REVIEW OF PUBLIC HEALTH RISKS AND GROUNDWATER EXPOSURE FROM PRESENCE OF 1,4-DIOXANE ON LONG ISLAND

National Center for Suburban Studies

Jared S. Garfinkel and Dr. Sandra J. Garren

Hofstra University

CONTENTS

Tables

Figures

Introduction

Water quality on Long Island has been studied for many years (Perlmutter, 1972; Kimmel 1984; Becker, 2014). Long Island is a sole source aquifer serving 2.6 million people in Nassau and Suffolk County. In general terms, Long Island is made up of four major hydrogeologic units relevant to drinking water. The Magothy, Raritan and Lloyd aquifers are part of the Northern Atlantic Coastal Plains Aquifer System. The Upper Glacial Aquifer is an unconfined aquifer formed during the last ice age by glacial till left behind from receding glaciers. Below that, the Magothy Aquifer is a semi-confined aquifer that supplies most of Long Island's drinking water being the largest aquifer on Long Island. The Raritan Confining Unit underlies the Magothy Aquifer and confines the Lloyd aquifer, Long Island's deepest aquifer.

Drinking water is managed locally by water districts. There are approximately 34 water districts in Nassau County and 8 water districts in Suffolk County. Water districts publish annual drinking water quality reports as required by federal and state regulations. These regulations involve testing for known contaminants and reporting as necessary. Supply wells that exceed national drinking water quality standards are often shut down.

The Safe Drinking Water Act of 1974 and subsequent provisions give the United States National Environmental Protection Agency (NEPA) regulatory authority over drinking water quality. This include the regulation of more than 90 contaminants, the monitoring of unregulated contaminants, and maintenance of a list of candidate contaminants. The New York State Department of Environmental Conservation (NYSDEC) monitors surface water and groundwater with NEPA oversight.

After a series of high-visibility national incidents in the 1970's involving toxic waste there was a call for Congress to act on storing and cleaning up hazardous waste facilities. The

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) was passed in 1980. Superfund has since helped manage the responses to hazardous material releases that threatened the environment in prominent cases like Love Canal, and after the natural disasters Hurricanes Katrina and Rita and Superstorm Sandy.

A list of remediation sites is maintained at the national and state levels. An uncontrolled or abandoned site can be added to the National Priorities List if it contains hazardous waste or other contamination that requires federal action. Long Island is home to more than 250 superfund sites in various stages of remediation (Newsday, 2016).

There have been recent public health concerns about the presence of 1,4-dioxane (a.k.a. “dioxane”) in drinking water. Dioxane is found on Long Island in concentrations higher than the national average (“Schumer, Gillibrand”, 2017). It is classified as a probable human carcinogen because there is inconclusive evidence that it causes cancer in humans, yet there have been several studies showing a risk for cancer in animals (Kano, 2009). The lifetime risk of cancer from an exposure of 0.35 μg/L in drinking water has been estimated to be one in one million extrapolated from the cancer risk in livers of female mice (“1,4-Dioxane”, 2014).

Dioxane is expected to be highly mobile in groundwater due to its physical and chemical properties (Abe, 1999; Zenker, 2003). Dioxane is not naturally degraded or attenuated in wastewater treatment plants. Advanced methods are required to treat dioxane (Stepien et al., 2014). Pilot- and full-scale projects have shown that dioxane can be degraded using an ultraviolet radiation and hydrogen peroxide method based on current knowledge of dioxane treatment methods (Maurino, 1997; Meunier et al., 2014).

Although 1,4-Dioxane is listed as a probable carcinogen, it is not currently regulated by the National EPA (NEPA). However, NEPA mandated water quality testing of 1,4-dioxane in water districts serving more than 10,000 individuals to determine the need to regulate it. It was included in the Third Unregulated Contaminant Monitoring Rule (UCMR3) under the Safe Drinking Water Act to determine if it requires regulation. Meanwhile, a number of states have set health standards for the synthetic organic compound:

a) New Jersey has set an interim ground water quality criterion of 0.4 μg/L
b) Connecticut has set a drinking water Action Level of 3 μg/L
c) Massachusetts has set a drinking water guideline of 0.3 μg/L
d) Colorado has set an interim ground water quality criterion of 0.35 μg/L
e) California has set a notification standard of 1 μg/L for drinking water
f) New Hampshire has established a reporting limit of 0.25 μg/L for public water supply well samples

Dioxane is used as a stabilizing agent for TCA and other chlorinated industrial agents. It can be found in consumer products, solvents, and is produced as a byproduct of a chemical process called ethoxylation. Industrial sites and dry cleaners using detergents or solvents that have 1,4-dioxane in them may be point sources on Long Island. Of remediation sites on Long Island, 98 have known 1,1,1-trichloroethane (TCA) contamination (Newsday, 2016).

