STREAM SIMULATION IN AN ANALOG MODEL OF THE GROUND – WATER SYSTEM ON LONG ISLAND, NEW YORK

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 77-58

Prepared in cooperation with

Nassau County Department of Public Works
Suffolk County Department of Environmental Control
Suffolk County Water Authority
New York State Department of Environmental Conservation

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle STREAM SIMULATION IN AN ANALOG MODEL OF THE GROUND-WATER SYSTEM ON LONG ISLAND, NEW YORK	5. Report Date September 1977 6.
7. Author(s) Arlen W. Harbaugh and Rufus T. Getzen	8. Performing Organization Rept. No. USGS/WRI 77-58
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 5 Aerial Way Syosset, New York 11791	10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 343 U.S. Post Office & Courthouse Albany, New York 12201	13. Type of Report & Period Covered Final 14.

15. Supplementary Notes Prepared in cooperation with Nassau County Department of Public Works, Suffolk County Department of Environmental Control, Suffolk County Water Authority, New York State Department of Environmental Conservation.

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

*Analog models, *Streams, Groundwater, New York

17b. Identifiers/Open-Ended Terms

Long Island, N.Y., Seepage

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	20
	20. Security Class (This Page) UNCLASSIFIED	22. Price

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September 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

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CONVERSION FACTORS AND ABBREVIATIONS

SI[1/] units	Multiply by	To obtain English units
meters (m)	3.281	feet (ft)
cubic meters per second (m^3/s)	35.31	cubic feet per second (ft^3/s)

SYMBOLS USED IN EQUATIONS

h_{node}	hydrologic head at a model node (in meters)
$h_{surface}$	average elevation of a stream surface at a model node (in meters)
I_{node}	electric current representing ground-water discharge rate from one stream node (in milliamperes)
K	constant of proportionality (in square meters per day)
Q_{node}	discharge rate of ground-water from one stream node (in cubic meters per day)
R	electric resistance (in ohms)
V_{node}	electric potential at a model node (in volts)
V_{ref}	electric potential representing average elevation of stream surface at a model node (in volts)
V_{supply}	electric potential of an adjustable voltage supply (in volts)

1/ International System (metric) units

STREAM SIMULATION IN AN ANALOG MODEL OF THE GROUND-WATER ON LONG ISLAND, NEW YORK

by

Arlen W. Harbaugh and Rufus T. Getzen

ABSTRACT

The stream circuits of an electric analog model of the ground-water system of Long Island were modified to improve representation of the relationship between streamflow and ground-water levels. Assumptions for use of the revised circuits were that (1) streams are strictly gaining, and (2) ground-water seepage into the streams is proportional to the difference between streambed elevation and the average water-table elevation near the stream. No seepage into streams occurs when water levels drop below the streambed elevation. Regional simulation of hydrologic conditions during the 1962-68 drought on Long Island was significantly improved by use of the revised stream circuits.

