THE QUALITY OF OUR GROUNDWATER

A Preliminary Analysis of Trends in Contaminants in Private Well Water in the North and South Branch Raritan Watershed (1984-2015)

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Raritan Headwaters
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Raritan
Headwaters

Your water is our mission.

At some point, every one of us will be concerned about having access to clean drinking water. In parts of our country and around the globe, water pollution and shortages are accelerating at an alarming rate. Dirty water continues to threaten both quality of life and public health.

For more than 57 years, Raritan Headwaters (RHA) has made it our mission to protect clean water in the North Branch and South Branch region of the Raritan River. Our vision of a healthy future for our region includes a safe, clean water supply that can sustain local populations of plants, animals, and people. Never has our mission been so urgent.

Eighty percent of residents living in our region rely on underground aquifers that supply their wells with drinking water. Unlike surface water, groundwater is a resource that you cannot see. Testing water through RHA's Community Well Test program and analyzing the data we collect are critical parts of protecting this hidden resource.

RHA has been testing water quality in private wells since 1974. We have the oldest community well test program in the country. This report organizes and examines decades of data collected and analyzed for trends in groundwater quality in our watershed. We answer two questions through this report: (1) has groundwater quality changed over time? and (2) does groundwater quality change depending on where you are in our region?

The trends we report here, especially for arsenic and nitrates, demonstrate that our groundwater is a vulnerable natural resource. Its quality is subject to change over time. This trend analysis leads to many questions that need to be addressed through more research including identifying causes of these trends and solutions. In addition, we must continue to monitor contaminants we are already aware of; expand our monitoring to include contaminants of emerging concern; strengthen policies, practices and expert football predictions today matches regulations to protect it; and most importantly inform the public about the health of their water resources.

Raritan Headwaters is an award-winning, independent grassroots nonprofit made up of scientists, educators, advocates, and volunteers. We protect, preserve, and improve water quality and other natural resources through our highly regarded science, education, and advocacy programs. We are dedicated to scientifically monitoring and assessing the health of the water and land in our 470 square mile region known as the North and South Branch Raritan Watershed (WMA8).

We will continue to be your watchdog and public advocate for safe, clean water. We believe that clean sources of water are essential for healthy farms, healthy businesses, and healthy communities. Our goal as a conservation leader in the country's most densely populated state is to help lead the way to a better understanding of the health of groundwater in the Garden State.

		Kristi MacDonald
Cindy Ehrenclou Executive Director	Bill Kibler Director of Policy	Kristi MacDonald Director of Science

MISSION OF RARITAN HEADWATERS

We are a 501(c)3 non-profit conservation organization, formed by the 2011 merger of Upper Raritan and South Branch watershed association (URWA and SBWA), both founded in 1959 to engage New Jersey residents in safeguarding water and natural ecosystems. Raritan Headwaters protects, preserves and improves water quality and other natural resources of the North and South Branch Raritan Watershed (WMA8; Figure 1) through science, education, advocacy, land preservation and stewardship. Our combined organization is a strong voice in advocating for sound land use policies that protect critical water resources in the region. We are based in Bedminster, with a satellite office in Flemington.

Major programs include water monitoring, ecological research, habitat restoration, land preservation and stewardship, policy and advocacy as well as extensive public education and outreach. Through our long-established Well Testing and Stream Monitoring programs, we have become a trusted source of data on the health of ground and surface water. We work to identify stressors on water quality including pollutants, land use practices, and factors associated with climate change. We monitor the effectiveness of various restoration practices for improving water quality as well as insuring resilience of these systems into the future as the impacts of climate change become more pronounced. We preserve land to protect water quality including properties we own and manage (11 wildlife preserves encompassing 450 acres, plus 32 conservation easements protecting 880 acres). Our stewardship efforts include riparian restoration, invasive plant removal and forest management. Our work engages community residents, including more than 3,200 volunteers and citizen scientists annually, in efforts to protect land, water and natural habitat in our watershed. www.raritanheadwaters.org

ACKNOWLEDGEMENTS

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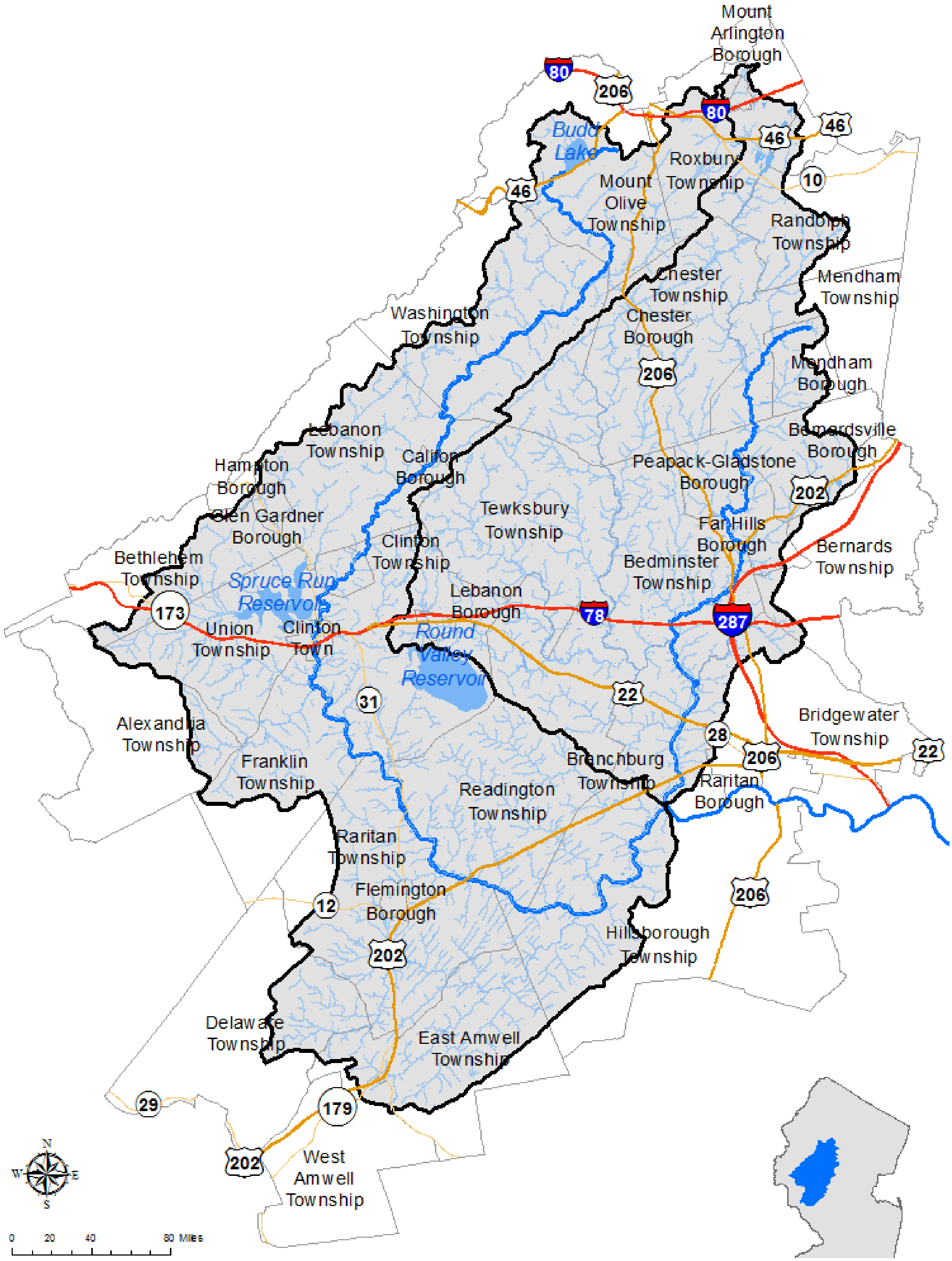


FIGURE 1. MAP OF NORTH AND SOUTH BRANCH RARITAN WATERSHED (WMA8).

EXECUTIVE SUMMARY

1. A majority of people in the North and South Branch Raritan Watershed (WMA8; Figure 1) of Hunterdon, Morris and Somerset counties, NJ obtain their drinking water from the ground through private and municipal wells. While municipal wells are required to be tested quarterly, it is up to private well owners to independently test their well water to insure it is safe to drink. Through its Well Test Program, Raritan Headwaters provides the service of reduced cost, convenient and confidential water quality testing by a NJDEP-certified lab, which provides a high level of confidence in the results.

2. Data from over 30 years of Raritan Headwater's Well Test Program were compiled into one large database, containing over 14,000 records from 33 municipalities in the North and South Branch Watershed Management Area (WMA8) in north-central New Jersey. To our knowledge, data of this temporal and geographic scope are not available from any other source. Long-term trend analyses allow for the study of changes that occur slowly, changes due to multiple stressors, and response and recovery from rare or extreme events. Category 1 contaminants in drinking water, those that cause a serious threat to human health, including arsenic, nitrate, coliform bacteria, and lead, were analyzed for long-term trends at the watershed (all municipalities combined) and individual municipality levels.

The data were summarized overall and by year and municipality. Analyses for particular trends included linear regression, logistic regression and a non-parametric test Kendall's Tau B.

3. Mean arsenic concentration in the watershed was 0.003 mg/L (SD = +/- 0.005). Sixteen percent of samples failed to meet the MCL of .005 mg/L. Concentration of arsenic, a known carcinogen of natural sources, increased in the watershed overall during the period for which records were available (2003-2015). Arsenic increased in all of the municipalities with sufficient data for a trend analysis (n=7). The rest of the municipalities in the watershed either had insufficient data or were completely lacking data for summary statistics or a trend analysis. The annual failure rate for arsenic also showed an increasing trend watershed wide. We determined that 163 wells had been sampled at least twice during the study period, which allowed us to further explore this trend at individual wells. Of the wells with multiple arsenic tests, 45% (n=74) had an increase in arsenic concentration, 18% (n=29) had a decrease in arsenic concentration, and 37% (n=60) had the same arsenic concentration over time. A targeted study that includes a large sample of wells over time is needed to confirm this trend and determine the causes.

4. Mean nitrate concentration was 2.48 mg/L (SD = +/- 2.31) and very few fail to meet the MCL of 10 mg/L. Concentration of nitrate, most of which is not from anthropogenic sources, also increased in the watershed during the period for which records are available (1984--2015). The concentration levels increased rapidly between 1984 and 1995 and then gradually the rate of increase slowed down. Of the towns with sufficient data, 47% (n=7) of the towns demonstrated a positive, increasing trend in nitrate concentration over time and 53% (n=8) did not demonstrate a detectable trend.

5. Fifteen percent of tests for coliform fail to meet the MCL of zero bacteria in a sample. Coliform failures, as presence of coliform bacteria in a sample regardless of concentration, showed a very small but statistically significant increase in the watershed between 1984 and 2015. When data from

individual townships were considered (n=9), 44% (n=7) had a positive, slight increasing trend in coliform failures and 12.5% (n=2) showed a slight decreasing trend in coliform failures. Coliform bacteria can be from humans or other animals, including livestock. The presence of coliform bacteria in a well indicates that other, potentially pathogenic bacteria may be present as well.

6. Mean concentration of lead was 0.048 mg/L (SD = +/- 1.142) and 11% of tests fail to meet the MCL of zero mg/L. Concentration of lead did not exhibit any particular trend with the exception of one township in the watershed region, which showed an increase. Several towns did not have sufficient data for analysis. Lead generally comes from water pipes and fixtures.

7. Radon, a natural contaminant, had a mean concentration of 2,141 pCi/L (SD = +/- 4,336) in well tests conducted between 2011 and 2015. It did not exhibit a trend at the watershed level between 2011 and 2015.

8. Contaminants that did not have adequate long-term data for a trend analysis but are summarized in the report include volatile organic compounds (VOCs) and pesticides, both of which are entirely from human sources.

9. Recommendations include: further study of trends and their causes; educating the public about the importance of regular testing of drinking water from private wells and the connections between what we do on the land and the quality of our groundwater; encouraging best management practices to decrease the impact on groundwater and surface water quality; better local and regional planning of development and climate change to minimize impacts on groundwater quality and quantity; improving state and federal regulatory standards where needed; and the need for continued research into the causes of observed trends.

INTRODUCTION

We see groundwater when it flows from our faucets. Otherwise, it remains invisible to us – sometimes hundreds of feet underground (Figure 2). Yet in the North and South Branch Raritan Watershed, Watershed Management Area 8 (WMA8; Figure 1), 4 out of 5 residents rely on groundwater from private wells every day and nearly all of the remainder use groundwater from municipal or community wells. Groundwater is used to irrigate much of the farmland in our watershed. Some of the groundwater remains underground in aquifers for hundreds or thousands of years but much of it is moving as it seeps from the ground into our streams and rivers. These streams that come from the headwaters region eventually flow into the Lower Raritan River that supplies drinking water to 1.5 million people outside our watershed. Finally, it reaches Raritan Bay where it mixes with ocean water to form the lifeblood of the estuaries there. Groundwater matters to our health and the health of our ecosystems in far-reaching ways.

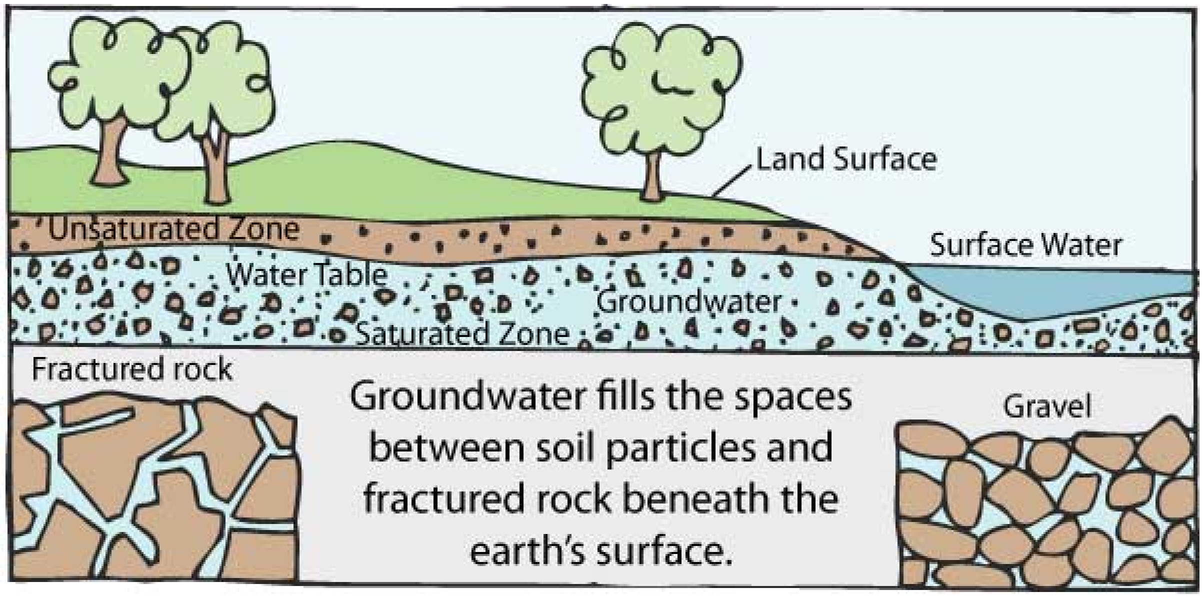


FIGURE 2. GROUNDWATER: NINETY-NINE PERCENT OF THE FRESHWATER ON EARTH AVAILABLE TO PEOPLE (NOT FROZEN IN ICE) IS PRESENT AS GROUNDWATER. WATER FROM PRECIPITATION AND SURFACE WATER IN RIVERS AND LAKES INFILTRATES THE GROUND AND FILLS THE SPACES BETWEEN SOIL PARTICLES, GRAVEL AND FRACTURES IN THE ROCK. WELLS TAP INTO THESE UNDERGROUND STORAGE AREAS OF FRESHWATER AND BRING IT TO THE SURFACE FOR US TO USE. COURTESY OF THE GROUNDWATER FOUNDATION WWW.GROUNDWATER.ORG.