A similar investigation to this has been conducted by Citizens Campaign for the Environment and resulted in a map available to the public on their website (Somma, 2017). This current research will be used to identify possible research directions. Furthermore, research will be focused on causes of 1,4-dioxane contamination and its effects on groundwater in addition to public health. Statistical analysis was conducted using publicly available data from water districts, Newsday, and WaterTraq.

Methodology

The levels of dioxane in Nassau and Suffolk counties, the water district boundaries, and remediation sites found in Nassau and Suffolk were collected. Inquiries were made with Nassau water districts and the SCWA. A Freedom of Information Law request was filed with the Nassau County Health Department to ask for data related to individual supply well water quality readings. Several water districts in Nassau County were asked to send supplemental data packages to the annual drinking water quality report for the years in which dioxane was reported. WaterTraq data was used to show point data for supply wells in Suffolk County.

Some data was available online including a Newsday database that reported concentrations of 1,4-dioxane for many water districts on Long Island. The Long Island Index, Nassau Assessor's Office and Suffolk County Water Authority provided electronic copies of polygon shapefiles of water districts in Nassau and Suffolk. Remediation site polygons were downloaded from the New York State GIS Clearinghouse website.

A map of Long Island concentrations of 1,4-dioxane was created from data available from Newsday and WaterTraq. The use of Excel and GIS was central to the creation of maps and images related to the geographic distribution of 1,4-dioxane. An Excel pivot table was created to find the average concentrations of dioxane for each water district. WaterTraq data was copied from the website to a spreadsheet in Excel to be processed for creating a shapefile in ArcMap.

In ArcMap, an attribute field was added to the Nassau Assessor's Office GIS data for water district boundaries in Nassau County and the concentrations were manually entered for each water district based on Annual Drinking Water Quality Reports in Nassau County. Data from the WaterTraq and Newsday databases were used to map the geographic distribution of 1,4-dioxane in Suffolk.

Descriptive statistics were used to graph dioxane in Nassau and Suffolk County water districts. Supply well point data was available for 1,4-dioxane measurements in some Suffolk County Water Authority Distribution Areas. Known remediation sites with hazardous material contamination were mapped.

Results

The highest reading on Long Island was in Hicksville, at almost 100 times the EPA's recommended health safety standard. This well has since been shut down. Bethpage, Bowling Green, Garden City, Hicksville, Levittown, Jericho, Plainview, Garden City, Village of Hempstead, and Water Authority of Western Nassau had levels of dioxane over 10 times the human health standard set by the EPA (0.35 ppb). A map was produced to visualize the geographic distribution of 1,4-dioxane on Long Island (Figure 1).

