MODELING *N*-NITROSODIMETHYLAMINE AND TRICHLOROETHYLENE CONCENTRATIONS IN THE WILMINGTON, MASSACHUSETTS, WATER SUPPLY SYSTEM: 1974 TO 2000

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Table of Contents

List of Figures

List of Tables

List of Appendices (Appendices are contained in a separate document)

Executive Summary

Between 1987 and 1995 more children were diagnosed with brain cancer, leukemia, and Hodgkin's disease than expected in two census tracts in Wilmington, Massachusetts, based on state-wide childhood cancer rates. The discovery of *N*-nitrosodimethylamine (NDMA), a potent carcinogen, in the Maple Meadow Brook (MMB) aquifer led to the hypothesis that exposure to NDMA – and possibly other chemicals including trichloroethylene (TCE) – in the drinking water supply may in part explain the elevated cancer rates. NDMA is believed to have formed in the environment from precursor compounds from chemical manufacturing activities at the former Olin Corporation chemical plant, now a Superfund site, located in Wilmington about ½ mile from the MMB aquifer water supply wells. When these wells were pumping, NDMA that had dissolved into ground water beneath the Olin Site was drawn into the wells and thereby introduced into the Wilmington water supply system. Four of the five water supply wells in the MMB aquifer were permanently deactivated in 2002 and the fifth in 2003. TCE was also found in the water supply wells and in the drinking water distribution system in the early 1980s; however, the source of TCE is unknown.

The purpose of this study was to develop monthly concentration time histories of NDMA and TCE at specific Wilmington addresses for use by the Massachusetts Department of Public Health (MA DPH) in an epidemiological study. The major tasks were to (1) develop ground water flow and transport models to estimate historical NDMA concentrations within the aquifer and at the town water supply wells, and (2) develop a water distribution system model to estimate monthly-average pollutant concentrations in individual water supply pipes between 1974 and 2000 for NDMA and between 1981 and 2000 for TCE. The period 1974 to 2000 was selected for NDMA to bracket the earliest and latest possible exposure dates for children in the health study; 1981 was selected for the start of the TCE study because 1981 was the earliest date TCE was measured in the water distribution system.

To estimate the initial arrival time of NDMA to the wells and how NDMA concentrations at those wells changed over time, ground water flow and transport models were constructed. The underlying conceptual model was based on an earlier ground water model created by the Olin Corporation. The ground water models were configured to simulate changes in the three-dimensional flow field and resulting transport of NDMA through the aquifer at monthly time steps from 1965 through 2003. This simulation period begins earlier and ends later than the primary study period (1974 – 2000) in order to simulate the initial dispersion of NDMA into the aquifer, and to produce results that can be compared to measured concentrations collected in 2003 at each supply well.

The ground water flow and transport models were developed using MODFLOW and MT3D, respectively. The flow model was calibrated to historical measurements of potentiometric head at monitoring wells located across the model domain and at various depths. The transport model was calibrated to NDMA measurements in the water supply wells collected in 2003. Sources of NDMA were specified by assigning constant concentrations in areas with known high concentrations located deep within the MMB aquifer. Previously, the primary source of NDMA was believed to be dense aqueous phase liquid (DAPL) resulting from waste disposal and located in deep bedrock depressions near the Olin site. Our model results suggest the existence of an additional DAPL source of NDMA located within the MMB aquifer near the water supply wells in depressions known as the Western Bedrock Valley. This additional source is supported by measurement data collected within the aquifer. NDMA was also assumed to be a conservative substance not subject to formation or decay within the aquifer.

Based on historical records, which suggest that NDMA reached the MMB aquifer near the water supply wells in the early 1970s, the ground water model simulations estimate that NDMA reached the Chestnut St. #1 well in 1974 and the Butters Row #1 well in 1981. These two wells contained the highest NDMA concentrations ranging from approximately 50 to 250 ng/L. Both Butters Row #2 and Chestnut St. #1A/2 wells contained lower levels of NDMA and were contaminated for shorter periods of time relative to the Butters Row #1 and Chestnut St. #1 wells. Measurements indicate that NDMA did not reach the Town Park well, which was located farther to the north in the MMB aquifer relative to the other wells.

A hydraulic model of the Wilmington water distribution system was also developed using a commercially available software application, WaterCAD, to simulate the transport of NDMA and TCE from the supply wells and Butters Row Water Treatment Plant (WTP) to each point in the town's distribution system. The distribution model was based on a model of the system that had been developed for the town's water department in 2001 as well as various studies carried out for the water department, historical logs of system improvements reported in the town's annual reports, assessor's maps, and road maps. NDMA concentrations were specified for the supply wells and the Butters Row WTP using the results of the ground water model. The NDMA simulations of the water distribution system were performed at monthly time steps from 1974 through 2000. For TCE, the simulation period spanned from June 1981, when the Butters Row WTP was brought online, through 2000. The ground water model was not used to simulate TCE transport due to a lack of information on potential sources to the aquifer. Therefore, the TCE concentrations in water discharged from Butters Row WTP were based on historical measurements collected at the WTP. For both NDMA and TCE, all other water supply sources outside the MMB aquifer were assumed to have concentrations of zero. Both contaminants were also assumed to be conservative substances meaning they were not subject to chemical reactions that would result in their formation or decay within the distribution system.

The water distribution system model was evaluated by comparing simulated TCE concentrations against measurements collected at six locations throughout the system on July 31, 1986. The spatial penetration of contaminants into the system was found to primarily depend on the proportion of water discharged from the contaminated supply wells in the MMB aquifer and from the Butters Row WTP relative to the total town-wide water supply rate. The magnitude of concentrations in the distribution system strongly depended on the concentrations of the MMB aquifer source wells and the WTP. The contaminant distribution also depended to a lesser extent on the water demands of industrial and commercial users relative to domestic users, and on the pipe network configuration, which varied over the simulation period.

Based on the water distribution model results, simulated NDMA concentrations steadily increased from 1974 to June 1979 due to the initial contamination of the Chestnut St. #1 well. The extent of NDMA within the system, however, was relatively small with 31% of all pipes exceeding 1 ng/L and 12%

exceeding 50 ng/L. From July 1979 to May 1981, all wells in the MMB aquifer had been deactivated except Town Park, which was not contaminated with NDMA. However, when the Butters Row WTP was brought online in June 1981, NDMA concentrations rapidly increased. From 1981 through 2000, the spatial extent and magnitude of NDMA in the system varied widely from month to month, with the monthly mean and maximum concentrations computed across all pipes ranging from 5 – 39 ng/L and 12 – 114 ng/L, respectively. The percent of all pipes in the system with concentrations exceeding 50 ng/L reached a peak of 63% in November 1991. In March 1998, 27% of all pipes had concentrations exceeding 100 ng/L. NDMA exposure was primarily limited to the southern, central and western areas of town; exposure in the northern and eastern areas was relatively low because these areas primarily received water from uncontaminated sources (i.e., the northern water supply wells and Sargent WTP).

The water distribution model results also that TCE exposure was greatest from 1983 through 1986 due to high levels observed at the Butters Row WTP. Similar to NDMA, the greatest cumulative exposure occurred in locations near the Butters Row WTP within the southern, central and western areas of town. The highest TCE levels occurred in 1985 when the mean TCE concentration across all pipes reached 26 ug/L, and 60% of all pipes had concentrations exceeding 20 ug/L. From 1990 through 2000, TCE levels were below detection limits at the WTP and across the system.

Sensitivity analyses were performed to evaluate the impact of alternative model configurations, parameters, and input datasets on model results. For the ground water flow model, the sensitivities to alternative spatial discretization, simulation time step durations, and various hydraulic parameters were evaluated by comparing changes in the simulated potentiometric head at monitoring well locations near the MMB aquifer wells. The sensitivity of the water distribution model to diurnal variability in water demands was also evaluated.

Primary sources of uncertainty in the model results include the inability to simulate the transport of DAPL with conventional modeling tools, and uncertain knowledge with respect to (1) the timing, location, and source strength of contaminant source areas, (2) the assignment of historical pumping rates, and (3) the representation of changes in the physical configuration and operation of the water distribution system. An uncertainty analysis was performed by varying both the arrival time of DAPL to the Western Bedrock Valley in the MMB aquifer, and the pumping rates for supply wells during the period when pumping data were most limited. The results of this analysis provide uncertainty ranges of monthly NDMA concentrations for each pipe in the distribution system to be incorporated in the analyses performed by MA DPH.

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We are grateful to Mr. Mike Woods and Mr. Cliff Preble at the Wilmington Water Department for providing information on the water distribution system, to Ms. Naomi Slagowski for help with compiling the historical water quality data, and to the three peer reviewers, Dr. Morris Maslia, Dr. Noelle Selin, and Dr. Mary Ward, who provided useful comments on our report. Funding for this work was provided by MA DPH and a grant to MA DPH from ATSDR.

1 INTRODUCTION

The Massachusetts Department of Public Health (MA DPH) has determined that between 1987 and 1995 more children were diagnosed with brain cancer, leukemia, and Hodgkin's disease in two census tracts in Wilmington, Massachusetts than expected based on state-wide childhood cancer rates (MA DPH, 2002). The discovery in 2002 of *N*-nitrosodimethylamine (NDMA), a potent carcinogen (IARC, 1978), in the Maple Meadow Brook (MMB) aquifer has led to the hypothesis that exposure to NDMA, and possibly other chemicals, in the drinking water supply may in part explain the elevated cancer rates. However, no NDMA measurements were made in the water distribution system until February 2003, five months after the four of the water supply wells were shut off (the fifth was shut off in 2003); thus, the extent to which Wilmington residents may have been exposed to NDMA by consuming contaminated ground water from the MMB aquifer is unknown.

The major source of NDMA to the MMB aquifer is waste disposal from the Olin Corporation site (US EPA, 2005), which is located approximately ½ mile southeast of the former MMB aquifer supply well field (Figure 1.1). NDMA was not manufactured on the site nor was it a known byproduct of chemical manufacturing; however, due to its widespread distribution near the Olin Site and within the aquifer the U.S. Environmental Protection Agency (US EPA) concluded it is likely that NDMA-precursor compounds were present in waste materials released into lagoons, pits, and ditches on the site, and that these precursors then reacted in the subsurface to form NDMA (US EPA, 2005).

In addition to NDMA, trichloroethylene (TCE), a chlorinated volatile organic compound and probable human carcinogen (IARC, 1995), was detected in the Wilmington water supply system in the 1980s. The highest TCE levels were found in Butters Row wells #1 and #2 with concentrations of 620 and 438 μg/L, respectively. TCE was also present in finish water from the Butters Row Water Treatment Plant (WTP) reaching a maximum of 27 μg/L indicating that TCE was not completely removed during treatment. As a result, TCE was also detected at several sampling stations in the water distribution system at elevated levels (i.e., > 5 μg/L, the current drinking water standard for TCE). The highest concentrations of TCE were found in the system between 1981 and 1988.

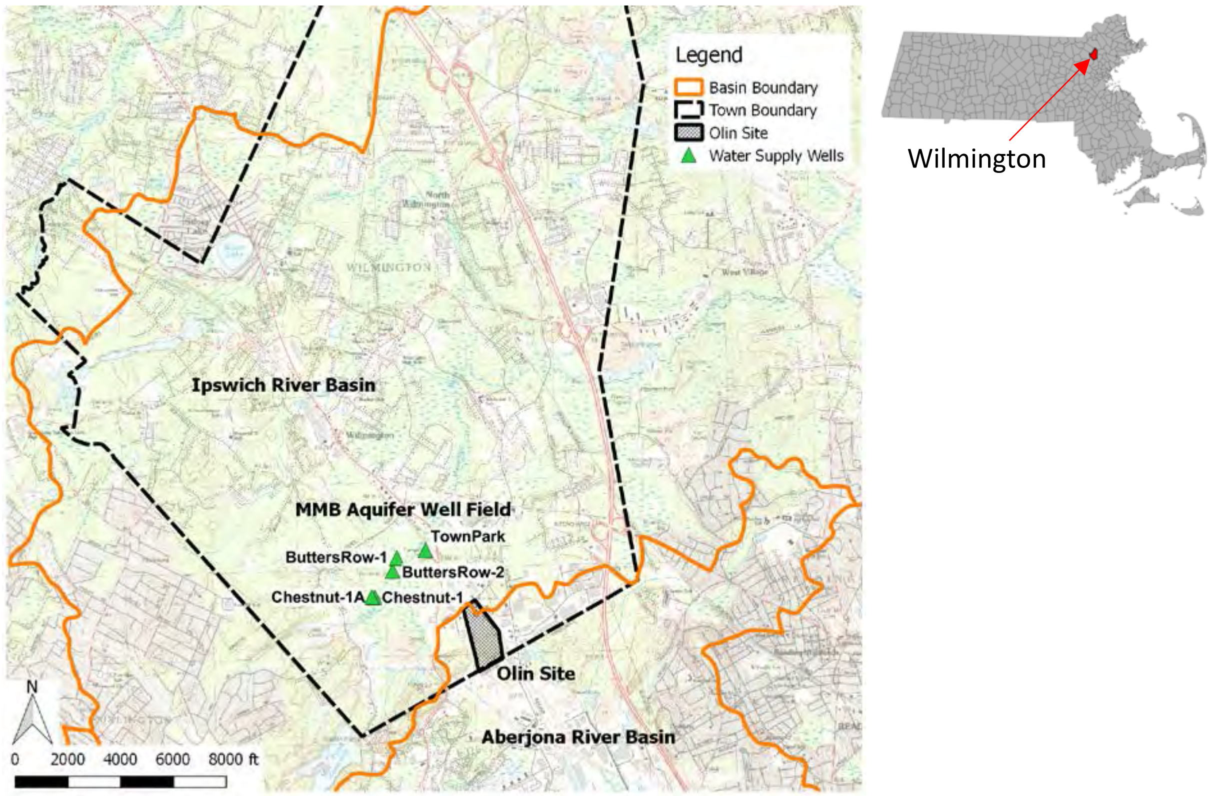


Figure 1.1: Location of Olin Site and Maple Meadow Brook aquifer water supply wells in Wilmington, MA.

1.1 Scope of Work

The primary goal of this study was to reconstruct monthly time histories of NDMA concentrations at each point within the Wilmington water distribution system. The results are intended to be used by MA DPH for determining whether an association exists between exposure to NDMA and the timing and location of disease incidence. In addition to NDMA, time histories of TCE concentrations were also reconstructed throughout the distribution system for use by MA DPH to determine if it also was associated with disease incidence.

The specific tasks that were carried out in meeting these goals include the following:

1. Develop ground water flow and transport models to simulate the transport of NDMA from contaminant source areas to the water supply wells in the MMB aquifer, and reconstruct monthly time histories of NDMA concentrations at each well from 1965 through 2003.
2. Develop a solute transport model for the water distribution system to simulate changes in NDMA concentrations at each point within the distribution system from 1974 through 2000. This time period was selected to be consistent with the period during which adverse health impacts were observed in Wilmington. The results are provided to MA DPH as monthly time series of NDMA concentrations for each pipe segment in the distribution system.

3. Conduct sensitivity analyses to evaluate the impact of alternative model configurations and parameter values on the simulated NDMA concentrations in both the aquifer and the water distribution system.
4. Conduct an uncertainty analysis by varying selected model inputs that have the greatest uncertainty and impacts on the simulation output. Results are provided as a monthly time series specifying uncertainty ranges of NDMA concentrations at each location in the distribution system given uncertainty in the selected model inputs.
5. Use the water distribution model to simulate the transport of TCE from the Butters Row WTP to each location in the distribution system based on historical TCE concentration measurements of the WTP's finish water from 1981 through 2000. The ground water models were not used to simulate TCE due to limited information on potential TCE sources to the aquifer. Similar to NDMA, results are provided as monthly time series of TCE concentrations for each location in the distribution system.

1.2 Organization of the Report

This report describes our effort to reconstruct monthly time histories of NDMA and TCE concentrations throughout the Wilmington water distribution system. The report contains seven main sections. In Section 2, we summarize background information relevant to the development of the ground water and water distribution system models. Section 3 provides a conceptual model of the system and describes the compilation of various datasets used for model development. In Section 4, we describe the development of the ground water and water distribution system models including the input datasets, parameter values, model calibration approaches, and sensitivity analyses. Section 5 presents results of the model calibrations, sensitivity analyses, and final simulations describing the temporal and spatial distribution of NDMA and TCE within the water distribution system. Sources of uncertainty are described in Section 6 and simulations are carried out to generate uncertainty ranges for the simulated NDMA concentrations at each location in the distribution system. The significance of the results and our conclusions are discussed in Section 7.

A description of historical chemical manufacturing activities at the Olin site as well as a review of contaminants reported in the MMB aquifer and water distribution system are provided in Appendices A through E. While these histories are useful for developing a more complete understanding of the constraints on the modeling effort (e.g., dates of chemical manufacturing activities, maximum reported chemical concentrations), it is not essential that these appendices be read prior to reading the main sections of the report.

Five additional appendices are provided: Appendix F contains historical ground water pumping rates that were used in the ground water model, Appendix G contains construction records for the water pipes that were used in the water distribution system modeling, Appendix H contains the concentrations of NDMA estimated by the ground water model in the water supply wells, Appendix I contains the record of water quality monitoring data from the Wilmington Water Distribution System, and Appendix J contains estimates of industrial/commercial water demands that were used in the water distribution model.

2 BACKGROUND

Prior to model development, background information was reviewed on the hydrogeology of the Olin site and MMB aquifer (Section 2.1), and on the structure and operation of the Wilmington water distribution system (Section 2.2).

2.1 HYDROGEOLOGY OF THE MAPLE MEADOW BROOK AQUIFER

The Olin Site lies near the surface water divide between the Ipswich River basin to the north and Aberjona River basin to the south (Figure 1.1). Surface topography in the area reflects the general topography of the underlying bedrock surface. A bedrock ridge line, at an elevation of 70 to 80 feet NGVD, runs diagonally across the lower/middle of the Olin facility from southwest to northeast (Figure 2.1). The bedrock surface dips into the Eastern Bedrock Valley to the southeast and into the Western Bedrock Valley to the northwest (Figure 2.2). At the southeast corner of the Olin site, bedrock rises to an elevation of over 100 feet NGVD. There is also another area of low-elevation bedrock, called the Southern Bedrock Channel, which spurs southwest of the Western Bedrock Valley near the Chestnut Street supply wells (Figure 2.2).

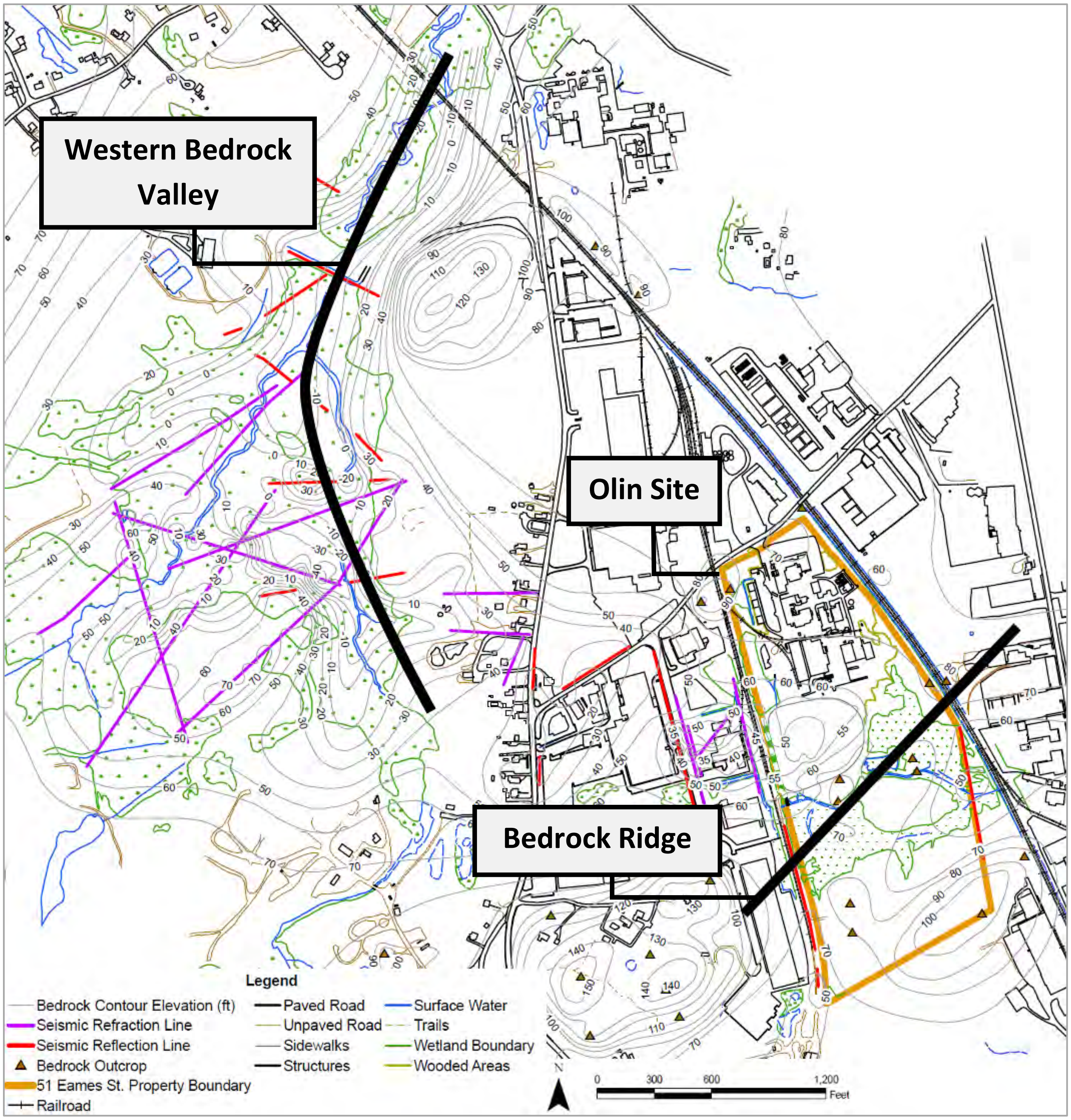


Figure 2.1: Top of bedrock elevation (feet, NGVD) at the Olin Site and Maple Meadow Brook aquifer where purple and red lines show alignment of seismic surveys used in interpretation of top of bedrock. Adapted from MACTEC (2007).

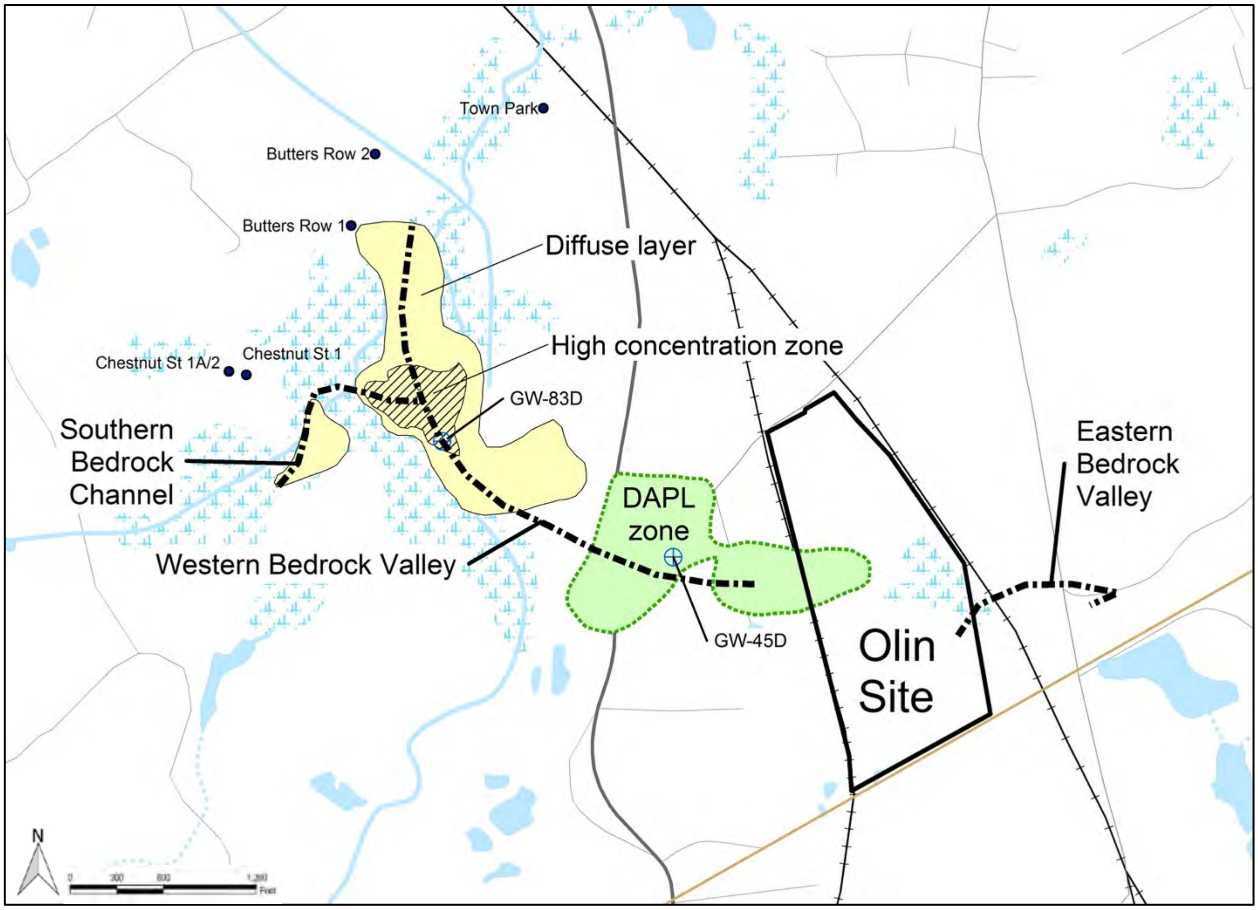


Figure 2.2: Major subsurface features of the Olin Site and Maple Meadow Brook aquifer. Based on GEI (2002) and Geomega (2003).

The bedrock underlying the Olin site consists of crystalline metamorphic and igneous rocks including gneiss, diorite, gabbro, and quartzite (Baker et al., 1964). These rocks, when intact, have very low hydraulic conductivity and are a negligible factor in ground water flow (USGS, 1995). However, rocks in the Wilmington area are generally fractured and folded. Fractures in the rock may be very efficient pathways for the flow of ground water, but the density and continuity of such fracturing varies widely. Consultants to Olin have determined that the bedrock is not an important factor in the flow of ground water from and around the site (Geomega, 2001a; MACTEC, 2007).

The geology atop the bedrock reflects many features created by Massachusetts's glacial geologic past. The bedrock is typically mantled by glacial till. Glacial till is the deposit created beneath moving glaciers and includes a considerable fraction of fine-grained soils created when glaciers slowly grind down the rock surface. This material has a low hydraulic conductivity on the order of 1 feet per day (Toppin, 1987), meaning it does not easily conduct the flow of ground water. The thickness of the till ranges from 10 to 20 feet in the Western Bedrock Valley, but is thinner or absent elsewhere (Geomega, 2001a). Where present, the till is generally an effective barrier to ground water flow between the bedrock and overlying soils.

New England bedrock valleys were typically filled with sand and gravel deposited by streams that flowed from the melting glaciers (USGS, 1995). Such glacial outwash deposits have only a small fraction of fine grained soils and are composed largely of sand and gravel. When such deposits are thick and spatially extensive, they are productive aquifers that can be used for municipal water supplies and other large volume ground water supplies. Such is the case for the Western Bedrock Valley, northwest of the Olin Site (Geomega, 2001a; Castle, 1959). The Western Bedrock Valley extends first northwesterly from the Olin site, but then turns to the northeast and beneath Maple Meadow Brook (Figure 2.1 and Figure 2.2). The Maple Meadow Brook aquifer was tapped by five wells to supply water to the town of Wilmington in locations known as Chestnut Street, Butters Row, and Town Park (Figure 2.2).

Swamp deposits as thick as 30 feet also overly part of the outwash deposits in the Maple Meadow Brook aquifer (Geomega, 2001a). These deposits consist of swamp muck and peat created in wetlands on the land surface. The swamp deposits have low hydraulic conductivity and, where present, act as a confining bed atop the glacial outwash.

Ground water flow beneath the Olin site reflects the bedrock and surface topography but is modified by ground water pumping (Geomega, 2001a). Although relatively little surface water drains northward from the Olin site (Figure 1.1), there is more northward ground water flow from the site. Ground water from the northern and western parts of the site flows towards the north and west, eventually to the Maple Meadow Brook aquifer. Ground water from the eastern and southern parts of the site flows east and south, where it discharges to shallow ditches near the eastern boundary of the Olin site and then flows south towards the Aberjona River.

2.2 Description of the Wilmington Water Distribution System

This section describes significant features of the water distribution system and changes over the study period that influence the transport of dissolved compounds introduced from contaminated ground water. The description relies on material documented in engineering reports prepared for the Wilmington Water Department by various consultants including Whitman & Howard (1973), FST (1988), and SEA Consultants (1996).

2.2.1 Water Sources

Over the study period (1974 – 2000) Wilmington's public water supply was derived solely from ground water sources located in three general regions within the town (Figure 2.3). The Barrows, Browns Crossing, and Salem Street wellfields are located east of Interstate Highway 93 (I-93) in the northern part of town. These wells are clustered around the Sargent Water Treatment Plant (WTP). The Butters Row #1, Butters Row #2, Chestnut Street #1, Chestnut Street #1A/2, and Town Park wells are in the southern part of town near the Butters Row WTP. Only four of these five wells (excluding Town Park) within the Maple Meadow Brook Aquifer are known to have been impacted by NDMA. The Shawsheen Avenue and Aldrich Road wells are located in the western part of town. Water supply wells have been taken out of service at various times due to changes in water quality (Table A.2 in Appendix A).

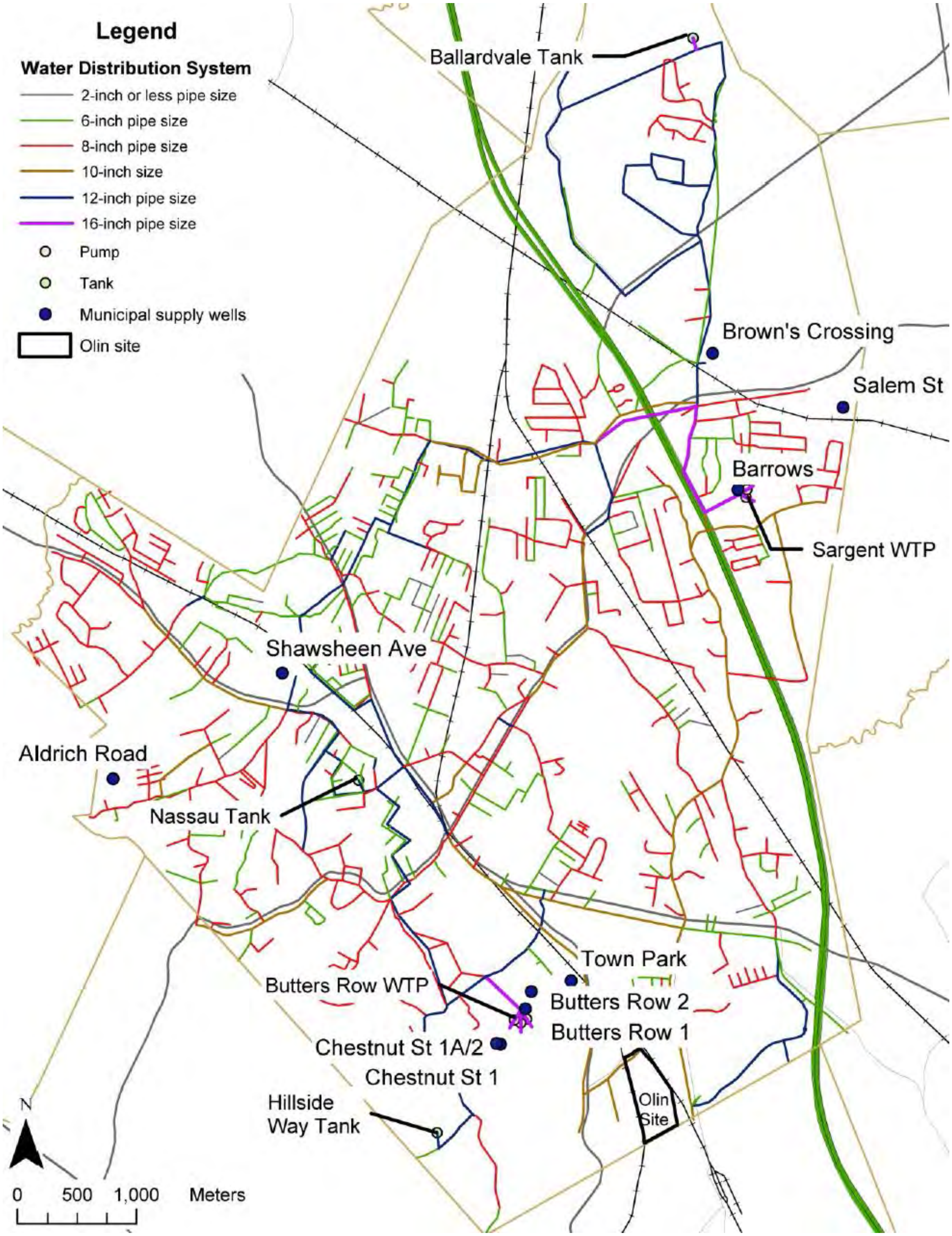


Figure 2.3: Map of the Wilmington water distribution system in 2000.

The Aldrich Road well has been out-of-service due to poor water quality since 1973. The Butters Row #1 well was technically in-service, but not used due to poor water quality over a period between 1973 and 1977. The Chestnut Street #1 well was taken offline between July 1979 and June 1981 due to TCE contamination. This well and the Butters Row wells were brought back online in June 1981 when the Butters Row WTP was brought online. Butters Row #1, Butters Row #2, Chestnut St. #1, and Chestnut St. #1A/2 wells were taken out of service in 2002 and the Town Park well was taken out of service in 2003. The combined pumping rate for all wells is shown in Figure 2.4 (see Section 3.2 and Appendix F for more details).

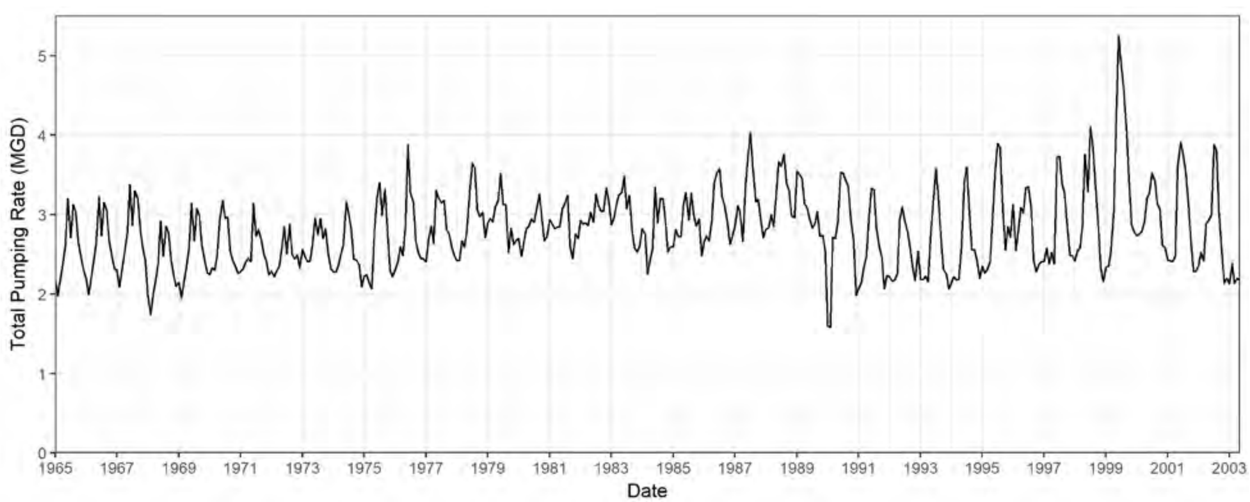


Figure 2.4: Total monthly rate of pumping reported by Wilmington water department

2.2.2 Water Treatment

By end of the study period in 2000, all water was being treated at either the Edmund Sargent WTP or the Butters Row WTP. The Butters Row WTP was brought online in June 1981 to treat water from the southernmost well field located in the MMB aquifer (including the Butters Row #1, Butters Row #2, Chestnut St. #1, Chestnut St. #1A/2, and Town Park wells). The Shawsheen Ave. well was connected to the Butters Row WTP in 2000, before which it injected water directly into the water distribution system. The Sargent WTP was brought online in May 1989 to treat water from the northern well field (including the Brown's Crossing, Barrows, and Salem St. wells).

The Butters Row WTP process is described in terms of its potential to remove NDMA during treatment. NDMA has not been observed in wells contributing to the Edmund Sargent WTP, so a comparable discussion of the treatment process at that plant is not included. The Butters Row WTP is designed to treat 3 million gallons per day (MGD), but it can treat up to 4 MGD in emergency situations. Raw well water is first passed through an aerator to remove volatile compounds. Next, chemicals are mixed with the water including alum (aluminum sulfate, a coagulant), a polymer to aid coagulation, lime for pH adjustment, potassium permanganate to oxidize iron and manganese, and chlorine gas for disinfection.

The water then passes through a gentle mixer to promote flocculation and a sedimentation tank where the large particles settle by gravity. While in the sedimentation tank, the water is exposed for about 100 minutes to ambient sunlight that is filtered through skylights overhead. After the sedimentation tank, water passes through granular activated carbon filters to promote removal of fine particles and hydrophobic organic compounds. The treated water is then stored in a 220,000-gallon clearwell and sent to the distribution system after receiving a final dose of chlorine (Geomega, 2002a). The potential impact of these water treatment processes on NDMA removal is described in Appendix E.

2.2.3 STORAGE TANKS

The water distribution system includes three storage tanks: Ballardvale, Nassau, and Hillside Way (Figure 2.3). These tanks help maintain the water pressure within the distribution system and provide reserve capacity for fire flow and other more common high demand periods. The available storage capacity for each tank, defined as the storage volume above elevation 270 feet, is 2.0 million gallons (MG) for Ballardvale Tank, 0.16 MG for Nassau Avenue Standpipe, and 0.56 MG for Hillside Way Standpipe.

Figure 2.5 and Figure 2.6 show the storage tank water volumes relative to the 1 AM volume for July 1, 1995 and July 1, 2000, respectively. The sum of the peak storage volumes for the three tanks on July 1, 2000 was 0.6 million gallons (about 20% of the daily demand). The flow in and out of storage on July 1, 2000 was less substantial.

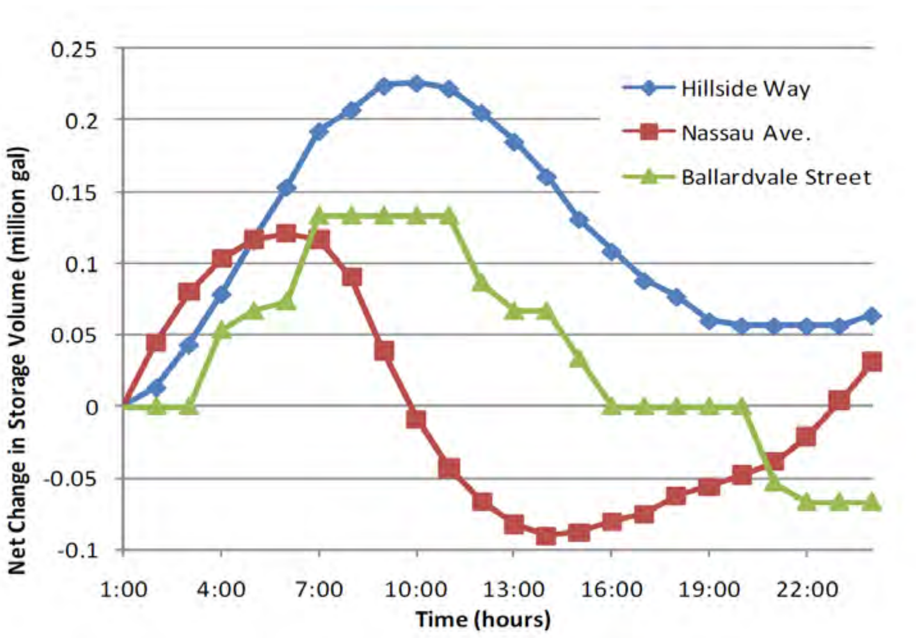


Figure 2.5: Storage tank water volume relative to 1 AM storage volume on July 1, 1995.Positive values denote volumes in excess of the starting volume.

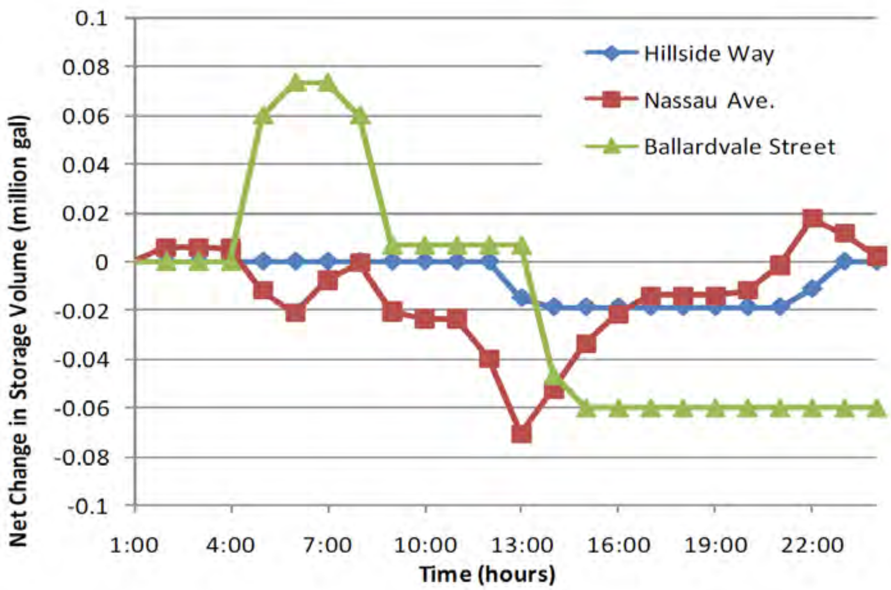


Figure 2.6: Storage tank water volume relative to 1 AM storage volume on July 1, 2000. Positive values denote volumes in excess of the starting volume.

2.2.4 Pipe Network

Changes to the distribution system network have been documented in the water department section of the town's annual reports. A detailed record of these changes is provided in Appendix G. Over the study period, the most substantial expansion to the pipe network occurred in the largely commercial area in the northernmost portion of town. This expansion of the system included the installation of the Ballardvale tank. New pipes were also installed to serve residential development. In older areas of town, some small diameter pipes were replaced by larger diameter pipes, and new pipes installed to eliminate the number of dead-end points within the system. There were also many large water mains installed to link the storage facilities and water sources.

3 Conceptual Model and Data Gathering

In this section we describe the conceptual model used to develop the ground water flow and transport models as well as the compilation of historical records for ground water pumping rates, water demands, and water quality that were used in development of the ground water and water distribution system models.

3.1 Conceptual Model

The quality of the ground water beneath the Olin site reflects a long history of disposal of waste materials from chemical manufacturing processes. The Olin facility began operation in 1953 as National Polychemical, Inc. (NPI), a manufacturer of specialty chemicals for the rubber and plastics industries (MACTEC, 2003b). National Polychemicals became a subsidiary of Stepan Chemical Company in 1968, which operated the facility until 1980 when it was sold to Olin Corporation. It was operated by Olin until its closure in 1986. See Appendix A for a detailed history of chemical manufacturing and waste disposal practices at the facility.

During its initial years of operation, untreated wastewaters were discharged to unlined lagoons on the facility (Figure C-2 in Appendix C) and allowed to seep into the ground (CRA, 1993). Disposal to the east and west pits and the “Lake Poly” lagoon is believed to have commenced in 1956. After construction of a warehouse in the location of the east and west pits in 1964, discharge to the “acid pits” began. In 1970, Stepan instituted treatment to neutralize acid wastewater and lined the lagoons. At first, the effluent from the lined lagoons was released to the ditches on the south side of the facility, but the discharge was diverted to the municipal sewer after sewer lines were constructed in 1972.

The Olin facility manufactured a broad range of products and thus produced a variety of wastes (CRA, 1993). Predominant chemicals included sodium and ammonium salts, urea, sulfuric acid, and various sulfates. The lagoon wastes therefore had high salinity and acidity. These wastes created unique chemical and physical conditions: the high salinity water was denser and therefore seeped down into the ground water beneath the site (Smith et al., 1997). It then pooled in low depressions on top of the underlying bedrock and persists today as three pools of Dense Aqueous-Phase Liquid (DAPL) on the west of the site (Figure 3.1) (AMEC, 2013).

The DAPL exists as an essentially distinct phase of salty, acidic water in the subsurface. Similar dynamics occur in coastal areas where fresh ground water floats atop salty water from the ocean. The interface between the fresh and salty water is not distinct in either the coastal zone or the Olin site: salt and chemicals diffuse (or mix) upward from the salty water layer into the fresh water layer creating a zone of intermediate concentration. At the Olin site, this water of intermediate concentration has been named the “diffuse” layer (GEI, 2002).

The pools of DAPL are characterized by high concentrations of inorganic ions (including sulfate, chloride, calcium, sodium, and ammonia), low pH, and a variety of organic compounds (including NDMA, acetone, bromoform, methyl ethyl ketone, methyl butyl ketone, toluene, trimethylpentanes, benzoic acid, bis(2-ethylhexyl) phthalate, 4-bromophenyl-phenylether, naphthalene, and phenol) (Smith et al., 1997). MACTEC (2003b) reports an NDMA concentration as high as 16,000 ng/L at one monitoring well (GW-45D) installed within the DAPL zone. From these DAPL pools, NDMA diffused into the Maple Meadow Brook aquifer where it was found at a maximum concentration of 25,000 ng/L in monitoring well GW-83D (MACTEC, 2007) (Figure 3.2).

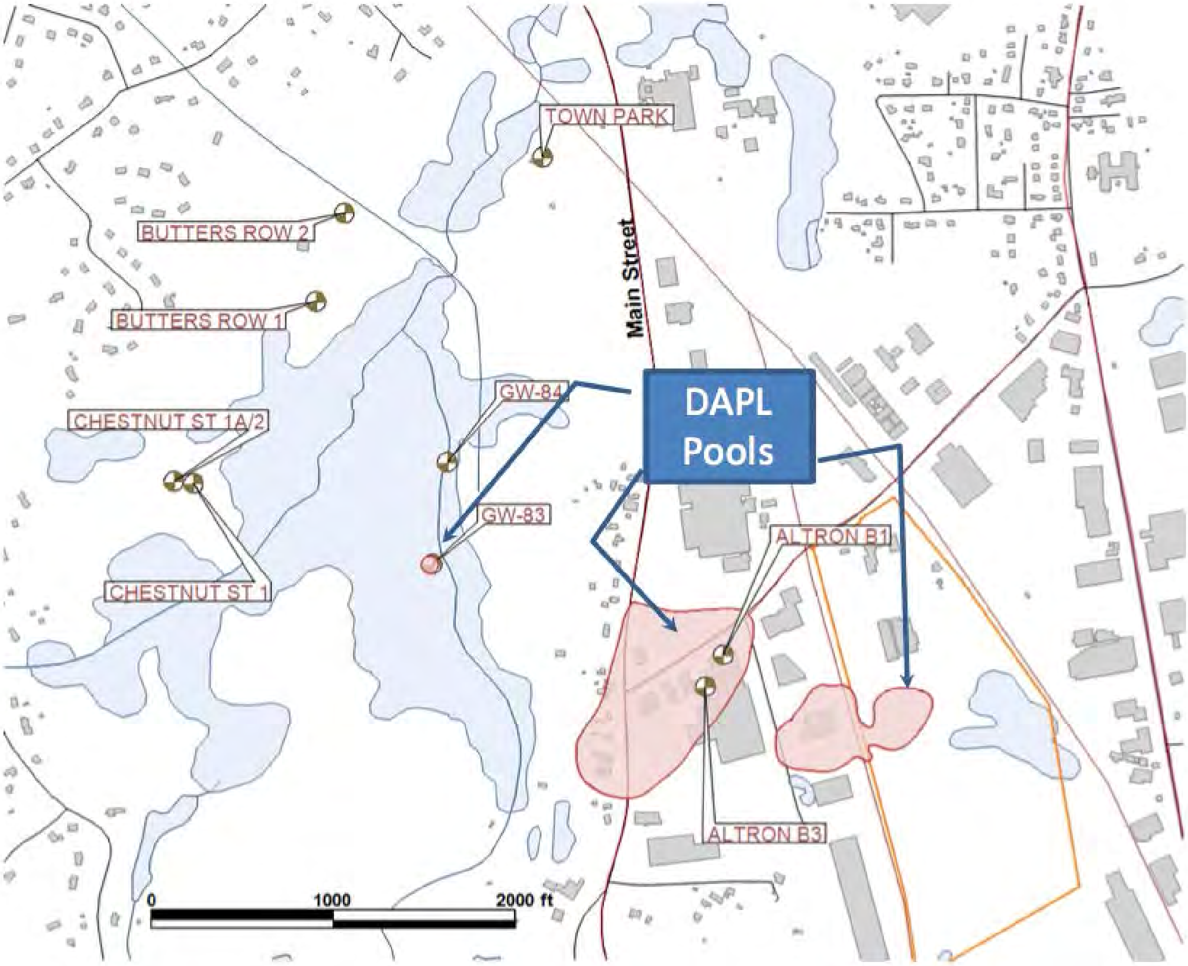


Figure 3.1: Location of DAPL pools. Adapted from Figure 2.1-7 of AMEC (2013).

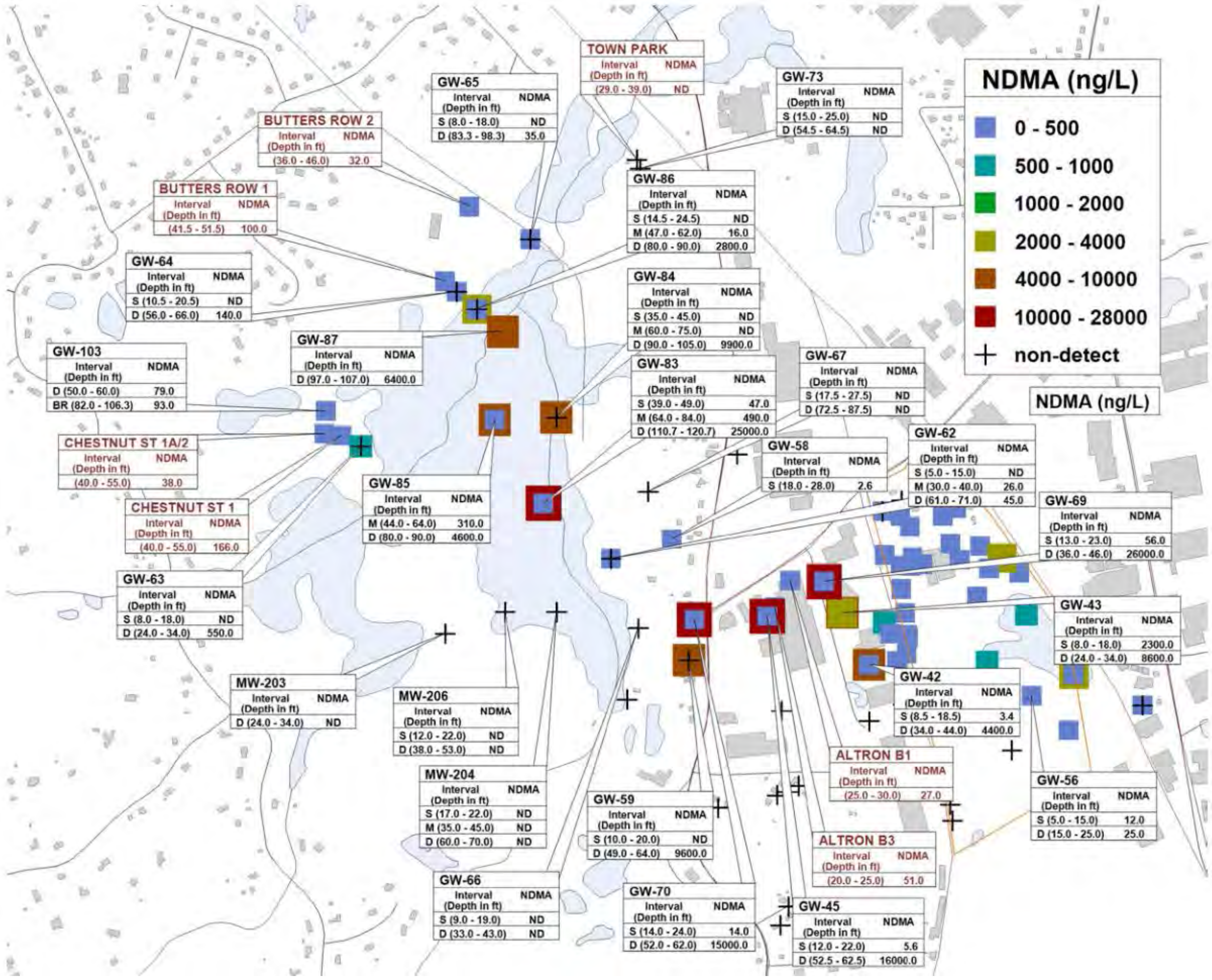


Figure 3.2: Maximum reported NDMA concentration in monitoring wells from 2002 through 2004

Based on this information, ground water simulations of dissolved NDMA were based on the following conceptual model:

1. Existing DAPL pools located within bedrock valleys were considered the principal sources of NDMA and associated indicator compounds to ground water;
2. Subsurface movement of DAPL occurred largely due to gravity-induced flow within bedrock valleys and was immobilized due to bedrock saddles that prevented the continued transport and formation of downslope DAPL pools;
3. Transport of NDMA and other constituents from DAPL pools into overlying ground water occurred by diffusive transport; and

4. NDMA was assumed to be a conservative substance within the aquifer meaning it was not subject to chemical reactions or other processes resulting in its formation or decay during transport from the DAPL pools to the water supply wells.

3.2 Municipal Supply Well Pumping Records

Ground water pumping from the five municipal water supply wells comprised a major withdrawal of water out of the MMB aquifer during the study period. This pumping had a large effect on the three-dimensional flow field and transport of NDMA from the DAPL pools to the supply wells and ultimately into the water distribution system. To accurately simulate historical ground water flow and transport conditions, time histories of monthly pumping rates from each municipal supply well in the MMB aquifer were reconstructed for the ground water model simulation period (1965 – 2003) using the best available datasets and information.

In addition to the MMBA wells, monthly pumping rates were also estimated for the municipal supply wells located outside the MMB aquifer in the northern and western areas of the town. Although these wells were not used in the ground water model, they were included as water supply sources in the water distribution model from the start of the simulation period, 1974, until 1989 when the Edmund Sargent WTP went online and began treating all water pumped from these other wells. From 1989 to the end of the distribution model period (2000), water from these wells was represented by the finished water produced by the Sargent WTP. Table 3.1 lists the periods of operation and pump capacities of the Wilmington water supply wells.

Table 3.1: Periods of operation and pump capacities of municipal water supply wells

Well Name	Installation Year[1]	Period of Operation[2]	Rated Pump Capacity (MGD)[3]
Southern Well Field (MMB Aquifer)			
Butters Row #1	1971	Jan 1971 – Dec 1972 Jul 1981 – Oct 2002	1.3
Butters Row #2	1979	Jul 1981 – Nov 2002	1
Chestnut Street #1	1960	Jan 1965 – Jun 1979 Jun 1981 – Aug 2002	1
Chestnut Street #1A/2	1992	Feb 1992 – Oct 2002	0.75
Town Park	1965	Jan 1965 – Jan 2003	0.5
Northern Well Field			
Barrows	1957	Jan 1971 – Dec 1984 Jun 1989 – May 2003	0.75
Brown's Crossing	1927	Jan 1974 – May 2003	1.5
Salem Street	1969	Jan 1979 – May 2003	1
Other Wells			
Aldrich Road	1966	Jan 1966 – Dec 1972	0.5
Shawsheen Ave.	1965	Jan 1965 – May 1989 Sep 2000 – May 2003	0.75

[1] Obtained from IEP (1990)
[2] Limited to the ground water simulation period, Jan 1965 – May 2003. Some wells were active before and/or after this period.
[3] Obtained from FST (1988) and SEA (2001)

Figure 3.3 shows the period of operation for each well at annual time steps. Among the MMBA wells, the Chestnut St. #1 and Town Park wells were the first to be installed in 1960 and 1965, respectively. In 1971, the Butters Row #1 well was installed only to be taken offline in 1972 due to water quality issues. The Chestnut St. #1 well was later taken offline in June 1979 following detection of elevated TCE concentrations. In June 1981, the Butters Row WTP was brought online to address the water quality issues from the three existing MMBA wells (Butters Row #1, Chestnut St. #1 and Town Park) and also to treat water from the newly installed Butters Row #2 well. The final MMBA well, Chestnut St. #1A/2, was installed in 1992 and also treated at the Butters Row WTP. Four of the MMBA wells were discontinued in 2002, and Town Park in 2003.

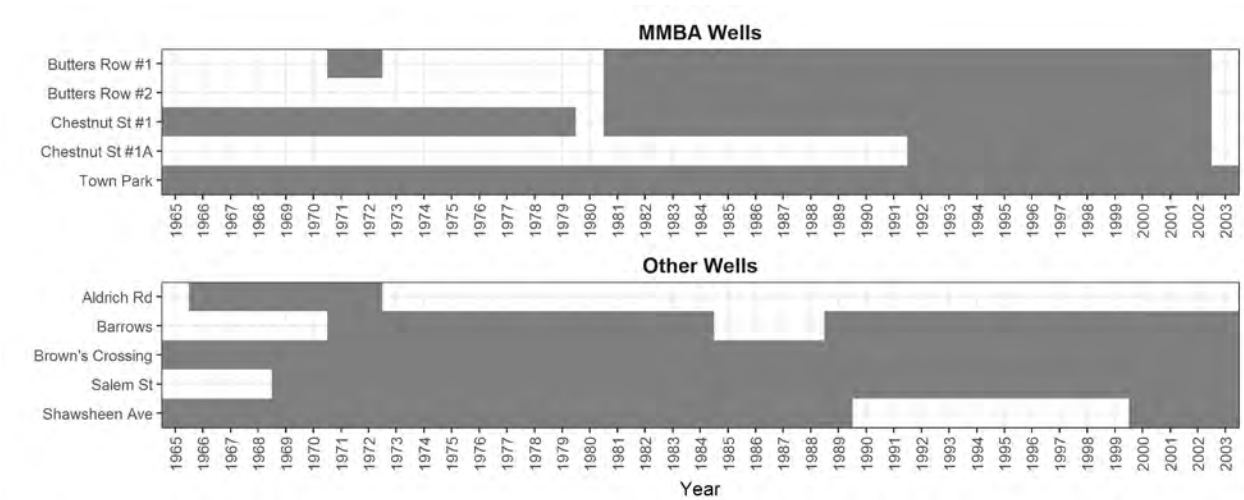


Figure 3.3: Periods of operation for each water supply well

Figure 3.4 summarizes the various datasets and methodologies used to reconstruct time histories of the monthly pumping rates at each well. Direct measurements of monthly pumping rates at each well were only available for January 1989 through 2003 and obtained from MACTEC (2005, Table 3-1). Prior to that, the monthly pumping rates were estimated using other information including total town-wide pumping, and total inflow to the Butters Row WTP.

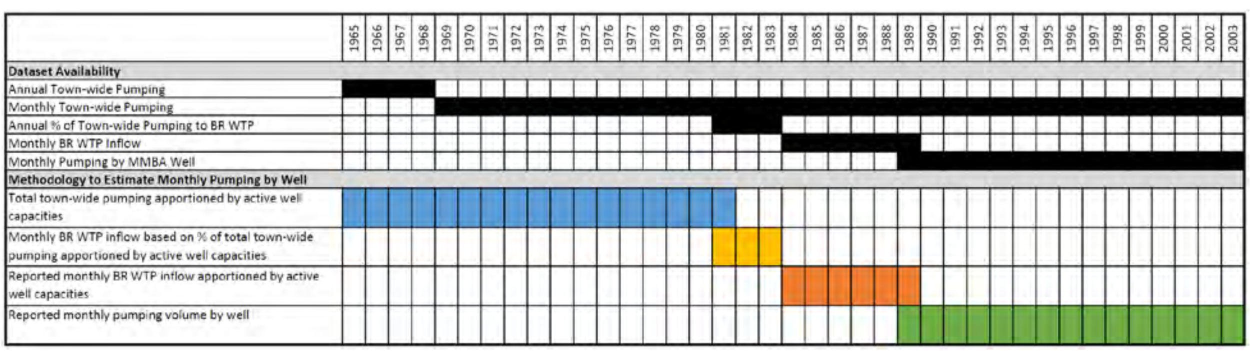


Figure 3.4: Datasets and methodologies used to estimate monthly pumping rates of the municipal supply wells

The following summary describes the data sources and methodologies for each of the four periods shown in Figure 3.4. The resulting pumping rates for each well for each month of the simulation period are provided in Appendix F.

- *January 1965 - May 1981*: Total annual (Jan 1965 – Dec 1968) and monthly (Jan 1969 – May 1981) town-wide pumping volumes were obtained directly from the town's water department. For the earlier period, the total annual pumping volumes were disaggregated to monthly values using the seasonal distribution from 1969 when total monthly pumping volumes were first available. Months when individual water supply wells were active/inactive during this period were determined from annual reports prepared by the water department. For each month, the total town-wide pumping volume was apportioned between the active wells based on the rated pump capacity of each well (Table 3.1) relative to the total capacity of all active wells in that month.

