TABLE 2.4

WATER ELEVATIONS: SPRING FRESHET 1987
STAFF GAUGE READINGS

1. Nottawasaga River at Edenvale (Hwy. 26 bridge, downstream face)

Date	Time	Geodetic Elevations (m)
April 07, 1987	18:34	182.505 (1)
April 08, 1987	7:19	182.630
	14:29	182.655
	18:45	182.655
April 09, 1987	7:33	182.680
	17:20	182.655
April 10, 1987	8:07	182.63
	16:41	182.58
April 11, 1987	14:30	182.505
April 12, 1987	13:51	182.380
April 13, 1987	9:36	182.280
April 15, 1987	8:00	181.980

2. Nottawasaga River at Wasaga Beach (Schoonertown bridge)

Date	Time	Geodetic Elevations (m)
April 07, 1987	20:12	177.467 (2)
April 08, 1987	6:57	177.427
	14:49	177.457
April 09, 1987	7:13	177.457
	17:42	177.467
April 10, 1987	7:50	177.457
	16:57	177.447
April 11, 1987	14:13	177.417
April 12, 1987	13:33	177.417
April 13, 1987	8:58	177.397 ("O" mark on staff gauge)
April 15, 1987	7:45	(readings discontiued - below "O" mark on staff gauge)

(1) Benchmark MTC 798122 Elev. 186.788 m.
Tablet in Concrete site on south side of Highway 26, 104.0 m west of concrete bridge over Nottawasaga River and 117.4 m south of centreline of Highway 26.

(2) Town of Wasaga Beach benchmark elev. 183.70 m.
Top of south west anchor bolt in light standard on Oxbow Park Road 149.64 m south of intersection of River Road West and Oxbow Park Road.
Dwoper Model Cross-section No. 27; Chainage 5,607 m.

3.0 HYDROLOGIC INVESTIGATIONS

Within the Nottawasaga basin, recording hydrometric stations have been established and maintained by the Water Survey of Canada and the Ontario Ministry of the Environment to provide flow observations on the tributaries and main branch of the river. Historic flow records are an important source of frequency based information that provide an insight into the flow potential within the watersheds under the jurisdiction of the Conservation Authority.

Despite the density of the flow monitoring network, a requirement often arises to establish the flood hazard at intermediate ungauged locations. In these instances, existing development may be exposed to the flood hazard or urban growth may require an accurate assessment for planning purposes. Hydrologic models which simulate the runoff response of a basin to precipitation or snowmelt are increasingly used for this purpose especially when the record period for hydrometeorologic information also makes it possible to extend the database of flow records. Computations with the models consist of an accurate determination of the annual flood hydrograph from the hydrometeorologic data collected during the event and subsequent frequency analysis of the annual flow series to produce frequency based estimates of flood discharges.

In recent years, the effects of urban development and agricultural drainage on the timing and quantity of runoff has caused considerable concern to water resource planners and administrators. Depending on the increase in imperviousness and the degree of improvements made to local drainage systems, larger flood peaks can be produced which result in monetary damages to floodplain structures, agricultural lands and natural watercourses. Historical flow records will not provide estimates of the flood hazard arising from changes in basin response to inputs of precipitation or snowmelt. However, calibrated hydrologic models have demonstrated a capacity to accurately predict the future flood hazard especially when basin features related to drainage improvements are represented explicity in the simulation.

Hydrologic models of the Nottawasaga River basin and the smaller catchments of the Pretty and Batteaux Rivers plus the Black Ash, Silver and Sturgeon Creeks were established to provide frequency based estimates of flood magnitudes at numerous locations throughout the catchments and to quantify the effect of urbanization and agricultural drainage improvements. The flood standard which defines floodplain limits for regulatory purposes within the Nottawasaga Valley Conservation Authority continues to be the flood resulting from the Timmins storm (1961) event. These flood discharges were also calculated with the precipitation runoff model in order to provide a uniform hydrologic basis for flood profile computations.

3.1 Existing Database

3.1.1 Meteorological Records

The hydrologic model (QUALHYMO) used on the Nottawasaga Basin requires two input data time series: precipitation and temperature. The following sections outline the procedures used to develop the hourly precipitation and temperature databases.

