



Analysis of the Hydrogeologic Framework, Groundwater Availability and Water-Supply Sustainability of Western Long Island, New York

*By Frederick Stumm and Paul E. Misut,
USGS New York Water Science Center, Coram NY*

U.S. Geological Survey Project Proposal
January 2016

Problem

Long Island's sole-source aquifer system, including the Lloyd, Magothy, Jameco, and upper glacial aquifers, supplies groundwater for over 2.8 million people. As a coastal aquifer system, it is susceptible to saltwater intrusion. Past pumpage and sewerage in Kings and Queens Counties, N.Y. (figure 1), resulted in increased salinity in the upper glacial and Jameco aquifers (Buxton and Shernoff, 1999). In addition, simulation of hypothetical future well pumpage in Queens County by the U.S. Geological Survey (USGS) has predicted increasing salinity in the Magothy aquifer in western Nassau County (Misut and Voss, 2007), and recent research indicates that saltwater intrusion of the Lloyd aquifer has occurred along the southern shores of Kings and Queens Counties due to public-supply pumpage. For example, analysis of geophysical logs at a Lloyd aquifer test well at John F. Kennedy International Airport from 1989, suggests that about 80 percent of the Lloyd aquifer was intruded with saltwater (figure 2). Similarly, new geothermal- and industrial-well drilling in Queens County indicates local differences in the hydrogeologic framework and groundwater flow that were not anticipated in previous groundwater-flow modeling efforts. This has prompted questions about the accuracy of previously simulated groundwater pathlines, source-area delineations, and the location of the freshwater-saltwater interface and its landward movement.

Currently, there is no USGS monitoring of groundwater levels, and no network of deep outpost wells to monitor saltwater intrusion in Kings and Queens Counties. It has been about 10 years since the position of the saltwater-freshwater interface in the Magothy and Lloyd aquifers was last assessed (Misut and Voss, 2007). Analysis of historical supply and industrial wells in Kings County suggests the Lloyd aquifer maybe intruded by saltwater representing a western threat to public-supply that must be delineated in addition to a southern threat. Knowledge of groundwater-flow paths, source areas, and the movement of the freshwater-saltwater interface is essential for making informed planning decisions about public-supply strategies including rebalancing of pumping, improvement in the operation of the recharge basin network, and plans for future contingencies related to climate change and New York City water supply disruption.