- *June 1981 - December 1983*: The total quantity of water treated at the Butters Row water treatment plant was first computed from total town-wide monthly pumping rates and the annual percentage of that total supply treated at the Butters Row WTP, which was derived from the water department's annual reports. The total amount of water treated at the Butters Row WTP in each month was then allocated between the four active MMBA wells based on the average fraction of total treated water supplied from each well and in each month from 1989 through 1991 based on reported monthly pumping rates in Table 3-1 of MACTEC (2005). Only data through 1991 were used to estimate the monthly fractions associated with each well; later years were excluded due to the addition of the Chestnut Street #1A/2 well in 1992, which affected the proportion of total treated water coming from each of the other four MMBA wells. The total monthly pumping rates from all non-MMBA wells were then computed by subtracting the total volumes treated at Butters Row WTP from the total town-wide pumping volumes. The pumping rates for the individual non-MMBA wells were then determined based on the ratio of individual well capacity to the total active well capacity.
- *January 1984 – May 1989*: The same method as the previous period was used except the monthly treated volume for Butters Row WTP was based on reported values from Table 3-1 of MACTEC (2005) instead of being estimated from the average annual percentage of total supply treated at Butters Row WTP.
- *June 1989 - May 2003*: The monthly volume pumped from each well was based on reports by the water department to MA DEP Division of Water Supply. These rates of pumping are presented in Table 3-1 of MACTEC (2005). Pumping volumes from the active wells outside the MMBA (Barrows, Brown's Crossing, and Salem St.) were treated at the Sargent WTP for which monthly treated volumes of finished water were obtained from the water department.
- *June 2003 - December 2003*: Because all wells in the MMB aquifer had been discontinued, pumping rates did not need to be estimated for this period.

Figure 3.5 shows the final estimated monthly pumping rates for the five water supply wells located in the MMBA. Figure 3.6 shows the total estimated pumping from the MMBA stacked by individual well, the sum of which represents total municipal supply pumping from the MMBA. Figure 3.7 shows the percent of that total for each well. The change in variability of the fraction of total MMBA pumping from each well around 1989 is due to the incorporation of monthly pumping records for individual wells, which were only available starting in 1989.

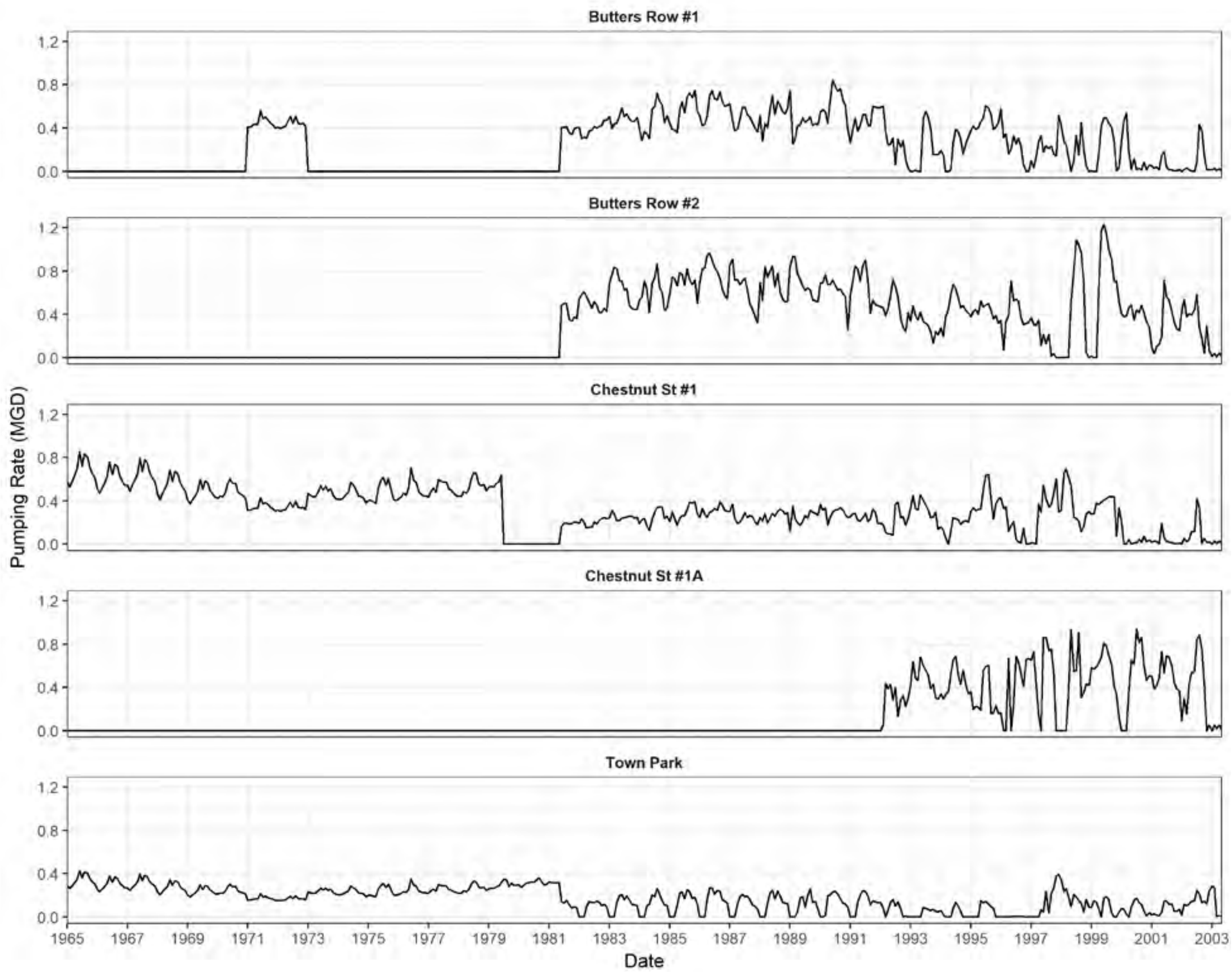


Figure 3.5: Estimated monthly pumping rates at MMBA water supply wells, Jan 1965 – May 2003

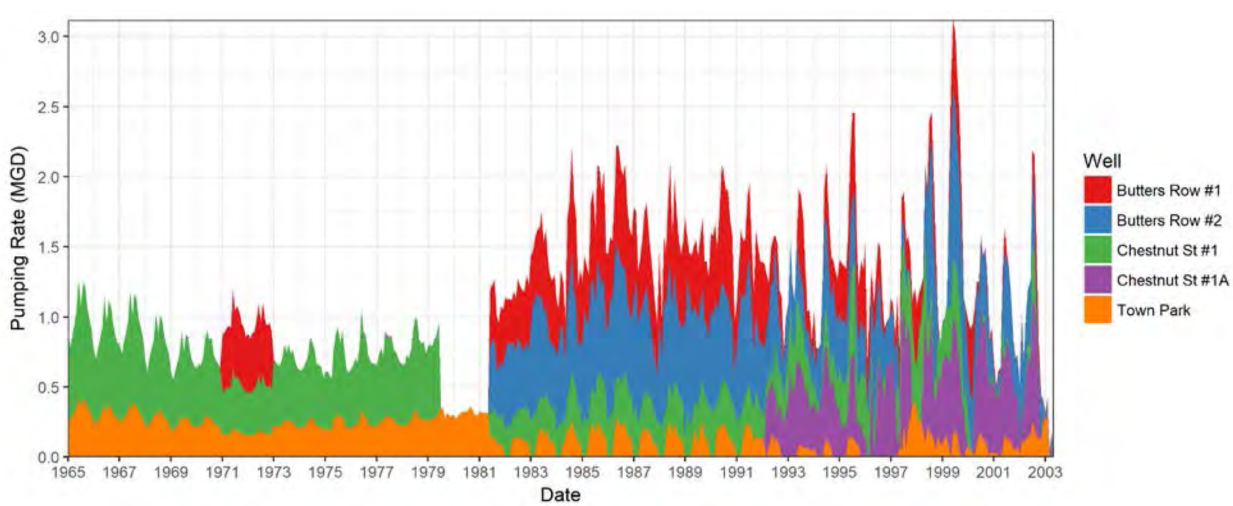


Figure 3.6: Total estimated monthly pumping rates in MMB aquifer, Jan 1965 – May 2003

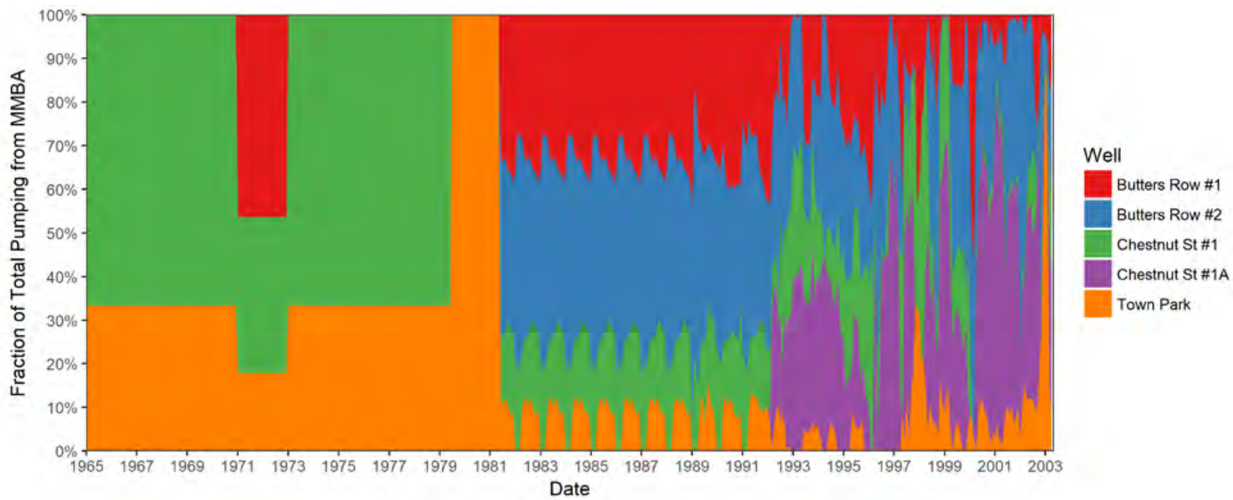


Figure 3.7: Fraction of total estimated monthly pumping rates by well in MMB aquifer, Jan 1965 – May 2003

Figure 3.8 shows the estimated monthly pumping rates for the wells located outside the MMBA from January 1974 to May 1989. After this period, the pumping rates for each individual well were not needed for the model because all water from these wells was represented in the total discharge rate from the Sargent WTP.

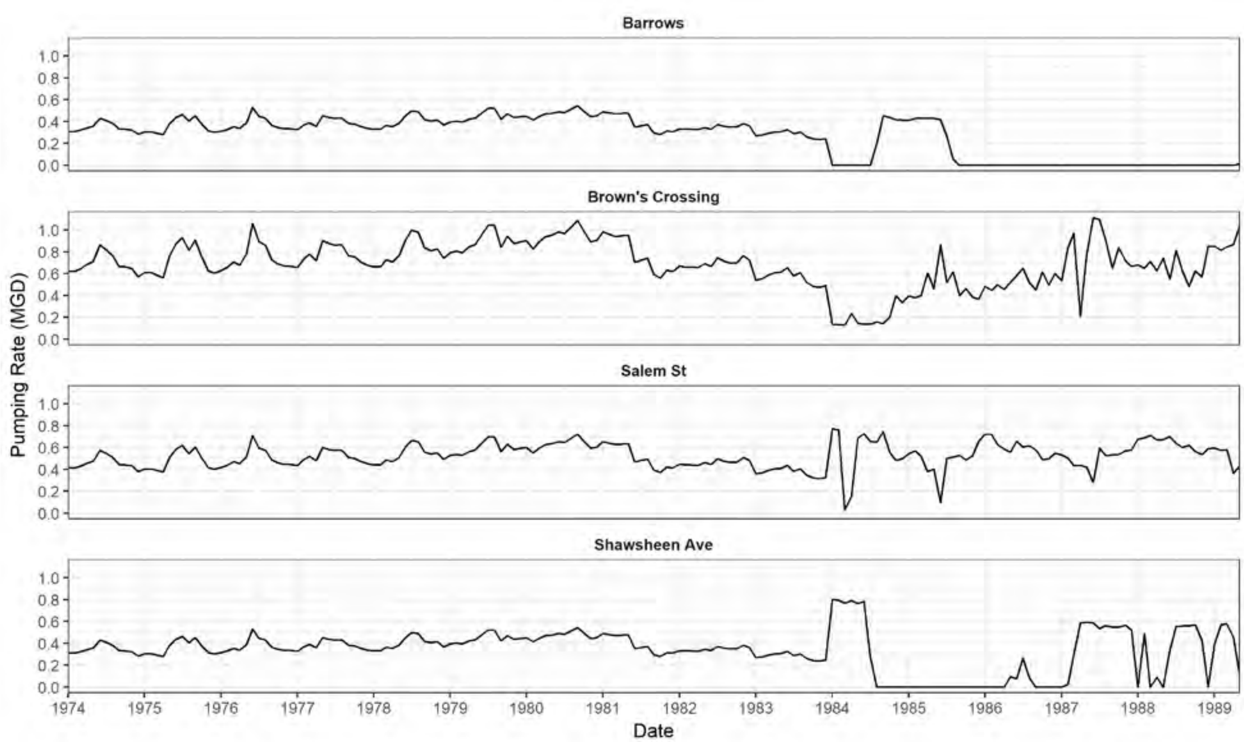


Figure 3.8: Estimated monthly pumping rates at non-MMBA water supply wells, Jan 1974 – May 1989

Figure 3.9 shows the total estimated monthly pumping rates among 1) the five MMBA wells and 2) the other town water supply wells. The sum of the pumping from these two well groups is equal the total town-wide pumping rate. Figure 3.10 shows the fraction of total monthly pumping for each group of wells. From 1965 to June 1979, pumping from MMBA accounted for between 27 and 40% of total town-wide pumping. From July 1979 to May 1981, the Town Park well was the only well in the MMBA that was operation due to water quality issues at the Chestnut St. #1 and Butters Row #1 wells. In June 1981, the Butters Row WTP was brought online to treat water pumped from the Butters Row #1 and #2, Chestnut St. #1 and Town Park wells, the sum of which accounted for 39% of total town-wide pumping, which rose to 50% in 1983. From 1984 through 2002, the fraction of town-wide pumping between the MMBA and non-MMBA wells appears more variable due to the use of monthly pumping records. Prior to 1983, historical data on pumping rates from individual wells was not available, and thus the monthly pumping rates were estimated using total town-wide pumping records apportioned based on active pump capacities. The four Butters Row and Chestnut St wells were deactivated in 2002, and the Town Park well was later deactivated in 2003.

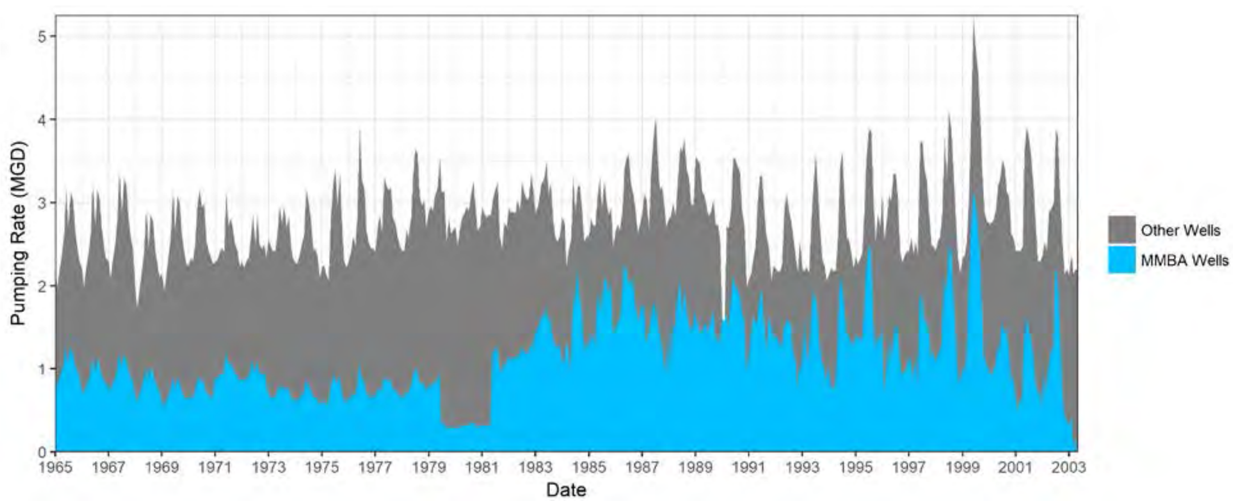


Figure 3.9: Total estimated monthly pumping rates in MMBA wells and other supply wells, Jan 1965 - May 2003

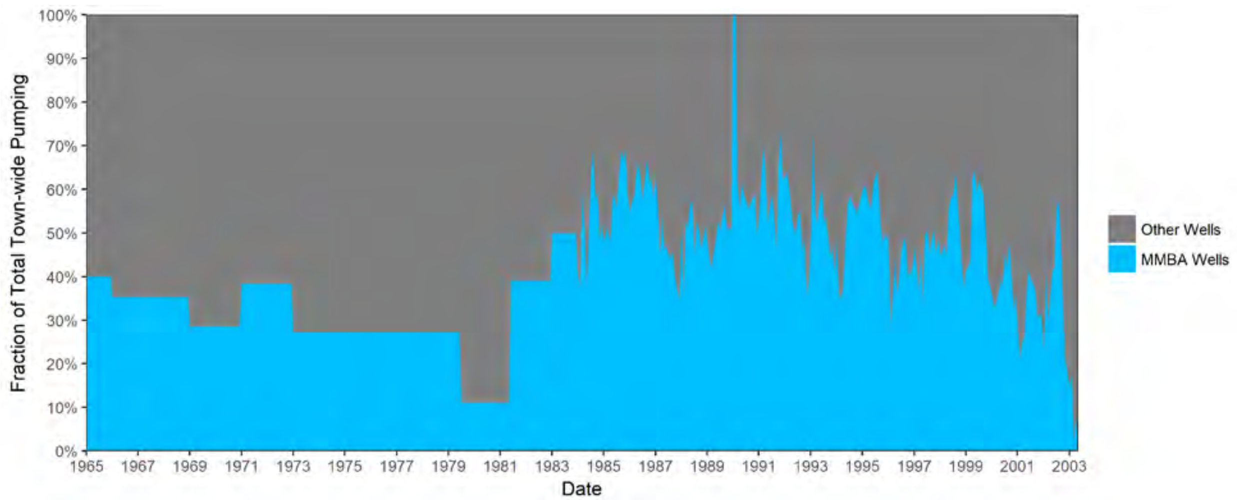


Figure 3.10: Fraction of total estimated monthly pumping rates for MMBA wells and other supply wells, Jan 1965 - May 2003

3.3 Remediation Well Pumping Records

In addition to the municipal water supply wells, there were two ground water remediation wells that also pumped water out of the MMBA during the study period. These two wells, B-1 and B-3, were installed at the former Altron (now Sanmina) industrial facility in 1977 and 1985, respectively, in the southeastern part of the aquifer near the Olin site (see Figure 4.1 below for their locations).

Monthly pumping rates from each of these two remediation wells were estimated using data presented in Geomega (2003). The B-1 well was active from October 1977 through February 2000, and the B-3 well was active from January 1985 through May 2003 (Geomega, 2001b). From 1985 through 1993, Smith (1997) reported an average total pumping rate for the two pumps of 0.136 million gallons per day (MGD). The pumping rate for each well was assumed to be half of this total, or 0.068 MGD each. From 1977 through 1984 before the B-3 well was installed, the pumping rate for B-1 was assumed to still be 0.068 MGD. From 1994 through 2003, monthly pumping rates at each well were based on reported weekly rates from Geomega (2006). Figure 3.11 shows the reconstructed time series of monthly pumping rates for the two Altron remediation wells.

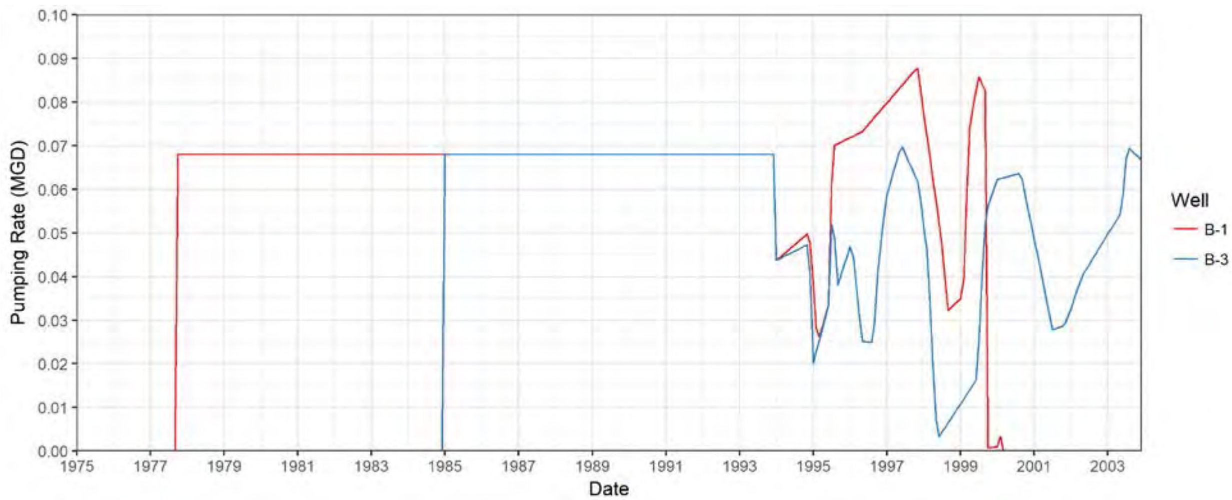


Figure 3.11: Estimated monthly pumping rates by the Altron remediation wells, 1975 – 2003

3.4 Water Demands for Industrial/Commercial Users

Preliminary model simulations showed that the distribution of NDMA emanating from the Butters Row WTP was sensitive to the magnitudes and locations of industrial and commercial water demands. These users have a large effect on pollutant transport through the system because they withdraw greater quantities of water out of the system relative to individual domestic users. To accurately represent the spatial and temporal distribution of these large demands, historical records were obtained the town's water department.

The process began by reviewing a summary of digital usage records provided by the Water Department for the period 2002 – 2015 (digital records were only available for this period). These records included the name and address of the largest 100 industrial and commercial users, as well as their total water usage over that period from which an annual average usage rate could be computed. Based on this list, the top 20 users with the largest demands over this period were identified. These users accounted for approximately 90% of the total industrial and commercial demands over the 2002 – 2015 period.

We then visited the Water Department archives and compiled historical billing and meter card data over the study period for the largest 20 users. For each of these users, the quarterly volume of usage was recorded at various points in time. For most users, usage records were obtained for one quarter every 1 to 5 years. Records on the installation dates of water meters were also compiled when available to determine the earliest possible date of usage for the corresponding user. For a few select users, all four quarterly billing records were obtained within a single year to determine if there were seasonal patterns in usage. These data showed that most industrial users did not have a significant or consistent seasonal usage pattern. Therefore, a usage rate for one quarter in a given year was assumed to represent the usage rate for that entire year. Gaps in usage data for each user were estimated by linear interpolation from the nearest two data points.

After the historical usage data were compiled, time histories of monthly usage demands were reconstructed for each of the largest industrial and commercial users. Quarterly usage rates were disaggregated to monthly rates assuming usage for all three months within the quarter was constant. If only one quarter of data was available in a given year, then that usage rate was assumed to represent the entire year. If multiple quarters were available, then the mean of those rates was used to represent the entire year. Years for which no data were available were estimated using linear interpolation between the two closest years with data. Table 3.2 lists the usage period and the average annual usage rate during that period for each user. Appendix J provides the dataset of historical usage records and the final estimated annual usage rates for each user.

Table 3.2: Estimated usage period and mean annual usage rate for each industrial/commercial user.

Billing Address	Usage Period	Mean Annual Usage Rate (gpm)
1 Burlington Road	1974 - 1999	27
1 Jewel Drive	1976 - 2000	82
100 Eames Street	1974 - 2000	19
100 Fordham Road	1974 - 2000	9
200 Ballardvale Street	1984 - 2000	7
201 Lowell Street	1974 - 2000	132
24 Industrial Way, Woburn[1]	1974 - 1977	143
251 Ballardvale Street	1974 - 2000	46
330 Ballardvale Road	1974 - 2000	4
350 Fordham Road	1974 - 2000	9
45 Industrial Way	1974 - 2000	26
50 Fordham Road	1974 - 2000	38
51 Eames Street	1974 - 2000	4
60 Concord Street	1974 - 2000	13
65 Industrial Way	1974 - 2000	11
730 Main street	1974 - 2000	49
80 Industrial Way	1974 - 2000	37
804 Woburn Street	1974 - 2000	141
829 Woburn Street	1974 - 2000	26
850 Main Street	1974 - 2000	18
90 Industrial Way	1978 - 2000	4

[1] User was physically located in the town of Woburn, but obtained water from Wilmington

Figure 3.12 shows the estimated total annual usage rates for the largest industrial and commercial users over the study period, as well as similar estimates from 1980 to 1995 as reported by SEA Consultants (1996) for comparison. The two datasets show reasonable agreement, but are not equal due to different methodologies. SEA Consultants (1996) did not describe the origin of their data nor which specific users were incorporated in their estimates; therefore, we could determine whether it was more or less accurate than our own estimates. However, the two datasets show general agreement with a decreasing trend from the early-1980s to mid-1990s.

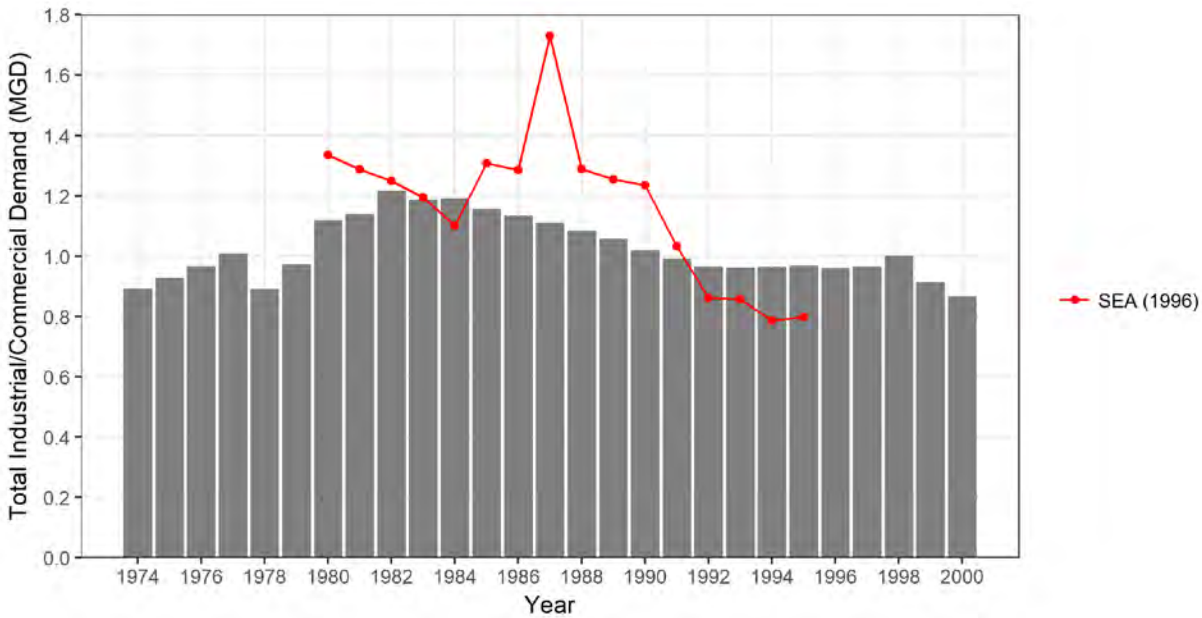


Figure 3.12: Annual total industrial/commercial demands estimated in this study and in SEA (1996)

As a further check of our estimates, we subtracted the total estimated annual industrial and commercial usage from the annual town-wide water supply rates to estimate domestic water demand. Using population data from SEA Consultants (1996), the domestic demand in gallons per day per capita was then calculated and is shown in Figure 3.13. These values range from about 75 to 120 gal/day/capita, which are typical for the region and therefore suggests the total industrial/commercial demand accounted for a reasonable fraction of the total town-wide supply.

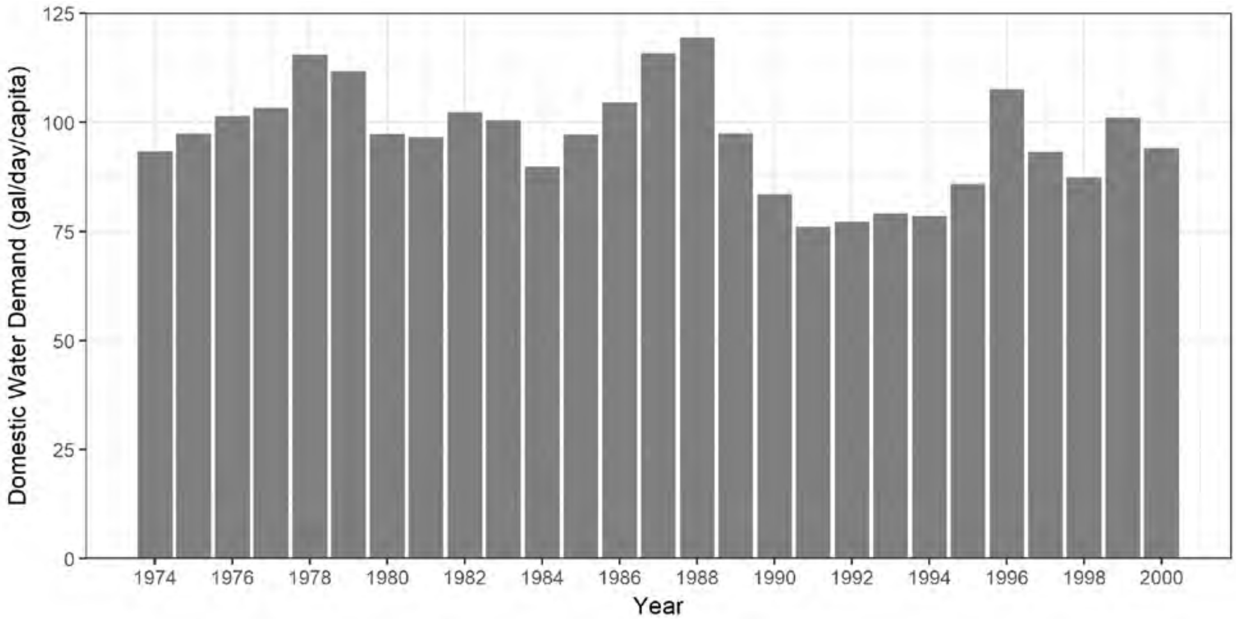


Figure 3.13: Average annual domestic water demand per capita estimated from total town-wide supply and major industrial/commercial user demands.

3.5 Water Quality Data

In October 2002, NDMA was detected in water samples from the Butters Row #1 and #2 wells and the Chestnut St. #1 and #1A/2 wells, and therefore these four wells were taken offline (US EPA, 2005). On February 24, 2003, the four wells were turned on again and pumped to waste for two days before being sampled and analyzed for NDMA. The results of the analysis are shown in Table 3.3. These are the only reported measurements of NDMA in water samples from the drinking water supply wells. All five wells were discontinued after the samples were collected in 2003 and have not been used for drinking water supply since then.

Table 3.3: NDMA concentrations measured in well water samples collected on February 26, 2003. Data from MACTEC (2003b).

Water Supply Well	NDMA Concentration (ng/L)
Butters Row #1	100
Butters Row #2	32
Chestnut St. #1	166
Chestnut St. #1A/2	38
Town Park	Not detected

NDMA measurements of Maple Meadow Brook aquifer water have also been performed to characterize contamination emanating from the Olin Site. This data was provided to us by MA DEP for the period July

1998 through May 2003 (C. Pyott, MA DEP, personal communication, 2006). Additional data was obtained from a study of NDMA contamination completed as part of the Olin Site investigation (MACTEC, 2003a, 2003b, 2004a, 2004b, 2007) as well as from routine monitoring of the aquifer (Geomega, 2005; MACTEC, 2005) (see Appendix C and Appendix D).

Historical TCE measurements were obtained directly from the Wilmington Water, which began measuring chlorinated volatile organic compounds (Cl-VOCs) in 1979 following the discovery of Cl-VOCs in municipal wells in nearby Woburn, MA. The Wilmington Water Department provided paper copies of water quality testing results as well as results compiled previously in an Microsoft Excel spreadsheet (M. Woods and C. Preble, Wilmington Water Dept., personal communication, 2006). The dataset contained TCE measurements from the water supply wells, the water treatment plant and the water distribution system (see Appendix D and Appendix I).

4 Model Development

Three numerical models were developed to simulate the transport of pollutants through the MMB aquifer from the DAPL pools to the water supply wells, and subsequently from the water supply wells to residents and other end users throughout the Wilmington water distribution system.

The three models include a ground water flow model, a ground water contaminant transport model, and a water distribution model. The ground water flow model simulates changes in the three-dimensional flow field and potentiometric heads within the MMB aquifer in response to changes in well pumping and other hydrologic conditions. The results of the flow model are then used by the ground water transport model to simulate the transport of NDMA from the DAPL pools to the town's water supply wells. Finally, the water distribution model simulates the transport of NDMA from the supply wells to end users for the study period from 1974 through 2000.

The water distribution model was also used to simulate the transport of TCE from the Butters Row WTP to end users from 1981 through 2000. For this simulation, the boundary conditions representing TCE concentrations at the Butters Row WTP were assigned based on historical measurements of TCE in the finished water. The ground water models were not used for the TCE simulations due to lack of information on potential sources of TCE to the aquifer.

The following sections describe the methodologies and datasets used to develop each of these three models.

4.1 Ground water Flow Model

A numerical ground water flow model was developed to reconstruct monthly time-histories of the three-dimensional flow field and potentiometric head in the MMB aquifer. In a numerical ground water flow model, the region of interest (the model domain) is discretized into a set of rectangular grid cells with common hydraulic properties. Physical laws describing the conservation of water and the relationship between potentiometric head and flow are represented by a set of equations whose solutions determine the head within each model cell and the horizontal and vertical flow rates between adjacent cells.

For this study, the U.S. Geological Survey's (USGS) numerical finite-difference model, MODFLOW (McDonald and Harbaugh, 1988), was selected for its ability to simulate the complex groundwater flow features found in the MMB aquifer. MODFLOW is a finite difference code that solves groundwater flow equations in three-dimensional systems under heterogeneous conditions for either steady-state or transient conditions. The model represents flow through the saturated portion of the aquifer. Simulated reductions or increases in the water table automatically modify the simulated saturated zone through changes in the active height of the uppermost layer and drying or wetting of individual nodes. The code imposes no constraints in vertical or horizontal resolution, allowing for accurate simulation of convergent flow where heads may be expected to change rapidly over relatively short distances. Representation of boundary conditions permit physically-realistic simulations of flow at hydrologic boundaries, such as streams, groundwater divides, and wells – all of which were present in the MMB aquifer. MODFLOW also incorporates representation of recharge and unconfined storage processes through the assignment of spatially variable specific storage and specific yield properties. MODFLOW is available for free as public domain software. The Groundwater Vistas v6 model interface (ESI, 2004) was used to construct the model, perform the simulations, and post-process the results.

The model developed for this study was based in large part on the ground water flow model originally described in Geomega (2001a), and later revised in Geomega (2006). Geomega developed their model to estimate the capture zone for each Wilmington water supply well, evaluate the seasonal movement of the ground water divide in the MMB aquifer, and compare alternative ground water remediation strategies. Although the input files for the Geomega model were not available for use in this study, the associated reports described the model configuration and results with sufficient detail to allow us to reconstruct their model and capture the salient features of the aquifer.

Development and calibration of the ground water flow model consisted of several steps. First, the horizontal and vertical domains of the area being modeled were established and discretized into rectangular grid cells. Next, boundary conditions representing no-flow, river and drain fluxes, constant head, recharge and well pumping were assigned to individual grid cells. Physical parameters such as the hydraulic conductivity and specific yield rates were then assigned based on values from the Geomega model. Once the physical representation and input datasets were defined, the model was calibrated to potentiometric head measurements compiled from various sources using transient simulations. The model was calibrated by adjusting model parameters in order to minimize the error in simulated potentiometric heads relative to the historical observations. Sensitivity analyses were also performed to evaluate the impacts of the spatial discretization, size of the simulation time steps, and values of various model parameters on the model's performance. The following sub-sections describe each of these steps in more detail. The results of the ground water flow model were used as a basis for the ground water contaminant transport model described in Section 4.2.

4.1.1 Domain and Discretization

The horizontal boundary of the model domain was based on that used in the Geomega (2001a) model and is generally consistent with zones of elevated bedrock that act as barriers to ground water flow. The domain was first discretized into grid cells with a uniform length and width of 50 feet based on a visual inspection of the Geomega (2001a) model and using best engineering judgment regarding the minimum discretization necessary to result in precise calculations of head gradients and the three-dimensional flow field.

The initial discretization was then refined to increase the spatial resolution in areas within the vicinity of the town's water supply wells. Reducing the size of the grid cells enhances the model's ability to accurately solve the system equations in locations with small scale features or large pumping rates that result in relatively large changes in head over short distances. The areas around the water supply wells were selected for increased resolution because pumping from these wells results in large changes in potentiometric head, thus having the highest sensitivity to the grid resolution. The grid rows and columns that passed near these supply wells were split in half yielding cells with a uniform length and width of 25 feet around the water supply wells. The grid resolution was not refined around the Altron B-1 and B-3 remediation wells because pumping rates of these wells were significantly lower than those of the water supply wells, and thus generated smaller potentiometric head gradients. A sensitivity analysis of the discretization showed that this refinement caused small changes on the order of +/- 0.1 feet in the simulated potentiometric head in these areas (see Section 5.1.3.1). Figure 4.1 shows the final extent and discretization of the horizontal model domain along with the bottom elevation of each grid cell and the location of each pumping well. Bottom elevations were obtained from Geomega (2006).

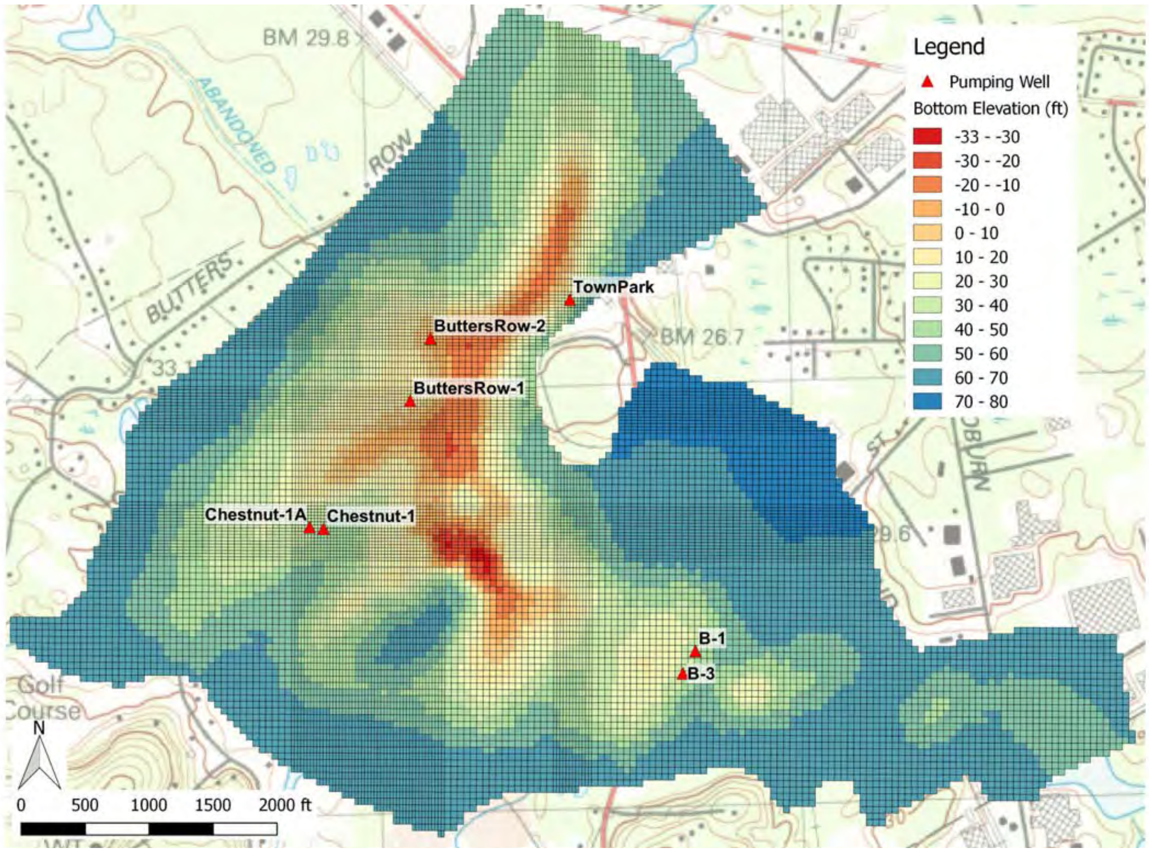


Figure 4.1: Horizontal domain and discretization of the ground water flow model

The vertical domain of the model was initially segmented into three layers. The bottom elevations of the top layer and middle layers were set to 60 feet and 30 feet above mean sea level, respectively, except in areas where elevated bedrock exceeded these elevations. In areas of elevated bedrock, the bottom elevations of the top and middle layers were adjusted as necessary to result in a minimum thickness of two feet within the bottom two layers. The bottom layer was bounded below by the bedrock elevations, which were obtained from Geomega (2006). Variations in the bedrock elevations are important aspects of the model because bedrock depressions have been shown to be reservoirs of DAPL emanating from the Olin site. A primary feature of the bedrock surface is a deep channel known as the Western Bedrock Valley (WBV) (see Figure 2.1 and Figure 2.2 above), which extends west from the Olin site to just east of the Butters Row wells. The high concentration DAPL that was originally discharged at the Olin site is believed to have flowed down along the bedrock surface and into the WBV under the influence of gravity (see Section 2.1).

The number of vertical layers was later increased from three to five by dividing the middle and top layers vertically in half. This increase in vertical discretization was performed to better simulate downward head gradients near the water supply wells and to better represent vertical differences in contaminant concentrations within the ground water transport model. The thickness of the bottom-most layer was not changed. Figure 4.2 includes a series of east-west cross-sections showing the change in thickness and elevation of each vertical layer across the model domain.

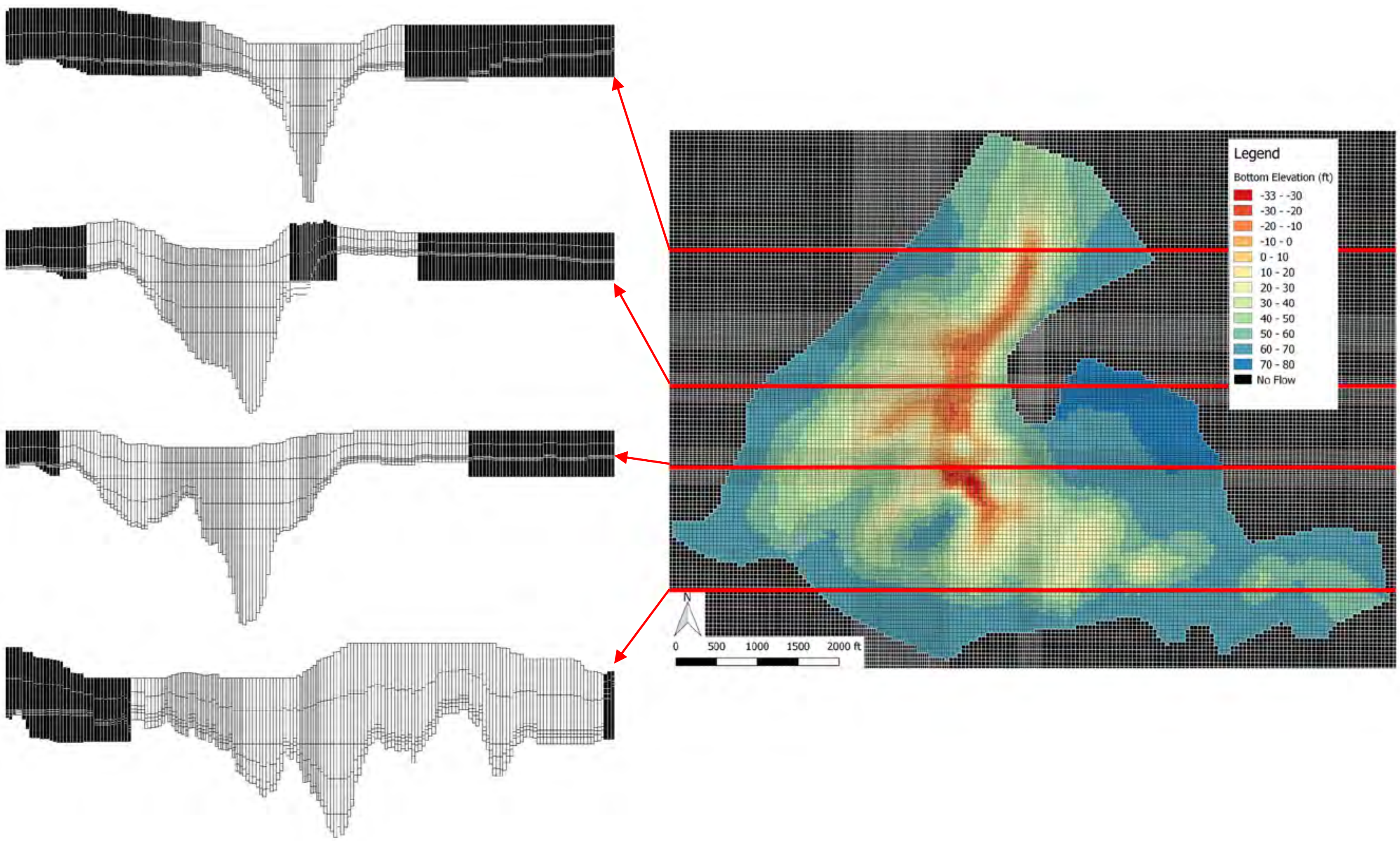


Figure 4.2: Cross-sections showing vertical layer discretization along east-west transects.

4.1.2 Boundary Conditions

After discretizing the horizontal grid and vertical layers, boundary conditions were assigned to individual grid cells. The following types of boundary conditions were implemented:

- **No Flow**
- **River**
- **Drain**
- **Constant Head**
- **Recharge**
- **Pumping**

Figure 4.3 shows which cells were assigned no-flow, river, drain and constant head boundary conditions within each of the five vertical layers. No-flow boundary conditions were assigned to all cells outside the model domain. Recharge boundary conditions representing rainfall infiltration (i.e., vertical recharge) were assigned to all cells in the top model layer. Horizontal recharge representing runoff from adjacent rock outcrops were also assigned around the perimeter of the model domain based on Geomega (2006). Well pumping boundary conditions were assigned to the grid cells corresponding to locations of the five water supply and two remediation pumping wells as shown in Figure 4.1. The following sub-sections describe each type of boundary condition in more detail.

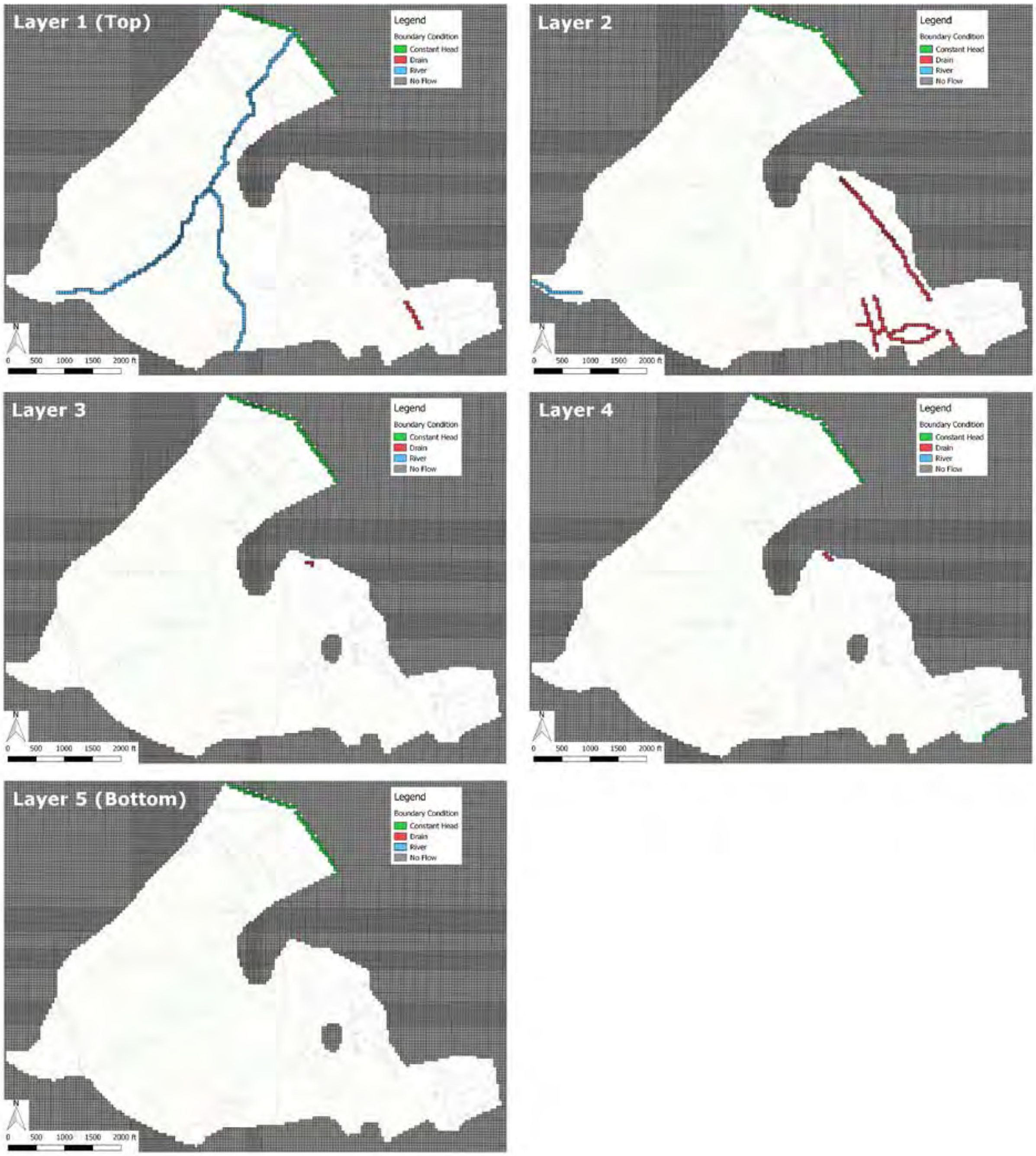


Figure 4.3: Boundary conditions assigned to grid cells in each layer of the ground water flow model.

4.1.2.1 Rivers

River boundary conditions were assigned to grid cells located along the Maple Meadow Brook and its tributary, Sawmill Brook (Figure 4.3). A river boundary condition allows for bi-directional flow between the aquifer and the overlying surface water bodies. The rate of flow exchange is proportional to the difference between the potentiometric head of ground water and the water surface elevation (i.e. stage) of the river in each grid cell. The flux rate between the river and the aquifer is computed as the product of this head difference and a conductance parameter, which controls the resistance to flow based on the composition of the river bed. When the ground water head falls below the elevation of the stream bed, the flow rate is the product of the conductance and the depth of water within the river. For each river boundary condition cell, the conductance, bed elevation, and a monthly time series of river stage were assigned.

The conductance of each cell was calculated in Groundwater Vistas as the product of the length, width, and hydraulic conductivity of the river bed within the cell, and divided by the bed thickness. The width, hydraulic conductivity and thickness were assumed to be constant across all river grid cells with values of 10 feet, 1 feet/d, and 1 feet, respectively. The length of the bed within each cell was computed automatically by Groundwater Vistas based on the flowline delineation of the rivers.

The river stage in each cell was set to a constant value in all months except when the river became dry (see next paragraph). The stage values in each cell were based on measured water stage as reported in Law (1998), Law (1999), Law (2002), MACTEC (2003a), and MACTEC (2005). The bed elevation in each cell was set to 3 feet below the river stage in each cell.

During the initial calibration of the ground water flow model, we observed several large-magnitude, short-term depressions in water elevation of monitoring wells located near water supply wells that were not captured by the model. This was thought to be an important flow-field feature because these events likely coincided with dry stream conditions during which the capture zone to a well would temporarily increase in size. Because historical river stage data were not available over the entire simulation period, we used a linear regression model to estimate the occurrence of depressed water levels based on estimated recharge and total pumping within the MMB aquifer. This resulted in the identification of month-long stress periods during which the river boundary conditions were modified to represent dry conditions by setting the stage equal to the bed elevation. The occurrences of dry conditions are specified in Table 4.1.

Table 4.1: Estimated occurrences of dry river conditions

Year	Months
1983	July – September
1984	September – October
1986	October
1987	July – September
1988	July – October
1990	July – August
1991	July
1993	July – August
1994	August
1995	July
1997	July – October
1998	September – October
1999	July – October
2002	August – September

4.1.2.2 Drains

Drain boundary conditions were assigned to represent flood-control drains located around the Olin site in the eastern portion of the model as shown in Geomega (2001a, Figure 15) (Figure 4.3). Drain boundary conditions are similar to river boundary conditions, except flow can only occur in one direction: from the aquifer to the drain. Drainage flows occur when the potentiometric head of the ground water exceeds the specified water surface elevation within the drain. Drains are therefore only active when the ground water head is relatively high. The water elevation in each drain cell was determined by examining the topography of the area. The specified drain stages were maintained at a constant elevation over the duration of the simulation.

4.1.2.3 Recharge

Recharge boundary conditions represent the influx of water to the aquifer from either rainfall infiltration (vertical recharge) or runoff from neighboring rock outcrops outside of the model domain (lateral recharge). During the initial model development, vertical recharge was assigned to all grid cells in the top model layer at a rate of 20.1 inches per year, which is the same rate used in Geomega (2001a). Lateral recharge zones around the model boundary were also defined in the top vertical layer based on Figure 14 of Geomega (2001a).

However, preliminary results showed that the model did not adequately capture seasonal patterns in potentiometric head measured at various monitoring wells. Over the course of the year, recharge rates tend to vary with lower rates occurring during the summer due to high evapotranspiration, and higher rates during winter due to snow melt and low evapotranspiration. To better capture this seasonal variability, a monthly time series of vertical recharge was constructed for the entire simulation period.

Monthly recharge rates were estimated from historical rainfall data for the town of Wilmington using the methodology presented by Lyford and Cohen (1987). Lyford and Cohen applied a water balance technique to estimate the amount of water available for recharge based on total rainfall in six communities in the northeast United States. Their results for Middletown, CT were assumed to be representative of conditions in Wilmington. For each month of the year, Lyford and Cohen report the total amount of water available for recharge based on long-term average monthly rainfall. Using this dataset, we calculated the average percent of total annual rainfall that is available for recharge in each month (Table 4.2). The percentages in that table show little or no recharge occurring from May through August, and that the highest recharge rates occur in November through December as well as March.

Table 4.2: Monthly average water available for recharge. Computed from results for Middletown, CT in Lyford and Cohen (1987).

Month	% Of Annual Precipitation Available for Recharge
January	7.0
February	7.8
March	9.3
April	2.8
May	0.2
June	0.0
July	0.0
August	0.0
September	2.3
October	4.6
November	9.0
December	9.2

To estimate the amount of recharge in each month over the simulation period, we used the following method:

1. For each month, compute the 12-month sum of total precipitation prior to that month.
2. Multiply the previous 12-month precipitation by the corresponding factor in Table 4.2 for the given month.
3. Reduce the amount of available water from step 2 by 15%, which was applied to improve the model calibration.

Monthly rainfall totals were obtained for the town of Wilmington from the Massachusetts Executive Office of Energy and Environmental Affairs website (http://www.mass.gov/eea/agencies/dcr/water-res-protection/water-data-tracking/rainfall-program.html; accessed March 2015). The monthly measured rainfall and estimated recharge for the simulation period from 1965 through 2003 is shown in Figure 4.4. The average annual recharge rate based on these monthly rates is 22.8 in/yr, which is similar to the constant value of 20.1 in/yr used by Geomega (2001a).

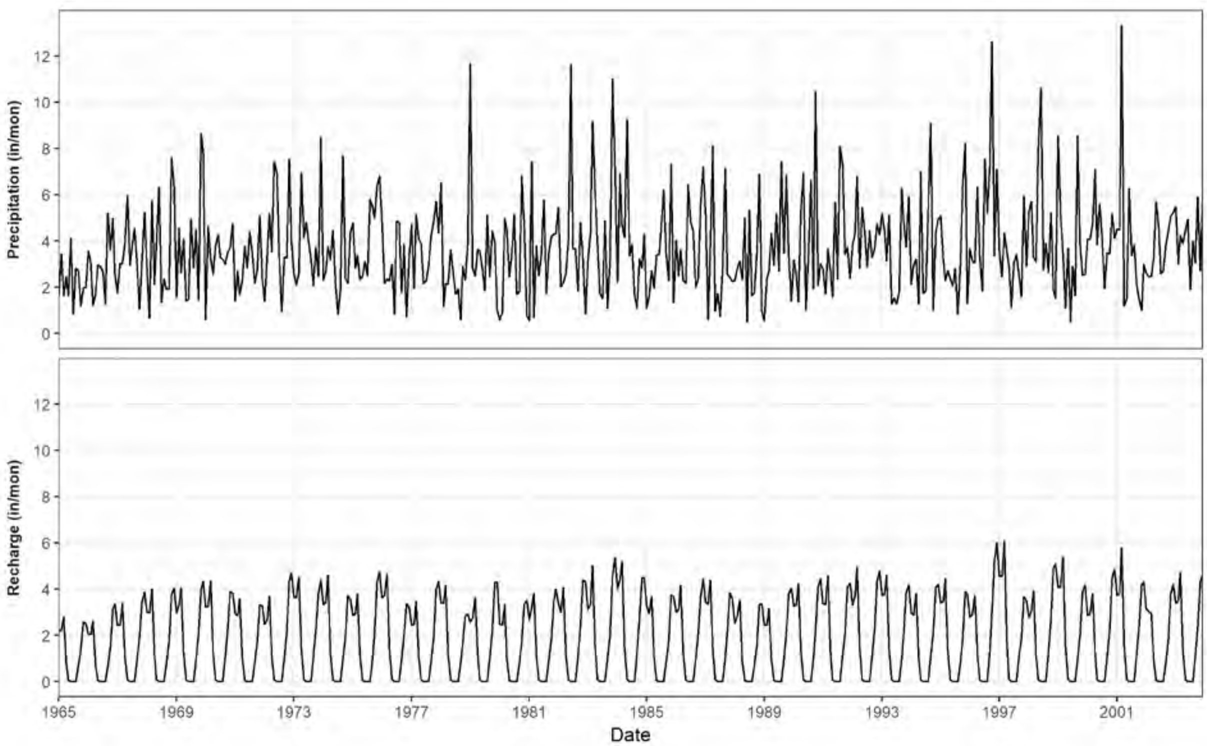


Figure 4.4: Monthly measured precipitation and estimated recharge

4.1.2.4 Well Pumping

Well pumping boundary conditions were assigned to grid cells corresponding to the locations of the five water supply and two remediation wells (Figure 4.1). The vertical layer associated with each well was assigned based on the top and bottom elevations of the well screen (Table 4.3). The monthly pumping rates for each well were reconstructed for the entire simulation period from various data sources as described in Sections 3.3 and 3.4.

Table 4.3: Screen elevations and vertical layers associated with pumping wells

Pumping Well	Screen Elevation Range (feet)	Vertical Layer(s)
Altron B-1	60 – 65	2
Altron B-3	65 – 70	2
Butters Row #1	33.5 – 43.5	4
Butters Row #2	35 – 45	3, 4
Chestnut St #1	45 – 60	2, 3, 4
Chestnut St #1A/2	45 – 60	2, 3, 4
Town Park	42.7 – 52.7	3, 4

4.1.2.5 Constant Head

Constant head boundary conditions were assigned to grid cells along the northern boundary of the model where Maple Meadow Brook flows out of the model domain. The specified head at each cell was set to a constant value equal to the land surface elevation. These boundary conditions were applied based on the assumption that where the Maple Meadow Brook and its tributary cross the northern boundary of the model, flow would be to be directed toward the stream and parallel to the boundary of the model domain.

4.1.3 Physical Parameters

4.1.3.1 Hydraulic Conductivity

Hydraulic conductivity represents the resistance to ground water flow due to the composition of the subsurface materials and is specified using three parameters, one for each direction in three dimensions. The grid cells in each layer were grouped into zones with each zone having constant values for the three hydraulic conductivity parameters. The delineation of these zones was based on that in Geomega (2001a, Figures 16, 17, and 18). The values were initially set equal to those used in Geomega (2001a), but later adjusted during the model calibration process. Figure 4.5 shows the hydraulic conductivity zones in each model layer and Table 4.4 lists the calibrated horizontal and vertical conductivity values corresponding to each zone.

