U.S. Department of the Interior
U.S. Geological Survey

SIMULATION OF THE EFFECTS OF DEVELOPMENT OF THE GROUND-WATER FLOW SYSTEM OF LONG ISLAND, NEW YORK

Water-Resources Investigations Report 98-4069

Prepared in cooperation with the
NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS,
SUFFOLK COUNTY DEPARTMENT OF HEALTH SERVICES,
SUFFOLK COUNTY WATER AUTHORITY, and the
NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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Table 9. Ground-water budget for conditions during 1968-83 on Long Island

County	Recharge	Discharge			
	Precipitation and returned water[1]	Pumpage[2]	Stream	Shore	Subsea
Kings and Queens	136	77	12	56	2
Nassau	346	185	55	82	14
Western Suffolk	339	87	123	126	25
Eastern Suffolk	472	58	135	239	17
Total	1,293	407	325	503	58

[1]Total recharge at the water table, includes (1) water returned to the ground-water system after use, and (2) decreases in recharge that result from diversion of runoff in Kings and Queens Counties. (See table 6.)

[2]Includes total public-supply, industrial-commercial, and agricultural pumping.

boundary discharge were in Kings, Queens, and Nassau Counties, where discharge to streams was reduced by more than 60 percent, but these effects diminish rapidly eastward through Suffolk County.

The patterns of ground-water flow have been considerably altered, even in areas where most of the pumped water is returned to the system, because much of the pumping is from the basal zone of the Magothy aquifer (model layer 3) and induces increased flow downward into the confined aquifers from above (compare table 10 and table 5). Table 10 indicates that downward flow to the Magothy aquifer (layers 2 and 3) has increased significantly from predevelopment conditions, which is consistent with pumping (table 7) and the attendant drawdown (figs. 23 and 24). The amount of flow entering model layer 2 has increased by 40 percent, and the amount entering layer 3 has increased by nearly 100 percent. Increased rates of ground-water movement to deep aquifers increases the possibility of contamination from land-surface sources in these aquifers which were once considered insulated from such contamination.

Table 10. Distribution of ground-water flow with depth during 1968-83 as represented in model

County	Model layer[1]			
	1 (water table)	2 (Magothy and Jameco)	3	4 (Lloyd)
Kings and Queens	136	50	44	4
Nassau	346	236	191	5
Western Suffolk	339	179	119	17
Eastern Suffolk	472	183	92	8
Total	1,293	648	446	34

[1]Flow into layer 1 is recharge from precipitation and returned water; flow into layers 2, 3, and 4 is leakage from the overlying layer.

1960'S DROUGHT CONDITIONS

Long Island experienced a prolonged drought during 1962-66. The decrease in recharge from precipitation over this period caused many streams to reach their lowest recorded flows and ground-water levels to decline by as much as 10 ft below the norm (Cohen and others, 1968). Detailed records of streamflow and ground-water levels during the drought allow an evaluation of the response of base flow to this stress. The following section describes the response of the ground-water system to the 1960's drought, and the model representation of the exchange of water between streams and the ground-water system that enables simulation of the response of base flow to changing ground-water levels.

Hydrologic Stress

For the purposes of this analysis, the only stress on the ground-water system during the drought period is assumed to be the loss of recharge through the natural decrease in precipitation during the drought. The precipitation measured at the Mineola and Setauket stations (fig. 1) during the drought is shown in figure 25. The 1962-66 period has the lowest 5-year average precipitation for the 100 years of record at the Setauket station.