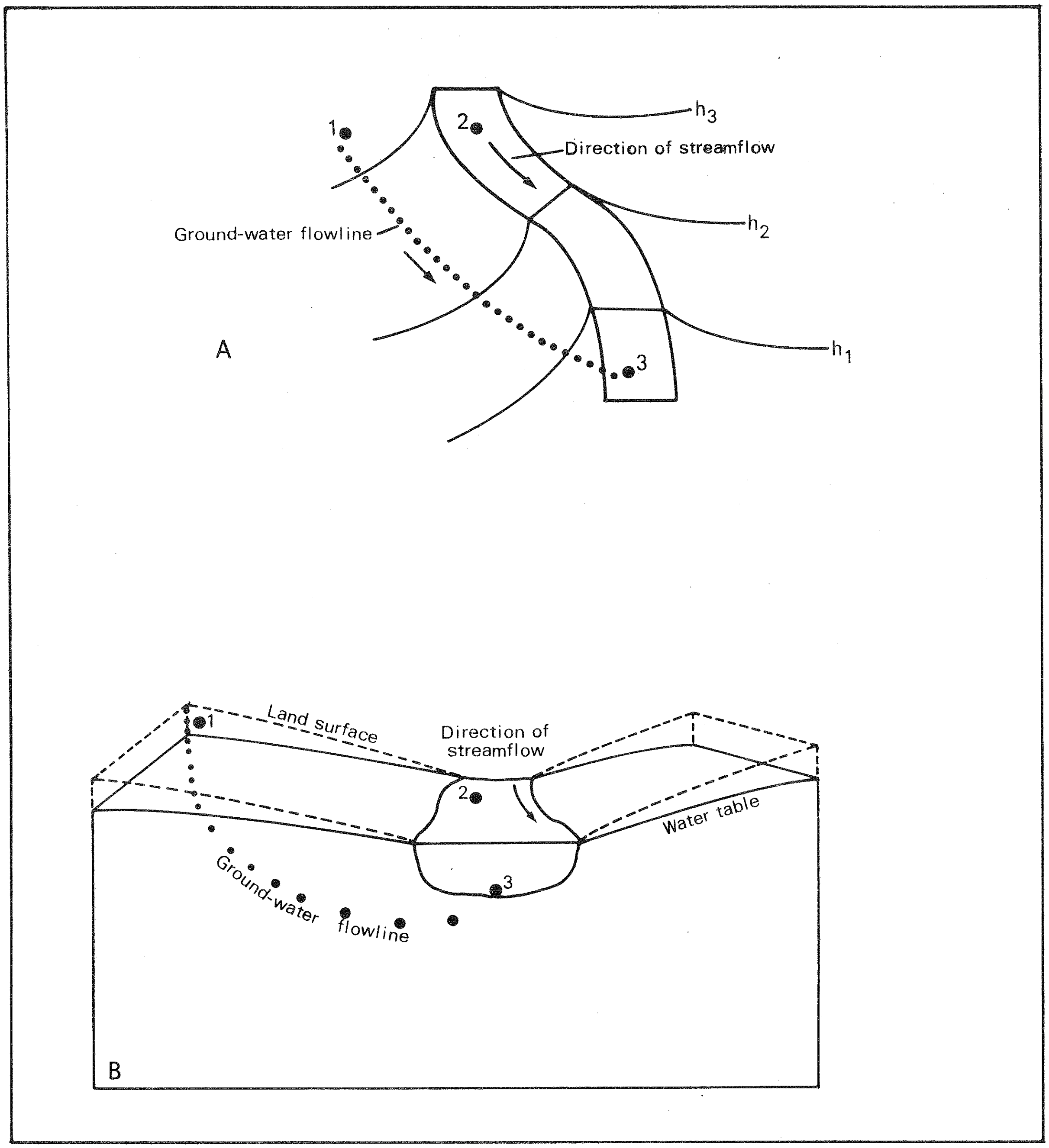


Figure 1.--Ground-water flowing near a gaining stream: (A) from above; (B) in three dimensions. Water moves along a path from point 1 to point 3 rather than directly toward the stream from point 1 to point 2. In (A), lines h_1, h_2, and h_3 are ground-water equipotential contours. They are not shown in B because in three dimensions they would be complex surfaces.

INTRODUCTION

The U.S. Geological Survey has constructed a regional three-dimensional electric-analog model to simulate the Long Island ground-water reservoir and associated streams (Getzen, 1975). The electrical circuits in the original model simulated Long Island's streams adequately for an initial model verification; however, subsequent experience with the model indicated that in some types of simulations, these circuits resulted in an inaccurate model response.

The purpose of this report is to describe the revised circuitry for simulating streamflow and how it improves model response to hydrologic stress.

DESCRIPTION OF LONG ISLAND STREAMS

Long Island is underlain by a large ground-water reservoir consisting of three major aquifers. The upper glacial aquifer is uppermost; the Magothy and Lloyd aquifers underlie it. Long Island's ground-water system is described in numerous reports, most recent of which are Cohen, Franke, and Foxworthy (1968) and McClymonds and Franke (1972). These reports state that 95 percent of streamflow on Long Island is derived from ground-water seepage.

Although Long Island streams are small, with an average flow of about 1.1 m^3/s in the largest stream (U.S. Geological Survey, 1975), as a group they are estimated to carry 50 percent of the water that naturally leaves the ground-water system (Cohen, Franke, and Foxworthy, 1968, p. 58). Long Island has about 65 periodically or continuously gaged streams and tributaries; most of these are less than 5 miles long and have an average annual flow of less than 0.3 m^3/s. Numerous ungaged short streams have lesser flows.