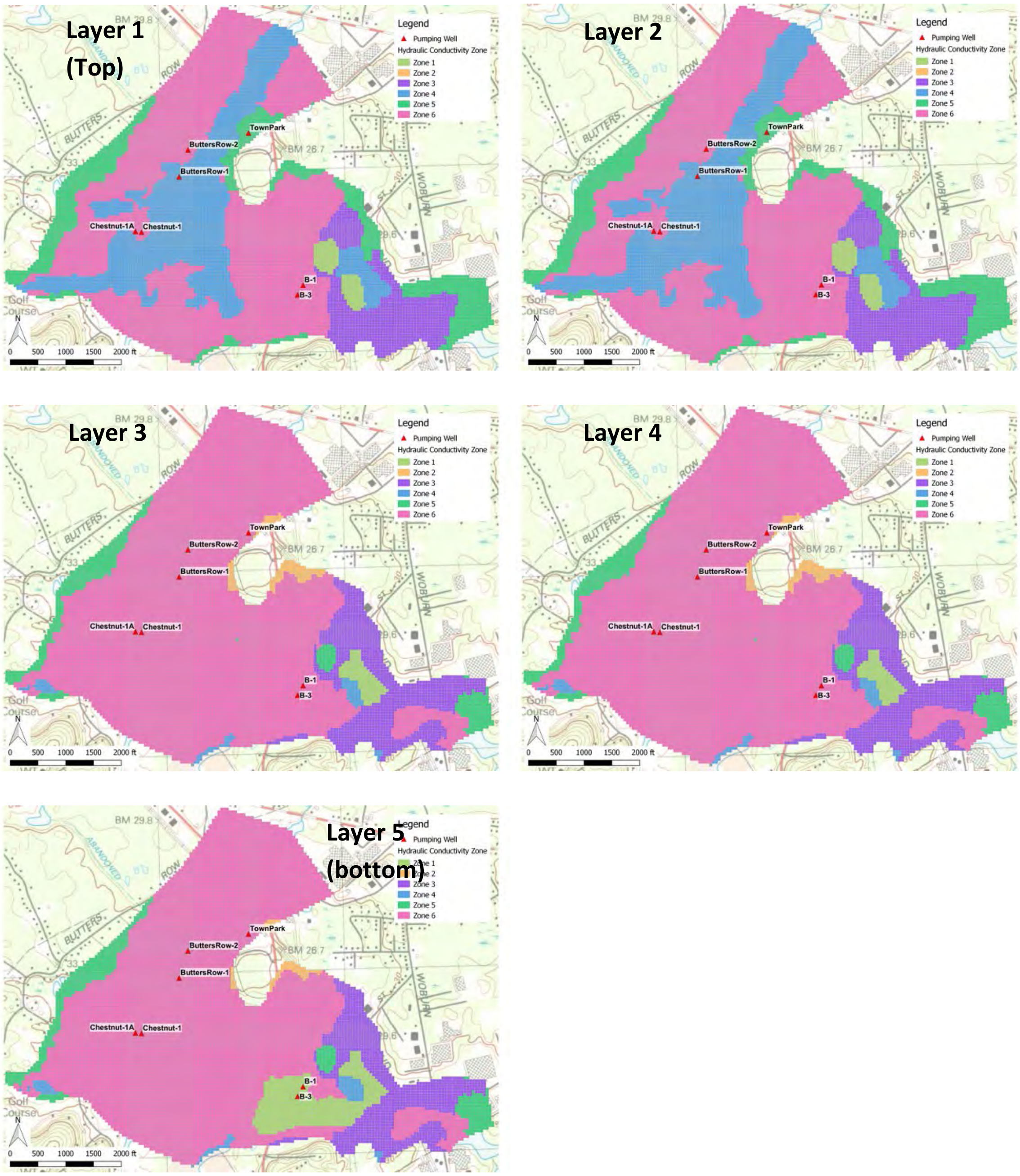


Figure 4.5: Hydraulic conductivity zones in each model layer

Table 4.4: Horizontal and vertical hydraulic conductivity values for each zone

Zone[1]	Horizontal Hydraulic Conductivity K_x, K_y (ft/d)	Vertical Hydraulic Conductivity K_z (ft/d)
1	2	0.5
2	10	2
3	75	15
4	25	6
5	100	20
6	225	50

[1] See Figure 4.5 for delineation of each zone

4.1.3.2 Specific Storage and Specific Yield

The specific storage parameter determines the volume of water that can be injected or released per unit volume of aquifer material per unit change in head. For the confined layers (i.e. all layers except the top layer), the specific storage is multiplied by the layer thickness to yield the storage coefficient, also known as storativity, which determines the volume of water injected or released per unit area and per unit change in head. The specific yield represents the amount of drainable water from an unconfined layer (i.e. the top layer). Specific storage and specific yield were set to uniform values of 0.005 per foot and 0.25, respectively, throughout the model domain.

4.1.4 *Simulation Period and Time Steps*

Although the study period was from January 1974 through December 2000, the simulation period for the ground water model was set to January 1965 through December 2003. The ground water simulation period began 10 years earlier than the start of the study period to simulate the initial dispersion of NDMA from the DAPL pool located near the Olin site, which is believed to have begun in the mid-1960s (see Section 3.1). The simulation period was also extended three years beyond the end of the study period to generate results that could be compared against observed NDMA concentrations in the water supply wells, which were measured in 2003.

The 39-year simulation period (1965 – 2003) was divided into 468 stress periods, one for each month. A stress period represents a period of time during which all parameters and input data (e.g. pumping, recharge) are constant. Each stress period was further subdivided into 2 calculation time steps to increase the temporal accuracy of the model. Reduced time step sizes are sometimes necessary in situations where there are rapid changes in the system, which typically occur in response to large changes in the rates of pumping or recharge from month to month. However, a sensitivity analysis of the time step size showed virtually no change between 1 and 2 calculation time steps per stress period (see Section 5.1.3.2). Model output was configured to only save results from the second time step in each stress period. Therefore, the results for a given stress period represent conditions at the end of the corresponding month.

4.1.5 Calibration Targets and Approach

Calibration of the ground water flow model was performed using transient (i.e., time-varying) simulations. The transient calibration relied on historical potentiometric head measurements that were obtained from a variety of sources including CRA (1991), CRA (1993), Smith (1996), Smith (1997), Law (1998), Law (1999), Law (2002), MACTEC (2003b), MACTEC (2005), and MACTEC (2007). Additional potentiometric head data for the eastern portion of the site that were not otherwise found in any available references were obtained by digitizing the water level plots in Figures A-1 through A-91 of Geomega (2006).

The transient calibration of the ground water flow model was performed by adjusting the stage and conductance of the river boundary conditions, vertical and lateral recharge rates, elevations of drain boundary conditions, and values for the hydraulic conductivity parameters. The goal of the calibration was to match the salient features of the flow field between the Olin site and the town's water supply wells, and to minimize the mean and standard deviation of the residuals of the simulated and observed potentiometric heads. Minimization of the mean residual reduces the bias in the model simulation (i.e. simulated heads being consistently too high or too low), while minimization of the standard deviation reduces the variability about the observed data. Throughout this process, parameter values were constrained to physically plausible values based on best engineering judgement. The primary focus of the calibration was on model performance within the Maple Meadow Brook Aquifer and near the water supply wells. Less attention was focused on minimizing the residuals in the vicinity of the Olin facility in the eastern portion of the model domain.

4.1.6 Sensitivity Analyses

A series of sensitivity analyses were performed to evaluate the impacts of alternative model configurations and parameter values on the results and calibration. These analyses focused on evaluating 1) the horizontal discretization of the model grid, 2) the length of the simulation time steps, and 3) the values of model parameters. For the spatial discretization and simulation time steps, alternative versions of the model configuration were used while leaving all other parameters and inputs held constant. The simulation results were compared to the observed potentiometric heads at monitoring wells located near the town's water supply wells. For the model parameters, each parameter was evaluated one at a time using a multiplication factor ranging from 0.1 to 10 and thus generating simulation output over a large range of potential parameter values. For each iteration, summary statistics of the model error were computed using the same observation data as the model calibration. The sensitivity of the model calibration to changes in each parameter was then evaluated with respect to the change in the error statistics. The results of these analyses are provided in Section 5.1.3.

4.2 Ground Water Contaminant Transport Model

A numerical ground water transport model was developed to simulate advection and dispersion of NDMA through the MMB aquifer from the deep DAPL pools to the town's water supply wells. The only sources of NDMA were assumed to be the DAPL pools resulting from disposal activities at the Olin facility, which are believed to have settled in bedrock depressions near the Olin site and in the Western Bedrock Valley (Figure 2.2). NDMA was assumed to be a conservative substance that is not subject to any chemical reactions that would result in its formation or decay within the aquifer. See Sections 2.1 and 3.1 for further discussion of the information and conceptual models upon which these assumptions were based.

The ground water transport model was developed using MT3D (Zheng, 1990), which is a public domain modeling package designed to be used with MODFLOW. MT3D is a finite difference code that simulates three-dimensional advective and dispersive transport in groundwater. MT3D offers several attractive features that led to its use in this study: first, MT3D utilizes the simulated flow results calculated in MODFLOW without any modifications in format, making it an efficient companion to MODFLOW; second, like MODFLOW, the MT3D code imposes no constraints on representation of either vertical or horizontal resolution; and third, it allows contaminant loading processes to be simulated by specification of concentration values at specific nodes (e.g., the dissolution of NDMA from DAPL into flowing groundwater).

The ground water transport model utilizes the same grid discretization and simulation time steps as the ground water flow model. The following sub-section describes the parameters, boundary conditions and input datasets for the transport model.

4.2.1 *Transport Parameters*

The contaminant transport model uses a single set of dispersivity parameters to determine the rate at which NDMA is dispersed through the ground water. The dispersivity is defined using three separate parameters, one for each direction in three dimensions. Due to a lack of data to calibrate the transport model, the default values of 10, 3, and 0.5 feet were assigned for the longitudinal, horizontal, and vertical dispersivities, respectively. Because NDMA was assumed to be a conservative substance that is not subject to formation or decay from chemical reactions within the aquifer, no reaction rate parameters were enabled in the model.

4.2.2 *Boundary Conditions*

The diffusive process that moves NDMA out of the DAPL phase and into the ground water was represented by specifying a constant NDMA concentration within the bottom layer at grid cells corresponding to the locations of the DAPL pools. Transport into the overlying layers occurs through dispersion from the bottom layer into grid cells of layer 4, which is the next vertical layer. From layer 4, continued upward movement into the shallow portions of the aquifer occurs through additional dispersive mixing. Advection between the vertical layers can also occur due to vertical ground water flow towards any grid cells discharging to rivers, drains, or pumping wells.

During initial model development, the transport model was configured to only include the large DAPL pool located along Main Street and near the Olin site (Figure 2.2). This DAPL pool was assumed to be the principal source of NDMA at the time. However, for the simulated concentrations at the water supply wells to be of an appropriate order of magnitude relative to the measured concentrations, it was necessary to set the concentration in this pool to a value that exceeded measured concentrations at the nearby Altron remediation wells and other intermediate monitoring wells within the MMB aquifer. The relatively low NDMA concentrations measured at GW-62 in particular were not consistent with a single

DAPL pool at Main Street that could reach the town water supply wells with NDMA concentrations approaching or in excess of 100 ng/L. As NDMA enters the aquifer from the Main Street DAPL pool, its concentration likely decreases over time and space due to NDMA mass losses associated with discharges to the intermediate streams, as well as from dispersion of the plume within the aquifer.

In order to achieve closer agreement between the simulated and measured NDMA concentrations, a second DAPL pool was defined within the Western Bedrock Valley. AMEC (2013) shows the existence of this DAPL pool, but with a limited extent around monitoring well GW-83 (Figure 3.1); however, the actual extent of this pool is unknown due the low number of monitoring wells in this area. The extent of the WBV DAPL pool was defined in our model based on the High Concentration Zone depicted in Geomega (2002b, Figure 4) (see Figure 2.2 above).

To account for the travel time of the WBV DAPL plume from the Olin facility to its final location, we assumed that the plume initially arrived and began serving as a NDMA source in January 1972, approximately 16 years after the beginning of disposal operations at the Olin facility. At the initial arrival time, approximately 25 percent of the final extent was assigned a constant concentration boundary condition. The area was then gradually increased to its full extent by June 1979. The other DAPL pool located beneath the Olin site, however, was assumed to exist with its full extent at the start of the simulation in January 1965.

Figure 4.6 shows the extent of the constant concentration boundary conditions, all of which were only assigned to grid cells in the bottom vertical layer. Note that this figure shows the full extent of the DAPL pool in the WBV, which was gradually increased in size from 1972 to 1979. In each of these grid cells, a constant concentration of NDMA was set to 1,100 ng/L based on the calibration process described in the following section. Although higher concentrations were measured at some locations in the MMB aquifer (see Figure 3.2), the ground water model required a constant NDMA concentration representative of average concentrations over time and space in or to properly simulate the concentrations measured in the drinking water wells in 2003.

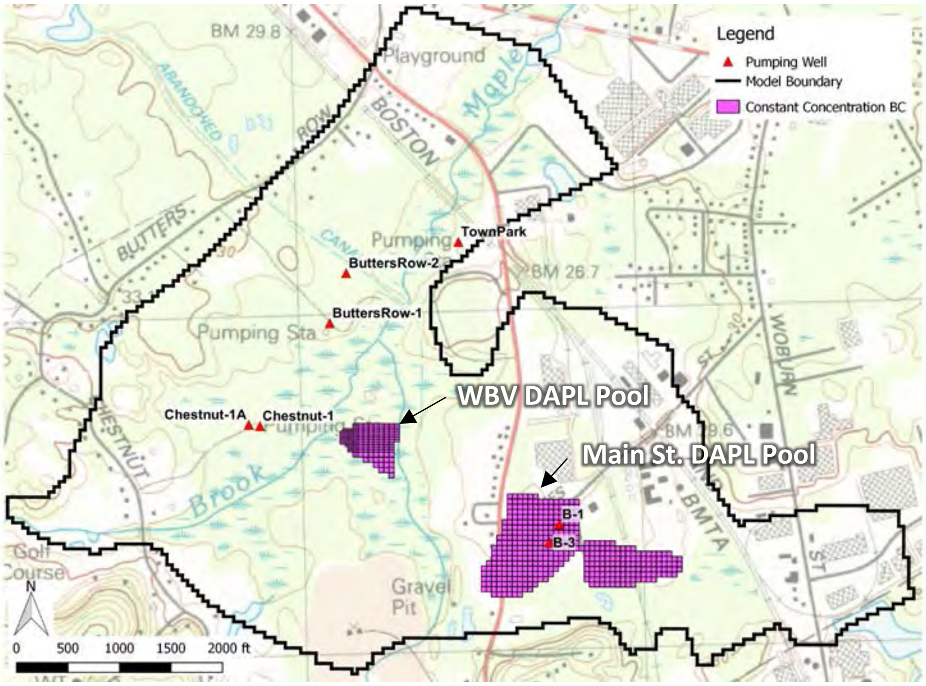


Figure 4.6: Constant concentration boundary conditions in bottom layer.

4.2.3 Calibration Targets and Approach

The ground water transport model was calibrated by adjusting the concentration of NDMA associated with the boundary conditions in the bottom layer grid cells that represent the DAPL pools. The same concentration was applied in all grid cells for both DAPL pool locations (Main St and Western Bedrock Valley). The concentration was adjusted so that the simulated NDMA concentration in each of the town water supply wells showed reasonable agreement with corresponding measurements collected in February 2003. The final NDMA concentration that resulted in the closest agreement between the simulated and observed concentrations was 1,100 ng/L (see Section 5.1.2).

Because measurements of NDMA in the water supply wells were only available on a single day during the simulation period, we were unable to perform a more rigorous calibration targeting other parameters such as the dispersivity. Additional calibration approaches were investigated, but we ultimately concluded there were insufficient data available to support further calibration. The model results were qualitatively evaluated by comparing changes in the concentrations of other solutes, namely chloride, sodium, sulfate, and ammonium, at each water supply well over time. These solutes typically have high concentrations associated with DAPL, and therefore serve as a proxy for better understanding the arrival time of NDMA from the DAPL pools to the supply wells. This comparison is provided in Section 5.1.2 below.

4.3 Water Distribution System Model

A numerical model of the Wilmington water distribution system was developed to 1) simulate the transport of NDMA from the MMBA water supply wells to each end user in the system from 1974 through 2000, and 2) simulate the transport of TCE originating at the Butters Row WTP from 1981 through 2000.

The water distribution model is based on a representation of the physical system, which includes the pipe network, pipe properties (e.g., diameter, roughness), water supply wells, water treatment plants, pumps, and valves. Time-varying boundary conditions are defined by input datasets representing the flow rates and concentrations at each water supply well and water treatment plant (i.e. the supply nodes), and the end user water demands at each pipe junction (i.e., the demand nodes). Based on the representation of the physical system and these boundary conditions, the model solves a series of mathematical equations that determine the flow, velocity, pressure, and pollutant concentration in each pipe segment across the network. The simulation results describe both the spatially-varying hydraulic conditions and concentrations across the system, as well as how those properties change over time within each pipe segment.

The water distribution system model used in this study is based on previous models developed for the town water department to support long-term planning efforts. The first version of the model was constructed using the KYPipe modeling software to assist in the development of the 1988 master plan (FST, 1988). The master plan document contains maps of the modeled network; however, digital files containing the original input datasets and system configuration were not available at the beginning of this study. The 1988 model was later updated to support the 1996 and 2001 master plans (SEA Consultants, 1996; SEA Consultants, 2001). For these plans, the model was converted to WaterCAD, a modeling software platform from Bentley Systems. A digital file containing the WaterCAD model input dataset was made available for our use from the Wilmington Water and Sewer Department (Mike Woods, personal communication). This file served as the starting point for development of the model used in this study.

4.3.1 System Representation

The representation of the physical system was based on the initial WaterCAD input file provided by the town's Water and Sewer Department. After an inspection of the system pipe network and diameters, we determined that this input file was a draft version of the model described in SEA Consultants (2001). We subsequently revised the model to ensure it represented the configuration of the system as it existed in year 2000, which is the last year of the simulation period. The input file was reviewed and updated with additional information about the pipe network obtained from SEA Consultants (2001) and the annual town report for 2000. After ensuring that the model represented the year 2000, it was revised sequentially back in time to represent the system as it existed in each year going back to the beginning of the study period (1974). Information on the construction of new pipes over this period were obtained from various reports including SEA Consultants (2001), SEA Consultants (1996), FST (1988), Whitman & Howard (1973), and the annual town reports.

A chronological list of changes to the pipe network is compiled in Appendix G. This list identifies the road along which each pipe was installed, along with the pipe length and diameter. Each line in the table also describes the action taken and a qualitative estimate of the level of confidence and the importance of the pipe removed with respect to the flow through the system. Pipes within a subdivision were generally determined to be of low importance relative to the large water mains that convey water from one portion of the town to another. Based on this information, the model files were updated by adding or removing pipes from the system for each simulation year. In some cases, the section of pipe was easily identified, as for instance in the event of construction at new subdivisions. In other cases, the constructed pipe was not explicitly represented in the system model, in which case no action was taken to represent the constructed pipe. Throughout this process, we used our best judgment to identify the locations of the pipe segments as described in the annual reports. Additional references used to help in identification of pipes include a color-coded map of the year of construction on a lot-by-lot basis obtained from an online assessor's map, as well as system maps in Whitman & Howard (1973), FST (1988), and SEA Consultants (1996). The water department staff also provided some plans on request to support our investigation. However, plans from the 1970s and 1980s were not generally available.

Ultimately, we created a series of model input files defining the configuration of the water distribution system for each year between 1974 and 1989 and for every other year between 1990 and 2000. Figure 4.7 shows a schematic of the system for the year 2000 including the pipe segments and nodes, water treatment plants and storage tanks. Note that although the three storage tanks are shown in this figure, they were not included as part of the model simulation. Changes in storage tank volumes occur on a sub-daily time scale (see Section 2.2.3); however, the water distribution system model was configured to simulate steady state conditions for each monthly time step using extended period simulations. Therefore, the model could not be used to simulate the hourly changes in storage tank volumes at this temporal resolution. Figure 4.8 shows the pipe roughness (Hazen Williams C) values, which ranged from 60 to 130. The material type for each pipe was assigned to ductile iron.

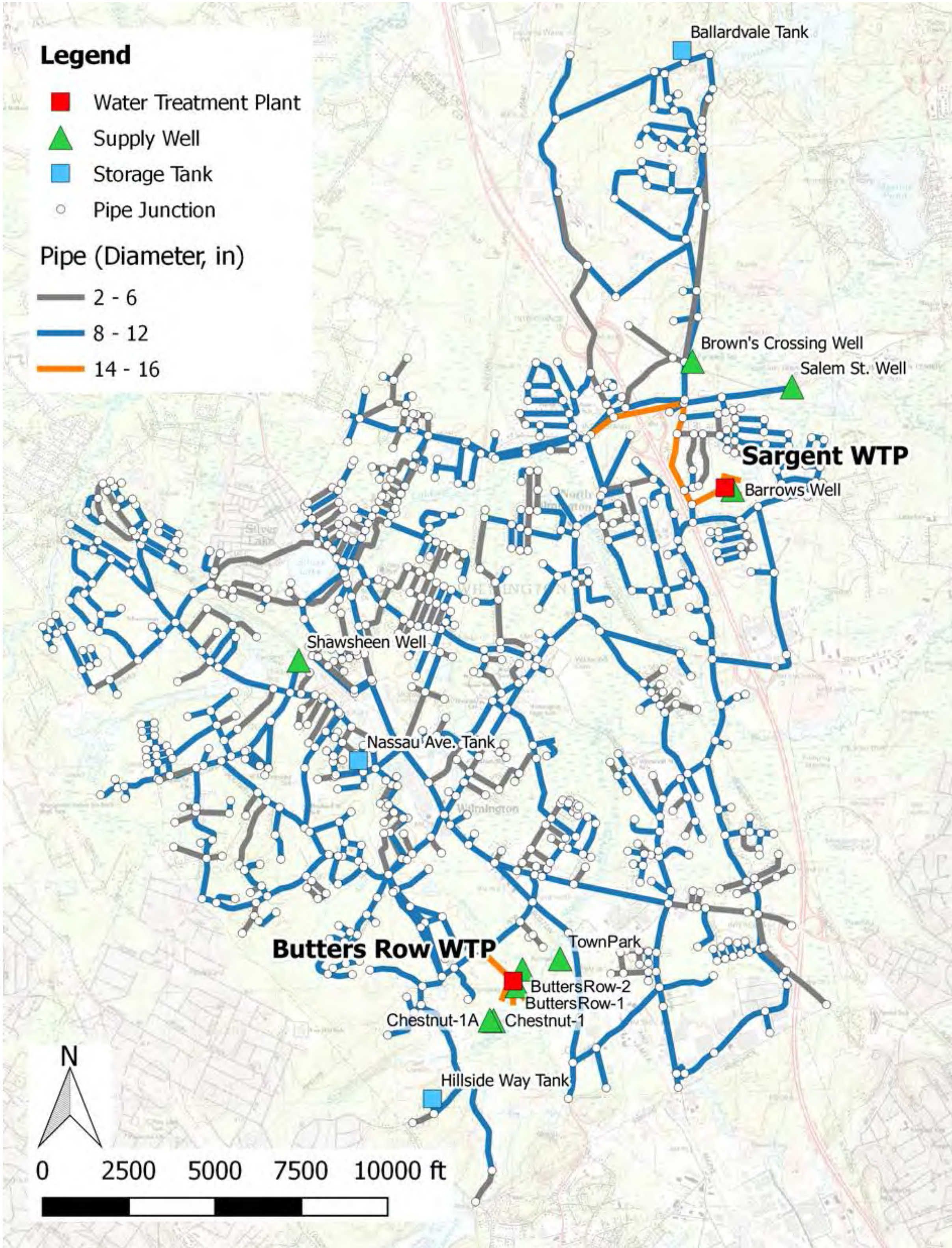


Figure 4.7: Wilmington water distribution system model schematic.

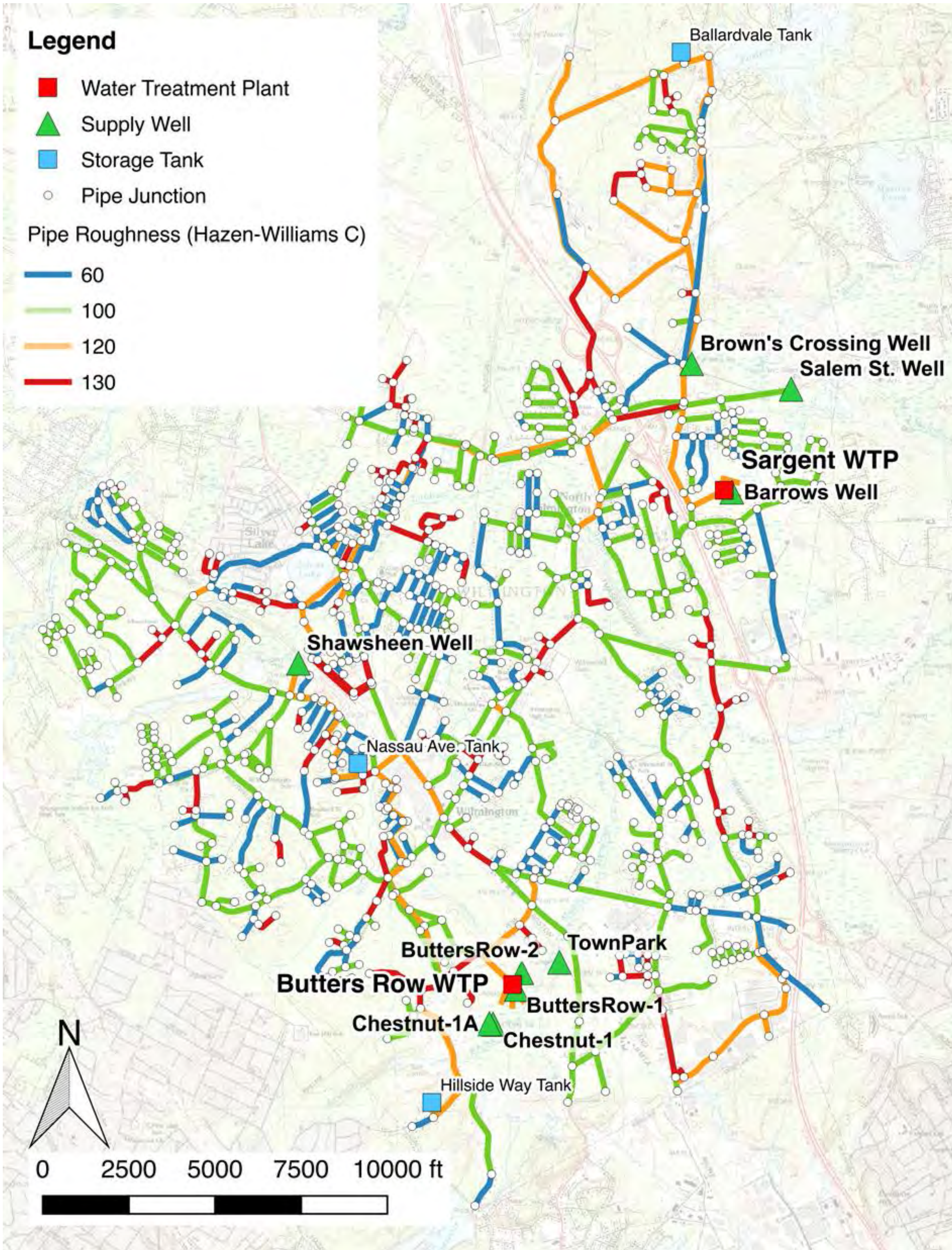


Figure 4.8: Pipe roughness in Wilmington water distribution system model.

4.3.2 BOUNDARY CONDITIONS

The water distribution model requires two types of boundary conditions:

1. Water supply flow rates and associated contaminant concentrations at each supply node
2. Water demand rates for domestic and industrial/commercial users at each withdrawal node

The water supply flows and concentrations were applied at model nodes (i.e., pipe junctions) located closest to the water supply wells and water treatment plants (Sections 4.3.2.1 and 4.3.2.2). The demands were then assigned to the remaining nodes that were not used for water supply. Water demands were assigned separately for industrial/commercial and domestic users (Section 4.3.2.3). Figure 4.9 shows which nodes were used for each type of boundary condition. The following sub-sections describe the datasets used to assign the inflows, concentrations, and demands at each node.

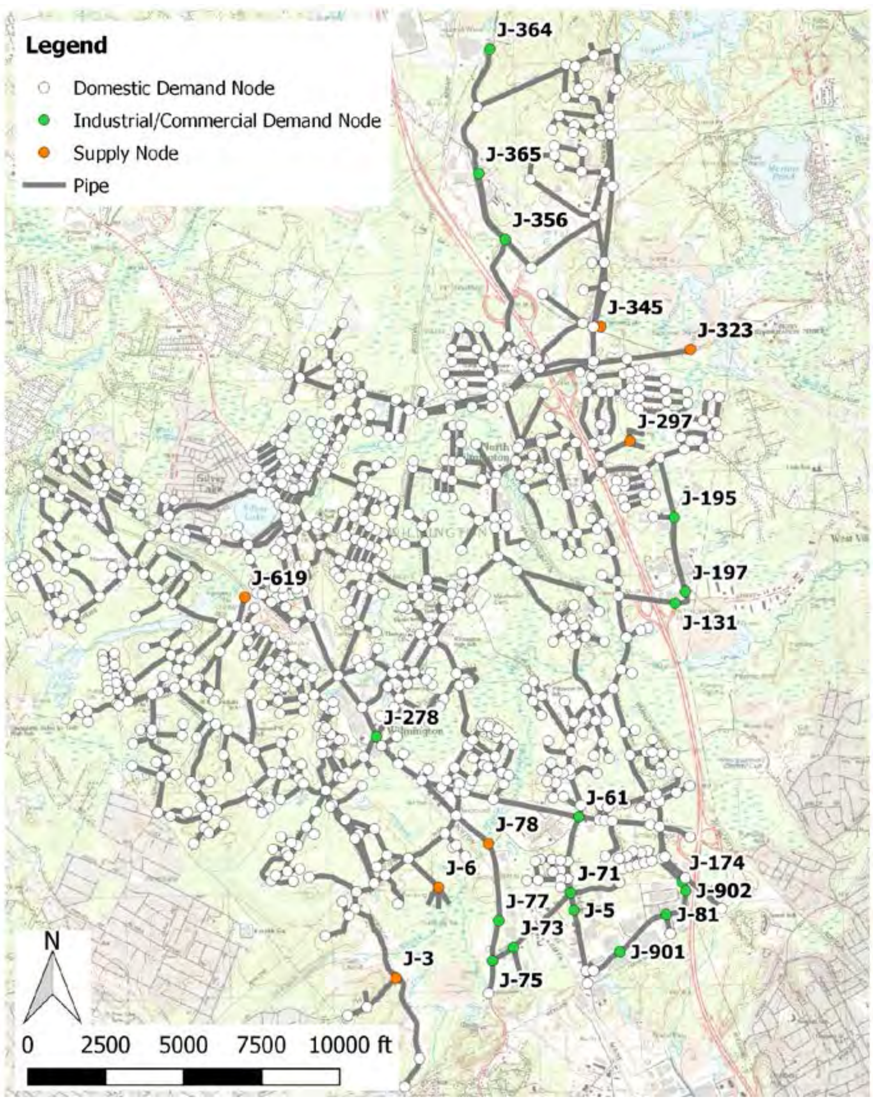


Figure 4.9: Water distribution system nodes for domestic demands, industrial/commercial demands, and water supply

4.3.2.1 Water Supply Flow Rates

Monthly flow rates were assigned to each water supply node to represent the discharge of water into the distribution system. Table 4.5 lists the model node ID assigned to each supply well and water treatment plant (see Figure 4.9 for node locations).

Table 4.5: Model node IDs for each water supply well and water treatment plant

Supply Well/WTP	Node ID
Chestnut St. #1	J-3
Chestnut St. #1A/2	J-3
Butters Row #1	J-6
Butters Row #2	J-6
Butters Row WTP	J-6
Town Park	J-75
Barrows	J-297
Sargent WTP	J-297
Salem St.	J-323
Brown's Crossing	J-345
Shawsheen Ave.	J-619

The supply nodes that were active in each year varied over the simulation period due to changes in the town's water supply system. At the beginning of the simulation period in 1974, the town's water supply was obtained directly from the pumping wells that were in service at the time (Chestnut St. #1, Town Park, Salem St., Shawsheen Ave., Barrows, Brown's Crossing). The flow from each well was injected directly into the corresponding model node (Table 4.5). Although the Aldrich and Butters Row #1 wells already existed, both had been temporarily deactivated prior to the start of the simulation period. The Butters Row #2 and Chestnut St. #1A/2 wells had not yet been constructed.

In June 1981, the Butters Row WTP was brought online and used to treat water pumped from the four existing wells located in the MMB aquifer (Butters Row #1, Butters Row #2, Chestnut St. #1 and Town Park). The total flow rate for this WTP was calculated as the sum of the pumping rates from the individual wells, which were the same as those used as boundary conditions for the ground water flow model (see Section 4.1.2.4). The total flow for Butters Row WTP was assigned to its corresponding node (J-6). In 1992, the Chestnut St. #1A/2 well was constructed and added to the supply rate for Butters Row WTP.

For most of the simulation period, the Shawsheen Ave. well located in center of town injected water directly into the water distribution system. However, this well was deactivated in June 1989 due to water quality concerns. In 1998, a dedicated main was installed to transfer water from the Shawsheen Ave. well to the Butters Row WTP for treatment, and production was restarted in July 2000. The pumping rates for the Shawsheen Ave. well were therefore added to the rate of finished water from the Butters Row WTP for July 2000 through December 2000.

Pumping from the three northern wells (Barrows, Salem St., and Brown's Crossing) was injected directly into the water distribution system until June 1989 when water from these wells was redirected for treatment at the Sargent WTP. Monthly production rates for Sargent WTP were obtained directly from the water department.

Figure 4.10 shows the monthly flow rates for each supply well during the periods when each well was pumped directly into the water distribution system (i.e. pumping rates are shown as zero when the well pumping was being treated at one of the two WTPs). These rates are based on the reconstructed monthly histories described in Section 3.2. The Butters Row #1 well is not shown in this figure because it had been deactivated in 1972 before the start of the simulation period, and was not reactivated until the Butters Row WTP was online. Similarly, Butters Row #2 and Chestnut St #1A/2 are not shown because they were installed at the time of and after the construction of the WTP, respectively. Figure 4.11 shows the monthly production rate for the two WTPs. The total town-wide supply rate is shown in Figure 4.12 as a stacked area plot showing the relative contribution from individual supply wells and WTPs over time.

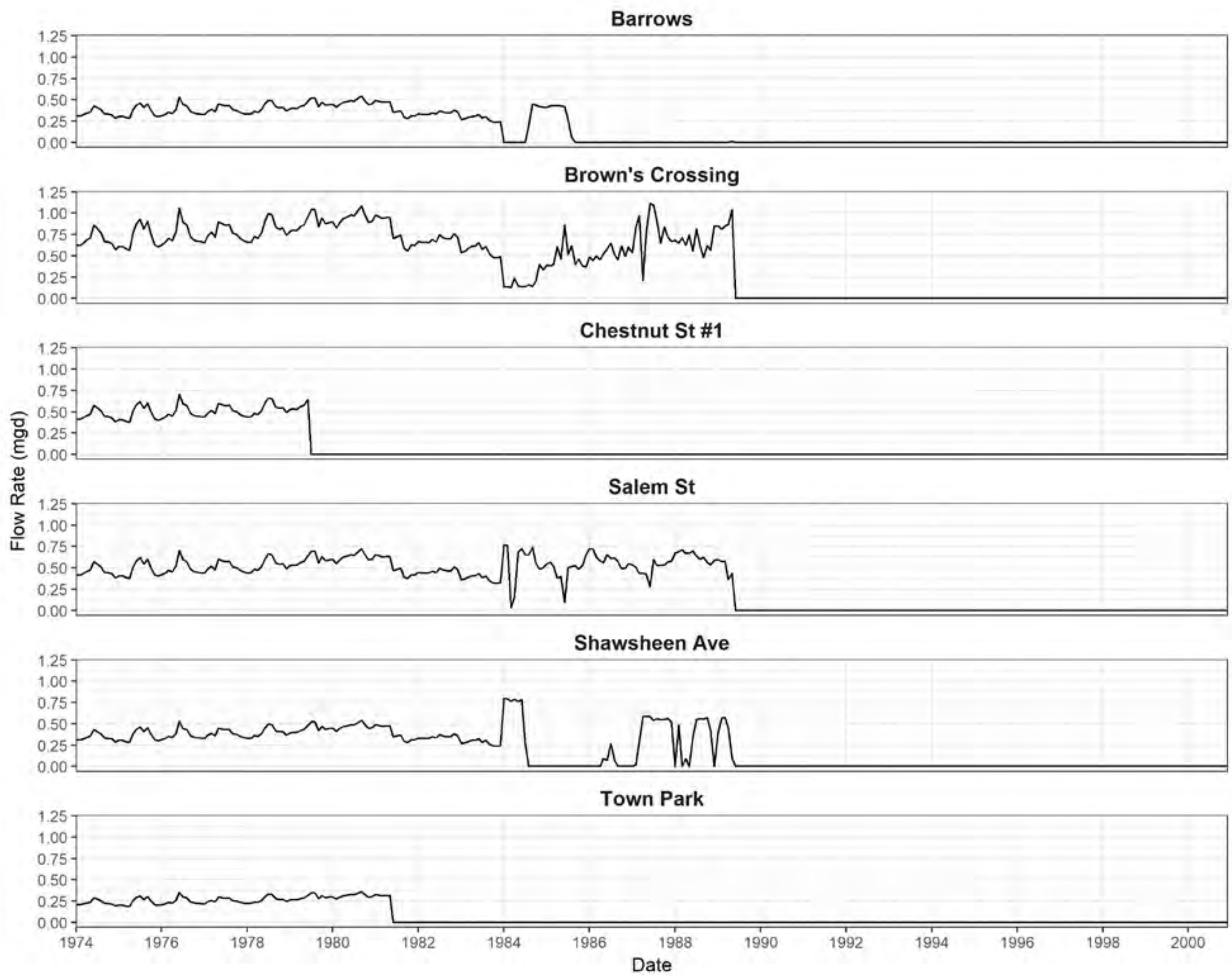


Figure 4.10: Discharge rates for each water supply well

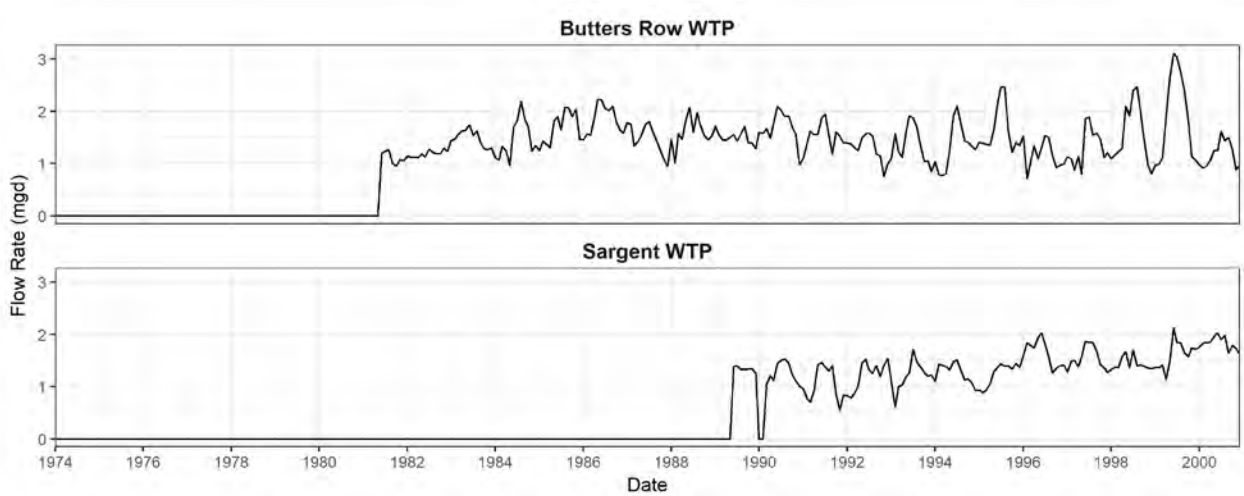


Figure 4.11: Discharge rates for Butters Row and Sargent water treatment plants

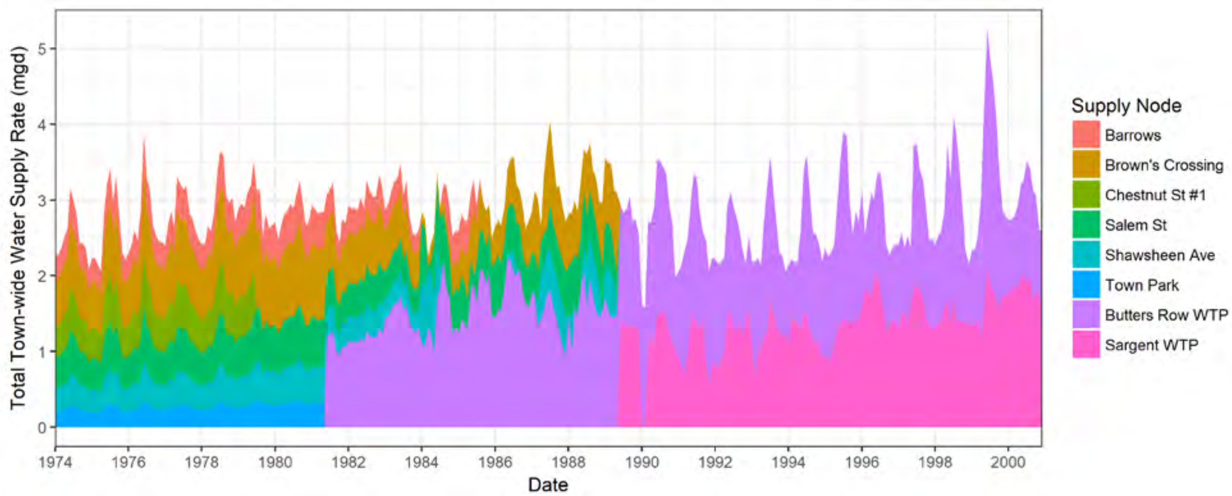


Figure 4.12: Total town-wide water supply rate represented as sum of individual sources, 1974 – 2000

4.3.2.2 Pollutant Concentrations at Water Supply Nodes

In addition to the flow rates, monthly concentrations of NDMA and TCE were assigned to each water supply node to specify the contaminant levels associated with all inflows to the distribution system.

4.3.2.2.1 NDMA Concentrations

The monthly NDMA concentrations at each MMBA well were assigned using the results of the ground water transport model (see Section 5.1.4). When the Butters Row WTP was brought online in 1981, the concentration of its finished water was computed using the flow-weighted mean concentration based on the flow rates and concentrations from the individual supply wells in each month. Use of the flow-weighted mean concentration ensured that the total mass of NDMA entering the system from the WTP was equal to the total mass being pumped from the aquifer by the individual wells. The concentrations for wells located outside the MMB aquifer and for the Sargent WTP were all assumed to be zero because there was no evidence of NDMA originating from these sources. We also assumed there was no change in NDMA concentration due to the treatment process (see Section 2.2.2).

4.3.2.2.2 TCE Concentrations

TCE concentrations at the water supply nodes were based on historical data as opposed to ground water modeling results because TCE sources in the subsurface were insufficiently characterized to enable ground water transport modeling. A re-constructed time history of monthly TCE concentrations in the Butters Row WTP finished water was generated from discrete measurements collected by the water department from 1981 through 1998. Data from individual wells were either not available or very limited prior to 1981, and therefore the TCE simulation corresponded to the period when the Butters Row WTP was online (June 1981 through December 2000). Concentrations at the supply wells outside the MMB aquifer and at the Sargent WTP were assumed to be zero making Butters Row WTP the sole source of TCE to the system.

Of the 100 TCE measurements in Butters Row WTP finished water from 1981 through 1998, 16 were reported as non-detects, for which the concentration was set to the reported detection limit (i.e., 0 – 1 ug/L). To re-construct a monthly time history of TCE, the mean concentration was first computed for each month in which two or more samples were collected. For months in which no samples were collected, the concentration was estimated by linearly interpolating between the mean concentrations of closest two months for which measurements were available. The result was a time series of monthly-mean TCE concentrations, which is shown in Figure 4.13 along with the individual measurements. TCE concentrations were highest from 1983 through 1987 and reached a maximum monthly average of 25.8 ug/L in August 1985. In 1987, the concentrations fell rapidly and were consistently below the detection limit starting in 1991.

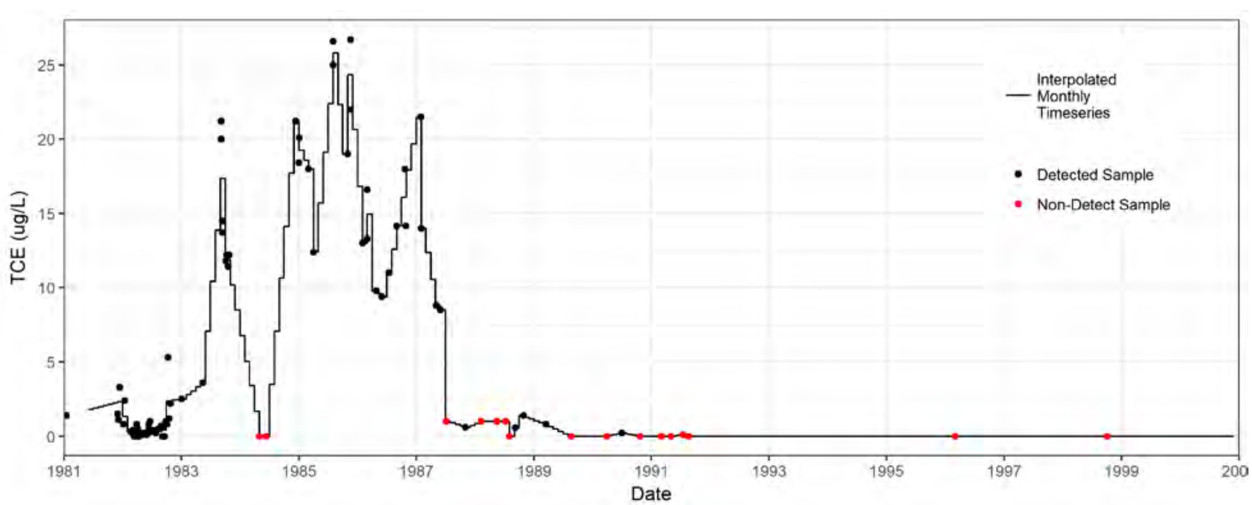


Figure 4.13: TCE samples and interpolated monthly timeseries at Butters Row WTP

4.3.2.3 Water Demand Rates

Monthly water demands were assigned to each model node that was not used as a water supply node (see Figure 4.9 above). Demands were assigned based on two types of end users: industrial/commercial users and domestic users. Demands for the largest industrial/commercial users were first assigned to the nodes located nearest to the billing address of each user (Table 4.6, see Figure 4.9 for node locations). Reconstruction of the monthly demand time histories for these users and a summary of historical usage rates are described in Section 3.4.

Table 4.6: Billing address and corresponding model node ID for each industrial/commercial user

Billing Address	Node ID
804 Woburn Street	J-5
829 Woburn Street	J-5
201 Lowell Street	J-61
100 Eames Street	J-71
1 Jewel Drive	J-73
51 Eames Street	J-75
850 Main Street	J-75
730 Main street	J-78
45 Industrial Way	J-81
65 Industrial Way	J-81
60 Concord Street	J-131
90 Industrial Way	J-174
350 Fordham Road	J-195
100 Fordham Road	J-197
50 Fordham Road	J-197
1 Burlington Road	J-278
200 Ballardvale Street	J-356
330 Ballardvale Road	J-364
251 Ballardvale Street	J-365
24 Industrial Way	J-901

After assigning demands for the industrial/commercial users, the remaining total domestic demand was computed by subtracting the sum of the industrial/commercial demands from the total town-wide water supply rate for each month. The total domestic demand was then allocated equally among all remaining nodes in the model (i.e. those not used for water supply or industrial/commercial demands, see Figure 4.9). Using this approach, the total system-wide demand in each month equaled the total town-wide water supply rate based on the assumption that there was no significant net change in water storage among the three storage tanks or elsewhere in the system over any given month. Figure 4.14 shows the total monthly industrial/commercial and domestic demands over the simulation period. The industrial/commercial demands do not show any seasonal pattern because they were based on annual average demands (see Section 3.4).

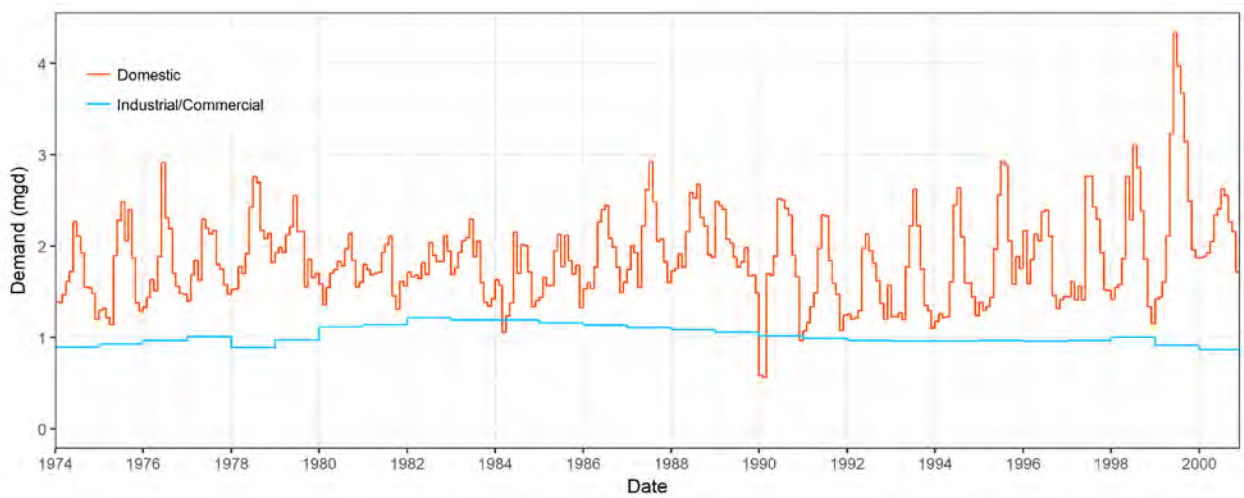


Figure 4.14: Total monthly domestic and industrial/commercial demands

4.3.3 Model Evaluation Approach

Water distribution models are typically calibrated against flow and pressure measurements at various locations across the system and at different points in time to ensure the hydraulic behavior of the model is accurate. However, the town water department informed us that flow and pressure data were not available, and therefore we were unable to calibrate the distribution model in a similar manner as the ground water models. We therefore assumed that the hydraulic parameters in the model (e.g., pipe roughness and material) as specified in the original WaterCAD input file that we were provided were sufficiently accurate.

Although a calibration was not possible, a model evaluation was performed in which the simulated TCE concentrations at multiple points within the system were compared against measurements collected by the water department in July 1986. This comparison allowed us to determine whether the model accurately simulated the spatial distribution of a pollutant emanating from the Butters Row WTP.

The water department collected TCE measurements at six locations in the distribution system on July 31, 1986. Unfortunately, they did not collect a measurement at the Butters Row WTP on that same date. We therefore estimated the TCE concentration in the WTP finished water by computing the average of two measurements taken 17 days before and 32 days after that date (11 ug/L on July 14, 1986 and 14 ug/L on September 1, 1986). The average concentration at Butters Row WTP was thus set to 12.5 ug/L. All other boundary conditions (supply flow rates and demands) were set to the values corresponding to the month of July 1986. The northern wells outside MMB aquifer were assumed to have a TCE concentration of zero. The results of this evaluation are provided in Section 5.2.1.

In addition to TCE, we also considered using measurements of nitrogen compounds for a similar type of model evaluation. Geomega (2002a) describes an investigation of the potential nitrification of ammonia to nitrite in the Wilmington water distribution system. As part of that investigation, samples were collected from April 2000 through October 2001 at nine locations within the water distribution system and analyzed for ammonia, nitrate, and nitrite (Figure 4.15). Based on the concentrations of nitrate (Figure 4.16), we noted that:

- Most of the variability in the measured concentrations can be explained by the variability in concentrations of the Butters Row WTP finish water.
- There is no appreciable time-lag between changes in concentration at the Butters Row WTP and elsewhere within the system.
- Several measurement locations periodically deviate from the nitrate concentrations recorded at the Butters Row WTP finish water. These locations include 27 Hillside Way, Pet Shop, 21 Jones Ave, and 5 Rhode Island Road.

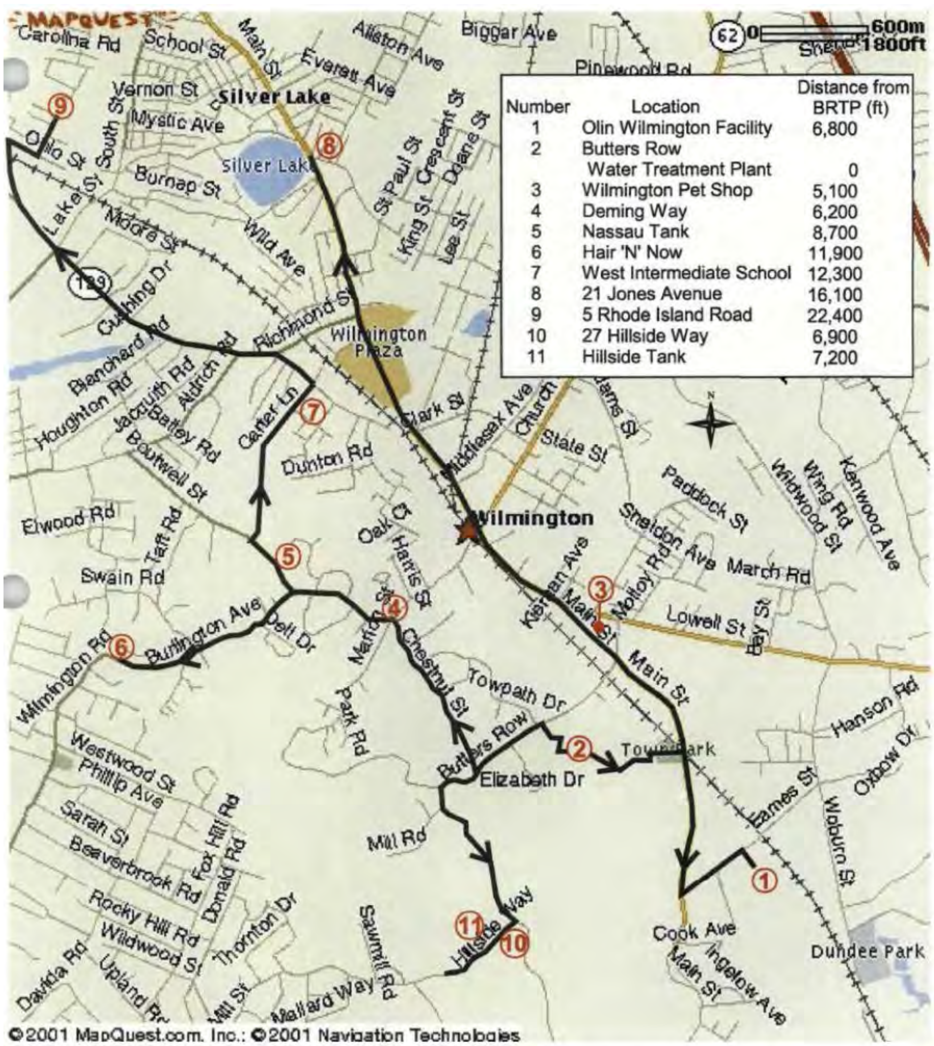


Figure 4.15: Nitrogen compound measurement locations within Wilmington water distribution system. From Figure 1 of Geomega (2002a).

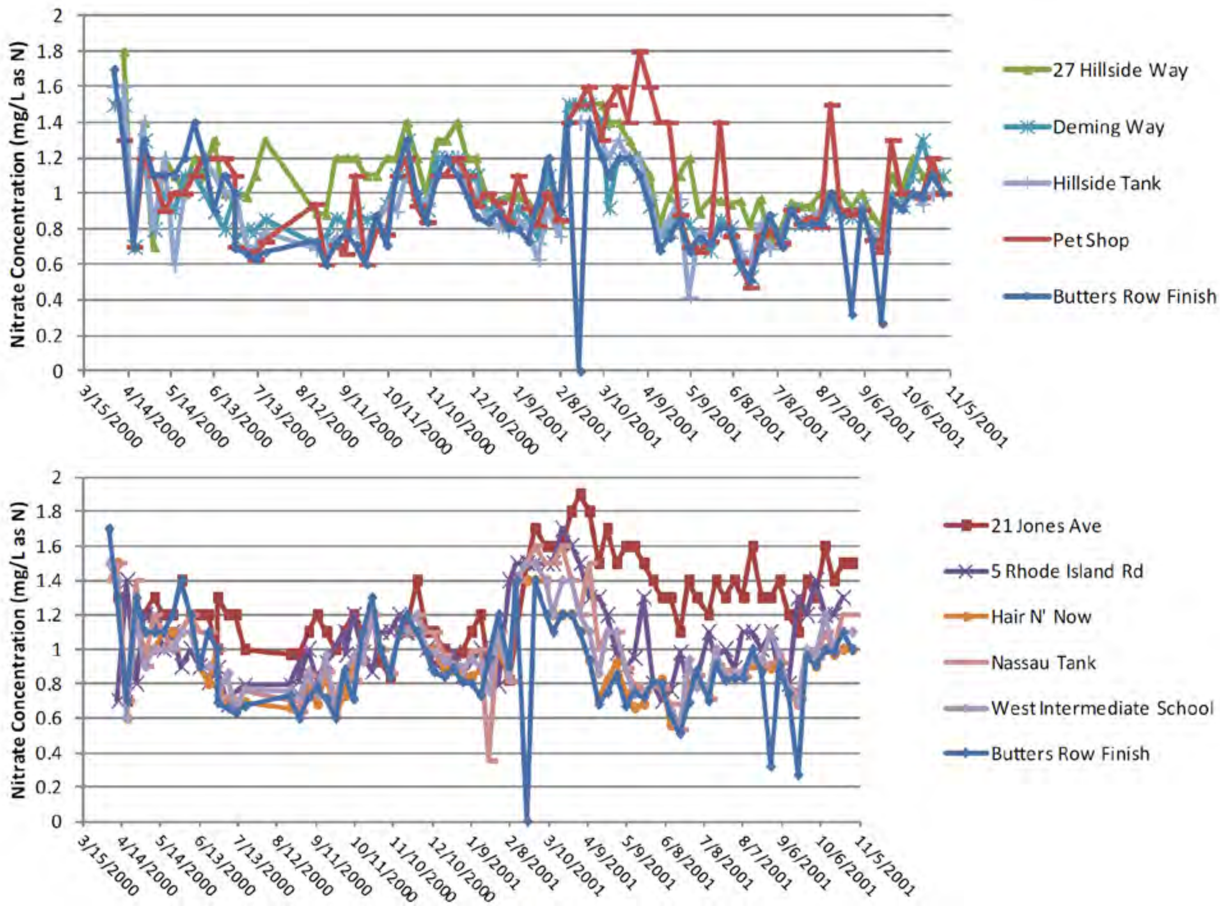


Figure 4.16: Nitrate concentrations collected during Geomega (2002a) investigation of nitrogen compounds in Wilmington water distribution system.

The nitrate measurements across the distribution system closely matched the concentrations at the WTP over time. However, unlike TCE, we could not assume that the concentrations of these compounds were zero for the Sargent WTP. To perform this evaluation, it would be necessary for 1) the nitrate concentrations from the Butters Row WTP and Sargent WTP to have distinctly different concentrations and 2) records of nitrate concentrations over the period of record for both treatment plants to be consistent over time. Neither of these conditions was met. While there were multiple measurements of nitrate at the Butters Row WTP, only one known nitrate measurement was available for Sargent WTP on January 4, 2000. On that date, the nitrate concentration in the Sargent WTP finish water was 1.3 mg/L as N. On the same date, the Butters Row WTP finish water had a nitrate concentration of 1.1 mg/L as N. The similarity in nitrate concentrations from the two treatment plants was thus not favorable for evaluating the spatial distribution of water originating from each WTP across the water distribution system.

Despite the limitations in the nitrate concentration dataset, the distinctly higher concentrations seen in the measurements taken at 21 Jones Avenue do seem to provide some information about the limits of the penetration of water delivered by the Butters Row WTP into the water distribution system. Moreover, the distinct time history of nitrate concentrations at this location are consistent with results from the water distribution transport model, under which water from the Butters Row WTP did not reach the water main at 21 Jones Avenue during any month in the year 2000.

Ammonia concentrations measured during the Geomega (2002a) investigation were also considered for their potential to validate the results of the water distribution system model. Ultimately, however, the absence of ammonia at one location led to the conclusion that ammonia was not a conservative substance within portions of the water distribution system. Therefore, ammonia was consequently ruled out as a potential solute that could be used to evaluate the model.

4.3.4 Sensitivity Analysis

The distribution system model was configured to simulate the average steady state conditions of each month in the simulation period. For each month, the supply and demand rates were held constant. The resulting concentration for each pipe is therefore considered representative of the average condition over the course of the month. It is understood that unrepresented temporal variability within each month will result in deviations from these monthly averages. This temporal variability may result from demand fluctuations over the course of a day as well as the filling and emptying of storage tanks.

A sensitivity analysis was performed to evaluate the impacts of diurnal variability in water demands on the spatial distribution for a pollutant emanating from the Butters Row WTP. The model was configured to perform a transient simulation for a single 24-hour period. Time-variable water demands were assigned to all nodes to reflect typical changes in demand over the course of a day with peaks in mid-morning and late afternoon. The outflow rates from the treatment plants were assumed to be constant. The impact of diurnal demand variability was assessed by comparing maps showing the percent of flow originating from Butters Row WTP within each pipe over the course of the day (see Section 5.2.2 for results).

5 Results

The ground water flow and transport models described in the previous section were calibrated and then used to reconstruct monthly time histories of NDMA concentrations in the town’s water supply wells located in the MMB aquifer from 1965 through 2003. Section 5.1 describes the results of the calibrations, sensitivity analyses, and the final simulations. The results of those simulations were then imported into the water distribution model to simulate transport of NDMA throughout the distribution system and generate monthly concentrations at each withdrawal location from 1974 through 2000. The water distribution model was also used to reconstruct time histories of TCE concentrations based on concentrations measured in the Butters Row WTP finished water from 1981 through 2000. The results and an evaluation of the water distribution model are provided in Section 5.2.

5.1 Ground Water Flow and Transport Model

5.1.1 Ground Water Flow Model Calibration

The ground water flow model was calibrated to historical observations of potentiometric head measured at monitoring wells located near the Olin site and within the MMB aquifer (see Section 4.1.5 for the data sources). For each observation at a given monitoring well, the simulated head corresponding to the location and depth of the well was subtracted from the observed head yielding a measure of error (also known as a residual). The distribution of residuals provides a basis for evaluating the accuracy and calibration of the model.

Table 5.1 summarizes the error statistics of the final calibration. Overall, there were 6,568 observations collected at 185 separate wells from 1991 through 2000. The mean error was -0.10 feet, which is sufficiently small to conclude that the model does not exhibit any significant bias (i.e., simulated heads are not consistently above or below observed heads). The mean absolute residual was 1.17 feet indicating that, on average, the difference between the simulated and observed heads were slightly more than 1 feet. Finally, the root mean squared error (RMSE) was 1.58 feet, which is 0.27 feet greater than the RMSE of 1.31 feet reported by Geomega (2006), but still within an acceptable range. The differences are primarily due to our focus on calibrating to water levels in the northwestern portion of the model within the MMB aquifer, whereas Geomega was focused more on the wells located on or around the Olin site. In addition, some error is the result of the observations being collected at a single point in time, whereas the model simulations reflect the conditions at the end of each month. Therefore, there is some temporal misalignment between the simulated and observed values.