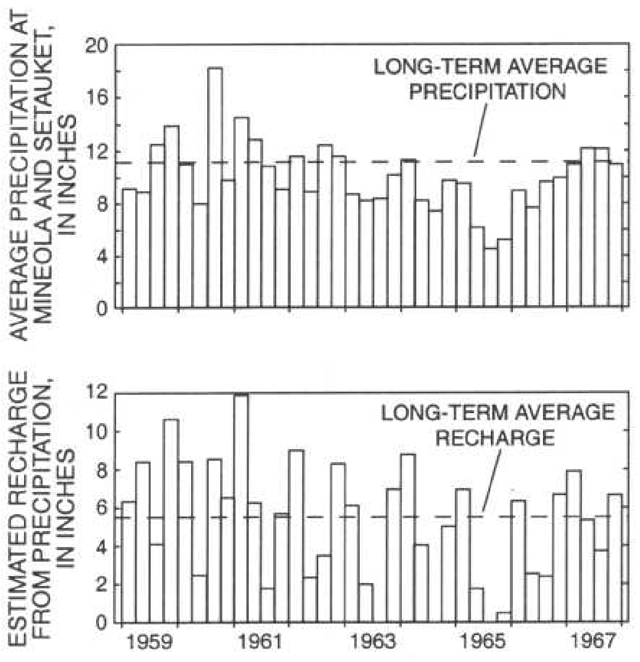


Figure 25. Quarterly precipitation recorded at Mineola and Setauket, N.Y., and estimated ground-water recharge during the 1960's drought.

Recharge from precipitation was calculated through a simple water-budget approach outlined in Reilly and others (1983). The approach yields an estimate of monthly recharge during the drought and used (1) values of average monthly evapotranspiration estimated by Warren and others (1968), and (2) a value for maximum soil moisture deficit of 1.5 inches, which yielded the best simulation results within a range of values (1.0-1.75 inches) tested. The calculation allowed for recharge when monthly precipitation exceeded both the monthly evapotranspiration and the accumulated soil moisture deficit, and increased soil moisture deficit up to its maximum when monthly evapotranspiration exceeded monthly precipitation.

The estimated quarterly ground-water recharge from precipitation during the 1960's drought is plotted in figure 25. Ground-water recharge was close to average during 1961 and 1962 but was more than 30 percent below average during the next 4 years. The decrease in recharge was most severe in 1965, when it was more than 60 percent below the average.

Ground-Water System Response

The major hydrologic responses to the 1960's drought were changes in ground-water discharge to streams (base flow) and declines in ground-water levels. The analysis focuses on eastern Nassau and Suffolk Counties because water levels in western Long Island were being affected by development at this time. The simulation of predevelopment conditions was used as initial conditions in the simulation because they were a close approximation of the base flow and water levels in eastern Nassau and Suffolk Counties before the drought. The period simulated was 1959-67, which incorporates antecedent conditions. The changes in stress during the period were represented in quarterly intervals.

Base Flow

The measured and simulated base flow of selected streams in Suffolk County through the drought are presented in figure 26. Base flow decreased noticeably in 1963 and, in most streams, had a maximum decrease of 25 to 60 percent. Streams with long channels that extend far inland (for example, Nissequogue, Carlls, Connetquot Creeks, and Peconic River) show the greatest seasonal variation and the greatest percent decrease in base flow during the drought because their headwaters lie close to the ground-water divide, where water-table declines are greatest. Stream headwaters are most vulnerable to large fluctuations in base flow and to drying up.

Streams were represented as head-dependent flow boundaries for the drought simulation to allow the model to calculate changes in base flow, using the "drain" representation of McDonald and Harbaugh (1988). This boundary representation requires definition of two parameter values for each grid cell:

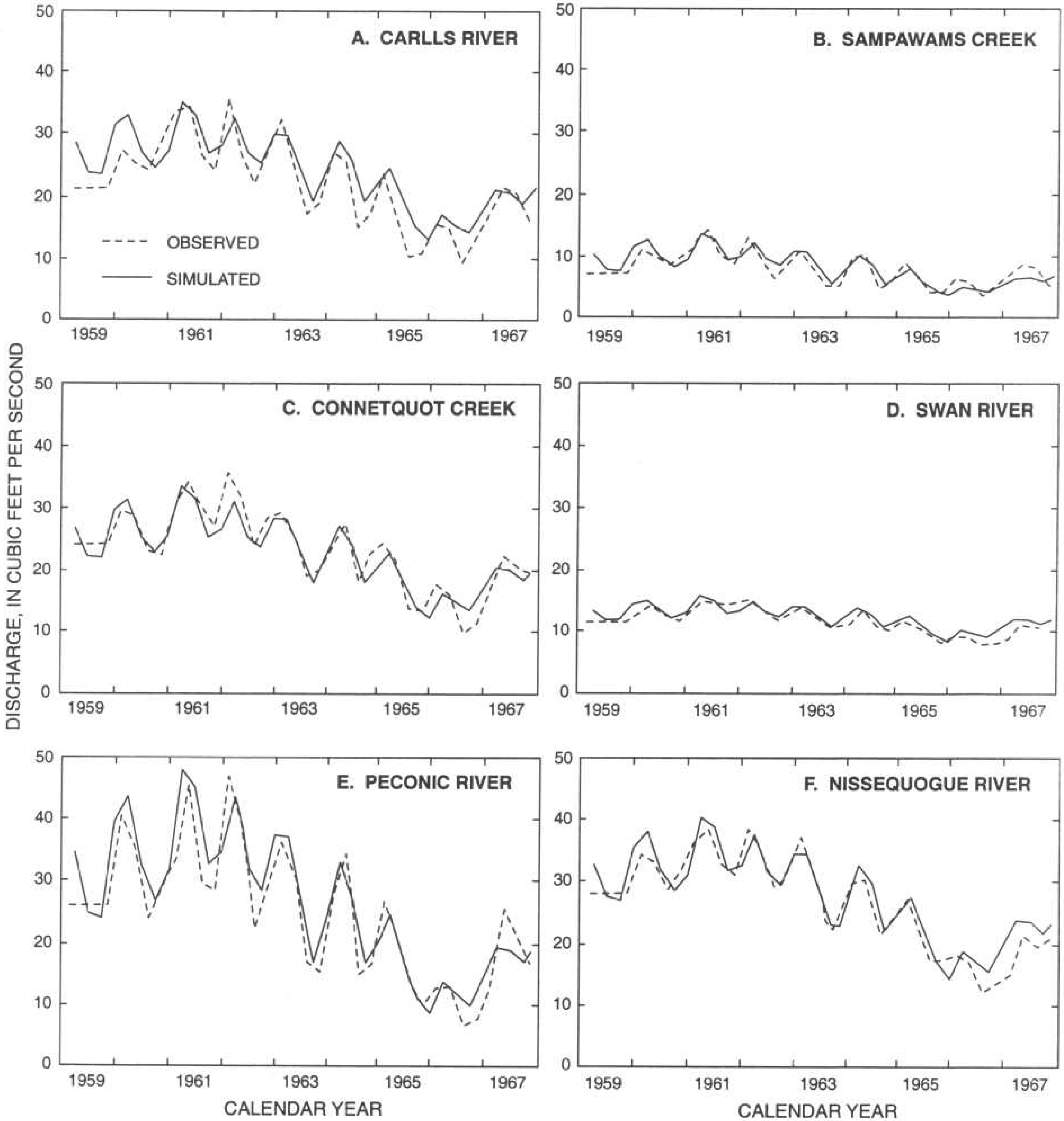


Figure 26. Simulated and measured base flow during the 1960's drought at: A. Carlls River. B. Sampawams Creek. C. Connetquot River. D. Swan River. E. Peconic River. F. Nissequogue River. (Locations shown in figure 3.)

(1) drain conductance *(C)*—the hydraulic conductance representing the hydraulic connection between the aquifer and the stream at the model's grid scale, and (2) drain or stream altitude *(DA)*—when declining ground-water levels equal or declined below *DA*, discharge to the drain is ceases. The ground-water discharge to the stream (Q_s) is defined by the equation

$$Q_s = C\,(h_a - DA), \qquad (2)$$

where h_a is the head in the model cell.

The head difference $(h_a\text{-}DA)$ indicates the amount of drawdown required to "dry up" a stream cell. DA was estimated as the lowest stream channel altitude within the model cell (estimated from USGS 7-1/2 minute topographical maps); h_a was assumed to be the average water-table altitude in the cell (from the simulation of predevelopment conditions). The drain conductance *(C)* was directly calculated from equation 2, assuming Q_s equaled the value of ground-water discharge to the model cell for the simulation of predevelopment conditions. This representation allows discharge to the stream to decrease as water levels are drawn down, until the required drawdown *(ha-DA)* is achieved, and ground-water discharge to the stream in that cell ceases.

Both the magnitude and rate of decrease in base flow are reproduced accurately by the model, as are seasonal trends through the drought (fig. 26). The similarity between simulated and measured values corroborates the concept of exchange of water between the stream and aquifer and its representation in the model.

