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Hydrologic Interpretations Based on Infrared Imagery of Long Island, New York

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2009-B

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By EDWARD J. PLUHOWSKI

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2009-B

Six remote-sensing flights over Long Island identified areas of heavy ground-water discharge

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 75–190389

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 30 cents
Stock Number 2401-2067

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

HYDROLOGIC INTERPRETATIONS BASED ON INFRARED IMAGERY OF LONG ISLAND, NEW YORK

By Edward J. Pluhowski

ABSTRACT

Six remote-sensing flights over Long Island's north and south shores were made during the period July 13, 1967, to February 25, 1970. Infrared imagery in the 8- to 14-micrometer range was obtained; results varied from poor to excellent in quality.

The ability of the RS 7 and Reconofax IV imagers to discern thermal contrasts of as little as 1° to 2°C (Celsius) permitted identification of areas of heavy ground-water discharge. These areas were concentrated primarily along the eroded headlands of the north shore and in the lower reaches of watercourses draining into Great South Bay. Only a few highly localized examples of direct ground-water discharge into the embayments along Long Island's south shore were detected in the imagery.

Thermal loading emanating from a powerplant near Oceanside is shown to be quickly dissipated in Middle Bay. Specific examples show that infrared imagery may also be used to identify circulation patterns, ice cover, changes in stream-temperature regimen, and the location of sewer outfalls. Optimal time for the collection of infrared imagery for hydrologic studies on Long Island is in summer and in winter, when surface-water thermal differences are relatively large.

INTRODUCTION

PURPOSE

The unique capability of infrared sensors to discern surface-temperature variations synoptically over a large area provides the hydrologist with a powerful tool. It allows him to identify numerous hydrologic phenomena, such as circulation patterns in large bodies of water, areas of ground-water discharge, dispersion of heated waters, and geologic features controlling ground-water and surface-water movement.

Long Island is particularly suited to remote-sensing techniques. It is hydrologically independent of surrounding land masses in that precipitation is its only natural source of fresh water. Almost everywhere, the large ground-water reservoir beneath its surface can be tapped for dependable water supplies. Accordingly, Long Island's water managers are especially interested in the mechanisms of saturated flow and in locating areas of ground-water discharge. One of the purposes of this study is to identify areas of ground-water outflow into streams and into the brackish bays surrounding the island.

A second objective is to define the effects of man's activities on stream temperatures. Western Long Island is nearly completely urbanized, whereas central Long Island is undergoing urban development in almost all sections. These drastic environmental changes have altered stream discharges (Seaburn, 1969) and lowered ground-water levels (Franke, 1968) in Nassau County. The temperature patterns in a stream subjected to such sharp hydrologic disruptions are quickly changed, usually to the detriment of the stream's ecology (Pluhowski, 1970, p. D46). Thermal loading of the numerous brackish bays and wetland areas surrounding the island will impose stresses on resident biologic communities. The dynamics and areal extent of heated-water plumes in the vicinity of powerplant outfalls can be identified using remote-sensing techniques (Cory and Nauman, 1970).

COOPERATING AGENCIES

As indicated in the following table, the National Aeronautics and Space Administration (NASA) was the principal agency supplying flight capability and remote-sensing equipment for this study.

Cooperating agency	*Date of flight*	*Quality of imagery*
NASA	July 13, 1967	Good to excellent.
USGS [1]	Apr. 19, 1967	Fair to poor.
NASA	Jan. 18, 1968	Fair to good.
RADC [2]	June 17, 1969	Good.
NASA	Sept. 19, 1969	Poor.
NASA	Feb. 25, 1970	Fair to good.

[1] U.S. Geological Survey.
[2] Rome Air Development Center, Griffiss Air Force Base, Rome, N.Y.

Many factors affected the quality of the imagery; however, instrument malfunctions and poor weather conditions were the major deterrents to good-quality imagery. Thermal infrared scanners, principally the RS 7 and the Reconofax IV imagers, were used on all flights. Flight altitudes ranged from 2,000 to 4,500 feet. The flight patterns (fig. 1) were parallel to the north and south shorelines over areas of heavy ground-water and surface-water outflow.

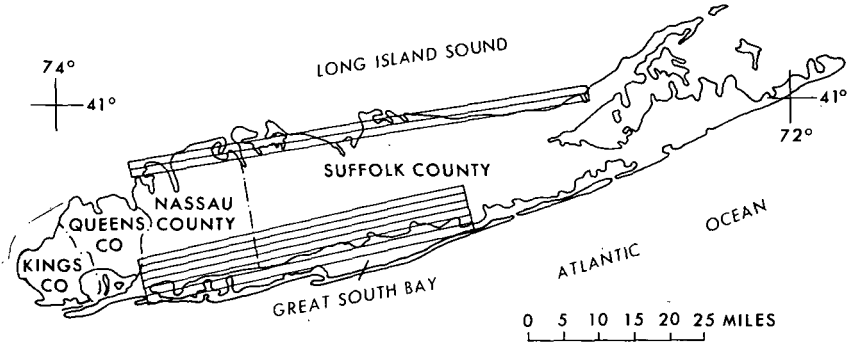

FIGURE 1.—Remote-sensing flight patterns over Long Island, N.Y.

ACKNOWLEDGMENTS

The author would like to express his thanks to Philip Cohen, hydrologist-in-charge of the U.S. Geological Survey, Mineola, N.Y., subdistrict office, for his cooperation in providing technical and logistic support. Field personnel of the Mineola office assisted the author in obtaining predawn ground-truth data for the April 19, 1967, overflight, and their help is greatfully acknowledged. Gareth E. Debrava assisted in the ground-truth data program throughout the study period.

HYDROLOGIC SETTING

The unconsolidated deposits forming the ground-water reservoir on Long Island rest on bedrock (fig. 2). The top of the bedrock, which is at or near land surface in the northwest part of the island, dips toward the southeast to a depth of about 2,000 feet in south-central Suffolk County (Cohen and others, 1968, p. 18). The three principal aquifers are: (1) upper glacial aquifer, (2) Magothy aquifer, and (3) Lloyd aquifer. As shown in figure 2, ground water moves predominantly downward in areas of recharge in the north-central part of the island; movement is nearly parallel to land surface in the south-central part and turns upward near the south shore. About 95 percent of the total streamflow in southwestern Suffolk County is derived from ground-water discharge (Pluhowski and Kantrowitz, 1964, p. 35).

