A MODEL FOR THE DETERMINATION OF THE NATURAL STREAMFLOW OF VENISON CREEK

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INTRODUCTION

Water takings for the irrigation of tobacco in Ontario reduce streamflow during the months of July and August in most years. Yakutchik and Lammers (5) estimated streamflow reduction for Big Creek at Delhi in the order of 70% for the period July 30 to August 1, 1964, due to irrigation takings in that basin. These reductions affect the natural functions of streams, and cause water use conflicts between stream users.

For the management of water resources in such basins, knowledge is required regarding (i) the amount of water available during peak water demand periods; (ii) the amount of water likely to be used from various sources; and (iii) the relative effects of water takings from different sources on streamflow. Information regarding the natural flows available for use is often scarce, since streamflow records for many of the streams in Southern Ontario began after the practice of tobacco irrigation was established in the early 1950's. Therefore, there is a need for a method to estimate natural streamflow patterns in order to evaluate the effect of water takings. Such information is important to the development of improved water management systems in the region.

A streamflow determination model has been developed for the generation of estimates of natural mean daily streamflow. Input for the model includes records of existing daily streamflow, and water takings from ground and surface water sources. Venison Creek basin has been used as a verification site for the model, the basin characteristics being suitable for the study, and hydrometric and observation well data being available (3).

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MODEL DEVELOPMENT

For this study, the natural discharge of a stream is defined as the discharge generated in the basin under existing land use. A large number of man-made ponds are part of the existing land-use pattern of Venison Creek and have increased the total free water surface of the basin. Their effects are incorporated in the natural discharge as defined.

The model is based on three assumptions regarding the effects of various types of water takings on streamflow reduction:

(i) Takings from streamflow have a direct effect on streamflow reduction.
(ii) Takings from surface-water storage areas not located on the stream (i.e. farm ponds) do not affect streamflow.
(iii) Takings from groundwater resources have an indirect effect on streamflow reduction.

Assumption (i) is readily apparent. Assumption (ii) is valid for the case involving intermittent streams, but is not strictly true for permanent streams. Assumption (iii) considers that groundwater takings, whether from wells or ponds dug to below the water table, reduce the rate of groundwater discharge to the streams, due to locally reduced hydraulic heads and gradients of the water table to the streams. Such reductions remain until the aquifers from which the water has been withdrawn have been recharged to their capacity. This normally occurs only during the spring recharge period, about 200 days after the water taking occurs.

It has further been assumed in the model that the effects of groundwater takings on streamflow, observed at an inventory point at a downstream gauge, will lag the actual takings by several days. Initially, there will be local adjustments in the water table. Additional takings at the same or nearby sites will result in additional water-table adjustments. The effects of these takings are cumulative, because each additional groundwater taking will add to the existing effects of previous takings. Therefore, the effects of groundwater takings on streamflow will be of little significance during the start of the irrigation period but will increase steadily as the irrigation period progresses until groundwater takings cease.

A basic relationship for natural streamflow determination may be expressed:

$$Q = M + D + I \qquad (1)$$

where

Q = natural streamflow;
M = measured streamflow;
D = direct streamflow losses due to streamflow takings; and
I = indirect streamflow losses due to groundwater takings.

For a consideration of mean daily streamflow values, the D and I terms may be expressed as:

$$D_{t_n} = \frac{P}{T} \sum_{t=n-(T-1)}^{n} S_t \qquad (2)$$

and

$$I_{t_n} = AR \sum_{t=1}^{n-b} G_t \text{ for } n \leqslant m+b, \qquad (3)$$

or

$$I_{t_n} = ARC^{[n-(m+b)]} \sum_{t=1}^{m} G_t \text{ for } n > m+b \qquad (4)$$

where

D_{tn} = mean daily streamflow loss due to direct streamflow takings, on the nth day following the commencement of irrigation in the basin for a selected year under study;

P = scale factor to convert reported daily streamflow takings to total daily streamflow takings;