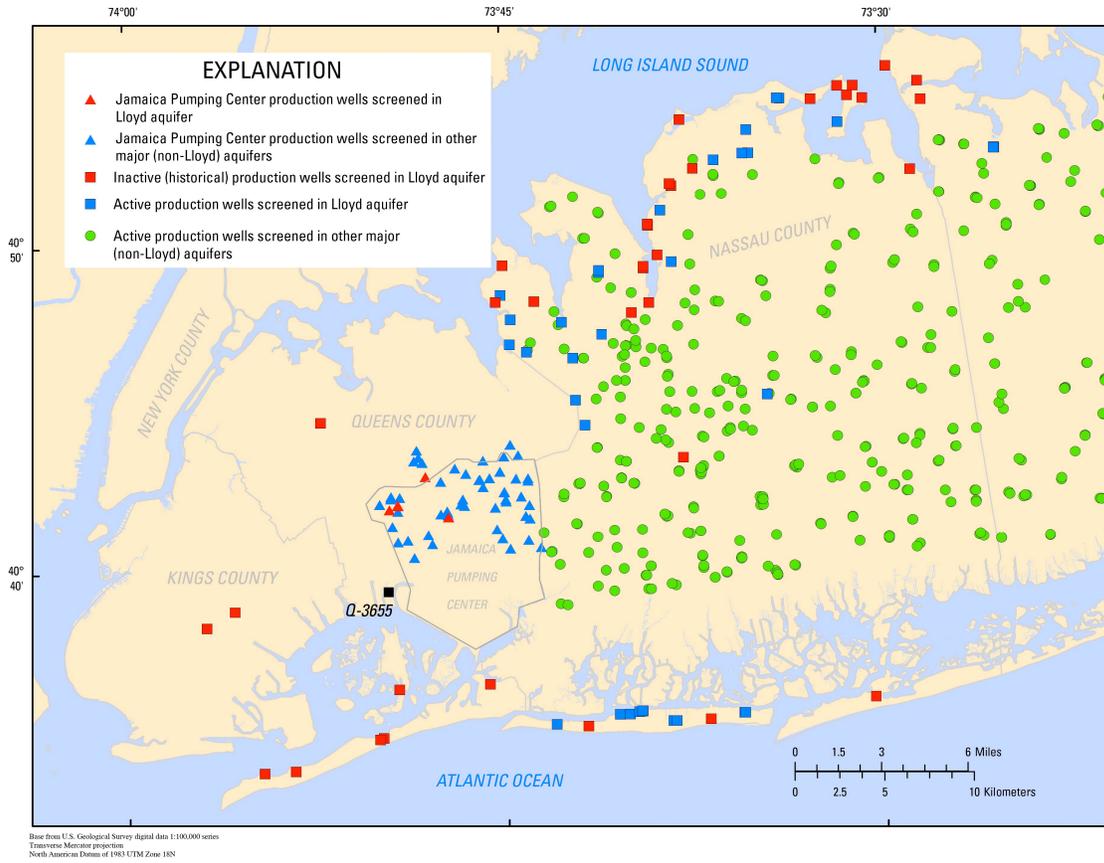


Figure 1. Location of the project study area, active, and historical inactive production wells.