The flow of ground water from areas of high elevation toward a stream channel of lower elevation is illustrated in figure 1. Because the Long Island streamflow system is complex, and ground-water flow patterns are difficult to measure, ground-water flow is usually represented in two dimensions (fig. 1A). However, only the three-dimensional view (fig. 1B) can accurately depict the true flow system. A stream line (fig. 1A) shows the path of water, which enters the water table as precipitation at point 1 near the stream and moves vertically, laterally, and downslope toward the stream, eventually entering it. Water usually does not move perpendicular to the stream channel, but at an angle determined by the water-table gradient both in the downstream direction and toward the stream. Water entering the ground at point 1, for example, would not reappear at point 2, but at point 3. The factors that control this flow pattern are (1) areal distribution of recharge to the ground-water reservoir, (2) water-surface elevation along the length of the stream in relation to adjacent water-table elevation, (3) stresses such as those produced by pumping wells, and the effects of other nearby streams, which control the geometry of the ground-water drainage area for a particular stream, (4) variation in hydraulic conductivity and specific yield of the aquifer in the area draining to the stream, and possibly (5) clogging effects (reduced hydraulic conductivity) at the stream/aquifer interface. None of these factors has been analyzed in detail for any Long Island stream. A dividing surface is formed by the deepest flow lines that enter the stream; below this surface, flow lines do not intersect the stream. This surface and the flow system above it are termed the stream subsystem.

The flow lines beneath the subsystem go deeper into the subsurface, from where they continue into the ocean at or beyond the shore. The stream subsystem for Long Island cannot be measured precisely; it differs from stream to stream and temporally depending on water-table fluctuations.

Changes in the altitude of either the stream surface or the water table result in changes in the rate of seepage of ground water to the stream. During periods without precipitation, streamflow is derived entirely from ground-water storage. Almost immediately after precipitation ceases, water stored in the stream banks begins to enter the stream, but water in storage at the outer edges of the ground-water drainage area does not move toward the stream noticeably until days or even weeks after precipitation ceases. Throughout a period of no precipitation, a gradual water-table decline occurs over the whole basin, and rates of ground-water discharge to the streams constantly decrease accordingly. This process is called ground-water, or base-flow, recession. Pluhowski and Kantrowitz (1964) found discharge from one Long Island stream, Champlin Creek, to be directly related to average water-table levels near the stream. However, all five factors described in the preceding paragraphs would have to be completely evaluated in order to quantitatively relate the change in base flow to water-level changes in the aquifer. Although none of these factors is well known at present in relation to Long Island streams, it is clear that streamflow fluctuations are significant and should be incorporated into any model of the Long Island ground-water system.

SCOPE OF STREAM SIMULATION ON THE ANALOG MODEL

The analog model of Long Island represents the aquifer system by five layers constituting the two major aquifers. The top two layers represent the upper glacial (water-table) aquifer, and the bottom three represent the Magothy aquifer. The Lloyd aquifer is not simulated. The thickness of each model layer is proportional to the thickness of the aquifer represented. Each layer is divided into blocks. The depth of each block represents the thickness of the layer, and the length and width of each block each represent 1,830 m. The center of each block is termed a "node." The top layer of the model is designed to represent the stream subsystem, which ranges in estimated thickness from 0 to 12 m at different locations. These estimates were made from idealized flow-line calculations on a vertical two-dimensional model (Franke and Cohen, 1972). Because the stream subsystem is represented by only one layer on the model, it is modeled in only two dimensions.

The analog model was designed to simulate time intervals of greater than 1 year. Stresses were applied to the model at the average rate determined for 1-year periods or longer. Thus, seasonal fluctuations of water levels and the corresponding fluctuations in ground-water seepage to streams are not modeled. The error in predicted water levels caused by this averaging was generally assumed to be small, but the error in resulting model streamflow could be large because seasonal streamflow fluctuation are large.

Each modeled stream is represented by the series of top-layer nodes that most closely approximates the actual location of the streambed. Because of the large area represented between nodes (1,830 m), stream location on the model is not precise, and the streams are simulated as being 1,830 m wide. In a few places, two streams are modeled as one because they fit within the same set of nodes. About 60 streams and tributaries are represented on the model and range in length from 1 to 11 nodes. A typical stream is represented by 3 to 4 nodes. All methods of simulating seepage to streams described below use this system of stream representation.

INITIAL METHODS OF MODELING SEEPAGE FROM A STREAM NODE

Because of their relatively small size and nearly total dependence on ground-water discharge, Long Island streams cannot be modeled as constant head boundaries as larger streams often can. In the initial construction and verification of the analog model (Getzen, 1975), two methods of stream modeling were used. The first was used only for steady-state analysis and assumed that streamflow was directly proportional to the head gradient between adjacent stream nodes. A resistor (termed a stream resistor) was connected between adjacent nodes (fig. 2A), and its resistance was adjusted to give proper steady-state flow. The second method also assumed that flow was dependent on head gradient between stream nodes, but not linearly. Diodes, which were put in series with each stream resistor, provided the nonlinearity and also allowed the model streams to stop flowing as the gradient decreased (fig. 2B).