T = travel time, in days, of streamflow from farthest water-taking site on the stream to the inventory station at downstream gauge;

n = day number following the commencement of irrigation in basin;

t = time, in days;

S_t = reported daily streamflow taking on day t;

I_{tn} = mean daily streamflow loss on the nth day due to takings from groundwater;

A = constant, characteristic of the study basin;

R = scale factor to convert reported groundwater takings to estimated total groundwater takings;

b = average delay time, in days, before the effects of groundwater takings on previous days are felt in streamflow reduction at the inventory station;

G_t = reported groundwater taking on day t;

C = constant, characteristic of the study basin;

m = day number, counted from first day of irrigation, for last day of water takings from groundwater.

Equations (2), (3) and (4) were substituted into equation (1) to form:

$$Q_{tn} = M_{tn} + \frac{P}{2}[S_{tn-1} + S_{tn}] + AR\sum_{t=1}^{n-5} G_t$$

for

$n \leqslant m + 5$

and

$$Q_{tn} = M_{tn} + \frac{P}{2}[S_{tn-1} + S_{tn}] + ARC^{[n-(m+5)]}\sum_{t=1}^{m} G_t$$

for

$n > m + 5.$

STUDY BASIN AND TEST DATA

Venison Creek, a tributary of Big Creek, lies on the Norfolk sand plain, north of Lake Erie. The basin is about 19 km long and 5 km wide, and has an area of about 90 km^2. The location of the basin and observation sites are shown in Figure 1.

The watershed above the Water Survey of Canada hydrometric gauge on Venison Creek was selected as the study area. The area above the gauge is about 78 km^2 and represents about 82% of the total Venison Creek basin.

Water used for irrigation of tobacco crops was estimated from water-taking records[a] on file with the Ministry of the Environment for the 1967, 1968 and 1969 irrigation seasons. This estimation was carried out by:

1. Compilation of a list of permits issued by the Ministry to tobacco growers in the study basin.
2. Compilation, assessment, and classification of water-taking records submitted to the Ministry by the permittees for the three irrigation seasons.
3. Determination of daily totals of reported water takings from each of the categories and sources of supply.

Classification of these records was based on the following types of withdrawal sites utilized:

1. Withdrawal from groundwater resources through water takings from wells and sandpoints and from dugout ponds not connected to a stream or located in a streambed of an intermittent stream.
2. Withdrawal from surface-water resources through water takings from:
   (i) Streamflow, on-stream dugout ponds and dugout ponds connected to streams; or
   (ii) Surface-water storage behind dams on permanent or intermittent streams.

The accuracy of water-taking records depends on the irrigator. Information is submitted annually by the irrigator regarding dates of taking, duration and time of operation, and details of the irrigation system (4). Water use is calculated on the assumption that the average irrigator operates his irrigation system at the recommended pressure specified by the sprinkler manufacturer.

WATER USE ASSESSMENT

During the period 1967 to 1969, only 54-65% of the known irrigators submitted records satisfactory for analysis. Statistics on irrigators and water-taking records are shown in Table 1.

TABLE I STATISTICS ON IRRIGATORS AND WATER-TAKING RECORDS

Year:	1967	1968	1969
Total irrigators	102	102	105
Irrigators holding permits†	99	99	102
Permitted water sources‡	108	108	113
Irrigators submitting suitable records (%)	65	61	54

† Certain irrigators are exempted.
‡ Certain irrigators use more than one water source.

Figure 2 reveals a histogram of the number of irrigators reporting water takings and the histogram of the total reported daily takings. These histograms portray three patterns of water use. The histogram for 1968 shows a period of intensive water use as compared to 1967 and 1969.

Water is withdrawn from three main sources in the basin: groundwater, streamflow, and surface-water storage. Figure 3 shows histograms of water use by source for 1968.

The following assumptions were used to estimate total daily and seasonal irrigation water use in the study area:

(i) All irrigators possessing permits to take water would have submitted water-taking records when they had taken water.
(ii) Irrigators whose takings are exempt under water-use legislation would have irrigated according to the same ratio as the irrigators having permits to take water.
(iii) Irrigators who submitted unsuitable water-taking records would have irrigated in the same manner and on the same days as those submitting suitable records.