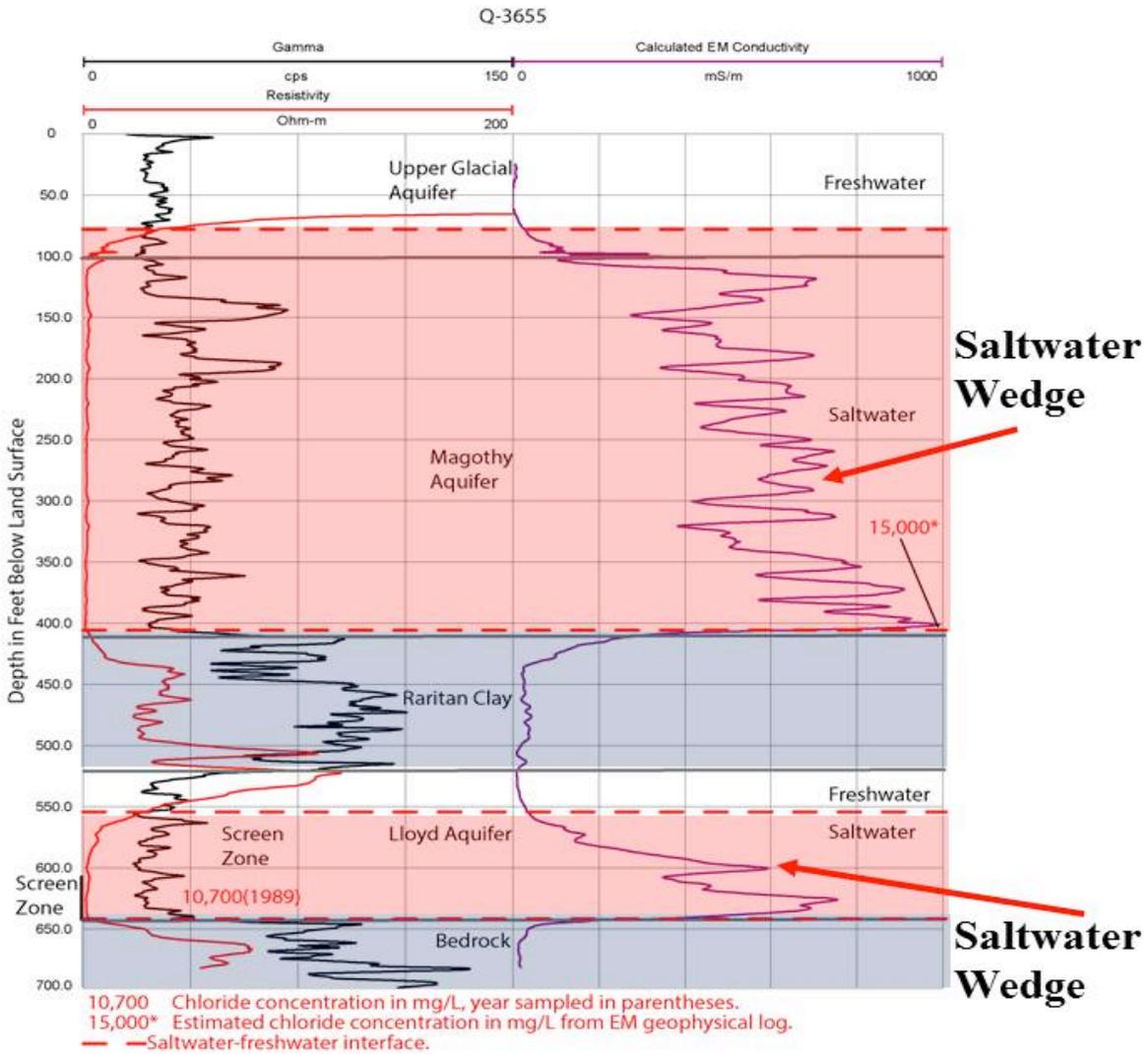


Figure 2. Delineation of saltwater intrusion in the Magothy and Lloyd aquifers in well Q-3655 through analysis of geophysical logs. (Well location shown in fig. 1).

Background

Water-supply wells on Long Island are affected by fate and transport of naturally occurring saltwater in surrounding coastal surface waters, and by human-derived contaminants entering the groundwater system from the land surface. An increased understanding of the fate and transport of contaminants and factors that affect them is useful for future planning purposes and to optimize water-supply operations. For example, establishing and limiting pumping rates to a maximum safe level may prevent degradation of water quality for wells near a freshwater-saltwater transition zone. Information concerning USGS programs to develop groundwater simulation methods is available at <http://water.usgs.gov/ogw/techniques.html>.

Until about 2010, the USGS worked in cooperation with the New York City Department of Environmental Protection to simulate the impacts of proposed alternative pumpage scenarios involving Kings and Queens County water-supply wells (Buxton and others, 1999; Buxton and

Smolensky, 1999; Kontis, 1999; Misut and Monti, 1999; Misut and Voss, 2007). These studies utilized coarsely discretized, steady-state groundwater-flow models with the freshwater-saltwater interface initially represented as fixed boundaries, and later represented as movable boundaries in order to predict changes in salinity at well-observation points. Due to a lack of data concerning offshore and deep-onshore parts of the groundwater system, however, there was and remains considerable uncertainty in predicting the outcomes of proposed alternative water-supply scenarios. New hydrogeologic data and interpretations have become available since the last modeling study was conducted, which may now be incorporated into a new model. Likewise, there are new data on changes in hydrologic stresses, including changes in present and projected future pumpage, changes in groundwater recharge and discharge, and changes related to climate change. During 2015, a federal funding arrangement was initiated for USGS to conduct regional groundwater-flow modeling on Long Island. Objectives of the ongoing study include reworking the hydrogeologic framework, and producing an accurate, three-dimensional representation of the age of groundwater throughout the entire flow system, to be calibrated to water quality data. In addition to the federally-funded USGS modeling study, New York State Department of Environmental Protection has funded a local USGS study to produce a comprehensive set of groundwater delineations for all of the streams and estuaries of Long Island, based on the federal study.

There are three main reasons why it is important at this juncture to develop a groundwater flow model. First, the situation with regard to failed sustainability demands it. Second, new data has either recently become available, or is proposed here. Third, technological improvements in groundwater-flow simulation methods have been made. Between the most recent (2007) study and the present (2016), the following advancements should be included in an updated model, in order to provide a robust modelling tool:

1. Increased computing capacity allows for finer model grids and time step sizes. Groundwater-flow model accuracy is related to discretization, and these technological improvements are an opportunity to improve previous groundwater models and our understanding of the cumulative effects of projected future pumpage on the region's water resources. In the most recent USGS study of Kings and Queens Counties, model calibration was conducted on the basis of a present conditions steady state, with limited transient-state modeling of future hypothetical scenarios. At present, it is technically feasible to conduct more accurate model calibration on the basis of transient-state, historical conditions of observed water level changes and salinity changes.
2. Improved USGS model codes allow for more accurate and robust mathematical solutions and representation of physical mechanisms. In the most recent USGS study of Kings and Queens Counties, the SUTRA code was applied. At present, the SEAWAT code is available. SUTRA and SEAWAT were recently compared in a USGS saltwater intrusion study of Manhasset Neck (Misut and Aphale, 2014). Groundwater-flow model accuracy is related to model coding, and the technological improvement of a new model code is an opportunity to further our understanding of the cumulative effects of projected future pumpage on the region's water resources.
3. At present, an open source USGS graphical user interface is available for USGS model codes including SEAWAT and MODFLOW. This is an improvement over the proprietary user interfaces used in previous studies of Kings and Queens Counties because it allows for a broader base of the public to use these models. Furthermore, it increases the ease of use of models and facilitates model improvements, through greater capabilities for

automated model construction. This technological improvement is an opportunity to further our understanding of the cumulative effects of projected future pumpage on the region's water resources.

4. At present, the USGS has completed a project to integrate inverse modeling techniques into its open source graphical user interface, which facilitates model sensitivity analysis and parameter estimation. Groundwater-flow model accuracy is related to the completeness of model calibration exercises, and this technological improvement is an opportunity to improve previous groundwater models and our understanding of the effects of projected future pumpage on the region's water resources.

Improvements to a new model would include the following categories: mathematical, computer-related, and representation of the hydrogeologic framework and water-use. Improvements in each of these categories would be ultimately beneficial for policymaking because it is imperative that policy is guided by accurate predictions and a complete understanding of the groundwater system.

Objectives

The primary objectives of this investigation are as follows:

- Due to a lack of deep Lloyd observation wells, a network of Lloyd aquifer outpost monitoring wells will be installed. The approximate costs of this objective are given separately and it may be possible to administer this work through a third party to avoid substantial USGS overhead costs.
- Monitor groundwater levels, sample chloride concentrations, and collect an advanced suite of geophysical logs at well network that combines the current observation-well network with newly drilled wells as they become available.
- Determine the current location, thickness, and chloride concentration (used to assess salinity) of the freshwater-saltwater interface based on the new data and available historical information. Delineate a revised hydrogeologic framework in critical areas such as northern and central Kings and Queens Counties from new and available core samples and geophysical logs.
- Construct a groundwater-flow and interface model by combining pre-existing USGS models within the study area with new data as it becomes available. Preliminary simulations will be rapidly published in an extended abstract format to help guide decisions about the location of new outpost-monitoring wells, interpretation of initial data, and management response to significant changes in stress such as reactivation of Queens supply wells.
- Construct detailed hypothetical scenarios of pumpage and hydrologic conditions in Kings, Queens, Nassau, and western Suffolk Counties.
- Finalize groundwater-flow models and evaluate freshwater-saltwater-interface movement, including delineation of groundwater-flow pathlines at supply-well capture zones susceptible to saltwater intrusion. The model grid shall be variably spaced with focus on Nassau, but coarsely extended to natural hydrologic boundaries including New York Bay (Kings County) and the Connetquot/Nissequogue River Corridor (Suffolk County).

- Evaluate changes in groundwater pathlines as a result of hypothetical scenarios at inland well sites in Queens and Nassau Counties, not susceptible to saltwater intrusion, but at risk of water-quality degradation from other sources of known contamination.

Relevance and Benefits

As the Nation’s premier earth sciences agency, the USGS applies existing and emerging technologies to develop new methods of assessing geologic and hydrologic conditions. The proposed scope of work will advance knowledge of the hydrogeologic framework in the area and will enhance and protect the quality of life by advancing our scientific understanding of the groundwater-flow system, determine the location of saltwater in the major aquifers, and predict the sustainability of these aquifers to future pumping stresses. Through use of this knowledge to set rules, water suppliers and policymakers can better manage the western Long Island aquifer system.