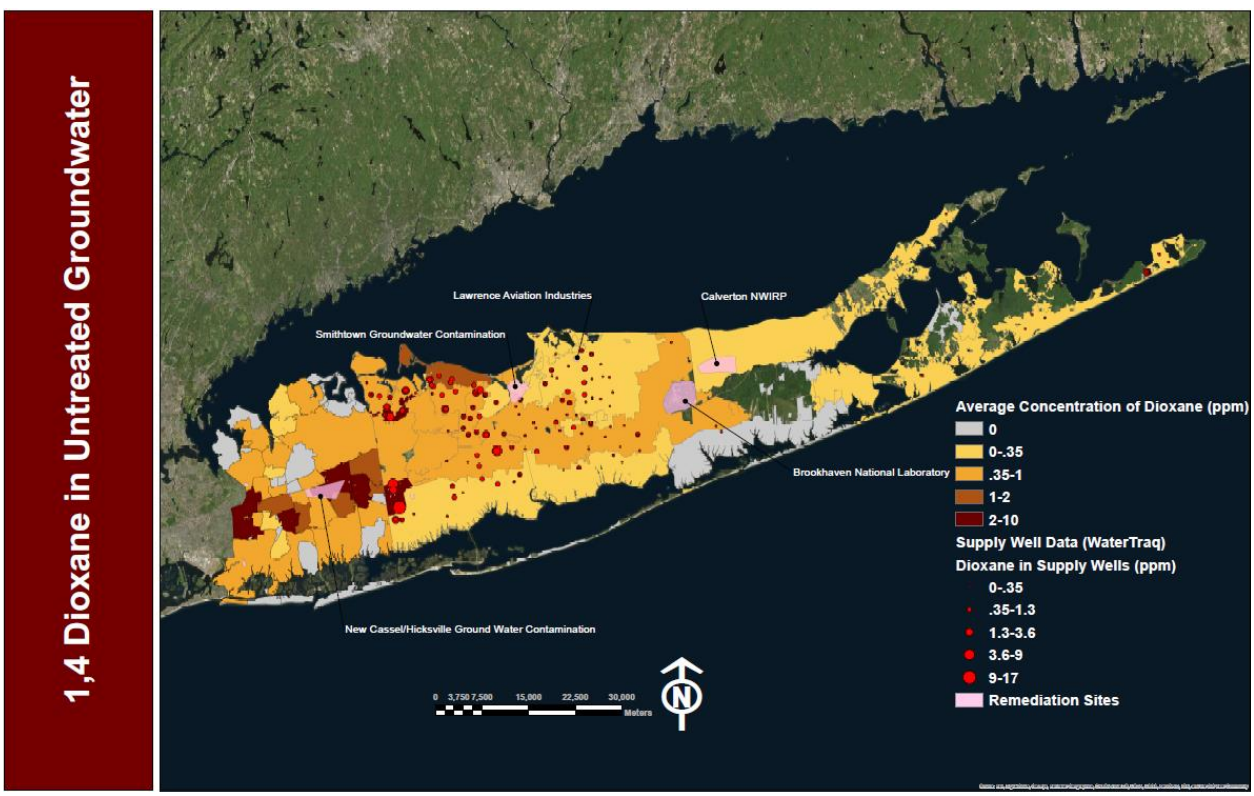

Figure 1. **Geographic Distribution Map of Dioxane on Long Island.** A comprehensive visual map of Long Island with hot spots of dioxane represented in graduated colors. Selected remediation sites are labeled. Note that while the westernmost remediation site, New Cassel/Hicksville Ground Water Contamination, is closely related to groundwater contamination, those in the east are not as well correlated to high concentrations of dioxane. This suggests that the analysis of remediation site exposure to groundwater is complicated and requires further study. There appears to be a gap between the cluster on the border of eastern Nassau and western Suffolk and a cluster in western Nassau. Even within the cluster in western Nassau, there appears to be a mini-gap. Speculatively, there could be separate sources for the contaminated wells in Water Authority of Western Nassau, West Hempstead, and the Hicksville/Bethpage/Bowling Green/Plainview/East Farmingdale Clusters.

The data are described below in general terms and statistically significant terms. There were wide variations in data availability for each water district. (Tables 1 and 2). The data is lognormally distributed, meaning the logs of the results are distributed along a normal curve. This is a common distribution found in natural phenomena. The average reading for dioxane was found to be higher than 0.35ppb, a value recognized to be equivalent to a one-in-one-million chance of cancer over a lifetime exposure to 1,4-dioxane (Figures 2 and 3).

Table 1. **Nassau County Water District Data Count.** This table shows that the data in this study varied in the amount collected for each water district. The range of available dioxane readings was from one to twenty-five.

Nassau County Water District	Number of Readings
Albertson Water District	10
Aqua NY - Sea Cliff	2
Aqua NY, Inc.	3
Bethpage Water District	10
Bowling Green Estates Water District	2
City of Glen Cove	5
City of Long Beach[1]	1
East Meadow Water District	8
Franklin Square Water District	5
Garden City Park Water District	10
Greenlawn Water District	18
Hicksville Water District	15
Jericho Water District	25
Levittown Water District	6
Locust Valley WD	6
Long Island American Water Corporation	8

Manhasset Lakeville Water District	6
Massapequa Water District[1]	18
Plainview Water District	13
Port Washington Water District	11
Roosevelt Field Water District	6
Roslyn Water District	3
South Farmingdale Water District	6
Uniondale Water District	4
Village of Freeport[1]	6
Village of Garden City	11
Village of Hempstead	2
Village of Mineola	6
Village of Rockville Centre	2
Water Authority of Great Neck North	12
Water Authority of Western Nassau	6
West Hempstead Water District	2
Westbury Water District	14

[1] These water districts had no uncensored data values.

Table 2. **Suffolk County Water District Data Count.** The Suffolk County Water Authority and other Suffolk County water districts have a wide range of sizes and number of constituents served. The range of dioxane readings in each district in Suffolk is from 1 to 54. This does not include the WaterTraq point data from supply wells.

Suffolk County Water District	**Number of Readings**
Dix Hills Water District	8
Hampton Bays Water District	1
Riverhead Water District	1
Saint James Water District	2
Smithtown Water District	1
South Huntington Water District	9
Stony Brook Water District	3
Suffolk County Water Authority, Area 1	24
Suffolk County Water Authority, Area 10	14
Suffolk County Water Authority, Area 11	21
Suffolk County Water Authority, Area 12	54
Suffolk County Water Authority, Area 14	2
Suffolk County Water Authority, Area 15	44
Suffolk County Water Authority, Area 20	2
Suffolk County Water Authority, Area 23	6
Suffolk County Water Authority, Area 26	8