Ground-Water-Level Declines

The decline in ground-water levels during the 1960's drought is indicated by monthly changes in the average water level in seven "key wells" in western Suffolk County (fig. 27), and a map of total drawdown during the drought (fig. 28). (The "key wells" were

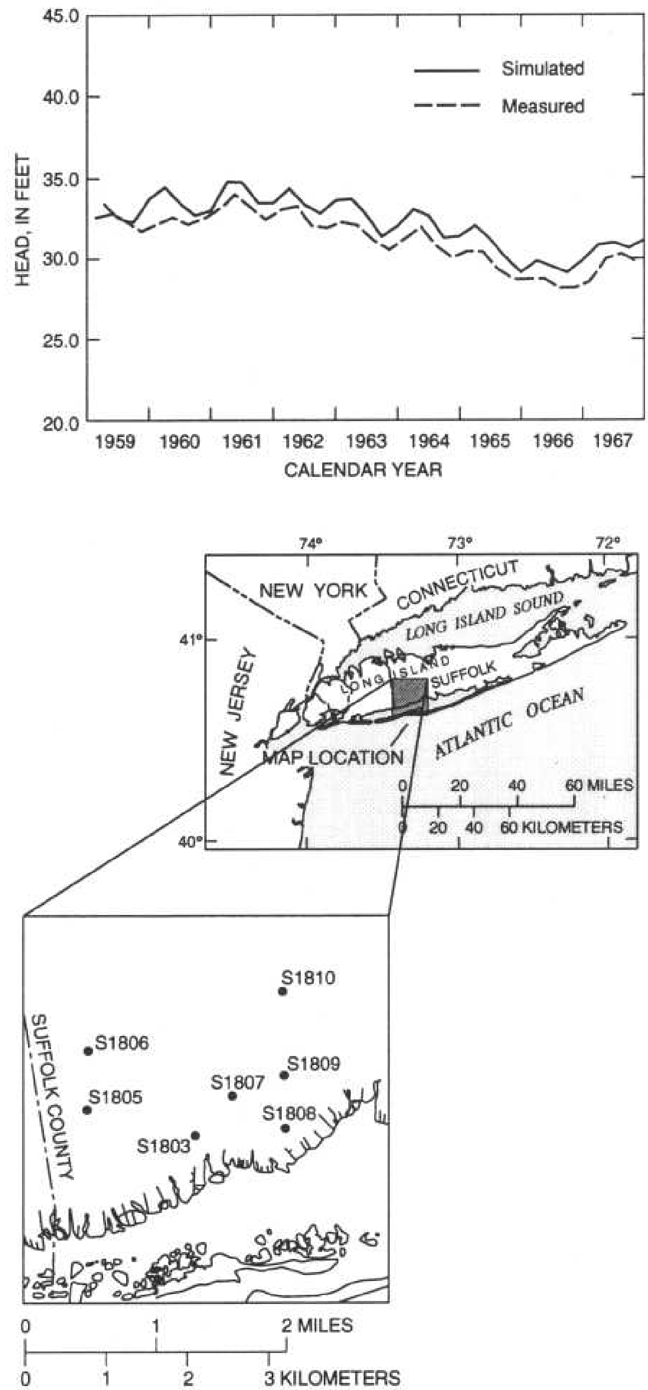


Figure 27. Average simulated and measured water levels in seven "key wells" (water-table) in western Suffolk County during the 1960's drought. (Well locations shown on map.)