Approach

The USGS or other group will drill deep wells at about ten selected locations where no nearby wells currently exist. The USGS will use these new wells, the current observation-well network in Nassau and western Suffolk Counties, and other data sources to analyze and model the groundwater flow system. The pre-existing network consists of shallow and deep wells in western Nassau County (Great Neck, Manhasset Neck, Inwood, and Long Beach), and some shallow wells in Kings and Queens Counties.

During and after completion of the newly drilled wells, the following work will be performed:

- collect split- spoon core samples and analyze core samples for hydrogeologic-unit mapping,
- extract and analyze filter-press samples for chloride concentration,
- collect geophysical logs including gamma, normal electrical resistivity, and electromagnetic (EM) induction conductivity and magnetic susceptibility logs from the network of wells to determine the geologic framework and thickness, estimated concentration, and location of the freshwater-saltwater interface in the aquifer system,
- sample the well network to determine the chloride concentration, and integrate these data with the geophysical data to delineate the location of the freshwater-saltwater interface, and
- monitor groundwater levels using periodic and continuous measurements, and re-log the outpost wells to collect conductivity logs periodically—both before and during pumping of the reactivated Jamaica water-supply wells— to determine the presence and rate of saltwater intrusion in the Magothy and Lloyd aquifers. Geophysical monitoring will also include currently existing observation wells in Inwood, Long Beach, Great Neck, Manhasset Neck and surrounding areas in Nassau County.

Chloride breakthrough curves, locations of Magothy and Lloyd aquifer cones of depression, and geophysical logs from historical wells will be used to determine the locations of outpost well drilling. In addition, preliminary model simulations will be used to help guide the selected locations for outpost well drilling. A preliminary model will be constructed by refining the all

available USGS Nmodels including (Masterson and others, 2013; Misut and Aphale, 2014; Misut, 2014; Misut and Voss, 2007; and Misut and Monti, 1999). Field techniques will include water-level measurements, chloride-concentration sampling, core sample analysis, and periodic (biannual) borehole geophysical logging using EM methods as described in Stumm (1993; 2001) and Stumm and others (2002).

The USGS will use the density-dependent solute-transport -model SEAWAT (Langevin and others, 2007) to represent saltwater-interface dynamics, and the particle tracker MODPATH (Pollock, 1994) to delineate source areas. The finalized model will utilize an updated hydrogeologic framework in Kings and Queens Counties (a subset of the framework that is being developed by the USGS for the five boroughs of New York City in cooperation with the New York City Department of Design and Construction), and new delineations of the freshwater-saltwater-interface in the Magothy and Lloyd aquifers in Kings, Queens, and Nassau Counties. The SEAWAT model will be calibrated to match field-measured groundwater levels and the newly delineated freshwater-saltwater interface locations, by varying parameter values, boundary conditions, and model discretization. The following scenarios will be simulated:

1. Scenarios of (a) no change from present conditions and (b) continuation of current trends in public supply pumping and water use. In addition to accurately representing pumping rates and locations, all related aspects of water usage are represented, including pumping for non-drinking water purposes, management of surface water flows, and subsurface water injections, such as from geothermal systems. It is unknown whether the present pattern of water usage is generally sustainable; however, there are certainly hotspots of heavy pumpage at risk of causing saltwater intrusion or other types of water quality degradation. By projecting current conditions into the future (to about the year 2050), many insights for guiding management practices may be initially uncovered.
2. Scenarios of change in groundwater recharge due to climate-change-related increases in air temperature, evapotranspiration, and precipitation intensity would be considered. Some of these factors may decrease groundwater recharge, leading to a decrease in groundwater availability, while others factors may increase groundwater recharge and availability, and perhaps cause flooding problems. The effect of the sum total of these factors is complex and unknown, but may be approached through computer simulation. These scenarios include simulation of a future reoccurrence of the drought characteristic of 1962-66.
3. Scenarios related to New York City groundwater demand would continue to be modeled, including short-term and as-permitted (long term) reactivation of Queens supply wells. These scenarios may lead to a decrease in the sustainability of the Nassau County water supply system.
4. In an extreme water supply disruption, it may be economical for Nassau water suppliers to transfer water to New York City even if the practice is less than ideal from a sustainability perspective. Simulations to explore the feasibility and sustainability of strategies such as the following may be considered: (a) increased pumping rates of currently-operating deep-supply wells that have excess capacity, (b) reactivation of unused but permitted Nassau supply wells that may have high water treatment burdens,

and (c) construction of new upper glacial supply wells that may simultaneously serve other purposes such as groundwater flood control or geothermal cooling. These scenarios would include reactivation of Queens supply wells.