Suffolk County Water Authority, Area 27[1]	2
Suffolk County Water Authority, Area 30	4
Suffolk County Water Authority, Area 32[1]	2
Suffolk County Water Authority, Area 35[1]	2
Suffolk County Water Authority, Area 39[1]	4
Suffolk County Water Authority, Area 4[1]	2
Suffolk County Water Authority, Area 44[1]	2
Suffolk County Water Authority, Area 5	4
Suffolk County Water Authority, Area 53[1]	8
Suffolk County Water Authority, Area 54[1]	8
Suffolk County Water Authority, Area 55[1]	4
Suffolk County Water Authority, Area 57[1]	2
Suffolk County Water Authority, Area 6	14
Suffolk County Water Authority, Area 60	3
Suffolk County Water Authority, Area 7	2
Suffolk County Water Authority, Area 8	2
Suffolk County Water Authority, Area 9	10

[1] These water districts had no uncensored data.

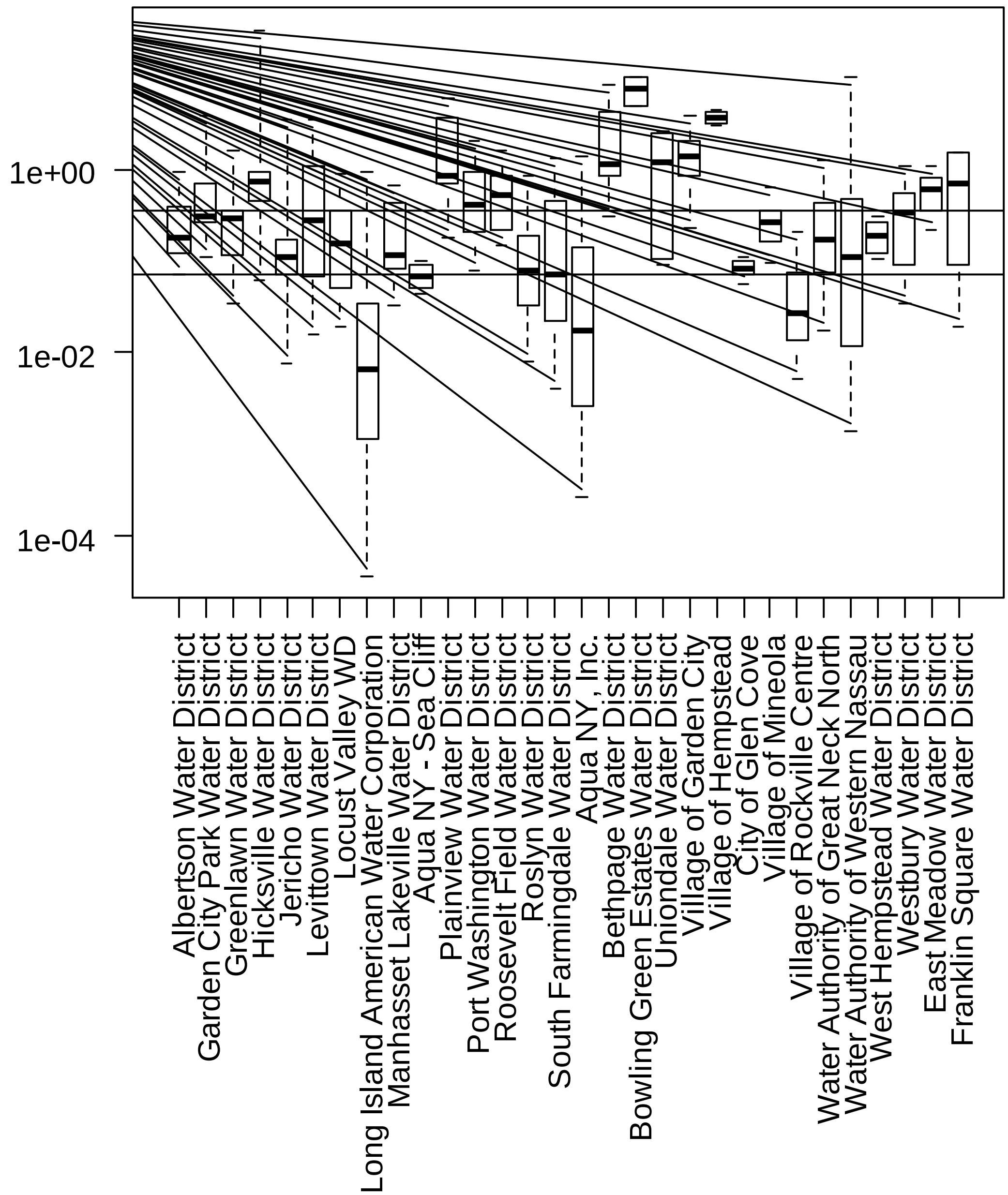

Figure 2. **Censored Box Plots of Nassau County Dioxane Concentrations Using R.** This is a box plot chart of concentrations of dioxane across all available readings, across all years of screening and supply wells. The lower horizontal line represents the limit of detection for dioxane, 0.07 ppb. The upper horizontal line represents the health standard set by the EPA, 0.35 ppb. The following water districts did not have uncensored data: City of Long Beach, Massapequa Water District, and Village of Freeport. For these water districts, we report that the level of dioxane is between zero and 0.07 ppb.