The two principal landforms of the island include a backbone of dissected rolling hills formed by terminal moraines and, abutting the hills, a gently southward-sloping outwash plain (fig. 2). Eroded headlands that have steep bluffs are common along the north shore. Barrier beaches, which are depositional features, have formed beyond the south shore of the "mainland" part of the island.

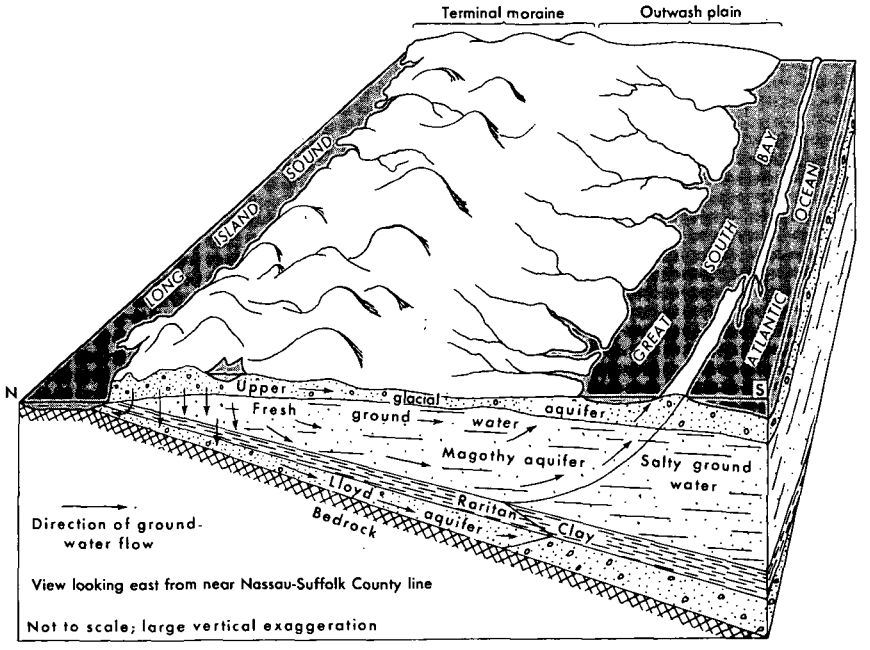

FIGURE 2.—Schematic block diagram of Long Island showing generalized geology, ground-water flow pattern, and landforms.

A large part of the drainage on Long Island is provided by southward-flowing watercourses. Most streams are short, generally less than 3 miles in length. Under natural conditions, streamflow is perennial in all but the uppermost reaches of the streams. Virtually all watercourses are classified as "gaining" streams; some reaches receive as much as 2.3 cfs (cubic feet per second) per 1,000 feet of channel length from the ground-water reservoir (Pluhowski and Kantrowitz, 1964, p. 51). In contrast with south-shore streams, north-shore watercourses are generally widely separated. The topographic divide is near or, in some areas, along the crest of the eroded headlands facing Long Island Sound. Accordingly, with the exception of the Nissequogue River, most northward-flowing streams are poorly developed and are relatively short.

In addition to providing a dependable source of fresh water, Long Island's aquifer system yields water of nearly uniform temperature. Ground-water temperatures tend to be cooler than surface-water temperatures in summer and warmer in winter. Because the degree of tonal contrast sensed by infrared imagers is directly related to surface-temperature differences, maximum tonal contrasts between areas of concentrated ground-water discharge and receiving surface-water bodies are achieved in winter and summer. Accordingly, sharp

tonal contrasts detected in thermal infrared imagery of streams or along shorelines may be indicative of zones of ground-water discharge.

BASIC RADIATION THEORY

All matter having temperatures greater than absolute zero emits electromagnetic radiation due to the motion of various charged particles that make up atoms. The amount of energy emitted by a "black body" can be computed from the Stephan-Boltzman radiation law:

$$W=\sigma T^4 \tag{1}$$

where

W=rate of radiation emittance (calories per square centimeter per minute);
σ=Stephan-Boltzman constant; and
T=absolute temperature (degrees Kelvin).

Few, if any, materials in nature radiate energy as black bodies. Equation 1 represents the maximum possible rate of energy that matter can emit at a given temperature. The ratio of the actual energy radiated to maximum possible is called emissivity. The emissivity of water is independent of water temperature or dissolved solids and is estimated to be 0.97 (Anderson, 1954, p. 97).

Electromagnetic energy is propagated as waves. The wavelength of maximum emittance for a specified temperature is given by Wien's law:

$$\lambda_m T=0.2897 \text{ cm-°K} \tag{2}$$

where

λ_m=wavelength of maximum emittance and
T=absolute temperature (°K).

The sun's surface temperature is estimated to be 6,000°K, so that solar energy is most intense at a wavelength of about 0.5 micrometers. The wavelengths of maximum spectral emittance of all terrestrial matter are much longer, commonly 10 to 12 micrometers, which is in the thermal infrared range.

Part of the energy emanating from terrestrial sources is absorbed by certain atmospheric constituents, notably water vapor and carbon dioxide. Water vapor absorbs most strongly at 2.5 to 3, 5 to 7, and greater than 13.5 micrometers, whereas carbon dioxide absorbs strongly at 4.3 and 14 to 15 micrometers. The atmosphere is virtually transparent to terrestrial back radiation at 3 to 5 and 8 to 13 micrometers, the so-called "windows" in the atmosphere. The infrared imagers used over Long Island detect radiation in the 8- to 13-micrometer range.

DISCUSSION OF IMAGERY

RELATION OF INFRARED IMAGERY TO SURFACE TEMPERATURE

The approximate location and areal extent of all imagery referred to in this report are shown in figure 3. Considerable distortion, inherent in the scanning process, is evident in the upper and lower parts of some of the figures. For any particular imager, the amount of distortion is largely a function of the scan sweep and aircraft altitude.

The imagery obtained near East Islip (fig. 4) helps to illustrate the usefulness of infrared techniques for delineating surface-temperature variations. This imagery was obtained (as was all the imagery shown in this report) during predawn hours to eliminate possible extraneous effects of solar heating and reflectance. The flight was made under clear skies on July 13, 1967. Dark tones indicate cold surfaces, whereas light areas are relatively warm. For example, the waters of Great South Bay in the foreground appear light and were quite warm, about 25°C (Celsius). The prominent dark band across the bay near the middle of the imagery is due to an instrument malfunction.