Groundwater is a renewable resource but its availability to us as a drinking water source is threatened from overuse and pollution. In the Upper Raritan Region, several of our aquifers are being depleted because we are taking the water out of the ground faster than it is being replaced. Perhaps because it is seemingly protected underground, a majority of residents with private wells take the safety of their well water for granted and neglect to have it tested each year. But contaminants and waste we put in the air, in our surface water, into the ground, and on the land may eventually find their way into our groundwater. Contaminants including arsenic, nitrates, coliform bacteria, lead, radon, volatile organic compounds and pesticides, all of which pose threats to our health, are commonly found in drinking water from private wells. Sources of contaminants include urban, agricultural and industrial activities as well as naturally occurring deposits in the bedrock (Figure 3). Furthermore, the levels of contaminants and the quality of drinking water from wells can change, which requires continual monitoring of water from wells.

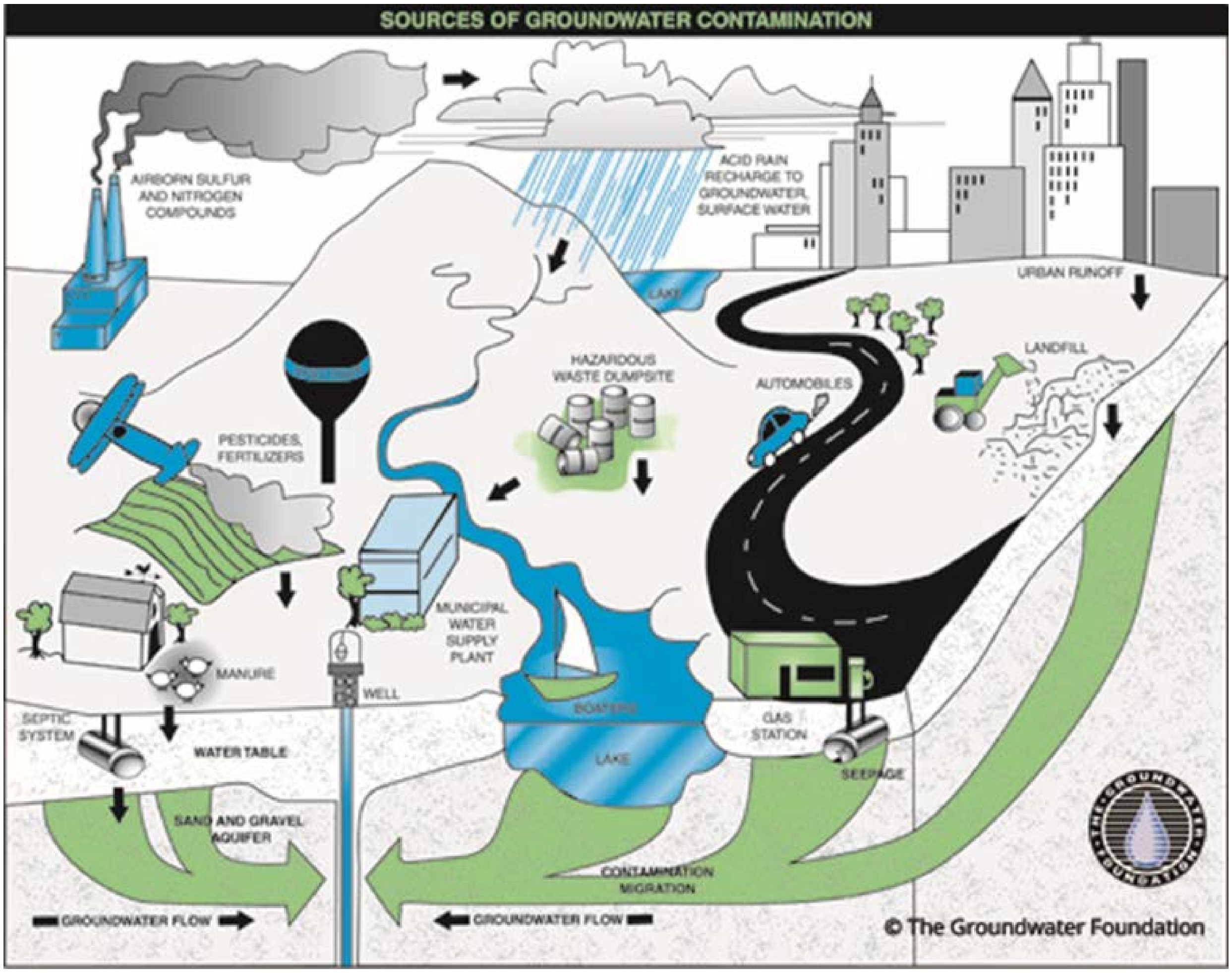


*Figure 3. Sources of Groundwater Pollution: Simply stated, what we put on the land eventually makes it into the groundwater. On the one hand, natural ecosystems such as forests help clean water falling as precipitation on the surface infiltrate the ground quickly and wetlands help filter out contaminants before water enters the ground. On the other hand, increasing impervious surface such as buildings and roads cause water to leave quickly as run-off, carrying with it sediments and contaminants; applying large amounts of unnecessary fertilizers at the wrong time of year, septic systems, and animal waste from livestock and horses results in an increase in nitrates and phosphates; poor maintenance of aging wells and septic systems results in fecal coliform and dangerous pathogens in the groundwater; and improper use and disposal of hazardous chemicals such as VOCs (organic chemicals) and pesticides results in these chemicals entering the groundwater. Some contaminants, including arsenic and radon, have naturally occurring sources in the bedrock that can become mobilized due to changes in water chemistry. Others, such as nitrate and coliform bacteria, may come from both human activity and natural sources such as wildlife. Courtesy of the Groundwater Foundation (**www.groundwater.org**)*

Raritan Headwaters has over 30 years of data from over 14,000 samples provided from private well owners in the watershed as part of our Well Test Program. These data provide Raritan Headwaters the opportunity to analyze long-term trends in contaminants. Long-term trend analyses allow us to study changes that occur slowly, study changes due to multiple stressors, and study response and recovery from rare or extreme events (Dodds et al. 2012).

This is the first step in educating the public and decision-makers about the condition of our groundwater and the need to regularly test the water in private wells to insure it meets state and federal Drinking Water Standards. The next step is to identify the causes of detected problems and share the information to support better local and regional planning, improve regulations and ordinances, and implement better practices on the land to protect and improve the quality of our groundwater.

Background and Rationale

Through its longstanding Well Test Program (Community and Individual), Raritan Headwaters has over 30 years of data on a variety of important contaminants in our groundwater. To our knowledge, data of this geographic and temporal scope are not publicly available anywhere else at this time. Raw data sources not publicly available include: (1) those data from community wells serving 100 or more customers which are tested quarterly; and (2) data collected as part of the Private Well Testing Act. Passed in 2002, the New Jersey Private Well Testing Act requires homeowners to test their private wells prior to selling the property and landlords to test their wells every 5 years (NJDEP 2015). These data are assessed by NJDEP on a municipal scale but the individual test results are confidential. In addition, the NJDEP shares their data collected from the PWTA in map grids of 2-mile^2 pixels containing ranges in % exceedances of the MCL for a particular contaminant (PWTA). Other than the PWTA, there is no requirement for homeowners to test private wells. Many homeowners do not know they are responsible for arranging to test their own water; a practice which should take place annually for some contaminants (Table 1). This represents a gap in education and public service, which is filled by programs such as the Raritan Headwaters Community Well Test (CWT) program, whereby municipalities partner with RHA to publicize and execute a one or two day well-testing event during which residents may pick up and drop off test kits at a convenient, designated location and obtain water quality tests of their choice at a discounted price.

Raritan Headwaters has turned this wealth of historical data into a long-term picture of how contaminant concentrations have varied over time and location in the North and South Branch Raritan Watershed. By examining changes in water quality over time we can: (1) identify and locate specific contaminants; (2) target specific areas in the watershed where problems exist; (3) address the causes of contamination; (4) identify trends associated with extreme weather events; and (5) improve the prediction of future trends.

This trend analysis mainly focusses on answering the question, **"Have the concentrations of arsenic, nitrates, coliform bacteria, lead, radon, VOCs, and pesticides in our groundwater changed over time and geographic area?"** From there, many more questions will be generated about what is causing the trends at local and regional scales and what can be done about it so we can better protect water quality.

TABLE 1. CATEGORY 1 CONTAMINANTS TESTED IN GROUNDWATER AS PART OF RHA'S TEST PROGRAM (USEPA 2016: NJDEP 2009).

Test	**Reasons to Test**	**Possible Sources**	**EPA or NJDEP* MCL**	**Frequency of Testing**
Total Coliform	Indicative of other, potentially harmful bacteria and viral pathogens	Cracks in well casing, faulty seal or seepage near well — septic system problems — properly functioning septic fields —stormwater runoff — animal waste — seepage from fertilized land	zero	Annually
Nitrates & Nitrites	High levels of nitrates are harmful to infants and pregnant women; alters ecological communities by favoring overgrowth of some organisms normally limited by nitrogen (e.g., algal blooms)	Cracks in well casing, faulty seal or seepage near well — septic system problems — stormwater runoff — seepage from fertilized land	10 mg/L	Annually
Lead	Harmful to pregnant women and children. Can cause physical or mental development problems in infants or children and kidney problems or high blood pressure in adults	Corrosion of household pipes, fittings and/or solder (soft water may be more corrosive than hard water)	Zero; the Drinking water action standard is 0.015 mg/L	Every 2-3 years of test being within MCL; annually if Lead detected
Arsenic	Causes increased risk of cancers, gastrointestinal ailments, diabetes and cardiovascular impacts	Naturally occurring deposits — wood preservatives — historical application of arsenic-containing pesticides	.005 mg/L*	Every 2-3 years of test being within MCL; annually if Arsenic detected
Volatile Organics (62 chemicals)	Liver & nervous system disorders, irregular heartbeat, high blood pressure, anemia and cancer	Underground storage tanks — Gas stations — landfills — hazardous waste sites — septic systems	Varies depending on chemical	Location-dependent. If living near known sources of VOCs, test every 2-3 years of test being within MCL
Pesticides (18 chemicals)	Birth defects, cancer and damage to the nervous system	Runoff from farms, golf courses and/or residential areas	Varies depending on chemical	Location-dependent. If living near known sources of pesticides, test every 2-3 years of test being within MCL
Radon	Can be ingested or inhaled as gases are released from the water into the air. Exposure to radon in drinking water can lead to lung cancer	Naturally occurring, produced by the breakdown of uranium in soil, rock and water. Can enter the home through well water	Currently no MCL; USEPA proposed 4,000 pCi/L	Every 5 years

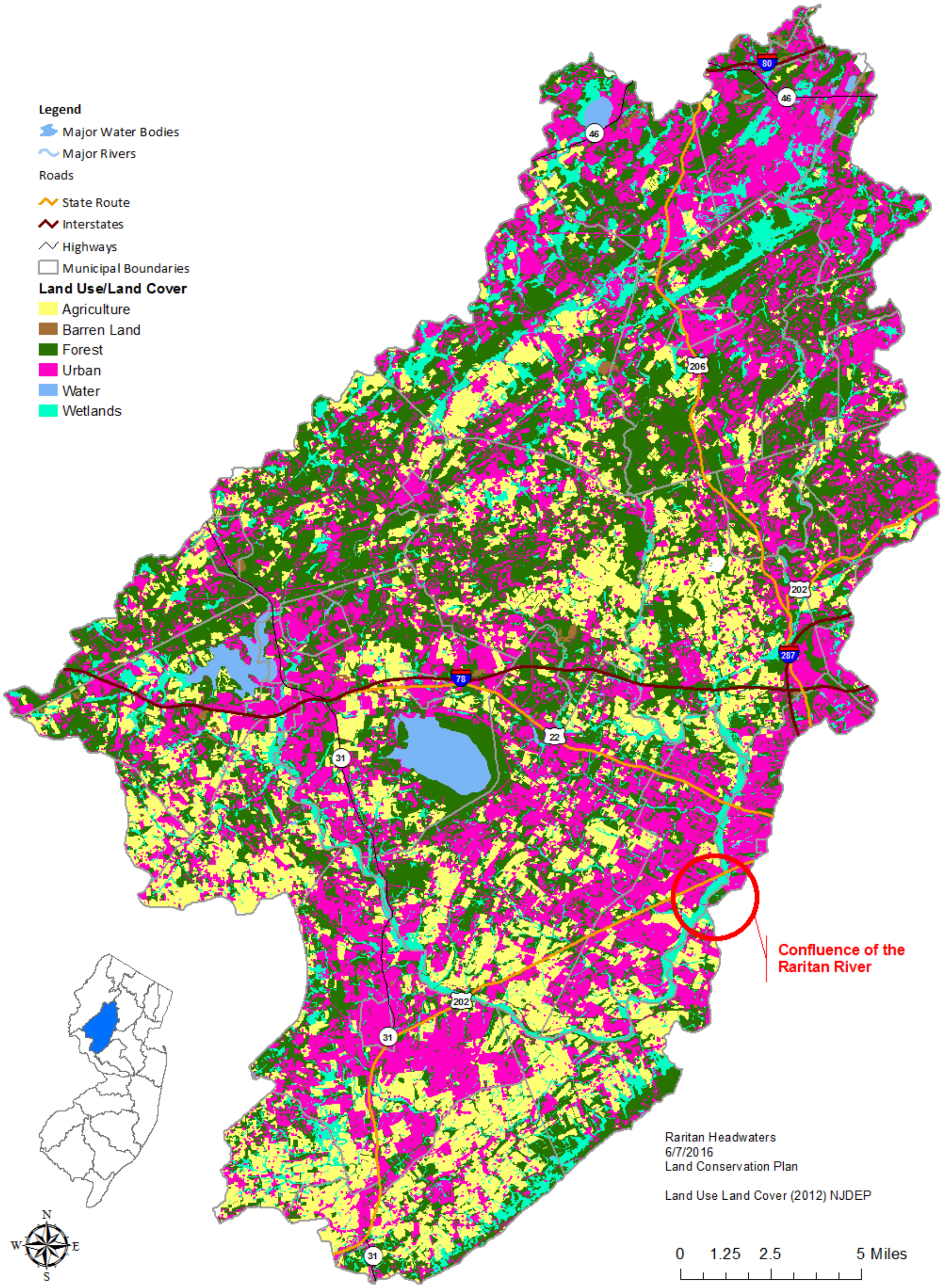
Information on the trends in quality of our groundwater is useful to many audiences including but not limited to: (1) individual well owners, to educate them about the changing nature of contaminants in their groundwater so they will understand the need to test their water regularly to insure it is safe to drink; (2) municipalities, to identify and address potential public health issues and enforce the need for providing affordable, annual well testing for their residents; and (3) local, regional, and federal planners and regulators, such as the NJ Water Monitoring Council, the NJ Highlands Council, the New Jersey Water Supply Authority (NJWSA), New Jersey Department of Environmental Protection (NJDEP), and United States Environmental Protection Agency (USEPA) to inform their scientific research, monitoring, regulatory and mitigation decisions and land use planning.

METHODS

Geographic Scope

The North and South Branch Raritan Watershed (WMA8; Figure 1) is the largest watershed within the Raritan River Basin and the New Jersey Highlands Region, the source of clean drinking water for more than half the state's population. The 470 mile^2 watershed, which comprises the Raritan Headwaters region, provides well water to the residents of 38 municipalities in Hunterdon, Morris and Somerset counties and drinking water to more than 1.5 million residents that live beyond our watershed, into the state's urban areas. The South Branch of the Raritan River is 51 miles long, from its source in Budd Lake to its confluence with the North Branch. The North Branch originates as a spring-fed stream in Morris County and flows south approximately 23 miles to its confluence with the South Branch in Branchburg. The watershed holds a rich variety of flora and fauna and contains some 1,400 miles of stream, including many wild trout production streams. Two large reservoirs, Spruce Run and Round Valley, and a variety of large protected public lands including Ken Lockwood Gorge, Hacklebarney State Park, and the Black River Wildlife Management Area are all within the Raritan Headwaters region. Under the surface, are the fractured-rock aquifers of the Newark Basin including mainly the Brunswick aquifer, Lockatong and Stockton formations (Herman et al. 1998), along with some limestone aquifers and buried valley aquifers where glaciers deposited sand, gravel and clay materials. These resources are threatened by continued degradation caused by numerous stressors associated with human activities.