Because these methods depend basically on head gradient between stream nodes, they do not correctly simulate the real streams because in the real streams it is the head gradient toward the streams that determines seepage into or out of them. Although these initial methods can be applied to steady-state flow conditions and to some few transient-state flow conditions, it is easy to imagine instances in which they would give poor results. For example, great stresses to the real ground-water system could cause the water-table elevation to drop below the streambed

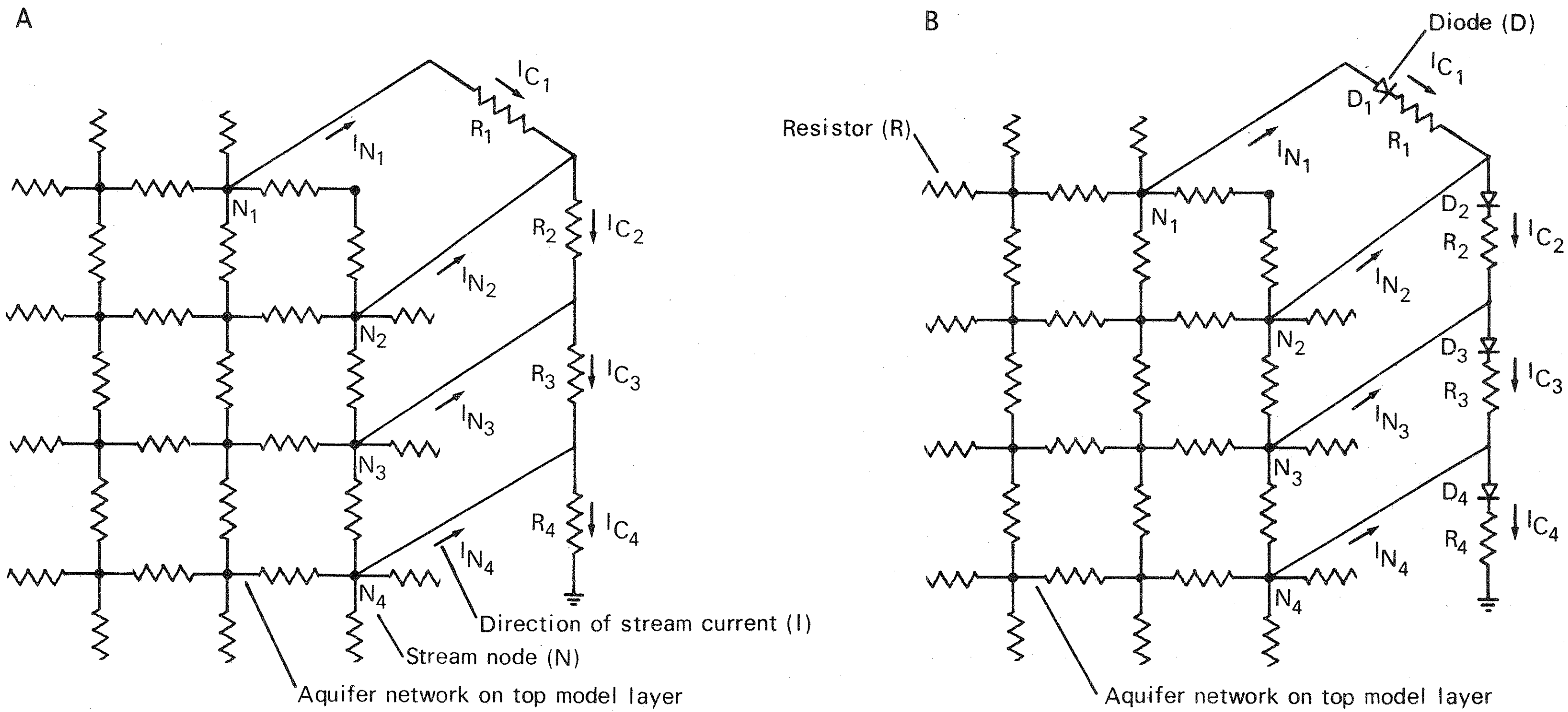


Figure 2.--Initial stream circuits used in model: (A) with resistors alone; (B) with resistors and diodes. Cumulative stream currents $I_{C1} \ldots I_{C4}$, which represent cumulative ground-water seepage from stream nodes $N_1 \ldots N_4$, depend on the values of $R_1 \ldots R_4$ and the voltage differences (head gradients) between adjacent stream nodes. Stream currents $I_1 \ldots I_4$ represent seepage from individual stream nodes.

elevation in some areas. Although ground-water seepage to these streambeds would cease, a substantial downstream head gradient in the water table could remain. With either of the initial modeling methods, the modeled streams would erroneously continue to gain ground water.