Water temperatures were measured using a YSI telethermometer. Land-surface temperatures were obtained with a Barnes PRT-5 radiation thermometer. This instrument detects radiant energy emitted

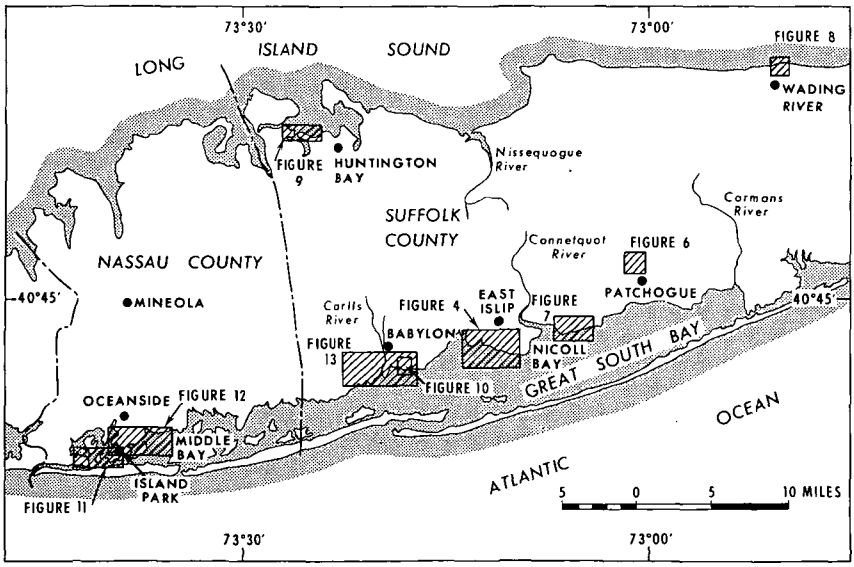

FIGURE 3.—Approximate location and areal extent of imagery shown in report.

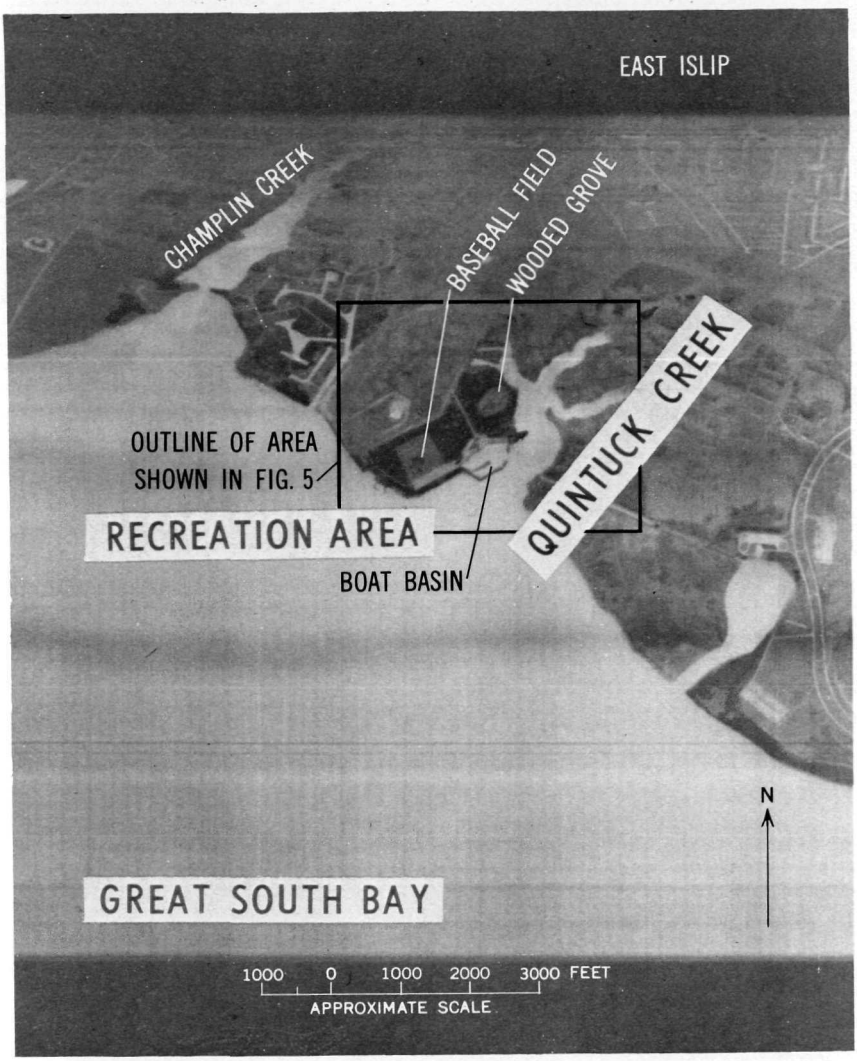

FIGURE 4.—Imagery obtained July 13, 1967, of the East Islip recreational area, showing tonal contrasts in a town park and boat basin. (Imagery from NASA.)

from the surface over which it is held. The optical system of the detector alternately takes readings at the surface whose temperature is desired and at an accurately calibrated reference black body. The difference between the two radiation fluxes is converted to an electrical signal that varies with temperature. Direct temperature readings are made from a dial whose reported accuracy is $\pm 0.2°C$. Temperatures were obtained by holding the radiation thermometer within about 3

feet of all ground surfaces. Close proximity to radiating surfaces reduces atmospheric attenuation of signal due principally to water vapor.

The results of the radiation-thermometer survey at East Islip are illustrated in figure 5. The coldest temperatures (20.5° to 20.7°C) were recorded in a large sandy tract surrounding a baseball field and an oval wooded grove northeast of the field. As seen in figure 4, this sandy area is very dark; the baseball field and the wooded grove appear as medium-gray tones, and the parking lot adjacent to the baseball field is a very light tone. The forested grove and most of the baseball field had a surface temperature of 23.2°C, nearly 3°C warmer than the surrounding sandy tract. The asphalt parking lot, which retained much of the solar heat from the previous day, had a temperature of 25°C, or about 4.5°C higher than the sandy tracts. A temperature differential of only 2°C was enough to show sharp tonal contrasts between the