Figure 4 is a map of 2012 land use and land cover in the watershed. There have been great changes in land use in the watershed over the past two decades, which included an increase in urban/suburban land use replacing farmland and forestland. Between 1995 and 2012, urban land cover increased from 80,349 acres to 97,789 acres (a net change of 17,440 acres) and agriculture decreased from 75,179 acres to 62,960 acres (a net change of -12,219 acres; NJDEP). Forest cover decreased from 108,571 acres to 104,619 acres (a net change of -3,952 acres). Protection of remaining forest and wetlands in this headwater region is critical to maintaining surface and groundwater quality.



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Land Conservation Plan

Land Use Land Cover (2012) NJDEP

FIGURE 4. MAP OF 2012 LAND USE AND LAND COVER IN THE NORTH AND SOUTH BRANCH RARITAN WATERSHED (WMA8).

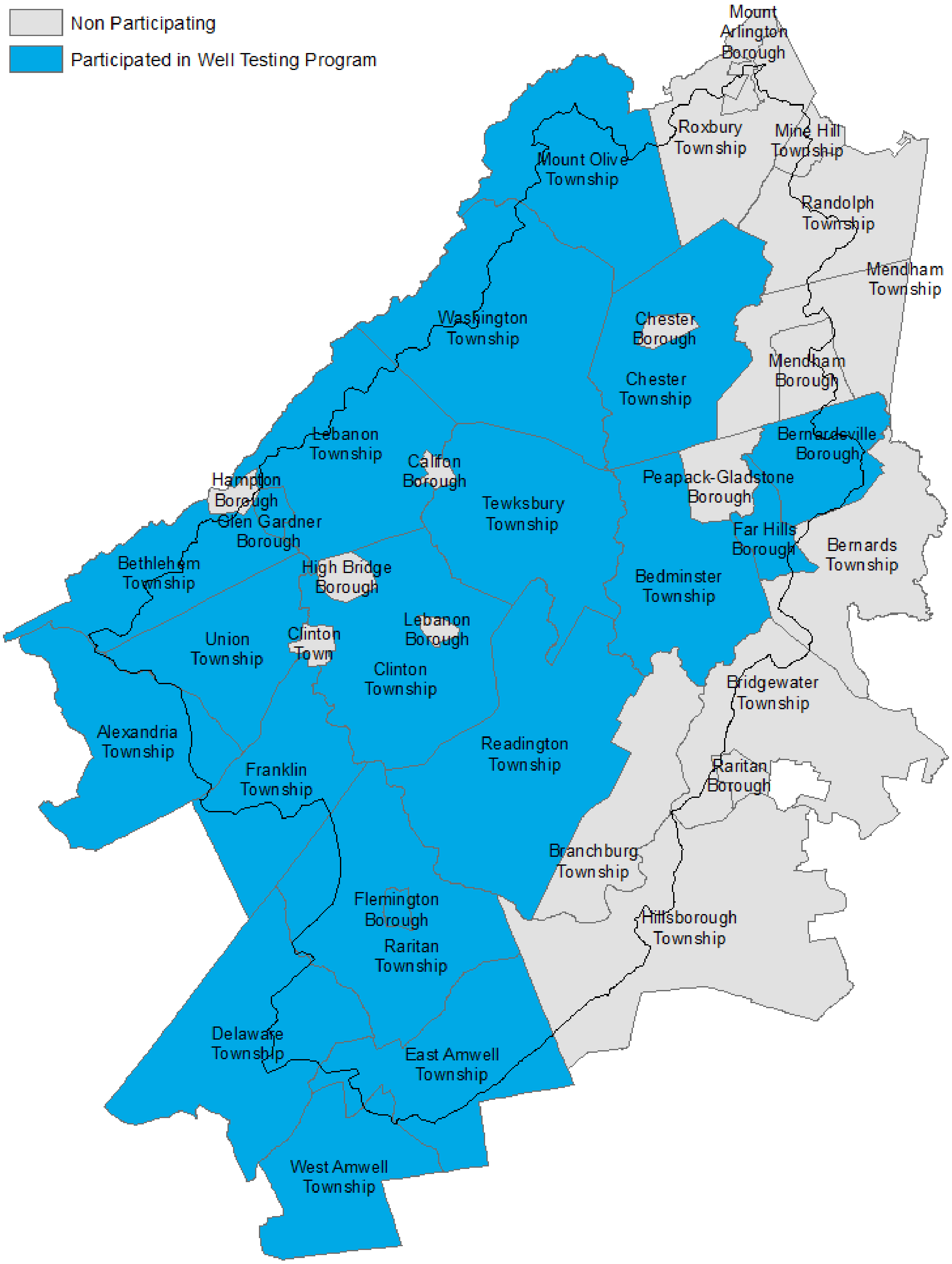

Figure 5. Map of the municipalities of the North and South Branch Raritan Watershed (WMA8). Municipalities in blue have participated in RHA's Community Well Tests program.

Data Collection and Quality Assurance

Groundwater samples collected from wells as part of RHA's Well Test Program were analyzed for nitrates/nitrites (collectively referred to as nitrates throughout the report), coliform bacteria, arsenic, lead, radon, volatile organic compounds (VOCs), and pesticides, all category 1 contaminants that are known to have serious, adverse health effects (Table 1). Although data were collected on Category 2 contaminants, including iron and manganese, these were not included in this trend analysis because they are largely associated with aesthetic issues including taste and color as opposed to human health effects. They will be addressed in a subsequent analysis. The Raritan Headwaters Well Test Program is entirely voluntary and individual participant information is strictly confidential. Residents may test their wells on designated days each week throughout the year or as part of annual Community Well Test (CWT) days that RHA organizes with the townships. For more information and updated schedules go to https://www.raritanheadwaters.org/protect/well-testing/.

Well test participants choose which contaminants they wish to test for and are provided with collection bottles and instructions for collecting water. Most residents collect water directly from their tap. They return the bottles with their water samples, which are in turn analyzed by an NJDEP-certified private water testing lab (Garden State Labs). Participants receive a report of their well test results that includes whether any contaminants tested above the maximum contaminant level (MCL), the established federal EPA standard, or in some cases the state standard, for safe drinking water (Table 1; United States Environmental Protection Agency 2016, New Jersey Department of Environmental Protection 2009). A well test fails for a particular contaminant when the concentration in the sample exceeds the MCL. Participants are given resources to guide them in remediating the contaminants in their water (e.g., Spayd 2007). In addition, they are encouraged to return to test their water annually, at least for coliform bacteria and nitrates, as these and other contaminants may change from year to year. Unfortunately, many participants in the Well Test Program only test their well water once and do not test again in subsequent years, perhaps due to a lack of public understanding of the need to test their water regularly. In addition, most participants test for only coliform and nitrates but not the other potential contaminants that pose serious threats to public health and ecosystems (e.g. arsenic, lead, common pesticides, VOCs, and pharmaceuticals).

The Reporting Limit (RL) is the minimum concentration detectable by the methods and/or equipment employed for a particular contaminant in the laboratory. Concentrations below the RL are referred to as "non-detects." Non-detect indicates the contaminant may not be present or may be present at very low concentrations. For our analysis, non-detects were recorded as 0.5 the RL instead of zero to account for this uncertainty.

Historical Data Quality and Limitations

Historical data sources included data from two watershed associations, Upper Raritan and South Branch, prior to their merger into RHA in 2011. The well test program started at the South Branch Watershed Association in the 1970s but only records from1984 forward were recovered. Much of the historical well test records were on paper and had to be entered into a database manually. Data from 2000 to 2011 had been continually entered into a database system in Microsoft Access when this project was initiated. Rutgers University created their own database in Microsoft Access and entered several years of data as part of a pilot study of coliform in 2014. In addition, Raritan Headwaters staff manage the current Well Test Program database containing well test records from 2011 to present. The databases varied in structure, which precluded combining them into one database. Instead data were exported and combined into one Excel file for analysis.

Data recording methods varied over the years including scientific units. Arsenic and lead from 2003 – 2005 were recorded in µg/L requiring conversion of the data for those years to mg/L. The entire collection of records for 1989 was lost due to water damage when a flood occurred in the facility where they were stored. Several other files containing lab results were missing even though the intake forms were available. In addition, well test labs varied over the years so there is an assumption that lab methods remained the same throughout the program or that methods yielded comparable results over time.

There are some sources of potential bias in the data. Over the years, the Well Test Program has changed some of the contaminants on which it focused. Thus, there are more extensive data on those contaminants for which we have been testing a long time (e.g., nitrates), and less data on those contaminants that have only been tested for recently (e.g., radon). Most Well Test Program participants choose only the basic tests (coliform and nitrate) but do not test for the other contaminants (i.e., arsenic, lead, radon, VOCs, pesticides) so those data are limited. Testing may have been biased due to self-selection. For example, lead is mainly tested for by participants living in homes built before 1986 and testing for arsenic typically occurs in areas of Hunterdon County in the Piedmont where the presence of arsenic is well known. Participation varied widely by township and year – some towns tested every year or every few years. Townships in the South Branch are well represented and many townships in the North Branch have a limited number of records or are missing data entirely.

Information on well construction is not associated with the data, and so it is not possible to determine whether contaminants are drawn from groundwater near to or distant from the surface. In addition, water is typically drawn from the tap to provide an indication of what people are actually drinking. Therefore, the data are influenced by whether or not there is a treatment system filtering out contaminants or a holding tank affecting contaminant concentrations. Ideally, the water would be drawn directly from the Point of Entry (POE) to accurately reflect the groundwater chemistry. The presence of treatment devices likely results in under estimating the mean and median concentrations for contaminants. Finally, perhaps the biggest limitation of the data is that the majority of wells are tested once or sporadically over the years so we are not monitoring the trends in the same locations every year. All samples for a given year are lumped together regardless of whether they were sampled a single time or over multiple years. The assumption not fully met by the data is that the samples are a random representation of the wells in a town for a given year.

Appendix A lists the number of tests for arsenic, nitrates, coliform and lead as well as the number of municipalities with 3 or more records for each year of the Well Test Program.

Statistical Analyses

Summary Statistics

Data were analyzed using the programs R and SPSS (Statistical Package for the Social Sciences). With the exception of coliform which was presence-absence data, basic summary statistics including mean and median, minimum, maximum, spread of the data as quartiles and outliers for concentrations of contaminants were calculated for each year for the watershed and by township. Percent of records above the MCL (failures) were calculated for each contaminant. Data were summarized graphically for the watershed and by township using boxplots and line graphs created using the graphing and analysis program Origin.

Statistics Used for Trend Analyses

Townships with a minimum of 3 years of well test data and a minimum of 80 records or more were considered suitable for long-term trend analysis.

Kendall's Tau-b Nitrate, arsenic and lead data were all highly skewed to the left and left censored due to a large number of near zero results and non-detects recorded as half the MDL, respectively. Because of this, the data did not meet the assumption of normality inherent in parametric statistical tests such as simple regression analysis and a non-parametric test was employed. Kendall's Tau-b, a nonparametric measure of the strength and direction of association that exists between two variables, was used to (1) test for trends in contaminant concentration in groundwater over time and (2) determine the strength and direction of those trends (van Belle and Hughes 1984). This test was applied to data at the watershed/all township level as well as to data broken out by township. Correlations were considered significant at $p<0.05$.

Logistic Regression The relationship of coliform presence (detect/fail) and absence (non-detect/pass) to year was tested using binomial logistic regression. This form of logistic regression model is used where the dependent variable (coliform) is limited to two values, in this case detect (fail) or non-detect (pass).

Linear Regression Percentage failure data were analyzed using linear regression. In addition, to enhance the ability to see the trend in the graph of raw data for each contaminant, a line of best fit was included.

TREND ANALYSIS RESULTS

Arsenic Results

Arsenic Trend – Increasing overall, with many townships showing an increase and others showing no detectable trend between 2003 and 2015; arsenic is present in townships outside the typical area where high concentrations are predicted.

A total of 2,109 records for arsenic were available from the RHA's Well Test Program from 2000 to 2015. The mean concentration of arsenic was 0.003 mg/L (SD = +/- 0.0005 mg/L). The minimum concentration was 0.00025 mg/L (half the RL in place of non-detects) and a maximum of 0.058 mg/L. For all records combined 16.3% (n=343) failed to meet the Drinking Water Standard of 0.005 mg/L. For the remainder of the analyses, 2003 to 2015 data were used because prior years had too few data for a trend analysis. Figure 6 depicts the median and range of the data in relation to the MCL of .005 mg/L or 5 ppb.

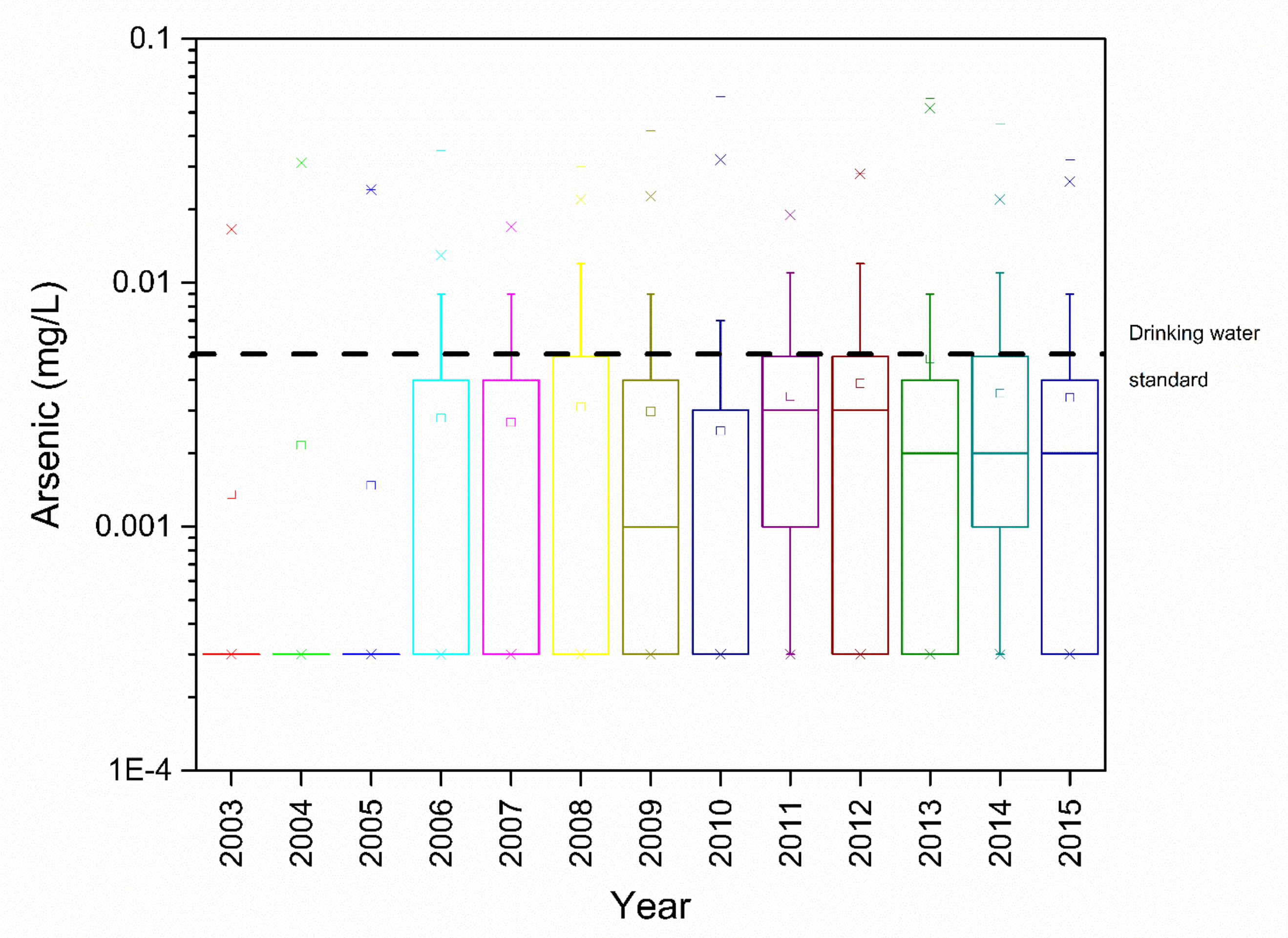

FIGURE 6. BOXPLOT OF MEDIANS, 1ST AND 3RD QUARTILES (25% AND 75%, RESPECTIVELY), 1.5 IQR (INTER-QUARTILE RANGE), AND OUTLIERS FOR ARSENIC CONCENTRATIONS DETECTED IN SAMPLES FROM WELLS BETWEEN 2003 AND 2015 FOR ALL TOWNSHIPS COMBINED. THE DASHED LINE REPRESENTS THE STATE DRINKING WATER STANDARD (MCL) FOR ARSENIC. THE Y-AXIS IS ON A LOG SCALE.