REVISED METHOD OF MODELING SEEPAGE FROM A STREAM NODE

For the revised model stream design, streams are assumed to be strictly gaining. The amount of infiltration from streams to the ground-water system is negligible because water infiltrates naturally from the streams only during times of storm runoff, which are infrequent. The assumption that water does not infiltrate from streams to the ground-water system implies that open-channel flow is of no consequence to the ground-water system. Only water that seeps into the stream and thus leaves the ground-water system is modeled. The seepage from any stream node is assumed to be directly proportional to the difference between the height of the water table at that node and the average stream-surface elevation at that node. Seepage to the stream node stops when the model water table falls below the average stream surface. Thus, seepage from a given node is expressed by the equations:

$$Q_{node} = K\,(h_{node} - h_{surface}) \quad \text{for } h_{node} > h_{surface} \qquad (1a)$$

$$Q_{node} = 0 \quad \text{for } h_{node} \leq h_{surface} \qquad (1b)$$

where K is constant. There is no direct dependence on heads at nodes above or below the given stream nodes. Since Q_{node} is the seepage from a single node, total streamflow at any point on the model stream is the sum of the seepage from all nodes upstream from that point. The h_{node} is the average water-table elevation over the area of the node (approximately 3.4 km^2). The $h_{surface}$ is the average elevation of the stream surface at the node. In the real stream system, this elevation changes according to the amount of water in the stream, but the change is small compared to the corresponding changes in water-table elevation. In the upper and middle reaches of real streams, the water-surface elevation is generally very close to the streambed elevation because of the shallow stream depth. In the tidal reaches of the streams, the water surface is significantly above the streambed, but still nearly constant at the average tide level. Therefore, $h_{surface}$ at every stream node is also assumed to be constant.

The electrical equations analogous to equations 1a and 1b are:

$$I_{node} = \frac{1}{R}\,(V_{node} - V_{ref}) \quad \text{for } V_{node} > V_{ref} \qquad (2a)$$

$$I_{node} = 0 \quad \text{for } V_{node} \leq V_{ref} \qquad (2b)$$

The adjustable supply voltage (V_{supply} in fig. 3A) sets V_{ref} according to the equation:

$$V_{ref} = V_{supply} + 0.5 \text{ volts} \tag{3}$$

The 0.5 volt is the characteristic junction voltage loss of the transistor and is constant except when the transistor is just turning on. The early turn-on characteristic of the transistor results in a nonlinearity, as I_{node} goes from 0 to 0.005 milliamperes (fig. 4), but this is insignificant in its effect on overall stream behavior. V_{ref} is determined graphically by extrapolating the linear part of the graph to the V_{node} axis (I_{node} = 0).

The supply voltage must be very stable because a change of a tenth of a volt causes a large percentage change in the current from a stream node. Integrated circuit voltage regulators were used for this purpose except where supply voltages had to be below the range of the integrated circuits--about 2.5 V. In those cases, which are typical of nodes near the model shore, simple resistor voltage dividers were used to get smaller voltages from a regulated supply voltage. The integrated circuits are desirable because of their stable output voltage over a wide current range, but the voltage dividers were found to be adequate whenever they were necessary.