The scale factors used to convert reported water takings to estimated water takings are presented in Table II. Application of these scale factors to the reported annual amounts of irrigation water use yields estimates of total annual amounts of irrigation water use.

GROUNDWATER STAGE VS. GROUNDWATER DISCHARGE RELATIONSHIPS

Relationships were established between the mean daily groundwater stage in observation well 3A in the basin and the natural streamflow under baseflow conditions at the stream-gauging station on Venison Creek (1, 2). This observation

[a] Ontario Water Resources Commission. Unpublished water-taking records of the Water and Well Management Branch, Division of Water Resources.

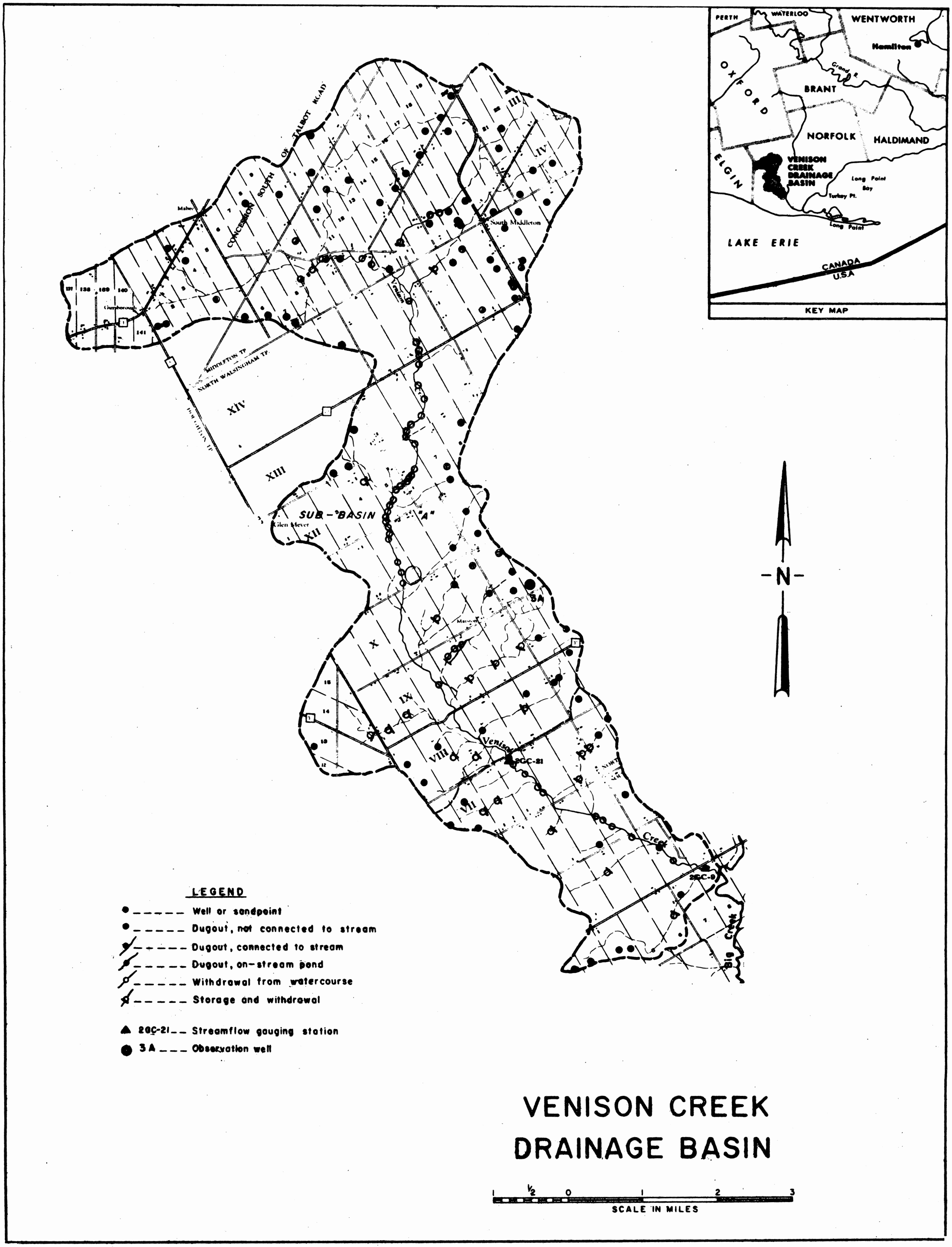

Figure 1. Venison Creek drainage basin.

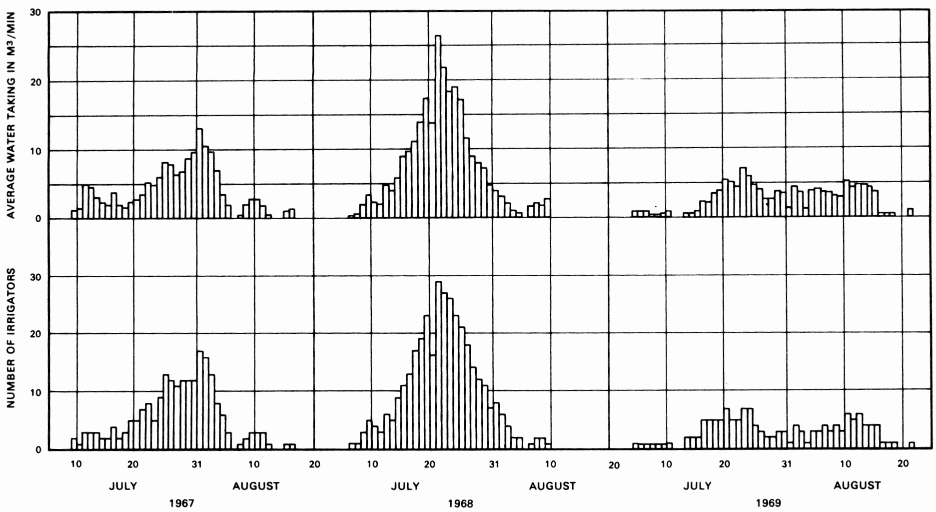

Figure 2. Number of irrigators reporting taking water and their total daily takings, 1967-1969.