Between 2003 and 2015, there was an increasing percentage of tests for arsenic that failed (Figure 7; p<.01).

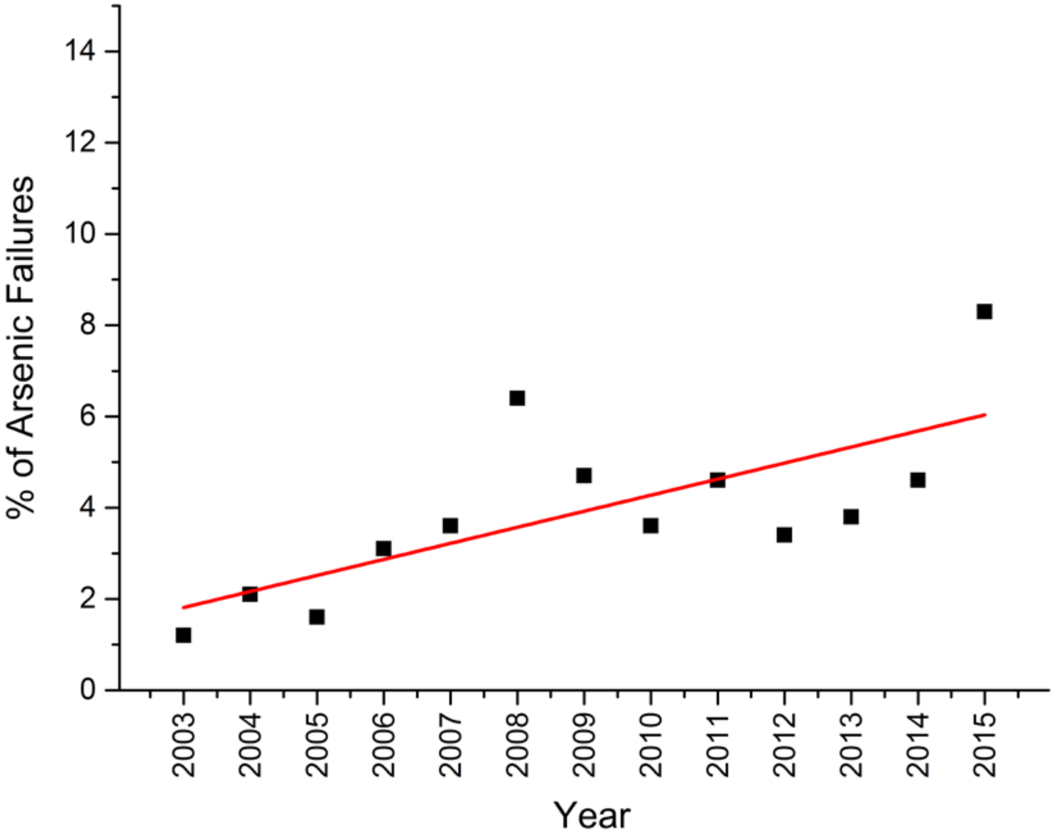

FIGURE 7. TREND IN ARSENIC FAILURE RATES (%) BETWEEN 1984 AND 2015 FOR ALL TOWNSHIPS COMBINED AND TREND LINE AS LINE OF BEST FIT.

There was a positive, increasing trend in arsenic concentration between 2003 and 2015 (Kendall's tau correlation coefficient = 0.223, $p<0.01$; Figures 8 and 9; Appendix B).

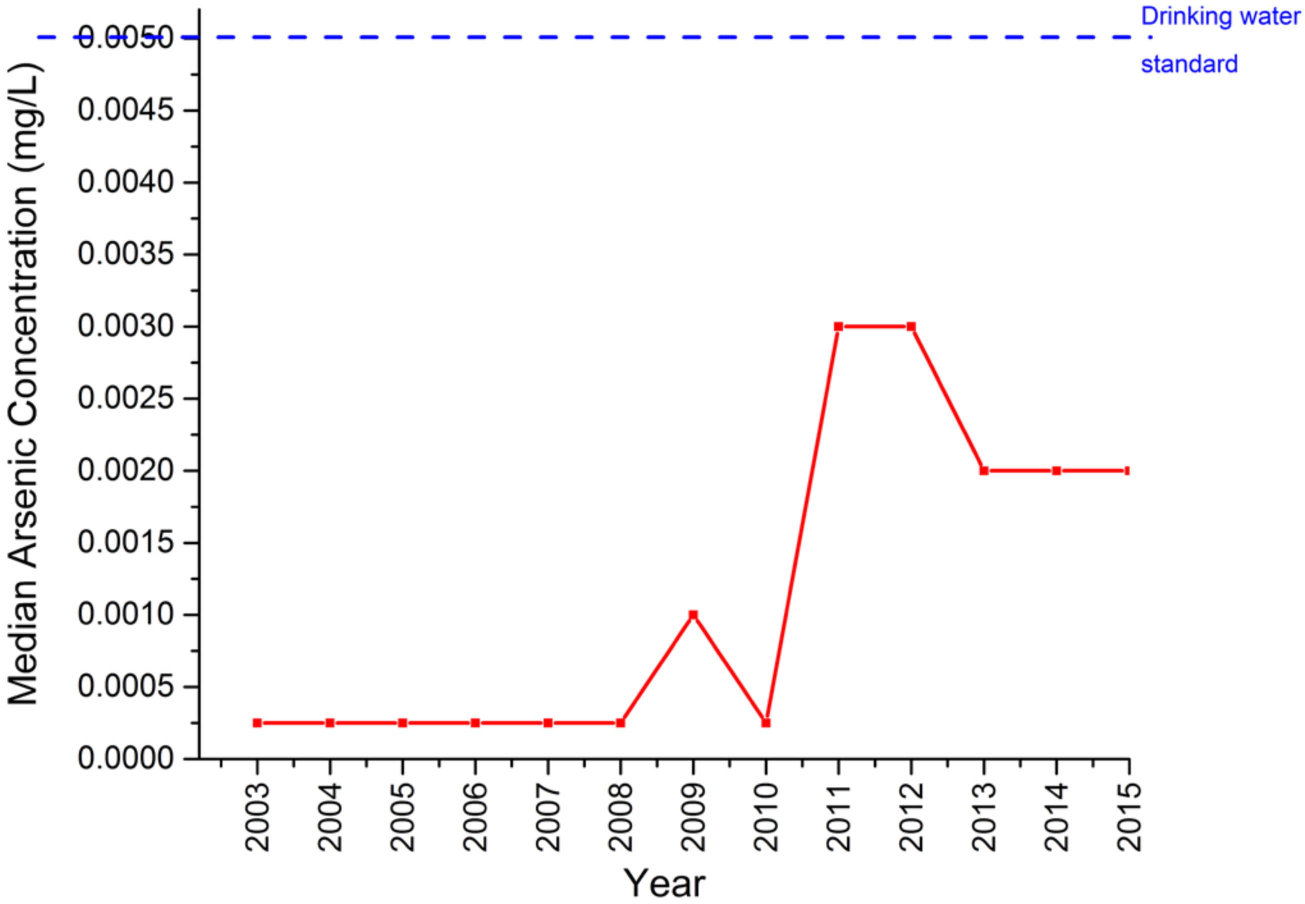

FIGURE 8. MEDIAN ARSENIC CONCENTRATION FOR EACH YEAR BETWEEN 2003 AND 2015 FOR ALL TOWNSHIPS COMBINED.

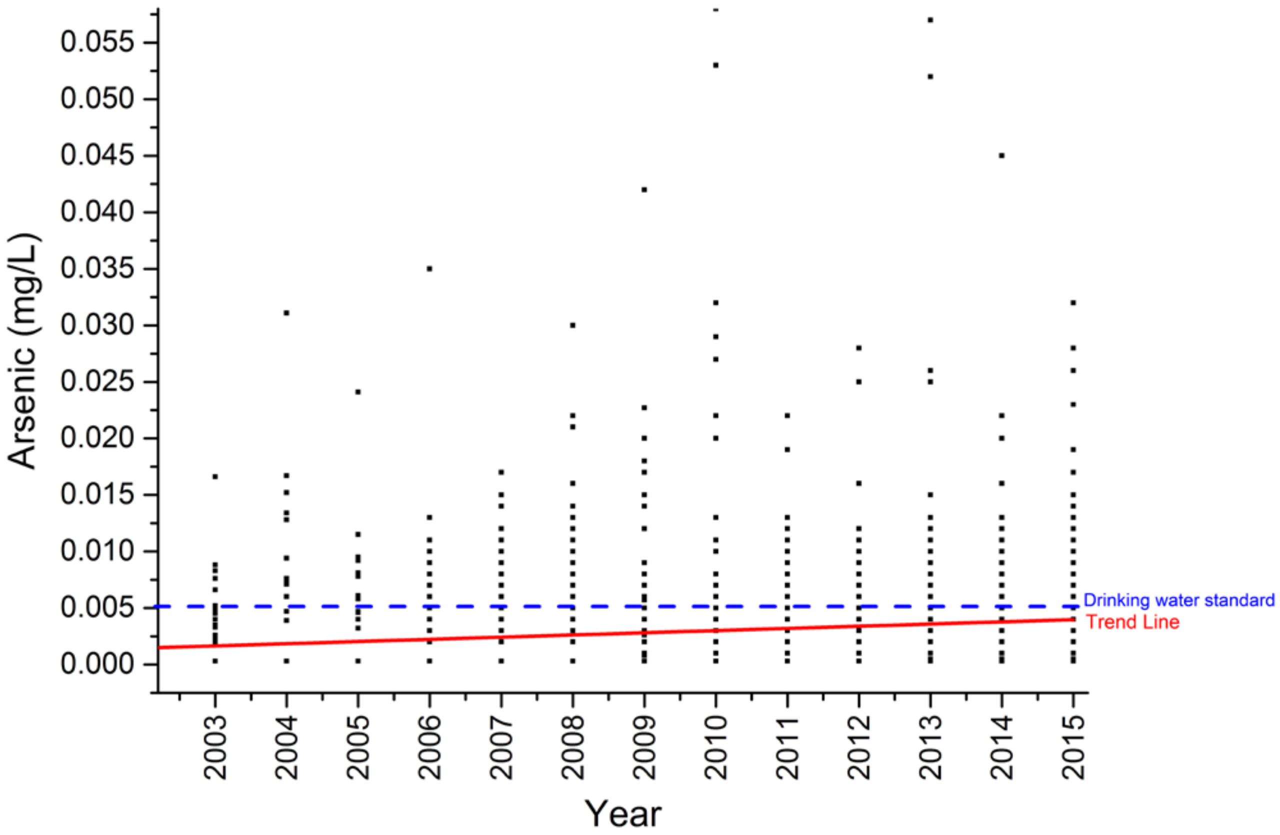

FIGURE 9. SCATTERPLOT OF RAW ARSENIC CONCENTRATIONS FROM WELL TESTS BETWEEN 2003 AND 2015 IN ALL TOWNSHIPS COMBINED AND TREND LINE AS LINE OF BEST FIT.

Forty-seven percent (n=7) of townships (100% of the towns with sufficient data) showed a positive, increasing trend in arsenic concentration. 53% (n=8) townships had insufficient data for a trend analysis of arsenic (Figure 10 and Appendix B). The remaining townships did not have tests for arsenic on record with Raritan Headwaters.

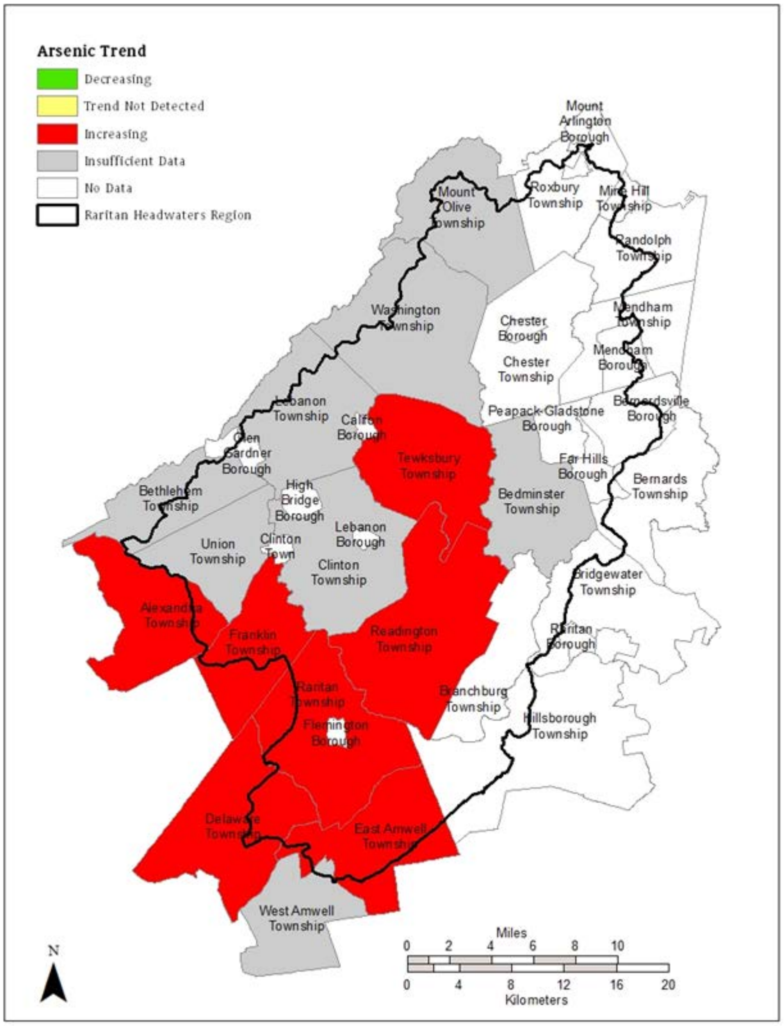

FIGURE 10. ARSENIC TRENDS BY TOWNSHIP BETWEEN 2003 AND 2015.

Changes in Arsenic Concentration at Individual Wells

In order to confirm the observed trend of increasing arsenic was a real phenomenon as opposed to solely a statistical trend, we collated test results from individual wells where arsenic tests had been repeated at least once (i.e., a minimum of 2 samples) between 2003 and 2015. We determined that 163 wells had been sampled at least twice during the study period. Of these samples, 45% (n=74) had an increase in arsenic concentration, 18% (n=29) had a decrease in arsenic concentration, and 37% (n=60) had the same arsenic concentration over time (Figure 11).