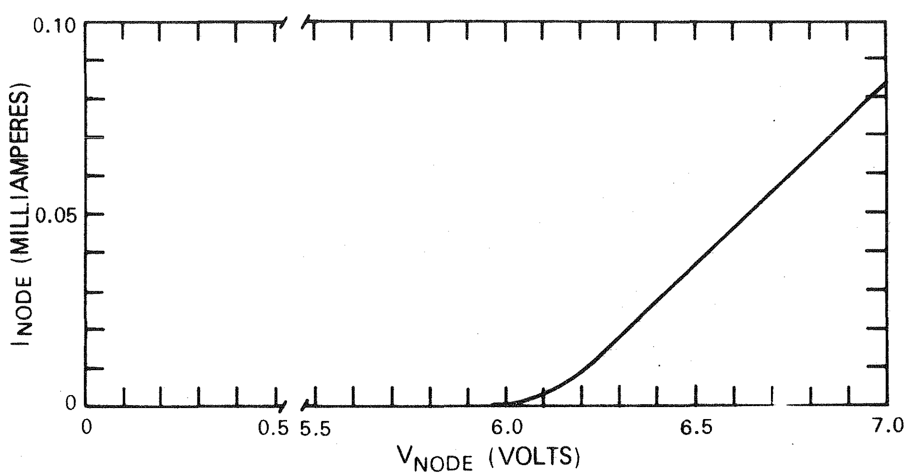


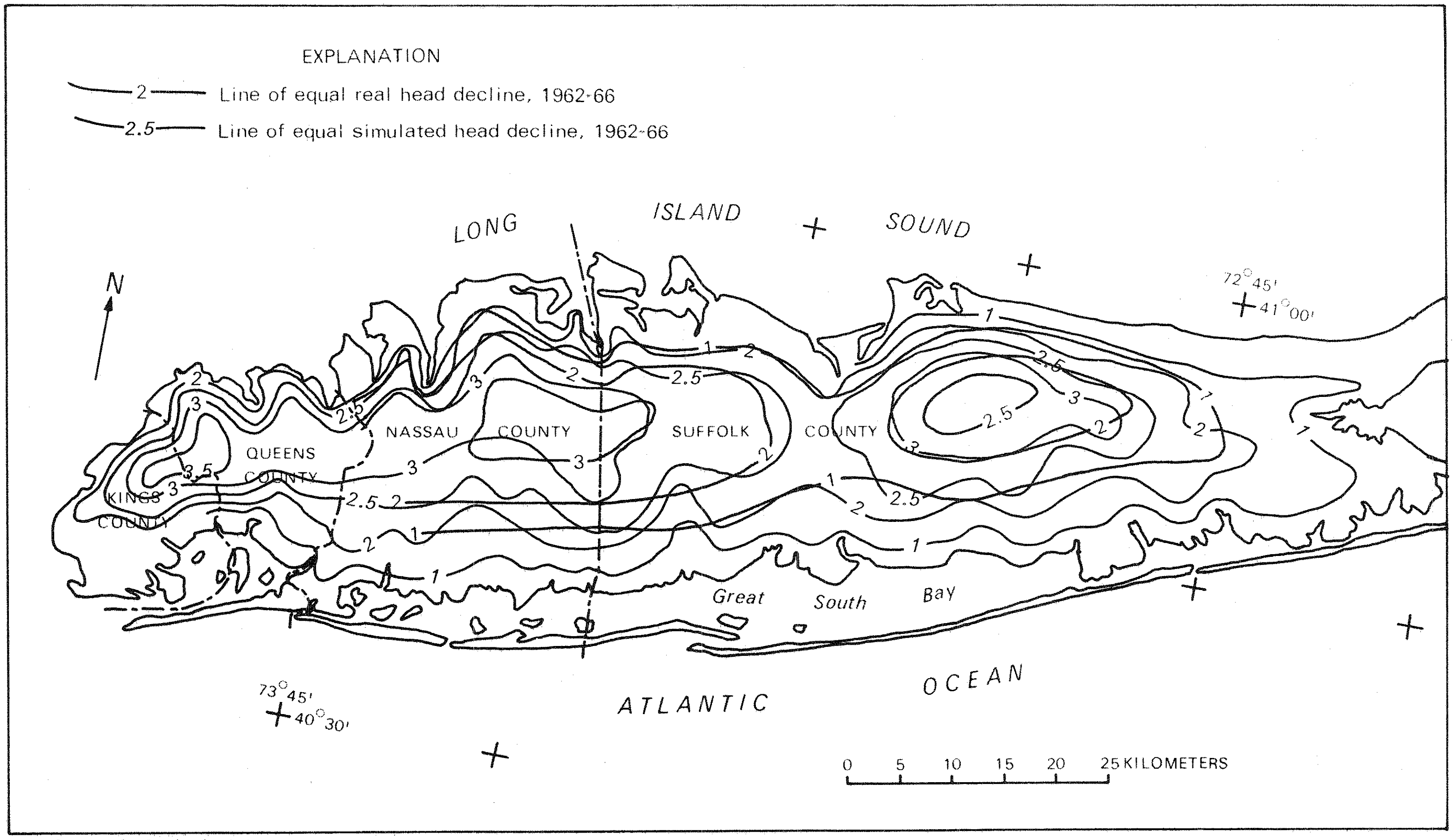
Figure 4.--Electrical behavior of a typical revised stream circuit in model.