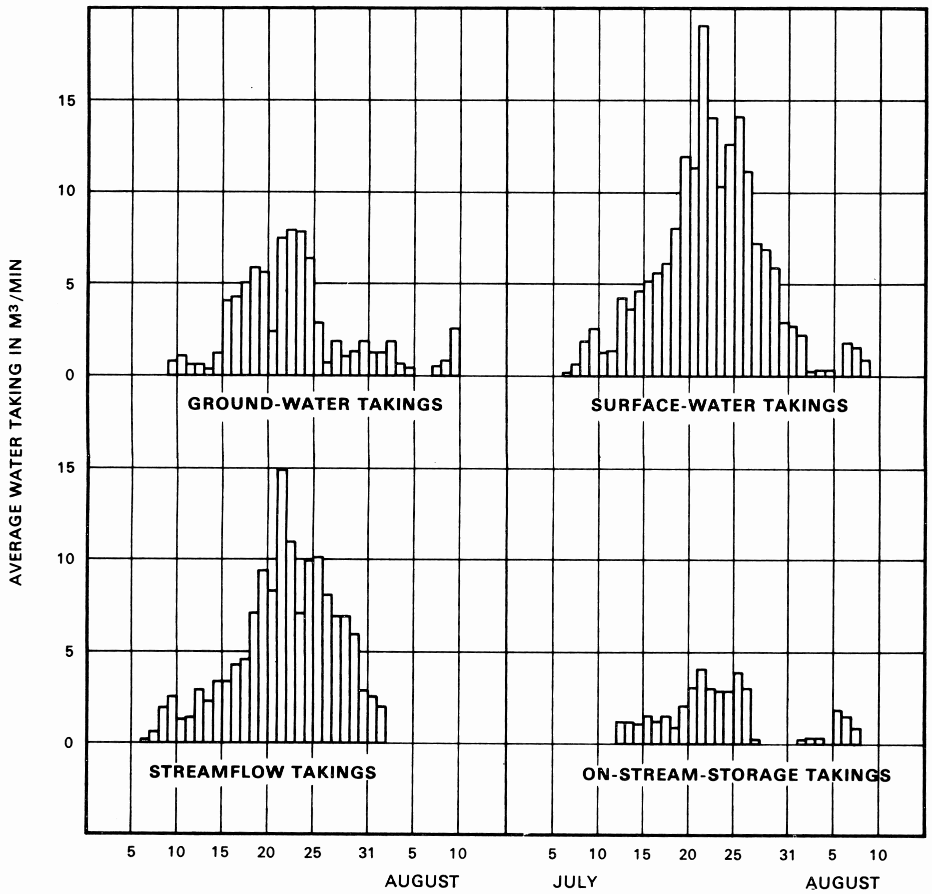

Figure 3. Reported daily water takings from indicated sources in 1968.

well was selected because the water table at this site would not have been affected by water takings from the nearest groundwater-taking sites. Relationships were established for June to September periods, 1967 to 1969.

The relationships for 1968 are shown in Figure 4. It was often necessary to use streamflow data after irrigation had commenced to provide flow data for a certain water stage range. However, these data were for the early part of the irrigation period and were adjusted upwards for amounts of estimated daily water takings from streamflow.

The annual relationships were consistent within each June to September period, with the exception of the 1968 relationship, but were not consistent among the 3 yr. The exception in 1968 was caused by an unusually heavy storm which resulted in a substantial rise in the water table.

Seasonal curves of groundwater stage and stream discharge under baseflow conditions were used as rating curves to estimate the natural baseflow during and shortly after the irrigation period using groundwater stage as control. A trace of the estimated natural groundwater discharges is shown in Figure 5 for the 1968 irrigation period.

MODEL FITTING

Four basin constants, A, b, C, and T, were determined for the Venison Creek basin. The travel time, T, of equation (2) was estimated to be 2 days. The time of concentration under storm runoff conditions was calculated to be about 9 h. Under baseflow conditions, the travel time would be considerably larger due to energy losses in the stream channels. It was assumed, therefore, that the effects of water withdrawal from the headwaters of Venison Creek would be observed the next day in a reduction of natural streamflow at the inventory station.

The terms A and b of equation (3) were empirically determined from rating curves of groundwater stage versus groundwater discharge using stage data as control. From trial runs on 3 yr of irrigation and baseflow data, the values $A = 0.03$ and $b = 5$ days were selected.

The C term of equation (4) was calculated from 3 yr of water-use data by solving the common ratio of the geometric series whose first term was equated to the unaccountable streamflow reduction effects of groundwater takings. The C values were 0.93, 0.94, and 0.95 for the 3 yr of record. A mean of 0.94 was selected for use in equation (4).

Equations (5) and (6) were used to estimate daily values of natural streamflow during and after each annual irrigation period during 1967-1969.

The hydrographs of recorded streamflow, estimated natural streamflow, and natural baseflow for the 1968 irrigation season are shown in Figure 5. The closeness of fit between the model output values of natural streamflow and the independently derived estimates of natural streamflow under baseflow conditions is good, despite the fact that satisfactory water use information was available for only about 61% of the known 1968 irrigators.