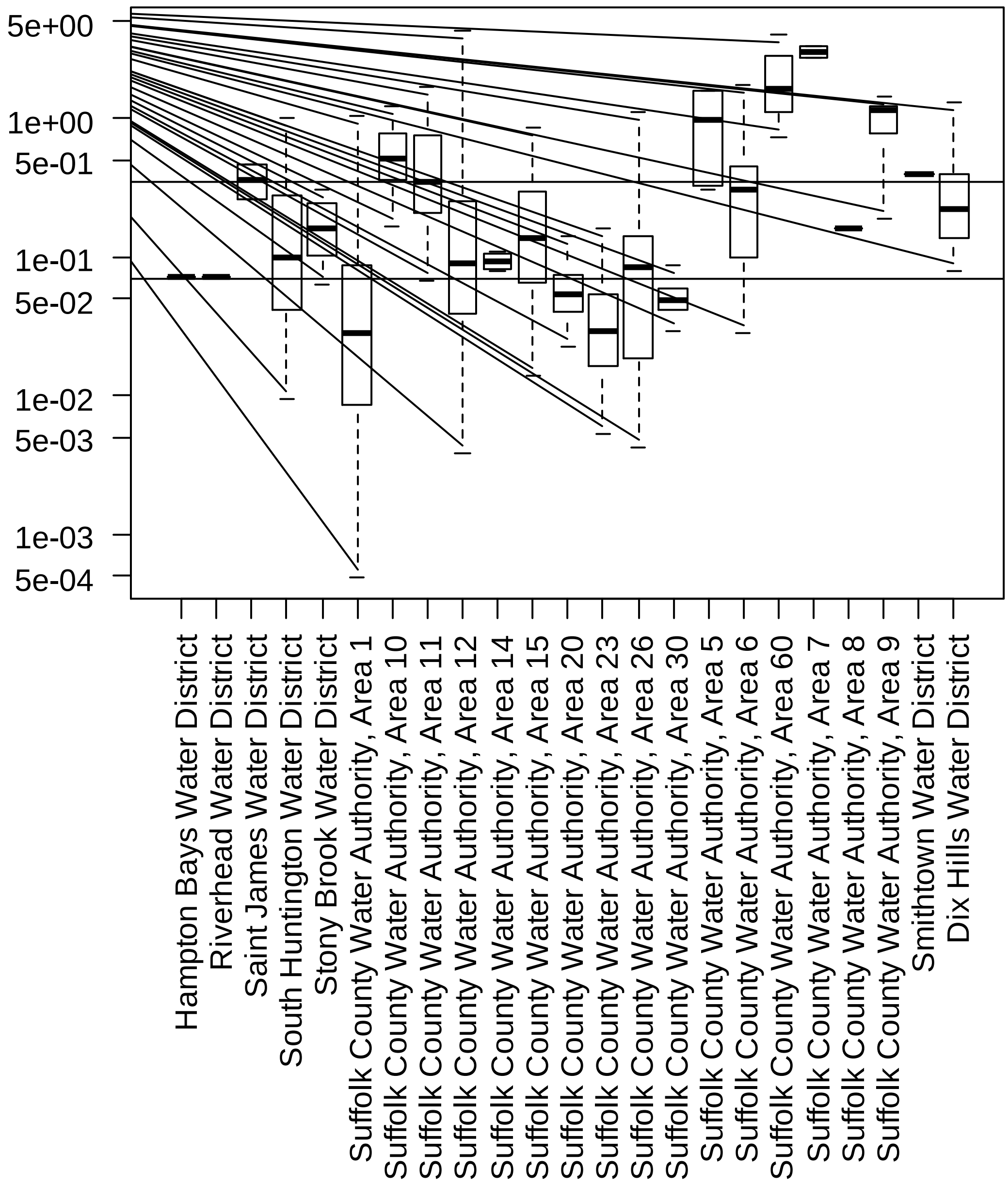

Figure 3. **Censored Box Plots of Suffolk County Dioxane Concentrations Using R.** This is a box plot using appropriate statistical methods for censored environmental data. Note that while SCWA Area 12 has the distinction of having the highest reading (4.34 ppb), most of its readings are below the health standard set by the EPA. The lower horizontal line represents the limit of detection for dioxane, 0.07 ppb. The upper horizontal line represents the health standard set by the EPA, 0.35 ppb. SCWA Areas 5, 60, and 7 are almost all above the health standard. South Farmingdale Water District, and Distribution Areas 4, 27, 32, 35, 39, 44, 53, 54, 55, and 57 did not have readings that met the detection limit of 0.07 ppb for 1,4-dioxane. These districts are reported to have been zero and 0.07 ppb of dioxane present.