3.1.1.1 Precipitation

Station Selection

The first step in selecting the precipitation stations to be used in this study was to obtain from the Atmospheric Environment Service, Environment Canada, a list of all stations within the rectangular areas bounded by latitudes 43°30' and 45°00' and longitudes 79°00' and 81°00'.

From this list, precipitation stations were selected based on their proximity to the Nottawasaga Basin, and the amount of data available at the station. All stations in and around the study area with a significant period of record were included. Table 3.1 lists the selected stations along with their time step and period of record. Data for all these locations (Figure 1.1) was obtained on magnetic tape from the Atmospheric Environment Service.

Data Preparation

Most of the precipitation data available within the Nottawasaga Basin is at a daily time step, while the hourly data is found outside or near the edge of the basin. To make full use of all data, and provide complete coverage of the study area, the following procedures were performed.

(a) The following eight daily stations with complete periods of records were selected as base stations:

Orangeville
Glen Haffy
Midhurst
Maple
Monticello
Mount Forest
Fergus
Essa

(b) A mathematical relationship was derived between each of the remaining daily stations and the eight base stations. This was done using multiple linear regression techniques.

(c) The missing data at each station were filled in using the relationships derived in (b). At this point, the daily precipitation database was complete at all stations for the period 1962 to the present.

TABLE 3.1

PRECIPITATION STATIONS

Location	AES Station Number	Period of Record
Daily Stations		
Alliston	6110216 6110218	1967-1974 1973-1984
Beeton	6110667 6110661 6110663	1968-1971 1962-1969 1971-1984
Collingwood	6111793	1962-1974
Cookstown	6111859	1972-1984
Essa	6112340	1962-1984
Glen Haffy	6152833	1962-1984
Midhurst	6115099	1962-1983
Orangeville	6155790	1962-1984
Redickville	6146939	1962-1984
Shanty Bay	6117684	1973-1984
Shelburne	6147693	1981-1984
Thornbury	611HBEC	1968-1984
Wasaga Beach	6119294	1979-1981
Hourly Stations		
Barrie	6110557	1968-1984
Bolton	6150825	1978-1984
Fergus Shand Dam	6142400	1962-1984
Grand Valley	6142991	1975-1984
Maple	6154950	1962-1975
Mount Forest	6145503	1962-1984
Orillia	6115820	1965-1984

For example, (Appendix D), in order to obtain a complete record of daily precipitation at Collingwood from 1962 to present, the nearby meteorologic stations at Orangeville, Essa and Thornbury were selected and a multiple linear regression equation was established by standard statistical techniques.

Collingwood daily precipitation (preferred model) = Orangeville daily precipitation x 0.1264 + Essa daily precipitation x 0.4126 + Thornbury daily precipitation x 0.5933

Missing daily readings at Collingwood were infilled by application of the foregoing equation (preferred model). However, only Orangeville and Essa represent "bare stations" with complete records; therefore, for those days in which missing records occur at Thornbury, it was necessary to select "bare stations" further from Collingwood. A "secondary model" was established between Collingwood and Monticello, Orangeville, Midhurst and Essa by multiple linear regression techniques.

Collingwood daily precipitation (secondary model) = Orangeville daily precipitation x 0.1326 + Monticello daily precipitation x 0.1532 + Midhurst daily precipitation x 0.2667 + Essa daily precipitation x 0.5001

This secondary model was employed to estimate daily precipitation readings at Collingwood when corresponding daily readings were missing at Thornbury.

Data files of the recorded daily precipitation and the infilled records for each of the seventeen meteorologic stations were transferred to the Authority in digital format for future reference.

(d) The daily data were distributed into hourly amounts by using the closest hourly station as a guide. The percentage of the daily total occurring in each hour was set equal to that of the guide station.

If the closest hourly station had zero precipitation or missing data then the next closest hourly station was used. This substitution process was continued, if necessary, until all hourly stations had been examined. If there was still no suitable guide station, the daily total was divided into 24 equal amounts.

(e) Hourly precipitation data is not available during below zero (Celcius) temperatures at most AES stations due to gauge freeze-up. The Mount Forest station, however, provides six-hour data for the entire year. This six-hour data was divided into six equal hourly amounts and used in (d).

(f) The hourly data at each station was written to a computer disk file in the required format for the QUALHYMO model.