Table 5.1: Summary statistics of ground water flow model calibration.

Number of Monitoring Wells	185
Number of Observations	6,568
Mean Error	-0.10 ft
Mean Absolute Error	1.17 ft
Root Mean Squared Error	1.58 ft

Time series of simulated and measured potentiometric heads in the eastern portion of the model area around the Olin site are shown in Figure 5.1 and Figure 5.2 for shallow and deep monitoring wells, respectively. Similar comparisons are shown for shallow and deep monitoring wells located in the MMB aquifer in Figure 5.3 and Figure 5.4, respectively. These four figures only include wells with multiple observations; wells with only one or a couple observations are not shown here but included in the error statistics above. In general, the simulated time histories replicate the transient seasonal trends with an appropriate range between seasonal peak heads. For the most part, the simulated heads are relatively unbiased, although exceptions exist where the simulated heads are consistently greater than or less than the measured head.

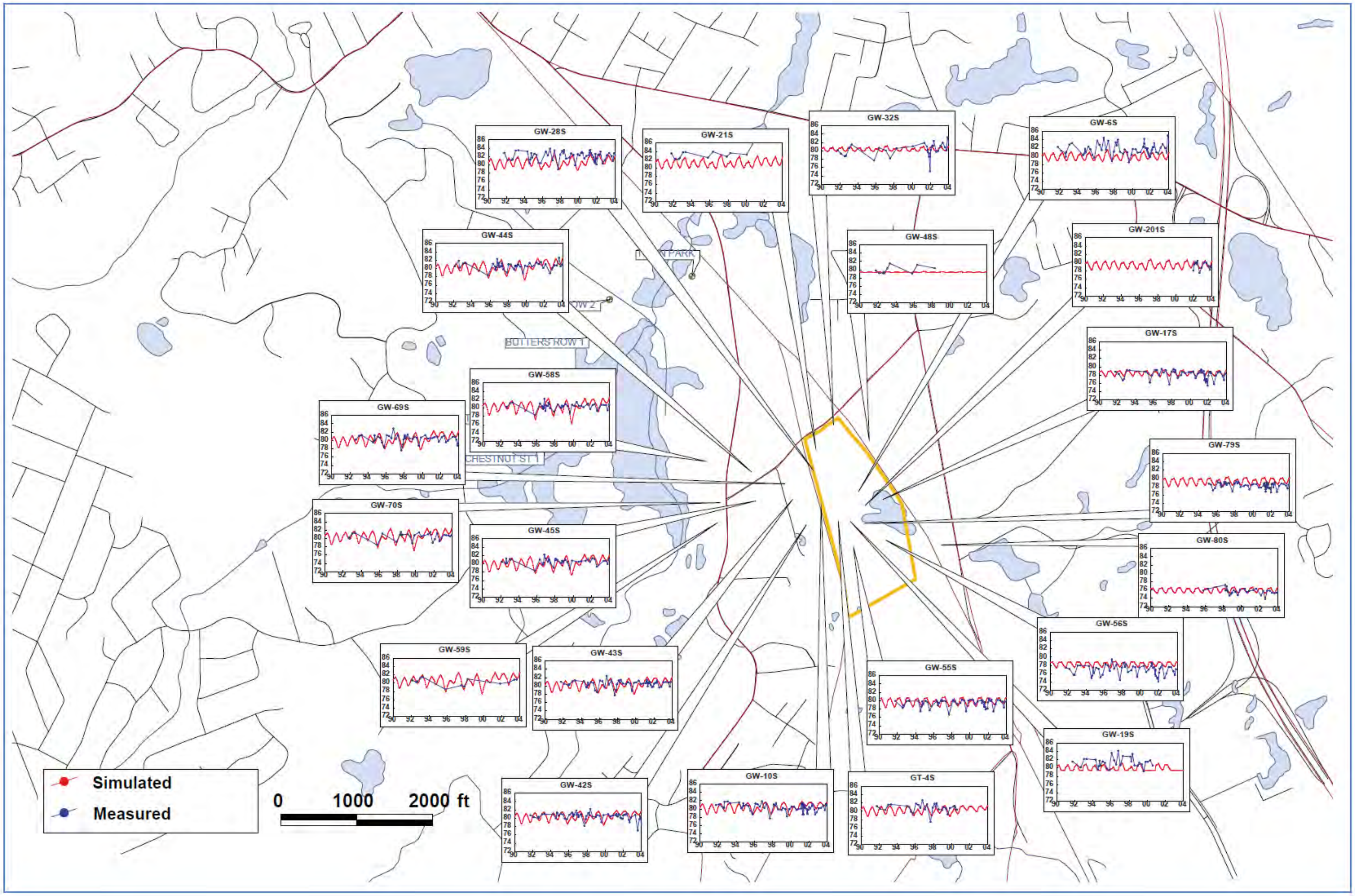


Figure 5.1: Simulated and observed water levels in representative shallow wells within eastern portion of model domain.

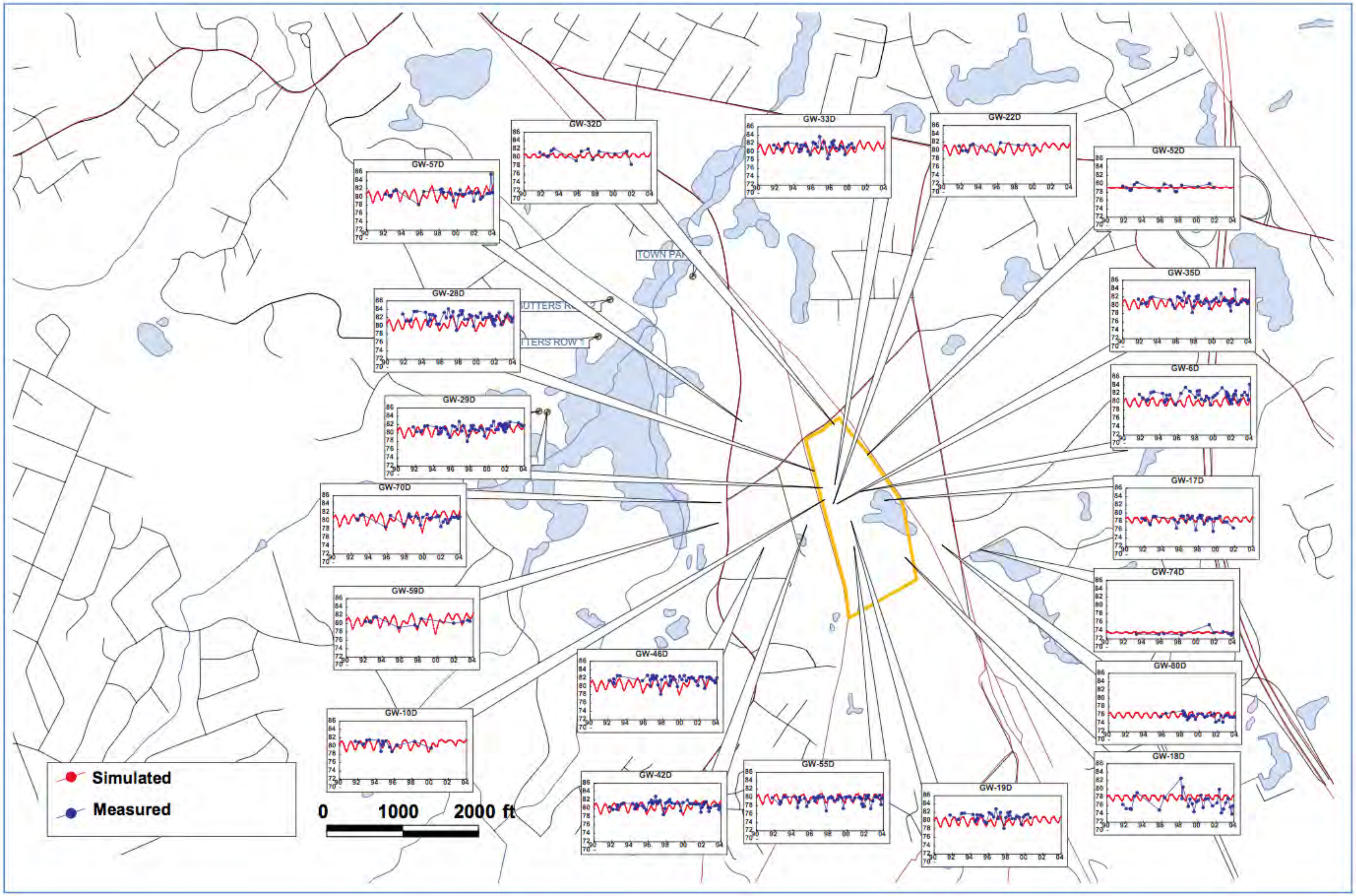


Figure 5.2: Simulated and observed water levels in representative deep wells within eastern portion of model domain.

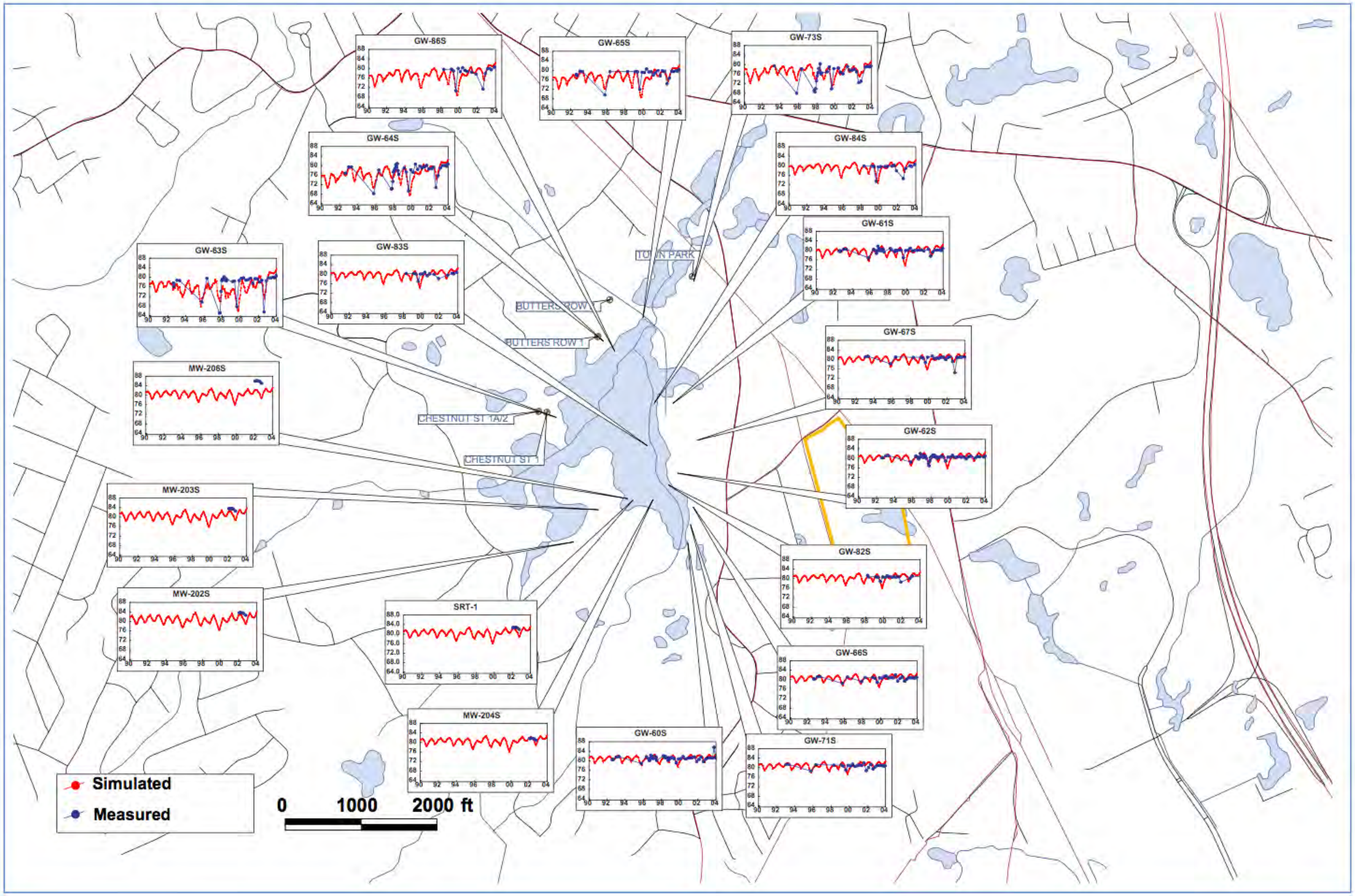


Figure 5.3: Simulated and observed water levels in representative shallow wells within Maple Meadow Brook aquifer

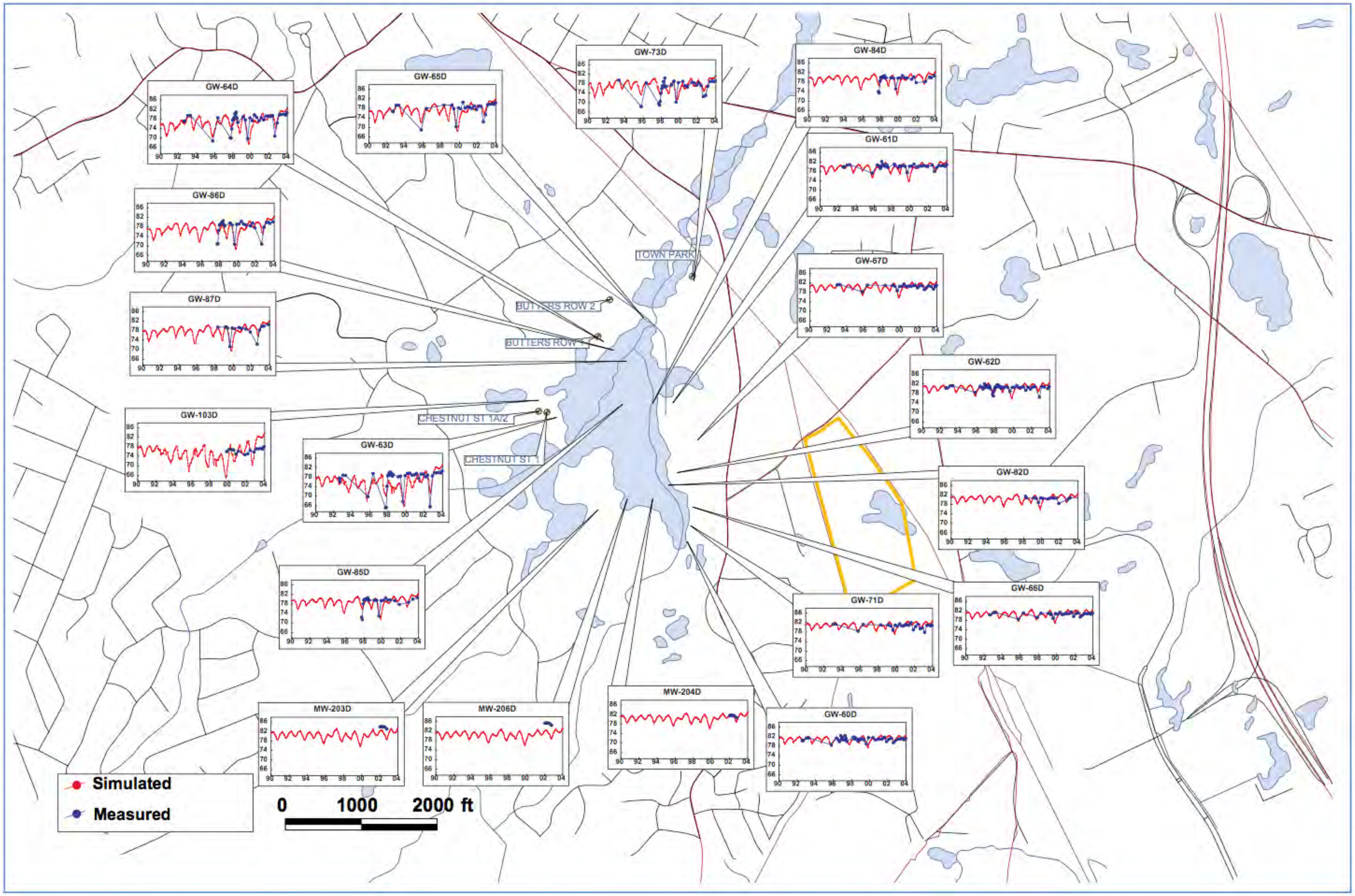


Figure 5.4: Simulated and observed water levels in representative deep wells within Maple Meadow Brook aquifer

Figure 5.5 contains a scatter plot of the simulated versus measured heads for each of the five model layers. A perfect calibration in plots of this type is indicated by target and measured heads closely scattered along the 1:1 line of equivalence represented by the dotted black lines. In general, most residuals are scatted about this 1:1 line of equivalence. The top layer (Layer 1) showed a smaller range of simulated and observed water levels relative to the other layers.

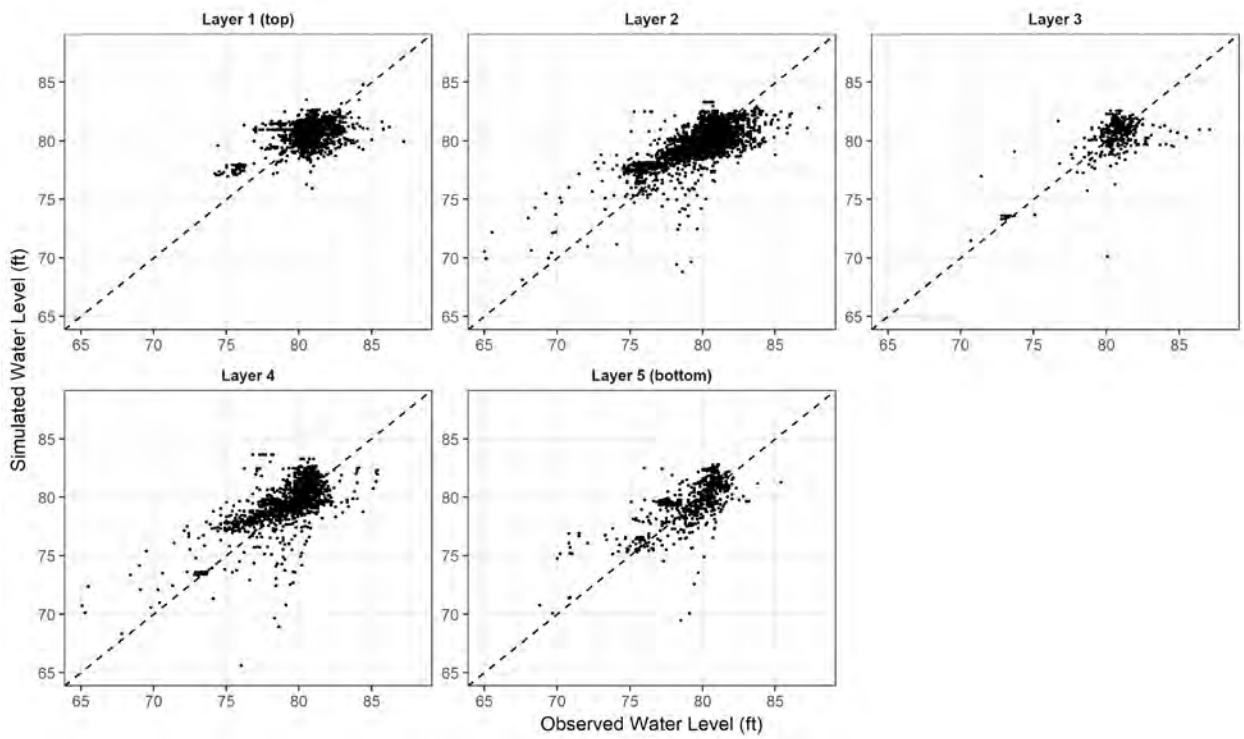


Figure 5.5: Comparison of simulated and observed head levels in each model layer. Dotted black line indicates the 1:1 line of equality.

The mean and standard deviation of residual values were also calculated for each monitoring well and histograms generated to display the distributions of these values. By calculating the residual statistics for individual wells, wells with more measurements do not dominate the residual statistics as they do when doing a simple evaluation of residuals statistics for all measurements. A map of the mean residual for each monitoring well is shown in Figure 5.6. Histograms of the residual mean and standard deviation per well are plotted in Figure 5.7. The mean residual per well reflects the bias in the model simulations while the standard deviation reflects the variability in the residual. Figure 5.8 shows the cumulative frequency distribution of the mean residual per well. This figure shows that 55% of wells had a mean residual less than 0.5 feet, 71% less than 1 foot, and 90% less than 2 feet.

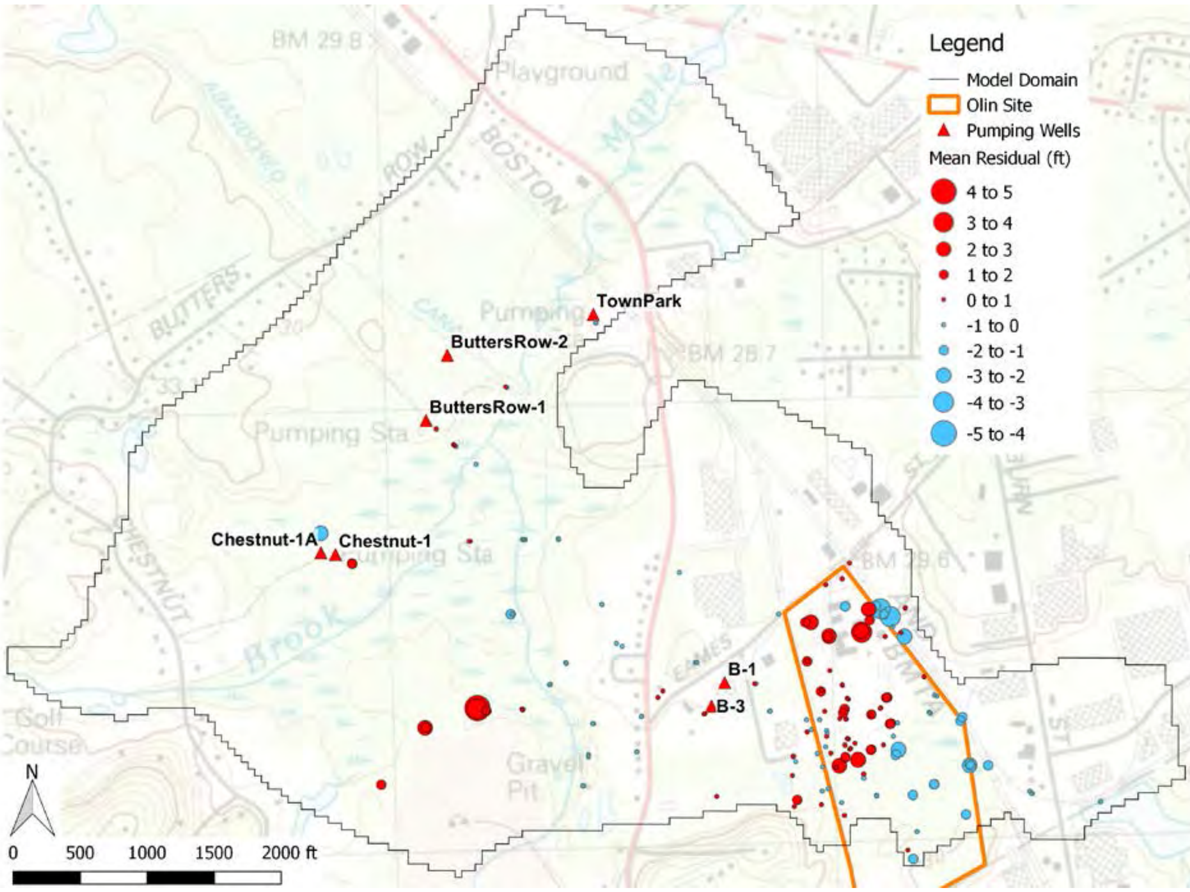


Figure 5.6: Map of mean potentiometric head residual for each monitoring well.

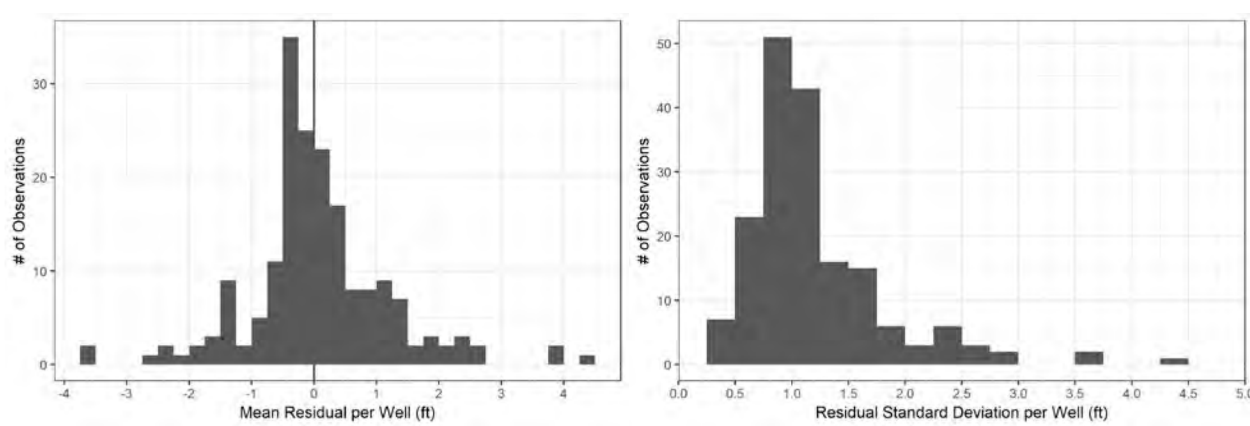


Figure 5.7: Histograms of mean and standard deviation of residuals per well.

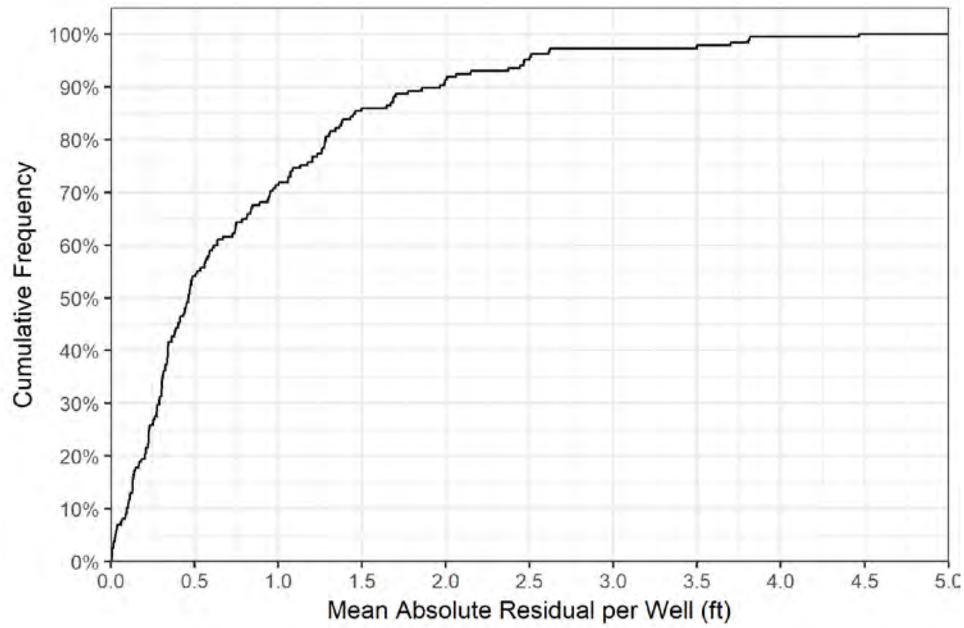


Figure 5.8: Cumulative frequency distribution of mean residual per well.

5.1.2 Ground Water Transport Model Calibration

The ground water transport model was calibrated by adjusting the constant NDMA concentration specified at the boundary condition cells representing the DAPL pool sources (see Figure 4.6) in order to achieve agreement between the simulated and measured NDMA concentrations at the water supply wells collected on February 26, 2003 (see Section 3.5). A constant concentration of 1,100 ng/L associated with the DAPL sources was found to yield the best agreement between the simulated and measured data, a comparison of which is shown in Table 5.2 as well as in Figure 5.10 through Figure 5.14 below.

Table 5.2: Comparison of measured and simulated NDMA concentrations at each MMBA water supply well in February 2003

Water Supply Well	Measured NDMA Concentration (ng/L)	Simulated NDMA Concentration (ng/L)
Butters Row #1	100	158
Butters Row #2	2	37
Chestnut St. #1	166	89
Chestnut St. #1A/2	38	33
Town Park	Not Detected	0

Ideally, additional water quality data such as concentrations of other conservative substances would be used to further calibrate the model and allow for fine-tuning of the source locations and timing as well as model parameters such as the dispersivity. However, after reviewing available data and information on potential sources of these other contaminants, we determined that a more rigorous calibration similar to that performed for the ground water flow model was not feasible. Instead, we present the following qualitative evaluation of other water quality parameters that supports the inputs and boundary conditions assigned in the model. Specifically, we discuss the correlation between the concentrations of NDMA and other major ions, and then review historical records of those ions measured at the MMB aquifer wells that provide some indication regarding the arrival time of NDMA at each well.

The arrival time of NDMA to the MMB aquifer water supply wells is not known with certainty; however, different lines of evidence and reasoning, when considered together, have bearing on arrival time estimates which informed the assignment of the model boundary conditions. First, we tested the hypothesis that NDMA and commonly-measured major ions (chloride, sodium, sulfate, and ammonia), both of which originate from the DAPL are correlated. To this end, all available ground water data in which the major DAPL ions and NDMA were simultaneously measured were analyzed to determine the degree to which concentrations were correlated. Our analysis was completed with data from MACTEC (2005) and is shown in Figure 5.9. Although the dataset was limited, it showed moderately strong linear correlations between the concentration of NDMA and the concentrations of chloride, sodium, sulfate, and ammonia. The coefficient of determination (R^2) was at least 70% for all four ions. The correlation was generally improved by exclusion of outlier data points associated with monitoring well GW-83D, which was screened in the DAPL. With well GW-83D excluded the coefficient of determination increased to 90% for sodium and 85% for chloride. Because it is readily converted to nitrite and nitrate, ammonia is the least conservative of these constituents, and not surprisingly showed the weakest correlation of the four.

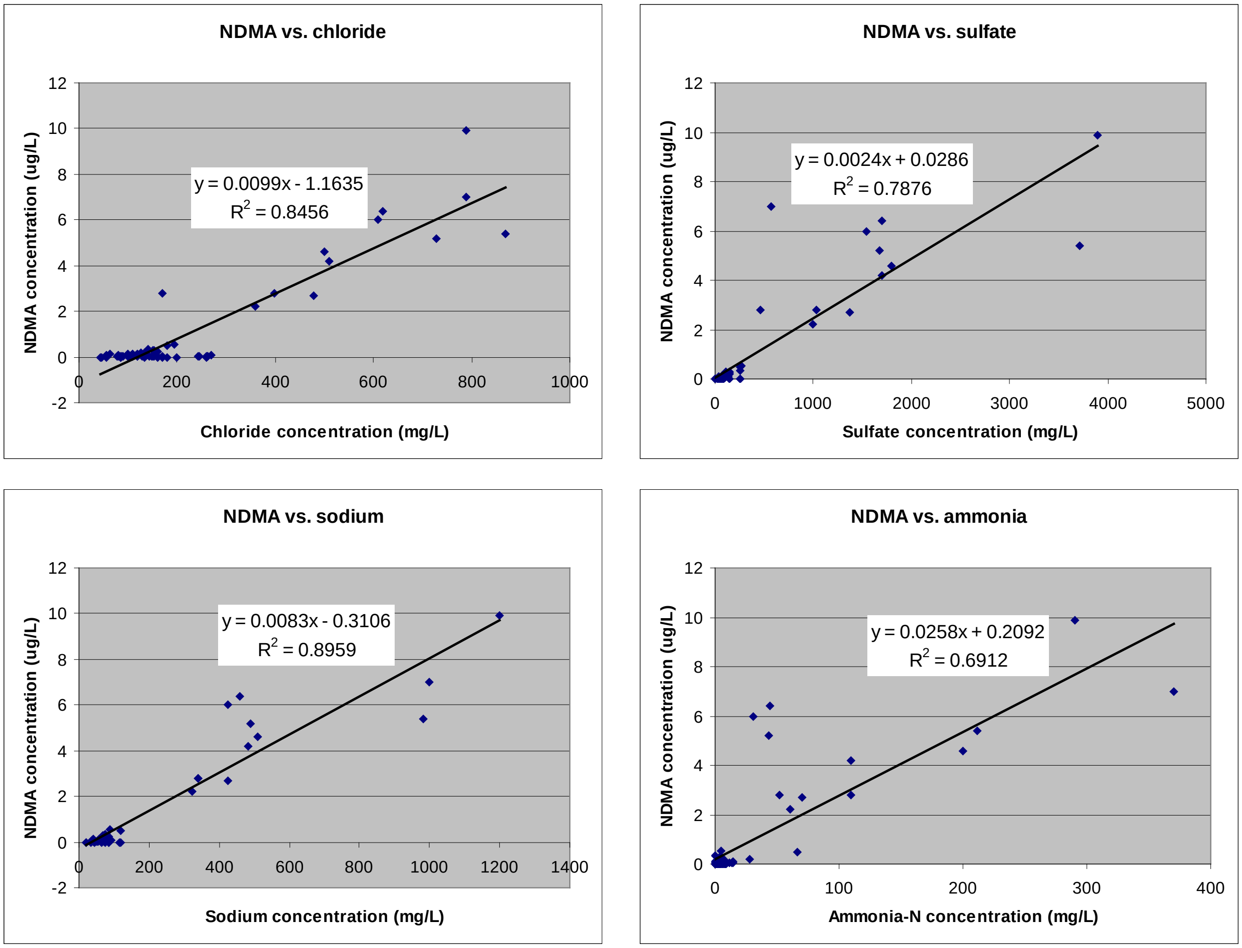


Figure 5.9: Correlation of NDMA concentration with concentrations of chloride, sulfate, sodium, and ammonia in ground-water samples. Data from MACTEC (2005).

Historical records of these major ions were obtained from the Wilmington water department and extend back 10-25 years depending on the well and analyte (Table 5.3). The period of record for most ions is from the 1970s until the wells were shut off in 2003. Earlier records for Cl^- (only) were found for Butters Row #1, Chestnut St. #1 and Town Park (note that the original source for the 1960s Cl^- data, according to Geomega (1998), was a Whitman and Howard report of 1974 that had been prepared for the Wilmington Board of Water and Sewer Commissioners).

Based on the time-series plots shown in Figure 5.10 through Figure 5.14, concentrations of these ions do not appear to have been uniformly distributed in either space or time in the aquifer within the vicinity of the supply wells. For example, Town Park, Chestnut St. #1A/2 and Butters Row #2 wells appear to have received lesser inputs of the major ions compared to Chestnut St. #1 and Butters Row #1. Therefore, these ions may serve as useful source-indicator compounds. In addition to the Olin site, the sources of these ions to the aquifer include application of road salt to local streets (Na^+ and Cl^-) and possibly leachate from the Maple Meadow Landfill (NH_3/NH_4^+). Because sulfate is present at high concentrations

(>10,000 mg/L) in the DAPL layer, SO_4^{2-} may be a particularly useful indicator for the presence of materials emanating from the Olin site.

Table 5.3: Record of major ion measurements in MMBA wells.

Well	Period of pumping	Period of major ion measurements
Butters Row #1	1971-2002	1977-2003: Na^+, SO_4^{2-}, NH_3/NH_4^+; 1966-2003: Cl^-
Butters Row #2	1981-2002	1979-2003: all four major ions
Chestnut Street #1	1961-2002	1974-2003: Na^+, SO_4^{2-}, NH_3/NH_4^+; 1963-2003: Cl^-
Chestnut Street #1A/2	1991-2002	1992-2003: all four major ions
Town Park	1964-2003	1974-2003: Na^+, SO_4^{2-}, NH_3/NH_4^+; 1964-2003: Cl^-

Of the five wells, Town Park had the lowest SO_4^{2-} and NH_3/NH_4^+concentrations. Concentrations of Na^+ and Cl^- were also generally low in this well, but they increased over time possibly due to road salt inputs to the aquifer in the vicinity of the well. No NDMA was detected in this well when measurements were made in all five MMBA wells in 2003 (MACTEC, 2003a). In Chestnut St. #1A/2, the newest of the five wells, SO_4^{2-} concentrations were relatively low throughout its pumping history; however, steady increases in Cl^- and Na^+ concentrations and a very slight but steady increase in NH_3/NH_4^+ was observed. The NDMA concentration in the water sample collected from this well in 2003 was 38 ng/L (MACTEC, 2003a).

Pumping was started in Butters Row #2 in 1981, after which there was a steady increase in Cl^- and Na^+ concentrations, and slight but steady increase in NH_3/NH_4^+concentrations. SO_4^{2-} concentrations were low and relatively constant over time, similar to Chestnut St. #1A/2 and Town Park. The NDMA concentration in the water sample collected from this well in 2003 was 32 ng/L (MACTEC, 2003a). Chestnut St. #1 was pumped continuously from 1965 to 2002, except for a two-year period from 1979 to 1981. High concentrations of Na^+, Cl^-, SO_4^{2-}, and NH_3/NH_4^+ occur in this well after the early 1990s, coinciding with the beginning of pumping at the nearby Chestnut Street #1A/2 well. The NDMA concentration in the water sample collected from Chestnut St. #1 in 2003 was 166 ng/L (MACTEC, 2003a).

Pumping was started in Butters Row #1 in the earlier 1970s but was stopped after two years. When pumping was restarted in 1981, relatively high concentrations of all four major ions were observed right away and throughout the 22-year well operation period. The NDMA concentration in the water sample collected from this well in 2003 was 100 ng/L (MACTEC, 2003a).

By 1986 the SO_4^{2-} concentrations in Butters Row #1 are about 2-fold greater than in Butters Row #2. Because Butters Row #1 is the more southerly of the two wells and closer to the DAPL, this suggests that by 1986 DAPL material has already reached Butters Row #1. Cl^-, Na^+, and NH_3/NH_4^+ concentrations were also consistently higher in Butters Row #1 compared to Butters Row #2 further supporting the conclusion that Butters Row #1 was drawing in more DAPL material compared to Butters Row #2. A similar pattern is observed in the two Chestnut St. wells where well #1 (which is more southerly and closer to the DAPL and started pumping about 30 years before well #1A/2) contains generally higher concentrations of chloride, sodium, and ammonia, as well as modestly higher levels of sulfate.

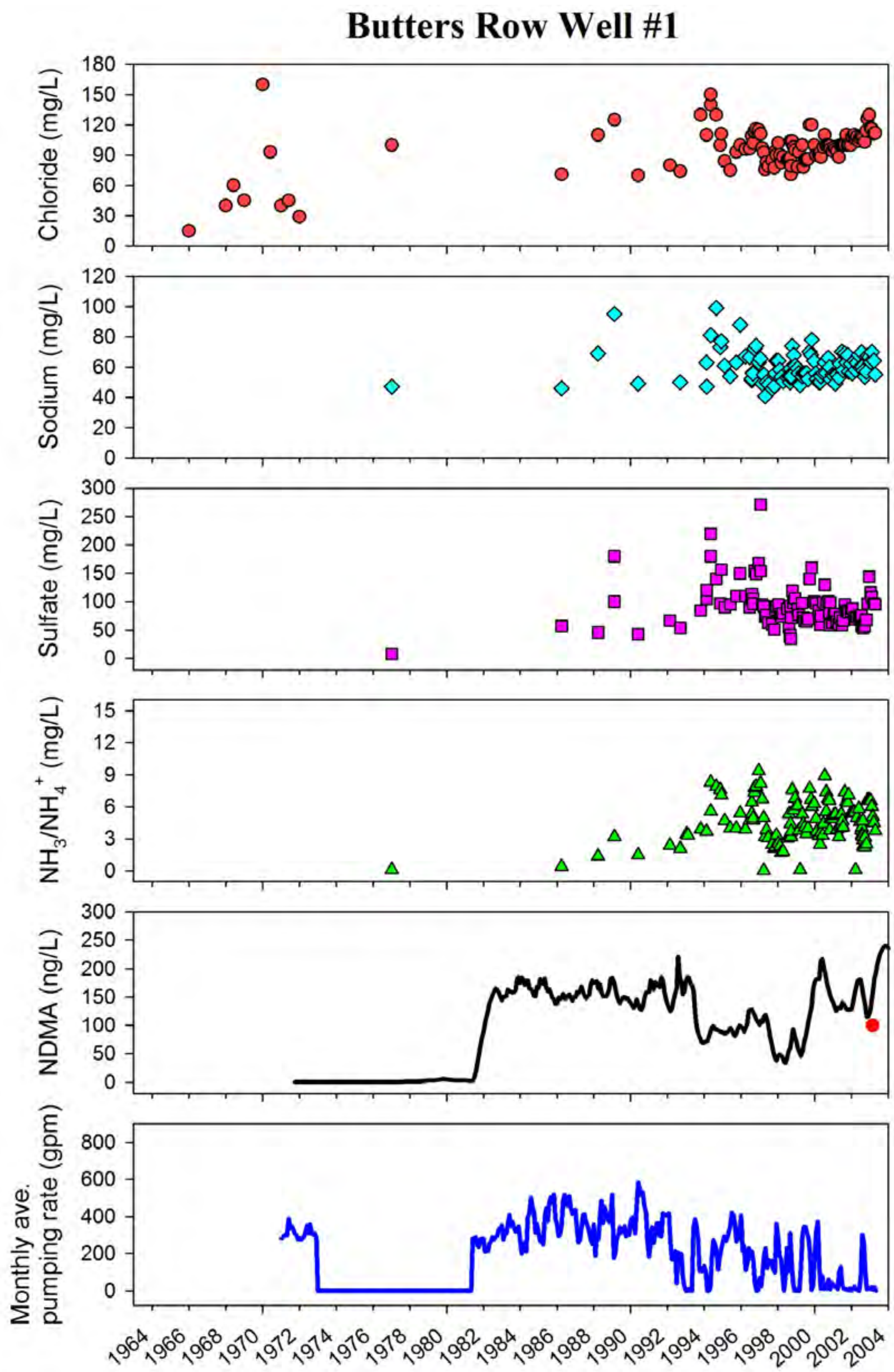


Figure 5.10: Measured concentrations of major ions and NDMA (red dot), simulated NDMA concentrations (black line), and estimated pumping rates at Butters Row #1. ***Note that testing of well water was performed before Butter's Row #1 was brought on line.***

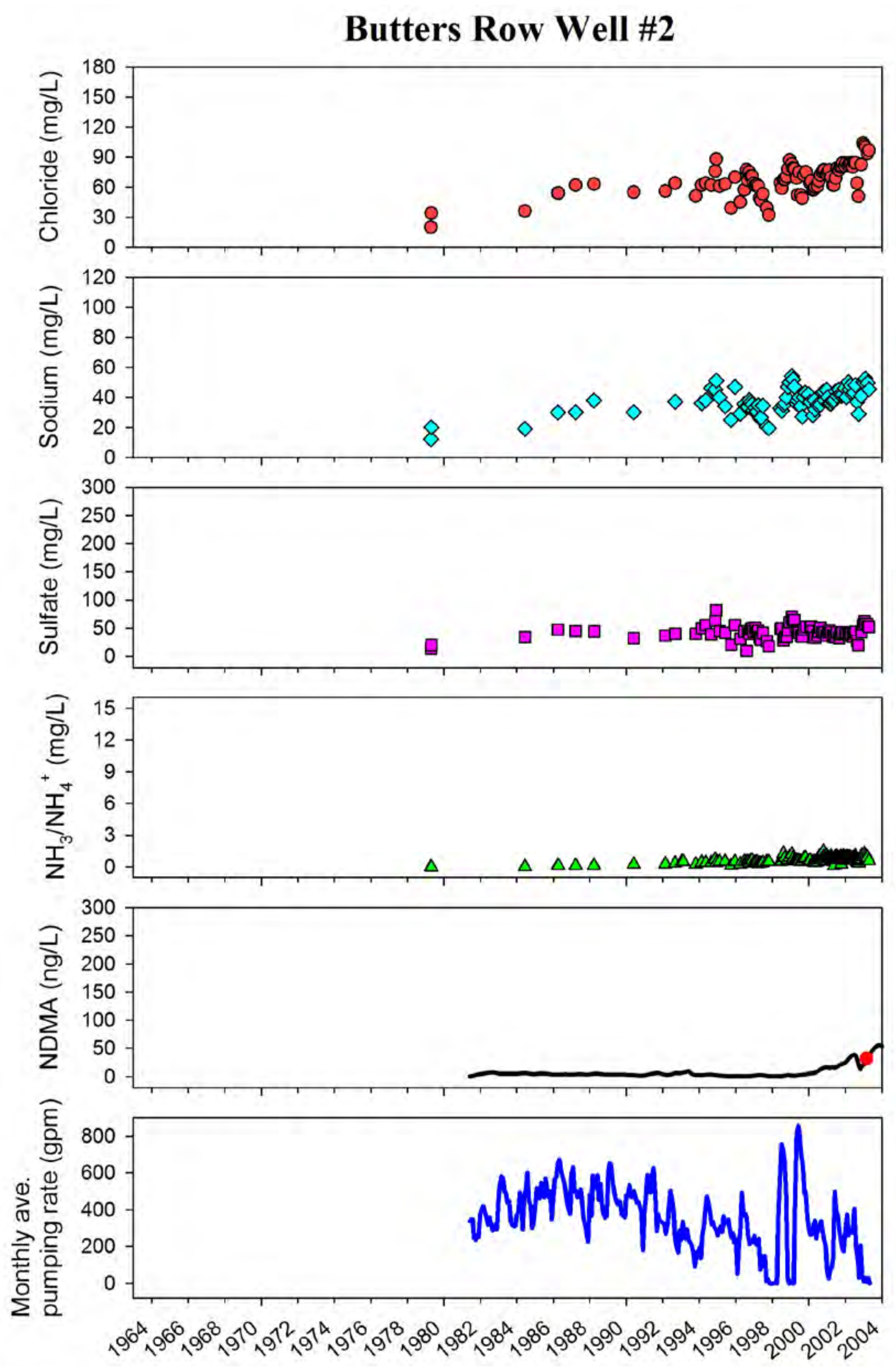


Figure 5.11: Measured concentrations of major ions and NDMA (red dot), simulated NDMA concentrations (black line), and estimated pumping rates at Butters Row #2.

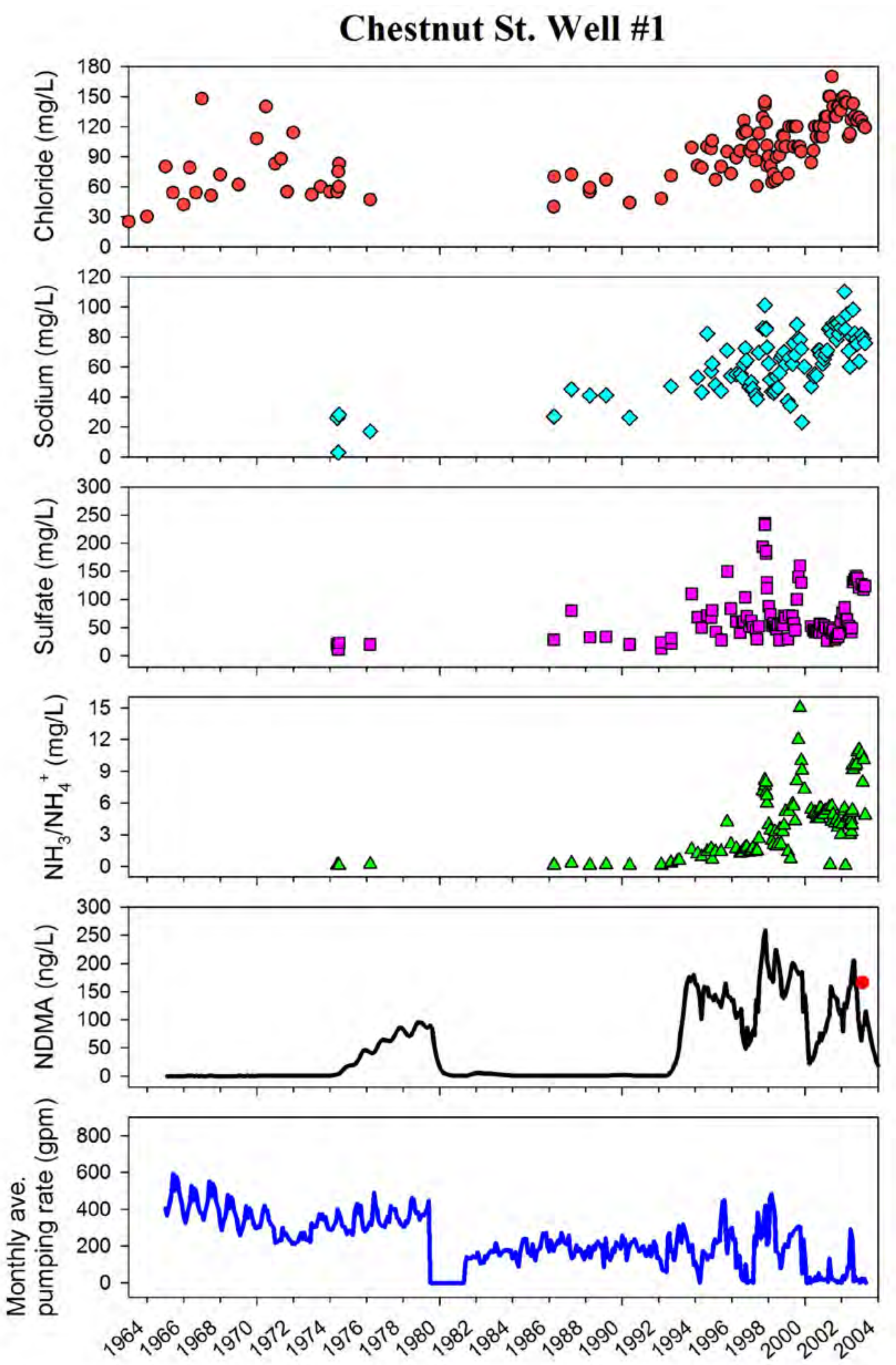


Figure 5.12: Measured concentrations of major ions and NDMA (red dot), simulated NDMA concentrations (black line), and estimated pumping rates at Chestnut St. #1.

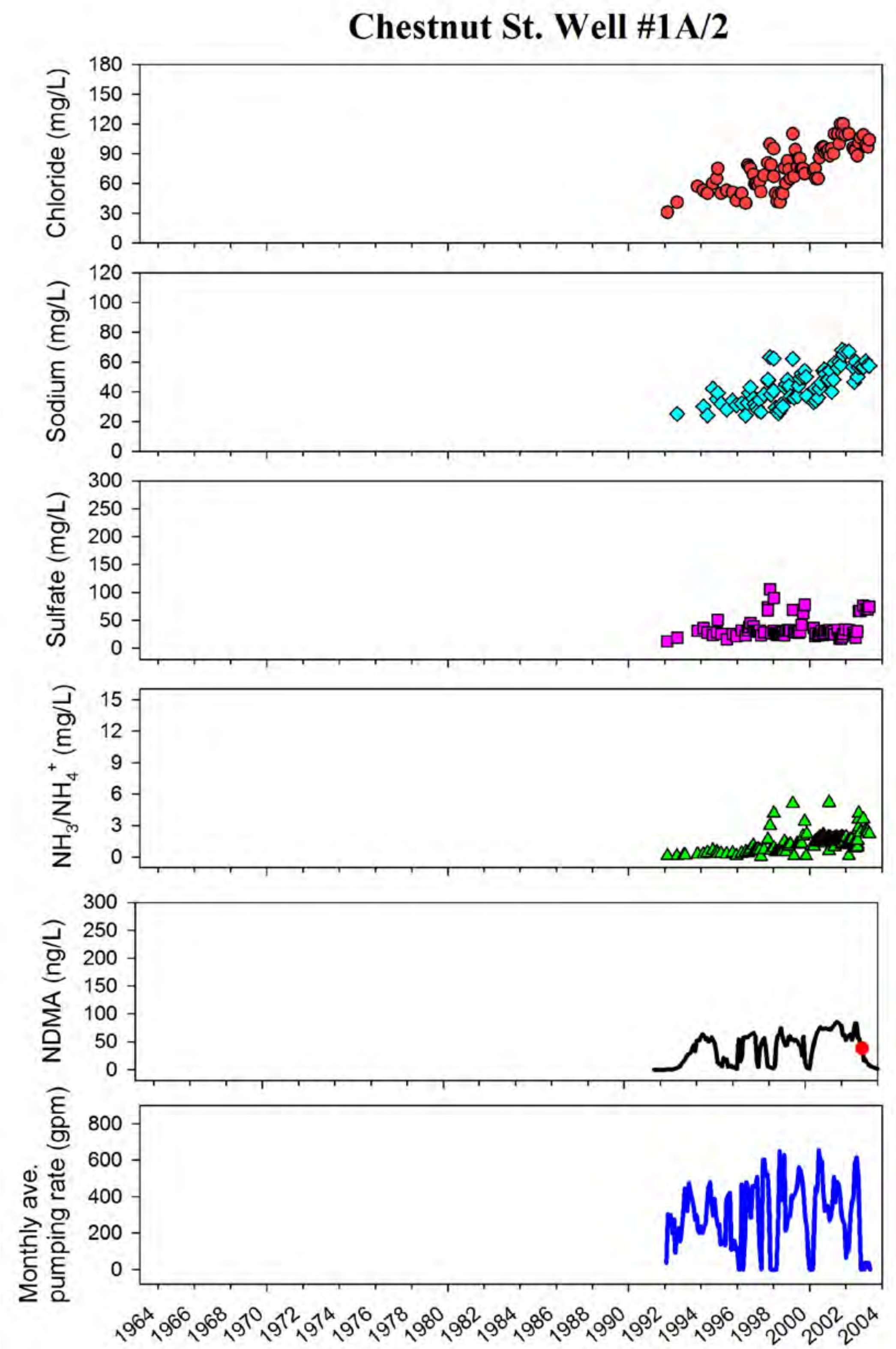


Figure 5.13: Measured concentrations of major ions and NDMA (red dot), simulated NDMA concentrations (black line), and estimated pumping rates at Chestnut St. #1A/2.

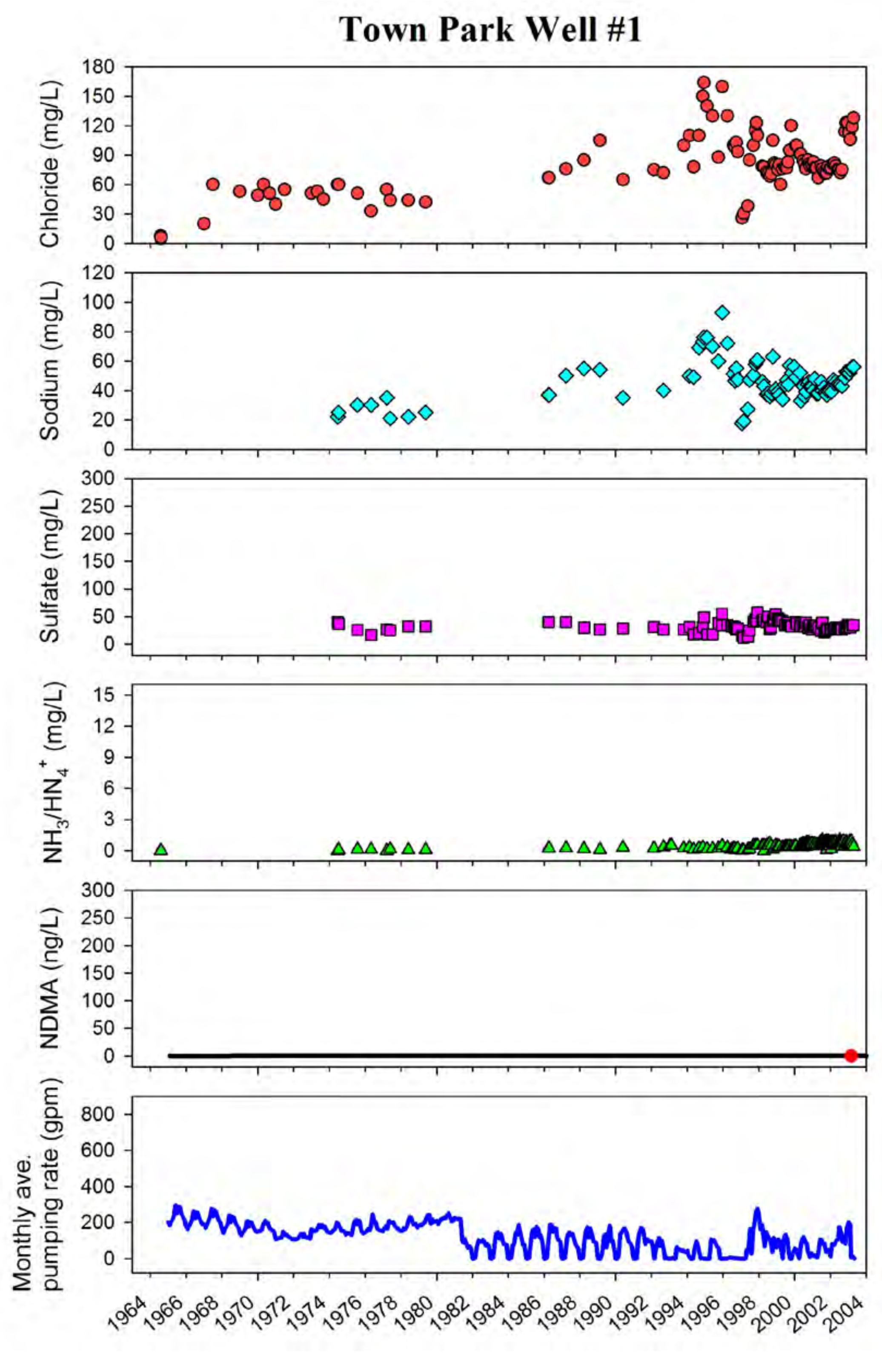


Figure 5.14: Measured concentrations of major ions and NDMA (red dot), simulated NDMA concentrations (black line), and estimated pumping rates at Town Park.

Based on the time-series plots for the major ions in Figure 5.10 through Figure 5.14, two conclusions can be made: (1) the data suggest that significant concentration increases occurred in Butters Row #1 no later than 1986 and continued to be elevated until the well was turned off in 2002; and (2) similarly, significant concentration increases in Chestnut St. #1 and Chestnut St. #1A/2 occurred in 1993 and continued to be elevated until the wells were turned off. These results support the simulated arrival time of NDMA to each well.

Evidence that contaminants from the Olin site likely reached the water supply wells earlier than 1986 is found in reports by CRA (1993) and Smith (1997). Both reports indicate that in the 1970s the Altron production well (B-1 in Figure 4.6) was found to be contaminated with dense green liquid consistent with descriptions of the DAPL emanating from the Olin site as early as 1964. According to Smith (1996) the dense layer "…is generally characterized by specific gravity greater than water, a slight to strong green color due to the presence of chromium, and sulfate concentrations exceeding 3,000 mg/L." CRA (1993) reports that the contamination was present in the well in 1977, while Smith (1997) reports that the contamination was present in the well in 1972. Therefore, the earliest arrival date of NDMA to the MMB aquifer supply wells may have been closer to the early-to-mid 1970s. The sensitivity of our results to the arrival time of DAPL to the Western Bedrock Valley is explored in Section 6.2.

5.1.3 Sensitivity Analyses

5.1.3.1 Domain Discretization

During the initial model development, the model grid was generated with a uniform row height and column width of 50 feet. However, prior to completing the model calibration, the grid rows and columns near the town's water supply wells were reduced to 25 feet. This area was selected for enhancement of the model grid resolution because the pumping from wells in the region resulted in large changes in potentiometric head over small distances that would yield the highest sensitivity to the model resolution. The model grids for both the initial and high-resolution versions of the model near the Wilmington water supply wells are shown in Figure 5.15 and Figure 5.16, respectively. All other model parameters were held constant and the model was run for the years 1975 through 2003 (note that this analysis was performed before the model simulation period was extended back an additional 10 years to begin in 1965). The resulting monthly simulated heads at the location of monitoring well GW-63S with both the initial and high-resolution models are shown in Figure 5.17. The resulting heads are nearly identical, although there is a tendency for the simulated heads with the high-resolution model to have slightly higher peak values and slightly lower minimum values (i.e., on the order of 0.1 feet less-than or greater-than that of the base case). We observed the same results by simulating heads at monitoring well GW-64S as shown in Figure 5.18. These results indicate that the initial model resolution of 50 feet was adequate. However, erring on the side of conservativeness, the high-resolution grid was used in model calibration and model applications.