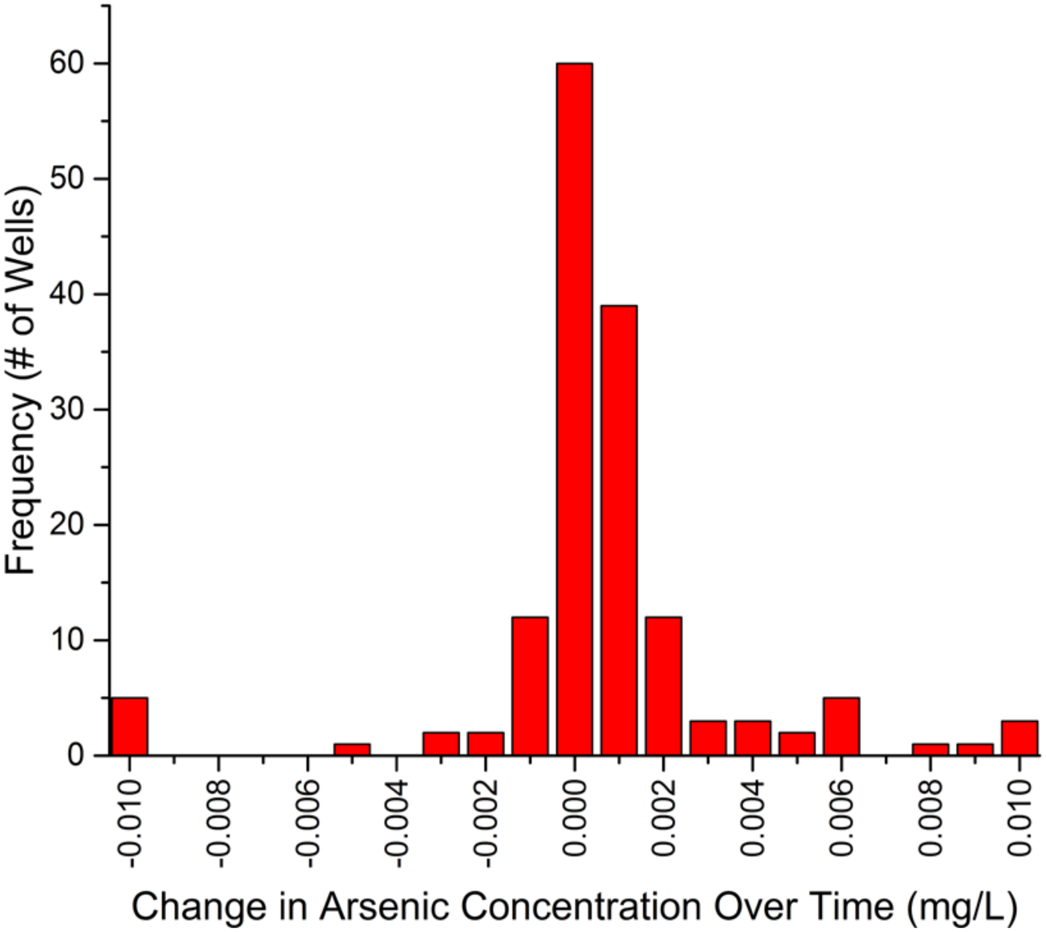

FIGURE 11. FREQUENCY (#) OF WELLS IN WHICH ARSENIC SHOWED A DECREASE, NO CHANGE AND INCREASE IN CONCENTRATION OVER TIME.

Discussion of Observed Trends in Arsenic

The analysis demonstrates that arsenic has increased in the groundwater overall, with many municipalities showing an increase and others showing no detectable trend between 2003 and 2015; arsenic is present in municipalities outside the typical area where the public are aware of high concentrations of arsenic. Arsenic is known to exist in high concentrations in underlying geological deposits, primarily pyritic black shale, in the Piedmont region of New Jersey that coincides with the southwestern portion of the watershed (NJDEP 2016; Zhu et al. 2008; Serfes et al. 2005). The presence of arsenic in groundwater in the Piedmont areas of the watershed is not surprising and is in agreement with published NJDEP data obtained from the Private Well Test Act in New Jersey. However, the results of this study bring up two potential problems not yet suggested by NJDEP or others monitoring arsenic in the groundwater in this region. First, arsenic concentrations appear to be increasing in the groundwater over time and second, arsenic concentrations may be dangerously high in areas of the watershed where it is not expected (e.g., areas outside the Piedmont). Vowinkel et al. (n.d.) suggest that more research is needed into the mechanisms that might mobilize arsenic from naturally occurring sources in the bedrock and from sediments in areas where arsenical pesticides were once heavily used.

Many studies of arsenic in groundwater document areas of the United States, including New Jersey, with high concentrations because of regional geology. Although there have been few studies of actual *trends* in arsenic concentration in groundwater in New Jersey, there have been studies in other areas of the United States and internationally that demonstrate increasing concentrations of arsenic occurring with change in well depth and change in groundwater chemistry.

Arsenic exhibits complicated chemical behavior. Arsenic in naturally occurring deposits can become mobilized in a variety of conditions including high pH, low oxygen (anoxic) conditions, and presence of organic carbon (reviews in Welch et al. 2000; Saxena et al. 2004). However, there are a variety of other complex interactions that can take place to mobilize arsenic including sulfide-driven arsenic mobilization in oxic conditions(e.g., Zhu et al. 2008). Ayotte et al. (2011) describe aquifer systems in which arsenic and other trace elements have been mobilized from bedrock from human-induced alterations to groundwater flow that results in changes in groundwater chemistry and mixing of chemically distinct aquifers. Arsenic in groundwater is the major source of arsenic to surface water through groundwater discharge into streams (Barringer et al. 2010).

Well depth may determine arsenic concentration depending on the deposits that are being tapped into as well as differences in geochemistry between well water from shallow and deep aquifers. Deeper wells may tap into bedrock with deposits high in arsenic as shallow aquifers are depleted by high densities of wells (see for example Winkel et al. 2011). Pumping from deeper wells may result in vertical migration of arsenic-containing groundwater because the well itself opens up cross flow between previously distinct aquifers. There may be a lag of a decade or more from the time the well is drilled to the detection of increased arsenic. As this phenomenon of arsenic contamination increasing with well depth has been heavily documented in countries such as Vietnam, Bangladesh, India and China, this scenario may be occurring in this region. Causes of deficits in shallow water aquifers from over-pumping of groundwater is likely exacerbated by the major decrease in groundwater recharge that occurs with urbanization and increased impervious surface (Chester and Gibbons 1996).

Historic use of arsenical pesticides (lead arsenates) was high in agricultural areas in the United States during the past century and resulted in arsenic residue in soils (Welch et al. 2000). Orchards, which were historically common in the Watershed, extensively used arsenical pesticides during the 1900s (Codling and Dao 2007; Codling 2007). It is believed that most of the arsenic applied as pesticides remains bound (adsorbed) to soil sediments, unless a change in chemistry causes the arsenic is desorb from sediments and become mobilized. In regions where land use is being converted from agriculture to urban, applications of phosphorous (P) and iron (Fe) to the soil as part of soil amendment, could result in loss of soluble arsenic (and lead) from surface soil and eventual infiltration into groundwater or runoff into surface waters (Codling and Dao 2007). Temperature increases microbial activity that mobilizes arsenic in soils when anoxic conditions are present as during flooding (Weber et al. 2010).

Other potential sources of arsenic are landfills or industrial facilities that may be leaching arsenic. In addition, arsenic was widely used as a wood preservative. However, the most substantial known source of arsenic in the watershed is as naturally occurring deposits in the bedrock. Further, carefully designed studies are needed to determine the extent of the trend of increasing arsenic and its causes.

Nitrate Results

Nitrate Trend – Increasing overall, with many townships showing an increase and others showing no detectable trend; after a steep rise between 1984 and 1997, rate of increase in nitrate levels appear to slow down.

A total of 13,175 records for nitrates were available from the RHA's Well Test Program from 1984 to 2015. The mean concentration of nitrate was 2.48 mg/L (SD = +/- 2.31) with a minimum concentration of 0.10 mg/L (half the RL) and a maximum of 64 mg/L. For all records combined a negligible percentage (n=101; .008%) failed to meet the Drinking Water Standard of 10 mg/L and only 12% (n=1,607) of tests were non-detects. The remainder of samples contained some level of nitrate. Well test samples with nitrate levels above the natural background level of about 1 mg/L were detected in 51% (n=6,764) of the tests. Figure 12 contains boxplots of median and range of nitrate concentrations over time in relation to the MCL of 10 mg/L.

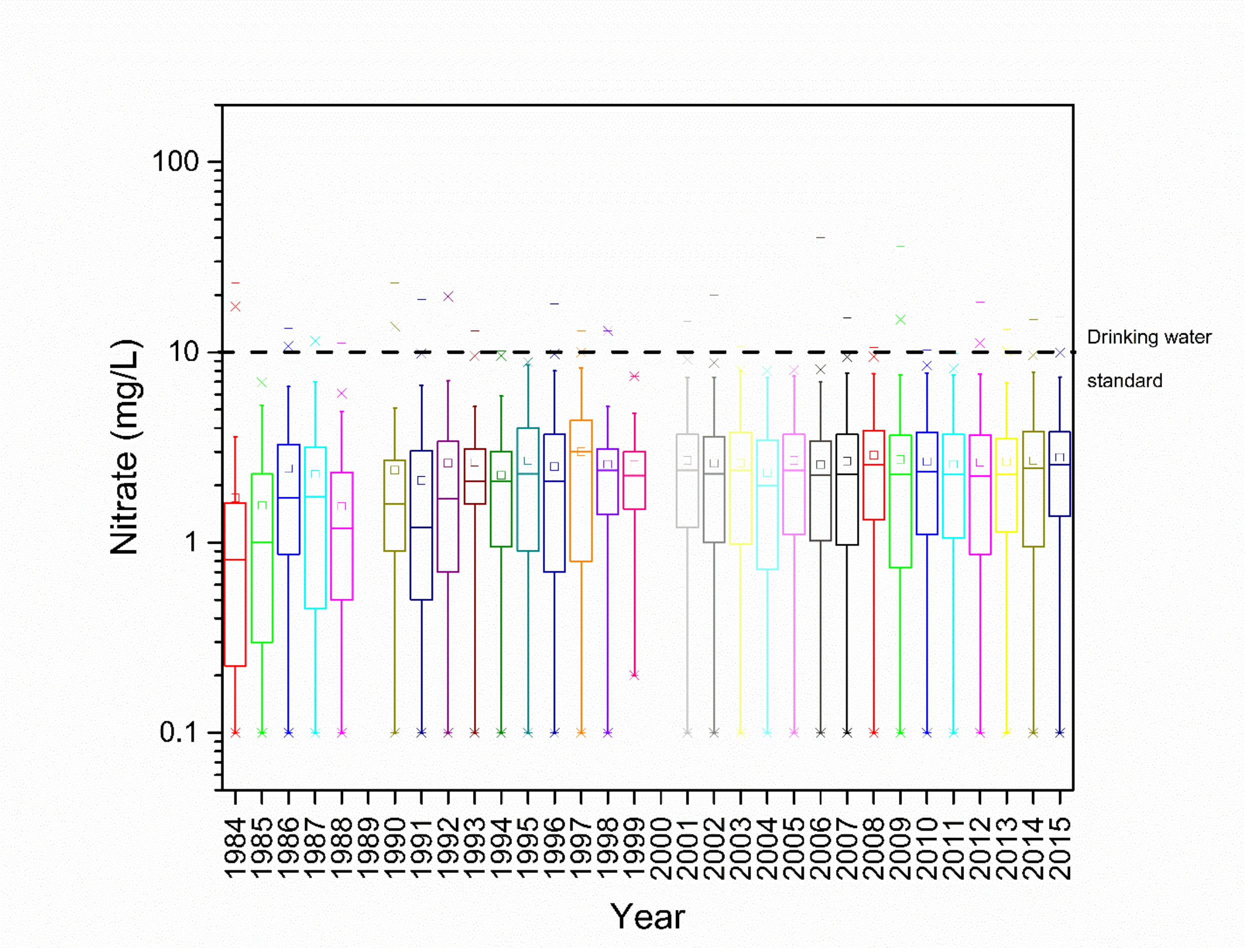

Figure 12. Boxplot of medians, 1st and 3rd quartiles (25% and 75%, respectively), 1.5 IQR, and outliers for nitrate concentrations detected in samples from wells between 1984 and 2015 for all townships combined. The y-axis is on a log scale.

There was a positive, increasing trend in nitrate concentration between 1984 and 2015 (Kendall's tau correlation coefficient = 0.101, p<0.01; Figures 13 and 14 and Appendix C). This trend was more pronounced between 1984 and 1997, with the rate of increase declining from 1997 to 2015. A graph of nitrate failures is not included because few tests for nitrate are above the Drinking Water Standard (MCL).

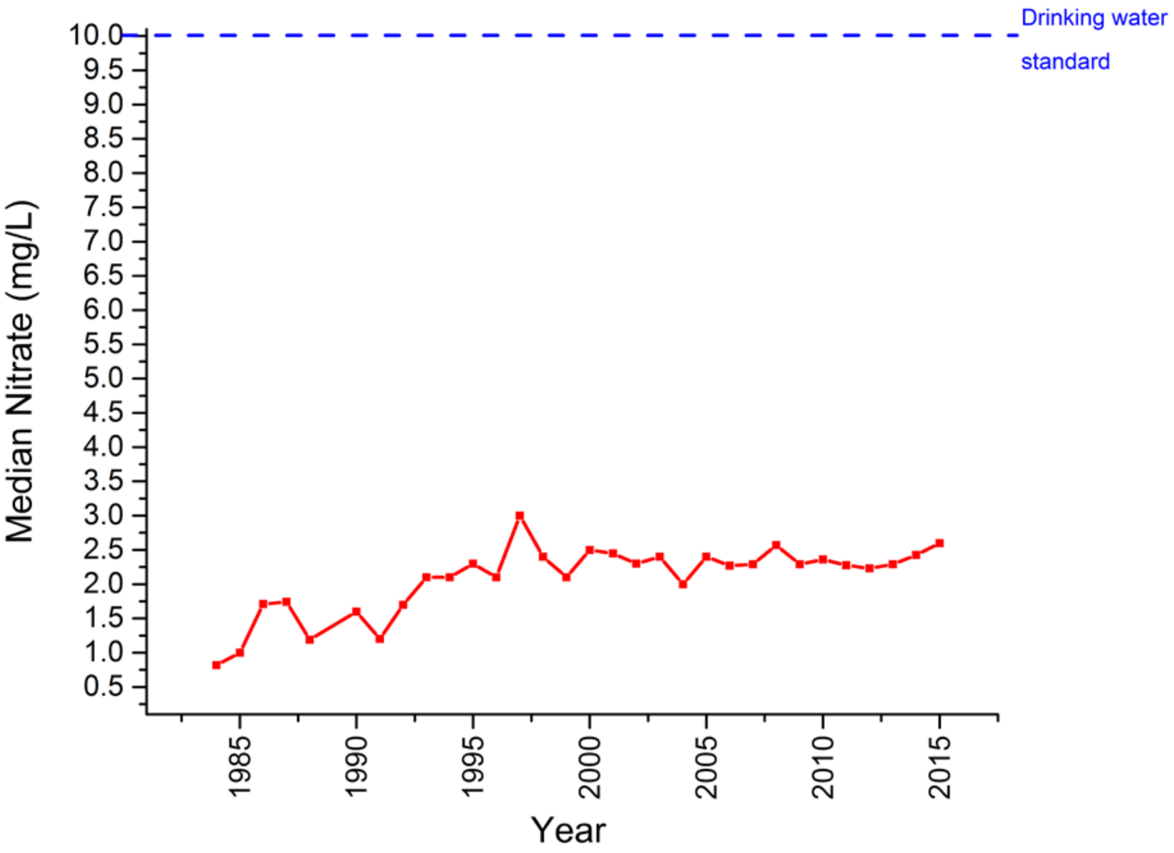

FIGURE 13. MEDIAN NITRATE CONCENTRATION FOR EACH YEAR BETWEEN 1984 AND 2015 IN ALL TOWNSHIPS COMBINED.