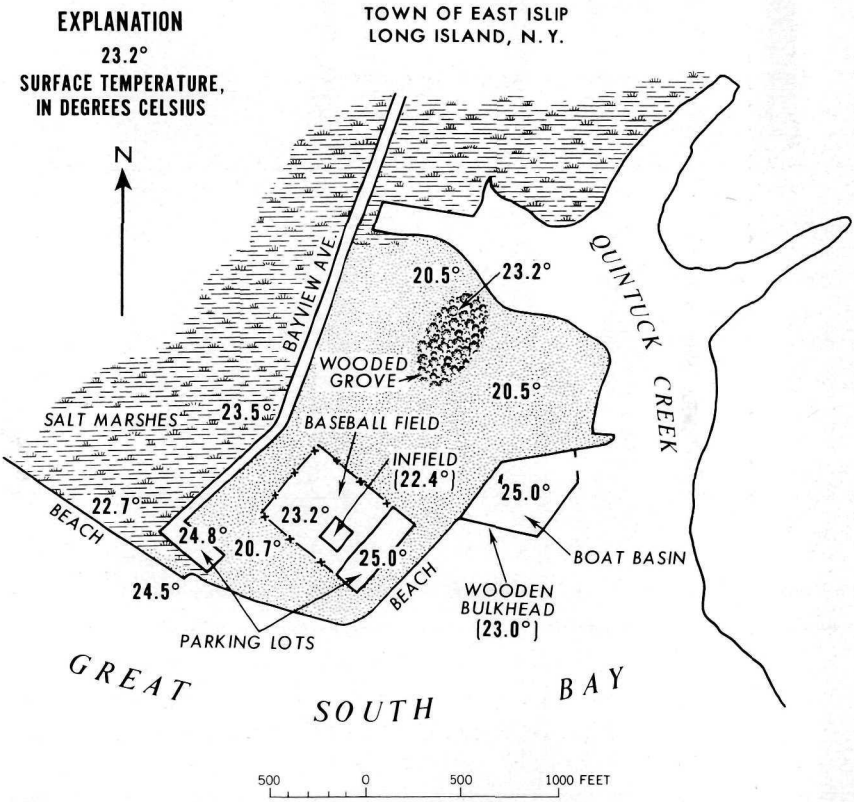

FIGURE 5.—East Islip recreational area showing surface temperatures of selected features on July 13, 1967, at about 0400 hours.

wooden bulkhead forming the town's boat basin and the adjacent bay water.

STREAM MORPHOLOGY

Owing to a steady inflow of relatively warm ground water, Long Island streams rarely, if ever, become completely frozen. Extensive surface cooling above impoundments does, however, create favorable conditions for complete ice cover on lakes and ponds during protracted cold spells.

Figure 6 depicts imagery obtained January 18, 1968, over the village of Patchogue. Despite the "fogging" south of Sunrise Highway, the fine detail of braided segments of the Patchogue River south of Canaan Lake is clearly evident. Predawn air temperatures at flight time were from −6° to −10°C. Subfreezing temperatures prevailed for several days prior to January 18; accordingly, ground-surface temperatures were well below freezing. Except for its extreme upper end, Canaan Lake was completely ice covered. Much of the lake appears dark gray in tone and contrasts sharply with the very light tone of the

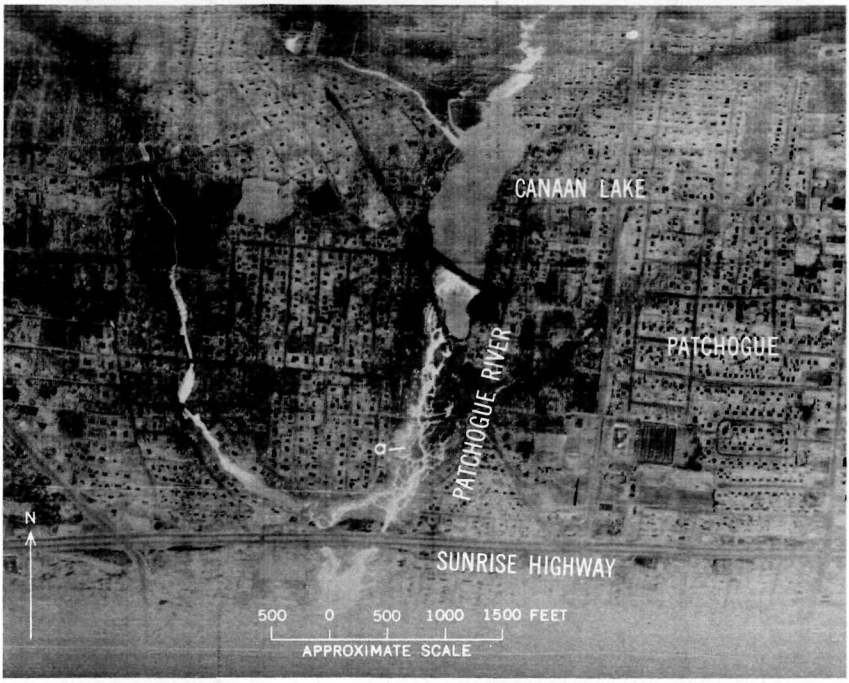

FIGURE 6.—Imagery obtained January 18, 1968, of the northern part of Patchogue, showing ground-water fed reaches of the Patchogue River above Sunrise Highway. (Imagery from NASA.)

ground-water-fed watercourses above and below the lake. Stream temperatures below Canaan Lake were about +7°C—at least 10°C warmer than the ice-covered surface of the lake. Under sufficient magnification the fine threadlike detail of the complex pattern of watercourses below Canaan Lake can be identified. The unusual cellular stream pattern at *a* in figure 6 represents a series of ditches used to drain a swampy area. Although the average width of the drainage ditches is only 2 to 3 feet, they are easily identifiable in the imagery. Much of the stream-channel detail shown in figure 6 is not visible in imagery obtained in the spring and fall when land-surface temperatures and water temperatures are nearly alike.

CIRCULATION PATTERNS

Mild weather prior to February 25, 1970, ensured ice-free conditions throughout Long Island for the flight made that day. Air temperatures ranged from 0° to 3°C during the predawn hours of February 25; skies were clear and the winds calm. As indicated in figure 7, the ice-free conditions presented a good opportunity to study circulation patterns along the north shore of Great South Bay. Temperatures in the brackish waters of the bay were from 1.5° to 2.5°C, whereas temperatures of the fresh-water streams ranged from 5.5°C at Brown Creek to 7.5°C at Green Creek. The thermal plumes of Ludlows, Green, and Brown Creeks are light and quite distinct against the darker gray tones of the colder bay. All three plumes indicate a general easterly movement of water in the bay. The Ludlows Creek plume shows a high degree of distortion apparently due to locally faster bay-water velocities than is evident in areas farther to the east. The more rapid circulation pattern in Nicoll Bay is doubtless due to the relatively large streamflow in the Connetquot River, which discharges into Nicoll Bay a short distance beyond the left (west) edge of figure 7.