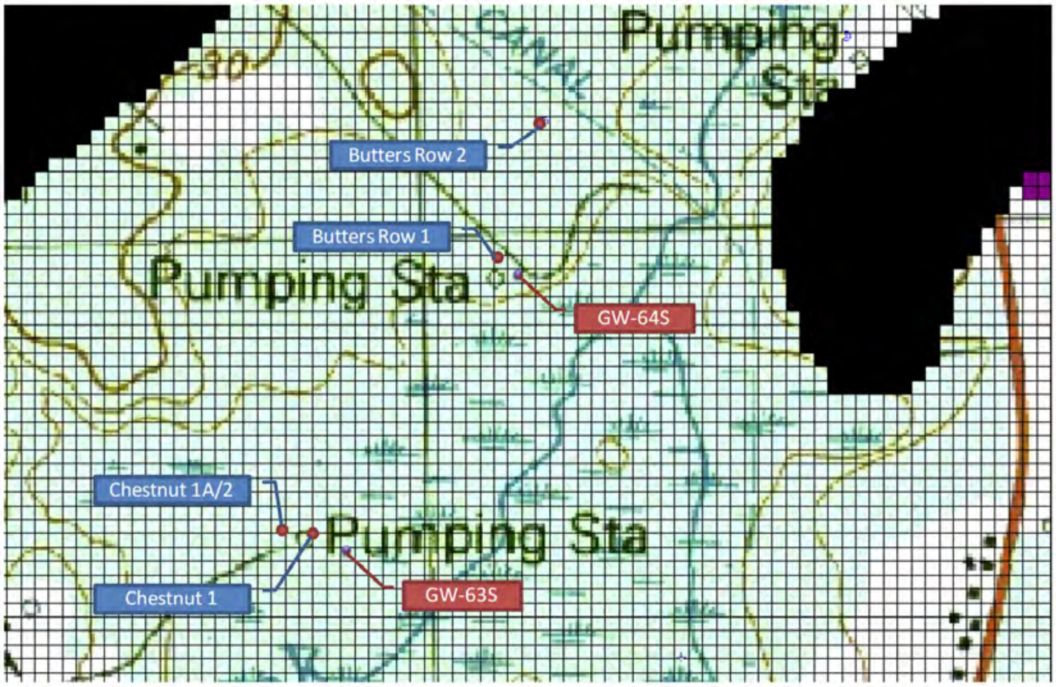


Figure 5.15: Initial low-resolution model grid with row height and cell width of 50 feet in vicinity of Butters Row and Chestnut Street water supply wells and monitoring wells GW-63S and GW-64S.

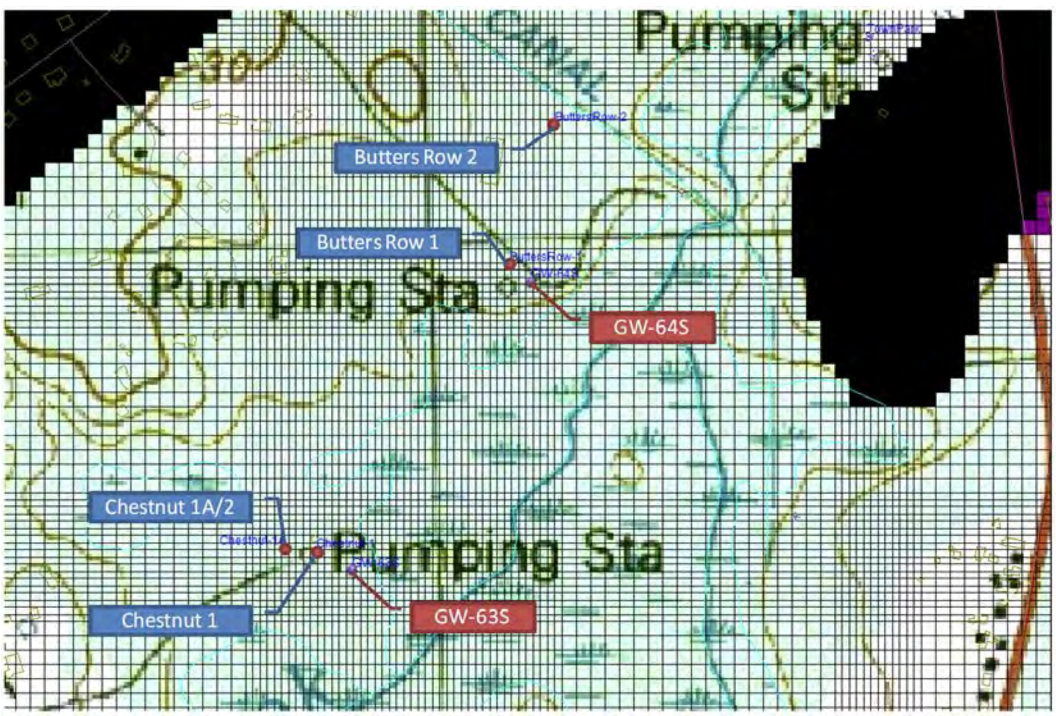


Figure 5.16: Modified high-resolution model grid with row height and cell width reduced to 25 feet in vicinity of Butters Row and Chestnut Street water supply wells and monitoring wells GW-63S and GW-64S.

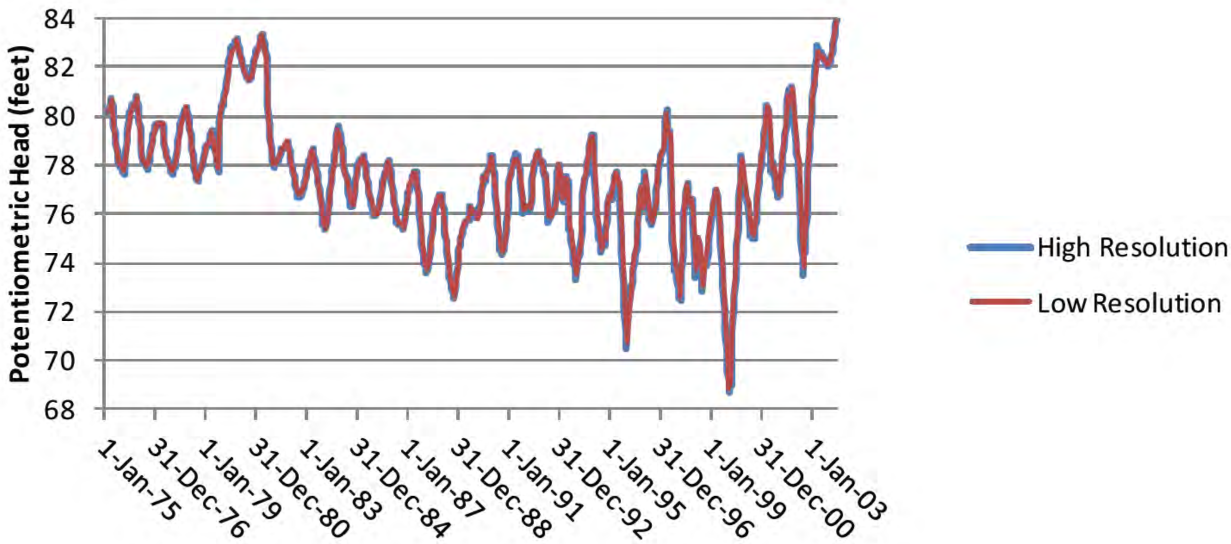


Figure 5.17: Simulated potentiometric head at monitoring well GW-63S in pre-calibration version of model using both the high- and low-resolution grids.

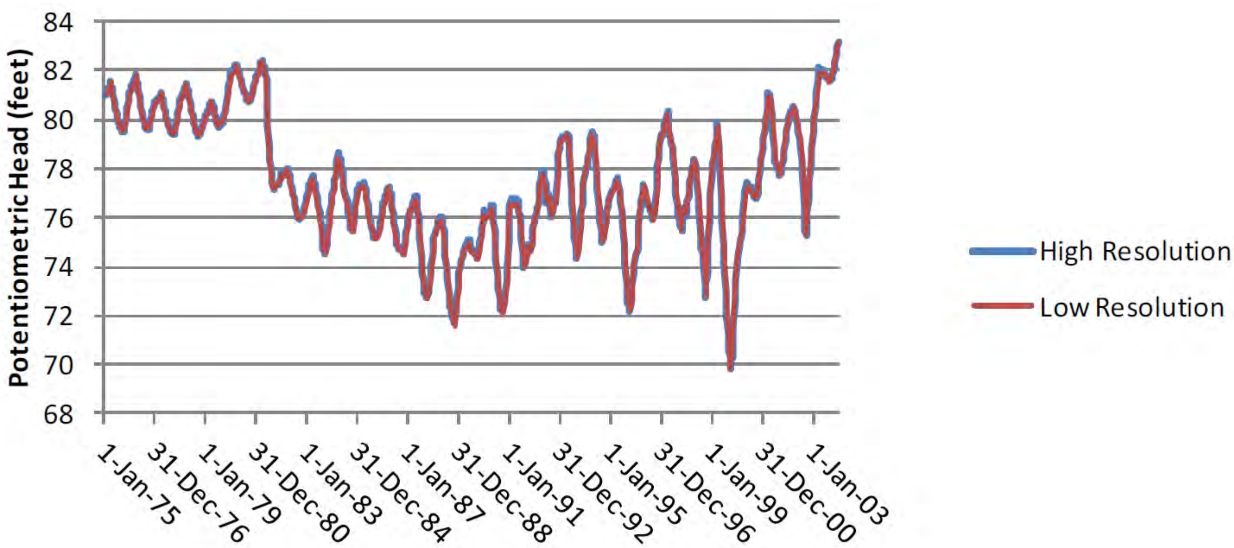


Figure 5.18: Simulated potentiometric head at monitoring well GW-64S in pre-calibration version of model using both the high- and low-resolution grids.

5.1.3.2 Simulation Time Steps

To judge the sensitivity of the model results to the flow model timestep duration, the number of calculations per timestep was increased from one under the initial simulations to two under the high temporal resolution simulations. Specifically, the calculation timestep was reduced from 1-month to ½-month in duration. Figure 5.19 and Figure 5.20 show the simulated potentiometric head at monitoring wells GW-63S and GW-64S, respectively, for calculation time steps of ½-month and 1-month durations. In both cases, the stress period conditions were changed at 1-month intervals. These figures show that the heads are practically identical for the two simulations, and therefore suggest that the initial simulation resolution was adequate. However, erring on the side of caution, the ½-month calculation timestep duration was employed in model calibration and model application runs.

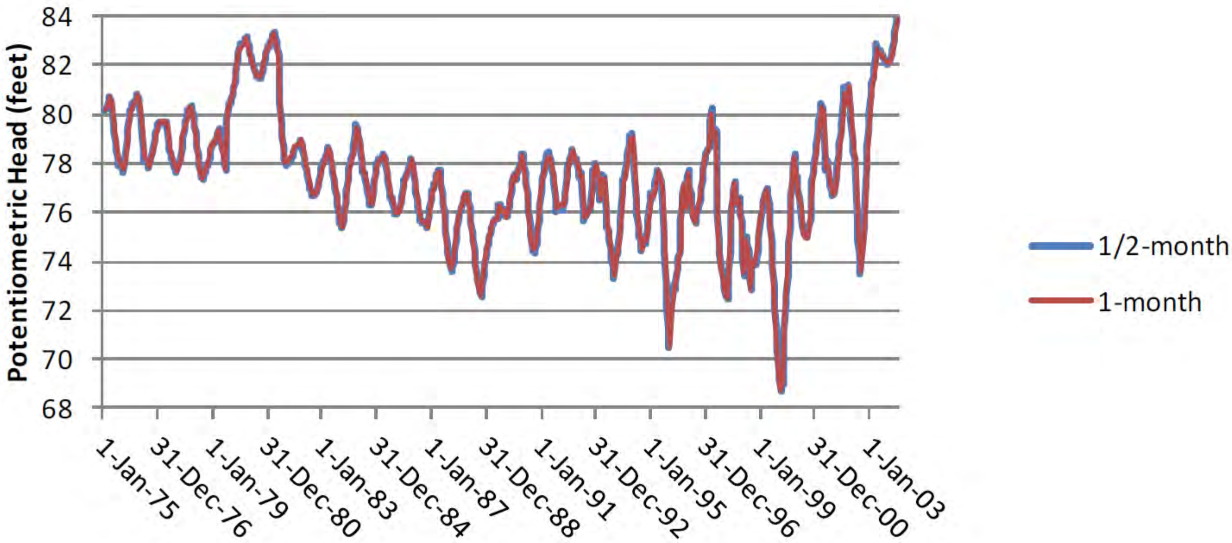


Figure 5.19: Simulated potentiometric head at monitoring well GW-63S using timestep durations of ½-month and 1-month.

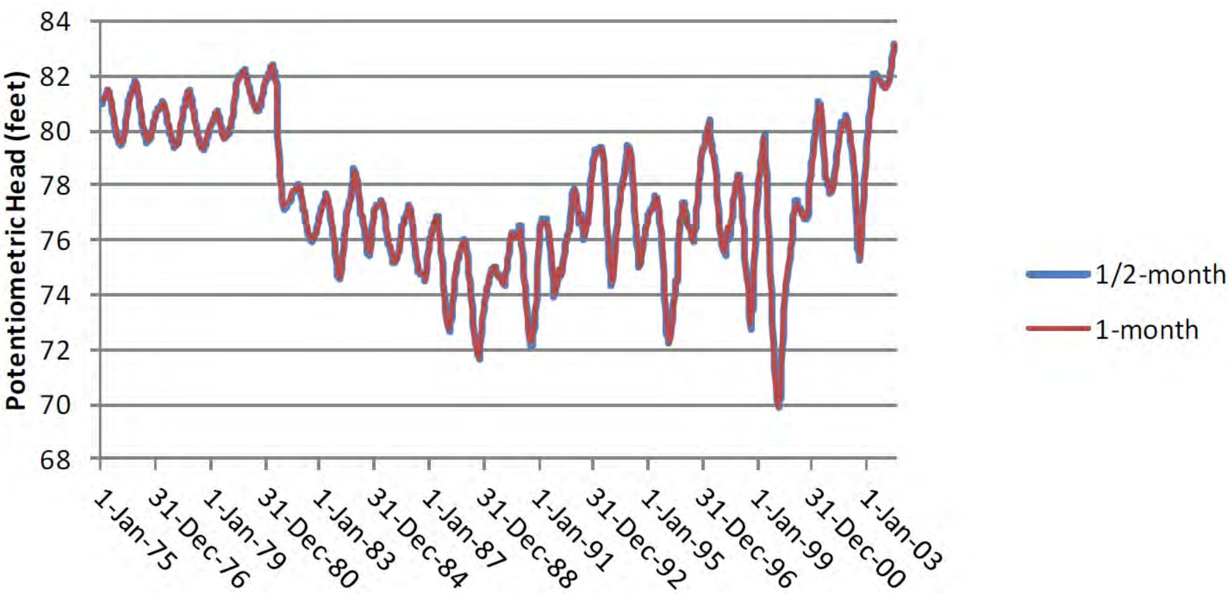


Figure 5.20: Simulated potentiometric head at monitoring well GW-64S using timestep durations of ½-month and 1-month.

5.1.3.3 Model Parameters

The final sensitivity analysis focused on evaluating the impact of varying individual model parameters on the overall error. Nine parameters were evaluated including the horizontal hydraulic conductivities for each of the six zones (see Figure 4.5 for zone delineations), vertical recharge, specific storage, and specific yield. Table 5.4 lists these parameters and their final calibrated values.

Table 5.4: Ground water flow model parameters evaluated in sensitivity analysis

Parameter	Description	Calibrated Value
Kxy-1	Horizontal hydraulic conductivity in Zone 1	2 ft/d
Kxy-2	Horizontal hydraulic conductivity in Zone 2	10 ft/d
Kxy-3	Horizontal hydraulic conductivity in Zone 3	75 ft/d
Kxy-4	Horizontal hydraulic conductivity in Zone 4	25 ft/d
Kxy-5	Horizontal hydraulic conductivity in Zone 5	100 ft/d
Kxy-6	Horizontal hydraulic conductivity in Zone 6	225 ft/d
Recharge	Vertical recharge	Time Variable
Ss	Specific storage	0.005 per ft
Sy	Specific yield	0.25

For each parameter, the value was adjusted using a series of seven multiplication factors ranging from 0.1 to 10 (specifically, 0.1, 0.2, 0.5, 1, 2, 5, and 10). Unlike the other parameters that were constant over the simulation period, the recharge was time variable meaning its value changed from month the month (see Section 4.1.2.3). For the recharge parameter, each monthly value was multiplied by the same factor. For each iteration, the calibration statistics were computed and summarized using the mean absolute error, and the root mean squared error. Plotting these two summary statistics versus the multiplication value provides insight into the sensitivity of the model to each parameter. Parameters that have the highest sensitivity will generate larger changes in the error rates due to larger changes in the simulation results. Ideally, the error values for each parameter when the multiplier is set to 1 should be lowest across all multiplication factors. This would mean that the error is minimized at its calibrated value.

Figure 5.21 and Figure 5.22 show the changes in mean absolute error and root mean squared error, respectively, for all nine parameters. Both figures show that the model is most sensitive to the horizontal hydraulic conductivity for zone 6 and the recharge rate as indicated by the large increases in error rates for changes in both parameters. The sensitivity to hydraulic conductivity for zone 6 is not surprising given that it contains the most grid cells. The specific storage (S_s) and specific yield (S_y) parameters showed increases in error for smaller values (multiplier < 1), and slight decreases in error for higher values (multiplier > 1). Although these results also suggest these parameters should be increased to reduce the error, the change in error was relatively small, and increased values would not have been physically plausible. The remaining hydraulic conductivity parameters (all zones other than 6) showed very little change in error statistics over the full range of multipliers indicating that the model is not sensitive to those parameters.

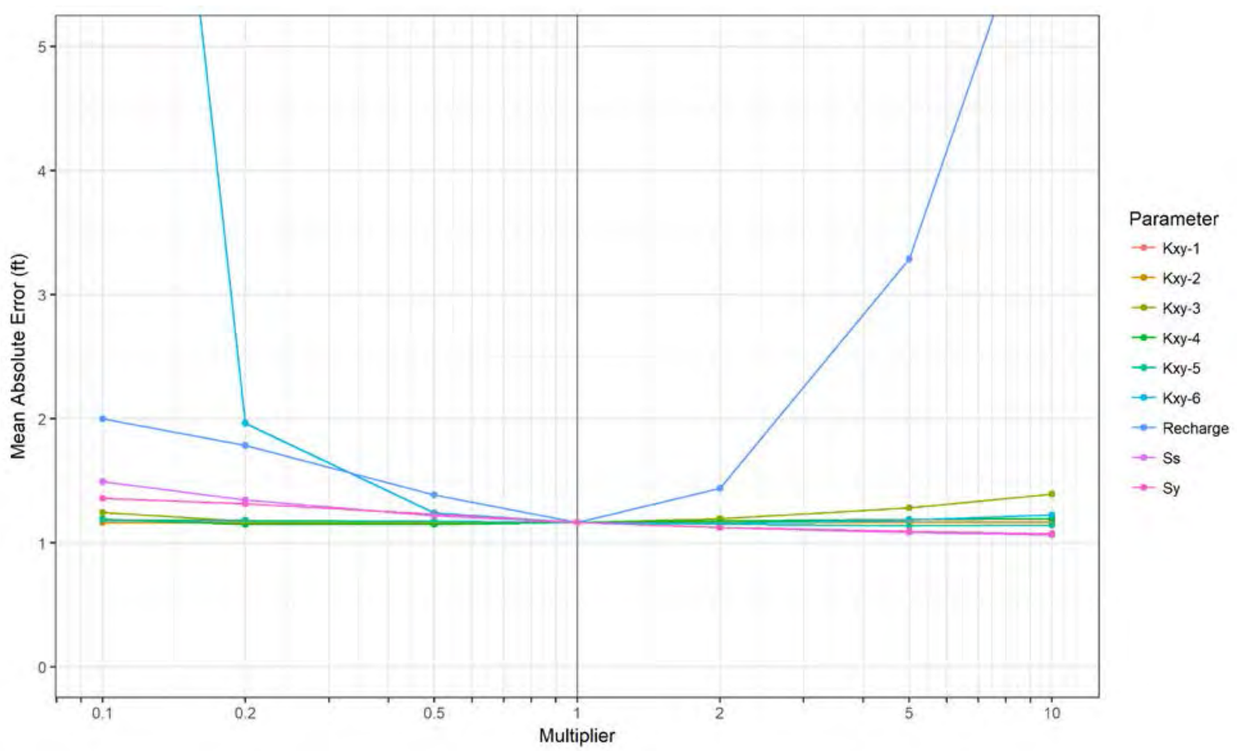


Figure 5.21: Sensitivity analysis of ground water flow model parameters using mean absolute error.

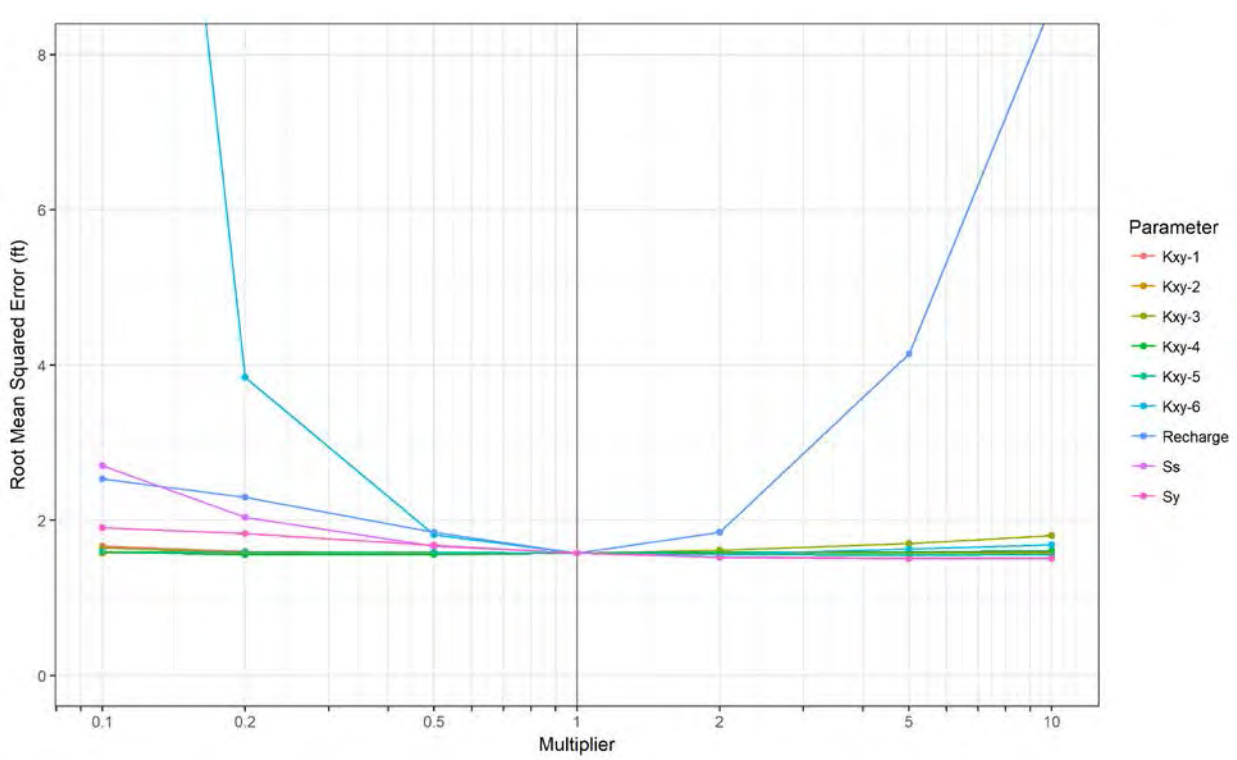


Figure 5.22: Sensitivity analysis of ground water flow model parameters using root mean squared error.

The results of all three sets of sensitivity analyses (horizontal discretization, simulation timestep, and model parameters) show that the ground water flow model is relatively insensitive to most of these factors, with the exception of the recharge rate and the horizontal hydraulic conductivity parameter for zone 6, which is the most common zone. Reducing the grid size in the vicinity of the water supply wells and reducing the calculation timestep duration resulted in negligible changes to simulated heads and in both cases the high resolution versions were retained for the final simulations. The recharge and hydraulic conductivity for zone 6 showed significantly greater sensitivity than the other hydraulic parameters. Furthermore, the results indicate that the calibrated values for these two parameters generated the lowest model error.

5.1.4 NDMA Concentrations in the MMB Aquifer and Water Supply Wells

The ground water transport model was used to simulate the dispersion and advection of NDMA out of the deep DAPL pools and into the aquifer from January 1965 to December 2003. As mentioned in Section 4.1.4, this simulation period begins before and ends after the primary study period (1974 – 2000) in order to simulate the initial dispersion of NDMA from the DAPL pools, and to provide simulation results for comparison to NDMA measurements collected in 2003 at each well.

Figure 5.23 through Figure 5.25 show the spatial distribution of NDMA concentrations in vertical layers 2 (2^{nd} from top), 3 (middle), and 4 (2^{nd} from bottom) of the aquifer at 3-year increments from 1965 through 2003. The top and bottom vertical layers are not included in these figures because the town's water supply wells only draw water from the middle three layers (see Table 4.3). Note that the color gradient representing concentration is based on a logarithmic scale. Monthly time series of the simulated NDMA concentrations and estimated pumping rates at each of the five water supply wells in the MMB aquifer are shown in Figure 5.26 through Figure 5.30. Note that concentrations are not shown when the pumping rate for a given well is zero, which results in the visible gaps in the lines representing concentration.

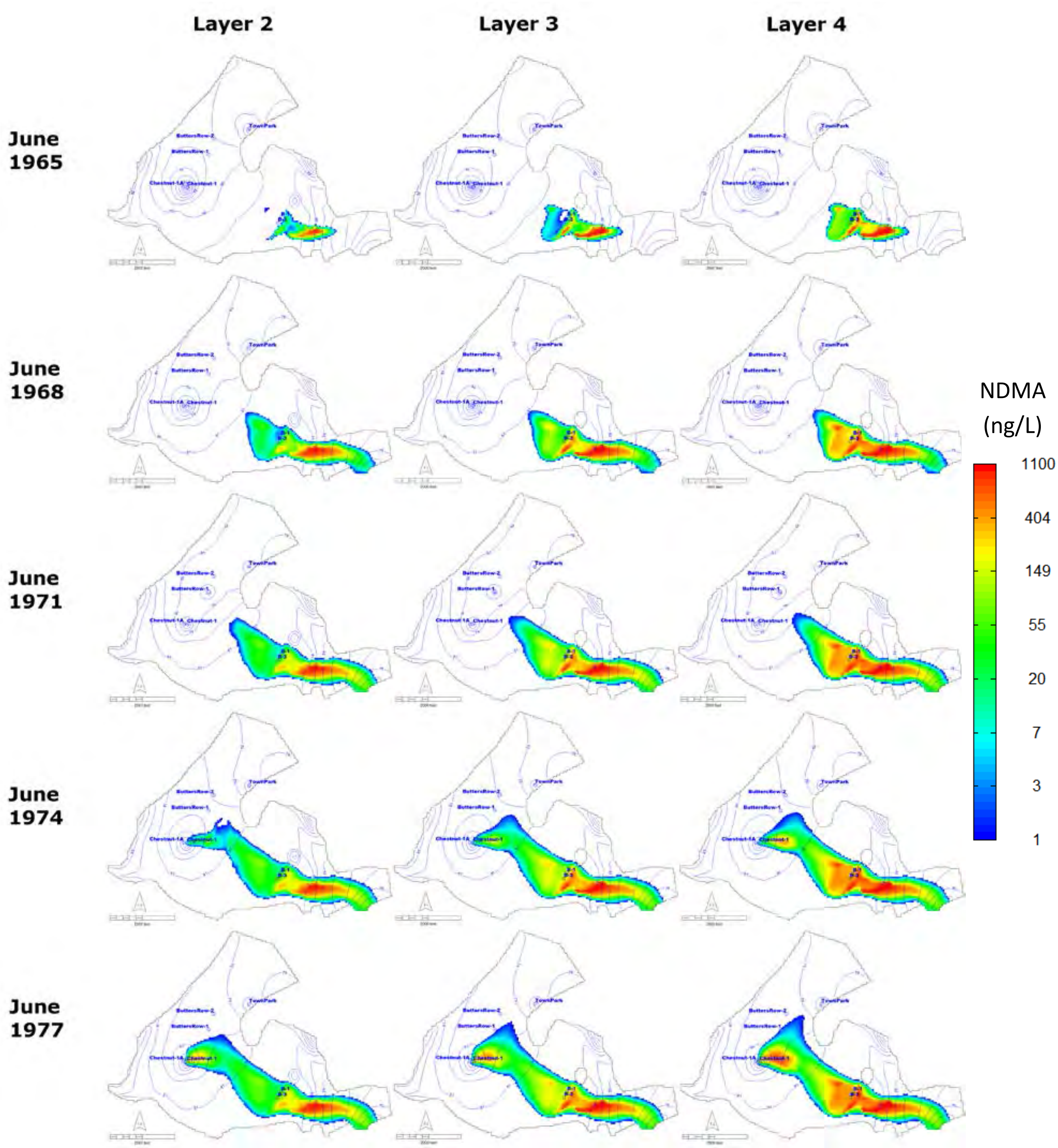


Figure 5.23: Simulated NDMA concentrations in model layers 2, 3 and 4 from 1965 – 1977.

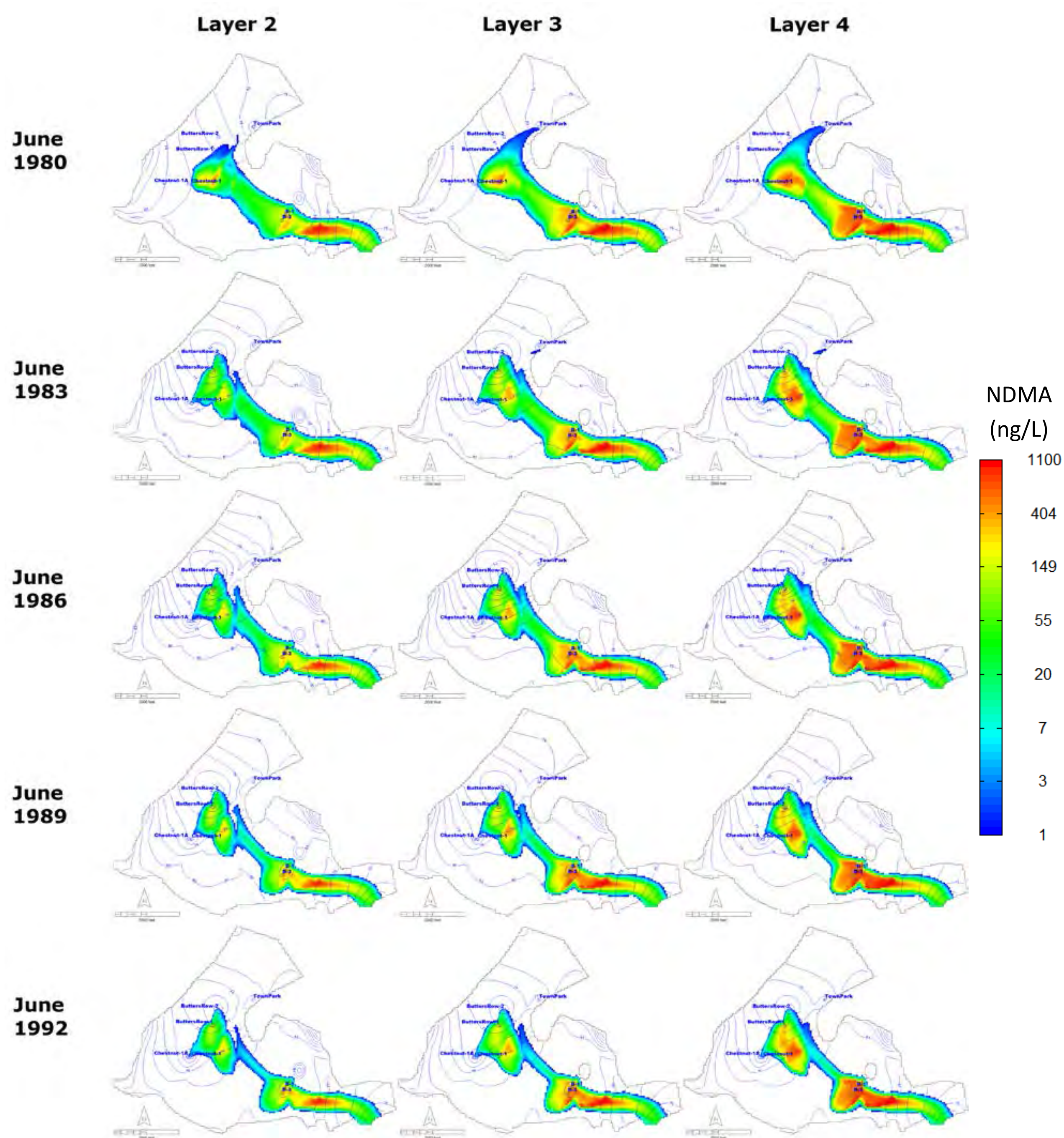


Figure 5.24: Simulated NDMA concentrations in model layers 2, 3 and 4 from 1980 – 1992.

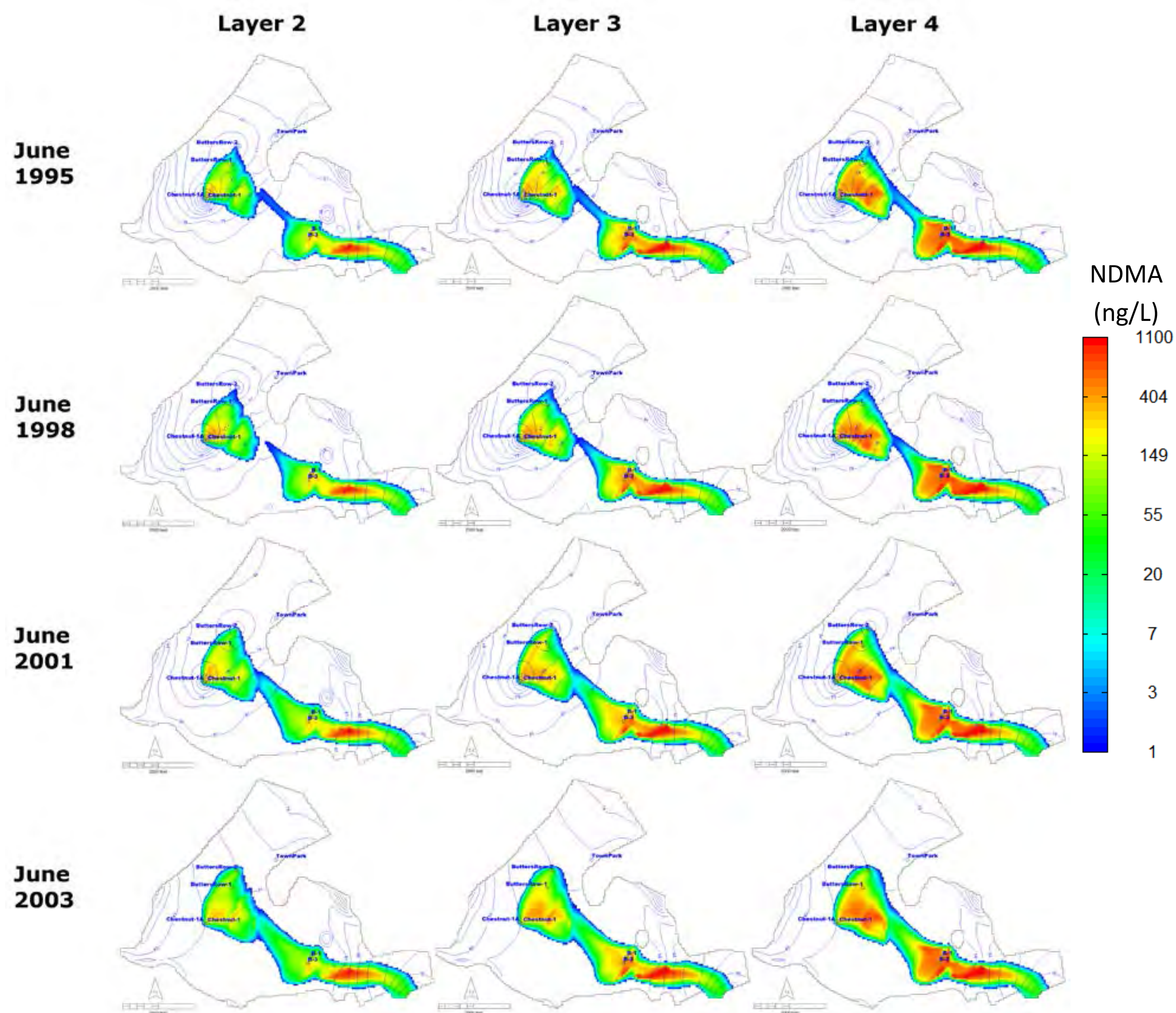


Figure 5.25: Simulated NDMA concentrations in model layers 2, 3 and 4 from 1995 – 2003.

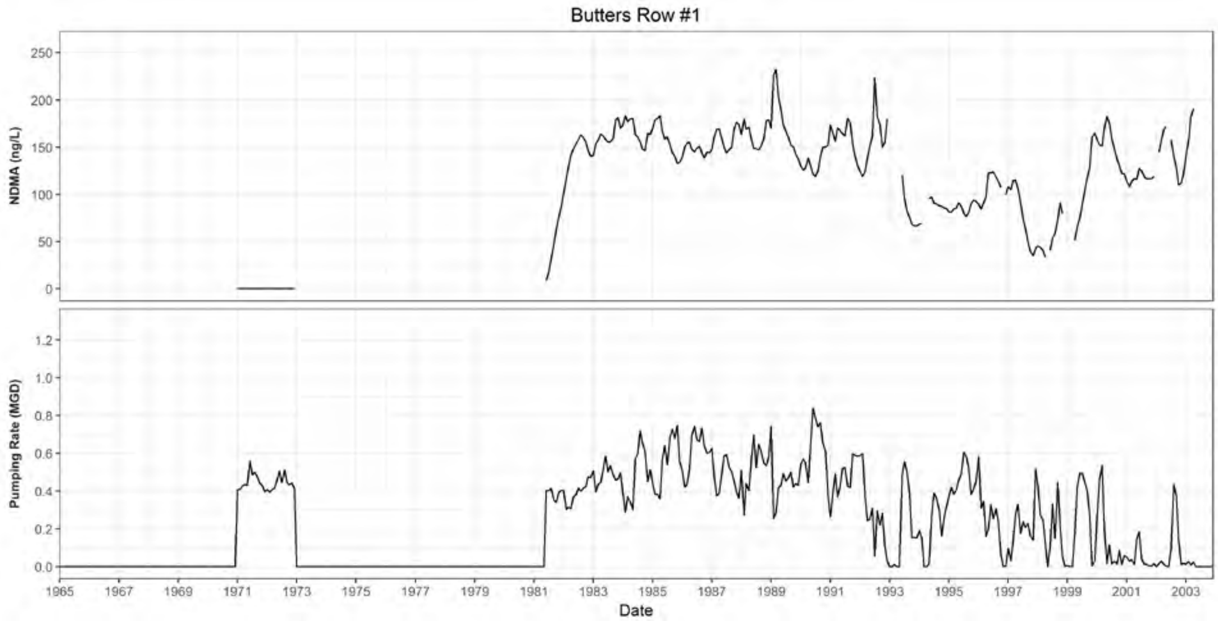


Figure 5.26: Simulated NDMA Concentration and estimated pumping rates at Butters Row #1 well. Concentrations are not shown for months when the pumping rate is zero.

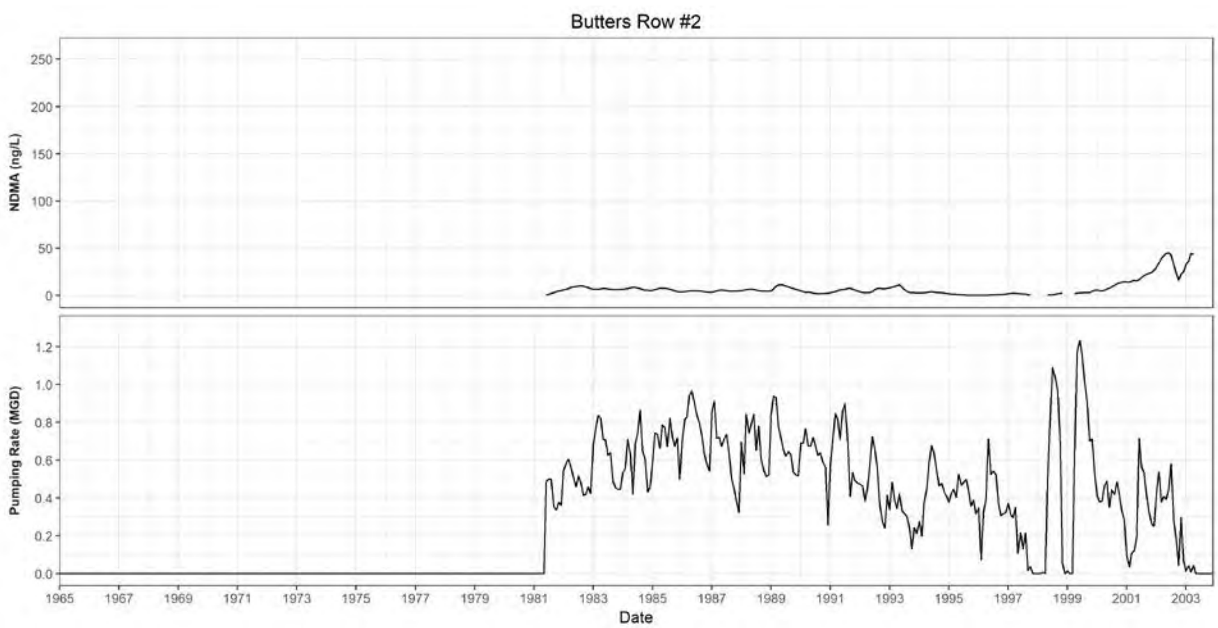


Figure 5.27: Simulated NDMA concentration and estimated pumping rate at Butters Row #2 well. Concentrations are not shown for months when the pumping rate is zero.

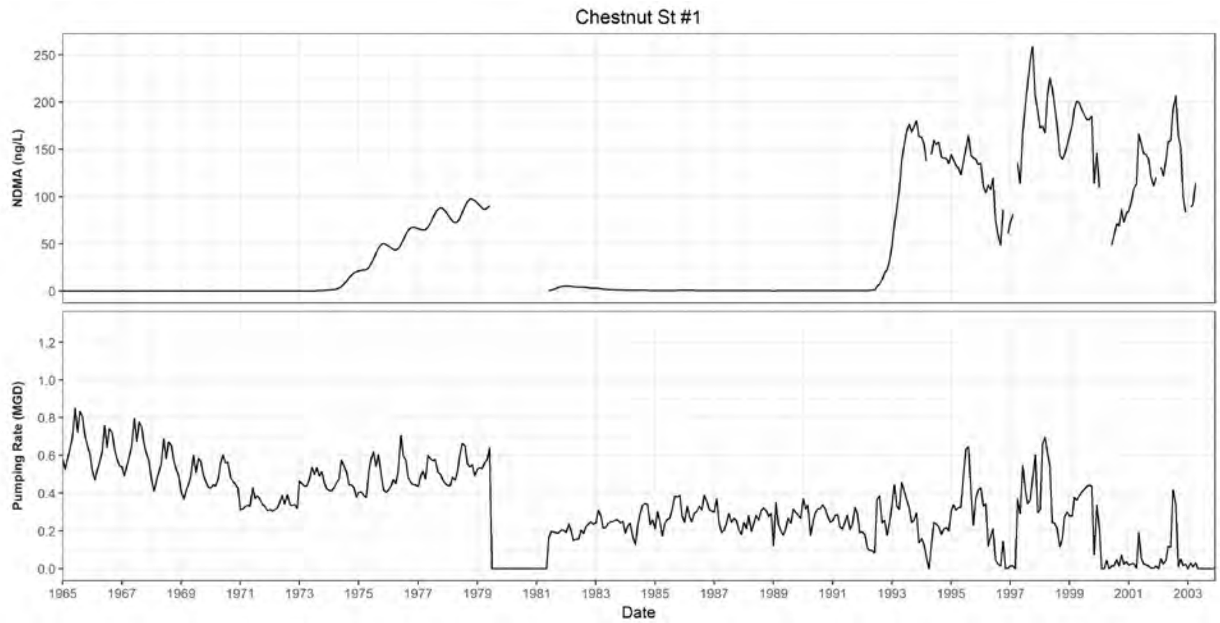


Figure 5.28: Simulated NDMA concentration and estimated pumping rate at Chestnut St. #1 well. Concentrations are not shown for months when the pumping rate is zero.

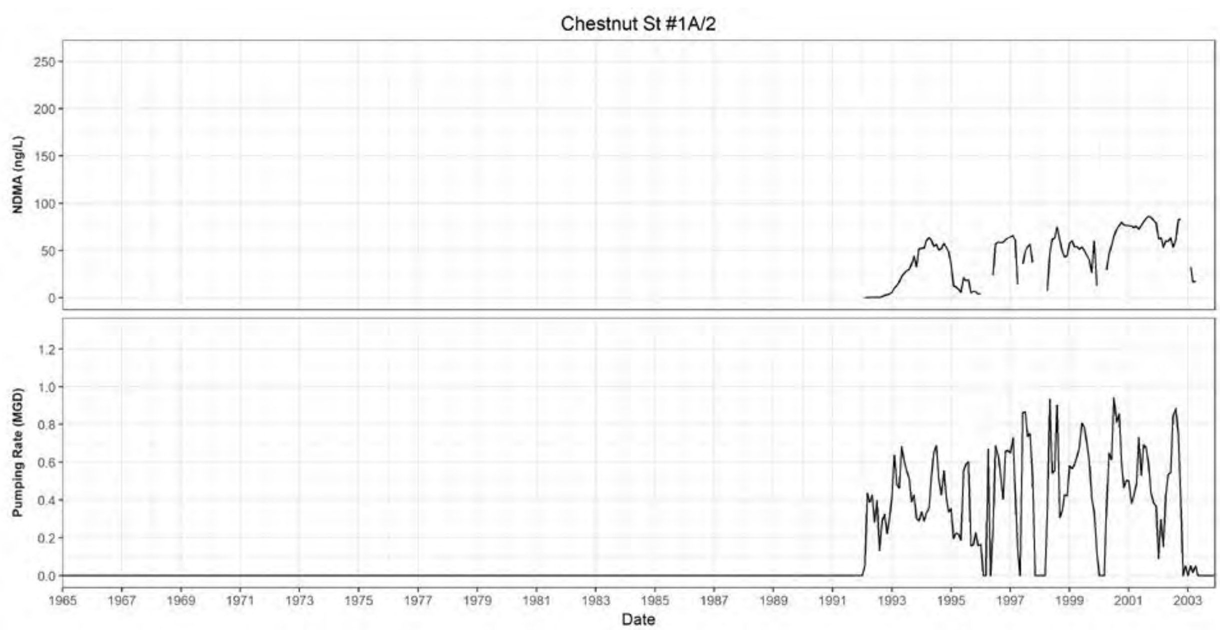


Figure 5.29: Simulated NDMA concentration and estimated pumping rate at Chestnut St. #1A/2 well. Concentrations are not shown for months when the pumping rate is zero.

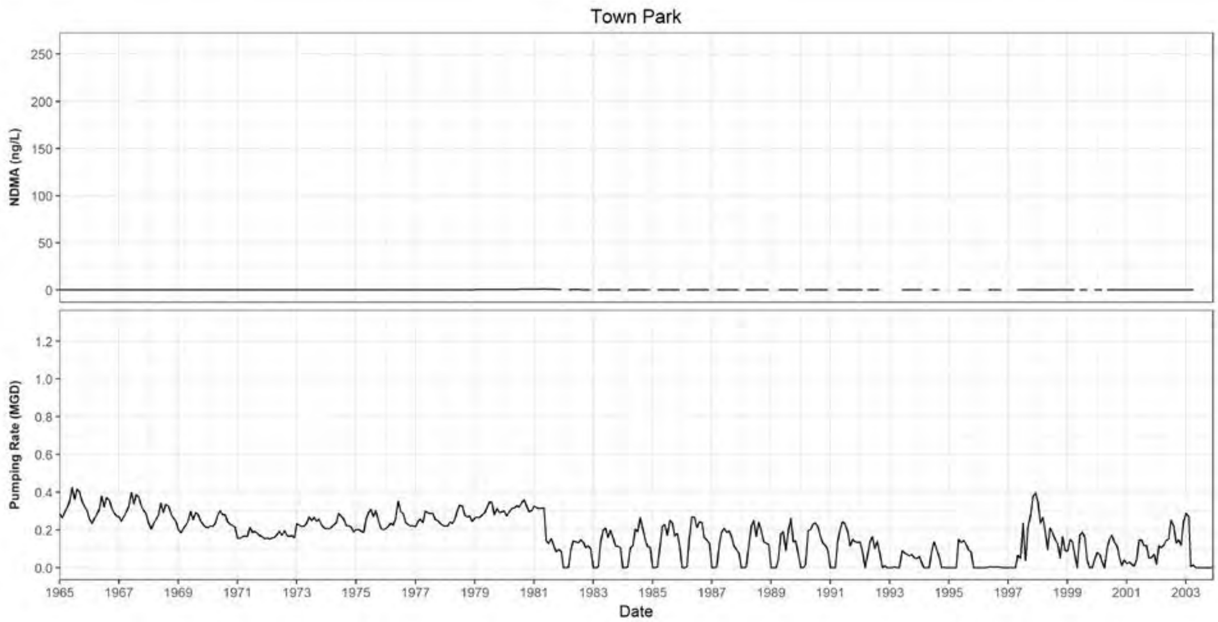


Figure 5.30: Simulated NDMA concentration and estimated pumping rate at Town Park well. Concentrations are not shown for months when the pumping rate is zero.

Changes in the extent, shape, and magnitude of NDMA in each layer reflect three key processes:

1. Vertical dispersion and advection of NDMA from the two DAPL pools in layer 5 (see Figure 4.6 for pool locations) results in a gradient of decreasing concentration from layers 4 to 3 to 2; however, the shape and extent of the plumes is similar across all three of these layers.
2. General ground water flow patterns cause NDMA to be transported in two primary directions: 1) from the Main St. DAPL pool near the Olin site to the southeast corner of the model domain and into the Aberjona river basin, and 2) from both DAPL pools (WBV and Main St) to the north towards the water supply wells in the MMB aquifer and to the east.
3. Pumping from the individual water supply wells creates capture zones drawing the plume towards the wells as the result of large changes in the head gradient and flow field. The shape of the plume in the MMB aquifer is strongly dependent on which supply wells were active at a given time and the relative pumping rates among the five wells.

From 1965 to 1971, NDMA dispersed out of the Main St. DAPL pool (located near the Olin site), resulting in an elongated plume stretching both towards the MMB aquifer to the northwest, and towards the Aberjona River to the southeast (Figure 5.23). By 1974, the second DAPL pool located in the Western Bedrock Valley began arriving and resulted in additional diffusion of DAPL directly into the MMB aquifer. At this time, NDMA first arrived at the Chestnut St. #1 well, which, along with Town Park, were the only two active wells.

From 1974 through 1980, pumping at both Chestnut St. #1 and Town Park created capture zones that pulled the plume towards each of these two wells (Figure 5.23 and Figure 5.24). The simulated concentration of NDMA in Chestnut St. #1 reached a peak of 97 ng/L in 1978, before decreasing after the well was temporarily shut off in 1979. Although the plume was also drawn towards the Town Park well, it did not ultimately reach this well. The Chestnut St. #1 and both Butters Row wells were activated in June 1981 when the Butters Row WTP was brought online. Activation of the Butters Row wells prevented the plume from spreading towards Town Park and resulted in a smaller spatial extent as shown for 1983.

From 1983 through 1991, continuous pumping from the two Butters Row wells resulted in a relatively stable plume, which was pulled away from the Chestnut St. #1 well (Figure 5.24). The month-to-month variability in NDMA concentration in each well reflects monthly changes in relative pumping rates of each well. In general, concentrations show a seasonal pattern with higher levels in the summer due to higher pumping rates relative to winter. Over this period, the average concentrations at Butters Row #1 and Butters Row #2 were approximately 160 and 6 ng/L, respectively (Figure 5.26 and Figure 5.27). The concentration was higher at Butters Row #1 because it was located closer to the source of the plume and therefore intercepted the NDMA before it could reach Butters Row #2. The concentration at Chestnut St. #1 remained below 3 ng/L over this period because pumping rates at the Butters Row wells were greater and thus drew the plume away from Chestnut St.

In 1992, the Chestnut St. #1A/2 well was activated and began drawing the plume back toward the Chestnut St. well field. As a result, the concentration at Butters Row #1 decreased to approximately 100 ng/L (Figure 5.26) while the concentration at Chestnut St. #1 increased to a peak of 180 ng/L in 1993, and later to an overall peak of 250 ng/L in 1997 (Figure 5.28). The concentration at Chestnut St. #1A/2, however, remained below 100 ng/L for the duration of the period because it was located on the far side of Chestnut St. #1 relative to the DAPL pool sources. In 1999, pumping rates were increased at Butters Row #2 and decreased at Chestnut St. #1 resulting in greater concentrations at the Butters Row wells and lower concentrations at the Chestnut St. wells.

5.2 WATER DISTRIBUTION SYSTEM MODEL

5.2.1 MODEL EVALUATION

The water distribution model was evaluated by comparing simulated TCE concentrations against measurements collected at six locations across the system on July 31, 1986. The purpose of this comparison was to evaluate whether the model accurately represents the spatial distribution of a pollutant originating from the Butters Row WTP. Measured concentrations were only available for the southern half of the network, and the concentrations were relatively uniform. The lack of measurements from the northern part of the distribution system is not ideal from the standpoint of robust evaluation of the model as there is no direct evidence that the model is properly predicting pollutant concentrations in the northern part of the distribution system.

Figure 5.31 shows the daily mean simulated and measured TCE concentrations at each sampling location. The network pipes are color-coded to show the distribution of TCE within the network. The simulated concentrations at all six locations were equal to the concentration assigned to outflow from the Butters Row WTP (12.5 ug/L). The measured concentrations ranged from 7.6 to 9.8 ug/L at these locations. The difference between the measured and simulated concentrations is likely due to natural variability as well as the lack of data on the TCE concentration at the WTP on the same day when the measurements were collected throughout the system (July 31, 1986). The concentration of the WTP finish water concentration (12.5 ug/L) was estimated as the average of two measurements collected on July 14 and September 1, 1986 (see Section 4.3.3). However, the actual TCE concentration at the WTP could have been lower on July 31, 1986 due to daily variability of TCE in the finished water.

These results confirm that the model accurately simulates the minimum transport distance of a pollutant originating at the Butters Row WTP. Because samples were not collected at any locations farther from the WTP where the simulated concentrations approach zero (i.e., the northern part of town), we were unable to evaluate the accuracy of the model across the entire system and in terms of the maximum distance pollutants are transported.

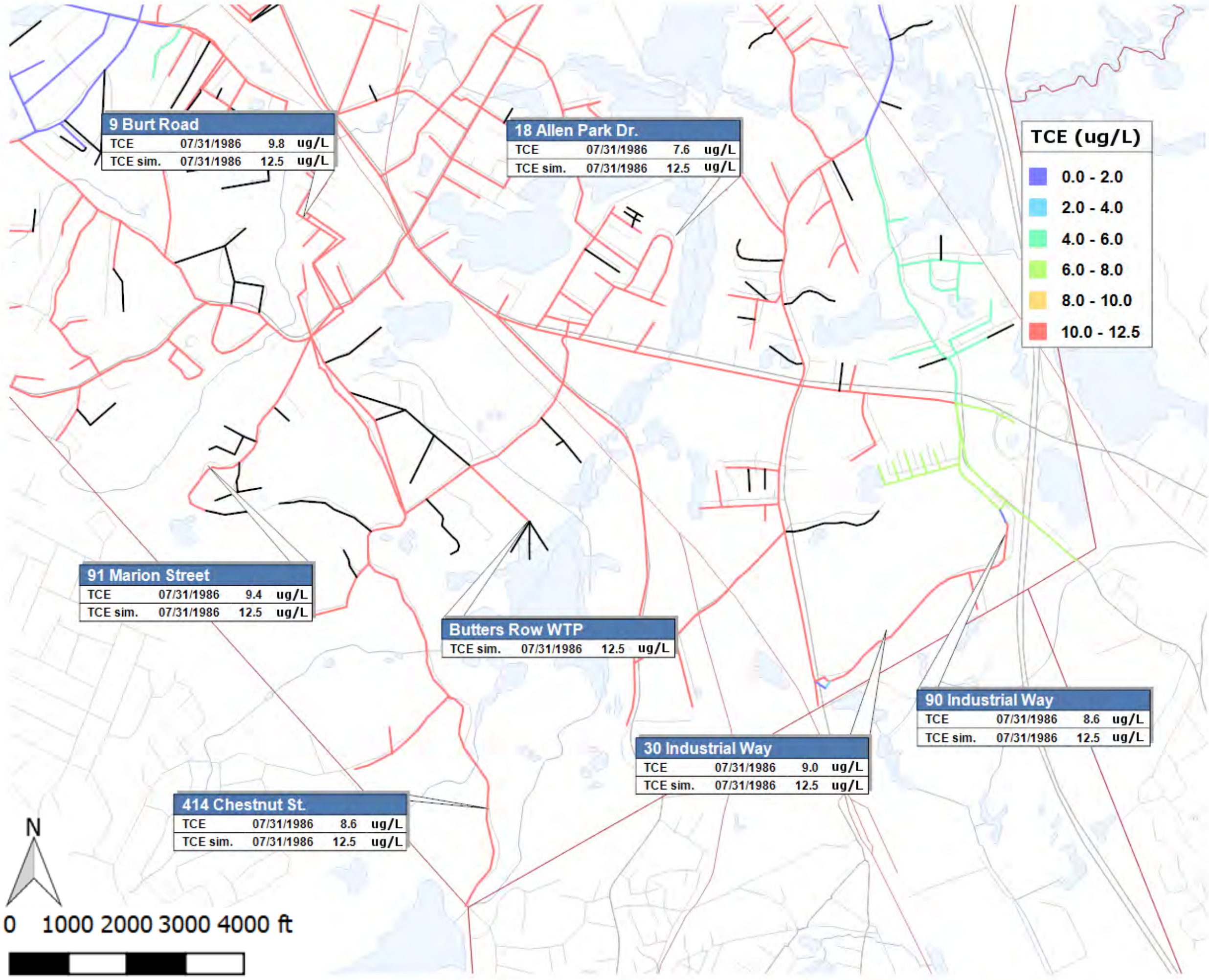


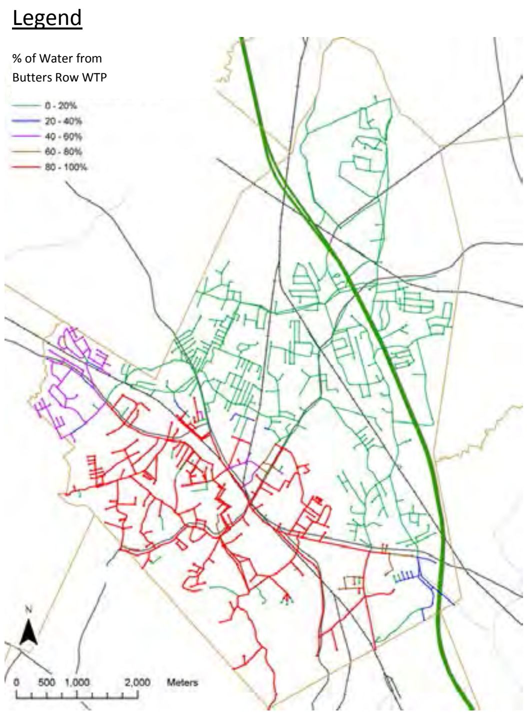
Figure 5.31: Simulated and measured TCE concentrations in the water distribution system on July 31, 1986. Black colored pipes were installed after 1986.

5.2.2 Sensitivity Analysis

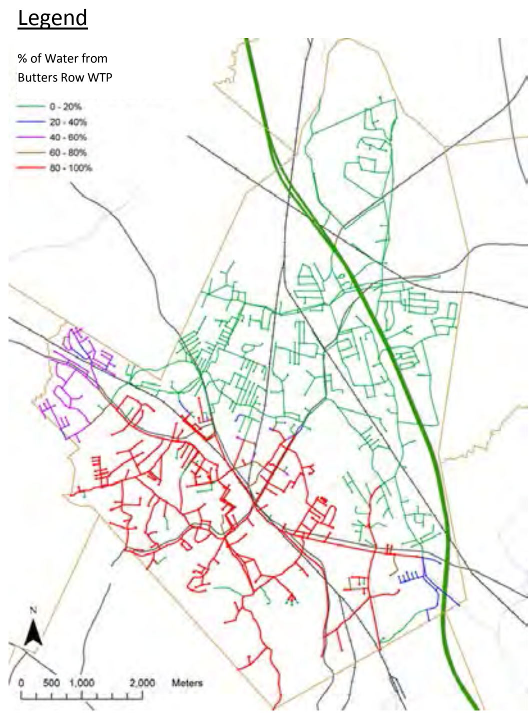
A sensitivity analysis was performed to evaluate the impact of diurnal water demand variability on the distribution of contaminants in the distribution network. The model was configured to perform a transient simulation for a single 24-hour period with time-variable water demands assigned to all nodes. The diurnal demand pattern was defined to reflect typical changes over the course of a day with peaks in mid-morning and late afternoon.

Figure 5.32 shows the simulated percentage of flow derived from the Butters Row WTP within each pipe at four-hour increments over the course of one day. The extent of the zone of elevated Butters Row flows is nearly the same over the simulated 24-hour period, although some pipes are seen to alternate between 0 and 100% Butters Row water primarily in the center of town and along the northwest-southeast boundary separating locations receiving water from the northern well field and those receiving water from Butters Row WTP. Therefore, we concluded that diurnal demand fluctuations did not have a significant effect on the spatial distribution of a pollutant emanating from the Butters Row WTP.

a. 12:00 am



b. 4:00 am



c. 8:00 am

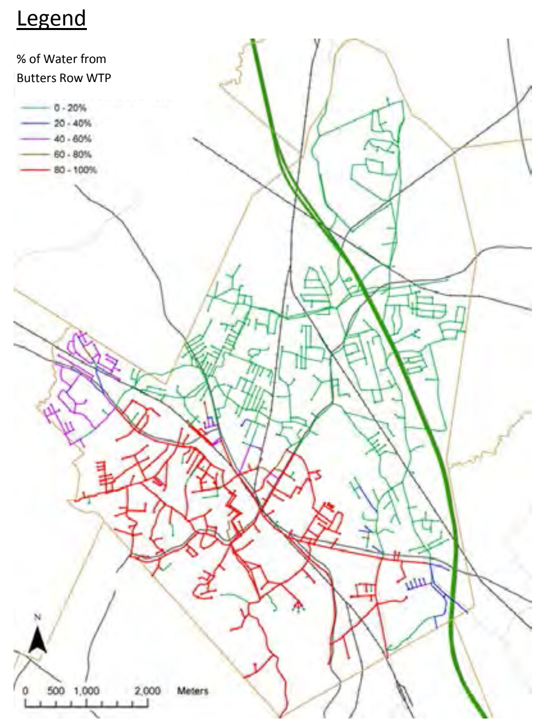
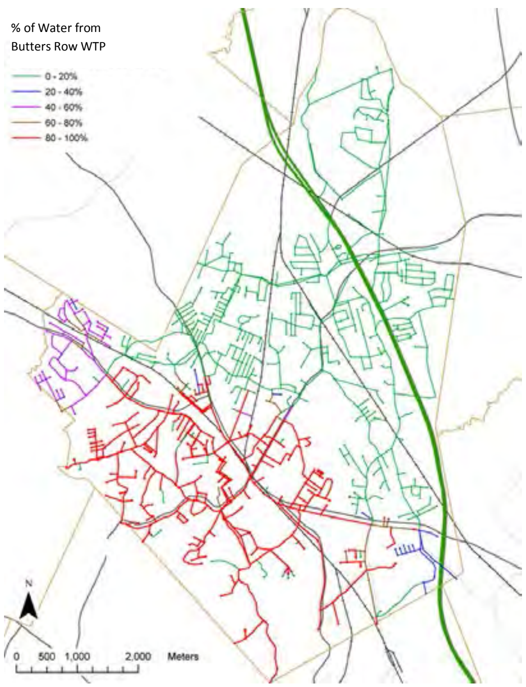


Figure 5.32: Percentage of water derived from Butters Row WTP during typical day (continued on next page).