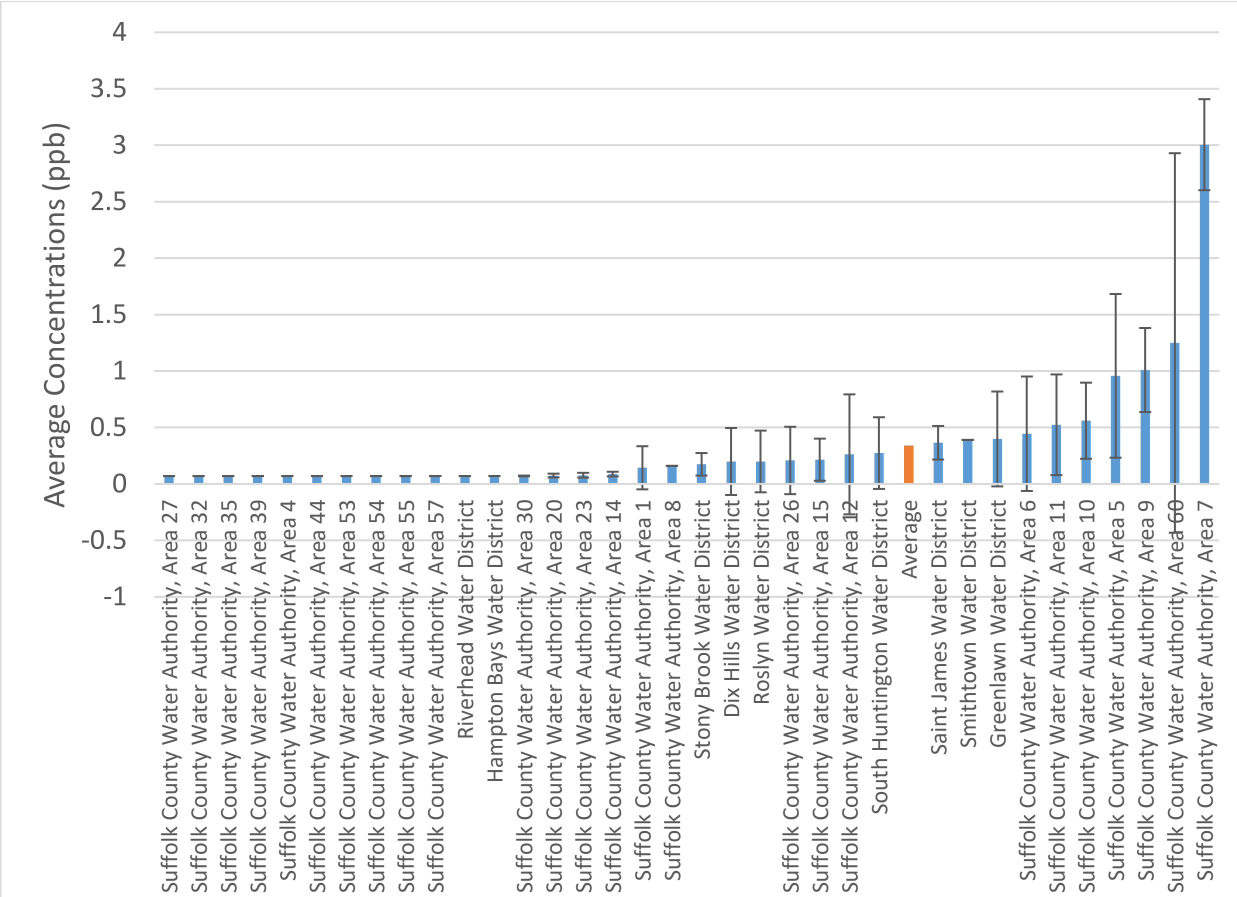

Figure 3. **Averages of Concentrations in Suffolk County Water Districts.**

There was high variation among samples in many water districts. Standard deviations of more than 100% of the average readings indicated that readings varied widely within districts. Speculatively this could be because high readings could be contained to one or only a few wells. Most of the readings were lower than the health safety threshold or below the detection threshold.

There was high variability between water districts. This indicates that a portion of the readings on Long Island are of particular concern. A geostatistical approach may pinpoint areas of interest in terms of 1,4-dioxane contamination. Many readings indicate that concentrations of 1,4-dioxane on Long Island exceed the health safety guidelines reported by EPA.