The final results of the above procedures was the establishment of an hourly precipitation database covering the whole of the Nottawasaga Basin from 1962 to the present.

3.1.1.2 Temperature

Temperature data at an hourly time step was available only at the Mount Forest station. This data was used for the whole study area. Any differences between the Mount Forest gauge and the conditions in a sub-basin were accounted for in the calibration of the snowmelt parameters.

3.1.2 Hydrometric Records

The location of the hydrometric stations within the NVCA are shown in Figure 1.1. The pertinent information related to each station is presented in Table 3.2.

Daily discharge data for all hydrometric stations was obtained for the period of record from the WSC. Hourly streamflow data was also obtained for Federal government stations from the WSC for the 1975-1984 period. These stations were: Willow Creek above Little Lake and at Midhurst; Mad River near Glencairn and Nottawasaga River at Baxter. Annual maximum instantaneous peak flows are also published by the WSC for each recording streamflow gauge over the entire record period.

Hourly streamflow for specific events during the 1975-1984 period were obtained from the Ontario Ministry of the Environment. These stations were: Pine River near Everett, Boyne River at Earl Rowe Park and Beeton Creek near Tottenham.

Hourly streamflow data for all stations is not available from early November to early March. The MOE data has several periods in the spring where hourly flow data was missing. The missing data in several cases restricted the events that could be selected for the calibration/validation of the QUALHYMO Model.

3.1.3 Snow Cover

The location of the snow courses within the NVCA are shown in Figure 1.1. The relevant information for each snow course is presented in Table 3.2.

The snow courses are operated by the NVCA and snow sampling is usually undertaken at the beginning and middle of each month during the winter/

TABLE 3.2

HYDROMETRIC STATIONS AND SNOWCOURSES

					DATA				
Ref. No.	Station	Agency	Station Type	Period of Record	Precipitation	Temperature	Wind Speed	Streamflow	Snow Course
1	Barrie	AES	Recording	1968-Pres	X	X			
2	Mount Forest	AES	R	1962-Pres	X	X	X		
3	Alliston	AES	Manual	1968-Pres	X	X			
4	Cookstown	AES	M	1972-Pres	X	X			
5	Beeton	AES	M	1975-Pres	X	X			
6	Collingwood	AES	M	1960-1975	X	X			
7	Wasaga Beach	AES	M	1972-70 1978-81	X	X			
8	Shelburne	AES	M	1981-Pres	X	X			
9	Tottenham	AES	M	1971-79	X	X			
10	Orangeville OWRC	AES	M	1961-Pres	X	X			
11	Elora Res. Stn.	AES	R	1970-Pres	X	X	X		
12	Nottawasaga River near Baxter	WSC	MC RC	1944-65 1966-Pres				X	
13	Baily Creek near Beeton	WSC	RC	1963-78				X	
14	Beeton Creek near Tottenham	WSC	RC	1977-Pres				X	
15	Boyne River at East Rowe Park	WSC	RC	1969-75 1977-Pres				X	
16	Pine River near Everett	WSC	RC	1970-75 1978-Pres				X	
17	Mad River near Glencairn	WSC	RC	1967-Pres				X	
18	Willow Creek above Little Lake	WSC	RC	1973-Pres				X	
19	Willow Creek at Midhurst	WSC	RC	1973-Pres				X	
20	Colwell	MNR	M	1977-Pres					X
21	Edenvale	MNR	M	1971-Pres					X
22	Mono Centre	MNR	M	1971-Pres					X
23	Maple Valley	MNR	M	1977-Pres					X
24	Tottenham	MNR	M	1971-Pres					X

spring period. At each snow course snowpack depth and water equivalent information is measured.

The snowpack data was useful for comparison of observed and simulated snowpack water equivalent for the various calibration/validation events.

3.2 Hydrologic Model

3.2.1 Description of the QUALHYMO Model

After careful review of the Conservation Authority's water management program and the requirement for hydrologic information concerning magnitude and frequency of flood discharges, the model, QUALHYMO (Ref. 10, 11), was chosen to estimate peak flows throughout the Authority's watershed under existing and future land use conditions. QUALHYMO is a simple continuous water quantity and quality simulation model which was developed in 1983 at the University of Ottawa for the analysis of stormwater detention ponds. The model can be used as a general tool for simulating rainfall-runoff; however, it is most suited to planning level analysis of river basins where the land surface is developing from a rural or undeveloped state to an urban land use.