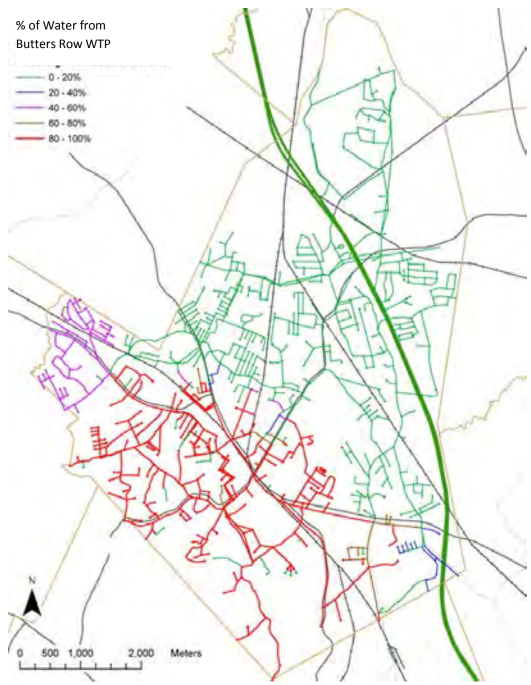
d. 12:00 pm

Legend



e. 4:00 pm

Legend



f. 8:00 pm

Legend

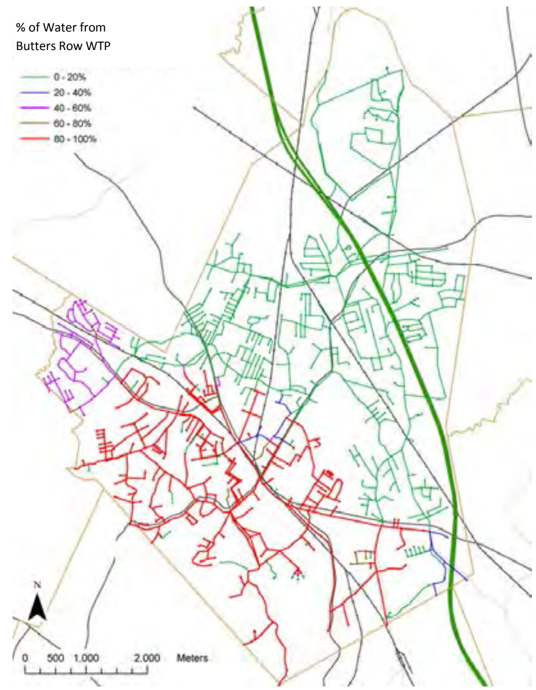


Figure 5.32: Percentage of water derived from Butters Row WTP during typical day (continued).

5.2.3 NDMA Concentrations in the Water Distribution System

The water distribution model was used to simulate the concentration of NDMA in each pipe segment of the distribution system from 1974 through 2000. Monthly NDMA concentrations at the MMBA water supply wells, and at the Butters Row WTP when it was brought online in 1981, were assigned using the ground water transport model results. All other sources including supply wells located outside the MMB aquifer and the Sargent WTP were assumed to have NDMA concentrations of zero.

The simulated NDMA concentrations are presented here using four methods to show changes in the spatial distribution and magnitudes of NDMA concentrations throughout the system. Figure 5.33 provides maps showing the simulated annual mean concentration of each pipe from 1975 through 2000 at five year increments. Figure 5.34 shows a map of the cumulative NDMA exposure in each pipe segment, which was calculated as the sum of the simulated NDMA concentration over all months in each pipe with combined units of ng/L-months. Some pipes have a lower exposure level because they were constructed after the start of the simulation period and thus had a shorter time period over which exposure was calculated. Figure 5.35 shows the monthly minimum, mean, median and maximum simulated concentrations computed across all pipes in the system for each month. The maximum concentration reflects the concentration in pipes directly connected to the contaminated source nodes (i.e., the individual water supply wells prior to June 1981 and Butters Row WTP thereafter). Figure 5.36 shows the percent of pipes exceeding threshold concentrations of 1, 25, 50, 75, and 100 ng/L to indicate changes in the extent and magnitude of NDMA penetration into the system between 1974 and 2000.

a. 1975 **b. 1980** **c. 1985**

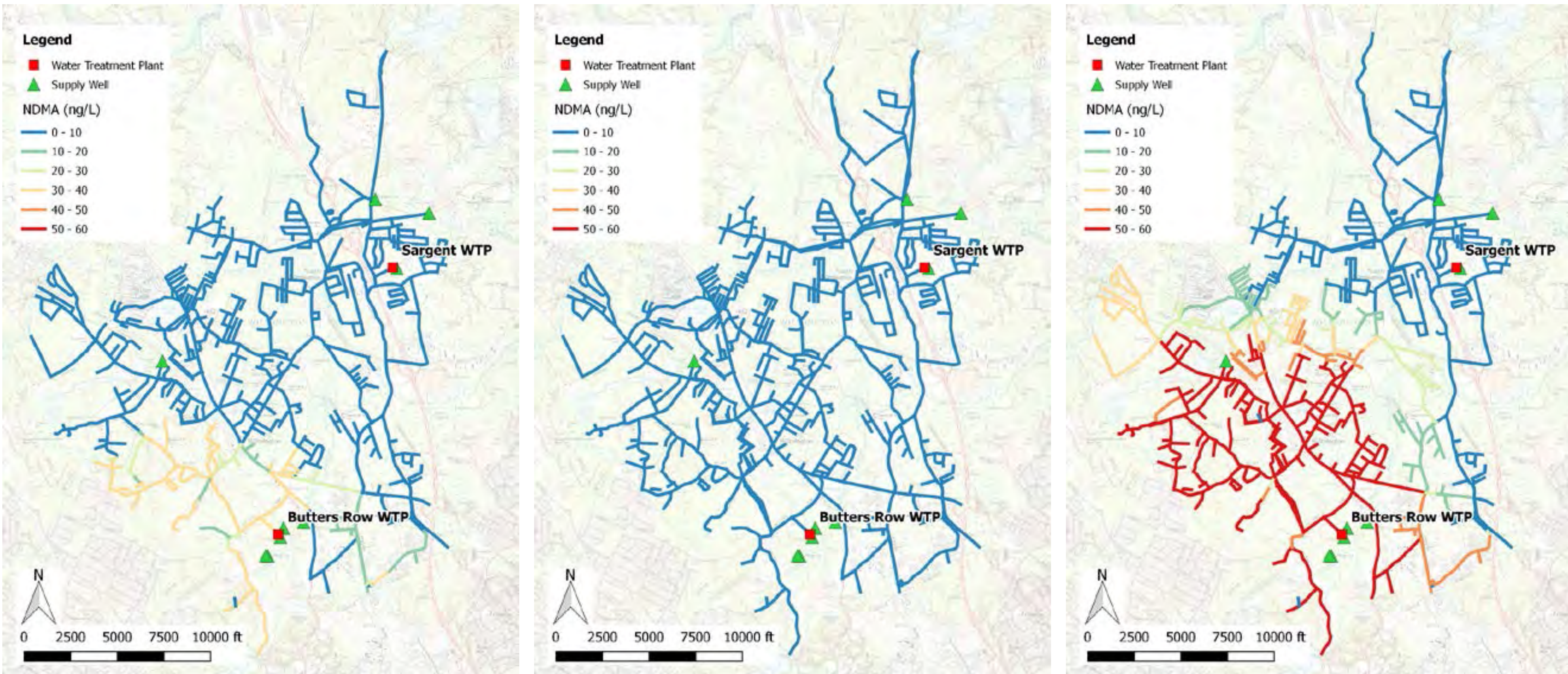


Figure 5.33: Annual mean simulated NDMA concentration by pipe from 1975 to 2000 (continued on next page).

d. 1990 **e. 1995** **f. 2000**

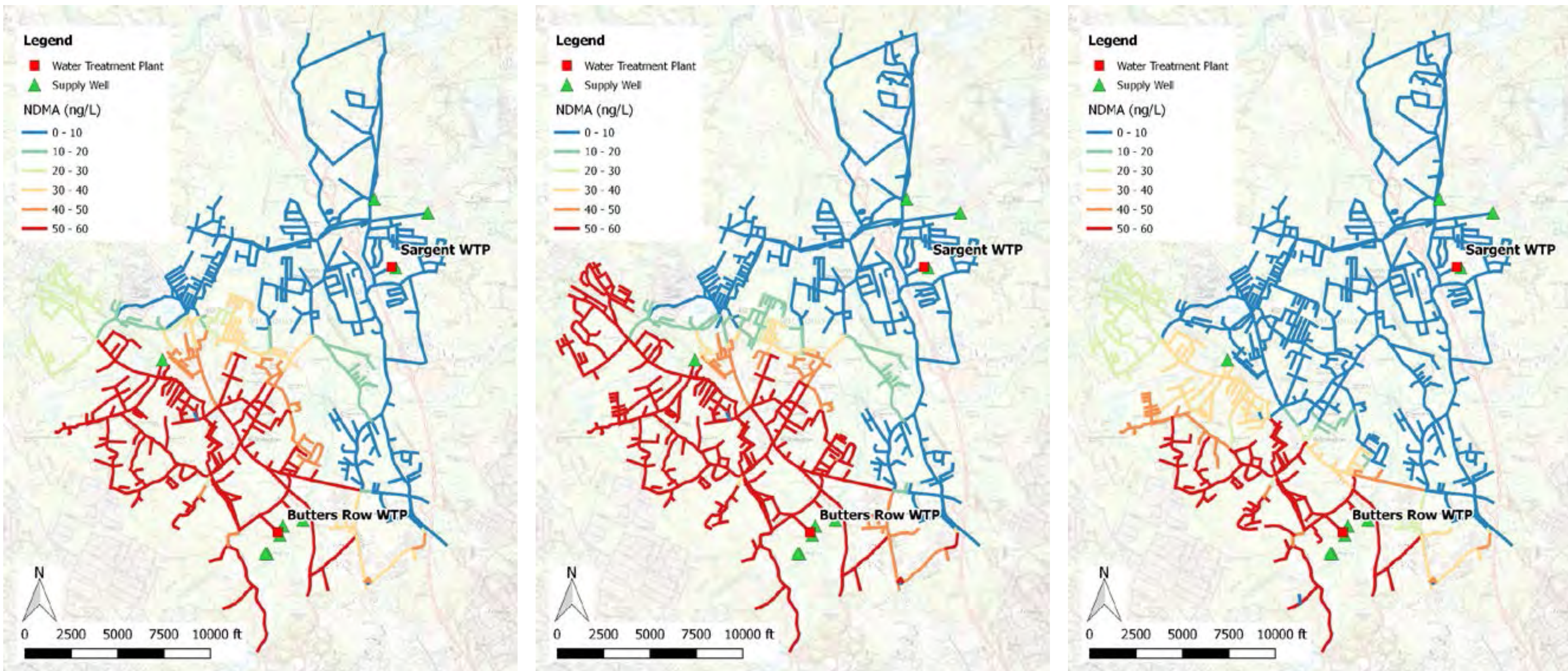


Figure 5.33: Annual mean simulated NDMA concentration by pipe from 1975 to 2000 (continued).

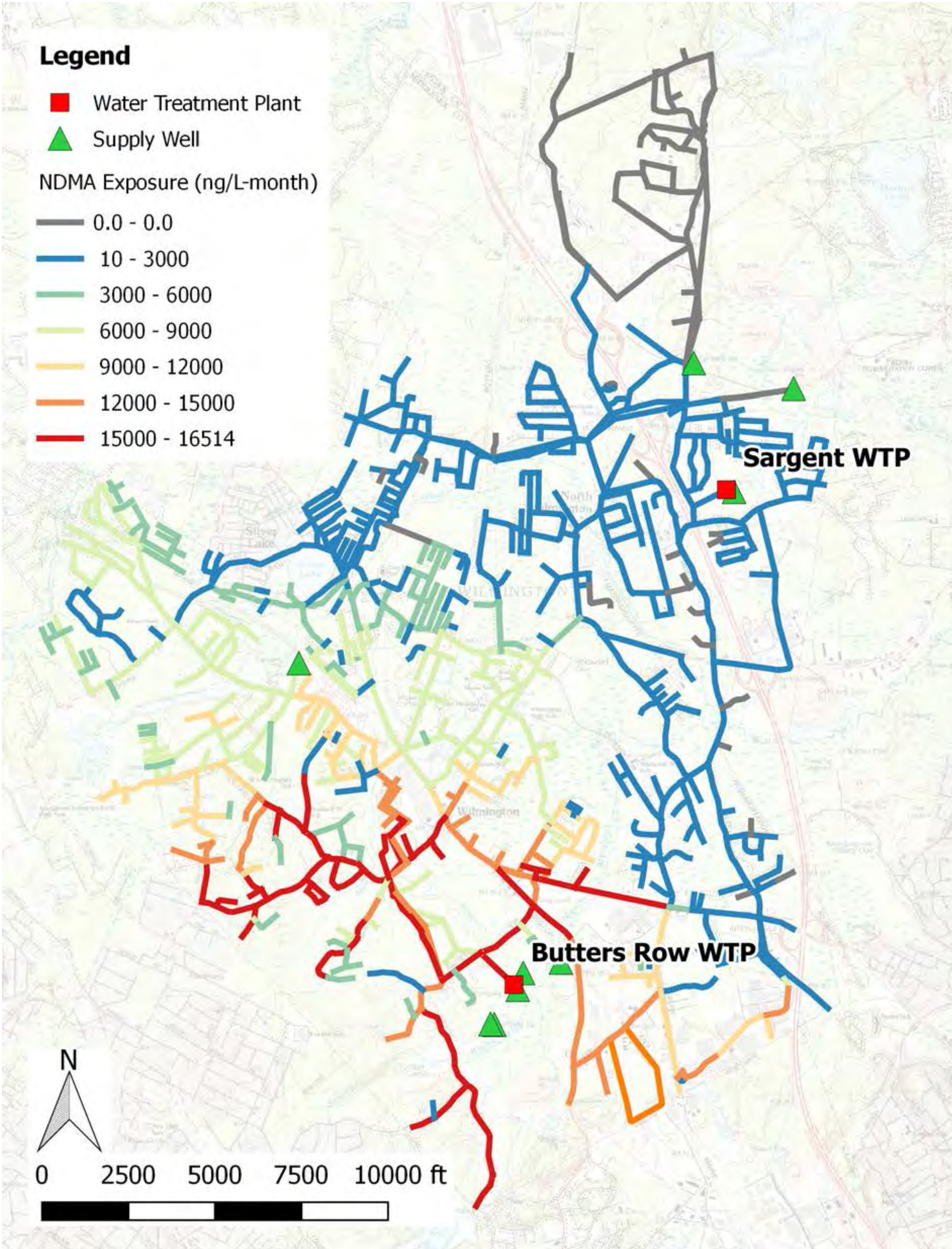


Figure 5.34: Cumulative NDMA exposure in each pipe segment, 1974 – 2000

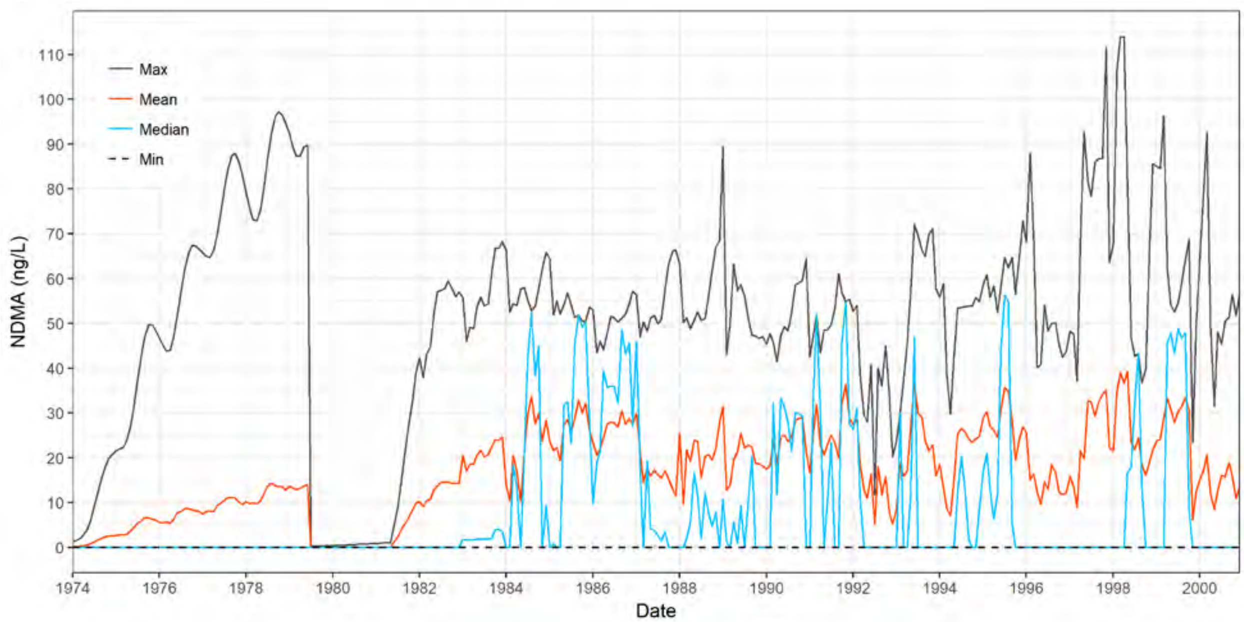


Figure 5.35: Monthly minimum, mean, median, and maximum simulated NDMA concentrations across all pipes.

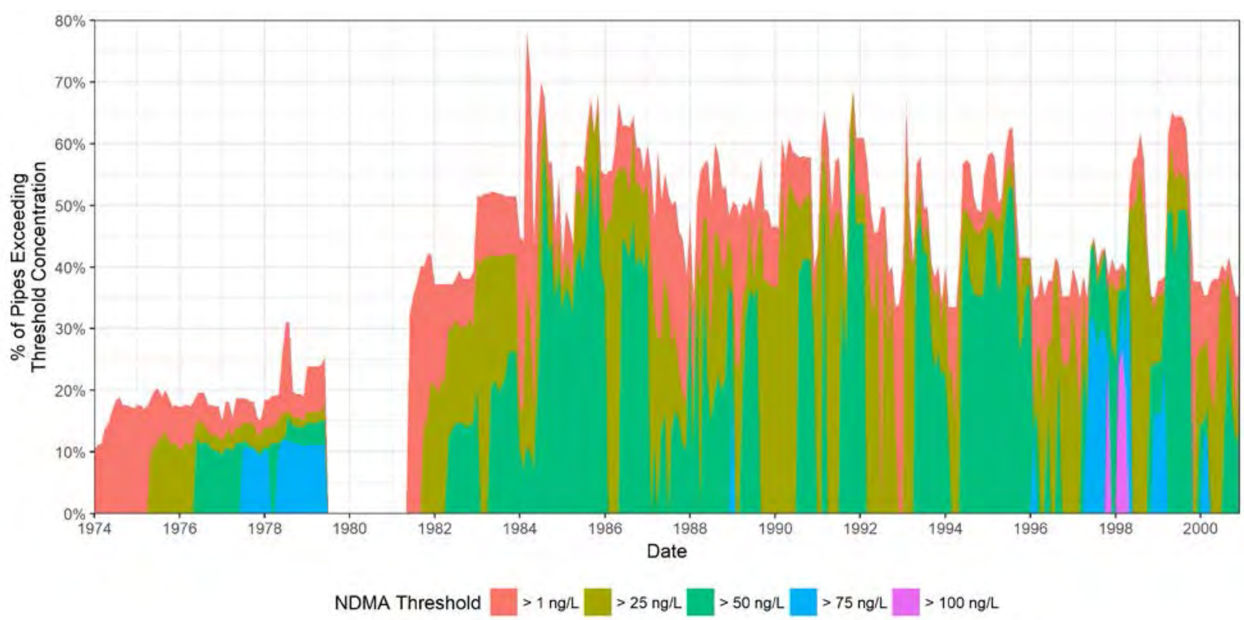


Figure 5.36: Monthly percent of pipes with simulated NDMA concentrations exceeding 1, 25, 50, 75, and 100 ng/L.

In 1974, NDMA began entering the system from water pumped by the Chestnut St. #1 well; NDMA concentrations increased in Chestnut St. #1 from 1 ng/L to a peak of 97 ng/L in October 1978 (Figure 5.35). During this period, the only other active well in the MMB aquifer was the Town Park well, which was located farther away from the DAPL pools (relative to the other wells) and therefore had a negligible concentration of NDMA. Although the maximum concentration was among the highest over the entire period, the spatial extent of pipes having high concentrations was relatively small compared to later years (Figure 5.35). In October 1978, 31% of pipe concentrations exceeded 1 ng/L and 12% exceeded 75 ng/L (Figure 5.36). Therefore, although NDMA concentrations were relatively high in pipes located near the Chestnut St. #1 well, the water from this well did not penetrate far into the system.

In July 1979, the Chestnut St. #1 well was deactivated due to the presence of TCE, which left Town Park as the only active supply well pumping from the MMB aquifer. Because the NDMA plume did not reach this well, there was no NDMA present across the entire system until June 1981 when the Butters Row WTP was brought online (Figure 5.33, Figure 5.35, and Figure 5.36).

In June 1981, the Butters Row WTP began treating water pumped from both Butters Row wells, the Chestnut St. #1 well, and the Town Park well. As discussed in Section 5.1.4 above, pumping from these wells created capture zones that resulted in transport of the NDMA plume into the Butters Row and Chestnut St wells. From 1982 through 1991 (before the Chestnut St. #1A/2 well was installed), the combined flow at Butters Row WTP had a concentration ranging from 38 to 89 ng/L (Figure 5.35). During this period, 35 to 78% of all pipes in the system had concentrations greater than 1 ng/L, and 0 to 63% had concentrations greater than 50 ng/L (Figure 5.36). Variability in the magnitude and spatial extent of NDMA concentrations primarily reflects month-to-month changes in the concentration at Butters Row WTP and the relative fraction of total water supply derived from that WTP.

In 1992, the Chestnut St #1A/2 well was added to the sources being treated by Butters Row WTP. From this year until 2000, the variability in maximum concentration and the percent of pipes exceeding the various thresholds increased to some degree. The highest maximum concentration was 114 ng/L, which occurred in April 1998. During this month, 27% of the pipes had concentrations exceeding 100 ng/L.

The map of cumulative NDMA exposure (Figure 5.34) shows that NDMA did not reach any of the pipes in the northeastern corner of town. NDMA exposure was primarily limited to the southwestern half of town as expected because this area is closer to the contaminated source wells and Butters Row WTP. The greatest exposure level was 16,514 ng/L-months, which occurred in the pipes directly connected to the Butters Row WTP.

Overall, the magnitude and spatial extent of NDMA concentrations across all distribution pipes varied from month to month based on the following key factors:

1. *Locations at which water pumped from the MMB aquifer entered the water distribution system*: Prior to June 1981, water was injected into model nodes corresponding to the locations of the individual wells. From June 1981 to the end of the simulation, all water pumped from the MMB aquifer was injected at the node corresponding to the Butters Row WTP. Although the supply

wells are located relatively close to the Butters Row WTP, this change in source node locations did have some effect on the spatial distribution of NDMA throughout the system.

2. *The percent of total town-wide supply originating from pumping in the MMB aquifer*: A greater fraction of town-wide supply originating from the MMB aquifer increased the penetration of NDMA into the system resulting in a larger spatial extent of pipes with detectable NDMA levels.
3. *Changes in the NDMA concentration at the source nodes*: The source NDMA concentrations affected the overall magnitude of concentrations within each pipe, and to a lesser extent the spatial distribution.
4. *The configuration of the physical pipe network*: Changes to the physical pipe network were incorporated in the model by adding/removing pipes in each year based on annual reports from Water and Sewer Department and other sources (see Section 4.3.1). These changes affected how water was routed through the system, and thus how NDMA was transported from the MMB aquifer wells and Butters Row WTP to end user locations.
5. *The relative fraction of total demand assigned to the industrial/commercial users (see Section 4.3.2.3)*: Because the industrial/commercial users were primarily clustered in the northeast and southeast parts of the town, higher demands for these users affected the spatial distribution of NDMA originating from the MMBA wells and Butters Row WTP.

5.2.4 TCE Concentrations in the Water Distribution System

In addition to NDMA, the water distribution model was also used to simulate monthly TCE concentrations in each pipe from June 1981 through December 2000. The TCE simulation period begins when the Butters Row WTP was brought online, which was seven years after the start of the NDMA simulation period. Because the ground water models were not used to simulate TCE transport in the aquifer, the TCE concentration assigned to the source node representing Butters Row WTP was based on historical measurements collected at the WTP (see Section 4.3.2.2.2). Water from the wells that supply the Sargent WTP (Barrows, Brown's Crossing, Salem St.) as well as the Shawsheen well, which is located outside the MMB aquifer, were assumed to have TCE concentrations of zero (consistent with water quality records in Appendix I).

Figure 5.37 shows the mean annual TCE concentration in each pipe from 1981 through 1989. Results are not shown from 1990 to the end of the simulation period (2000) because TCE was not detected in the Butters Row WTP and therefore simulated concentrations were zero in each pipe over this latter period. Figure 5.38 shows the cumulative exposure to TCE in each pipe over the entire simulation period. Exposure levels were calculated as the sum of TCE concentrations over all months, and reported in compound units of ug/L-months. Figure 5.39 shows the monthly minimum, median, mean, and maximum concentration computed across all pipes. Finally, Figure 5.40 shows the percent of pipes within each month having concentrations exceeding thresholds of 0.1, 1, 5, 10, and 20 ug/L.

a. 1981 b. 1982 c. 1983

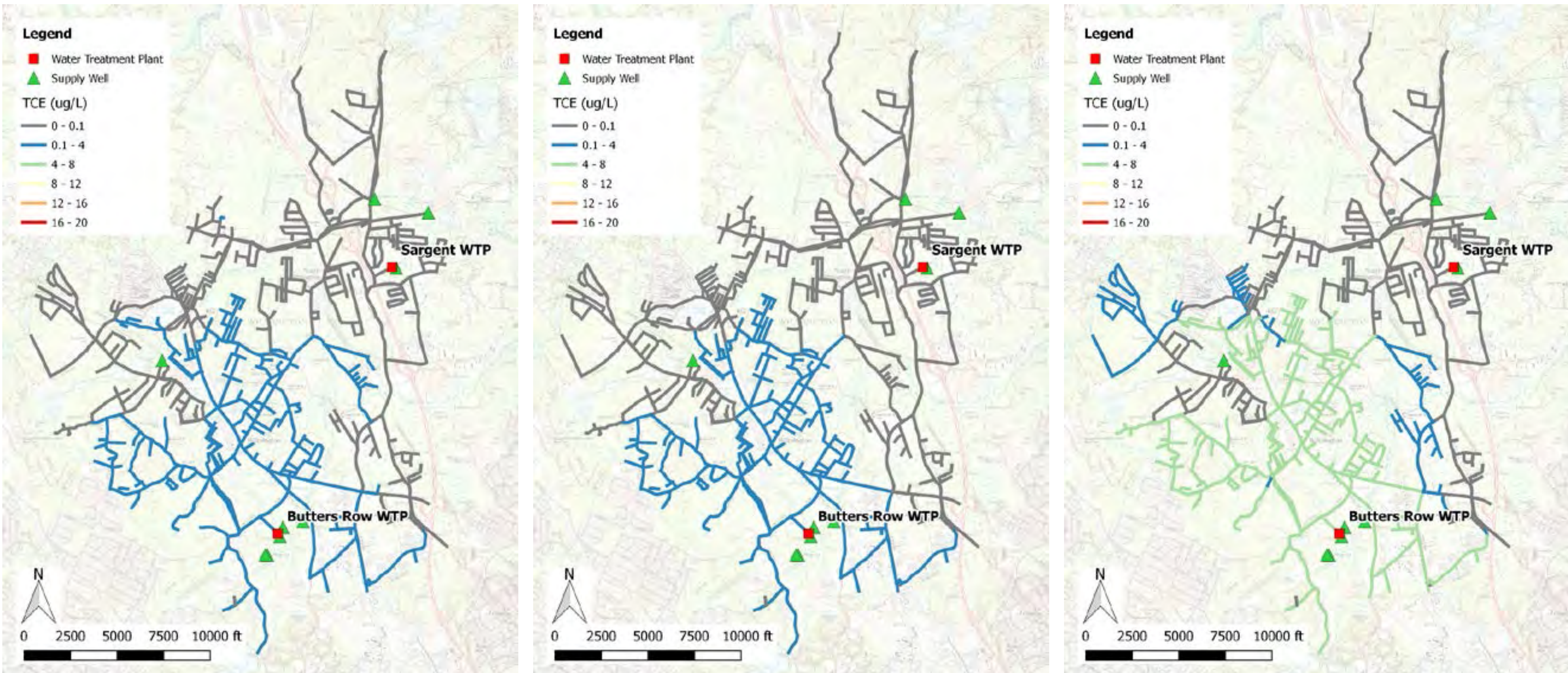


Figure 5.37: Annual mean simulated TCE concentrations in each pipe, 1981 – 1989(continued on next page)

d. 1984 e. 1985 f. 1986

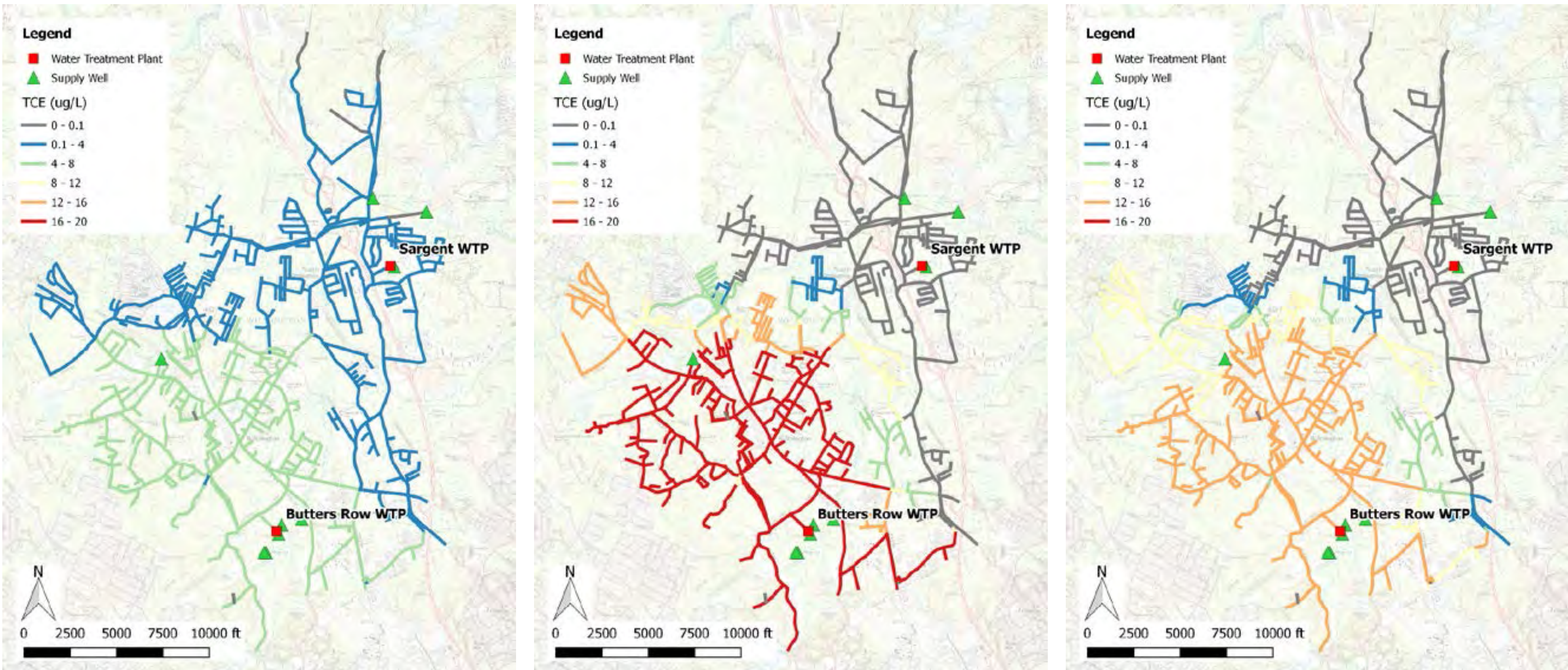


Figure 5.37: Annual mean simulated TCE concentrations in each pipe, 1981 – 1989 (continued)

g. 1987 **h. 1988** **i. 1989**

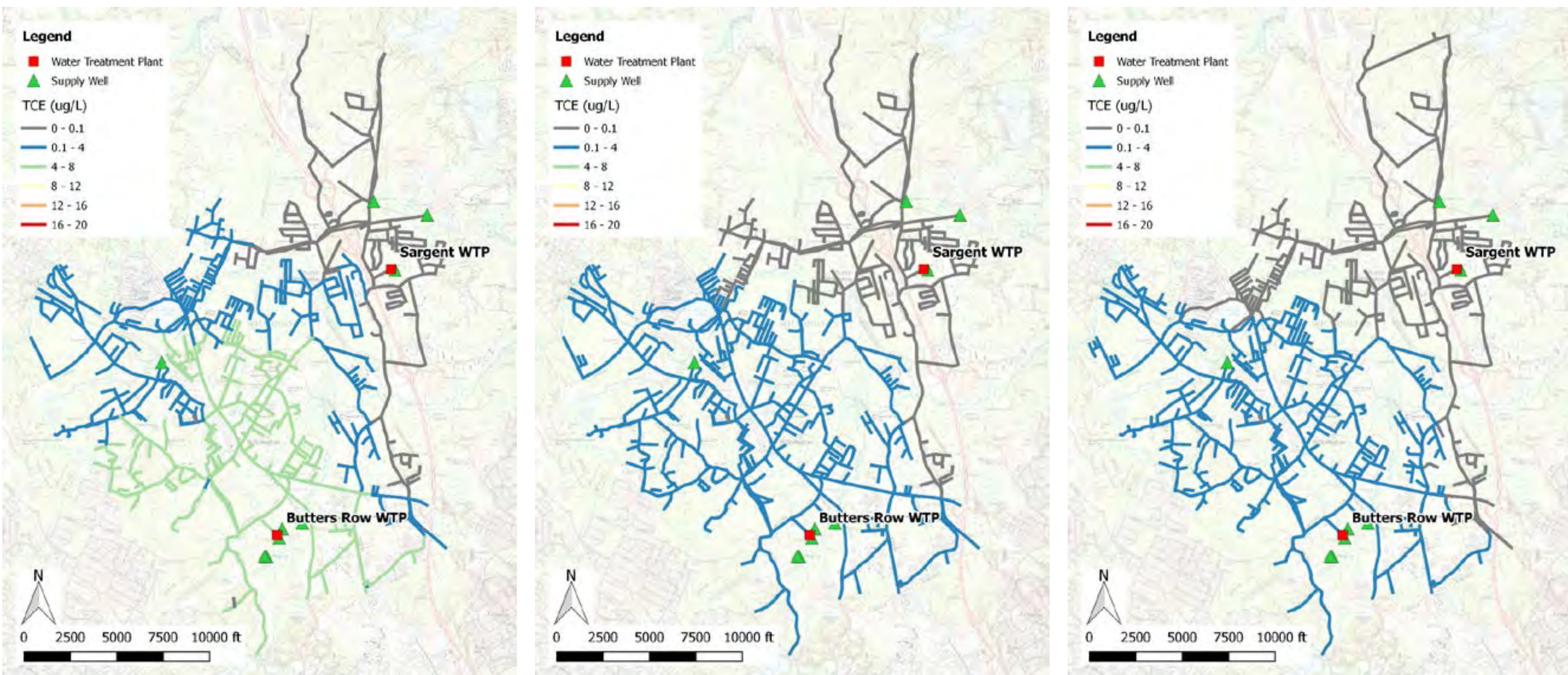


Figure 5.37: Annual mean simulated TCE concentrations in each pipe, 1981 – 1989 (continued)

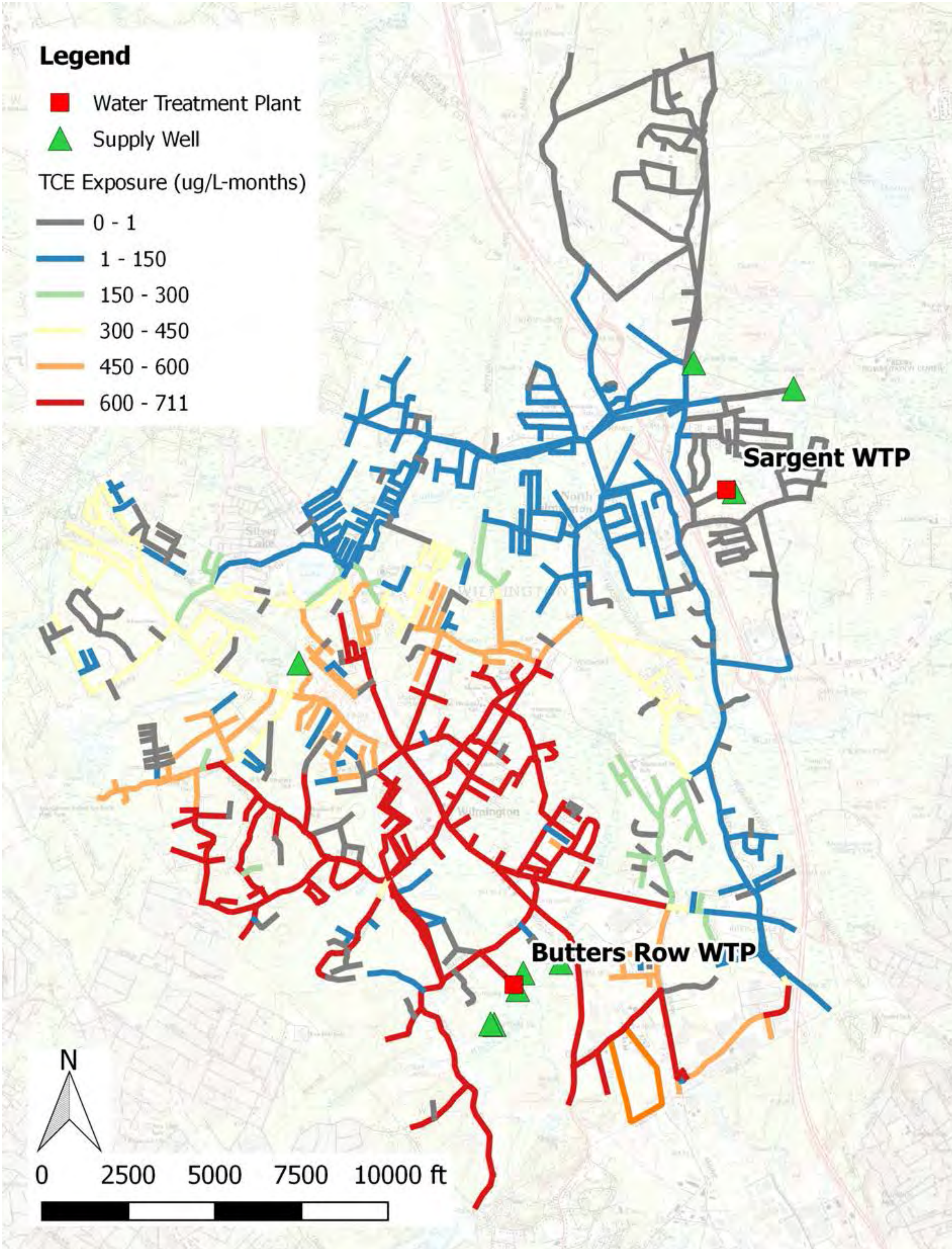


Figure 5.38: Cumulative TCE exposure in each pipe segment, June 1981 - December 2000

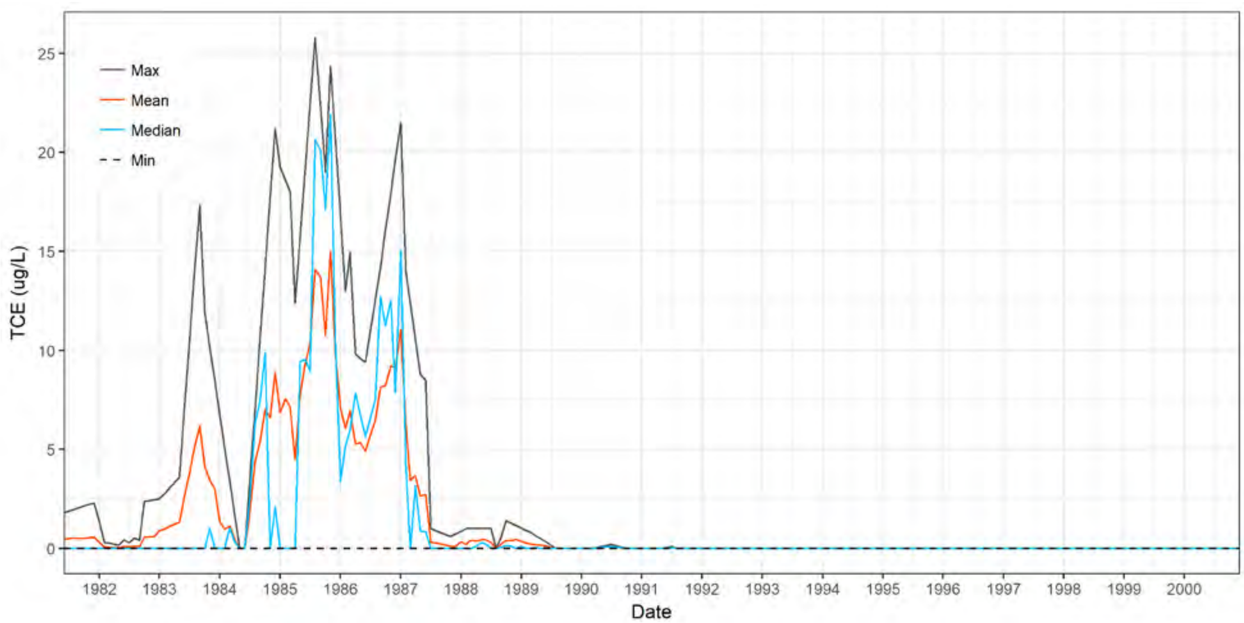


Figure 5.39: Monthly minimum, mean, median, and maximum simulated TCE concentrations across all pipes.

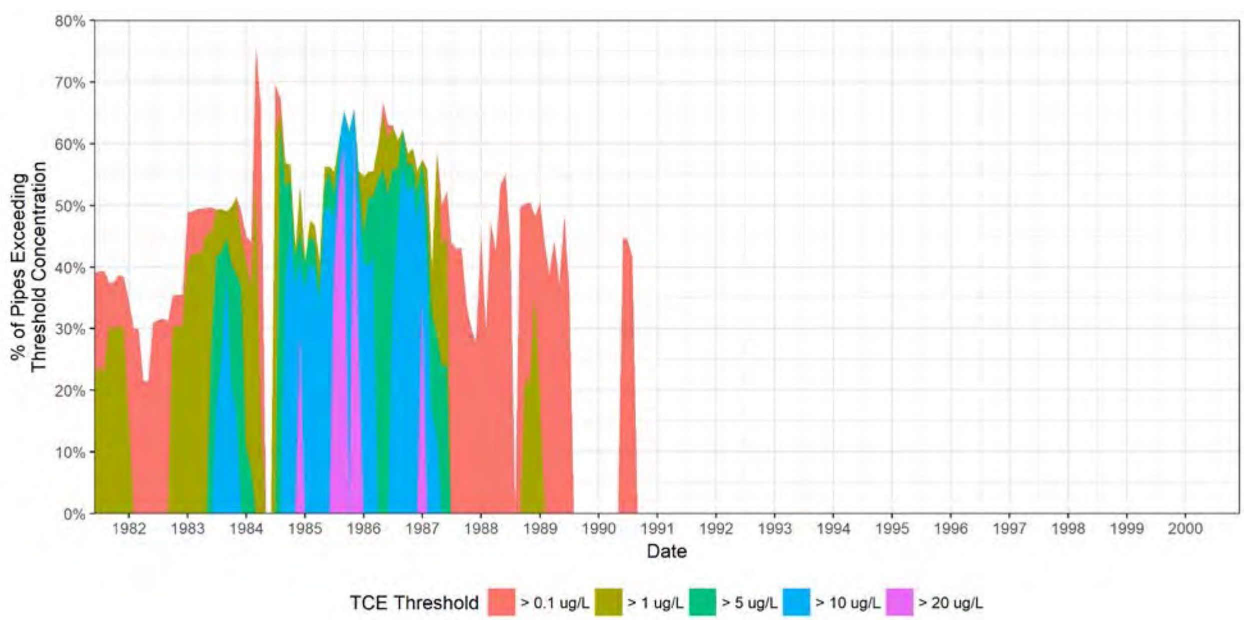


Figure 5.40: Monthly percent of pipes with simulated TCE concentrations exceeding 0.1, 1, 5, 10, and 20 ug/L.

Similar to NDMA, the distribution of TCE depended primarily on the concentration at Butters Row WTP and the fraction of total town-wide supply provided by this WTP relative to inflows from the northern supply wells and the Sargent WTP. In 1981 and 1982, TCE concentrations were relatively low (< 4 ug/L) due to low concentrations at the WTP. Annual mean concentrations began increasing in 1984 and reached a peak of 25.8 ug/L in August 1985. By 1988, concentrations dropped to relatively low levels (< 4 ug/L). From 1990 to the end of the simulation period in 2000, TCE concentrations were at or below detection limit.

The map of cumulative TCE exposure (Figure 5.38) is similar to that for NDMA with highest exposure levels occurring in the southeastern half of town. Negligible TCE exposure (< 1 ug/L-month) occurred in the norther eastern corner. The greatest TCE exposure levels were 711 ug/L-months in pipes directly connected to the Butters Row WTP.

Figure 5.39 and Figure 5.40 show that the magnitude and spatial extent of TCE in the distribution system were greatest in the mid-1980s. Prior to 1983, concentrations did not exceed 5 ug/L. From 1983 to 1987, TCE concentrations reached a maximum of 25.8 ug/L in August 1985, and the percent of pipes with concentrations exceeding 20 ug/L reached a maximum of 60% in November 1985. From 1988 to 1990, the maximum concentration did not exceed 2 ug/L and there was a very short period in late 1988 when any pipes exceeded 1 ug/L. From 1991 to the end of the simulation period, there was no TCE present in the system.

6 Model Uncertainty

Every numerical model is a simplification of a real system that must be defined based on limited knowledge and data; therefore, every model contains some uncertainty. This uncertainty can derive from an incomplete understanding of the key physical processes and their mathematical characterization, over-simplification of the conceptual model, homogenization of spatially variable properties, and assignment of uncertain model parameters. In this study, we have implemented a series of linked models to simulate the transport of NDMA through the aquifer from the deep DAPL pools to the water supply wells, and then from the wells to each point in the water distribution system. The ground water flow model was used to simulate changes in the three-dimensional potentiometric head and flow fields over time. The results of the ground water flow model were used in the ground water transport model to simulate advection and dispersion of NDMA through the aquifer, and ultimately generate time histories of NDMA concentrations at each water supply well. Finally, a water distribution system model was used to simulate the transport of NDMA from the water supply wells to each point in the system based on changes in the pipe network configuration and well pumping rates over time. Uncertainties in one model are therefore propagated into the next model. For example, uncertainties with respect to the ground water contaminant source will result in uncertainties in the simulated wellhead concentrations, which in turn leads to uncertainty in the simulated concentrations at each point within the distribution system.

In the following sub-sections, we provide a qualitative evaluation of the major sources of uncertainty for the three numerical models (Section 6.1) followed by a quantitative uncertainty analysis designed to generate uncertainty ranges around the simulated monthly NDMA concentrations at each location within the distribution system (Section 6.2).

6.1 Qualitative Evaluation

6.1.1 Ground Water Flow Model

Potential sources of uncertainty within the ground water flow model include the representation and parameterization of the natural physical system (i.e., hydro-stratigraphy, hydraulic conductivity, storage characteristics, and the location and behavior of boundaries such as drains and rivers), as well as uncertainty in the various input datasets such as well pumping and recharge rates. The ground water model domain includes 1) the MMB aquifer within the central and western portion and 2) the Olin site, which includes on-site and off-site drains in the eastern portion of the model. The results of the model calibration and sensitivity analyses described in Section 5.1 showed that the model was able to reproduce the measured potentiometric heads with a reasonable degree of accuracy, and that it was relatively insensitive to changes in many of the hydraulic parameters. Relative to the uncertainties associated with the transport and distribution system models and the well pumping rates (discussed below), we have a qualitatively high degree of confidence in the reliability and predictive ability of the ground water flow model to accurately represent changes in potentiometric head and resulting flows over space and time.

The historical pumping rates for the water supply wells are a major source of uncertainty to the ground water flow model. Over much of the period of interest, the pumping rates at individual wells were not metered and thus had to be estimated from limited historical data (in particular from pump capacities and records of total town-wide pumping from 1965 to 1981). We also noted an uneven level of quality for measured flow records from individual wells based on our review of the original paper charts that describe the rate of flow from individual wells. We found multiple periods for which the meters were not operating or were stuck such that they continually recorded flow when in fact there was none. Even during the period where flow data were available, these measurements likely contain multiple unquantifiable errors.

To estimate pumping histories prior to 1989, we estimated individual well pumping rates as being proportional to the reported capacity of each well. This introduces uncertainty because the town is not bound to produce from each well at rates that are proportion to the hydraulic capacity. The town likely deviated from this practice so as to improve the water quality. Based on the town's annual reports, we also noted that the effective capacities of particular wells were compromised periodically due to clogging of well screens and gravel pack materials. The town reported in several instances the rehabilitation of particular wells; however, the period prior to rehabilitation over which the capacity of individual wells would have been compromised is not known. We also were not confident that all rehabilitation activities were reported so we did not vary the flow rates over time from particular wells based on these accounts.

6.1.2 Ground Water Transport Model

Uncertainties in the ground water flow model are propagated to the transport model, which uses the flow model results to calculate NDMA transport through the ground water. Prior to the Butters Row WTP coming on line in June 1981, changes in the relative pumping rate of the Chestnut Street, Butters Row, and Town Park wells resulted in the NDMA-contaminated water from the aquifer to be introduced into different water mains associated with one or the other of these wells. After the treatment plant came on line, the relative rate of pumping between these wells is less problematic since all of the water from these wells was received by the Butters Row WTP and introduced to the distribution system at a single location.

In addition to the well pumping rates, another major source of uncertainty in the transport model is the location and strength of NDMA sources. NDMA sources were hypothesized to be the DAPL pools that accumulated on the bedrock surface. There are two general areas in which DAPL is represented in the transport model. Preliminary modeling efforts included only one of these two areas located near the Olin site. After examination of those initial results, we determined that a source in the Western Bedrock Valley was necessary to match the location and magnitude of NDMA concentrations measured in 2003 within the aquifer and at the water supply wells. The dissolution of NDMA into ground water flowing past the DAPL pools is indirectly observable based on downgradient concentrations. The exact nature of the physical processes resulting in the dissolution and transport of NDMA from the DAPL pools are not completely known and thus could not be represented using conventional ground water modeling software. The source strength was represented using specified concentration boundary condition nodes within the transport model, whose values are calibrated based on known concentrations at the five wells in 2003. Choices with respect to the location of source areas, source strength, and timing were based on the best available knowledge, but other reasonable selections consistent with available measurements could have been made that would have resulted in different simulated aquifer and wellhead concentrations. The hypothesized 1972 arrival time of the DAPL source within the Western Bedrock Valley represents our best judgment and is supported by transport calculations from the Olin site to the area of DAPL accumulation. However, the absence of NDMA measurements in the aquifer near the present-day DAPL source in the Western Bedrock Valley make the arrival times of both the DAPL source and subsequent NDMA capture by the water supply wells uncertain. Because the ground water transport model is used to set the wellhead concentrations in the water distribution system model, this uncertainty is propagated to the simulated concentrations within the water distribution system especially during the earlier years of the simulation period.

6.1.3 Water Distribution System Model

The water distribution system model consists of a representation of both the physical system (pipes, pumps, valves, and tanks) and the location and magnitude of water demand and supply. One of the largest efforts in this project was the compilation of the historical changes to the physical system. This process started from the model input files provided by the Wilmington Water Department consultants. These files represented the state of the system around the year 2000. We then reviewed the water department's annual reports to the town to identify which pipes to systematically add or remove between years. For the most part, we are relatively confident that we have accurately represented the major changes to the system that occurred over time. There are some locations where it was not clear as to the nature of particular pipes reported in the water department's annual reports; however, these are not likely to be significant with respect to the large-scale movement of water within the water distribution system.

The input dataset representing water demands across the system was based on the identification and assignment of the major demands from the largest industrial and commercial users, and then applying a uniform distribution of the remainder of the demand to represent domestic consumption across the system. Because digital records of water demands were not available for the study period, estimation of the magnitude and temporal changes in these demands is another source of uncertainty. Furthermore, areas with numerous short pipes may result in over-representation of water demand in those locations relative to the actual demand. Areas with longer pipes and high commercial or residential density would potentially have modeled demands that are under-represented by the assigned demands. Misassignment of demands could result in either an under-representation or over-representation of the impacted area within the water distribution system.

Uncertainty in the estimated well pumping rates also impacts the distribution of contaminants within the system. Over most of the simulated period, water supply is concentrated in either the MMB aquifer (to the southwest) or in the area around the Browns Crossing wellfield to the north. Only the wells screened in the Maple Meadow Brook aquifer are known to have withdrawn water with detectable concentrations of NDMA. The proportion of water introduced at the MMB aquifer wells relative to the overall water supply determines the spatial extent of the elevated NDMA concentrations within the system. Therefore, uncertainties with respect to withdrawals from the town's two major wellfield areas (around the Butters Row WTP and Edmund Sargent WTP) will result in uncertainties in the estimated spatial distribution of contamination within the water distribution network.

The results of the simulated contaminant concentrations indicate that most areas receive water from either the clean northern wells or from the contaminated Meadow Brook Aquifer wells, with a relatively small fraction of the system receiving a mixed supply. Therefore, underestimation of flow from the Maple Meadow Brook aquifer may result in simulated NDMA concentrations at particular pipes being zero, which would otherwise have higher concentrations were the flows from the Maple Meadow Brook aquifer simulated more accurately.

6.2 Uncertainty Analysis

A quantitative analysis was performed to generate uncertainty ranges for the simulated monthly NDMA concentrations at each location in the water distribution system. Uncertainty analyses can be applied using any one of a variety of different methods. One common method is to first define a probabilistic distribution for each parameter or input dataset that describes the range and probabilities of specific values. Given these distributions, a sampling algorithm such as Monte Carlo is then used to randomly assign specific values for each parameter and input. After the randomly-selected values are assigned, a model simulation is executed to generate one set of results. This process is repeated numerous times yielding a collection of output results generated from multiple combinations of different parameter and input values. These results are then aggregated by describing each output value (e.g., a distribution of concentrations for each pipe and for each month) as a probabilistic distribution. However, methods that use random parameter sampling typically require a large number of simulations and are therefore computationally intensive. Due to the long run time of the models, a simpler method was used that focused solely on those inputs and parameters for which the levels of both uncertainty and model sensitivity were greatest.

For this analysis, we first reviewed the relative uncertainty and sensitivity of all model assumptions, parameters and input datasets on the final model output. Those parameters and inputs for which the model sensitivity was known to be low (i.e., larges changes in the parameter or input value did not cause large changes in the output) were removed from consideration as were any parameters that were adjusted during model calibration. Input datasets that were based on relatively complete historical records or believed to be reasonably accurate were also excluded.

Ultimately, we selected two model inputs for which we had the lowest confidence (highest uncertainty) and that also caused a significant impact on the model results. For each of these inputs, we estimated the highest and lowest most likely values based on available information and our understandings of the aquifer and distribution system. The two inputs that were the focus of this uncertainty analysis included:

1. **Arrival Time of DAPL to the WBV**: our best estimate for the arrival date of DAPL from the Olin site to the WBV was 1972 (see Section 4.2.2). However, due to the lack of ground water quality data from the early 1970s, the exact timing is highly uncertain. Given our understanding of disposal activities at the Olin site and the rate at which we believe DAPL could have migrated towards the WBV, we estimated that this initial arrival time could have likely been 5 years earlier or later (1967 or 1977) than our initial estimate. This range in arrival time was implemented by shifting the start time of the constant boundary condition associated with the WBV DAPL pool in the ground water transport model (see Section 4.2.2).
2. **Pumping Rates for the MMBA Supply Wells from 1965 through May 1981**: monthly pumping rates for the water supply wells in the MMB aquifer were originally estimated using different historical records and methods, which varied over the course of the simulation period (see Section 3.2). From 1965 through May 1981, pumping rates at the individual wells were estimated using the annual or monthly total town-wide pumping rate, which was apportioned between the individual wells based on the capacity of each well relative to the total capacity of all active wells (including wells outside the MMB aquifer) in each month. In later years, additional datasets and historical records for the two WTPs and the individual wells improved our confidence in the accuracy of the estimated pumping rates. Therefore, for the sensitivity analysis we only focused on the pumping rates for years before the Butters Row WTP was brought online (i.e., prior to June 1981) as having the highest level of uncertainty. The simulation results also showed that pumping rates at these wells have high model sensitivity by affecting the three-dimensional flow field in the aquifer. To determine the most-likely range of each monthly pumping rate, we applied the same estimation method used during this period to later years for which historical pumping rate data were available for the individual wells (see Appendix F). By comparing the estimated and reported pumping rates in those later years, we determined that the amount of error ranged between -20 and +20% of the original estimated

values (see Section F.7 in Appendix F). Based on this error range, we increased and decreased the monthly pumping rates for each active well by 20% from 1965 through May 1981. For each alternative, the pumping rates of all active wells in the MMB aquifer were adjusted by the same percentage, and the pumping rates from the wells outside the MMB aquifer were commensurately adjusted such that there was no net change in the total town-wide pumping rates. No changes were made to the estimated pumping rates from June 1981 through the end of the simulation because we considered those estimates to have lower uncertainty due to additional data that was available. Figure 6.1 shows the estimated range of monthly pumping rate for each MMBA supply well. Note that no changes were made to the pumping rates for Butters Row #2 and Chestnut St. #1A/2 because these two wells were activated in June 1981 and January 1992, respectively.

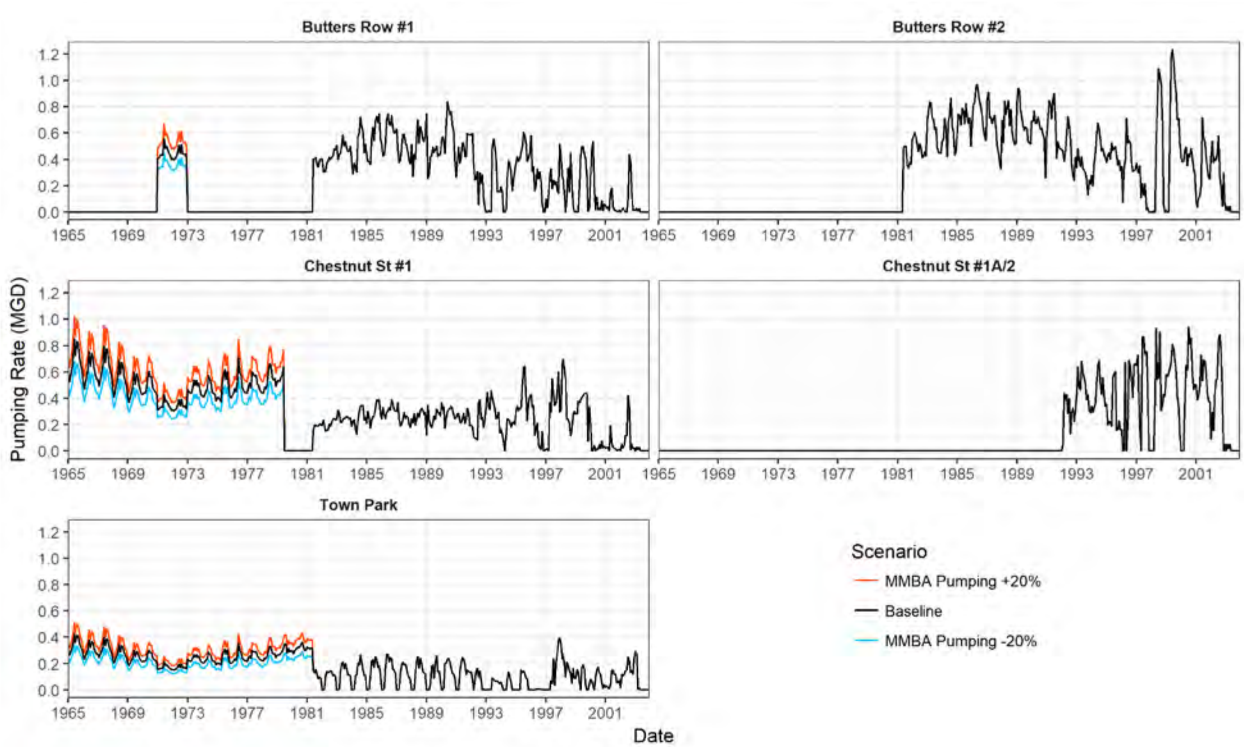


Figure 6.1: Range of pumping rates assigned to water supply wells for uncertainty analysis.