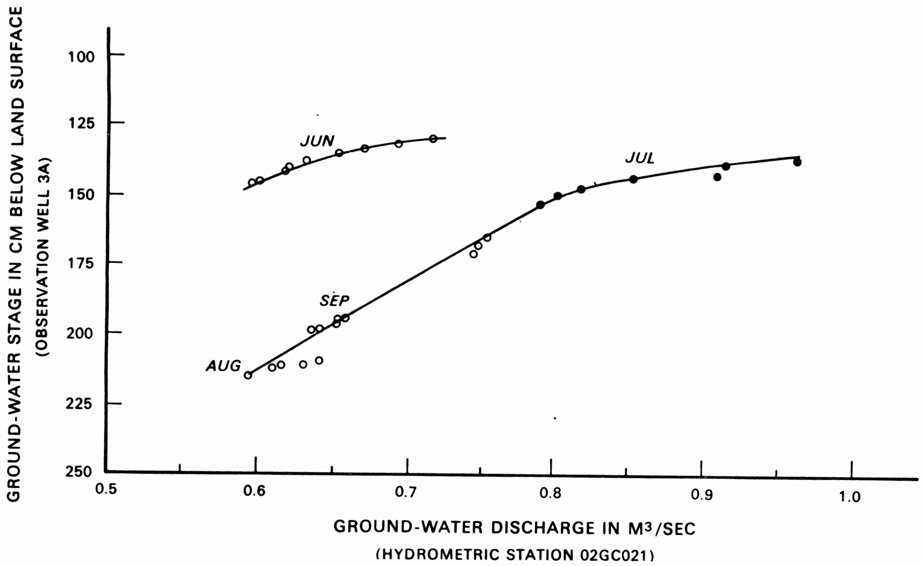

Figure 4. Groundwater stage and groundwater discharge relationships, Venison Creek drainage basin, June – September, 1968.