Several concepts in the QUALHYMO model have been retained from two earlier single event hydrologic models: HYMO (Ref. 12) which is a runoff model that has been tested and extensively used in Ontario for the hydrologic component of flood plain mapping studies and OTTHYMO (Ref. 13), which is gaining widespread acceptance in planning level studies of storm water management within urban areas.

Meteorologic input to the QUALHYMO model consists of hourly rainfall records or liquid input from snowmelt. During the winter period, precipitation is categorized as liquid or snow depending on air temperature relative to a specified threshold value at or near to 0° Centigrade. Snowpack accumulation and ablation is estimated by a temperature index equation.

In generating runoff from pervious land segments, the QUALHYMO model uses the U.S. Soil Conservation Service (Ref. 14) procedure to determine the excess moisture input to pervious areas. The soil moisture deficit of soils and the initial abstraction are updated by the model for each event to provide an accounting of initial moisture conditions. The initial abstraction is reduced by the antecedent precipitation over the preceding twenty-four hours and will recover to its user specified maximum in the absence of precipitation over the foregoing period of time. In the case of the soil moisture deficit, current values preceding an event are computed as a function of a variable Antecedent Precipitation Index which in turn is based on daily rainfall totals weighted by a recession coefficient with a system memory of approximately thirty days.

Runoff volume computations in impervious areas are carried out by reducing precipitation with an initial abstraction and subsequently applying a constant volumetric runoff coefficient. Inter-event updating of the initial abstraction is similar to the technique for pervious areas.

The QUALHYMO model calculates flow rates from flow volume by convolution of excess precipitation with two unit hydrograph shapes proposed by Nash (Ref. 15) and Williams (Ref. 16). Since runoff from pervious areas is convoluted separately from impervious areas, these can use either the same or different unit hydrograph shapes at the discretion of the modeller.

A kinematic approximation is used within QUALHYMO to route flows along river reaches. Hydraulics in the reach are represented either by a Manning flow equation or specified rating curve. Depth-flow velocity and depth-section area relationships for the channel are calculated by the model and used subsequently for flow routing purposes.

Calculation of base flow in the model is carried out with a single reservoir representing groundwater storage. A net inflow and outflow from the reservoir is calculated for each model time step with inflow taken as the difference between precipitation and runoff minus any losses to initial abstraction. Outflow is expressed as a function of a baseflow recession constant times the groundwater reservoir storage. Losses to deep groundwater storage are estimated as a constant proportion of the outflow from the groundwater storage reservoir and effectively reduce the contribution to baseflow.

3.2.2 Model Enhancements

In order to accommodate the flow travel and attenuation process within water courses of the Nottawasaga River basin, the kinematic approximation employed in the QUALHYMO model for streamflow routing was replaced by a hydrologic Muskingum method which incorporates the variable storage coefficient (VSC) (Ref. 12) method. The latter technique accounts for the variation in water surface slope and has been tested successfully on Ontario streams (Ref. 17).

A review of historical peak flow records in the Nottawasaga River basin indicates that annual peak events almost invariably occur during the spring freshet period. Many of the higher discharges involve a combination of snowmelt and rainfall. Based on findings of the snowmelt hydrology studies (Ref. 10) carried out for the Ontario Ministry of Natural Resources, the snowmelt model originally developed for the U.S. National Weather Service River Forecast System (Ref. 19) was added to the QUALHYMO model in order to improve computational accuracy during rainfall and snowmelt occurrences.

The NWS snowmelt model employs a temperature index procedure in which melt rates are proportional to the differences between the mean air temperature and a base temperature during periods without precipitation. A seasonal variation in the melt factor can be simulated to reflect the increase in solar radiation and the decrease in the albedo of a snow cover as the winter period progresses. During periods of precipitation a semi-empirical energy balance approach takes into account the net long wave radiation transfer to a snow cover, the latent heat transfer or sublimation of water vapour, sensible heat transfer due to the heat content of the air, and heat transfer to the snow cover which is caused by precipitation. Short wave radiation is considered zero during the occurrence of precipitation due to the presence of cloud cover. Meteorologic data required for computation is limited to air temperature and precipitation intensity during the snowmelt period.

