout the world, people have gathered in centralized communities for various reasons. The growth of these centres known as urban areas has brought about changes in land use from its virgin condition to artificially covered surfaces usually of impervious nature.

Urbanization is the change in land use from natural or agricultural land to various other land uses. It has been well established that changes from natural to urban conditions result in increased runoff peaks as well as increases in runoff volumes. The extent to which these runoff quantities change basically depends upon the type of development, basin physiographic characteristics, soil texture, and soil moisture conditions.

There are many factors which influence runoff characteristics and therefore important in assessing the effects of development on the runoff. In urban drainage basins, the flow pattern is characterised by three major subsystems which include surface subsystem, transport subsystem, and the recieving water subsystem (Kibler 1982).

This section deals with the general theory of rainfall-runoff relationships, a general theory of urban runoff, and the objectives of the research.

The primary issues in the rainfall-runoff relationships are discussed as follows.

1.2 Rainfall-Runoff Relationships.

The processes which link rainfall with runoff are essentially deterministic, that is they are governed by physical laws which are reasonably well known (Overton et al. 1976). Before runoff can take place, a number of physical conditions have to be fulfilled such as satisfaction of the soil moisture so that any additional water runs off or is lost to deep percolation.

The abstractions to precipitation include interception by vegetation, depression storage, and infiltration losses.

1.2.1 Interception.

This is the portion of rainfall which is stored temporarily on leaves of vegetation and eventually gets back to the atmosphere through evaporation. The amount of rainfall stored during a rainfall event is a function of vegetation type and height.

1.2.2 Depression Storage.

In general, smooth surfaces are very rare. Usually a natural basin contains a number of depressions. The quantity of rain which gets trapped in these depressions is termed depression storage. The proportion of rainfall which ends up as depression storage is basically a function of topography, presence of marshes or lakes, land use and prestorm conditions. Leveled ground will have less depression storage than land with terraces for the same soil conditions. Most of the water in depression storage returns to the atmosphere through evaporation.

1.2.3 Infiltration.

Infiltration is the movement of water from the soil air interface into the soil itself. Most of the losses from rain are due to infiltration losses. The losses are basically a function of the soil texture and the antecedent moisture levels. Runoff from rainfall only takes place if the intensity of rainfall is higher than infiltration losses. Even if the soil is dry if the intensity is higher than the soil can take, the excess rainfall will end up as surface runoff after satisfying the interception and depression storage.

1.2.4 Discussion of the Effect of Abstractions of Runoff Peaks and Runoff Volumes

Runoff quantities are functions of the rainfall abstractions described earlier but also of the moisture previous to the storm, and rainfall characteristics.

The volume of runoff depends on antecedent moisture conditions. The higher the antecedent moisture levels, the larger will be the runoff volume and peak flow. The higher runoff values are due to the lower abstractions required to fill or saturate the soil. Peak flows and runoff volumes also depend on the storm characteristics. The storm characteristics which influence these quantities are storm distribution, rainfall intensity, and rainfall duration.

Even or uniform distribution of precipitation has been found to increase basin base flow and to result in maximum peak flows. Precipitation which occurs on the lower portion of the basin would result in higher peak flow than an equal amount of precipitation which occurs on the upper portion of the basin because of channel storage effect (Linsley et al. 1982).

When rainfall intensity is lower than infiltration rate, all rain is lost into soil mass. Runoff volumes and peak flows also depend on surface cover which affects infiltration.

Maximum peak flows also depend on the duration of the storm(Td). For a duration less than basin time of concentration(TC), the resulting peak flows are less than if the duration was equal to time of concentration. The reason for this is that at a Td value less than TC, only a portion of the basin is contributing to the flow at the outlet while at TC equal to or greater than Td, all areas are contributing to outlet flow resulting in overall higher peak flows.

1.3 General Theory of Urban Runoff.

In an urban drainage basin, a predominant characteristic is the man made impervious pathways such as parking lots and streets which guide flows overland. As suggested earlier, a typical urbanised basin consists of three basic runoff subsystems which are: (1) Surface Runoff, (2) Transport Subsystem, and (3) Recieving Water Subsystem. (Kibler, 1982). These factors are discussed as follows.

1.3.1 Surface Runoff Subsystem.

The surface subsystem consists of total area, impervious proportion, and other hydraulic properties. The overland flow process transforms rainfall excess on the surface subsystem to inlet hydrographs. The hydrograph in turn is routed through sewers or drains to receiving subsystems.