GROUND-WATER DISCHARGE

Numerous examples of ground-water discharge into the brackish bays surrounding the island were found in both summer and winter imagery. Maximum thermal variation between ambient bay temperature and ground-water temperature during the warm and cold seasons permits clear identification of areas of concentrated ground-water outflow. Figure 8 shows imagery obtained along the north shore near the village of Wading River on June 17, 1969. Ground-water outflow into Long Island Sound is clearly visible along the shoreline (dark filmy areas) extending out as much as 600 feet into the sound. Ambient water temperatures in the sound were about 20°C, whereas ground-water temperatures were 5° to 10°C cooler.

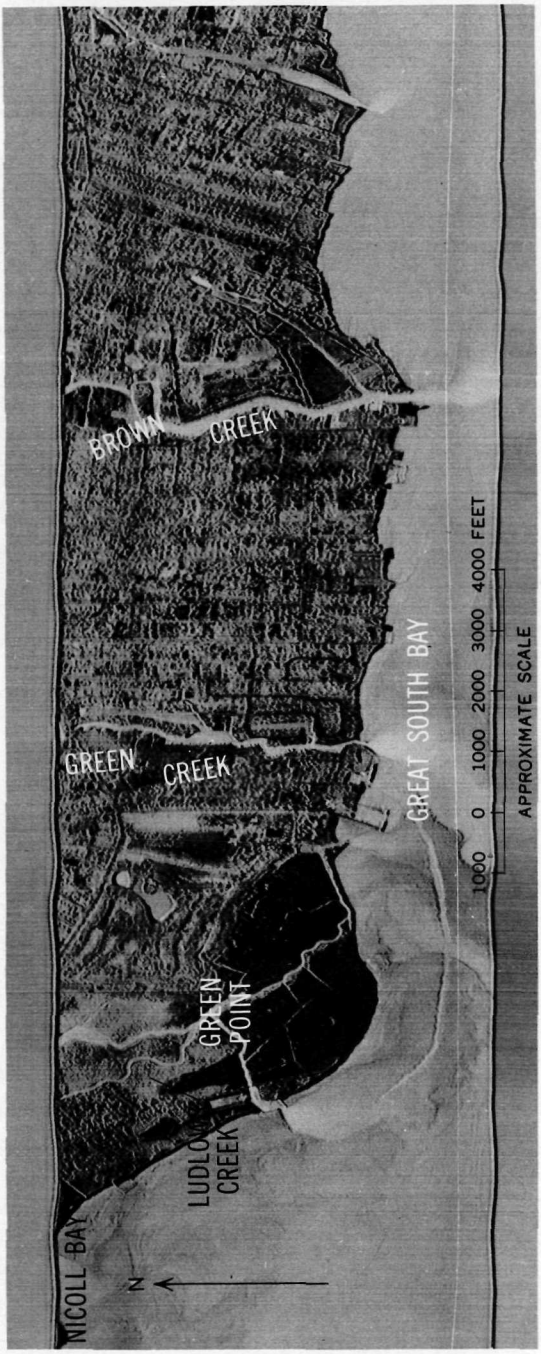

FIGURE 7.—Imagery obtained February 25, 1970, of Nicoll Bay and Great South Bay in the vicinity of Green Point, showing circulation pattern in the bays. (Imagery from NASA.)

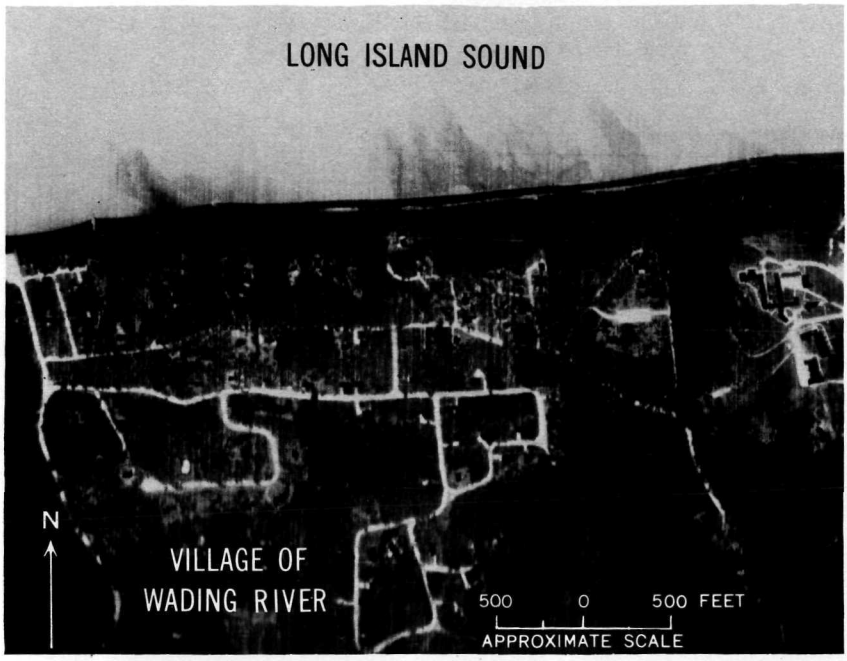

FIGURE 8.—Imagery obtained June 17, 1969, along the north shore of Long Island near Wading River, showing ground-water discharge into Long Island Sound. (Imagery from RADC.)

The tonal contrasts between ground-water discharge and the receiving waters surrounding the island is reversed in winter (figure 9). The imagery of Huntington harbor, obtained February 25, 1970, shows streamers of light (relatively warm) ground water along the shoreline entering the darker (colder) waters of Huntington Bay. Ambient water temperatures in Huntington Bay were about 2° to 3°C, whereas incoming ground water was about 6° to 9°C.