Nodes at the mouths of several model streams do not use the transistor circuits because the reference voltage had to be less than the 0.5-volt junction drop of the transistor. In these cases, electrical ground (sea level) is used as a reference (V_{ref}) for the stream resistance (R), leaving out the transistor and adjustable voltage supply. Because the transistor switch is excluded, infiltration from the stream will occur through R if the head at the nodes falls below sea level. This means that these nodes are operating like simple shoreline nodes rather than as stream nodes, which is probably valid here. New stream circuits were not installed in the area of the model representing Kings and Queens Counties because no streams exist there now.

Installation of the new stream circuits required that R be determined from each node. The design steady-state current was taken from initial stream circuits so that, according to equation 2, only a value for $V_{node} - V_{ref}$ was necessary to determine R. Although detailed quantitative data for each stream are lacking, the value for $V_{node} - V_{ref}$ was chosen to be between 0.75 and 1.0 volts (1.5 to 2.0 meters on the model), depending on stream location, by using topographic and water-table maps to obtain approximate differences between regional water-table levels and streambed elevations. Under design conditions, this is the decline in head that must occur before seepage from the node stops. After R is calculated and installed, the supply voltage must be adjusted until the chosen value for $V_{node} - V_{ref}$ is measured across R. This then assures that the design current is flowing out of the node. When these adjustments are made, the model steady-state water table should be the same as the steady-state water table of the initial stream circuits because the current flowing from each stream node is the same even though the circuit is different. However, response to model stresses will be different as a result of the new circuitry. Once R has been chosen, $V_{node} - V_{ref}$ may be changed so that model streamflow reflects initial streamflow conditions for any problem under study.

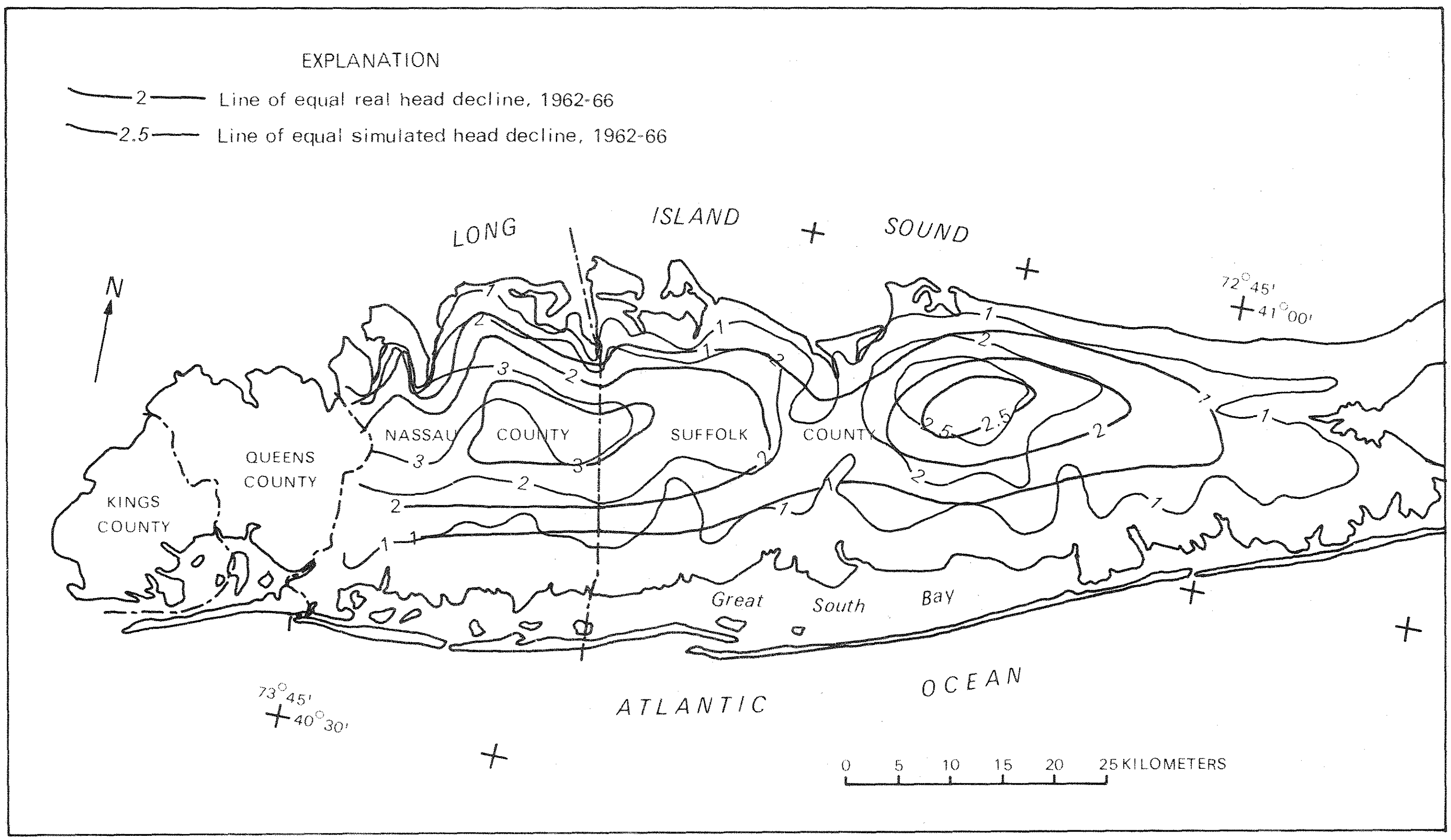
TESTING THE REVISED STREAM-SIMULATION METHOD