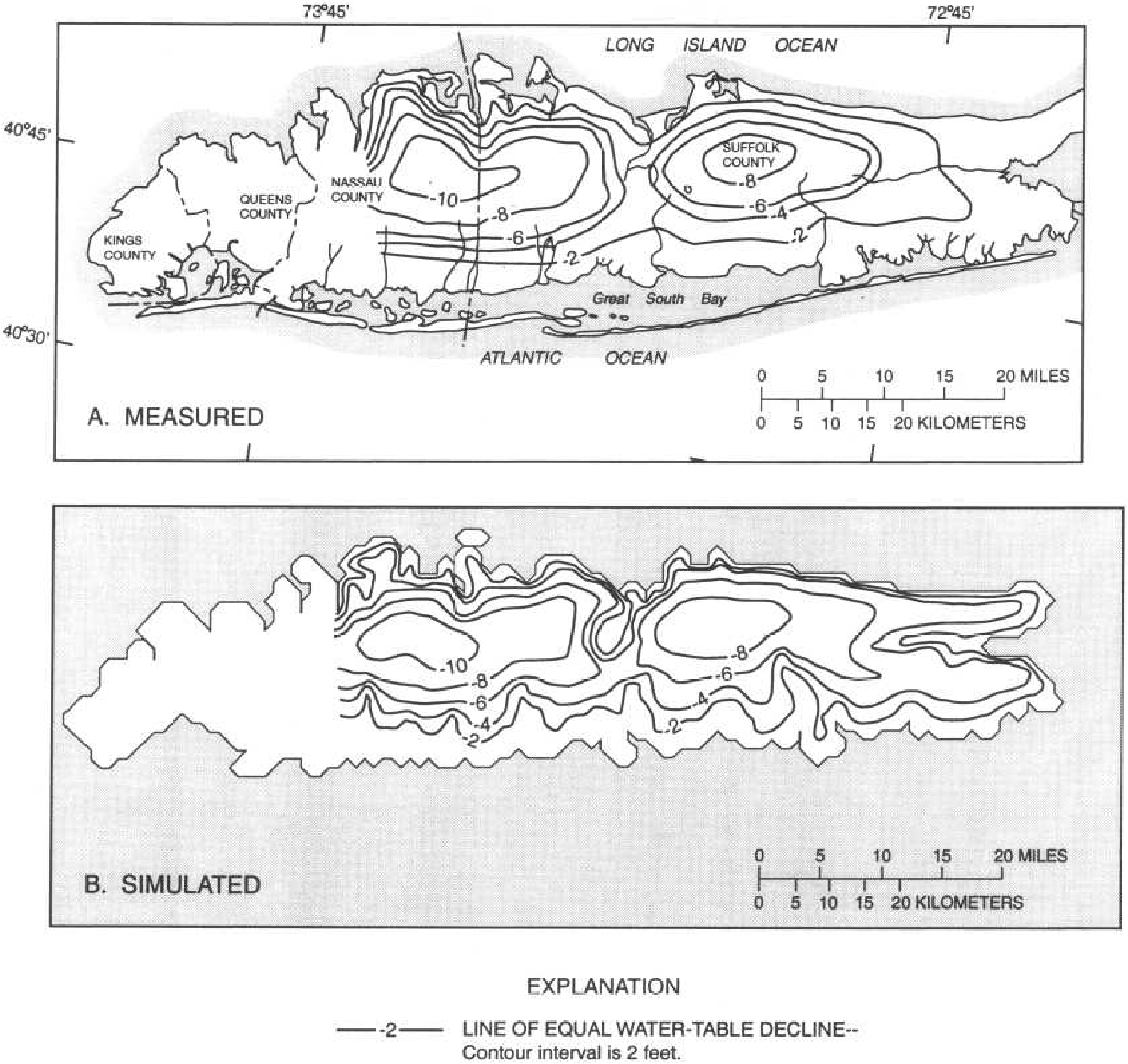


Figure 28. Maximum water-table decline during the 1960's drought (1961-66): A. Measured (from Cohen, and others, 1969, fig. 10). B. Simulated.

selected for long-term monitoring because they reflect average water-table conditions in western Suffolk County.) Water level declines began in 1963 and accelerated in 1964 and 1965, when little water-level recovery occurred during the wet season. Water levels began to recover in 1967 as recharge returned to normal (fig. 25). The largest total water-table decline was at locations farthest from the shore and streams; drawdown near streams is typically subdued because streams provide a source of water. The maximum declines exceeded 10 ft near the Nassau-Suffolk County border and 8 ft in central Suffolk County. Measured water levels declined (fig. 28A) a maximum of 13 percent, whereas the percent decreases in baseflow were much larger—25 to 60 percent (fig. 26), indicating that seepage to streams is highly sensitive to changes in ground-water levels.

Simulated ground-water levels during the drought closely match the measured levels (fig. 27) and show similar seasonal fluctuations. The simulated water-table decline during the drought (fig. 28B) is of the same general magnitude and distribution as the decline calculated from field measurements (fig. 28A), although simulated declines indicate smaller drawdown near stream channels. A lack of field data from near stream channels is probably the reason for the omission of these details on the map of measured data.