Outflow of liquid water from the snowpack is differentiated from snowmelt in the NWS computational approach by a snowpack heat accounting technique, which indicates whether water will be in a liquid or solid phase. Liquid water is retained in the snowpack against gravity drainage and the portion which exceeds this capacity is transmitted as outflow after a time lag which represents routing of meltwater through the snowpack.

The runoff which occurs within small urban catchments is quite sensitive to short duration intensities. QUALHYMO was also modified to allow 15 minute duration rainfall amounts to be input to the model.

3.2.3 Watershed Application

The QUALHYMO model for the Nottawasaga Valley River Basin was developed from readily available sources of watershed information which provided the most recent documentation of land use, soils and topographic features. Field surveys were also carried out to supplement the mapping coverage of major watercourses and watershed boundaries. The collection, compilation and subsequent calibration exercises undertaken with this data supplied the model with the most representative basin definition.

3.2.3.1 Basin Delineation

The initial stages of the model's development involved the examination of the watershed boundaries for the study basins. Suspect boundary areas identified by the Authority and areas noted by MacLaren Plansearch were inspected thoroughly utilizing 1:10000 air photos and available mapping.

Verification of the delineation of the boundary in these areas was also carried out through site inspections by field crews. These investigations yielded only small changes to the defined boundaries as delineated by the Authority.

For modelling purposes, the natural drainage system within the study area was divided into nine (9) major sub-catchments which discharge to either the Nottawasaga River or directly to Nottawasaga Bay. Further discretization of the drainage area was undertaken to provide distributed estimates of flood discharges at numerous locations throughout the drainage system (Figure 2.1). A total of 191 hydrologic units or sub-catchments were defined to adequately simulate the hydrologic characteristics of the basin (Table 3.3). The following criteria were used for the delineation of the units:

- flow locations requested by the Authority
- sites of installed streamflow gauges
- sites of urban development
- sites of significant changes in hydrologic features
- areas of floodplain mapping studies
- major transportation crossings.

3.2.3.2 Hydrologic Soil Classification

Soil series and drainage conditions information obtained from Canada Department of Agriculture Soil Survey Reports was transferred to a 1:50,000 scale map for the study area. The Hydrologic Soil Group Designation (Ref. 14, 20) for the NVCA is shown in Figure 3.1. This classification contains the four following major soil groups which reflect the intake of water at the end of long duration storms occurring after prior wetting and opportunity for swelling, and without the protective affects of vegetation. Infiltration is the rate at which water enters the soil at the surface, and which is controlled at the surface, and the transmission rate is the rate at which the water moves in the soil and which is controlled by the soil horizons.

Group A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well- to excessively-drained sands or gravels. These soils have a high rate of water transmission.

Group B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

3.2.3.3 Land Use

The Nottawasaga Valley River Basin is primarily a rural agricultural basin with a scattering of urban centers. Notable exceptions are found within the Nottawasaga Bay Fringe, where recreational and seasonal development has occurred and further to the south near Angus within the military establishment at C.F.B. Borden. The Minesing Swamp, north of Angus, is a major wetland resource.

One of the requirements of the study was to investigate the impact of changing land use from the present condition to proposed future plans. To facilitate this requirement, a land use inventory for each hydrologic unit was undertaken for both existing and future conditions.

The principle source of land use information used for all rural or agricultural lands for the existing condition was the 1983 Ontario Ministry of Agriculture and Food (O.M.A.F.) Agricultural Land Use Systems mapping. These maps are available for all townships at a 1:50,000 scale. The major land use categories extracted from this source for hydrologic analysis are listed below.

- row crop
- small grains
- pasture or range
- woods
- swamp

The future land use designation for the agricultural lands was obtained by comparing the Official Plans for each township to the designations determined for the existing conditions. The Official Plans identify those lands that will be converted to urban development; however, they do not classify the type of agricultural practice for the rural lands. It was assumed that the existing non-urban lands not designated for development will retain existing agricultural crops in the future.