Given that rainfall hyetograph is the input to surface subsystem and that time distribution of flow(hydrograph) is the output, the surface subsystem can be represented as shown in Figure 1.1. The resulting peak discharge and total volume of runoff depend on precipitation characteristics as pointed out earlier.

The extent to which overland flow phase of the runoff process predominates depends on the nature of the basin. For hydrologically small basins, overland flow predominates while for hydrologically large basins, channel flow predominates.

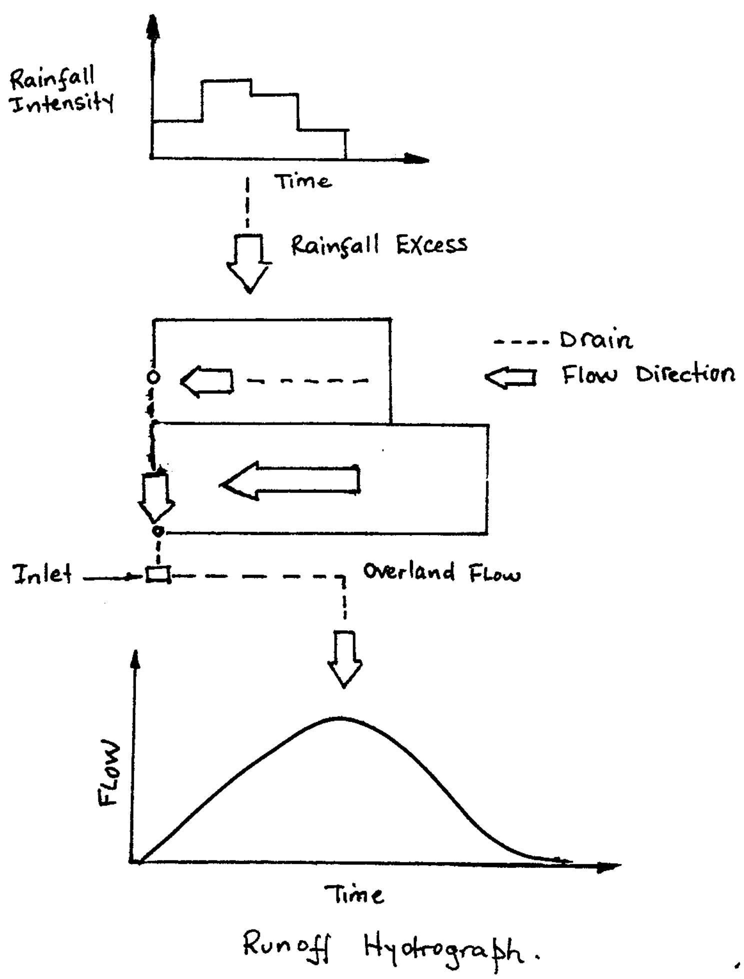

Figure I.I Surface Runoff Subsystem (after Kibler,1982)

1.3.2 Transport Subsystem.

The main function of the transport subsystem is to route the flows through a system of drains and sewers to inlets and eventually to recieving bodies. This subsystem consists of physical works. In the process of routing, the peak flows are generally attenuated by the storage effects in channels.

The transport subsystem is represented diagramatically in Figure 1.2.