HYDROLOGIC EFFECTS OF A WATER-SUPPLY STRATEGY FOR THE YEAR 2020

Demand for public water supply throughout Long Island is expected to increase through the year 2020. The increases will probably be greater in newly developing areas in the east (Suffolk) than in older, more stable areas to the west. Although permits for ground-water withdrawals are granted by NYSDEC, planning for future water supply is managed by three separate local governments—Nassau County, Suffolk County, and New York City (for Kings and Queens Counties). By necessity, development plans differ among counties, and strategies to meet long-term water-supply needs are evaluated by resource managers from all three areas.

The effects of local development strategies on the Long Island ground-water system extend beyond town and county boundaries; thus, changes in the magnitude and (or) distribution of pumping in one county can cause significant effects in the adjacent county and perhaps throughout the island. This discussion describes the effect of a proposed water-supply-development plan on the entire system and thereby enables each locality to evaluate the effect of its own plans in relation to the effect of plans in neighboring areas.

The ground-water model was used to simulate a likely scenario for islandwide ground-water development for the year 2020; the simulation results are compared with the conditions during 1968-83 and predevelopment. Values from the simulation of conditions during 1968-83 were used as the baseline condition; therefore, all projected changes in stress from then to the year 2020 were included, and the resulting simulation is assumed to indicate a steady-state hydrologic condition around the year 2020. The prediction of ground-water system response to this water-supply strategy is only an approximation; it can be used most effectively if compared to the predicted effects of other strategies to minimize adverse hydrologic effects of increasing development.

Projected Stress

Projections of increased water-supply demands, and specific plans to meet these demands, have been made by local resource managers in Nassau County (Holzmacher, McLendon and Murrell, P.C., 1980), Suffolk County (Dvirka and Bartilucci Consulting Engineers, 1987), and New York City (O'Brien and Gere, 1987). The net stress on the Long Island ground-water system in the year 2020 is estimated to represent a 57-Mgal/d increase over the net stress during 1968-83 (compare tables 6 and 11). Changing pumping locations, new deep wells, and added sewering cause a large change in the distribution of stress.

Kings and Queens Counties -- Increases in importation of water from sources outside Long Island probably will meet future increases in water-supply demand in Kings and Queens Counties, and may result in a sharp decrease from pumping levels in the mid 1980's. A conjunctive-use water-supply strategy for Kings and Queens counties has been considered that would stop continuous pumping and allow the ground-water system to

Table 11. Projected components of stress on the Long Island ground-water system for the year 2020

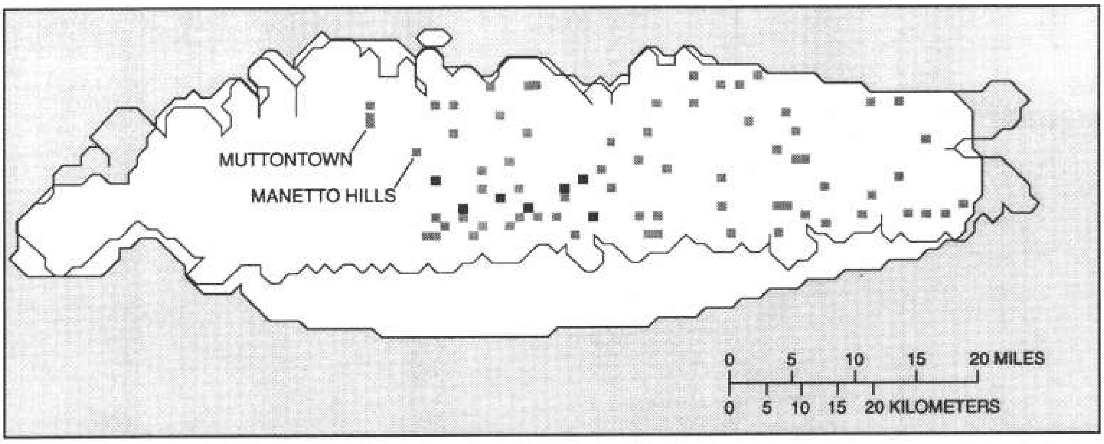
County	Components of stress				Net stress (sum of components)
	Public-supply pumpage	Returned water	Industrial-commercial/agricultural pumpage	Decreased recharge by increased runoff	
Kings and Queens	-30	+58	-16/0	-82	-70
Nassau	-208	+60	-6/0	0	-154
Western Suffolk	-98	+60	-9/0	0	-47
Eastern Suffolk	-80	+65	-4/-7	0	-26
Total	-416	+243	-42	-82	-297

recover to a maximum capacity, thereby enabling emergency ground-water pumping to supplement the surface-water supply system during short-term drought emergencies (Buxton and others, 1999). At the time of this analysis, pumping in Kings and Queens was assumed to be reduced to half its 1968-83 rate, to 30 Mgal/d by the year 2020 (table 11). Other components of stress in Kings and Queens Counties will likely remain unchanged.