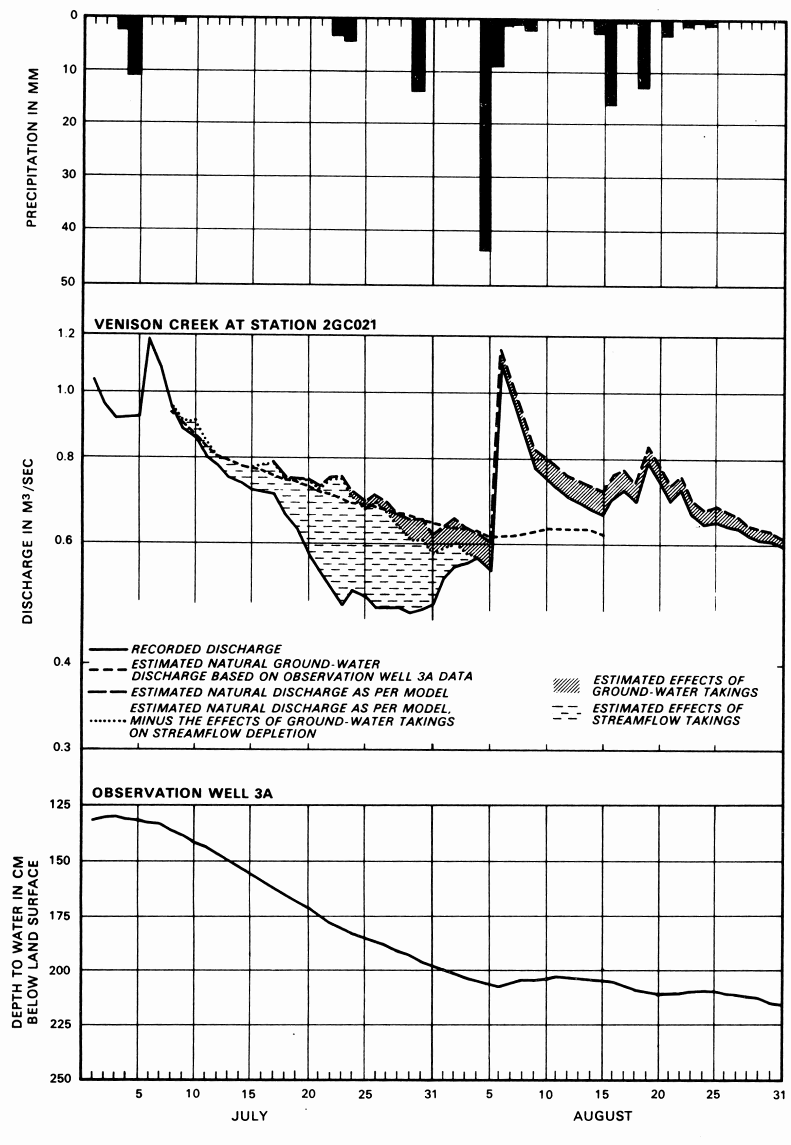

Figure 5. Estimated basin precipitation, and hydrographs of streamflow and water-table fluctuations, Venison Creek drainage basin, July and August, 1968.

CONCLUSIONS

The natural streamflow determination model satisfactorily estimated the natural streamflow of Venison Creek during periods of intensive irrigation water use. The closeness of fit between the model output values and independently derived estimates of natural streamflow under baseflow conditions is good. Testing of the model suggested that reliable estimates of natural streamflow could be generated with water-use information from about 54 to 65% of the known irrigators.

The streamflow reduction due to groundwater takings in Venison Creek basin was found to be significant, particularly during the latter part of the irrigation period. In 1968, about 56% of the estimated groundwater takings were accounted for in streamflow reduction estimates at the end of the irrigation period. These effects should be considered in the development of a water management scheme in the Venison Creek basin.

SUMMARY

Water takings for irrigation reduce streamflow during the months of July and August in most years. A determination model was developed for Venison Creek basin based upon inputs of streamflow, groundwater levels and water takings from several types of source by irrigators.

The model satisfactorily determines realistic estimates of natural streamflow and the effects on streamflow due to water takings for irrigation.

ACKNOWLEDGMENTS

Water-taking and observation well data made available by the Ontario Water Resources Commission and its financial assistance is gratefully acknowledged.

REFERENCES

1. Canada Department of Energy, Mines and Resources. 1967. Water Survey of Canada, Surface Water Data, Ontario.