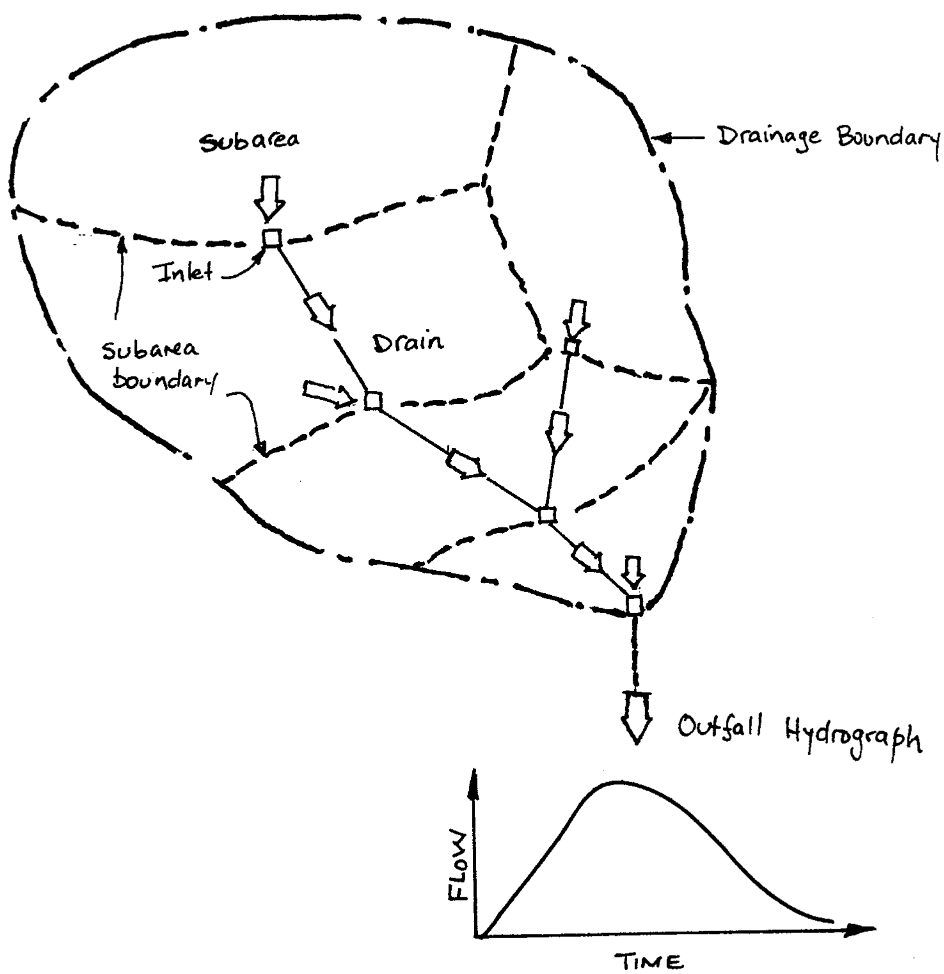

Figure I.2 Transport Subsystem (after Kibler, 1982).

1.3.3 The Receiving Subsystem.

Usually all urban drainage basins route their flows to either estuaries, lakes or rivers. Examination of the nature of the receiving body is beyond the scope of this study and is consequently not addressed any further in this thesis.

1.4 Description of the Watershed Characteristics.

This study was based on the Truro Creek watershed on the west side of the Winnipeg International Airport as shown in Figure 1.3. The basin considered is the watershed above the gauging station at Truro Creek near Assiniboine golf course as shown in Figure 1.3. This section gives a description of the basin physiographic features as well as existing and proposed land use patterns.

1.4.1 Basin Physiographic Features.

Truro Creek is one of the two creeks that drain the Winnipeg airport. The total drainage area is 6.29 square miles and the total stream length is 3.5 miles with a mean channel slope of 0.14 percent.

The watershed is divied into two subbasins as shown in Figure 1.4. Subbasin one has a total area of 4.44 square miles while subbasin two has an area of 1.85 square miles. Each of these subbasins is equiped with a seasonal gauging station as shown in Figure 1.4.

Truro Creek itself is an ephemeral creek which means that there is no flow during periods of no precipitation. Quantifiable flows are measured only after precipitation.

The overlying soil consists of black earth fine textured soils of depth ranging from 6 inches to 12 inches (Ehrlich et al. 1953). The underlying soil is predominantly heavy plastic clay while the vegetal cover mainly consists of gloves of willow and aspen. Table 1.1 shows a summary of the basin physiographic features.

This basin receives an average precipitation total of 21 inches of which snowfall constitutes an average of 5 inches and rainfall 16 inches. The normal highest precipitation occurs in June-July months well after snowmelt. Table 1.4 shows the average basin precipitation.

Table 1.1 Basin Physiographic Features

Physiographic Feature	Subbasin1	Subbasin2
Hydraulic length	13200 feet	13200 feet
Length to centroid	1.24 miless	1.40 miless
Slope of channel	0.14 percent	0.14 percent
Soil cover No.	83	89
Drainage Area	4.44 sq. mi.	1.43 sq. mi.