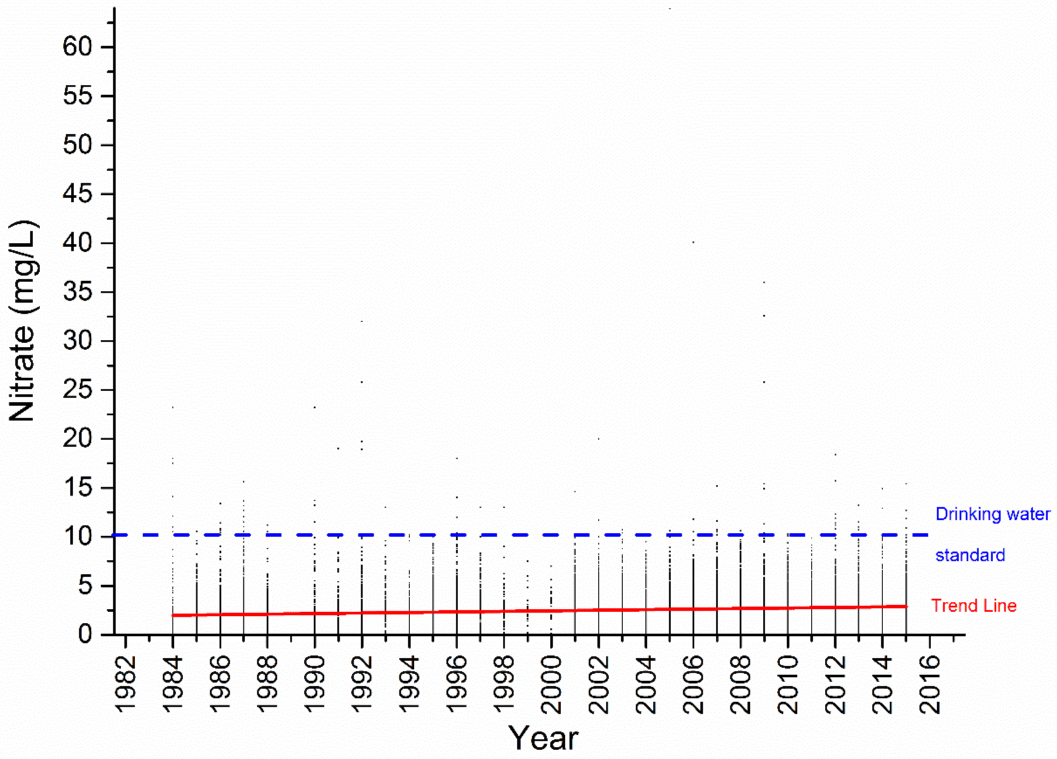

FIGURE 14. SCATTERPLOT OF RAW NITRATE CONCENTRATIONS FROM WELL TESTS BETWEEN 1984 AND 2015 FOR ALL TOWNSHIPS COMBINED AND TREND LINE AS LINE OF BEST FIT. THE TREND LINE IS INCLUDED FOR VISUAL PURPOSES BECAUSE THE DATA DISTRIBUTION DID NOT WARRANT A REGRESSION ANALYSIS.

Of the towns for which sufficient data were available 53% (n=8) did not demonstrate a detectable trend and 47% (n=7) demonstrated a positive, increasing trend in nitrate concentration over time (Figure 15 and Appendix C). Two towns did not have sufficient data for a trend analysis.

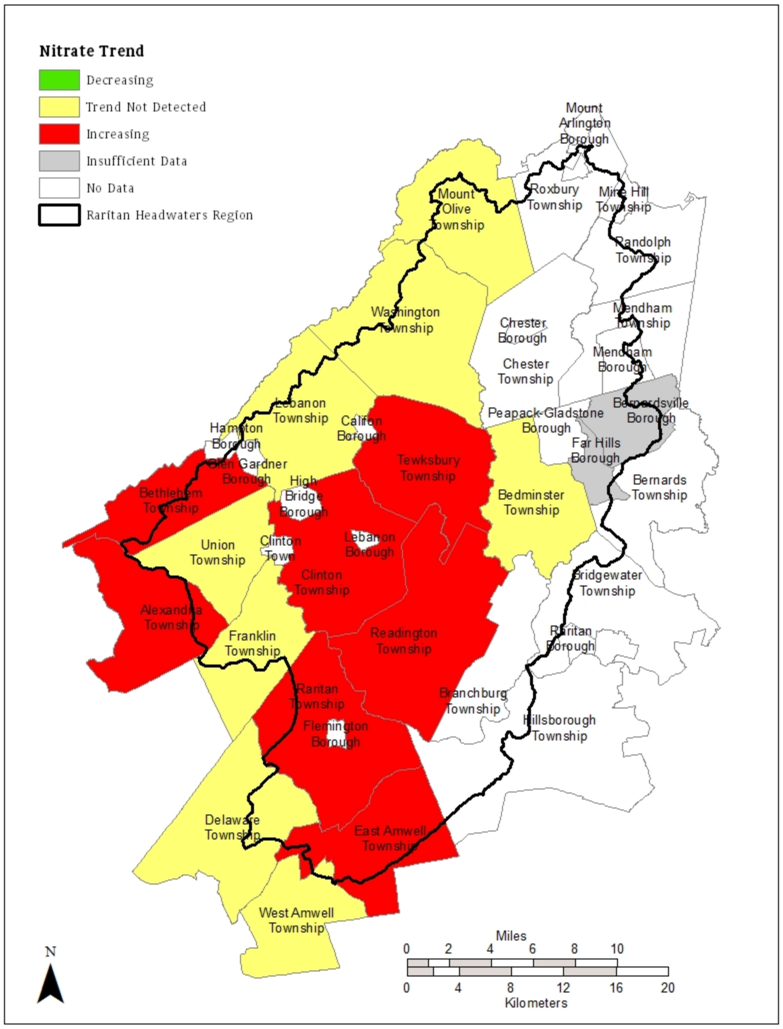

FIGURE 15. NITRATE TRENDS BY TOWNSHIP BETWEEN 1984 AND 2015.

Discussion of Observed Trends in Nitrates

Nitrate concentrations have increased overall, with many townships showing an increase and other showing no detectable trend. After a steep rise between 1984 and 1997, nitrate levels appear to be levelling off. This trend is in agreement with published studies of trends in nitrates nationally. More research is needed to explain the geographic trends detected in the data. The median nitrate concentrations in the watershed surpassed the estimated Highlands median of 1.25 mg/L (Baker et al. 2015) as early as the 1990s and is presently approaching a median of 3 mg/L. This relatively high level of nitrates in the watershed warrants further analysis. Possible explanations for the high numbers relative to the Highlands are a higher density of development and a longer time period and land area in agriculture in the lower parts of the watershed where the majority of the well tests originated.

Nutrients such as nitrogen (N) are important elements found in proteins and nucleic acids (e.g., DNA), which are the building blocks of all living things. Nitrogen takes the form of nitrate, nitrite, and ammonia/ammonium, and nitrogen gases in the soil and groundwater, with nitrate and ammonium being the most common. Bacteria in the soil and water naturally facilitate the production of nitrates (nitrification) from decaying organic matter and waste from animals and conversion of nitrate to nitrogen gas, via the process of denitrification, which is released to the atmosphere. Nitrate is naturally present in the water at background concentrations as measured in forests and wetlands in the New Jersey Highlands Region, of less than 1 mg/L (Baker et al. 2015). Anything above that level is attributed to human activities in a variety of land use types, including mainly agriculture and urban/suburban (USGS 1999; Dubrovsky et al. 2010).

A review of the sources of nitrates in groundwater is provided by Dubrovsky et al. (2010). Fertilizers applied to crops and lawns are the most significant source of nitrates to groundwater. In urbanized areas, on-site individual subsurface disposal systems (aka septic systems) and sewage treatment plants are major sources of nitrates to surface water and groundwater. Septic systems, even properly functioning ones, have drainfields that slowly release nitrates into the soil (Bowers n.d.; Appendix H). Thus, the higher the density of homes with septic systems and the older the homes, the higher the nitrate concentration in groundwater (highlands study?). This issue is a major focus on NJDEP's Water Quality Management Planning Rules (N.J.A.C. 7:15) and the Highlands Regional Master Plan, both adopted in 2008. Animal waste also can be a major source of nitrates to water in both agricultural (especially livestock) and urban settings. Flooding events and stormwater runoff mobilize animal waste, which then enters streams and groundwater. It is predicted for New Jersey that climate change will result in more precipitation, with more severe storms, resulting in more rapid transport of nitrate to surface water and groundwater.

The gradual levelling off of nitrate concentration over the past 2 decades after a steep increase may be a result of nitrates reaching deeper wells during recharge of deep aquifers during that same period of time as demonstrated by the national trend (Dubrovsky et al. 2010). A better understanding of groundwater recharge rates for the region will allow for a better interpretation of this interesting trend. An alternative hypothesis is that wells are being dug deeper, where nitrate levels are lower, as shallower aquifers are depleted with increasing development and unsustainable demands on groundwater supplies.

More research is needed to determine causes of the increasing trend in nitrate. It will be important to determine if the nitrate levels will continue to rise with increasing development, whether agricultural and residential applications of fertilizers is playing a major role in the trend, and whether the rise in nitrates is cause for concern. Further analysis and research into the variability in geographic pattern in nitrate trends will likely shed light on the sources. Levels of nitrates in most of the wells are well below the drinking water standard in most areas but represent a signature of human activities on the landscape.

Coliform Bacteria Results

Coliform Trend – A weak increasing trend watershed-wide but varies by township with the majority of towns showing a slight increase or no trend.

A total of 14,114 records for coliform were available from the RHA's Well Test Program from 1984 to 2015. For all records combined 15% failed to meet the Drinking Water Standard of zero organisms per sample. The slope of the regression line for percent coliform failures between 1984 and 2015 was not significant (p=0.256) when all townships in the well test program were combined watershed wide (Figure 16 and Appendix D).

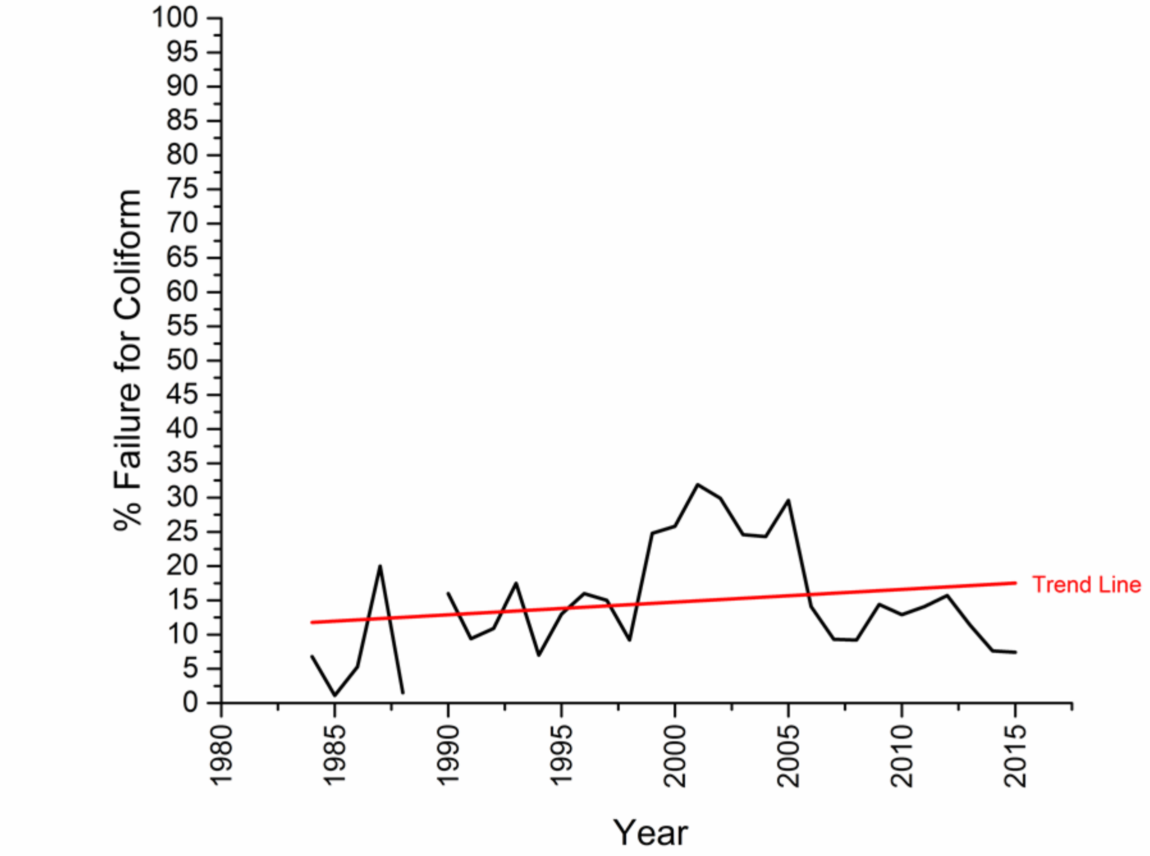

FIGURE 16. TREND IN COLIFORM FAILURE RATES (%) BETWEEN 1984 AND 2015 FOR ALL TOWNSHIPS COMBINED AND TREND LINE AS LINE OF BEST FIT. THE TREND LINE IS NOT SIGNIFICANT (P>0.05).

A logistic regression analysis was conducted to look for a relationship between coliform failure and year for all townships combined and by individual towns. For all townships combined, a test of the full model against a constant only model was statistically significant, indicating that the predictor (year) reliably distinguished between tests that failed for coliform and tests in which coliform was not detected (chi square = 40.735, p < .001 with df = 1). Nagelkerke's R^2 of .005 indicated a weak relationship between prediction and grouping (pass or fail). Prediction success overall was 85.4% (0% for fail and 100% for non-detect). The Wald criterion demonstrated that test year made a significant contribution to prediction (p < .001). Exp(B) value indicates that with each year there is a 1.017 increase in the chance of failing for coliform. Though this increase in failures with year is very small, it is statistically significant.

When individual townships were considered with enough data for a trend analysis, 44% (n=7) had a positive, slight increasing trend in coliform failures with year and 12.5% (n=2) showed a slight decreasing trend in coliform failures (Figure 17 and Appendix D). Again, these trends were small but significant. 44% (n=7) did not exhibit a detectable trend. Two townships had insufficient data for a trend analysis.

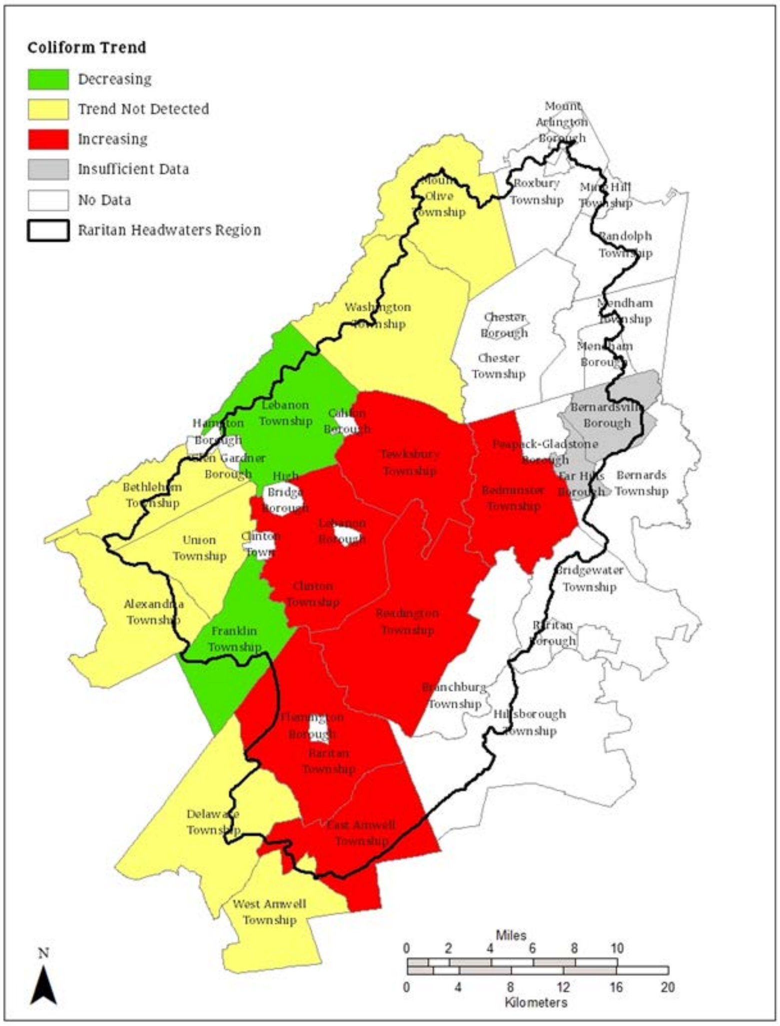

FIGURE 17. COLIFORM TRENDS AS FAILURE RATE BY TOWNSHIP BETWEEN 1984 AND 2015 BASED ON WALD P-VALUE (APPENDIX D). NOTE THE TRENDS WERE SMALL.