Ground-water outflow was commonly detected in imagery along the beaches at the base of the eroded headlands of Long Island's north shore. Evidence of ground-water discharge into the embayments along the south shore was rare and limited to a few lobate areas along the east end of Great South Bay. Stream development along the north shore is restricted, especially where the topography has been molded by erosional processes; steep bluffs have been formed just inland from the shoreline. In these areas, ground-water outflow is directed principally into Long Island Sound rather than into the relatively closely spaced watercourses such as those of the south shore. As noted earlier, streams intercept about 95 percent of the total ground-water outflow into Great South Bay. Although precise figures are not available,

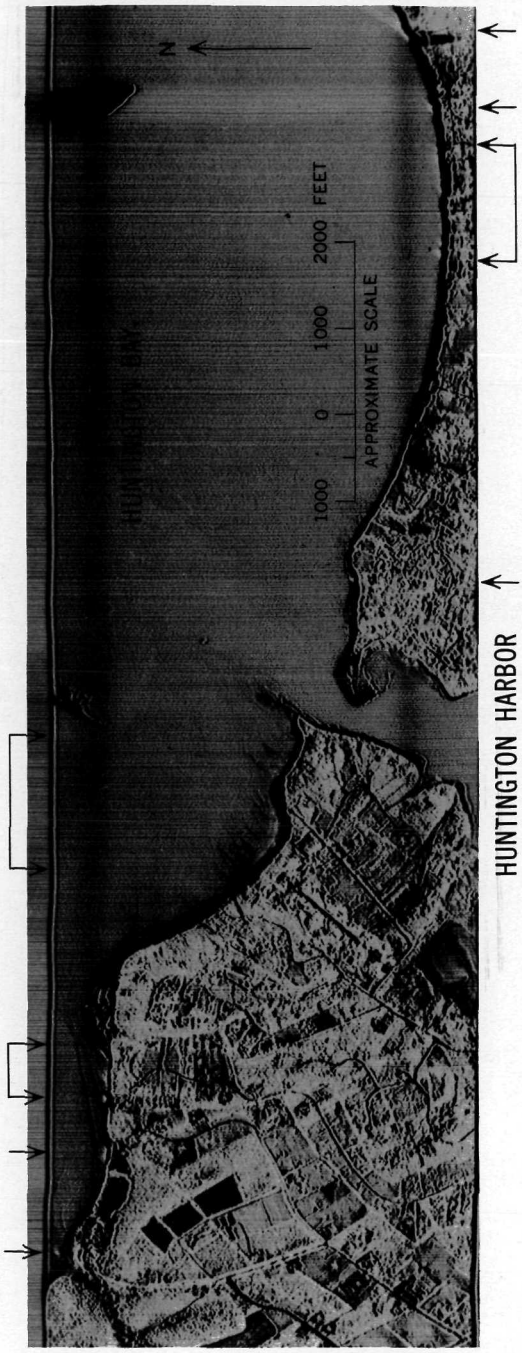

FIGURE 9.—Imagery obtained February 25, 1970, at the entrance to Huntington Bay, showing ground-water outflow. (Imagery from NASA.)

probably less than 25 percent of the northward-moving ground water to the east of the Nissequogue River basin is discharged as streamflow.

The pattern of ground-water inflow into the lower reaches of Willetts Creek near Babylon is illustrated in figure 10. A flow of cold ground water is shown entering the lower reach of Willetts Creek below Lake Capri. Water temperatures at flight time (June 17, 1969) were about 22°C in the pond and in Great South Bay, whereas the cold, darker toned ground water entered the stream at temperatures from 12° to 15°C. Lake Capri was created by highway earthfill and a stoplog control. As a result of the impoundment, ground-water levels were artificially raised above the dam, and a steepened water-table gradient was thereby created between the dam and the lower reach of the stream. The sharply increased gradient is the principal cause for the heavy concentration of colder ground water below Lake Capri.

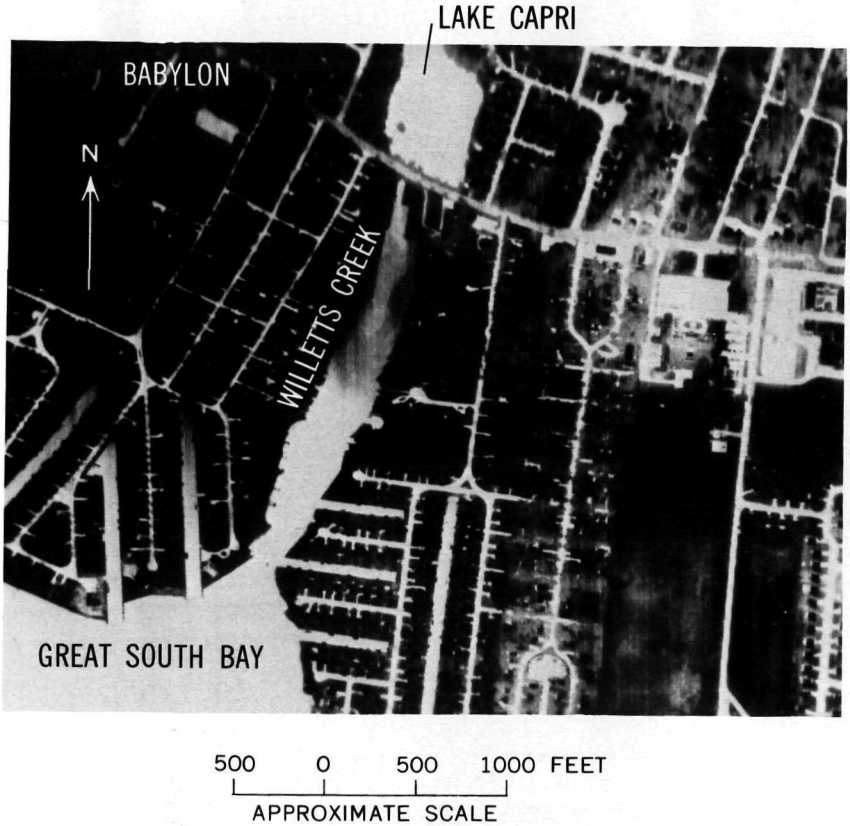

FIGURE 10.—Imagery obtained June 17, 1969, of the lower reaches of Willetts Creek, showing ground-water seepage into the creek. (Imagery from RADC.)

Stream reaches affected by large increments of ground-water inflow have been delineated by thermometric surveys (Pluhowski, 1961). Although useful in identifying areas of ground-water discharge, thermometric surveys are slow and subject to certain spatial and temporal constraints. Remote sensing using infrared imagers permits a synoptic view of an entire temperature field. Thus, maximum gaining reaches are quickly and positively identified.

EFFECT OF MAN'S ACTIVITIES

SEWAGE

Sewage from about 70 square miles in western and southwestern Nassau County is treated at the Bay Park sewage treatment plant near Oceanside. The amount of treated waste water discharged from the plant averaged about 50 million gallons per day in 1966 (Franke, 1968, p. B206). The outfall for the plant is off the southern end of Black Banks Hassock near Island Park. Effluent from the submerged plant outfall is visible (fig. 11) in the imagery taken February 25, 1970. The surface expression of the effluent is triangular, and the vertex of the triangle trails off to the southeast. The effluent is somewhat warmer than the receiving waters of Reynolds Channel, as indicated by the relatively lighter tone within the triangular wedge. Temperatures in Reynolds Channel were near 4°C, so the temperature of the effluent was probably a few degrees higher. This assumption appears reasonable because sewage is conveyed beneath the ground; accordingly it reaches thermal equilibrium at temperatures closely approximating those obtained just below the water table (6° to 9° C in winter).