Where:
Length to centroid refers to that length from subarea inlet to centroid of the area.
Soil cover No. is as for Soil Conservation Service Service (1978)

Table 1.2 Watershed Monthly and Annual Normal Precipitation

Month	Rain (in)	Snow (in)
January	0.01	0.98
February	0.03	0.78
March	0.24	0.83
April	1.00	0.45
May	2.15	0.10
June	3.16	Trace
July	3.16	0.00
August	2.90	0.00
September	2.07	0.01
October	1.15	0.22
November	0.28	0.84
December	0.03	0.94
Average Total	16.00	5.00

1.4.2 Existing and Proposed Land Use Patterns.

Currently subbasin 1 is still in its natural condition except for road developments. Subbasin two, however, has been partially developed into a number of facilities as described in Tables 1.3 and 1.4.

The proposed development consists of extending the existing facilities and construction of new runways as shown in Figures 1.5 and 1.6.

Figure 1.3 Study Area Location Map

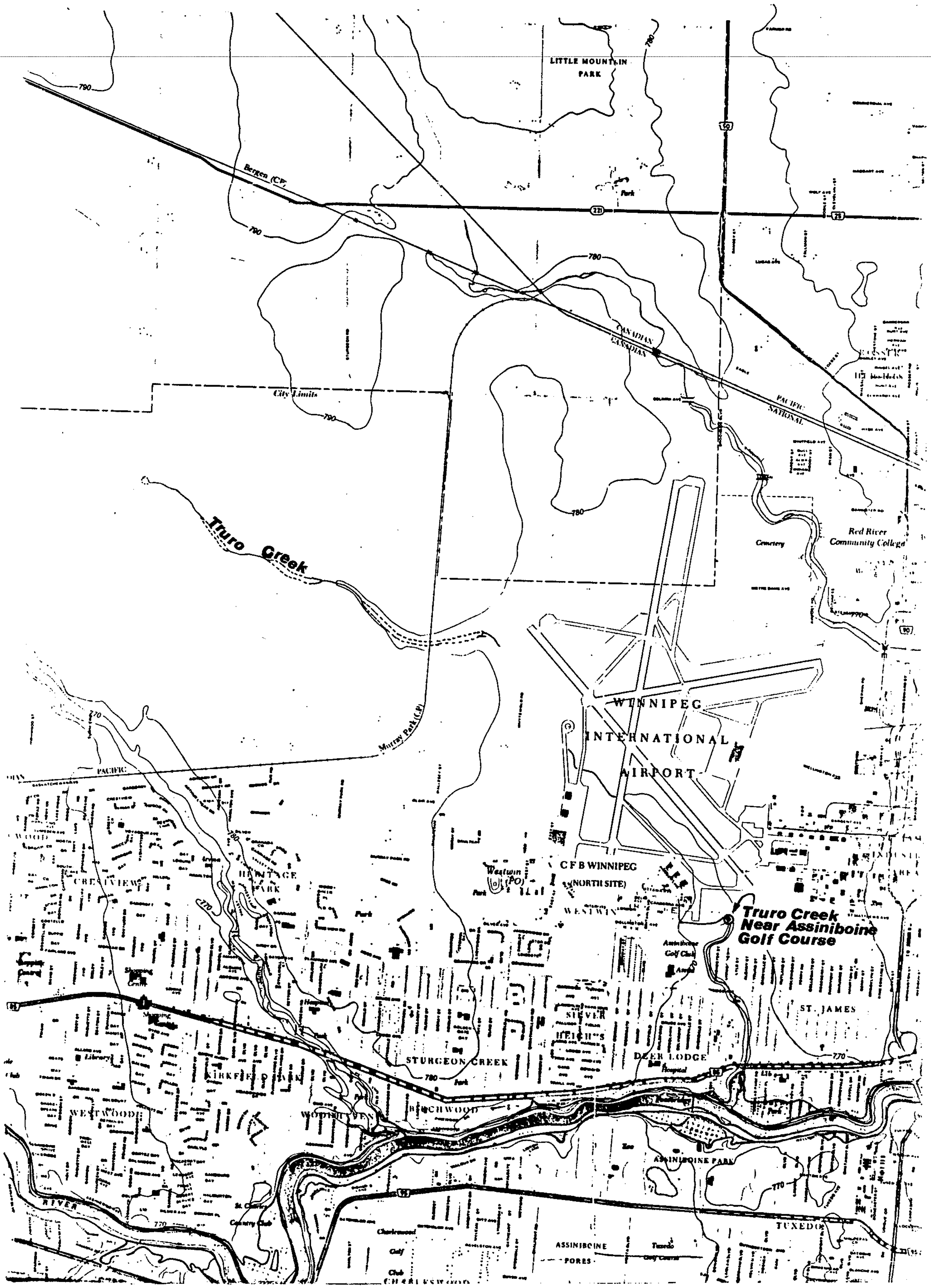

Figure 1.4 **EXISTING LAND USE**

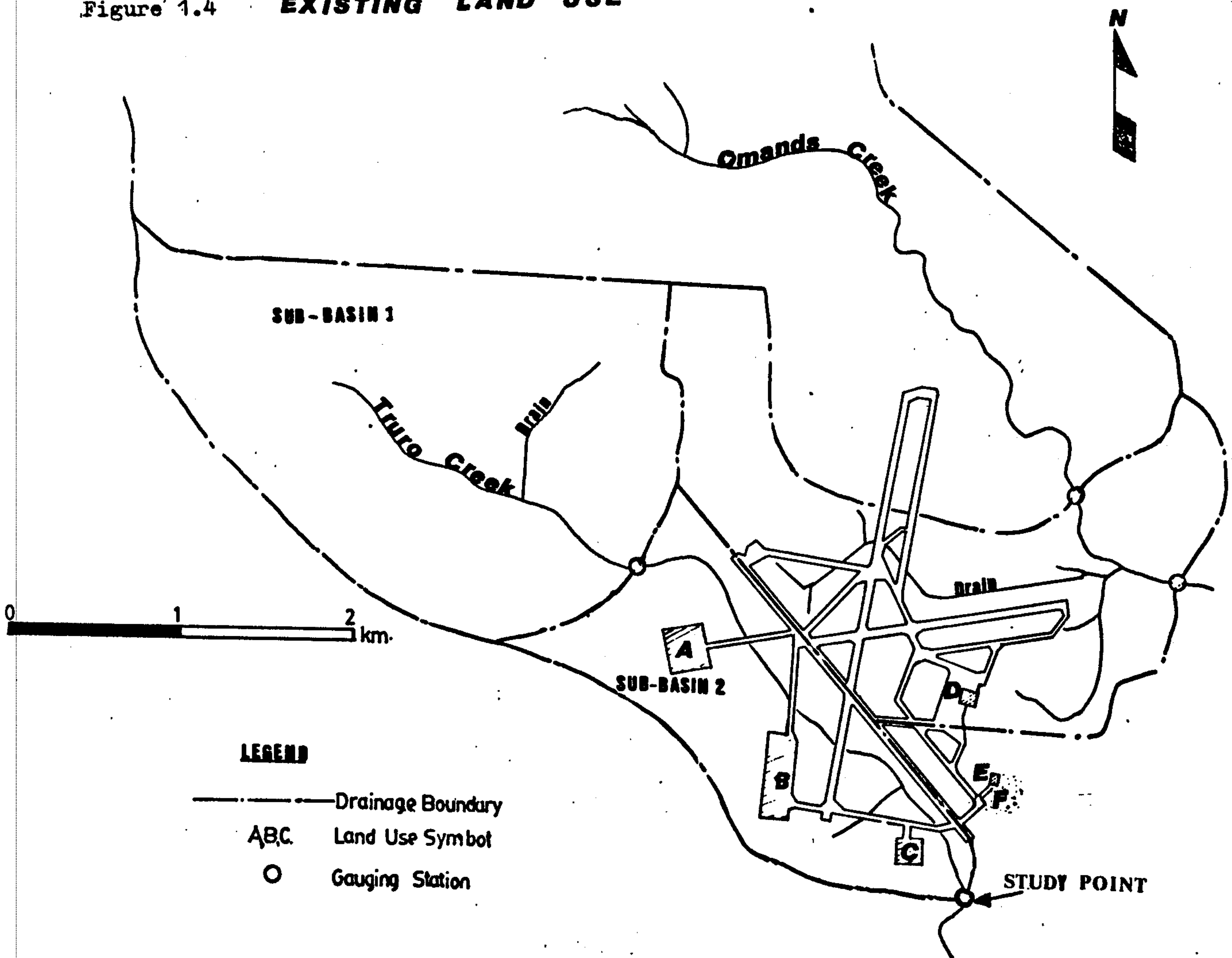

Table 1.3 Existing Land Use Pattern

Symbol	Land Use description
A	Airline Hangar
B	Department of National Defence
C	General Aviation
D	Airport Terminal Building
E	Aviation Support