Discussion of Coliform Bacteria Trends

The results demonstrate there may be a slight but statistically significant increase in coliform failures overall but the trend varies by township with the majority of towns showing a weak increase or no trend. Given that as wells and septic systems age there is a higher chance of the structures failing, which could result in bacteria entering the well, it is surprising that the trend was not more pronounced. The lack of an increase in the percentage of coliform failures means that further research is needed to determine whether the very small trends detected in the logistic regression at the watershed and municipal level is or is not cause for concern.

Regardless of the trend, private well owners must test annually for coliform. Coliform bacteria are present in the soil and most species are not pathogenic. However, wells that fail the test for coliform bacteria are likely to have additional bacterial and viral pathogens present (Abbaszedegen et al. 2003). Age and/or poor maintenance of wells and septic systems is associated with a greater chance that a breach in the structures may occur allowing coliform bacteria and, more importantly, fecal coliform and other disease-causing pathogens to enter the well. Therefore, it is recommended that residents regularly check and service their wells and septic systems.

Wells located near areas where livestock and horses are kept may be at risk for increased fecal coliform and other pathogens. Increased development brings with it a higher density of human and animal waste. Climate change may result in more extreme weather events, which in turn results in mobilization of bacteria from animal waste through stormwater runoff.

Lead Results

Lead Trend – Highly variable with no detectable trend watershed-wide.

A total of 2,455 records for lead were available from the RHA's Well Test Program from 1992 to 2015. The mean concentration of lead was 0.048 mg/L (SD = +/- 1.142) with a minimum of 0.0005 mg/L (half the RL) and a maximum of 49 mg/L. For all records combined 11% (n=268) of tests failed to meet the drinking water MCLG for lead of zero mg/L and 9% (n=224) failed to meet the Drinking Water Action Standard of 0.015 mg/L. No trend was detected in lead concentration watershed-wide/all townships combined between 1992 and 2015 (Kendall's tau correlation coefficient = 0.025, p>0.05; Figure 18 and 19 and Appendix E).

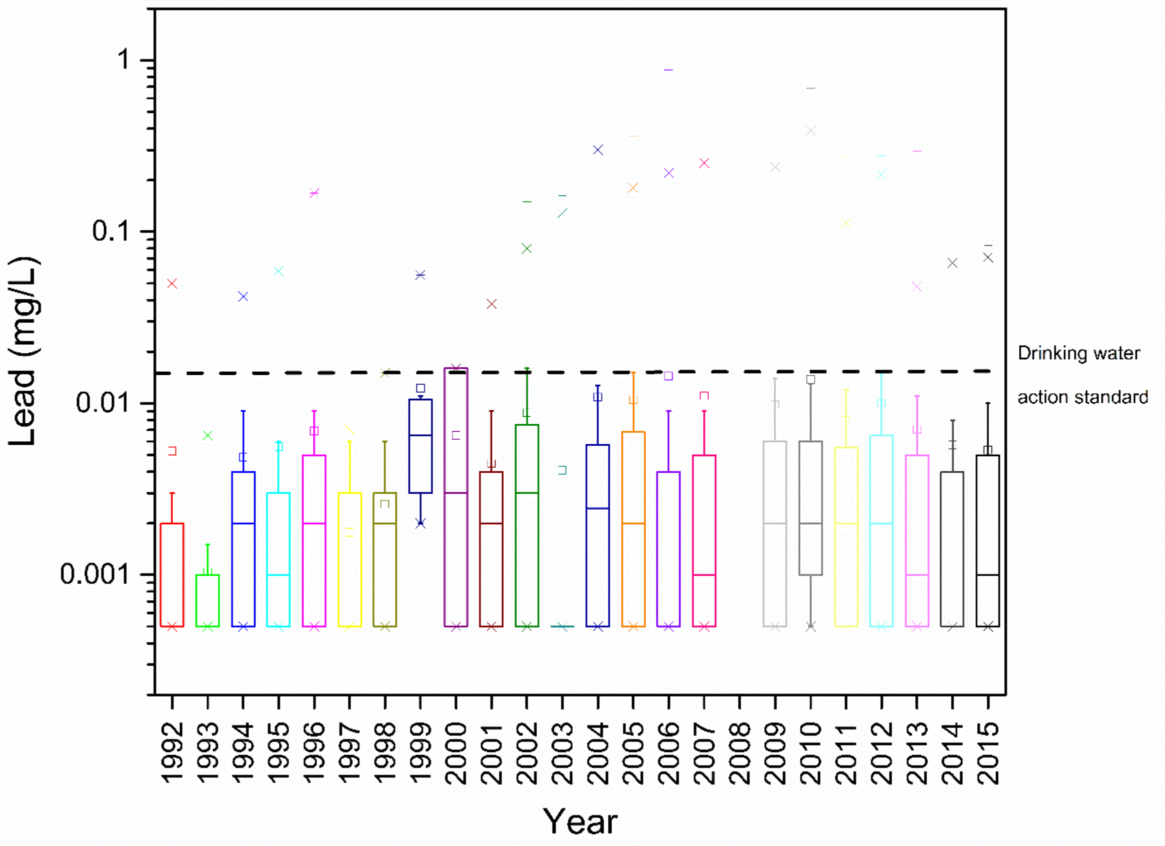

FIGURE 18. BOXPLOT OF MEDIANS, 1ST AND 3RD QUARTILES (25% AND 75%, RESPECTIVELY), 1.5 IQR, AND OUTLIERS FOR LEAD CONCENTRATIONS DETECTED IN SAMPLES FROM WELLS BETWEEN 1992 AND 2015 FOR ALL TOWNSHIPS COMBINED. THE Y-AXIS IS ON A LOG SCALE.

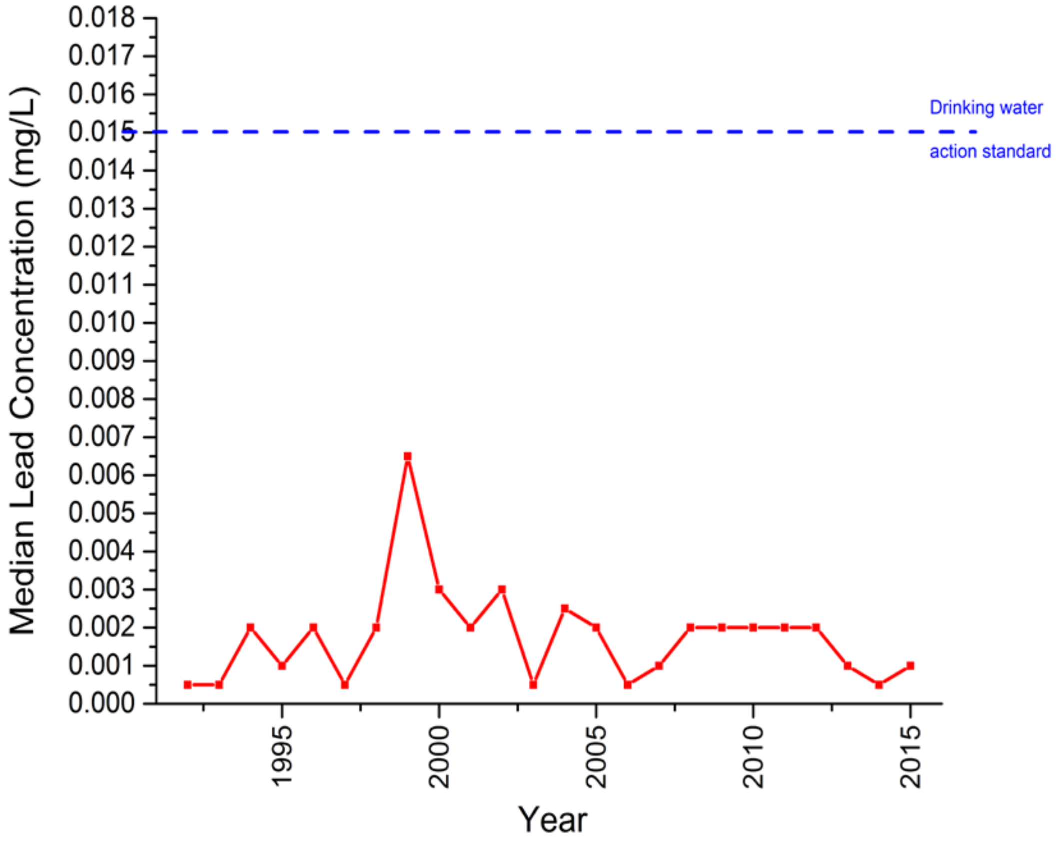

FIGURE 19. MEDIAN LEAD CONCENTRATIONS FOR EACH YEAR BETWEEN 1984 AND 2015 IN ALL TOWNSHIPS COMBINED.

Of the townships for which sufficient data were available 91% (n=10) showed no detectable trend and 9% (n=1) demonstrated a positive, increasing trend in lead concentration over time (Appendix E). Five townships had insufficient data for a trend analysis.

Discussion of Lead Results

Lead is neurotoxic at all concentrations, but has an action level of 15 mg/L for public water supply systems in this country. The World Health Organization recommends an action level of 10 mg/L. However, the ideal is to have no lead exposure at all, especially for young children. The results for lead in well test records in RHA's Well Test Program database are highly variable with no detectable trend watershed-wide over time or by municipality. However, further research is needed into whether the trend in higher concentrations is related directly to age of home.

Lead is present to some extent in water in part due to low concentrations in the environment. However, the largest source of lead in drinking water is from indoor plumbing. On June 19, 1986, Congress enacted the Safe Drinking Water Act Amendments of 1986, which included the "lead ban." This prohibited the use of lead pipe, solder or flux in public water systems, public notice requirements for lead, definition of lead free materials, and designation of lead solder above a certain lead concentration as a hazardous substance. In the United States, homes built prior to 1986 commonly contained lead in the pipes, fixtures, and solder, which is the likely source of lead in most drinking water. Thus, homes built prior to 1986 are at the greatest risk of having concentrations of lead that exceed the action level of 15 mg/L. Note that these homes are also at greater risk of having lead paint, which is an even greater concern for young children.

Some older water supply infrastructure and service connections to homes contain lead. The amount of lead concentrations in drinking water are affected by the chemical composition of the water including presence of chloride and dissolved oxygen, pH, temperature, water softness, and standing time of the water, soft, acidic water being the most solvent of lead (Schock 1989; Schock 1990). Changes in water chemistry could result in leaching of lead from pipes as seen happening in Flint, Michigan.

Radon Results

A total of 246 records for radon were available from the RHA's Well Test Program from 2011 to 2015. The mean concentration of radon was 2,141 pCi/L (SD = +/- 4,336) with a minimum concentration of 0 pCi/L and a maximum of 62,142 pCi/L. The EPA is currently in the process of setting an MCLG for radon in drinking water of 300 pCi/L, with an action standard of 4,000 pCi/L (USEPA, N.D.). A trend in radon concentration over time was not detected (Figure 20).

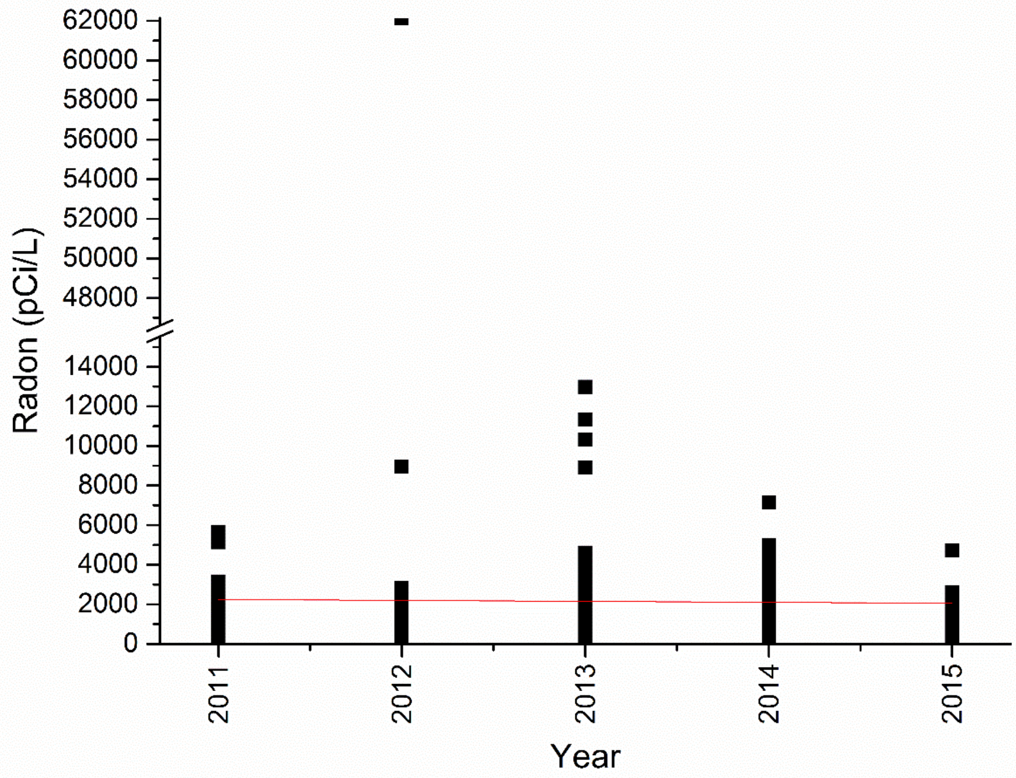

FIGURE 20. SCATTERPLOT OF RAW RADON CONCENTRATIONS FROM WELL TESTS BETWEEN 2011 AND 2015 FOR ALL TOWNSHIPS COMBINED AND TREND LINE AS LINE OF BEST FIT.

Volatile Organic Compounds (VOCs) Results

There were a total of 1,618 records for VOC tests (including 62 chemicals) between 1987 and 2015 (Appendix F). Of these, 209 (13%) tested positive for one or more VOC. The most common VOC was methyl tert-butyl ether (MTBE; n=62 samples), which was an additive to gasoline, no longer used as of 2006. A source is leaking underground fuel from old tanks. The range in concentration for MTBE was 0.10 to 47.7 µg/L with a mean of 3.80 µg/L. The MCL is 70 µg/L. Chloroform (n=27) is a THM (trihalomethane) and is typically the most common VOC in groundwater in the U.S. Chloroform is produced as a refrigerant and for a variety of other industrial uses. It is also a byproduct of wastewater disinfection, which is considered a major source to groundwater. The MCL for all THM combined is 80 µg/L. 1,1,1 -trichloroethane (n=14) and 1,1-dichlorethane (n=4) are man-made solvents. The MCL for 1,1,2-trichloroethane is 30 µg/L and for 1,1-dichloroethane is 50 µg/L. Acetone (n=23) and methylene chloride (n=1) are common lab contaminants as they are used to clean glassware and may be inadvertently added to the sample during analysis in the lab but could also be an environmental contaminant. The MCL for methylene chloride is 3 µg/L. 2-butanone (methyl ethyl ketone (MEK); n=24) is used as a solvent in vinyl films, paint removers, lacquers, varnishes, adhesives and cleaning fluids. It is a component of adhesives commonly used to join polyvinyl chloride (PVC) pipes and may be temporarily found in drinking water if water pipe repair or water well construction has recently occurred. 1,4-dichlorobenzene (n=2; MCL 75 µg/L) is primarily used to produce 3,4-dichloroaniline herbicides. Hexachlorobutadiene (1) is used in the synthesis of chlorinated hydrocarbons. Naphthalene (N=1) is used in the production of phthalic anhydride and is a component of mothballs. The MCL for naphthalene in New Jersey is 300 µg/L.

Pesticides

Pesticides include herbicides, fungicides, insecticides, rodenticides, and vermicides. There are 970 records of pesticide tests in RHA's well test database for the period 1987 to 2015. Of the samples, only 6 contained one or more pesticides. Of the 18 pesticides included in the current battery of tests (see Appendix G) only 8 have been detected in well samples between 1987 and 2015. These include Chlordane (3), Gamma-BHC (2), Dieldrin (2), Endrin (1), Heptachlor (1), Heptachlor epoxide (1), Toxaphene (1), Methoxychlor (1). The data on pesticides in this study were limited because most residents do not opt for this relatively expensive test. In addition, the pesticides included in the current list are not the most commonly applied agricultural pesticides and RHA is presently seeking funding to include the most common agricultural and household pesticides in the pesticide screening offered by Raritan Headwaters at an affordable rate for homeowners (Appendix G). For example, atrazine, glyphosate, and 2,4-D as well as several others not presently included.