THERMAL LOADING

The most striking feature of the imagery depicted in figure 12 is the intense area of thermal loading in Barnums Island Channel originating from a large powerplant near Island Park. Cooling water flows through the plant at about 20,000 gallons per minute. The cooling water, which is withdrawn from Hog Island Channel, is heated from 5° to 7°C in its passage through the plant. The heated water is then discharged into Barnums Island Channel and flows eastward into Garrett Lead. After rather complete mixing in Garrett Lead, the cooling water enters Middle Bay, where thermal equilibrium is quickly reached.

Another feature of the imagery in figure 12 is the trapped cold streamflow at the mouth of Millburn Creek. The sharp line of demarcation suggests that the warmer waters of Middle Bay (about 20°C) are overriding the cooler waters of Millburn Creek (about 16°C); there is little, if any, mixing occurring at the surface.

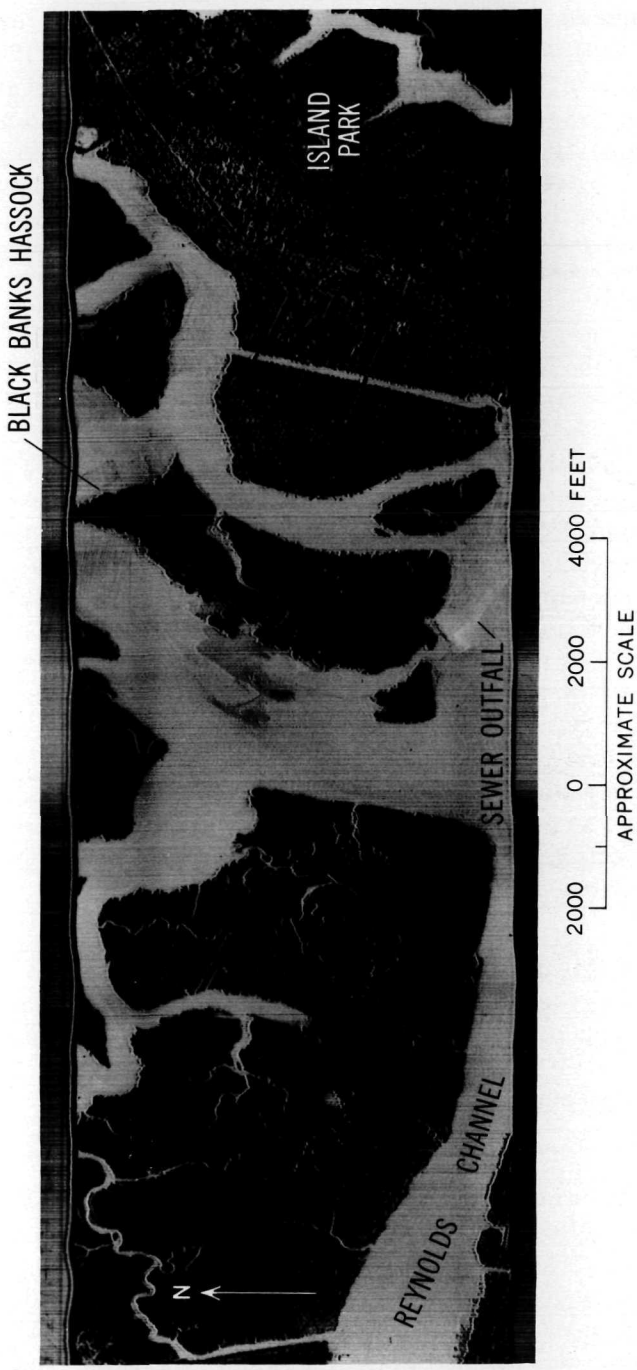

FIGURE 11.—Imagery obtained February 25, 1970, of Island Park and vicinity, showing sewage discharge into Reynolds Channel. (Imagery from NASA.)

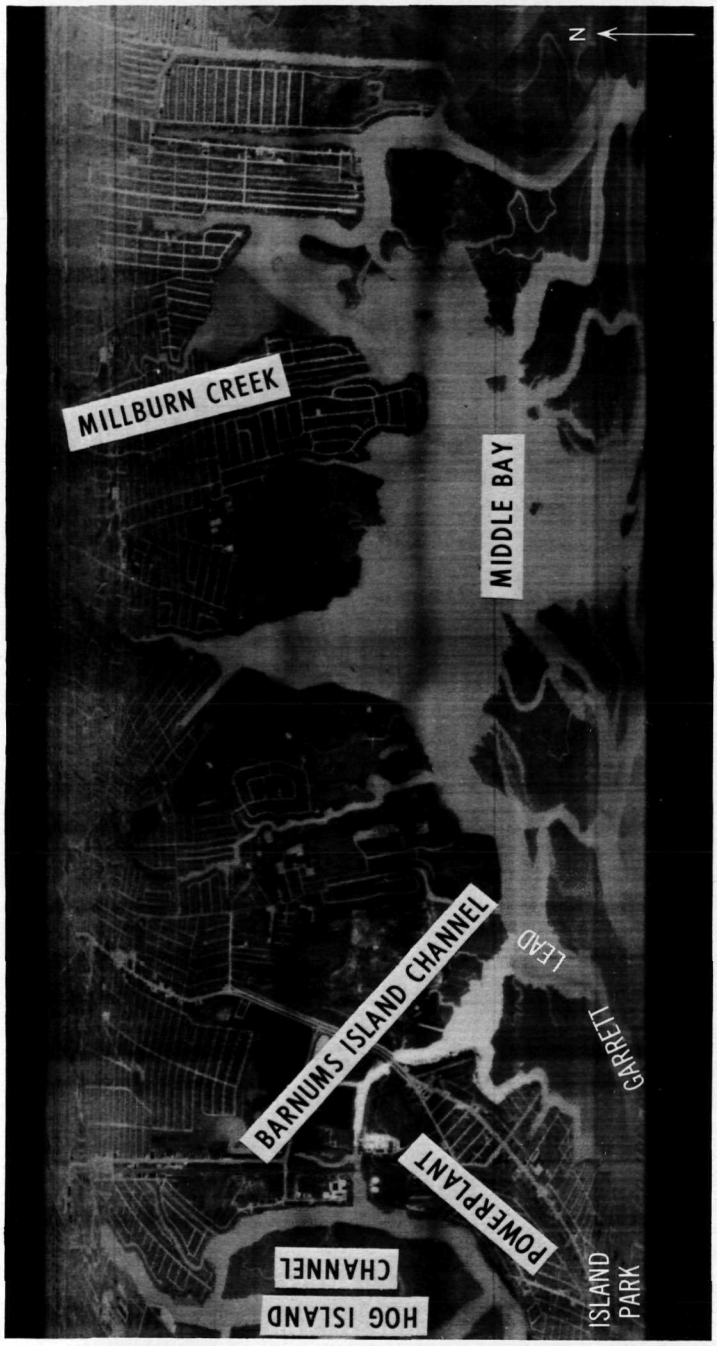

FIGURE 12.—Imagery obtained July 13, 1967, of Middle Bay and vicinity, showing tonal contrasts created by thermal loading from a powerplant at Island Park. (Imagery from NASA.)