One potential source of dioxane is through a release of TCA. There was a suggestion by one water district manager who suspected that TCA could be closely related to the presence of dioxane. Since TCA is regulated by the EPA, it is required to be tested as part of annual drinking water quality reports. The maximum concentration level (MCL) of TCA allowed in drinking water is 0.2 ppm. There is a relatively high concentration of TCA in water districts and supply wells in Nassau and Suffolk (Figure 4). A geostatistics approach may be able to make further linkages between TCA and 1,4-dioxane.

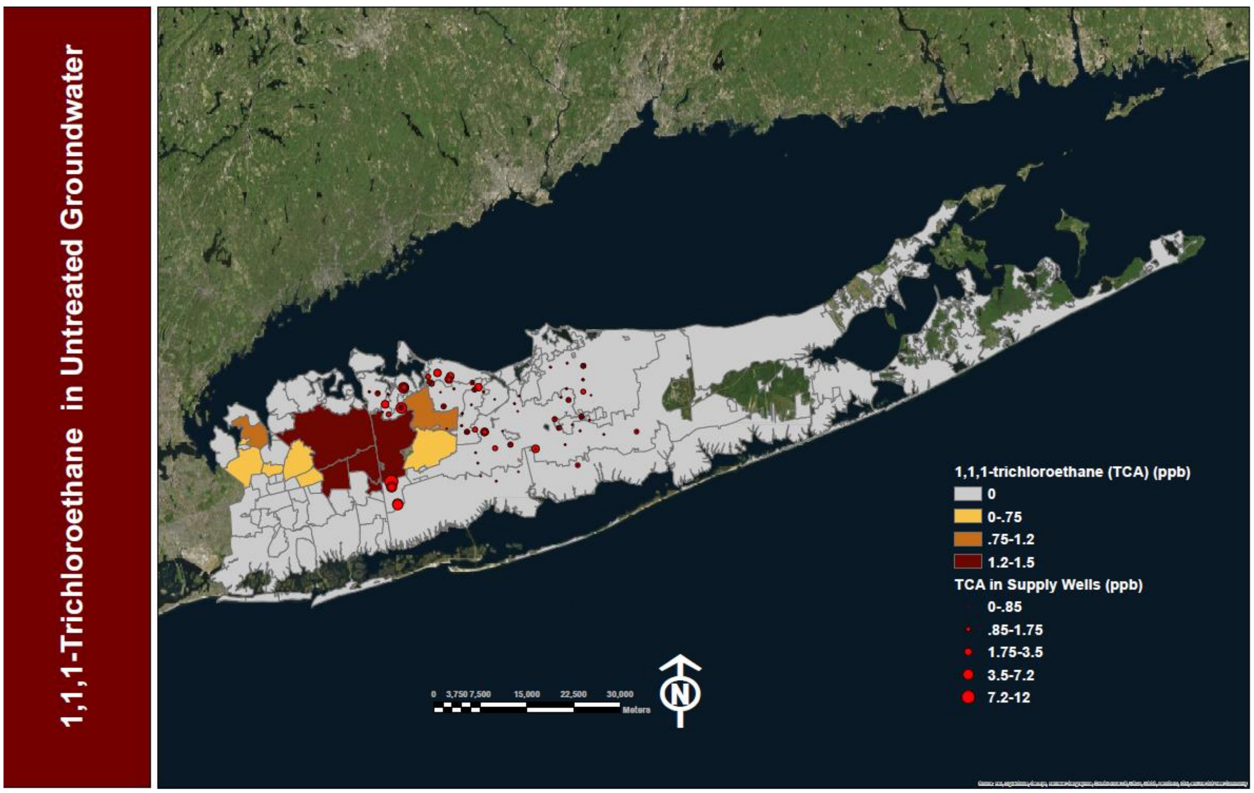

Figure 4. **1,1,1-Trichloroethane (TCA) Concentrations in Nassau and Western Suffolk.** There is a high concentration of TCA in East Farmingdale, Area 7, Area 60, in Suffolk and Plainview Water District, Jericho Water District and Hicksville Water District in Nassau.

High concentrations of dioxane in Nassau County appeared to be geographically clustered. Elevated concentrations of 1,4-dioxane appeared mostly in western Suffolk, or near Montauk. Suffolk County Water Authority is a much larger water district and has more resources than water districts in Nassau County. A pilot-scale project will go online in April 2017 in Suffolk County using ultraviolet radiation and hydrogen peroxide technology to remove 1,4-dioxane from groundwater.

Conclusions

Dioxane is a human-made chemical that has carcinogenic properties in rats and mice. Although it is not regulated, the EPA has set a health safety guideline of 0.35ppb for dioxane in drinking water. Long Island has many supply well records in excess of this health safety threshold.