Nassau County -- Pumping for public supply in Nassau County is projected to increase 16 percent from 179 Mgal/d during 1968-83 to 208 Mgal/d by the year 2020. A proposed new pumping center at Muttontown Preserve (fig. 29) would provide 14 Mgal/d and would enable a reduction of pumping in southwestern Nassau County, where ground-water levels and streams have been severely depleted under recent conditions. A second pumping center at Manetto Hills (fig. 29) is also being considered, but its effect was not evaluated in this analysis. The stress from industrial-commercial pumping is expected to remain relatively small.

An additional stress that will exacerbate the effects of increased pumping in Nassau County is a significant decrease in the amount of returned water as the area served by sanitary sewers is expanded. The full implementation of Sewage Disposal District 3 in southeastern Nassau County and the expansion of Sewage Disposal District 2 (fig. 30) will reduce the amount of pumped water that returns to the ground-water system from 89 to 60 Mgal/d (tables 6 and 11). Under recent conditions, about half the water pumped for public supply is returned to the system, whereas by the year 2020, less than 30 percent will be returned. The increase in the rate of pumping and decrease in the rate of return to the system will increase the stress on the ground-water system in Nassau County by 58 Mgal/d, or 60 percent (tables 6 and 11).

Suffolk County -- Pumping for public supply in Suffolk County is expected to increase 41 percent, to 178 Mgal/d; most of this increase will be in the eastern part of the county (tables 6 and 11). Locations of proposed pumping centers are shown in figure 29. A small increase in industrial-commercial pumping is expected in western Suffolk County, and a small decrease in agricultural pumping is expected in eastern Suffolk County. Hookup to the Southwest Sewer District (fig. 30) was already underway in the mid 1980's and is anticipated to discharge 28 Mgal/d to the ocean at full operation. This decreases by 20 percent the amount of public supply water that returns to the ground-water system in western Suffolk County—from more than 80 percent under recent (1968-83) conditions to about 60 percent by the year 2020. The net stress in western Suffolk will increase 124 percent to 47 Mgal/d (table 11), which is still less than one-third of the total stress in Nassau County. Although total pumpage in eastern Suffolk County will nearly double, the increase in net stress will be small, largely because, with a relatively small amount of sewering, most pumped water is expected to return to the aquifer system.



EXPLANATION

MODEL CELLS IN WHICH PUMPING WELLS ARE LOCATED

▪ PUBLIC SUPPLY WELLS

■ INDUSTRIAL COMMERICAL WELLS

Figure 29. Location of new pumping wells projected through the year 2020. All wells will pump from the basal Magothy aquifer (model layer 3).