Figure 1.5 **PROPOSED AIRPORT LAND USE**

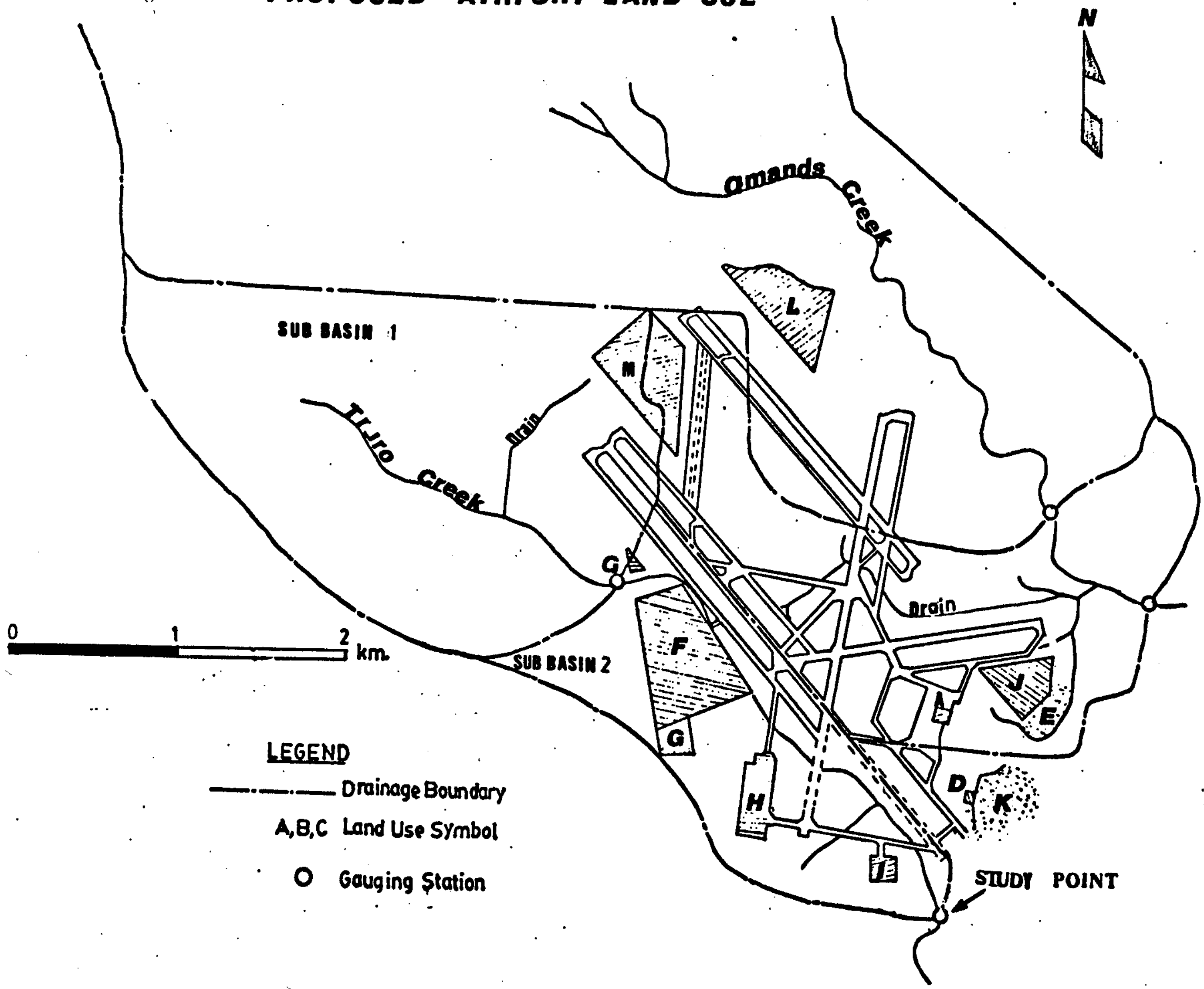

Table 1.4 Proposed Airport Land Use

Symbol	Land Use Description
A	Airport Terminal Building
B	Future Airport Terminal Building
C	Future Airline Hangar
D	Aviation Support
E	Aviation Support
F	Airline Hangar
G	Aviation Support
H	Department Of National Defence
I	General Aviation
J	Airline Support