INFLUENCE ON STREAM TEMPERATURES

Man has markedly altered stream-temperature patterns on Long Island by clear-cutting trees, constructing impoundments, and removing bank vegetation. Moreover, because of declining ground-water levels, the attenuating effect of ground-water inflow on stream-temperature fluctuations has been curtailed along many urban watercourses. The principal impact of these man-induced alterations in the overall heat budget of streams is to raise summer temperatures by 8° to 10°C. By way of contrast, winter stream temperatures in man-affected reaches average 1.5° to 3°C lower than in unaffected reaches (Pluhowski, 1970, p. D1).

Visual evidence of man-induced stream-temperature change is illustrated by imagery shown in figure 13. Great South Bay was warm (temperatures of 22° to 24°C at flight time), and therefore, the bay appears very light in the imagery. The Carlls River has been extensively developed for recreation principally by the creation of several large ponds (one of which is visible near the upper horizon of fig. 13). The extensive water surface created by the large impoundments on Carlls River greatly increases the amount of solar radiation absorbed by the stream. Accordingly, the temperature of Carlls River (about 21°C) is high relative to most other streams on the island. This fact is clearly illustrated by its light gray tone which is only slightly darker than the warm bay waters.

Santapogue Creek, slightly more than 1 mile west of Carlls River, appears as a very dark thread near the left margin of figure 13. Despite the fact that the stream flows through a suburban area, its temperature was relatively cold (about 16°C). Santapogue Creek has, to date, largely escaped environmental alterations in its immediate vicinity, so that stream temperatures there reflect nearly natural conditions. Sampawams Creek has been developed for recreational purposes. The total impact of man's activity on the stream is not so great as on Carlls River; however, Sampawams Creek has been subjected to a greater degree of urban development than Santapogue Creek.

The dark V-shaped coastal tract between Santapogue Creek and Carlls River is an extensive sand area having little or no vegetal cover. Under clear sky conditions, nocturnal radiational heat losses from exposed sand tracts are high. Accordingly, surface temperatures of such areas are low, and the sand tracts appear dark in the predawn imagery.

CONCLUSIONS

Infrared imagery is an effective tool which enables the hydrologist to use water temperature as (1) a tracer to detect areas of ground-

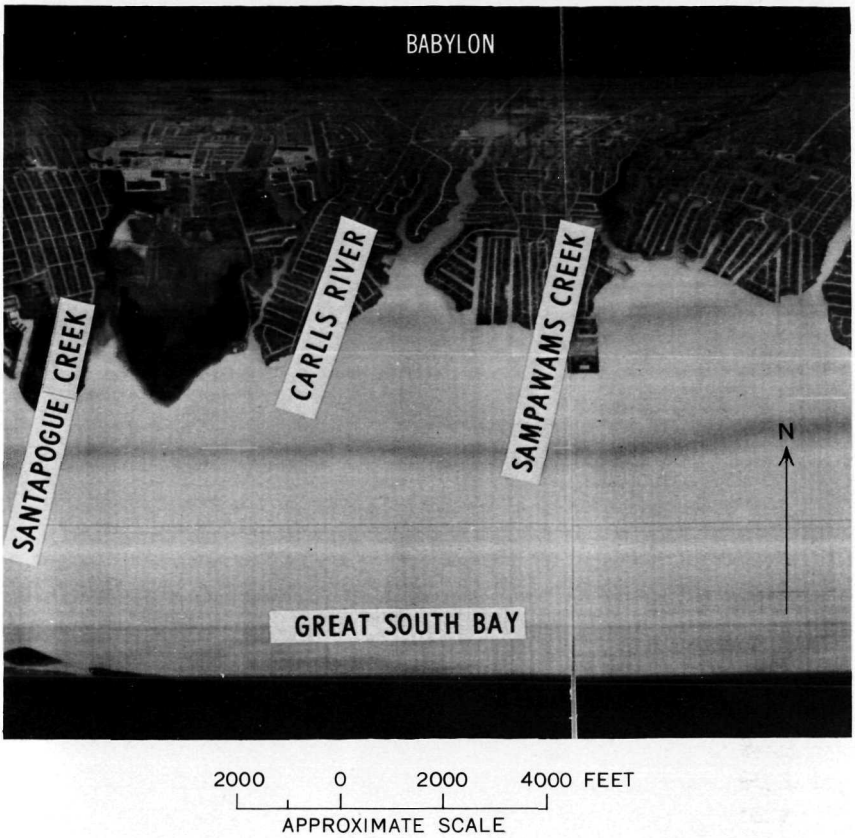

FIGURE 13.—Imagery obtained July 13, 1967, of Babylon and vicinity, showing the lower reaches of Santapogue Creek, Carlls River, and Sampawams Creek. (Imagery from NASA.)

water discharge, (2) a method to assess man's impact on temperature patterns, and (3) a means to identify circulation patterns in large water bodies.

Optimal flight conditions for remote sensing of ground-water outflow on Long Island prevail in the summer and winter seasons during predawn hours under clear skies. Lack of significant thermal contrasts between ground water and surface water in the spring and fall probably precludes the effective use of infrared imagery as a tool to detect subtle temperature-related hydrologic phenomena.

A well-planned field schedule to obtain ground-surface temperatures and water temperatures is an invaluable aid to imagery interpretation. Thermal imagery provides temperature-gradient infor-

mation between ground-control stations, and the observed ground-surface temperatures provide a means of image calibration.

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U.S. GOVERNMENT PRINTING OFFICE: 1972 O—450-447

Pluhowski—HYDROLOGIC INTERPRETATIONS, INFRARED IMAGERY, NEW YORK—Geological Survey Water-Supply Paper 2000-B

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JUN 19 1972

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