The revised method of stream modeling was tested by comparing a revised model simulation of ground-water declines resulting from the 1962-66 drought with that originally done for model verification (Getzen, 1975, fig. 36) and with real declines during the drought (Cohen, Franke, and McClymonds, 1969, fig. 10). The model verification before stream-modeling changes was good except that resulting drawdowns were larger than in the real system, especially near the south shore, where most of the streams are located (fig. 5). In this initial simulation, streamflow did not decrease as much during the drought as real streamflow had, and this caused model drawdowns to be too large.



Base from U.S. Geological Survey
Hartford, 1962; New York, 1967
Newark, 1967, 1:250,000 series

Figure 5.--Comparison of simulated head decline and observed (real) declines in the unconfined aquifer as a result of the 1962-66 drought. In this run, the initial stream circuits consisting of resistors and diodes were used (from Getzen, 1975, fig. 36).



Base from U.S. Geological Survey
Hartford, 1962; New York, 1967
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Figure 6.--Comparison of simulated head decline and observed (real) declines in the unconfined aquifer as a result of the 1962-66 drought. In this run, the revised stream circuits were used. (Observed head decline from Cohen, Franke, and McClymonds, 1969).

The drought-verification run incorporating the new method of stream simulation is shown in figure 6. Although model drawdowns are still greater in some areas than those found during the actual drought (Cohen, Franke, and McClymonds 1969), it is apparent that the new method of stream simulation significantly improved the model results. The water-table contours bend around the streams, indicating the expected influence of the streams in lowering the water table. The real water-table-change contours of Cohen, Franke, and McClymonds (1969) do not show these bends, most likely because not enough well records were available to show detailed water-level changes (O. L. Franke, oral commun., 1976). On a regional basis, however, the model-generated contours resulting from the revised method of stream simulation are quite close to those of the real system.

CONCLUSION

The revised method of stream simulation more closely approximates the conceptual operation of Long Island's streams and had closer agreement with the actual 1962-68 drought conditions than the initial method. However, no detailed study of an actual Long Island stream has been carried out to check the accuracy of the revised method. Because the model represents averages for a relatively large area and long time intervals, it cannot possibly reveal the complex variations in daily flow of a Long Island stream. Therefore, the simulated flow of any one stream should not be regarded as representative, but, rather, the streams should be considered collectively. Although the analog model can give only a regional view of the ground-water system of Long Island, the revised method of modeling streams should improve the accuracy of all aspects of the model and thereby extend its usefulness.

REFERENCES CITED

Cohen, Phillip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York Water Resources Comm. Bull. 62, 117 p.

Cohen, Phillip, Franke, O. L., and McClymonds, N. E., 1969, Hydrologic effects of the 1962-66 drought on Long Island, New York: U.S. Geol. Survey Water Supply Paper 1879-F, 18 p.

Franke, O. L., and Cohen, Philip, 1972, Regional rates of ground-water movement on Long Island, New York: U.S. Geol. Survey Prof. Paper 800-C, 7 p.

Getzen, R. T., 1975, Analysis of regional three-dimensional flow in the ground-water reservoir of Long Island, New York: U.S. Geol. Survey open-file rept. 75-617, 154 p.

McClymonds, N. E., and Franke, O. L., 1972, Water-transmitting properties of aquifers on Long Island, New York: U.S. Geol. Survey Prof. Paper 627-E, 24 p.

Pluhowski, E. J., and Kantrowitz, I. H., 1964, Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1768, 119 p.

U.S. Geological Survey, 1975, Water resources data for New York. 1974--Part 1. Surface water records: U.S. Geol. Survey open-file rept., 328 p. (Issued annually).