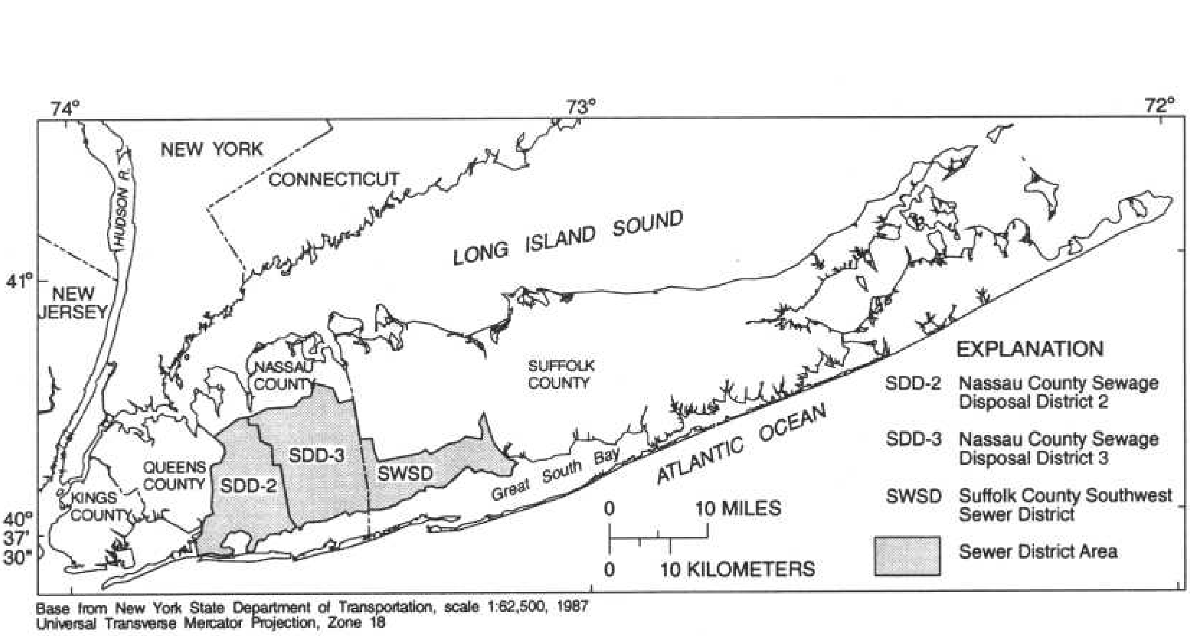


Figure 30. Location of Nassau and Suffolk County sewer districts.

The distribution of ground-water pumping as represented in the model is shown by county and model layer (aquifer) in table 12. The greatest increase in pumping is expected to be from the basal zone of the Magothy aquifer (layer 3) in Suffolk County, and the highest rate of pumping will remain in Nassau County from the basal zone of the Magothy aquifer. Projected changes from the distribution of pumping in 1983 to 2020 can be evaluated through comparison of table 10 and table 12.

Table 12. Distribution of ground-water pumping for public-supply, industrial-commercial, and agricultural uses for the year 2020, as represented in model

County	Model layer				Total
	1	2	3	4	
	(water table)	(Magothy and Jameco)		Lloyd	
Kings and Queens	24	2	17	3	46
Nassau	10	10	181	13	214
Western Suffolk	26	2	79	0	107
Eastern Suffolk	37	15	39	0	91
Total	97	29	316	16	458

Ground-Water System Response

The predicted hydrologic response to the water-supply development strategy for the year 2020 is presented in terms of (1) base flow; (2) movement of the saltwater-freshwater interface, (3) ground-water levels and flow patterns; and (4) the ground-water budget. These results provide a guide to water-resource managers who must define acceptable levels for the adverse effects of development and modify development strategies to meet these levels. The predicted response also is compared with simulated results for the predevelopment and recent hydrologic conditions to demonstrate the evolution of the development of the Long Island ground-water system.

Base Flow

Model predictions of base flow of major streams for the 2020 water-supply strategy are presented in table 13. Streams are represented in the model as drains, similar to simulations of the 1960's drought, however, recent stressed conditions were used as a baseline. Recovery of ground-water levels in Queens and western Nassau County is expected to increase base flow and restore flow in some dry stream channels (table 13 and fig. 31); the base flow of Flushing Creek, Springfield Stream, Simonsons Stream, Valley Stream, Motts Creek and Pines Brook will increase. From South Pond in western Nassau County eastward, however, base flow in all streams will decrease.

Base flow in East Meadow Brook, Bellmore Creek, and Massapequa Creek in Nassau County are estimated to decrease the most—their combined flows will decrease 92 percent, from 22.3 ft^3/s during 1968-83 to 1.8 ft^3/s by the year 2020. East Meadow Brook is projected to be dry from its headwaters to the gage. Base flow of Santapogue Creek, Carlls River, and Sampawams Creek in western Suffolk County together will decrease to about 60 percent of their flow during 1968-83. As indicated in the analysis of the 1960's drought, long streams that extend far inland are affected most severely; this is evident from comparing the estimated base flow in Massapequa Creek, Bellmore Creek, and East Meadow Brook with Milburn Creek, Cedar Swamp Creek, and Carman Creek in table 13. Streams east of Nissequogue and Connetquot Rivers will be less severely affected than those to the west because the increase in stress will be smaller and because the effects of stress in the west do not propagate past these large streams.

Saltwater-Freshwater Interface

The movement of the saltwater-freshwater interface between 1983 and 2020 cannot be determined by the islandwide model. Movement of the interface was assumed to be