1.5 Objectives of Research.

Most researchers have found that urbanization results in an increase in both peak flows as well as runoff volumes and a decrease in the time taken when effective rainfall begins and the peak flows occur thenceforth termed the time to peak. In predicting these changes, most of the researchers have used various rainfall-runoff model case studies and statistical approaches such as Beard (1979), and Keelway(1979). In most of these studies, emphasis has been on the effects of impervious proportion on cathment response. Bearing in mind that urban areas often lack enough data for detailed frequency analysis, various predictive models have been used without emphasis on the soil moisture conditions of the basin. The moisture levels in a basin keeps on changing with time and season making the whole basis of prediction difficult.

In some studies, experimental results based on initially dry soils have been used as values for basin infiltration losses. However, this infiltration loss is not only a function of soil type but also soil moisture conditions.

The objective of this research was to predict the impacts of extending Winnipeg airport on Truro Creek and to look at problems in predicting the impacts of urbanization in ungauged watersheds. The other objective was to predict changes in flows due to progressive development and to develop corresponding frequencies for degrees of development. The third objective was to explore the effects of soil moisture conditions on catchment response due to urbanization.

1.6 Methodology of Research.

In predicting the effects of changes in runoff due to changes in land use, the following procedure was adopted.

(i) Derivation of design storms for 2-year to 100-year storms.

(ii) Review of available models, model choice, calibration, verification and validation.

(iii) Assessment of the impacts of urbanization.

(iv) Conducting a sensitivity analysis.

Chapter II

REVIEW OF LITERATURE

Urbanization of a catchment area has generally been found to increase peak flows, volume of runoff, and to reduce the time to peak. There are two major factors which cause the above changes in runoff characteristics in urbanized basins. The first factor is covering of the parts of the catchment area with impervious surfaces such as streets and parking lots or buildings. This factor reduces the infiltration losses close to zero in the covered areas resulting in increased runoff volumes as well as increased peak flows.

The second factor is the increased conveyance efficiency of the basin caused by lining or straightening channels and installing sewers (Kibler,1982). This increase in conveyance efficiency results in an earlier occurrence of peak flows, hence a decrease in time to peak. It also results in reduced times of concentration thus allowing short duration high intensity storms to cause the whole basin to contribute simultaneously to outlet flows.

Both the effficiency of conveyance and imperviousness are therefore the causes of increased peaks and runoff volumes. Figure 2 shows the qualitative modification of runoff hydrograph from natural to urbanised basin for the same area and moisture conditions.

The extent of the increase in runoff quantities depends on the nature of development. In the case of development on hilly areas, generally slopes are reduced during construction which may increase time to peak (Bras, 1975). On the other hand, construction of buildings with parapet walls may also affect the runoff hydrograph by delaying the peak caused by storage effect of these roofs.