5. As sea level rises, saltwater intrusion occurs and the depth to groundwater decreases. Given the ever-increasing projections of sea level rise, we propose to model the middle and upper ranges of sea level rise accepted by New York State. At these projected sea level positions, the coastline likely moves inward, resulting in decreased total groundwater recharge (and sustainability of current pumping practices). Increased hydrostatic pressure of the saline groundwater body would significantly decrease freshwater recharge to the Lloyd Aquifer.
6. Scenarios of diversion of water to stream headwaters through shallow well pumpage, such as proposed for Massapequa Creek, may decrease sustainability.
7. A scenario of redistributed pumping to mitigate severe local problems would be considered, and include identification of sites within Nassau County exhibiting potential for future supply well development. This would likely increase water supply sustainability.
8. Water-conservation scenarios of decreased per capita water use and limitations on non-potable water pumpage such as domestic and/or golf course irrigation caps would be considered. This would likely increase water supply sustainability.
9. A scenario of increased recharge through re-engineering of recharge basins to maximize groundwater system benefit would be considered. This would likely increase water supply sustainability.

Products

Results of the investigation will be disseminated through two final reports in the USGS Scientific Investigations Report series, including a complete file archive of a predictive hydrodynamic model of western Long Island's aquifers. The first report will summarize results from the field investigation of groundwater levels, updated hydrogeologic framework, and delineation of the freshwater-saltwater interface in the Magothy and Lloyd aquifers. The report will include:

- maps and sections presenting the three-dimensional distribution of the hydrogeologic units,
- the location of the historical saltwater-freshwater interface in the Magothy and Lloyd aquifers within the study area,
- the current location, thickness, and chloride concentration of the saltwater-freshwater interface in the Magothy and Lloyd aquifers within the study area, and
- potentiometric-surface maps of the Magothy and Lloyd aquifers within the study area during the spring and summer.

The second report will document application of the groundwater-flow model and link to an online file archive where model data may be publicly accessed. The report will include:

- graphics of model representation of the hydrogeologic framework and present locations of freshwater-saltwater interfaces,
- graphics of model representation of observation, pumping, and hypothetical wells,
- timelines of hypothetical scenarios of future stresses (such as pumpage),
- graphics of simulated freshwater-saltwater-interface movement,
- graphics of simulated groundwater-flow paths and source areas, and
- statistics related to model calibration, sensitivity analysis, and model uncertainties.
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To manage the complex water supply system of Nassau County, it is useful to keep up-and-running a computer simulation tool that is available to the public in a non-proprietary format. This tool is a predictive hydrodynamic model of western Long Island’s aquifers. The model will be capable of determining the location of saltwater in the major aquifers, and predicting the sustainability of these aquifers to future pumping stresses, and represent the culmination of knowledge about the hydrogeologic framework and hydrologic stresses of western Long Island. Through use of this model, water suppliers and policymakers can better manage the western Long Island aquifer system.

Budget

The proposed USGS project will require a total funding of \$3,225,000 to cover the costs for salaries, drilling contract costs, supplies, laboratory costs, and other expenses. The drilling contract will require \$1,719,000; the hydrogeologic framework mapping, borehole geophysical logging, water-level elevation monitoring, and delineation of the current freshwater-saltwater interface in the major aquifers will require \$1,052,000; and the preliminary model estimates and final updated groundwater-flow model will require \$304,000. The USGS will provide a matching contribution of \$150,000. The proposed 2-1/2-year project is to begin April 1, 2015 and continue through September 30, 2017.