TABLE II NUMBER OF IRRIGATORS REPORTING TAKING WATER, HAVING PERMITS AND NOT REQUIRING PERMITS, AND SCALE FACTORS TO CONVERT REPORTED TO ESTIMATED TOTAL TAKINGS BY SOURCE, 1967-1969

Source	No. of irrigators												Scale factors to convert reported to estimated total takings‡		
	Reporting taking water			Reporting taking water by source			Having permits to take water from source			Exempted from requiring permits					
	(1)			(2)			(3)			(4)			(5)		
	'67	'68	'69	'67	'68	'69	'67	'68	'69	'67	'68	'69	'67	'68	'69
Groundwater	29	29	15	18	22	11	47	47	51	3	3	3	1.7	1.4	1.5
Surface water	37	41	13	25	34	12	58	58	59	0	0	0	1.5	1.2	1.1
Streams and dugout ponds connected to streams (streamflow)	29	32	10	21	27	9	44	44	45	0	0	0	1.4	1.2	1.1
Storage in permanent and intermittent streams	8	9	3	4	7	3	14	14	14	0	0	0	2.0	1.3	1.0

† The difference between the values in columns (1) and (2) is equal to the number of irrigators reporting taking water, but whose records were unsuitable for analysis.

‡ The scale factors were derived using the following equation; the terms in the equation refer to the values in the numbered columns:

$$\text{Scale factor} = \frac{\text{Col. (1)}}{\text{Col. (2)}} \times \frac{(\text{Col. (3)} + \text{Col. (4)})}{\text{Col. (3)}}$$

2. Canada Department of Energy, Mines and Resources. 1968, 1969. Water Survey of Canada, Provisional Streamflow Records, Ontario.

3. Lammers, W. 1970. Model for the determination of the natural streamflow of Venison Creek. M.Sc. Thesis, University of Guelph, Guelph, Ontario.

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5. Yakutchik, T.J. and W. Lammers. 1970. Water resources of the Big Creek drainage basin (Water Resources Report No. 2), OWRC, Toronto, Ontario.