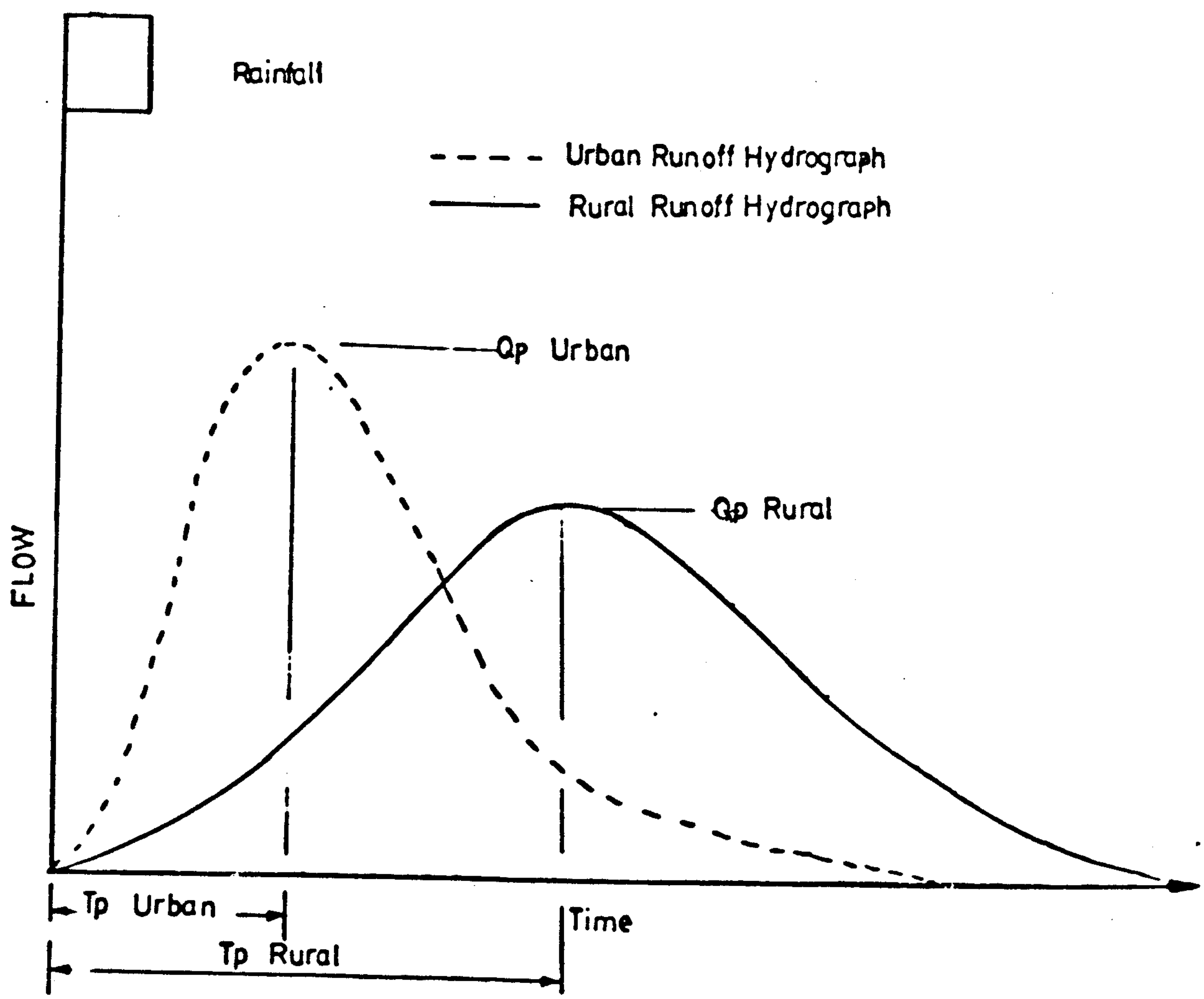

Figure 2 Comparison of Rural and Urban Hydrographs (after Kibler, 1982)

2.1 Historical Development of the Effects of Urbanization on Runoff Conditions

Work on the assessment of urbanization effects on catchment response started in the mid fifties. The effects have been measured in terms of peak flows(Qp), time to peak(Tp), and runoff volume(Vol). The results of most studies have shown that no universal formula that can be used to assess or predict these effects exists.

Sarma et al. (1969) have given detailed analysis of the previous studies. In the last decade, a number of additional studies have been done on this subject.

Dempster(1974) in his study found that with 40 percent of the watershed being impervious, the 2-year flood increased by 35 percent while the 50-year flood increased by 16 percent for the same conditions.

This and other evidence have shown that urbanization has very little effects on rare floods. Durbin(1974) has reported increases in peak flows of three to six times resulting from transition from rural to urban environment for the more frequent floods in his study in Santa valley, California. The 100-year flood however, showed no significant increases in peak flows.

Installing sewers in a watershed has also been found to cause higher peak flows because of increased conveyance efficiency. Bras(1975) has reported increases of 30 to 100 percent for a basin changing from natural to 100 percent sewer service with 50 percent of the basin under impervious cover for the 10-year flood. For the same conditions, the 50-year flood showed increases of 10 to 20 percent. Urbanization has also been found to decrease basin time to peak (Bras, 1975).

Urbanization has been found to have larger effects on smaller areas than larger ones because in small areas overland flow predominates while for larger ones, channel flow predominates and the effect of channel storage affects the peak flows. This is evident by studies done by McCuen et al.(1975).

Besides the size of the areas, the kind of development and the type of soils in the basin can have differing results for the same extent of development as reported by Bras (1975) and McCuen et al.(1975).

2.2 Engineering Aspects of Changes in Runoff Conditions.

Evaluation of the expected peak flows as well as volumes of runoff has been the goal of many engineers involved with the design of water related structures in municipalities. In municipal waterworks, the objective is to design the sewers and detention resevoirs for the predicted loading.