The urban areas, though small in comparison to the size of the basins, represent a significant portion of many of the individual sub-catchments. Their impact on the volume and rate of runoff can be significant on a local sub-watershed scale when imposed on the receiving streams. The identification of urban areas was first established through the examination of the Official Plans and Zoning By-laws for the towns and townships within the area. These documents also provided specific urban land use categories for the future condition. The urban land use categories and their associated

TABLE 3.3

HYDROLOGIC UNITS

Series	Watercourse/System	No. of Hydrologic Units
100	Nottawasaga River	43
200	Bailey and Beeton Creeks	16
300	Innisfil Creek	23
400	Boyne River	16
500	Pine River	17
600	Bear Creek	9
700	Willow and Marl Creeks	20
800	Mad River	19
900	Georgian Bay Inflows	28
	TOTAL	191

imperviousness which were adopted for hydrologic computations are listed below.

Urban Land Use Category	Percentage Impervious
Residential	35%
Commercial	75%
Institutional	70%
Industrial	70%

The above values represent average impervious conditions obtained from the Consultant's work for the Town of Vaughan (e.g. Town of Vaughan Design Criteria) and literature review (e.g. V.T. Chow, Handbook of Applied Hydrology, McGraw-Hill, 1964; Pg. 20-20) (Ref. 28).

The determination of existing conditions for the urban areas was undertaken through the use of existing land use mapping. In many instances this mapping had not been prepared by municipal planning departments. The 1:30,000 air photos (1983) and 1:10,000 mapping were employed in these cases to delineate the extent of the existing urban land use. It was assumed that the type of existing urban land use (Residential, Commercial, Institutional and Industrial) could be obtained from the Official Plan for the municipality.

Existing and future land use maps of the watersheds were provided to the Authority at a scale of 1:50,000.

3.2.3.4 Hydrologic Soil-cover Index

Land use and soil classification for each sub-watershed was compiled and the associated hydrologic soil-cover index for each land cover, and soil combination was assigned (Ref. 21). The representative index for each sub-watershed is presented in Appendix C.

Excess rainfall in pervious areas is calculated by the QUALHYMO model using the SCS relation:

$$Q = \frac{(P - ABSPER)*(P - ABSPER)}{(P - ABSPER + S^*)}$$

where;

Q = cumulative depth of runoff (mm)
P = cumulative depth of precipitation (mm)
$ABSPER$ = initial abstraction (mm)
S^* = loss parameter (mm)

In the QUALHYMO Model, S* and ABSPER are updated by the model on the basis of precipitation occurrence in order to provide an accounting of initial moisture conditions. In the case of S*, this is accomplished by expressing S* as a function of a variable Antecedent Precipitation Index, the API.

The API is determined from the following relation:

$$API_2 = APIK * API_1 + P_1$$

where:

APIK is a coefficient: 0.9 for daily time steps
P_1 is precipitation within time step 1, and the
API subscripts refer to conditions at the beginning of time step 1 and time step 2

The relationship that was found to be appropriate to relate S* and API is:

$$S^* = SMIN + (SMAX - SMIN)* \exp(-SK*API)$$

where:

SMIN and SMAX represent the range in S* and SK is a calibration parameter.

In order to apply the QUALHYMO model to the Nottawasaga River watershed, the following steps were taken:

i) Hydrologic soil-cover complexes (CN) were computed for each of the hydrologic soil group types and land covers in a watershed sub-catchment (hydrologic unit). A weighted average hydrologic soil-cover complex (CN) was calculated for the sub-catchment to correspond to the Soil Conservation Service Antecedent Moisture Condition I, II and III.

ii) The API sub-routine of the QUALHYMO model was used to analyze the hourly precipitation records between May and November for the Shelburne and Barrie precipitation stations over the 1963 to 1984 period and to calculate continuous API (Antecedent Precipitation Index) values at these two stations. It is noted that the hourly precipitation record at Shelburne was synthesized from daily records according to the procedure outlined in Section 3.1.1.1.

An API duration analysis of the two (Shelburne and Barrie) API sequences were carried out to determine the API values corresponding to the 15, 50 and 85 percent time of exceedance. It was established that for both stations the API values of 16.5 mm, 28.0 mm and 48.0 mm corresponded to the foregoing percentage exceedances respectively and therefore were applicable over the entire study area.

iii) an S* versus API curve was established for each sub-catchment. In order to obtain the general shape of this curve, the hydrologic soil-cover (CN) for each sub-catchment corresponding to the antecedent moisture conditions, I, II and III (point i) above) was converted to the