Contaminants of Emerging Concern

At present, RHA does not offer tests for contaminants that are of recent, emerging/re-emerging concern. These include pharmaceuticals, chloramines, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), dioxins and others. Raritan Headwaters is presently in the process of expanding its well test program to include a variety of important contaminants at an affordable price.

CONCLUSIONS & NEXT STEPS

The results of this trend analysis, especially the increasing concentrations of arsenic and nitrates in some wells, leads to many more questions about the cause of the trends and what should be done to address them. One thing is clear from this study and others in the literature, groundwater is a vulnerable resource and the quality of our drinking water is subject to change over time. Monitoring of water quality as well as quantity is necessary to insure that residents living in the North and South Branch Raritan Watershed and beyond have access to safe, clean drinking water. Given that only a small percentage of private wells in the watershed are tested on a regular basis, there is a critical need for education and outreach about where well water is coming from and what levels of contaminants it contains. In addition, education and incentives to improve our practices on the land will go a long way to protecting all of our water – groundwater and surface water.

Quantity and quality of groundwater is a major concern with increasing development and climate change. More research is needed into how these large-scale land use changes in the watershed have impacted and will continue to impact our water resources. Local and regional regulations, planning, and practices should be informed by sound science.

Next Steps

- Educate the public about the health threats associated with their drinking water and the need to test their water regularly for nitrates and coliform as well as periodically for arsenic, lead and other contaminants.
- Advise local municipalities about the importance of hosting a community well test program.
- Encourage exploration of the relationships between land use, climate change and water quality.
- Determine if groundwater chemistry has changed to allow for mobilization of arsenic from natural deposits and identify the causes of the change in chemistry.
- Likely connections of water quality to urbanization and climate change require addressing the issue through planning and best management practices (BMPs) at the local and regional levels.
- Housing density limits or advanced septic systems reduce nitrates in the groundwater from septic systems.
- Best management practices (BMPs) including proper storage and disposal of animal waste and proper maintenance of wells and septic systems.
- Determine whether recent state regulations limiting the application and concentration of nitrogen and other nutrients (e.g., phosphates) in fertilizers are effective in reducing nutrient levels in water.
- Encourage regular maintenance of wells and septic systems.
- Encourage proper storage and disposal of animal waste.
- Expansion of the Raritan Headwaters Well Test Program into municipalities not presently participating and to include more tests for contaminants not typically chosen by residents (e.g., arsenic and lead).
- Revision of the battery of pesticides we presently test, which are limited to those with established MCLs, to include tests for the currently most heavily applied chemicals in New Jersey.
- Inclusion of contaminants of emerging concern such as PFOAs in monitoring of groundwater.

- Working with partner organizations and communities to promote education and river friendly practices.

For more information about scheduling a Community Well Test for residents of your municipality or to have your own well tested, visit https://www.raritanheadwaters.org/protect/well-testing/

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APPENDIX A: NUMBER OF WELL TESTS (ARSENIC, NITRATES, COLIFORM AND LEAD) AND NUMBER OF MUNICIPALITIES PARTICIPATING BY YEAR

YEAR	# MUNICIPALITIES	# ARSENIC TESTS	# NITRATE TESTS	# COLIFORM TESTS	# LEAD TESTS
1984	3	--	232	241	--
1985	7	--	635	641	--
1986	6	--	262	264	--
1987	7	--	582	594	--
1988	9	--	743	752	--
1989	--	--	--	--	--
1990	4	--	198	244	--
1991	4	--	148	182	--
1992	5	--	252	271	--
1993	3	--	176	184	35
1994	3	--	224	227	112
1995	4	--	338	356	58
1996	11	--	520	652	69
1997	10	--	146	237	36
1998	6	--	86	148	21
1999	10	--	24	124	4
2000	8	3	29	137	3
2001	9	1	565	572	110
2002	10	4	455	553	111
2003	10	185	623	796	160
2004	11	83	452	563	100
2005	9	99	533	641	111
2006	9	120	523	620	120
2007	9	151	538	616	146
2008	9	207	568	638	170
2009	10	195	571	666	153
2010	11	267	620	692	171
2011	11	176	696	832	161
2012	14	95	523	596	143
2013	15	107	554	638	135
2014	13	171	606	657	141
2015	10	239	536	567	112

APPENDIX B: ARSENIC TREND RESULTS, NON-PARAMETRIC TEST FOR THE RELATIONSHIP BETWEEN ARSENIC CONCENTRATION AND YEAR.

Township	Number of Records	Mean (mg/L)	Standard deviation	Min (mg/L)	Max (mg/L)	Kendall's Tau-b (Correlation Coefficient)	p-value
All Combined	2,086	.00290	.00497	.0003	.0580	.220	<.001***
Alexandria	324	.00404	.00737	.0003	.0580	.159	<.001***
Bedminster	28	.00162		.0003	.0040	--	--
Bernardsville	0	--	--	--	--	--	--
Bethlehem	62	.00211	.00927	.0003	.0520	--	--
Clinton	55	.00082	.00120	.0003	.0520	--	--
Delaware	174	.00303	.00443	.0003	.0280	.139	.018*
East Amwell	91	.00523	.00737	.0003	.0450	.337	<.001***
Far Hills	0	--	--	--	--	--	--
Franklin	101	.00130	.00199	.0003	.0010	.324	<.001***
Lebanon	59	.00026	.00009	.0003	.0010	--	--
Mt. Olive	5	.00025	0	.0003	.0003	--	--
Raritan	382	.00358	.00486	.0003	.0570	.180	<.001***
Readington	529	.00322	.00322	.0003	.0311	.131	<.001***
Tewksbury	176	.00072	.00249	.0003	.0300	.287	<.001***
Union	60	.00080	.00128	.0003	.0060	--	--
Washington	4	.00025	0	.0003	.0003	--	--
West Amwell	20	.00311	.006334	.0003	.0260	--	--

*p-value is below .05; ***p-value is below .001; -- denotes insufficient or lack of data

APPENDIX C: NITRATE TREND RESULTS, NON-PARAMETRIC TEST FOR THE RELATIONSHIP BETWEEN NITRATE CONCENTRATION AND YEAR.

Township	Number of Records	Mean (mg/L)	Standard deviation	Min (mg/L)	Max (mg/L)	Kendall's Tau-b (Correlation Coefficient)	p-value
All Combined	**13,135**	**2.48**	**2.31**	**.10**	**64.00**	**.101**	**<.001*****
Alexandria	**904**	**2.90**	**2.02**	**.10**	**11.30**	**.081**	**<.001*****
Bedminster	**114**	**1.87**	**1.46**	**.10**	**6.94**	**.003**	**.963**
Bernardsville	**27**	**2.87**	**2.38**	**.10**	**13.64**	**--**	**--**
Bethlehem	**526**	**2.54**	**2.05**	**.10**	**9.82**	**.184**	**<.001*****
Clinton	**541**	**2.65**	**2.62**	**.10**	**25.80**	**.131**	**<.001*****
Delaware	**815**	**2.69**	**2.71**	**.10**	**19.00**	**-.003**	**.887**
East Amwell	**706**	**3.10**	**2.69**	**.10**	**32.00**	**.107**	**<.001*****
Far Hills	**9**	**4.05**	**2.63**	**.63**	**7.23**	**.117**	**.117**
Franklin	**427**	**2.41**	**1.96**	**.10**	**11.40**	**-.003**	**.924**
Lebanon	**583**	**1.93**	**1.69**	**.10**	**11.00**	**-.015**	**.606**
Mt. Olive	**148**	**3.13**	**2.67**	**.10**	**11.50**	**-.031**	**.621**
Raritan	**2,438**	**2.74**	**2.60**	**.10**	**64.00**	**.033**	**.020***
Readington	**3,010**	**2.60**	**2.16**	**.10**	**40.10**	**.214**	**<.001*****
Tewksbury	**2,179**	**1.67**	**1.76**	**.10**	**14.90**	**.171**	**<.001*****
Union	**303**	**2.69**	**2.07**	**.10**	**11.80**	**.075**	**.067**
Washington	**136**	**2.22**	**2.92**	**.10**	**23.20**	**.127**	**.064**
West Amwell	**89**	**2.47**	**2.57**	**.10**	**13.20**	**.043**	**.599**

*significant at p<.05; ***significicant at p< .001; -- denotes insufficient or lack of data

APPENDIX D: COLIFORM TREND RESULTS, BINARY LOGISTIC REGRESSION RESULTS FOR THE RELATIONSHIP BETWEEN COLIFORM BACTERIA FAILURE AND YEAR.

Township	Chi-square (1 df)	Nagelkerke's R^2	Prediction Success Coliform Failure (%)	Prediction Success Non-detect (%)	Overall Prediction Success (%)	Wald (p-value)	Exp (B)
All	40.735***	.005	0	100	85.4	<.001***	1.017
Alexandria	.280	.001	0	100	88.0	.597	.993
Bedminster	7.614**	.097	0	100	81.5	.008**	1.252
Bethlehem	4.222*	.019	0	100	91.1	.054	1.038
Clinton	10.212**	.035	0	100	88.8	.002**	1.054
Delaware	.920	.002	0	100	83.3	.339	1.010
East Amwell	21.948***	.064	0	100	87.0	<.001***	1.064
Franklin	12.655***	.038	.8	99.1	72.8	<.001***	.918
Lebanon	6.391*	.019	0	100	87.2	.009**	.947
Mt. Olive	.191	.003	0	100	90.1	.651	.932
Raritan	12.516	.008	0	100	85.6	.001**	1.024
Readington	4.253*	.002	0	100	80.8	.040*	1.010
Tewksbury	15.396***	.015	0	100	90.4	<.001***	1.031
Union	1.669	.012	0	100	95.0	.186	.967
Washington	.490	.011	0	100	95.0	.457	1.051
West Amwell	4.336*	.085	0	100	89.0	.063	1.089

*significant at p<.05; ** significant at p<.01; ***significicant at p< .001; -- denotes insufficient or lack of data

APPENDIX E: LEAD TREND RESULTS, NON-PARAMETRIC TEST FOR THE RELATIONSHIP BETWEEN LEAD CONCENTRATION AND YEAR.

Township	Number of Records	Mean (mg/L)	Standard deviation	Min (mg/L)	Max (mg/L)	Kendall's Tau-b (Correlation Coefficient)	p-value
All Combined	**2,420**	**.0486**	**1.1499**	**.0005**	**49.0000**	**.027**	**.075**
Alexandria	**193**	**.1520**	**1.8831**	**.0005**	**26.1000**	**.032**	**.562**
Bedminster	**36**	**.0385**	**.1296**	**.0005**	**.6890**	**--**	**--**
Bernardsville	**2**	**.0008**	**.0004**	**.0005**	**.0010**	**--**	**--**
Bethlehem	**122**	**.0071**	**.0208**	**.0005**	**.1620**	**.032**	**.645**
Clinton	**93**	**.0062**	**.0237**	**.0005**	**.2240**	**.196**	**.013***
Delaware	**154**	**.0088**	**.0305**	**.0005**	**.3260**	**.030**	**.617**
East Amwell	**122**	**.0032**	**.0068**	**.0005**	**.0560**	**.172**	**.015***
Far Hills	**5**	**.0010**	**.0006**	**.0005**	**.0020**	**--**	**--**
Franklin	**86**	**.0083**	**.0310**	**.0005**	**.2780**	**.065**	**.428**
Lebanon	**100**	**.0149**	**.0352**	**.0005**	**.2730**	**.034**	**.640**
Mt. Olive	**20**	**.0214**	**.0423**	**.0005**	**.1420**	**--**	**--**
Raritan	**369**	**.0057**	**.0304**	**.0005**	**.5400**	**.010**	**.800**
Readington	**604**	**.0354**	**.4270**	**.0005**	**9.8000**	**-.014**	**.651**
Tewksbury	**387**	**.1450**	**2.4948**	**.0005**	**49.0000**	**-.063**	**.093**
Union	**83**	**.0174**	**.0971**	**.0005**	**.8770**	**.122**	**.147**
Washington	**4**	**.0014**	**.0011**	**.0005**	**.0026**	**--**	**--**
West Amwell	**36**	**.0040**	**.0055**	**.0005**	**.0240**	**--**	**--**

*p-value is at or below .05; -- denotes insufficient or lack of data

APPENDIX F; VOLATILE ORGANIC COMPOUNDS (VOCs) INCLUDED AS PART OF THE WELL TEST PROGRAM WITH MEANS, MINIMUM, MAXIUM, AND NUMBER OF TIMES DETECTED FOR EACH COMPOUND.

	N	Minimum	Maximum	Mean	Std. Deviation
Dichlorodifluoromethane	0				
Vinyl Chloride	0				
Chlorethane	0				
Methyl tert-Butyl Ether	62	.10	47.27	3.7976	9.16145
trans-1,2-Dichloroethylene	0				
Isopropyl Ether	0				
1,1-Dichloroethane	4	1.10	17.00	7.3525	7.65265
2,2-Dichloropropane	0				
cis-1,2-Dichloroethylene	0				
Chloroform	27	.100	5.820	1.22167	1.398353
Bromochloromethane	0				
1,1,1-Trichloroethane	14	.00	198.00	18.8564	52.59612
1,1-Dichloropropylene	0				
1,3-Dichloropropane	0				
Dibromochloromethane	0				
1,2-Dibromoethane	0				
Chlorobenzene	0				
1,1,1,2-Tetrachloroethane	0				
o-Xylene	0				
m&p-Xylene	0				
Xylenes, total	0				
Isopropyl Benzene	0				
Bromoform	0				

1,1,2,2-Tetrachloroethane	**0**				
1,2,3-Trichloropropane	**0**				
n-Propyl Benzene	**0**				
Bromobenzene	**0**				
1,3,5-Trimethyl Benzene	**0**				
2-Chlorotoluene	**0**				
4-Chlorotoluene	**0**				
tert-Butylbenzene	**0**				
p-Isopropyltoluene	**0**				
1,3-Dichlorobenzene	**0**				
1,4-Dichlorobenzene	**2**	**.05**	**17.90**	**8.9750**	**12.62186**
1,2-Dichlorobenzene	**0**				
1,2-Dibromo-3-chloropropane	**0**				
1,2,4-Trichlorobenzene	**0**				
Hexachlorobutadiene	**1**	**.6**	**.6**	**.600**	**.**
1,2,3-Trichlorobenzene	**0**				
cis-1,3-Dichloroprophylene	**0**				
trans-1,3-Dichloropropylene	**0**				
tert-Butyl-Alcohol	**0**				
Acetone	**23**	**4**	**60**	**25.20**	**12.863**
2-Butanone	**24**	**3**	**29**	**10.95**	**5.865**
Methylenechloride	**1**	**2**	**2**		

APPENDIX G: PESTICIDES TESTED INCLUDED AS PART OF THE WELL TEST PROGRAM WITH MEANS, MAXIMUM, MINIMUM AND NUMBER OF TIMES DETECTED FOR EACH CHEMICAL.

	N	Minimum	Maximum	Mean	Std. Deviation
Aldrin	0				
alpha-BHC	0				
beta-BHC	0				
delta-BHC	0				
gamma-BHC	2	.124	.200	.16200	.053740
Chlordane	3	.500	1.783	1.35433	.739876
4,4'-DDD	0				
4,4'-DDE	0				
4,4'-DDT	0				
Dieldrin	2	.029	.047	.03800	.012728
Endosulfan I	0				
Endosulfan II	0				
Endrin	1	2.0	2.0	2.000	.
Endrin Aldehyde	0				
Heptachlor	1	.4	.4	.400	.
Heptachlor Epoxide	1	.2	.2	.200	.
Toxaphene	1	3.0	3.0	3.000	.
Endrin Ketone	0				
Methoxychlor	1	40.0	40.0	40.000	.

APPENDIX H: SEPTIC SYSTEM DESIGN INCLUDING A DRAINFIELD FROM WHICH NITRATES AND NITRITES LEACH INTO THE SOIL AND ARE BROKEN DOWN BY BACTERIA AS PART OF THE NITROGEN CYCLE.