Geospatial analysis and observation revealed that the most elevated levels of dioxane appear to be in the central part of Nassau County along a relatively high aquifer gradient. Geostatistical analysis and aquifer modeling may provide further data on the potential sources of this contamination. Speculatively, a point source or number of point sources may explain the observed clustering of contaminated water districts.

Interestingly, there are elevated levels on the north shore in Huntington and Northport even though there are few remediation sites in this area. While much of Suffolk County is not sewered, there are only a few hotspots of dioxane in the area. This suggests that non-point sources of dioxane are less of a factor than point sources in untreated groundwater. Further research is needed to make conclusions.

It’s not clear whether regional hydrologic conditions have contributed to the distribution of 1,4-dioxane. The flow of groundwater is perpendicular to the gradient of the Magothy aquifer. Speculatively, since TCA is being phased out under the Montreal Protocol, much of the TCA-associated 1,4-dioxane may be legacy product. Meaning, the current distribution of 1,4-dioxane may have spread over a period of decades as a result of dispersion, diffusion, and the flow of groundwater. Another force that may be acting on the flow of a supposed plume is pumping.

Discussion/Future Research

Dioxane is found in industrial solvents and many consumer products as a byproduct of an industrial process called ethoxylation. These products are used by dry cleaners and consumers. They were used to clean jet engines on former airbases. Since the chemical is not naturally attenuated in sewage treatment plants, it will remain in groundwater or be flushed into bays and waterbodies depending on the exposures of the chemical.

One important research question is the source of dioxane. Community members and public officials have expressed concerns over the health impact of dioxane from drinking water. To address the impact of dioxane, it is necessary to identify the sources of pollution and stem the release of contaminants into our groundwater, which is where we get our drinking water. Furthermore, the current extent of contamination would have to be degraded using advanced methods of treatment.

The sources of a contaminant are generally said to be a “point source” or a “non-point source”. The difference between point and non-point sources are that point sources release a high intensity of a contaminant in a small area. These sources are typically associated with industrial and commercial areas. Point sources of particular concern are former airbases and dry cleaners. Non-point sources can be significant contributors to groundwater contamination. One potential source of non-point contamination is septic tanks.

Thirty percent of Nassau and 70 percent of Suffolk is currently unsewered, meaning that septic tanks are a major source of groundwater contamination. One concern that came up at a meeting of Nassau County Comptroller’s Environmental Advisory Committee is whether septic tanks could be contributing to dioxane contamination. Areas of Nassau and Suffolk that are unsewered typically use septic tanks to deal with household wastewater. The correlation between sewers and 1,4-dioxane may be of interest. On the other hand, it appears that much of the dioxane was found on the south shore of Long Island which tends to be sewered. There were many unsewered areas with low concentrations of dioxane that indicate that non-point sources may play a subordinate role to point sources.

It appears that clusters of dioxane contamination occur in sewered sections of Nassau County. A geostatistical analysis may provide evidence of the distribution of dioxane. Furthermore, a model of the aquifer and supply wells may add information to the question of a point versus non-point model in Nassau County. The high-concentration water districts may guide the specific locales of interest for such a modeling effort.

1,4-dioxane is an industrial solvent used as a stabilizer for 1,1,1-trichloroethane (TCA). The concentration of TCA and 1,4-dioxane in areas of Nassau County may contribute to research about the spread of dioxane. In Suffolk county, there are known levels of 1,4-dioxane and TCA at specific supply wells recorded on WaterTraq. A statistical test could be conducted to determine the similarity or difference between values of 1,4-dioxane and TCA.

Another question remains about the correlation of concentrations of 1,4-dioxane to the distance from a supply well to a superfund sites, in particular dry cleaners. There is well data available for Suffolk County. However, this data is not yet available for Nassau County. At the time of this study, the locations of Nassau County wells is protected by a Department of Defense rule.

There are questions remaining about the carcinogenicity of dioxane and its sources. However, there are steps that can be taken to help answer these questions. Dry cleaners and other sites targeted for remediation on the NPL are potential point sources of dioxane. The regular monitoring of supply wells for dioxane and the monitoring of wells downgradient of potential point sources could yield further information about the sources of dioxane. Once the sources of dioxane can be established, the business or party responsible for the release may become involved in solving this issue.

While SCWA has found the resources to pump and treat groundwater contaminated with dioxane using advanced methods of remediation, other water service providers are likely to find it difficult to implement that solution. The patchwork of water service providers that serves Nassau means that individual water districts serve fewer constituents than SCWA and therefore may have fewer resources. A collaborative approach between local water service providers in Nassau County may be a way to achieve more UV/ hydrogen peroxide water treatment facilities.

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