Category	Fiscal year (October 1 through September 30)			Total
	2015	2016	2017	
Drilling contract ¹	\$431,000	\$1,288,000	\$0	\$1,719,000
Modeling	\$79,000	\$129,000	\$96,000	\$304,000
Hydrogeology	\$257,000	\$529,000	\$266,000	\$1,052,000
Federal match ²	\$37,000	\$73,000	\$40,000	\$150,000
Total	\$804,000	\$2,019,000	\$402,000	\$3,225,000

¹ Drilling contract includes USGS overhead (about 50 percent of total amount). These cost may be reduced through administration by other party. .

² Estimated amount is 10 percent of non-contract project costs, and subject to the availability of Federal matching funds at the time an agreement is developed.

References Cited

Buxton, H.T. and Shernoff, P.K., 1999, Ground-water resources of Kings and Queens Counties, Long Island, New York: US Geological Survey water-supply paper 2498, 113 p.

- Buxton, H.T., and Smolensky, D.A., 1999, A quantitative analysis of the development of the ground-water flow system of Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4069, 58 p.
- Kontis, A., 1999, Simulation of Freshwater-Saltwater Interfaces in the Brooklyn-Queens Aquifer System, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4067, 26 p.
- Langevin, C.D., Thorne, D.T., Jr., Dausman, A.M., Sukop, M.C., and Guo, W., 2007, SEAWAT version 4—A computer program for simulation of multi-species solute and heat transport: U.S. Geological Survey Techniques and Methods, book 6, chap. A22, 39 p.
- Licata, A. 2014, Draft Scope of Work for Water for the Future: Upstate Water Supply Resiliency Project, NYC Environmental Protection Memorandum dated October 10, 2014, 6 p.
- Masterson, J.P., Pope, J.P., Monti, Jack, Jr., Nardi, M.R., Finkelstein, J.S., and McCoy, K.J., 2013, Hydrogeology and hydrologic conditions of the Northern Atlantic Coastal Plain aquifer system from Long Island, New York, to North Carolina: U.S. Geological Survey Scientific Investigations Report 2013–5133, 76 p.
- Misut, P. E., Monti, Jack, Jr., 1999, Simulation of ground-water flow and pumpage in Kings and Queens Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4071, v, 50 p.
- Misut, P.E., and Voss, C.I., 2007, Freshwater-saltwater transition zone movement during aquifer storage and recovery cycles in Brooklyn and Queens, New York City, USA: *Journal of Hydrology*, v. 337, Issues 1-2, p. 87-103.
- Misut, P.E., 2014, Simulation of zones of contribution to wells at site GM–38, Naval Weapons Industrial Reserve Plant, Bethpage, New York: U.S. Geological Survey Scientific Investigations Report 2014-5036, vii, 58 p.
- Misut, P.E., and Aphale, O., 2014, Simulation of groundwater pathlines and freshwater/saltwater transition zone movement, Manhasset Neck, Nassau County, New York: U.S. Geological Survey Scientific Investigations Report 2013–5201, 71 p.
- Pollock, D.W., 1994, User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 94-464, 6 chapters.
- Stumm, F., 1993, Use of focused electromagnetic-induction borehole geophysics to delineate the saltwater-freshwater interface in Great Neck, Long island, New York, in Bell, R., Lepper, C., eds. *Symposium on the Applications of Geophysics to Engineering and Environmental Problems*, Vol. 2: Environmental and Engineering Society, proceedings, p.513-525.
- Stumm, F., 2001, Hydrogeology and extent of saltwater intrusion of the Great Neck peninsula, Great Neck, Long Island, New York: U.S. Geological Survey Water Resources Investigations Report, 99-4280, 41p.
- Stumm, F., and Lange, A.D., 2002, Hydrogeology and extent of saltwater intrusion of the Manhasset Neck peninsula, Long Island, New York: U.S. Geological Survey Water Resources Investigations Report, 00-4193, 42 p.
- Terracciano, S. A., 1997, Position of the freshwater/saltwater interface in southeastern Queens and southwestern Nassau counties, Long Island, New York, 1987-88: U.S. Geological Survey Open-File Report: 96-456, 17 p.