6.2.1 UNCERTAINTY RANGE OF NDMA CONCENTRATIONS AT MMBA SUPPLY WELLS

The ground water model was configured to run four additional simulations, one for each combination of increasing and decreasing the WBV DAPL arrival time and the MMBA well pumping rates. Figure 6.2 shows the simulated monthly NDMA concentration at each MMBA supply well for these four scenarios along with the original model output, which is labeled as "Baseline." These results show that the two uncertainty inputs only affected NDMA concentrations from 1965 through 1989. From 1990 through

2003, the simulated concentrations show no change from baseline, which was expected because the pumping rates were only varied from 1965 through May 1981 and the initial arrival time of the WBV DAPL pool did not affect the NDMA plume once it reached an initial state of quasi-equilibrium.

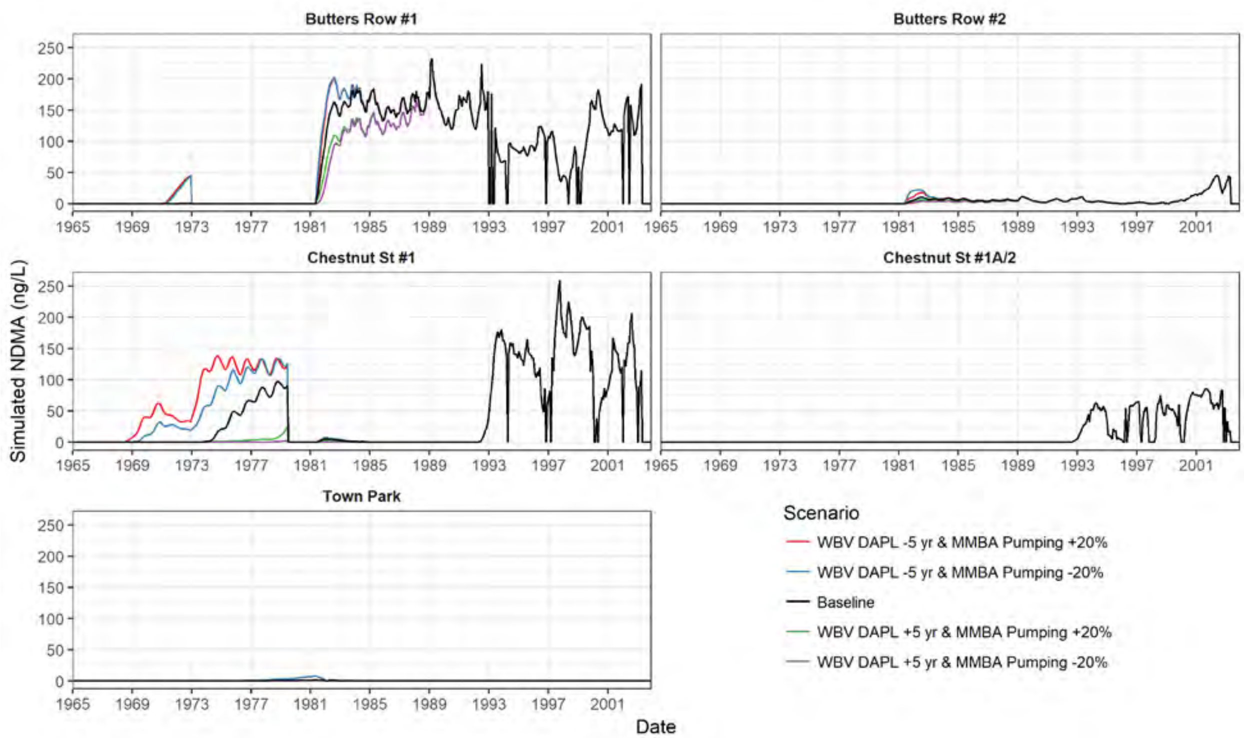


Figure 6.2: Simulated monthly NDMA concentrations in each MMBA supply well with varying WBV DAPL arrival time and MMBA well pumping rates.

The results show that the greatest effect on NDMA concentrations of varying the WBV DAPL arrival time and MMBA well pumping rates occurred at the Butters Row #1 and Chestnut St #1 wells. There were also small changes at Butters Row #2 and Town Park, but no change at Chestnut St #1A/2, which was not installed until 1992. Between the two uncertainty variables, adjustment of the arrival time for the WBV DAPL pool caused greater changes than adjustment of the MMBA well pumping rates. When the DAPL pool was set to arrive 5 years earlier and pumping rates increased by 20%, NDMA first reached the Chestnut St. #1 well in 1968 as compared to 1974 under the Baseline simulation. The earlier DAPL arrival time also resulted in the NDMA plume reaching Butters Row #1 before it was shut off in 1973, unlike the Baseline scenario in which NDMA did not reach Butters Row #1 until it was re-activated in 1981. Conversely, when the DAPL pool was set to arrive 5 years later, NDMA had just reached the Chestnut St. #1 well before it was shut off in 1979.

6.2.2 Uncertainty Range of NDMA Concentration in the Distribution System

The water distribution model was also used to simulate the four scenarios representing adjustments to the arrival time of the WBV DAPL pool and the pumping rates of the MMB aquifer wells. For each scenario, the simulated NDMA concentrations and well pumping rates of the MMBA wells from the ground water model were used as inputs to the water distribution model.

Figure 6.3 shows the maximum, mean, and median simulated NDMA concentration computed across pipes for the four uncertainty scenarios as well as the original ("Baseline") simulation. The results show a large range of maximum and mean NDMA concentrations from 1974 through 1979 before the Chestnut St. #1 well was shut off. The range in maximum NDMA concentrations reflects the range of concentrations at the Chestnut St. #1 well (Figure 6.2). Beginning in 1981, these ranges steadily decreased over time until 1989 when there were no differences from the Baseline scenario.

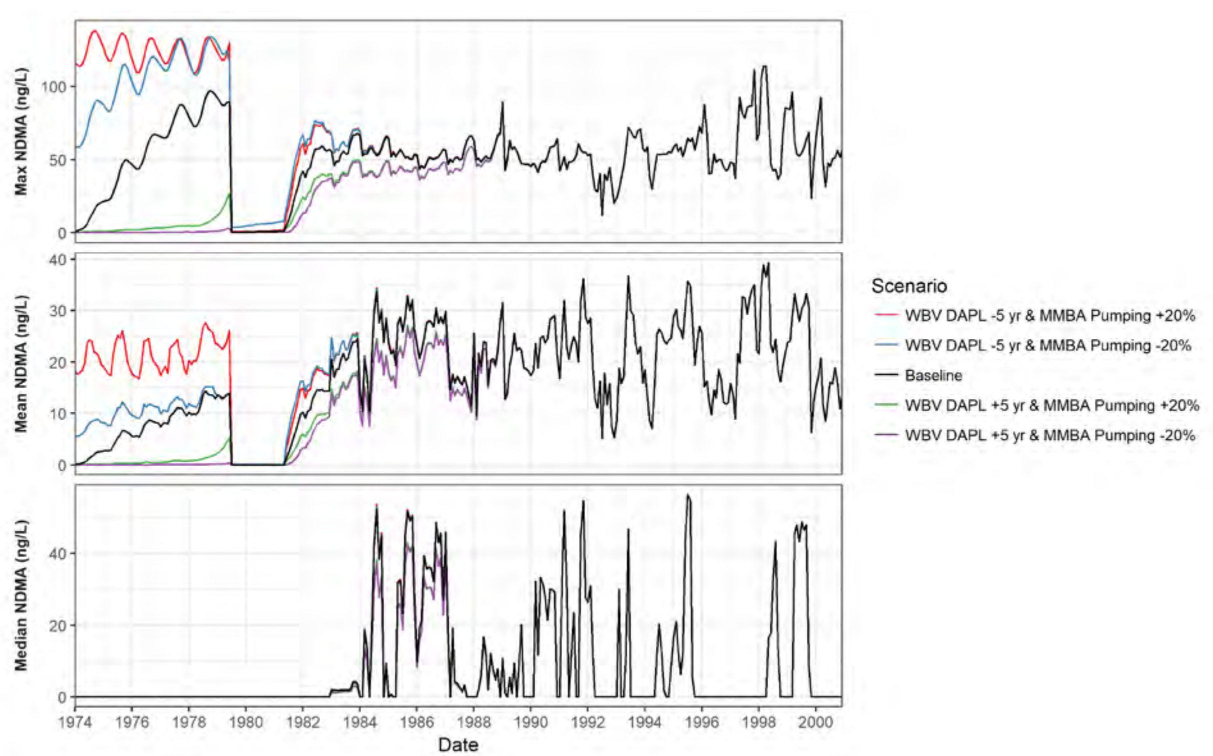


Figure 6.3: Maximum, mean, and median simulated NDMA concentrations computed across all pipes within each month with varying WBV DAPL arrival time and MMBA well pumping rates.

Figure 6.4 shows the percent of all pipes with simulated NDMA concentrations exceeding 25 ng/L for each of these scenarios. Once again, the largest changes occurred during the first 6 years of the simulation (1974 – 1979), with smaller changes from 1981 to 1989, and no changes after 1989. If the WBV DAPL pool arrived 5 years earlier and the MMBA well pumping rates were 20% greater than we originally estimated, then these results show that NDMA would have been present at concentrations of

25 ng/L or higher across 16 – 27% of the pipes from 1974 to 1979. However, if the arrival time was 5 years later, then no pipes would have had a concentration exceeding 25 ng/L until 1982.

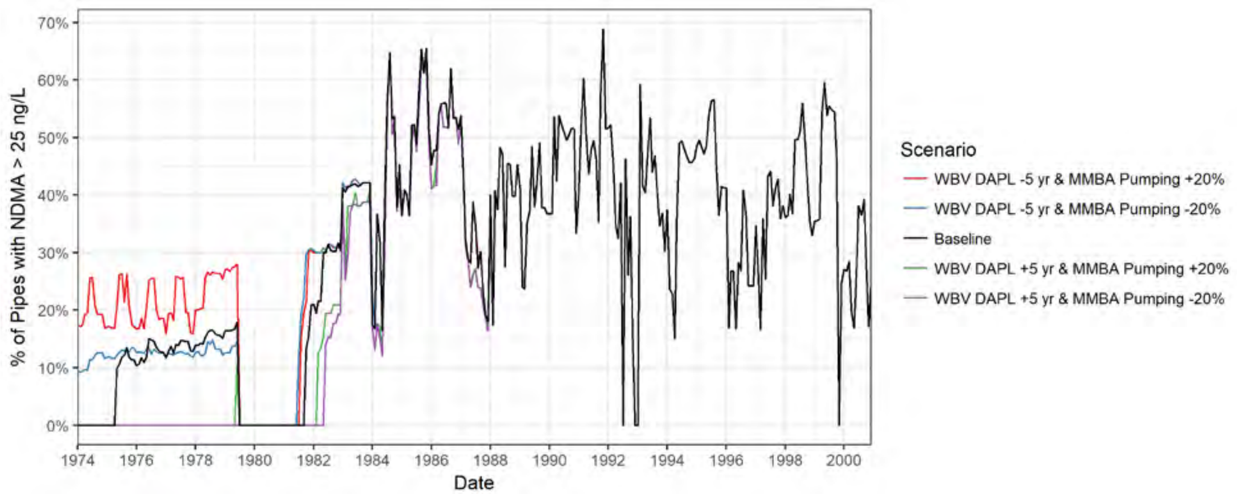


Figure 6.4: Percent of all pipes with simulated NDMA concentrations greater than 25 ng/L with varying WBV DAPL arrival time and MMBA well pumping rates.

In summary, the uncertainty analysis showed that changes to the arrival time of the WBV DAPL pool and to the pumping rates of the MMBA wells would result in large changes in the distribution and magnitude of NDMA in the distribution system primarily from 1974 to 1979, and to a lesser extent from 1981 to 1989. There were no differences in the simulated concentrations relative to the Baseline scenario in either model after 1989. Overall, these results reflect the greater uncertainty and lower confidence in the dynamics that occurred in the aquifer during the earlier years of the simulation due to limited data availability during that period. The results of these four scenarios were provided to MA DPH in addition to the Baseline results to evaluate the effect of this uncertainty on the results of their epidemiological analyses.

7 CONCLUSIONS

The goal of our effort was to reconstruct monthly time histories of NDMA and TCE concentrations at each point within the Wilmington water distribution system. The results are intended to be used by MA DPH for determining whether an association exists between exposure to NDMA and the timing and location of disease incidence.

The specific tasks that were carried out in meeting these goals include the following:

- Develop ground water flow and transport models to simulate the transport of NDMA from contaminant source areas to the water supply wells in the MMB aquifer, and reconstruct monthly time histories of NDMA concentrations at each well from 1965 through 2003.

- Develop a solute transport model for the water distribution system to simulate changes in (i) NDMA concentrations at each point within the distribution system from 1974 through 2000, and (ii) TCE concentrations at each point in the distribution system from 1981 through 2000.
- Conduct sensitivity analyses to evaluate the impact of alternative model configurations and parameter values on the simulated NDMA concentrations in both the aquifer and the water distribution system.
- Conduct an uncertainty analysis by varying selected model inputs that have the greatest uncertainty and impacts on model results.

In carrying out the study we have successfully developed and evaluated ground water flow and transport models as well as a solute transport model for the water distribution system. The results are provided to MA DPH as monthly time series of NDMA concentrations (with uncertainty ranges) for each pipe segment in the distribution system for each year of the study period (1974 – 2000). Monthly time series of TCE concentrations in each pipe were also provided from 1981 when the Butters Row WTP was brought online through 2000 (TCE simulations were not performed prior to 1981 due to lack of information on potential sources of TCE to the aquifer).

As a result of the study we have reached several conclusions:

1. NDMA contamination of the Wilmington water supply wells in the Maple Meadow Brook aquifer was driven by diffusion of NDMA out of DAPL pools that had settled in bedrock depressions near the Olin site and in the Western Bedrock Valley within the aquifer. Modeling results indicate that the Western Bedrock Valley DAPL pool was an important source and necessary to achieve the levels of NDMA measured in the MMBA water supply wells in 2003. However, the arrival time of DAPL to the Western Bedrock Valley was not known with uncertainty due to limited data; our best estimate is that DAPL originating from the Olin site arrived at the Western Bedrock Valley in 1972 +/- 5 years.
2. Ground water model simulations showed that NDMA initially arrived at the Chestnut St. #1 well in 1974 and the Butters Row #1 well in 1981. These two wells contained the highest NDMA concentrations ranging from approximately 50 to 250 ng/L. Both Butters Row #2 and Chestnut St. #1A/2 wells contained lower levels of NDMA and were contaminated for shorter periods of time relative to the Butters Row #1 and Chestnut St. #1 wells. Both simulations and direct measurements indicate that NDMA did not reach the Town Park well, which was located farther to the north in the MMB aquifer relative to the other wells.
3. NDMA simulations of the distribution system showed initial exposure with high concentrations (up to 97 ng/L) over a relatively small spatial extent due to contamination of the Chestnut St. #1 well. In 1981, the spatial extent of NDMA exposure increased due to additional contamination of the two Butters Row wells, which were activated when the Butters Row WTP was brought online. NDMA exposure was primarily limited to the southern, central and western areas of town; exposure in the northern and eastern areas was relatively low because these areas primarily received water from uncontaminated sources (i.e., the northern water supply wells and Sargent WTP). From 1981 through 2000, the spatial extent and magnitude of NDMA in the

system varied widely from month to month, with the monthly mean and maximum concentrations computed across all pipes ranging from 5 – 39 ng/L and 12 – 114 ng/L, respectively. The percent of all pipes in the system with concentrations exceeding 50 ng/L reached a peak of 63% in November 1991. In March 1998, 27% of all pipes had concentrations exceeding 100 ng/L.

4. The water distribution model results showed that TCE exposure was greatest from 1983 through 1986 due to high levels observed at the Butters Row WTP. Similar to NDMA, the greatest cumulative exposure occurred in locations near the Butters Row WTP within the southern, central and western areas of town. The highest TCE levels occurred in 1985 when the mean TCE concentration across all pipes reached 26 µg/L, and 60% of all pipes had concentrations exceeding 20 µg/L. From 1990 through 2000, TCE levels were below detection limits at the WTP and across the system.
5. In the 1980s chlorinated VOCs were regularly detected in the MMB aquifer supply wells, the Butters Rows treatment plant, and sampling stations in the Wilmington water distribution system. The most commonly detected compounds were TCE and 1,2-DCE. The highest concentrations were in Butters Row #1 and #2, while lower concentrations were present in Chestnut St. #1 and Town Park. The results also show that TCE and 1,2-DCE were present in finish water from the Butters Row treatment plant, indicating that these compounds were not completely removed during treatment. As a result, TCE and 1,2-DCE were detected at several sampling stations in the water distribution system. The highest concentrations of TCE measured at these sites were in excess of the current drinking water standard (5 ug/L).
6. The ground water flow model was calibrated to historical potentiometric head measurements at monitoring wells near the Olin site and in the Maple Meadow Brook aquifer from 1991 – 2000. The overall RMSE of the simulated heads was 1.58 ft, which is similar to other models developed for this area. A more limited calibration of the ground water transport model was performed based on the measured NDMA concentrations at the MMBA wells in 2003. The distribution model was unable to be calibrated due to lack of hydraulic (e.g., pressure, flow) data; however, a simulation of TCE emanating from the Butters Row WTP in July 1986 was performed to compare simulated concentrations against measurements at six locations in the distribution system. This comparison showed that the model is able to predict measured pollutant (TCE) concentrations within about 1 mile of the Butters Row WTP; however, due to a lack of measurements in the northern part of the distribution system, we were unable to evaluate model performance at greater distances from the treatment plant.
7. The spatial penetration of contaminants into the system was found to primarily depend on the proportion of water discharged from the contaminated supply wells in the MMB aquifer and from the Butters Row WTP relative to the total town-wide water supply rate. The magnitude of concentrations in the distribution system strongly depended on the concentrations of the MMB aquifer source wells and the WTP. The contaminant distribution also depended to a lesser extent on the water demands of industrial and commercial users relative to domestic users, and on the pipe network configuration, which varied over the simulation period.
8. Sensitivity analyses were performed to evaluate the impact of alternative model configurations, parameters, and input datasets on model results. For the ground water flow model, the

sensitivities to alternative spatial discretization, simulation time step durations, and various hydraulic parameters were evaluated by comparing changes in the simulated potentiometric head at monitoring well locations near the MMB aquifer wells. Among the tested parameters, only the hydraulic conductivity parameter and recharge rates showed high sensitivity in the ground water flow model. The sensitivity of the water distribution model to diurnal variability in water demands was found to be relatively low.

9. Primary sources of uncertainty in the model results include the inability to simulate the transport of DAPL with conventional modeling tools, and uncertain knowledge with respect to (1) the timing, location, and source strength of contaminant source areas, (2) the assignment of historical pumping rates, and (3) the representation of changes in the physical configuration and operation of the water distribution system. A quantitative uncertainty analysis was performed by varying both the arrival time of DAPL to the Western Bedrock Valley in the MMB aquifer, and the pumping rates for supply wells during the period when pumping data were most limited. Changes to the arrival time of DAPL to the WBV resulted in greater changes to the simulated NDMA concentrations than the changes in pumping rates. When the DAPL pool was set to arrive 5 years earlier than the original estimate and pumping rates increased by 20%, NDMA first reached the Chestnut St. #1 well in 1968 as compared to 1974 under the primary set of results. The earlier DAPL arrival time also resulted in the NDMA plume reaching Butters Row #1 before it was shut off in 1973, unlike the primary results in which NDMA did not reach Butters Row #1 until it was re-activated in 1981. Conversely, when the DAPL pool was set to arrive 5 years later, NDMA had just reached the Chestnut St. #1 well before it was shut off in 1979.

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APPENDICES FOR:

MODELING *N*-NITROSODIMETHYLAMINE AND TRICHLOROETHYLENE CONCENTRATIONS IN THE WILMINGTON, MASSACHUSETTS, WATER SUPPLY SYSTEM: 1974 TO 2000

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List of Appendices

A. Use, Manufacture and Disposal of NDMA-Precursor Chemicals at the Olin Site

Available historical documents describing chemical manufacturing and waste disposal activities at the Olin Site have been reviewed including the Comprehensive Site Investigation report prepared in 1993 by Conestoga-Rovers & Associates (CRA, 1993), the Supplemental Phase II Report by Smith Technology Corporation and other consultants (Smith et al., 1997), and the Phase II Comprehensive Response Action Status Report by MACTEC (2003c). The history is summarized here and described in more detail in EPA (2005).

During the 33-year history (1953-1986) of chemical manufacturing on the Olin site a variety of chemicals were produced including acids and bases, phthalates, oxidizing agents, phenols, metal salts, alkenes, alcohols, and aldehydes. Many of the chemicals used and produced on the site were nitrogen-containing compounds, including ammonia, amides, nitrosamines, and amines; however, there is no evidence that NDMA were used, produced (either intentionally or unintentionally) during chemical manufacturing, or disposed of on the site. It has thus been hypothesized that the high levels of NDMA observed in ground water beneath the site result from chemical reactions that occurred after wastes were placed in disposal areas on the property (see Appendix B). A list of the chemicals produced and their ingredients and waste products that could have given rise to NDMA or NDMA-precursor compounds at the Olin site is shown in Table A.1.

Based on Table A.1, several of the chemicals manufactured at the Olin site produced wastes that had the potential to form NDMA precursors. In particular, the manufacture Nitropore 5 PT required the use of sodium nitrite as one of the ingredients and produced dimethyl formamide as a waste material. Dimethyl formamide can hydrolyze to form DMA (MACTEC, 2003c), which can then react with nitrite by the nitrosation pathway to form NDMA (Mirvish, 1975). Another potential source of NDMA precursors at the Olin site is sanitary waste (sewage). Sanitary waste is a source of DMA (30-80 ug/L in primary effluent) and other unidentified NDMA precursors (Mitch and Sedlak, 2004).

Records show that prior to 1972 industrial wastewaters were discharged on the Olin Site into a sequence of unlined lagoons and pits, and that prior to at least 1981 sanitary wastes were discharged into septic tanks and a leaching field on site. A timeline of the waste disposal history at the Olin Site is shown in Table A.2. Although the facility began operation in 1953, CRA (1993) indicates that use of unlined pits for waste disposal began in 1956 with the start-up of the Kempore manufacturing process. Waste was discharged to two pits in the central area of the plant, named the East and West Pit in the site investigation, as well as to “Lake Poly”, named after the company that originally operated the facility, National Polychemicals. Sometime prior to 1964, the East and West Pits were filled and warehouses were then constructed on top of the former pits. A series of three pits, known as the Acid Pits, were constructed further south. These and Lake Poly were unlined until 1970, when they were replaced by lined lagoons. In 1972, the plant’s industrial wastewater system was connected to the newly constructed MDC regional sewer; however, sanitary wastes were discharged onsite until at least August 1981 (MACTEC, 2003c).

Table A.1. Materials Associated with Potential NDMA Precursors Used and Produced at the Olin Site

Product: Chemical name	Years of manufacture	Raw Materials	Waste Materials
<u>Opex</u>: Dinitrosopentamethylenetetramine	1953-1986	Hexamethylenetetramine Sodium nitrite Hydrochloric acid Ammonia	Sodium chloride Sodium nitrate Formaldehyde Ammonium chloride

<u>Kempore:</u> Azodicarbonamide	1956-1986	Hydrazine Urea Sulfuric acid	Sulfuric acid Urea Ammonium sulfate
<u>Kempore Dispersions:</u> Azodicarbonamide	1960-1986	Azodicarbonamide	None listed
<u>Hydrazine:</u> Hydrazine, semicarbazide	1963-1970	Urea Chlorine Sodium hydroxide Sulfuric acid	Ammonium sulfate
<u>OBSH/OBSC:</u> Oxybisbenzenesulfonylchoride Oxybisbenzenesulfonylhydrazide	1970-1975	Hydrazine Ammonium hydroxide Chlorosulfonic acid Diphenyl oxide	Hydrochloric acid Ammonium chloride Sulfuric acid Chlorosulfonic acid Sodium chlorosulfonate
<u>Wiltrol-N:</u> N-nitrosodiphenylamine	1965-1967	Diphenylamine Sodium nitrite Sulfuric acid	Sodium nitrite Sodium sulfate
<u>Nitropore 5PT:</u> 5-phenyltetrazole	1965-1975	Benzonitrile Sodium azide Sodium nitrite Ammonium chloride Dimethyl formamide Hydrochloric acid	Sodium chloride Sodium nitrate Dimethyl formamide Benzonitrile
<u>Nitropore OT:</u> Oxybisbenzenesulfonylhydrazide	1969-1986	Diphenyl oxide Chlorosulfonic acid Hydrazine Ammonia	Sulfuric acid Ammonium chloride Hydrochloric acid

[1]Chemicals listed as raw and waste materials was taken from MACTEC, 2003c; dates of manufacture were taken from CRA (1993). MACTEC (2003c) reports that Nitropore 5 PT was manufactured from 1973-1986. The discrepancy between these two reports is unresolved.

Table A.2. Timeline of Changes at Olin Site and in Wilmington Ground Water Pumping.

Year	Event
1953	Laboratory and chemical manufacturing plant constructed (EPA, 2005, pg. 12)
1953-1971	Facility operated as National Polychemicals, Inc. (NPI) (EPA, 2005, pg. 12). Plant expanded over this period. All waste discharged untreated to unlined lagoons until 1970
1953-1981	Septic tanks and leaching fields used for sanitary waste disposal (MACTEC, 2003c, pg. 5-11 - 5-12)
1953-1986	Chloride, sulfate, ammonia used as process chemicals (Smith et al., 1997)
1953-1986	Opex (N-nitrosopentamethylenetetramine) manufactured (CRA, 1993, Table 3.1) (MACTEC, 2003c, Pg. 5-11, indicates dates as 1956 to "at least 1983")
1955-1961	Phthalate plasticizers (dioctyl phthalate, dibutyl phthalate) manufactured (CRA, 1993, Table 3.1)
1956-1986	Kempore manufactured (CRA, 1993, Table 3.1)
1960-1986	Kempore dispersion manufactured (CRA, 1993, Table 3.1)
1961-1967	Phenolic and urea formaldehyde resins manufactured (CRA, 1993, Table 3.1)
September 1961	Chestnut Street 1 well installed and brought on line (Geomega, 2001b)
Early- to mid-1960s	Phenolic resins manufactured and disposed of in Lake Poly and possibly East and West Pits (Smith et al., 1997)
1962-1986	Wytox ADP (dioctyl diphenylamine) manufactured (CRA, 1993, Table 3.1)
1963-1970	Hydrazine produced on site (CRA, 1993, Table 3.1; MACTEC, 2003c, pg. 5-16)
1963-1986	Actafoam R-3 manufactured (CRA, 1993, Table 3.1)
1964	East and West Warehouses constructed on site of East and West Disposal Pits (EPA, 2005, pg. 12)
1964-1965	Acid Pits believed to have been constructed operated until replaced by lined lagoons in 1972 (EPA, 2005, pg. 12)
1964	Drill log for Olin Test Hole No. 1 indicates "green water" encountered at 32 feet depth (Smith et al., 1997)
July 1964	Town Park well installed and brought on line (Geomega, 2001b)
1965-1986	Wytox 312 (trinonylphenyl phosphate) manufactured (CRA, 1993, Table 3.1)
1965-1975	Nitropore 5PT (5-phenyltetrazole) manufactured (process likely to have produced NDMA) (CRA, 1993, Table 3.1) (MACTEC, 2003b, pg. 5-11 indicates manufacturing period was 1973-1986)
1965-1967	Witrol (N-Nitrosodiphenylamine or NNDPA) manufactured at Plant B with waste discharged to Lake Poly and Acid Pits (Smith et al., 1997; MACTEC, 2003c, pg. 5-11; CRA, 1993, Table 3.1))
1967	Kempore process changes from using sodium dichromate as product and generating chromium sulfate as waste to using sodium chlorate as product, generating sodium sulfate and sodium chloride as wastes (EPA, 2005, pg. 12; CRA, 1993, Table 3.1))
1968	National Polychemicals purchased by Stepan Chemical Company (EPA, 2005, pg. 12)
1969-1971	Lake Poly wastewater lagoon filled (Smith et al., 1997)
1969-1986	Nitropore OT (4,4'oxybisbenzenedisulfonylhydrazine) manufactured (CRA, 1993, Table 3.1)
1970	Stepan installed acid neutralization treatment system and discharged treated wastewater to ditches on property (EPA, 2005, pg. 12)
1970-1975	OBSC/OBSH produced on site with production of ammonium chloride as waste (MACTEC, 2003c, pg. 5-17)
1971-1986	Wytox PAP (alkylated phenol) manufactured (CRA, 1993, Table 3.1)
1971-1980	Facility operated as Stepan Chemical Company (EPA, 2005, pg. 12)
October 1971	Butters Row 1 well brought on line (Geomega, 2001b)
1972	Acid neutralization treatment system connected to MDC sewer system. Lined settling lagoons constructed for other wastes (EPA, 2005, pg. 12)

Year	Event
1972	Drill log for Altron indicates "green water" encountered at 67 feet depth (Smith et al., 1997)
January 1975	Calcium sulfate landfill starts accepting waste
October 1977	Altron (now Sanmina) starts supply well B1 (Geomega, 2001b)
March 1979	Butters Row 2 well put in service (Geomega, 2001b)
1980-1986	Facility operated by Olin Corporation (EPA, 2005, pg. 12)
1981	Olin re-lined Lagoon I (Smith et al., 1997)
August 19, 1981	Application to MDC for sewer permit indicates 1400 gallons per day of sanitary wastewater is discharged to on-site septic system (MACTEC, 2003c, pg. 5-12)
1982	Olin installs four extraction wells to control oil seep in East Ditch area (Smith et al., 1997)
1983	Olin re-lined Lagoon II (Smith et al., 1997)
1985	Altron (now Sanmina) starts supply well B3 (Geomega, 2001b)
July 1986	Production ceases at facility (ABB, 1993, pg 1-7)
September 1986	All operations cease at facility (ABB, 1993, pg 1-7)
April 1986	Earliest records of inorganic ion measurements at Town Park and Butters Row 2 wells
December 1986	Calcium sulfate landfill ceases accepting waste
March 1988	Earliest records of inorganic ion measurements at Butters Row 1 well
August 1991	Chestnut Street 1A well drilled (CRA, 1993, Appendix A)
February 1992	Earliest records of inorganic ion measurements at Chestnut Street 1A and 2 wells
August 1993	Chestnut Street 1A and 2 wells put in service (Geomega, 2001b)
September 2002	NDMA detected in samples from diffuse layer (MACTEC, 2003c)
September 28, 2002	Use of Chestnut Street well suspended (MACTEC, 2005)
October 8, 2002	Use of Butters Row No. 1 well suspended (MACTEC, 2005)
October 30, 2002	Use of Chestnut Street 1A well suspended (MACTEC, 2005)
December 5, 2002	Use of Butters Row No. 2 well suspended (MACTEC, 2005)
March 1, 2003	Use of Town Park well suspended (MACTEC, 2005)

Because the process (or processes) by which NDMA formed at the Olin site has not been clearly identified, and because available records do not adequately describe where and when particular chemical wastes were discharged on-site, it is not possible to reconstruct a precise history of NDMA formation on the Olin property. It may be reasonably hypothesized that chemical wastes from the manufacture of Nitropore 5PT may have reacted with each other or in the presence of other waste materials such as sanitary wastewater to form NDMA in the subsurface. MACTEC (2003c, pg. 5-10) goes further, stating that of the various production lines, "the only one…that may have had conditions favorable to the formation and direct discharge of NDMA to the waste stream…[was] the product Nitropore 5PT, which was also called Expandex 5PT." However, as noted by EPA (2005), the reported dates for Nitropore 5PT production are inconsistent in the site reports. CRA (1993) reports that Nitropore 5PT manufacturing occurred between 1965 and 1975 but MACTEC (2003c, Table 5) gives the years 1973 to 1986 (Table A.2). The differing dates given by CRA and MACTEC are important because prior to 1970 liquid wastes were disposed on-site in unlined lagoons while after 1973 industrial liquid wastes were discharged to the Metropolitan District Commission sewer system. Thus, wastes generated before 1970 at the Olin Site had the greatest opportunity to reach the subsurface. MACTEC (2003c) speculates that between 1973 and 1984 there were leaks in the disposal system at the facility as well as the sewer system that could have resulted in waste materials reaching the subsurface. MACTEC estimates that the volume of liquid wastes leaked from the sewer system was <1% of the historical discharge rates—however, it is unclear how this estimate was derived.

There are other potential sources of NDMA in addition to Nitropore 5PT according to EPA (2005):

Wastes from several other processes, when commingled in the unlined pits or MDC sewer, could have produced conditions associated with the release of constituents that could form NDMA in the waste stream, DAPL, or diffuse layer ground water (MACTEC, 2003c, pp. 5-11 to 12). Specifically, the processes for the manufacture of Opex, Kempore, Hydrazine, OBSC/OBSH, Wiltrol-N, and Nitropore OT produced wastes that when combined may have had the potential to result in NDMA formation (MACTEC, 2003c, pg. 5-11).

A summary of these potential NDMA-forming compounds based on CRA (1993) and MACTEC (2003c) is included as Table A.1. The following discusses our historical research of Nitropore 5PT and other Olin products implicated as potential sources of NDMA with particular attention to the likely manufacturing periods.

A primary product line for NPI was blowing agents, marketed under the Opex, Kempore, Nitropore, and Expandex trade names. A blowing agent is a substance added to plastic or rubber to produce pores or cells in the finished product (Lasman, 1965). NPI specialized in chemical blowing agents, materials that decomposed at elevated temperature and liberated gases. Many of the NPI products were nitrogenous compounds that liberated nitrogen gas. Some of these nitrogenous compounds were apparently the precursors of NDMA. Another class of blowing agents is the physical blowing agents, either compressed gases or volatile liquids that created gases through physical transformations such as evaporation. That class of agent is not an issue with respect to NDMA contamination of the Olin site.

The many trade names used by NPI, Stepan, and Olin confuse the identification of the actual chemical compounds used at the site. Not all products (i.e., trade names) can be uniquely identified as specific compounds. Our research of the literature indicates the possibility that individual compounds may have been marketed under multiple names (e.g., as both Kempore and Nitropore) and that there were certainly multiple products under each trade name (e.g., at least five different grades of Kempore). In order to understand more completely the different trade names, we researched the open technical literature (particularly papers published by NPI research scientist Henry R. Lasman) as well as patent and trademark records. A summary of the compounds reviewed is provided in Table A.3.

Table A.3. Potential NDMA Precursors Used and Produced at the Olin Site (based on CRA (1993) and MACTEC (2003c)).

Product: Chemical names	Years of manufacture	Chemical name(s)	CAS No.
Kempore Kempore Dispersions	1956-1986	1,1’-azobisformamide ABFA 1,1'-azodicarbamide ADC	123-77-3
Opex	1953-1986	*N,N’*-dinitrosopentamethylenetetramine DNPT	101-25-7
Nitropore OBSH Nitropore OT	1969-1986	4,4’-oxybis(benzenesulfonyl hydrazide) OBSH	80-17-1 and 80-51-3
OBSC	1969?-1986?	4,4’-oxybisbenzenesulfonylchloride OBSC	unknown

Nitropore 5PT Expandex 5PT	1973-1983	5 phenyl 1*H* tetrazole 5PT	18039-42-4
Hydrazine	1963-1970	hydrazine	302-01-2
Wiltrol-N	1965-1967	*N*-nitrosodiphenylamine NDPhA	86-30-6

Henry R. Lasman was described in a 1962 article (Lasman, 1962) as head of Technical Service Activities at NPI in Wilmington since 1957, having joined the NPI laboratory staff in early 1955. He published several papers in the early 1960s that provide some information on NPI products. In a paper in the Society of Plastics Engineers Journal, Lasman (1962) identifies Kempore R-125 as 1,1'-azobisformamide (ABFA) and Opex PL-80 as dinitrosopentamethylenetetramine (DNTP). He also refers to Expandex 177 as barium azodicarboxylate calling it one of "several experimental products that have been offered for foaming of polypropylene" "in the last two years." He describes the use of OBSH but does not identify it with an NPI product, citing instead Celogen BH as its trade name. (According to the on-line U.S Patent Office database, Celogen was registered in 1951 as a trademark of the U.S. Rubber Company Corporation (USPO, 2008).)

In 1963, Lasman and NPI colleague John Blackwood published a short article on ABFA foaming agent in the magazine Plastics Technology (Lasman and Blackwood, 1963). They identify three NPI products: Kempore 60, Kempore 125, and Kempore 200 (the last described as a "new type"). All are ABFA with the different numbers denoting different particle sizes, larger numbers indicating finer particles.

The annual Encyclopedia issue of Modern Plastics for 1965 (published in September 1964) includes a comprehensive review of foaming agents by Lasman as well as an advertisement for NPI Kempore foaming agents and a long list of trade names. The trade names include Kempore, Nitropore, Expandex, and Opex for NPI blowing agents. Lasman (1964) identifies ABFA as Kempore and N,N'-dinitrosopentamethylenetetramine as Opex 40 and Opex PL-80. He cites several references including an undated NPI bulletin for Kempore SD. OBSH is listed but not identified as an NPI product. He describes Expandex 177 as a "new experimental blowing agent." He also discusses some new types of blowing agents, including nitrososulfonamides, for which he cites U.S. Patent 3,125,602 issued to NPI. This patent, for N-alkyl-N-nitroso alkyl sulfonamides, was filed on November 29, 1957 and issued on March 17, 1964 to Henry A. Hill (President of NPI) and William P. ter Horst and assigned to NPI in Wilmingon (Hill and ter Horst, 1964). Lasman (1964) gives no trade name for the product however.

Lasman's most comprehensive review of blowing agents is a contribution to the Encyclopedia of Polymer Science and Technology (Lasman, 1965). According to Lasman, the first nontoxic organic blowing agent was DNPT, which was introduced in 1946 by Imperial Chemical Industries Ltd. (ICI). NPI products identified in this article include Kempore as ABFA, Expandex 177 as barium azodicarboxylate, RIA NC as urea, Poly-Zole as 2,2'-azobisisobutyronitrile, and Opex 80 and Opex 40 as 80% and 42% DNPT, respectively. Lasman also states that diphenyl-4,4'-disulfonyl diazide was test marketed from 1958 to 1960 as Nitropore. OBSH is again identified as Celogen, a U.S. Rubber Company product. Significantly, 5-phenyltetrazole is not mentioned in the review.

Lasman and other NPI (later Stepan) employees continued to publish an annual review of blowing agents in the annual Modern Plastics Encyclopedia issue of Modern Plastics. We reviewed the articles on blowing agents in the following issues of the Modern Plastics Encyclopedia: 1967 (Lasman, 1966), 1969-1970 (Lasman, 1969), 1970-1971 (Lasman, 1970), 1971-1972 (Lasman, 1971), 1972-1973 (LaClair, 1972), 1973-1974 (Bolduc, 1973), and 1978-1979 (Elsey, 1978). Of these various reviewers, only LaClair was not with NPI. The Modern Plastics Encyclopedia always included an advertisement for NPI products which, beginning with the 1969-1970 issue, contained a detailed listing of product lines. The written reviews and advertisements provide a chronology of NPI's products as follows:

- Kempore (ABFA) – 1965-1978
- Opex (DNPT) – 1965-1978
- Expandex 177 (barium azodicarboxylate) – 1965-1972 (advertised 1971-1972)
- Expandex THT (trihydrazino-s-triazine) – 1970-1972
- Expandex 5PT – 1972-1979
- Nitropore OBSH – 1970-1979
- Wiltrol-N (NDPhA) – 1969-1971
- Wiltrol-P (phthalic anhydride) – 1969-1971
- Poly-Zole AZDN (azodiisobutylnitrile) – 1965-1974

Although site investigations cite Nitropore 5PT as a possible NDMA precursor, the product is never listed, only Expandex 5PT which is presumably the same chemical. The annual reviews also mention newly patented blowing agents, not all of which seemed to have risen to commercial success. Among these were nitrososulfonamides (U.S. Patent 3,125,602) and N nitroso glycolurils (U.S. Patent 3,121,066) patented by NPI (Lasman, 1966).

Heck and Peascoe (1985) prepared an updated but much shorter review of blowing agents for the 1985 edition of the Encyclopedia of Polymer Science and Technology. A table of manufacturers and trade names lists Olin with the trade names Expandex, Kempore, Nitropore, and Opex. Unlike the 1965 edition, 5-phenyltetrazole appears in the 1985 edition. The discussion is brief, but cites U.S. Patent 3,442,829 held by Borg-Warner Corp. for the manufacturing method (Moore and Randall, 1969) and a Stepan Chemical Company bulletin for Expandex 5-PT with regard to decomposition properties.

Confusing the chemical names are their multiple usages. Milne (2005) lists both Kempore (five separate variations) and Nitropore as trade names for ABFA. Ash and Ash (1987) identify Nitropore OBSH as 4,4'-oxybis (benzenesulfonyl hydrazide) whereas MACTEC (2003c) calls it Nitropore OT (Table 5-3). Ash and Ash (1990) define Expandex 5PT as 5PT; Kempore 60/14FF, Kempore 60E, Kempore 125E, and Kempore 125FF as variations of ABFA; and Nitropore OBSH as OBSH. These are all identified as Olin products. Opex is not listed. By 1994, Ash and Ash attribute a similar, but different, list of products to Uniroyal: Expandex 5PT is still identified as 5PT, Expandex 175 as the barium salt of 5PT, Kempore as ABFA, Nitropore ATA as an ABFA/DNPT blend, and Opex 80 as "dinitro." ChemIndustry.com (2017) lists Expandex 5PT, Expandex OX 5PT, and Kempore 50XPT all as trade names for 5 phenyl 1H tetrazole. U.S. Patent 4,313,873 (Lim, 1982), filed in June 1979, also refers to Expandex OX-5PT by Stepan Chemical Co.

Howard and Neal (1992) list synonyms by Chemical Abstract Service (CAS) numbers. CAS 80-17-1 is given 18 different synonyms, including benzylsulfonyl hydrazide, benzylsulfonol hydrazine, and Nitropore OBSH. CAS 80-51-3 is also called Nitropore OBSH as well as OBSH, 4,4'-oxybis-benzenesulfonic acid dihydrazide, and eight other synonyms. CAS 101-25-7 is shown to have 27 synonyms, including DNPT and Opex. The 32 synonyms for CAS 123-77-3 include 1,1'-azobisformamide, Kempore, Kempore 125, Kempore R 125, and also Nitropore. Finally, CAS 18039-42-4 is matched with eleven synonyms, including Expandex OX 5PT, Expandex 5PT, Kempore 50XPT, and 5-phenyl-1H-tetrazole.

None of the available references included the trade name OBSC nor the chemical compound identified with it. No information was found on the Internet or in published references for 4,4'-oxybisbenzenesulfonylchloride or OBSC.

The NPI Wiltrol product line consisted of retarders used in rubber manufacturing. NPI's advertisements in the 1969-1970 through 1971-1972 issues of the Modern Plastics Encyclopedia list both Wiltrol-N (as nitrosodiphenylamine) and Wiltrol-P (as phthalic anhydride). The advertisement in the 1969-1970 edition indicates a 1968 copyright. Wiltrol-P is identified as CAS 85-44-9 (phthalic anhydride) on the WISER (Wireless Information System for Emergency Responders) List maintained by the National Library of Medicine within the National Institutes of Health, Health & Human Services (NLM, 2008). Olin site investigation documents identify Wiltrol-N as N-nitrosodiphenylamine (NDPhA) although we found little additional information about the compound. ATSDR (1993) describes NDPhA as a retardant used in the rubber industry. U.S. production peaked in 1974 and has since declined substantially due to the availability of newer, more effective products. As of 1990, Uniroyal Chemical Company in Geismar, Louisiana was the sole remaining U.S. manufacturer. As indicated in Table A.3, the manufacturing period identified for Wiltrol-N is 1965-1967, which is at odds with advertisements for the product in 1968 through 1971.

We also searched on-line patent and trademark records from the U.S. Patent Office (http://www.uspto.gov/) for the various NPI trademarks. Table A.4 summarizes the NPI trademark record. NPI filed for many U.S. patents over the years and a complete search was impractical. Several key patents were reviewed however.

Table A.4. NPI Trademark History (from USPTO, 2008).

Trademark	Date first used in commerce	Date applied for	Registration date
Expandex	December 20, 1957	February 6, 1958	September 22, 1959
Kempore	October 1, 1956	February 27, 1963	February 18, 1964
Nitropore	April 24, 1959	June 19, 1959	March 15, 1960
Opex	January 24, 1954	July 3, 1957	January 20, 1959
Wiltrol	September 26, 1955	March 30, 1966	November 8, 1966
Wiltrol-N	1964	April 22, 1976	January 11, 1977

Patent 3,873,477 was filed in December 1973 by National Polychemical/Stepan employees Walter Beck and John C. Blackwood (Beck and Blackwood, 1975) for "Metallic salts of tetrazoles used as blowing and intumescent agents for thermoplastic polymers." Page 2 says "One product useful as a high-temperature processing blowing agent is 5 phenyl tetrazole which has a decomposition temperature in the range of about 450° to 480°F, and, therefore, provides some limited use as a blowing agent in high-temperature processing polymers. This blowing agent is described in U.S. Pat. No. 3,442,829, patented May 6, 1969,..." Patent 3,442,829 (Moore and Randall, 1969) is assigned to Borg-Warner Corporation and was filed in November 1966. The subsequent NPI patent by Beck and Blackwood (1975) describes a method to make metallic salts of 5PT that eliminate some undesirable properties of the original compound. The patent on NPI's variation of 5PT was filed in December 1973. Another patent, by Lim (1982), includes a reference to Expandex OX-5PT as a commercial product available from Stepan Chemical.

Another patent filed by NPI is U.S. Patent 3,141,002 for barium azocarbonate (Hill, 1964). The patent application was filed in July 1959. Although not identified as such, the chemical formula shown in the patent matches that given by Lasman (1965) for Expandex 177 which he also calls barium azodicarboxylate. Lasman (1965) describes the material as a salt of azobisformic acid (i.e., ABFA). NPI also received U.S. Patent 2,988,545 for a manufacturing method for ABFA in 1961 based on an application filed in 1957 (Hill, 1961).

The other chemical manufactured at the site and identified as a potential source of NDMA is hydrazine. Hydrazine is a chemical used for a variety of applications, including as a manufacturing intermediate and a foaming agent for plastics (Rothgery, 2004). It is also an important component for the manufacturing of ABFA. Hydrazine was first synthesized in the late 1800s and manufacture in the United States began in 1953 at an Olin plant in Lake Charles, Louisiana. Several Wilmington NPI employees filed a patent in Great Britain for a new manufacturing process for hydrazine in March 1964 (Riley et al., 1967) but a similar U.S. patent was not found. The 1964 patent date corresponds well with the manufacturing start date of 1963 in Wilmington (Table A.3).

There are other possible sources of NDMA not identified by CRA (1993) or MACTEC (2003c). Our research of NPI patents indicated at least two products not on the list of possible NDMA sources. As discussed above, Lasman (1964) cited a new type of blowing agent, for N-alkyl-N-nitroso alkyl sulfonamides (Hill and ter Horst, 1964). Around the same time, ter Horst (1964) patented what he termed a “new class of blowing agents comprising the N-nitroso glycolurils.” Both of these compounds are formed by nitrosation and thus possible sources of NDMA. However, neither seems to have been manufactured in sufficient quantity to merit listing in the inventories by McBrien (1983) or Stepan (1980). Nonetheless, NPI’s research laboratory could have been a source of these and other NDMA source compounds during decades of operation.

In summary, our research focused on Nitropore 5PT, the compound implicated in site documents as the most likely source of NDMA and the compound for which different manufacturing dates are given. It appears based on the literature and NPI advertisements that Nitropore 5PT was never used by NPI as a trade name; rather the chemical 5PT was sold as Expandex 5PT. With respect to manufacturing dates, CRA (1993) indicates 1965-1975 while MACTEC (2003c) gives 1973-1983. The seeming absence of a manufacturing method for 5PT prior to the patent applied for in 1966 by Moore and Randall (1969) rules out 1965 as a manufacturing date for Nitropore 5PT at the Wilmington site. Further, Lim’s (1982) reference to Expandex OX-5PT in his 1979 patent application makes a manufacturing end date of 1975 doubtful. Finally, Expandex 5PT is identified by Stepan employee L.R. Boldoc as a new product in 1973 (Boldoc, 1973) and NPI only began advertising Expandex 5PT in 1972. In another internal inventory, by McBrien (1983), Expandex 5PT is listed but not Nitropore 5PT. It thus appears that the dates given by MACTEC (2003c) are the more plausible start and end dates for 5PT manufacture in Wilmington: 1973-1983, although a somewhat earlier start date seems likely given the product was advertised in 1972. Available company records indicate that Expandex 5PT was not manufactured in large quantity: McBrien (1983) indicates it was manufactured in the pilot plant until 1983; Stepan (1980) indicates it was manufactured from 1973 to 1980 in “limited quantities 24,000 lbs/yr.”

With respect to the other compounds identified as possible NDMA precursors, there seems to be some confusion in the literature as to which trades names went with which products. Nonetheless, trade magazine articles and advertisements by NPI seem clear and consistent: the trade name Kempore was used for ABFA, Nitropore for OBSH, Expandex for high-temperature agents that included 5PT and barium azodicarboxylate, and Opex for DNPT. Other sources also ascribe, incorrectly it appears, Kempore to 5PT and Nitropore for ABFA.

Despite the confusion of the various trade names, the available information discussed above largely confirms the manufacturing periods given in Table A.1 and Table A.3. The only anomalies identified are that some of the NPI trademark names were applied for well before the stated manufacturing dates. The Nitropore trademark was applied for in 1959 (Table A.4) but is not identified as being manufactured until 1969 (Table A.2). Similarly, Wiltrol was applied for in 1955 (Table A.4), but not manufactured until 1965. For one compound, OBSC, there is a significant data gap. No information on this compound was found in the literature or on the Internet. CRA (1993) lumps it with OBSH, but we have no independent information to verify that they were manufactured together or were even particularly compatible.

In summary, with the exception of the apparently erroneous dates given for Nitropore 5PT and Wiltrol-N, the available information generally corroborates the dates given by CRA (1993). The most likely manufacturing start date for 5PT products is circa 1973, most likely after 1970 when wastes began to be discharged to the MDC sewer. However, the other potential NDMA precursors were manufactured earlier, starting in 1953 and with additional product lines added in 1956, 1963, 1965, and 1969. Only one of these lines, for Wiltrol-N, is shown in Table A.3 to have terminated prior to the 1970 connection to the MDC sewer although the 1967 termination date appears doubtful based on NPI advertisements for the product until 1971. Thus, we can conclude that possible NDMA precursors reached the subsurface via disposal in on-site lagoons beginning as early as 1953 and at a generally increasing rate until 1970. Although the facility began operation in 1953, CRA (1993) indicates that the use of unlined pits for waste disposal began in 1956 with the startup of the Kempore manufacturing process.

B. Chemistry of NDMA Formation

Because of their carcinogenic potency NDMA and other nitrosamines have been the focus of many studies since the 1960s and 1970s. NDMA has been found in foods (e.g., preserved meats and fish, beer, cheese, baked goods), tobacco smoke, air, and chemical manufacturing wastes (IARC, 1978). NDMA has also been found at high levels in ground water at waste disposal sites, wastewater treatment plant effluent, and treated drinking water (Mitch et al., 2003). Although the US EPA has yet to establish a maximum contaminant level for NDMA in drinking water (US EPA, 2014), some states have been more proactive – for example, California set an interim action level for NDMA at 10 ng/L (CA-DHS, 2002).

NDMA formation has been shown to occur by three principal pathways: (1) nitrosation of dimethylamine (DMA) (Mirvish, 1975), (2) oxidation of DMA with monochloramine (Choi et al. (2002), and (3) transnitrosation (Buglass et al., 1973). Nitrosation typically involves the formation of nitrosyl cation (NO+) during the acidification of nitrite (Reaction 1) below. This step is then followed by the reaction of nitrosyl cation with DMA to form NDMA (Reaction 2) (Mirvish, 1975).

Reaction 1

$$HNO_2 + H^+ \leftrightarrow H_2O + NO^+$$

Reaction 2

$$NO^+ + (CH_3)_2NH \rightarrow (CH_3)_2N\text{-}N{=}O + H^+$$

This pathway is favored at a pH of 3.4; however, it has been reported that other chemicals including fulvic acid and formaldehyde can catalyze NDMA formation at circumneutral pH (Mitch et al., 2003).

Formation of NDMA by the oxidation of DMA with monochloramine was proposed by Choi et al. (2002) as a two-step process (Figure B.1). In the first step, DMA reacts with monochloramine (or with free chlorine in the presence of ammonia) via the Raschig Process to form 1,1-dimethylhydrazine (also referred to as unsymmetrical dimethylhydrazine or UDMH). In the second step, 1,1-dimethylhydrazine is oxidized by additional monochloramine to NDMA. Figure B.1 also shows that the reaction between monochloramine and DMA can lead to reversible chlorine transfer from monochloramine to DMA, which produces dimethylchloramine (DMCA). Choi et al. (2002) found the highest NDMA yield occurred when equimolar concentrations of DMA and monochloramine reacted at circumneutral pH.

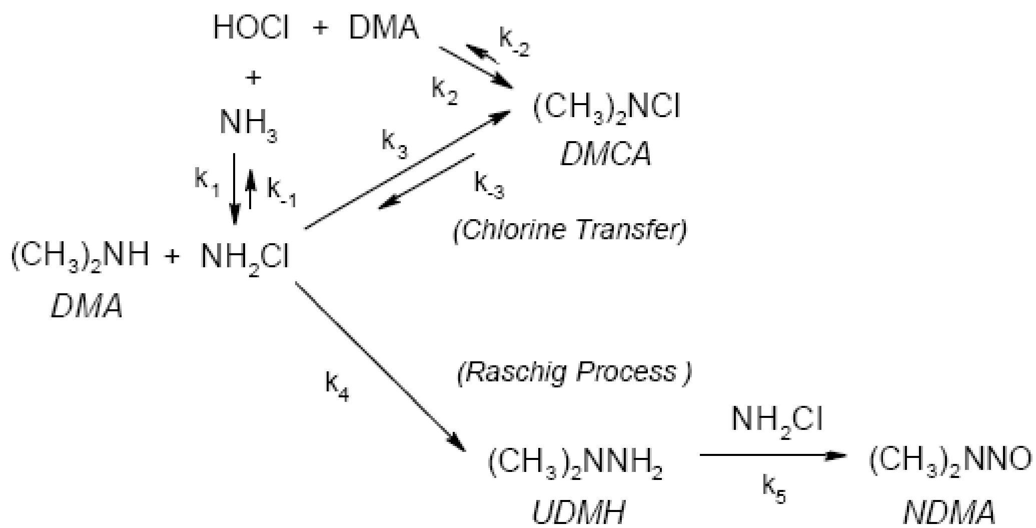

Figure B.1. Proposed pathway for NDMA formation during disinfection by free chlorine and monochloramine (from Choi et al., 2002).

The mechanism proposed by Choi et al. (2002) may be particularly important for NDMA formation in treated drinking water and wastewater because monochloramine and free chlorine are two of the most widely used chemicals for water disinfection. Choi et al. demonstrated that addition of 0.05 and 0.5 millimoles/L (mmol/L) of monochloramine to secondarily treated wastewater produced 3.6 and 111 ng/L of NDMA, respectively. In a similar experiment, Mitch and Sedlack (2004) showed that addition of 2 mmol/L of monochloramine to primary and secondary effluent from wastewater treatment plants produced NDMA levels in excess of 10,000 ng/L in some samples. Mitch and Sedlak also tested several model precursor compounds for their ability to form NDMA following treatment with monochloramine. Their results showed that DMA (which is present in sanitary wastewater), tertiary amines with dimethylamine functional groups, and dimethylamides all formed significant amounts of NDMA.

A third pathway for NDMA formation is transnitrosation: transfer of an –N=O group from a nitrosamine to another amine (e.g., Reaction 3) (Buglass et al., 1973).

Reaction 3

$$R_2N\text{-}N{=}O \; + \; R'_2NH \; \rightarrow \; R_2NH \; + \; R'_2N\text{-}N{=}O$$

This pathway requires a nitrosamine as a precursor compound, and is favored at low pH and in the presence of high concentrations of nucleophiles such as R'_2NH. Buglass et al. (and references cited therein) observed that N-nitrosodiphenylamine was among the most effective transnitrosation agents of the nitrosamines studied (i.e., most likely to transfer an –N=O group).

A summary of these three pathways and the required precursors is shown in Table B.1. Note that for each pathway, organic amines are required – either dimethylamine (DMA), tertiary amines with dimethylamine functional groups, or constituents that could be transformed into these precursor compounds.

Table B.1. NDMA Formation Pathways and Associated Precursors

Pathway	Precursors
Nitrosation of organic nitrogen compounds	1. Nitrite, nitrous acid and/or other constituents that could be converted to nitrite. 2. DMA and/or tertiary amines with dimethylamine functional groups (and/or constituents that could be transformed into these precursors)
Oxidation of organic amines with monochloramine	1. Monochloramine and/or chlorine (or hypochlorite) plus ammonia. 2. DMA and/or tertiary amines with dimethylamine functional groups (and/or constituents that could be transformed into these precursors)
Transnitrosation	1. Nitrosamine 2. DMA and/or tertiary amines with dimethylamine functional groups (and/or constituents that could be transformed into these precursors)

Kinetics experiments indicate that NDMA forms on the time scale of hours-to-days. Mitch and Sedlak (2004) reported that reaction of 2 mmol/L of monochloramine with 0.1 mmol/L DMA produced ~$5x10^{-6}$ mmol/L (370 ng/L) of NDMA after four hours and ~$2.6x10^{-3}$ mmol/L (190,000 ng/L) of NDMA after 10 days in the same experiment (however, NDMA levels were largely unchanged after one day). Similarly, Choi and Valentine (2002) showed that the reaction of 0.1 mmol/L of monochloramine with 0.1 mmol/L of DMA produced ~$1.6x10^{-4}$ mmol/L (12,000 ng/L) of NDMA after 24 hours. In addition, Choi and Valentine found that ~$2.7x10^{-5}$ mmol/L (2,000 ng/L) of NDMA was produced by reacting 0.1 mmol/L DMA and 0.1 mmol/L nitrite for 24 hours. These results suggest that although the reaction of DMA with nitrite is slower than with monochloramine, significant amounts of NDMA are formed by nitrosation in relatively short timescales (hours). This may be of particular significance for the Olin site where it is likely that NDMA is formed by nitrosation of amines.

To date, relatively few studies have investigated the occurrence of NDMA in treated drinking water. A survey of 142 water treatment plants in Ontario in 1997 showed that NDMA levels in most samples were <5 ng/L, but in some samples the levels were >9 ng/L (Ontario-MOEE, 1998). A study of water treatment plants in California (mainly in the San Francisco and Los Angeles areas) showed that only 3 of 20 chloraminated water supplies contained NDMA at levels >10 ng/L, while none of the eight plants that used free chlorine had NDMA above 5 ng/L (CA-DHS, 2002). Studies by Tompkins et al. (1995) and Tompkins and Griest (1996) also showed that treated drinking water samples typically contain <10 ng/L NDMA. Taken together, these studies show that NDMA levels in finished water at water treatment plants are typically <10 ng/L. Only one study (the CA-DHS study in 2002) was found in which NDMA was measured in the distribution systems downstream from treatment plants. In seven water distribution systems to which free chlorine was added prior to distributing the water, the average NDMA measurement was 1.2 ng/L and the highest was 2.5 ng/L, while in 20 systems to which monochloramine was added, the average concentration was 3.7 ng/L and the highest was 28 ng/L (CA-DHS, 2002). These results suggest that use of chloramine to maintain residual chlorine levels in water distribution systems yields somewhat higher levels of NDMA than free chlorine.

C. Chemical Contaminants Reported in the Maple Meadow Brook Aquifer

The discovery of contaminants beneath the Olin Site and in the Maple Meadow Brook aquifer has motivated efforts to characterize sources of chemical contamination to the aquifer. Although a comprehensive evaluation of all the possible sources within the watershed that supplied the Wilmington town wells has not been performed, three source areas of contamination have been identified: the Olin Site, the Maple Meadow landfill, and the trichloroethylene plume in the Western Bedrock Valley west of Main Street (Figure C.1). These three source areas are described below. The goal of this section is to review what is known about these source areas in relation to contamination of the aquifer. References to consultant reports that provide detailed site histories and geophysical investigations are provided in each subsection.

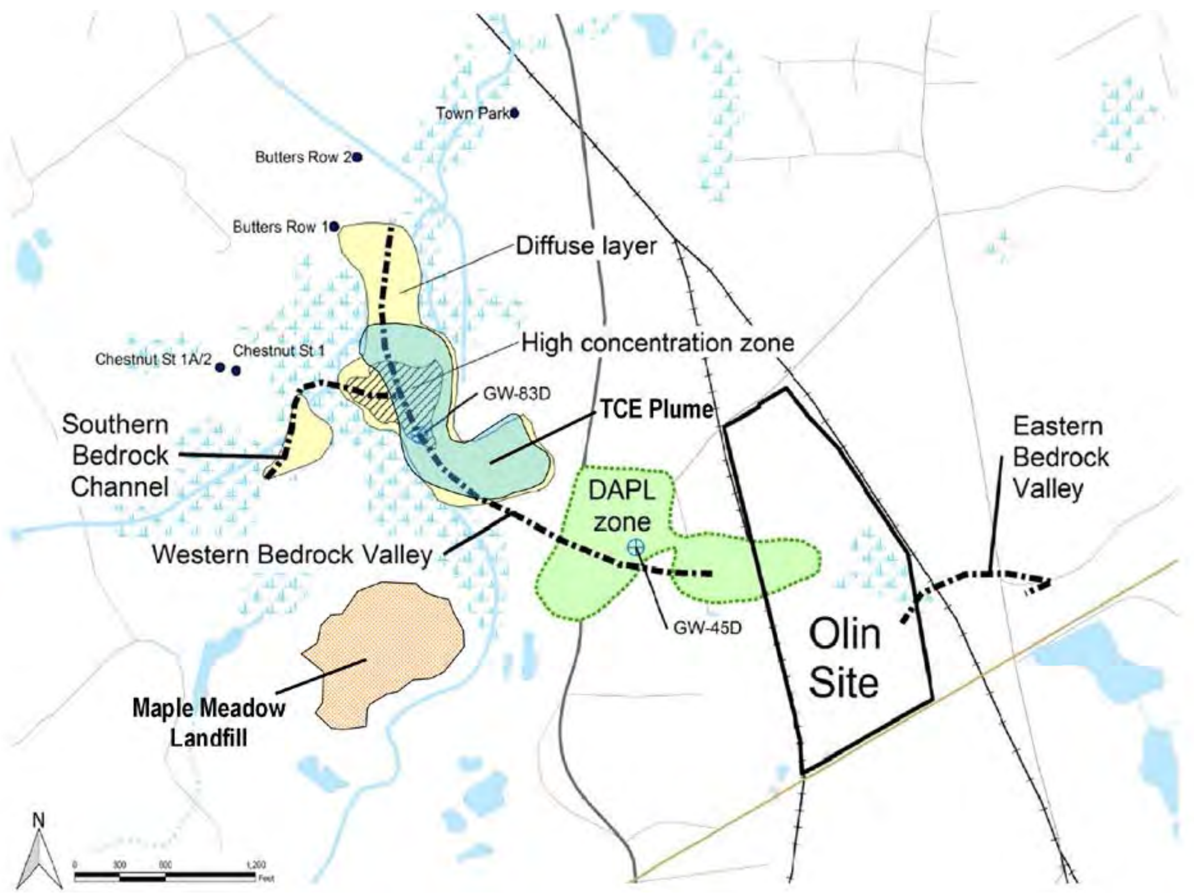

Figure C.1: Map of contamination source areas including Olin site, Maple Meadow Landfill and TCE Plum in Western Bedrock Valley. Adapted from GEI (2002) and Geomega (2003).

C.1 OLIN SITE

The quality of the ground water beneath the Olin site reflects a long history of disposal of waste materials from chemical manufacturing processes. The Olin facility began operation in 1953 as National Polychemical, Inc. (NPI), a manufacturer of specialty chemicals for the rubber and plastics industries (MACTEC, 2003c). National Polychemicals became a subsidiary of Stepan Chemical Company in 1968, which operated the facility until 1980, when it was sold to Olin Corporation. It was operated by Olin until its closure in 1986. See Appendix A for additional details on Olin site history.

During its initial years of operation, untreated processing wastewaters were discharged to unlined lagoons on the facility (Figure C.2) and allowed to seep into the ground (CRA, 1993). Disposal to the east and west pits and the "Lake Poly" lagoon is believed to have commenced in 1956. After construction of a warehouse in the location of the east and west pits in 1964, discharge to the acid pits began. In 1970, Stepan instituted treatment to neutralize acid wastewater and lined the lagoons. At first, the effluent from the lined lagoons was released to the ditches on the south side of the facility, but the discharge was diverted to the municipal sewer when it was constructed in 1972.

The facility manufactured a broad range of products and thus produced a variety of wastes (CRA, 1993). Predominant chemicals included sodium and ammonium salts, urea, sulfuric acid, and various sulfates. The lagoon wastes were therefore highly salty as well as acidic. This created unique chemical and physical conditions. The physical condition was a significant difference in the densities of the highly salty wastewater and underlying fresh ground water. The highly salty water was heavier and therefore sunk in the ground water beneath the site (Smith et al., 1997). It settled in low areas on the underlying bedrock and persists today as two pools of Dense Aqueous-Phase Liquid (DAPL) on the bedrock surface west of the site (Figure C.1) (Geomega, 2001a).

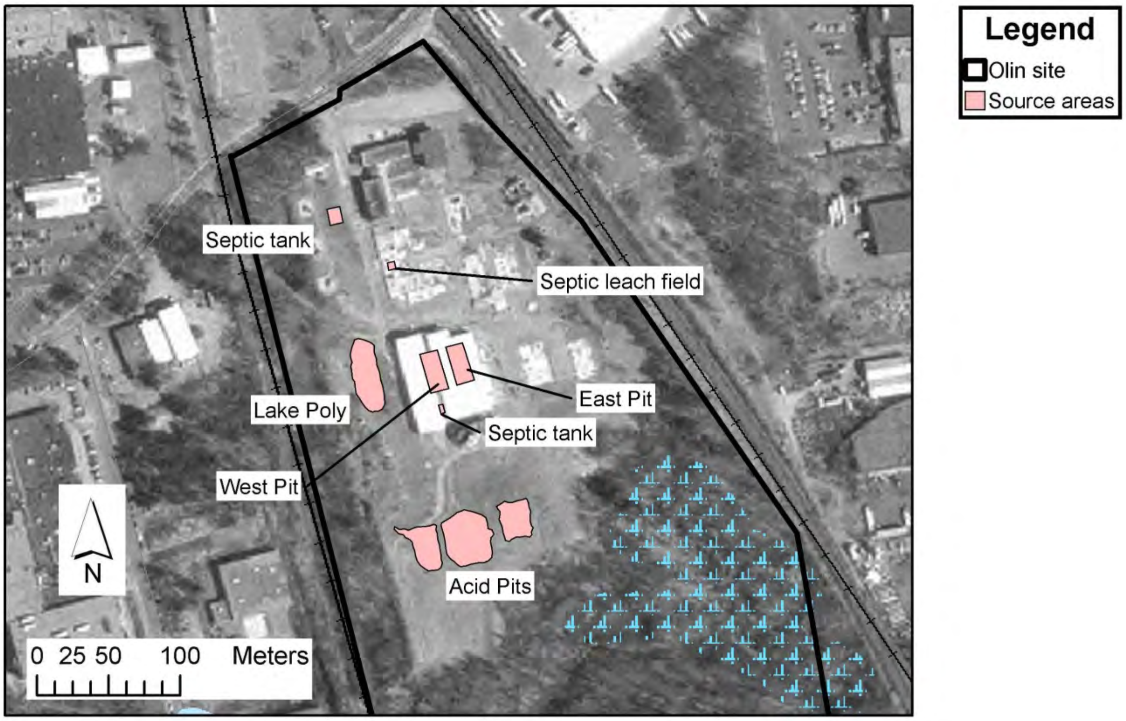

Figure C.2. Orthophoto showing details of surface and subsurface features at the Olin Site (disposal locations from GEI (2002), Geomega (2003), and EPA (2005))

The DAPL exists as an essentially distinct phase of salty, acidic water within the subsurface. Similar dynamics occur in coastal areas, where fresh ground water from inland floats atop salty water from the ocean. The interface between the fresh and salty water is not distinct in either the coastal zone or the Olin site: salt and chemicals diffuse (or mix) upward from the salty layer into the fresh layer, creating a zone of intermediate concentration, referred to as the “diffuse” layer (GEI, 2002).

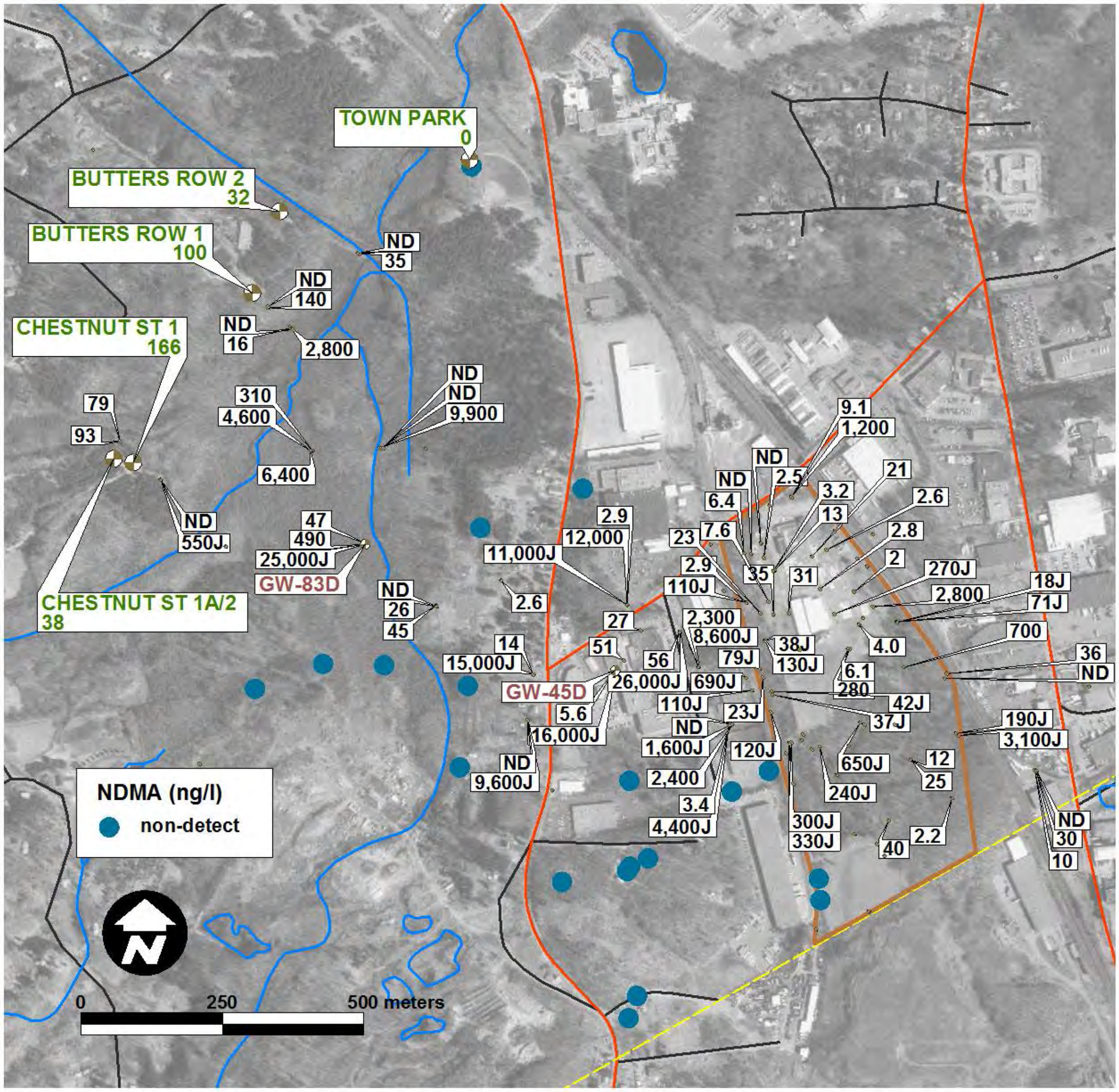

Figure C.3. Maximum concentrations of NDMA measured in ground water in years 2003 and 2004 on the Olin site and in the Maple Meadow Brook aquifer (data taken from MACTEC, 2007). Blue dots indicate samples containing no detectable NDMA. Sites with multiple concentrations stacked vertically represent samples collected at different depths, the deepest samples are at the bottom of the stack. "J" indicates the concentration is estimated.

The DAPL is characterized by high concentrations of inorganic ions (including sulfate, chloride, calcium, sodium, and ammonia), low pH, and a variety of organic compounds (including NDMA, acetone, bromoform, methyl ethyl ketone, methyl butyl ketone, toluene, trimethylpentanes, benzoic acid, bis(2-ethylhexyl) phthalate, 4-bromophenyl-phenylether, naphthalene, and phenol) (Smith et al., 1997). MACTEC (2003c) reports an NDMA concentration of 16,000 ng/L at monitoring well GW-45D in the DAPL zone. NDMA has spread to the Maple Meadow Brook aquifer as well, where it was found at a maximum concentration of 25,000 ng/L in monitoring well GW-83D (MACTEC, 2007) (Figure C.3).

In 2004 water samples from four monitoring wells (GW-83, -84, -86, and MP-2), representing DAPL, the diffuse layer, and overlying water, were analyzed by gas chromatography high resolution mass spectrometry for the presence of organic chemicals. Details of the analysis are described in Sovocool and Grange (2004). A total of 196 compounds were identified in the samples. Of these, 11 were also found in the field blank; therefore, only 185 compounds were uniquely attributable to the samples. The majority of the chemicals were present in the DAPL and diffuse layer samples; the fewest compounds were found in samples from the overlying layer.

One diffuse-layer sample (MP2-9) that contained significantly more organic chemicals than the other samples was analyzed in detail. This sample contained numerous halogenated and non-halogenated compounds including halogenated phenols (estimated concentration range = 1-1,000 ug/L), halogenated methanes (10-1,000 ug/L), diphenyl ether (50-500), brominated toluenes (10-100 ug/L), biphenyl (10-100 ug/L), phenol (10-100 ug/L), and halogenated diphenyl ethers (1-10 ug/L). Many of these compounds are characteristic of industrial wastes. The sample also contained benzonitrile (10-100 ug/L), benzoquinone (10-100 ug/L), dichlorobenzene (5-50 ug/L), benzothiazole (1-10 ug/L), polycyclic aromatic hydrocarbons (1-10 ug/L), and the insect repellant diethyl-n-toluamide (DEET) (1-10 ug/L). Cresols were also confirmed in the sample but not quantified, and two nitrophenol isomers were tentatively identified at relatively high levels (10-100 ug/L), but their presence was not confirmed using authentic standards. Low levels (1-10 ug/L) of several organic compounds were also found in the samples of overlying water. These included dichlorobenzenes, DEET, naphthalene, benzothiazole, benzophenone, and diphenyl ether.

Hydrazine and other amines and amine-containing compounds were not detected in the samples as they would have disintegrated due to the high temperature of the GC inlet. The report did not mention analysis of NDMA presumably because the analytical method used was not optimized for NDMA detection.

This report expands our knowledge of the kinds and amounts of organic compounds present in the DAPL and diffuse layers and water overlying in the Maple Meadow Brook aquifer. The results provide further evidence for the presence of high concentrations of industrial chemicals in the vicinity of the Wilmington water supply wells.

Despite the relevance of the Sovocool and Grange study we chose not to include their findings in our modeling effort because they reported chemical concentrations to within a factor of 10, which was too imprecise for our needs. Also, because the water samples were not collected from the drinking water supply wells, we do not have evidence that the chemicals measured actually reached the supply wells, nor do we have enough information to estimate their concentrations in the wells had the chemicals indeed reached them.

The information developed by Olin's consultants (e.g., MACTEC, 2003c), indicate that NDMA was never used, disposed of, or intentionally produced in the manufacturing processes, and that it is likely NDMA formed in the environment due to the reaction of waste chemicals that were dumped into unlined pits at the Olin facility. One possible specific pathway leading to NDMA formation in the subsurface at the Olin site is reaction of chemicals in sanitary wastewater. Prior to construction of municipal sewers, sanitary wastewater at Olin was disposed in on-site septic systems. Co-mingling of NDMA precursors in domestic sanitary waste (e.g., dimethylamine) with low-pH industrial wastewater in the ground water could have caused reactions that created NDMA (see Appendix B).

The subsurface pools of DAPL represent an enormous source of ground-water contaminants that was likely established before the facility was connected to the municipal sewer in 1972 and has persisted ever since. The natural direction of ground-water flow is generally northward past the DAPL pools and on to the Maple Meadow Brook aquifer. Under natural conditions, this ground water discharges to Maple Meadow Brook and its adjacent wetlands. With the pumping of high volume supply wells, the general direction of flow is similar, but the speed of ground water movement and the volume of flow increases due to the extra draw of water to the pumping wells. Ground water flowing past the DAPL pools becomes contaminated by chemicals dissolving from the DAPL.

The nature of the contaminant plume is depicted in Figure C.1, which shows a zone of contaminated ground water extending northwestward from the DAPL area to the Butters Row 1 municipal supply well. The plume is characterized by elevated concentrations of ammonia, chloride, sodium, and sulfate. Within the plume, about midway along the path to the supply wells, is what GEI (2002) defines as the high-concentration zone. Here, ammonia concentrations exceed 1,000 mg/L, chloride and sodium each exceed 5,000 mg/L, and sulfate is approximately 20,000 mg/L. GEI (2002) does not characterize NDMA concentrations within these plume areas; however, a later report by MACTEC (2007) shows concentrations of NDMA in the high-concentration zone are as high as 25,000 ng/L. Geomega (as reported in GEI, 2002, Appendix B) show that the high-concentration zone coincides with a deep depression in the bedrock surface. They ascribe the high concentrations to “remnant” DAPL in the depths of the depression. Concentrations downgradient of the high-concentration zone (i.e., in the vicinity of the Butters Row wells) are on the order of 30 mg/L of ammonia, 300 mg/L of chloride, 200 mg/L of sodium, 200 mg/L of sulfate, and >2,000 ng/L of NDMA (Figure C.3).

C.2 Maple Meadow Landfill

The Maple Meadow Landfill (Figure C.1) is potentially an additional source of pollutants to the Maple Meadow Brook aquifer (CDM, 2003). This 40-acre area received municipal solid waste from the Town of Wilmington and other sources from the mid-1950s through 1976. According to MADEP (2003), at least 15 acres of the total area is said to contain waste material disposed of below the water table. The entire landfill area lies within the Zone II area of the Wilmington water supply wells (see Zone II area map in GEI, 2002). A Zone II area is a conservative approximation of the contributing area to a water supply well. The June 2013 database of inactive and closed landfills within Massachusetts (MADEP, 2013) describes the landfill as unlined, with a closure status of *Incomplete*.

As part of the landfill closing process, the site was investigated in 2002 for the presence of chemical contaminants. The results are described in CDM (2003). Ground water testing indicated that only arsenic was present at levels in excess of the primary drinking water standard. The highest arsenic levels were >160 µg/L, while the lowest were <5 µg/L. In addition, Massachusetts Secondary Maximum Contaminant Levels were exceeded in some wells for total dissolved solids, chloride ion, iron, and manganese. Also, volatile organic compounds were detected in some wells, but at levels below all relevant water quality standards.

In surface water samples, no pollutants were present in excess of primary drinking water standards; however, at several locations iron and manganese concentrations were above Massachusetts Secondary Maximum Contaminant Levels. Many sediment samples contained toxic elements – arsenic, cadmium, chromium, copper, lead, mercury, and zinc – at levels above MA DEP’s Consensus-based Threshold Effect Concentration (TEC) values. Polycyclic aromatic hydrocarbons were also present in sediment samples at levels above the TECs. Extractable petroleum hydrocarbons and some volatile organic compounds (acetone, bromomethane, 2-butanone, and toluene) were also detected, but TECs for these compounds had not been developed at the time of the study.

TCE was detected at a maximum concentration of 1 µg/L. This led the MADEP to conclude that the landfill was not a source of TCE to water supply wells within Wilmington. NDMA was not detected in samples from two wells downgradient of the Maple Meadow Landfill (MADEP, 2003).

Because the municipal water met the MA Drinking Water Limits for all contaminants including arsenic, CDM (2003) reasoned that if chemicals from the landfill had reached the Maple Meadow Brook water supply wells, then the chemicals had either been removed during the water treatment process or had been diluted with clean ground water to low levels. The arsenic concentrations in well water samples collected in 2002 from Butters Row 1 and Chestnut St 1 were 11 and 8 µg/L, respectively, which were below the then current arsenic standard of 50 µg/L.

C.3 TRICHLOROETHYLENE

IEP (1990) reported that between 1977-1983 TCE levels in the Butter's Row wells and Chestnut St. #1 were consistently high (as high as 150 µg/L in 1979). Note that we were unable to locate published TCE data for this period; the earliest data we obtained was from 1983 (see Appendix I). IEP (1990) also reported that between 1979 and 1981, pumping of these wells was discontinued while the Butter's Row water treatment plant was being built. Also note that Butter's Row well #2 was not brought online until 1981 and that Butter's Row well #1 was offline between 1973 and 1981 (Appendix F); therefore, if Butter's Row wells #1 was being pumped while it was offline and Butters Row well #2 was being pumped prior to 1981, they were likely discharging to waste. Additional records of TCE measurements in samples from the water distribution system are provided in Appendix I.

Using data collected prior to 2000, GEI (2002) identified a trichloroethylene (TCE) plume in ground water in the Western Bedrock Valley west of Main Street (Route 38) (Figure C.1). The source of the TCE was not identified in the report. The highest concentrations were measured in GW-84D (240 µg/L) and GW-58D (460 µg/L). Only one of the drinking water supply wells (Chestnut Street 1) contained measurable TCE (~5 µg/L).

It is not known whether the TCE reported in the Butter's Row wells and Chestnut St. well #1 in the early 1980s by IEP (1990) and the plume reported in the Western Bedrock Valley by GEI in their 2002 report derive from the same source or source area. It is reasonable to infer that they do not for the simple reason that after ~1990 (and until the wells were turned off in 2002) TCE was not detected in the MMB aquifer water treated at Butters Row WTP (see Figure D.2). Had the TCE reported by IEP (1990) and GEI (2002) derived from the same source, then it is reasonable to expect that there would not have been a dramatic decrease in TCE levels in MMB aquifer well water after 1990.

D. HISTORICAL RECORD OF CHEMICAL CONTAMINANTS IN THE WATER DISTRIBUTION SYSTEM

Routine measurements of water quality in the Wilmington water distribution system were started in the 1970's and continue to the present. Over time the list of monitored chemicals has grown to comply with state and federal laws governing water quality monitoring in distribution systems. In the late 1970s the list of chemicals routinely monitored included major ions (e.g., calcium, magnesium, sodium, chloride, sulfate), minor ions (e.g., ammonium, nitrate, nitrite) and chlorinated volatile organic compounds (VOCs) – particularly one- and two-carbon (C_1 and C_2) compounds. Today the list includes many inorganic compounds as well as a large number of chlorinated and non-chlorinated VOCs and semi-volatile organic compounds (310 CMR 22.00).

The record of chemical pollutant measurements in the Wilmington system is uneven during the period of interest (1970s-2003): some chemicals have been measured at many locations at regular intervals since the 1980s (e.g., ammonia, nitrate, and nitrite), while others have only been measured a few times (e.g., NDMA) or at only a few locations (e.g., trihalomethanes). The record indicates that some of the Wilmington water supply wells, particularly those in the Maple Meadow Brook aquifer, contained elevated concentrations of toxic chemicals including chlorinated volatile organic compounds, nitrite, and NDMA. The record also indicates that trichloroethylene (TCE) and trihalomethanes were present in the water distribution system at levels that exceeded drinking water standards. Results for each of these groups of chemicals are described in the following subsections.

D.1 CHLORINATED VOLATILE ORGANIC COMPOUNDS

The Wilmington Water and Sewer Department first started to make routine measurements of chlorinated volatile organic compounds (Cl-VOCs) in 1979 following the discovery of Cl-VOCs in municipal wells in nearby Woburn, Massachusetts (C. Preble, Wilmington Water and Sewer Department, personal communication, 2006). Initially, only seven Cl-VOCs (trichloroethylene, tetrachloroethylene, 1,1- and 1,2-dichloroethylene, 1,1- and 1,2-dichloroethane, and 1,1,1-trichloroethane) were monitored; however, after new regulations were promulgated by the state in 1986, the number of routinely monitored Cl-VOCs (and VOCs, in general) increased significantly (310 CMR 22.00).

In the 1980s Cl-VOCs were regularly detected in water from the Maple Meadow Brook aquifer supply wells, the Butters Rows treatment plant, and several sampling stations in the Wilmington water distribution system (Table D.1 and Figure D.1). The most commonly detected compounds were trichloroethylene (TCE) and 1,2-dichloroethylene (1,2-DCE). The highest concentrations were found in Butters Row wells 1 and 2, while lesser amounts were found in Chestnut St. well 1 and Town Park well. The results also show that TCE and 1,2-DCE were present in finish water from the Butters Row treatment plant, which indicates that aeration and filtration through granular activated carbon were not completely effective in removing these compounds from the well water. As a result, TCE and 1,2-DCE were detected at several sampling stations in the water distribution system (see Table D.1 and Figure D.1). The highest concentrations of TCE measured at these sites were in excess of the current drinking water standard (5 µg/L). Samples from the Salem St., Shawsheen Ave., and Brown's Crossing wells and the finish water from the Sargent plant contained TCE and 1,2-DCE at levels at or below the detection limit of 1-2 µg/L. Thus, the source of the TCE and 1,2-DCE in the water distribution system appears to be the Maple Meadow Brook aquifer. CEQ (1981) and C. Preble (Wilmington Water and Sewer Department, personal communication, June 2006) indicate that septic system cleaners used by homeowners in the area were the main source of the solvents to the aquifer. After the late 1980s, the levels of Cl-VOCs in Butters Row wells 1 and 2 and the finished drinking water at the Butters Row treatment plant decreased <2 µg/L. Concentration histories for TCE and 1,2-DCE in Butters Row wells 1 and 2, and the finished drinking water at the Butters Row plant are shown in Figure D.2. A record of available Cl-VOC data is shown in Appendix I. TCE measurements in treated (finished) water from the Butters Row treatment plant – as opposed to wellhead concentrations – were used as inputs for modeling the spatial and temporal distribution of these chemicals in the water distribution system.

Table D.1. 1,2-Dichloroethylene and Trichloroethylene Measurements in Municipal Well Water and the Wilmington Water Distribution System from 1981 to 2002.

Sites	1,2-Dichloroethylene			Trichloroethylene		
	Period of Record	Records	Range (ug/L)*	Period of Record	Records	Range (ug/L)*
Butters Row WTP - Finish	1/81 - 10/02	84	<1 - 12.4	1/81 - 10/02	101	<1 - 27
Butters Row Well #1	9/83 - 10/02	52	<1 - 88.7	9/83 - 10/02	62	<1 - 620
Butters Row Well #2	9/83 - 10/02	54	<1 - 58	9/83 - 10/02	62	<1 - 440
Chestnut St. Well #1	9/83 - 10/02	51	<1 - 11	9/83 - 10/02	62	<1 - 26
Chestnut St. Well #1A/2	9/83 - 10/02	29	<1 - 7.3	4/93 - 10/02	29	<1 - 0.7
Town Park Well	11/85 - 4/02	50	<1 - 27	11/85 - 4/02	60	<1 - 200
Salem St. Well	9/81 - 9/88	3	<2	9/81 - 9/88	3	<2
Shawsheen Ave. Well	8/85 - 9/88	3	<2	3/88 - 9/88	2	<2
Brown's Crossing Well	2/79 - 9/88	3	<2	3/88 - 9/88	2	<2
Sargent WTP - Finish	3/90 - 1/02	19	<1	3/90 - 1/02	19	<1
Hillside (Way) Tank	8/92	1	<2	8/92	1	<2
90 Industrial Way	7/86	1	4.8	2/84 – 7/86	4	2 - 26
91 Marion Street	4/85 – 7/86	2	3.4 - 4.6	4/85 – 7/86	2	9.4 - 15
9 Burt Road	4/85 – 7/86	2	3.5 - 5.6	4/85 – 7/86	2	9.8 - 15
414 Chestnut St.	4/85 – 7/86	2	4 - 4.6	4/85 – 7/86	2	8.6 - 15
18 Allen Park Dr.	4/85 – 7/86	2	2.7 - 3.6	4/85 – 7/86	2	7.6 - 11
30 Industrial Way	7/86	1	4.6	2/84 – 7/86	3	7.6 - 11
Cross St. Hydrant	8/92	1	1	8/92	1	<1
11 Weber St.	9/02	1	2.2	9/02	1	<1

* ug/L = micrograms per liter (parts per billion)
Source of data: Wilmington Water Department, unpublished records, 2006.
Note: In Appendix E, “Compugraphic” = 90 Industrial Way; “Ferno Forge” = 30 Industrial Way.
Drinking water standards: TCE = 5 ug/L; 1,2-DCE = 70 ug/L.

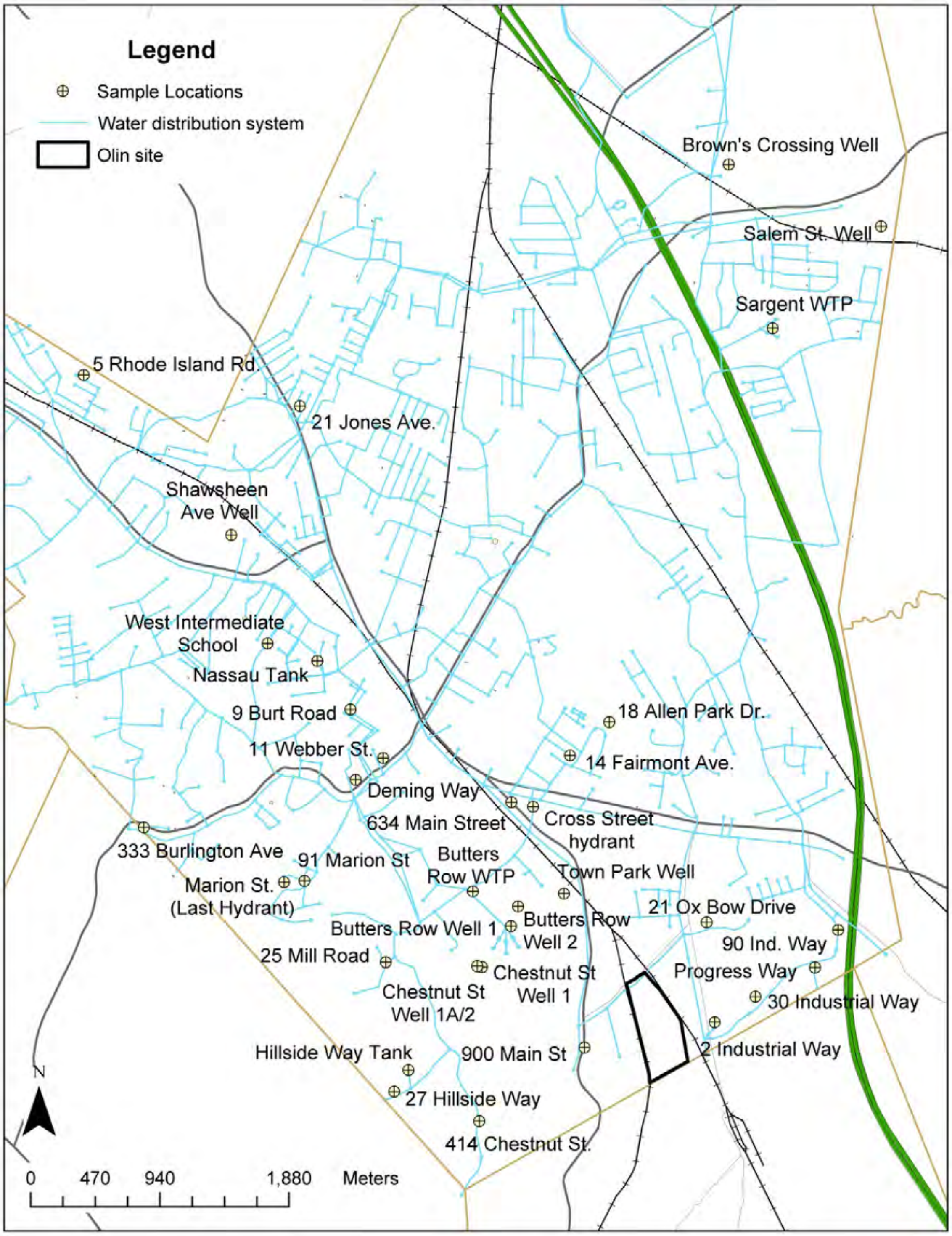

Figure D.1. Water quality monitoring stations in the Wilmington water distribution system.

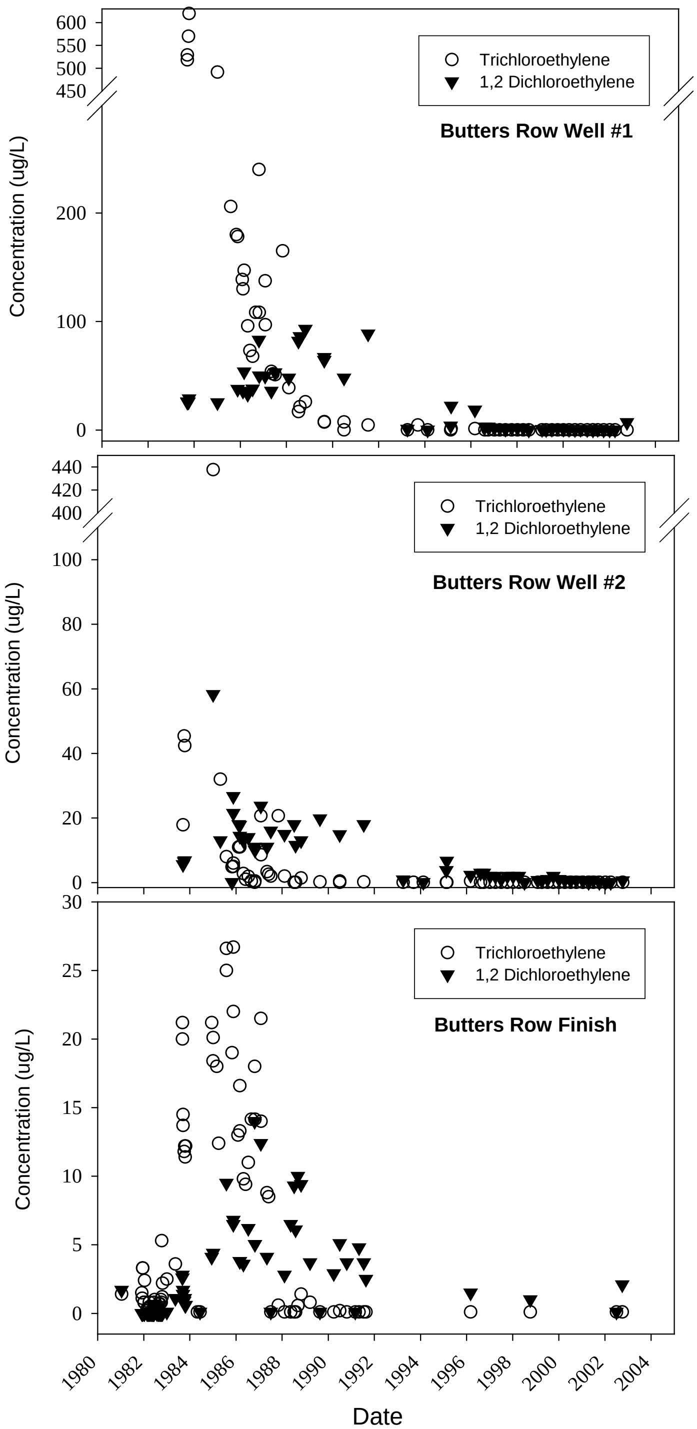

Figure D.2. Concentrations of trichloroethylene and 1,2-dichloroethylene in Butters Row wells 1 and 2, and finished drinking water at the Butter's Row water treatment plant (Wilmington Water Department, unpublished data, 2006).

D.2 TRIHALOMETHANES

Trihalomethanes (THMs) are disinfection byproducts that are formed by the reaction between halogenated disinfectants (typically chlorine) and dissolved organic matter naturally present in municipal waters (Sawyer et al., 2003). The major THMs formed are bromoform, chloroform, bromodichloromethane, and dibromochloromethane. The Wilmington Water and Sewer Department first started to make measurements of THMs in treated drinking water in 1982. From 1982 to 1986 eight sites in the water distribution system were regularly monitored: 90 Industrial Way, 414 Chestnut St., 30 Industrial Way, 2 Industrial Way, 47 Marion St., 9 Burt Road, a site on Progress Way, and 18 Allen Park Drive; however, since December 1986 only 90 Industrial Way and 414 Chestnut St. have been monitored. The locations of these sites are shown in Figure D.1. THM concentrations – reported as the sum of the concentrations of bromoform, chloroform, bromodichloromethane, and dibromochloromethane – were relatively low at the 9 Burt Rd. (2-13 µg/L), 47 Marion St. (2.3-16 µg/L), and 18 Allen Dr. (ND-34 µg/L) sites, while somewhat higher levels were found at the other sites (Table D.2). Levels in excess of 80 µg/L, the current drinking water quality standard for THMs, were measured at 90 Industrial Way, 414 Chestnut St., 30 Industrial Way, 2 Industrial Way, and Progress Way. At 90 Industrial Way, relatively high THM levels (>80 µg/L) were observed in both the early 1980s and relatively recently (2003 and 2005) (Figure D.3). In contrast, at 414 Chestnut St., high THM levels were observed only recently (2003, 2004, and 2005). Because elevated levels of THMs were not observed in the water distribution system until 2003, after the MMB aquifer wells were turned off, we did not attempt to model spatial and temporal variations in their concentrations within the distribution system. The record of THM data compiled for the Wilmington water distribution system is shown in Appendix J.

Table D.2. Measurements of Total Trihalomethanes in the Wilmington Water Distribution System from 1982 to 2006.

Sites	Period of Record	Total Trihalomethanes[1] (THM)	
		# Records	Range (ug/L)*
30 Industrial Way	11/82-7/86	13	5-92
2 Industrial Way	11/82-7/86	13	5-83
90 Industrial Way	11/82-1/06	67	<0.5-110
414 Chestnut St.	11/82-1/06	63	<0.5-200
Progress Way	11/82-7/86	13	7-102
47 Marion St.	11/82-7/86	10	2.3-16
9 Burt Rd.	11/82-7/86	9	2-13
18 Allen Park Dr.	11/82-7/86	12	ND-34

[1]Total trihalomethanes include bromoform, chloroform, bromodichloromethane, and dibromochloromethane
*ug/L = micrograms per liter (parts per billion)
Source of data: Wilmington Water Department, unpublished records, 2006.

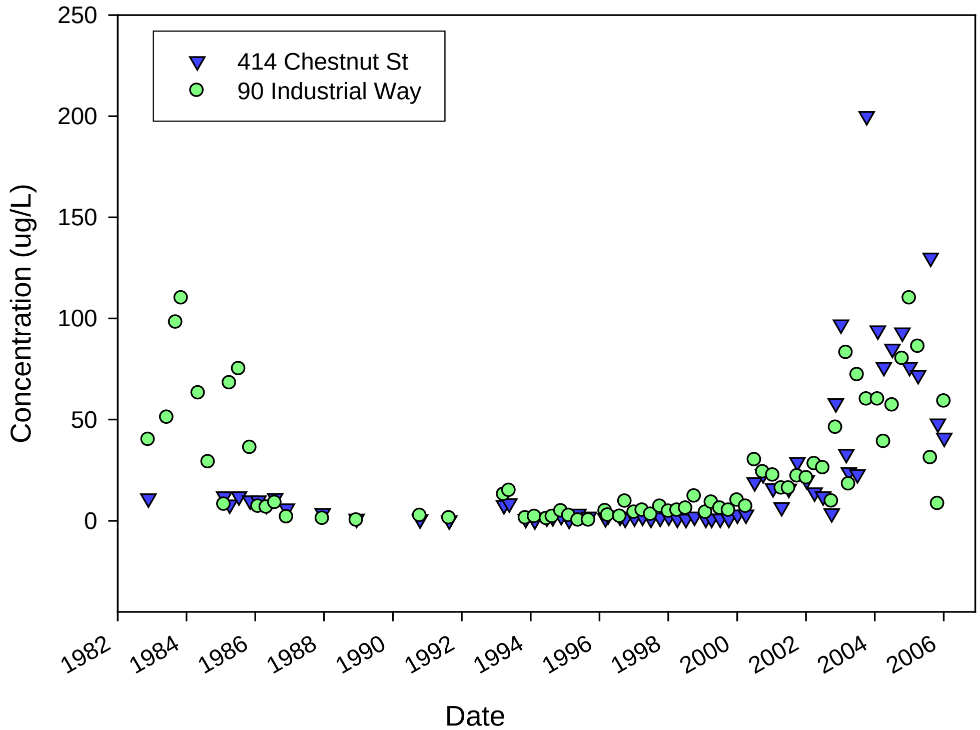

Figure D.3. Concentrations of trihalomethanes in finished drinking water at two points in the distribution system (Wilmington Water Department, unpublished data, 2006).

D.3 Ammonia, Nitrate, and Nitrite

Ammonia, nitrate, and nitrite are among the most commonly measured parameters in the Wilmington water distribution system. Measurements have been made in samples from more than 15 different sites in the system as well as samples from the supply wells and in the treated water just prior to distribution. The earliest regular measurements began at Chestnut St. Well 1 in 1975. Table D.3, Table D.4 and Table D.5 summarize the available data.

Ammonia levels are elevated in the Maple Meadow Brook aquifer due to contamination from the Olin site (see Appendix C). These elevated levels are reflected in measurements from some of the supply wells (e.g., Chestnut St. 1 and Butters Row 1). However, despite relatively high influent ammonia loads, the Butters Row Treatment Plant is effective in removing ammonia from the treated water. Geomega (2002a) demonstrated that ammonia is converted to nitrate (nitrification) in the carbon beds, and that some ammonia is converted to chloramines during chlorination. As a result, ammonia levels in the treated water are generally much lower than in the raw well water (Table D.3).

As shown in Table D.4, nitrate levels in well water samples and samples of treated drinking water from the distribution system were all below the maximum contaminant level for nitrate (10 mg/L as N) throughout the entire period of record. Nitrite levels were also generally low, but a few samples from two sites in the distribution system and influent water at the Butters Row treatment plant exceeded the maximum contaminant level for nitrite (1 mg/L as N). Nitrite levels were elevated several times in October 2002 at 27 Hillside Way and in August 2000 at 47 Marion

St. (last hydrant) (Figure D.1; Table D.5). These high nitrite levels could indicate the presence of nitrate reducing bacteria in biofilms in the pipes. Both the Hillside Way and the Marion Street pipes come to a dead-end at the ends of their respective streets. This likely favors long hydraulic residence times and hence conversion of nitrate to nitrite as dissolved oxygen is depleted by aerobic bacteria. Because there was little evidence that nitrite was a persistent and widely distributed pollutant in the distribution system, we did not attempt to model nitrite concentrations in WaterCAD.

Table D.3. Ammonia Measurements in Municipal Well Water and the Wilmington water distribution system from 1981 to 2006.

Sites	Period of Record	Ammonia (NH_3)	
		# Records	Range (mg/L)*
Butters Row WTP - Finish	5/81-12/05	170	0.02-2.5
Butters Row WTP - Raw	4/00-7/04	160	ND-4
Butters Row Well #1	6/84-10/02	91	0-9.3
Butters Row Well #2	6/84-12/02	201	0.03-2.5
Chestnut St. Well #1	7/75-2/03	86	0.06-15.2
Chestnut St. Well 1A/2	3/92-10/02	183	0-5.1
Town Park Well	7/75-2/03	137	0.07-0.82
Shawsheen Ave. Well	7/75-7/04	132	0.01-0.4
Sargent WTP - Finish	4/89-5/90	2	0.08-0.2
Hillside (Way) Tank	4/00-1/04	150	ND-2.6
Nassau Tank	4/00-1/06	149	ND-2.9
Deming Way	4/00-1/04	149	ND-4.3
900 Main St.	4/00-1/04	149	ND-4.2
634 Main St.	4/00-1/04	148	ND-4.9
333 Burlington Ave.	4/00-1/04	148	ND-2.8
27 Hillside Way	4/00-1/04	151	ND-1.7
21 Jones Ave.	4/00-1/03	146	ND-1.5
14 Fairmont Ave.	4/00-1/04	145	ND-2.6
5 Rhode Island Rd.	4/00-1/04	148	ND-2.5
91 Marion St.	1/03-1/04	8	ND-0.06
25 Mill Rd.	1/03-1/04	8	ND-0.07
21 Oxbow Dr.	1/03-1/04	8	ND-0.07
West (Intermediate) School	4/00-1/04	150	ND-2.8
47 Marion St. (Last Hydrant)	6/00-8/00	12	0.06-0.62

*mg/L = milligrams of ammonia-nitrogen per liter (parts per million)

Source of data: Wilmington Water Department, unpublished records, 2006.

Table D.4. Nitrate Measurements in Municipal Well Water and the Wilmington water distribution system from 1981 to 2006.

Sites	Period of Record	Nitrate (NO_3)	
		# Records	Range (mg/L)*
Butters Row WTP - Finish	5/81-12/05	164	0.08-1.7
Butters Row WTP - Raw	4/00-7/04	149	0.07-1
Butters Row Well #1	6/84-10/02	25	0.03-0.9
Butters Row Well #2	6/84-12/02	133	0.014 -1
Chestnut St. Well #1	7/75-2/03	10	0.1 - 0.2
Chestnut St. Well 1A/2	3/92-10/02	120	0.12-1.4
Town Park Well	7/75-2/03	120	0.06-1
Shawsheen Ave. Well	7/75-7/04	113	0.1-1.87
Sargent WTP - Finish	4/89-5/90	10	0.27-1.79
Hillside (Way) Tank	4/00-1/04	156	0.13-1.6
Nassau Tank	4/00-1/06	155	0.35-1.6
Deming Way	4/00-1/04	156	0.47-1.5
900 Main St.	4/00-1/04	155	0.28-1.5
634 Main St.	4/00-1/04	154	0.14-1.8
333 Burlington Ave.	4/00-1/04	155	0.42-1.5
27 Hillside Way	4/00-1/04	158	0.39-1.8
21 Jones Ave.	4/00-1/03	137	0.7-1.9
14 Fairmont Ave.	4/00-1/04	153	0.39-1.9
5 Rhode Island Rd.	4/00-1/04	155	0.52-1.7
91 Marion St.	1/03-1/04	14	0.17-0.66
25 Mill Rd.	1/03-1/04	14	0.36-0.83
21 Oxbow Dr.	1/03-1/04	14	0.79-1.2
West (Intermediate) School	4/00-1/04	156	0.49-1.5
47 Marion St. (Last Hydrant)	6/00-8/00	11	0.9-1.2

*mg/L = milligrams of nitrate-nitrogen per liter (parts per million)

Source of data: Wilmington Water Department, unpublished records, 2006.

Table D.5. Nitrite Measurements in Municipal Well Water and the Wilmington water distribution system from 1981 to 2006.

Sites	Period of Record	Nitrite (NO_2)	
		# Records	Range (mg/L)*
Butters Row WTP - Finish	5/81-12/05	160	0.001-0.028
Butters Row WTP - Raw	4/00-7/04	149	ND-1
Butters Row Well #1	6/84-10/02	25	0.001-0.02
Butters Row Well #2	6/84-12/02	133	0.001-0.36
Chestnut St. Well #1	7/75-2/03	6	0.002-0.04
Chestnut St. Well 1A/2	3/92-10/02	120	0.001-0.02
Town Park Well	7/75-2/03	120	0.001-0.05
Shawsheen Ave. Well	7/75-7/04	113	0.001-0.006
Sargent WTP - Finish	4/89-5/90	7	<0.002-<0.05
Hillside (Way) Tank	4/00-1/04	156	ND-0.46
Nassau Tank	4/00-1/06	155	ND-0.16
Deming Way	4/00-1/04	156	ND-0.37
900 Main St.	4/00-1/04	155	ND-0.093
634 Main St.	4/00-1/04	154	ND-0.052
333 Burlington Ave.	4/00-1/04	155	ND-0.7
27 Hillside Way	4/00-1/04	158	ND-1.3
21 Jones Ave.	4/00-1/03	138	ND-0.05
14 Fairmont Ave.	4/00-1/04	153	ND-0.054
5 Rhode Island Rd.	4/00-1/04	155	ND-0.16
91 Marion St.	1/03-1/04	14	ND-0.19
25 Mill Rd.	1/03-1/04	14	ND-<0.01
21 Oxbow Dr.	1/03-1/04	14	ND-0.02
West (Intermediate) School	4/00-1/04	156	ND-0.14
47 Marion St. (Last Hydrant)	6/00-8/00	11	0.007-1

*mg/L = milligrams of nitrite-nitrogen per liter (parts per million)

Source of data: Wilmington Water Department, unpublished records, 2006.

D.4 N-NITROSODIMETHYLAMINE

Based on our review of Olin Site reports, water quality data for the Wilmington water distribution system, and literature on NDMA chemistry, there appears to be two plausible sources of NDMA to the Wilmington water distribution system: ground water from the Maple Meadow Brook aquifer and in situ formation within the distribution system itself. The four wells that were contaminated with NDMA (i.e., Butters Row Wells 1 and 2, and Chestnut Street Wells 1 and 1A/2) were shut off before the water distribution was analyzed; thus, we do not know the NDMA concentrations in the water distribution system. However, based on the concentrations measured in these wells in February 2003 (Table D.6), it is reasonable to speculate that these concentrations reflect NDMA levels in influent water to the Butters Row treatment plant prior to the wells being turned off in the fall of 2002. Furthermore, due to its high solubility, low vapor pressure, low sorptivity, and low reactivity, it is unlikely that NDMA would be significantly removed by the treatment plant (Mitch et al., 2003). Based on some simple calculations our results suggest that <1% of the NDMA in the well water would have been treated (removed or transformed) by the Butters Row treatment plant (see Appendix E).

The second possible source of NDMA to the water distribution system is *in situ* formation. Studies by Choi et al. (2002) and Mitch and Sedlack (2002) indicate that NDMA can form in water distribution systems in the presence of free chlorine, ammonia, and dimethylamine (DMA) or some other form of organic nitrogen. It is known that chlorine is used as a disinfectant at the Butters Row WTP and that ammonia is present in the Butters Row finish water and water distribution system at levels in the range of 0.01 to 5 mg/L (Table D.3). However, because DMA is not listed as a priority drinking water pollutant, it has not been measured in the water treatment plant or in the water distribution system. Thus, there is no knowledge of its presence or absence in the system. Similarly, there is little information on DMA (which is present in human waste) as being a contaminant on the Olin site or in the Maple Meadow Brook (MMB) aquifer. In a study by Sovocool and Grange (2004) water samples from the MMB aquifer were analyzed by combined gas chromatography (GC), high-resolution mass spectrometry for the presence of a wide variety of organic compounds (including nitrogen-containing compounds) reportedly released on the Olin site. Compounds such as azodicarbonamide (Kempore), hydradicarbonamide (intermediate of Kempore), 4,4-oxybisbenzenedisulfonylhydrazine (Nitropore OT), and other hydrazine derivatives were scanned for in the samples but none of these compounds was detected. Sovocool and Grange speculated that these compounds may have thermally decomposed in the GC inlet and column. Thus, while it is clear that organic NDMA-precursors are abundant on the Olin site, it is unknown whether these compounds were transported (along with NDMA) through the MMB aquifer to the supply wells and the Butters Row water treatment plant.

Because the supply wells were shut off in 2002 and 2003 following the discovery of NDMA contamination, there was little opportunity to extensively investigate NDMA in the distribution system. Only one round of samples – which included raw water from the five MMB aquifer supply wells and treated water from 13 sites in the distribution system – was analyzed for NDMA. The results, shown in Table D.6, indicate that NDMA was detected at levels between 30 and 170 ng/L in four of the five wells, but not in any of the water distribution system samples (limit of detection was 2 ng/L). That NDMA was found in the supply wells but not in the distribution system is attributable to the fact that the NDMA-contaminated source wells were not discharging to the treatment plant (and hence the distribution system) at the time of sample collection. When the samples were collected for NDMA analysis on February 25 and 26, 2003, four of the MMB aquifer wells had already been shut off for 2 to 4

Table D.6. N-nitrosodimethylamine measurements in municipal well water and the Wilmington water distribution system[1].

Sites	Period of Record	# Records	*N*-nitrosodimethylamine (NDMA) Range (ng/L)*
Butters Row WTP - Finish	2/25/03	2	<2
Butters Row WTP - Raw	2/25/03	4	<2
Butters Row Well #1	2/26/03	1	100
Butters Row Well #2	2/26/03	1	32
Chestnut St. Well #1	2/26/03	1	166
Chestnut St. Well #1A/2	2/26/03	1	38
Town Park Well	2/26/03	1	<2
Hillside Way Storage Tank	2/25/03	1	<2
Nassau Ave. Storage Tank	2/25/03	1	<2
Deming Way	2/25/03	1	<2
900 Main St.	2/25/03	1	<2
634 Main St.	2/25/03	1	<2
333 Burlington Ave.	2/25/03	1	<2
27 Hillside Way	2/25/03	1	<2
14 Fairmont Ave.	2/25/03	1	<2
5 Rhode Island Rd.	2/25/03	1	<2
91 Marion Street	2/25/03	1	<2
25 Mill Road	2/25/03	1	<2
21 Oxbow Drive	2/25/03	1	<2
West (Intermediate) School	2/25/03	1	<2

*ng/L = nanograms per liter (parts per trillion)

[1]Butters Row wells 1 and 2 and Chestnut St. wells 1 and 1A/2 were turned off on or before December 2002. During sampling on February 26, 2003, these wells were turned on again but the water was pumped to waste and not added to the distribution system. This likely accounts for why no NDMA was observed in the water distribution system in the February 26, 2003 samples.

Source of data: MACTEC (2003a)

months (the fifth well, Town Park, was shut off on February 28, 2003), and prior to collecting the raw well water samples, each well was pumped to waste for two days. Had the wells been online at the time of sample collection, it is likely that NDMA would have been detected in the water distribution system samples. These results also suggest that NDMA was not being formed in situ in the distribution system in measurable amounts.

Although the mechanism by which NDMA formed in the subsurface at the Olin site has not been demonstrated, based on the records of chemicals manufactured and released at the site (see Appendix A) it may be inferred that NDMA was formed by one or more reaction pathways. According to the literature summarized in Appendix B, NDMA can form by addition of an –N=O group onto DMA (nitrosation), transfer of an –N=O group from a nitrosamine to an amine (transnitrosation), and oxidation of DMA by either monochloramine or free chlorine in the presence of ammonia. Reactants involved in each of these pathways were manufactured, used as raw materials, or produced as wastes on the Olin site. Ammonia and nitrite were used to manufacture Opex (dinitrosopentamethylenetetramine), a nitrosamine; nitrite was also used to manufacture another nitrosamine, Wiltrol-N (N-nitrosodiphenylamine); and dimethylamine was present in sanitary wastes released from on-site septic systems. Thus, the historical record suggests that NDMA may have formed on the Olin site by more than one reaction pathway.

E. Estimation of *N*-nitrosodimethylamine removal during Water Treatment

NDMA removal by the Butters Row WTP was estimated based on results reported by Fronk-Leist and Love (1983) and physical/chemical property data from EPI Suite 4.1.

The Butters Row plant is designed to remove bacteria, trichloroethylene (TCE), carbon dioxide, iron, manganese, and color from water. Influent water is first passed through an aerator where it mixes with air (air:water volumetric ratio = 50:1) to remove trichloroethylene and carbon dioxide. Next, alum, lime, potassium permanganate, and chlorine gas are rapidly mixed. The water is then passed through a gentle mixer to promote flocculation, and a sedimentation tank where large particles settle by gravity. While in the sedimentation tank, the water is exposed for about 100 minutes to ambient sunlight, filtered through skylights. Next, water passes through granular activated carbon filters to promote removal of fine particles and residual TCE. The treated water is then stored in a clearwell and sent to the distribution system after receiving a final dose of chlorine.

Due to its physical and chemical properties, the main processes in the Butters Row that could impact NDMA levels are aeration, photolysis and sorption onto activated carbon.

Fronk-Leist and Love (1983) showed that the aeration system in the Butters Row plant removed 89-91% of the TCE from influent waters, while the activated carbon removed another 50% of the residual TCE following aeration. Thus, the overall treatment efficiency was for TCE was 92-98%.

The chemical and physical properties of TCE and NDMA are compared below.

	Trichloroethene	N-nitrosodimethylamine
Formula	C_2HCl_3	$C_2H_6N_2O$
Molecular Weight	131.4 g/mol	74.1 g/mol
Melting point	-84.7 °C	<25 °C
Boiling point	87.2 °C	154 °C
Water solubility	1,280 mg/L	1,000,000 mg/L
Log Kow	2.42	-0.57
Vapor pressure	69 mm Hg	2.7 mm Hg
Henry's law constant	0.00985 atm-m^3/mol	1.82E-6 atm-m^3/mol
Atmospheric degradation rate constant (rxn with OH radical)	2.4E-12 cm^3/molecule-sec	2.53E-12 cm^3/molecule-sec

Compared to TCE, NDMA is highly soluble, non-sorptive for activated carbon, and has a relatively low Henry's law constant (a measure of the extent to which chemicals will volatilize from water). The ratio of the Kow of NDMA to that of TCE is nearly 0.001, which means that NMDA is much less sorptive for activated carbon compared to TCE; the ratio of the Henry's law constant of NDMA to that of TCE is about 5,400, which means that NDMA is much less likely to volatilize from water compared to TCE.

Some studies suggest that aqueous NDMA will photodegrade in the presence of sunlight. In one experiment, it was found that about 50% of NDMA in wastewater was photodegraded from shallow sunlit basins following 1 day of exposure (Mitch et al., 2003). However, because the sedimentation tanks at the Butters Row plant are 13 feet deep (4 m), the hydraulic residence time is only 100 minutes, and sunlight is filtered through glass ceiling panels, it is unlikely these conditions would stimulate significant direct photodegradation of NDMA.

Thus, based on the reported TCE removal efficiency of the Butters Row WTP and the differences in the chemical and physical properties of NDMA and TCE, we conclude that very little of the NDMA in influent well water would have been removed by the treatment plant.

For example, if there is 100 ug/L of both TCE and NDMA in the influent water (Fronk-Leist and Love (1983) report that the average TCE concentration in influent water was 94 ug/L), and the aeration system removes 98% or 98 ug TCE per liter of water, we estimate that only 0.02 ug (1/5400) of the NDMA would be removed per liter of water. And if the activated carbon system removed another 50% of the remaining TCE, but activated carbon is 1000-fold less efficient at removing NDMA, we then estimate that only 0.05 ug of NDMA per liter of water would be removed by activated carbon. Taken together (0.02 + 0.05 ug/L), this represents <1% removal of NDMA by aeration and activated carbon.

Retardation Factor for NDMA

Estimates of the retardation factor for NDMA in ground water range from 1 to 1.2; thus, sorption to aquifer solids is not expected to significantly impact NDMA transport in the subsurface.

The retardation factor, R, was calculated using the following equations:

$$R = 1 + \frac{k_d \rho_b}{n}$$

Where:

n = water-filled porosity = 0.3 (assumed)
ρ_b = bulk density = solid density x (1-n)
solid density = 2.65 (assumed)
k_d = solid-water partition coefficient = Koc x foc
Koc = organic carbon – water partition coefficient
foc = fraction of organic carbon in the soil = 0.01 (assumed)

Several estimates of Koc were used (from Hemond and Fechner-Levy, 2015):

logKoc = 0.937(logKow) – 0.006
logKoc = 0.94(logKow) + 0.02
logKoc = 1.029(logKow) – 0.18
logKoc = 0.524(logKow) + 0.855

F. ESTIMATED HISTORICAL PUMPING RATES, 1965 – 2003

Time histories of monthly pumping rates for each water supply well were reconstructed and used as input datasets for the ground water and water distribution models developed for this study. The availability and quality of historical pumping records varied widely over the simulation period (1965 – 2003). From 1965 to 1981, only the total town-wide supply rate was available and thus had to be disaggregated among the individual wells. From 1981 through 1988, the total flow rate from the Butters Row Water Treatment Plant (WTP) was either reported or could be estimated from available data, and then divided amongst the supply wells in the MMB aquifer. From 1989 through 2003, reported monthly pumping rates were available for each well. The following sections describe the data sources and methodologies used to reconstruct these monthly pumping rate time histories. Section 3.2 of the main report also provides an overview of these methods.

F.1 ESTIMATED PUMPING RATES: JANUARY 1965 – MAY 1981

From January 1965 through May 1981, the monthly pumping rates were estimated based on reported town-wide supply rates and the ratios of each pump capacity to the total active well capacity in each month. The total town-wide supply rates were provided by the Wilmington Water and Sewer Department. For 1965 through 1968, only the annual town-wide supply rate was available. These annual supply rates were disaggregated to estimate monthly rates using the fraction of the annual supply pumping in each month during 1969 (i.e., the monthly distribution of supply rates from 1969 was applied to the annual supply rates from 1965 though 1968). Figure F.1 shows the monthly total town-wide supply rate in millions of gallons per day (MGD) from January 1965 through May 1981.

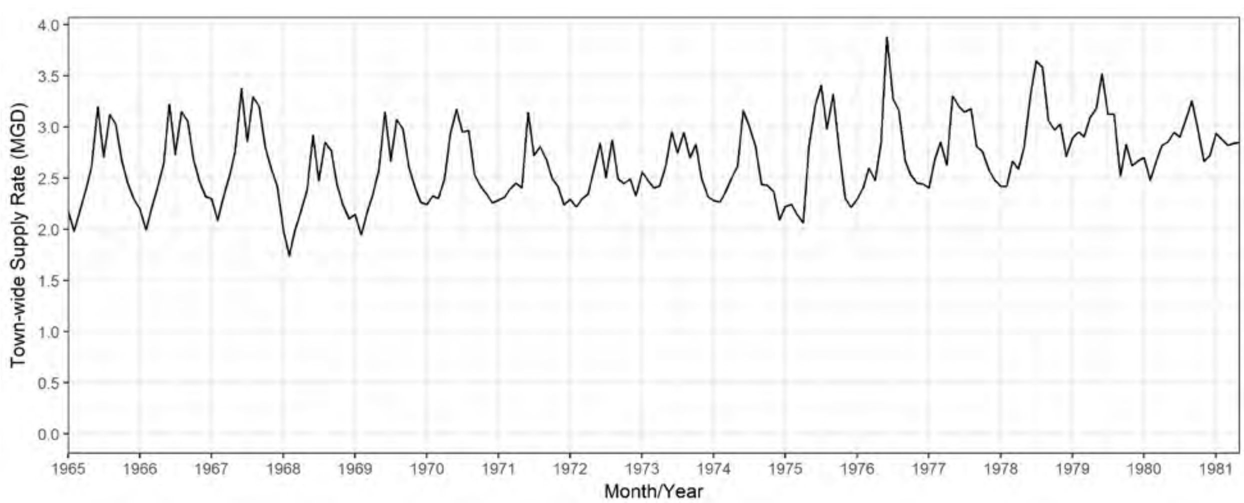

Figure F.1: Monthly town-wide supply rate, January 1965 – May 1981.

The month town-wide supply rates were apportioned to each well using the ratios of well capacity to the total active capacity of each well. Table F.1 lists the pump capacity of each well obtained from FST (1988) and SEA (2001).

Table F.1: Pump capacity of each water supply well.

Well Name	**Pump Capacity (MGD)**
MMB Aquifer Wells	
Butters Row #1	1.3
Butters Row #2	1
Chestnut Street #1	1
Chestnut Street #1A/2	0.75
Town Park	0.5
Other Wells	
Barrows	0.75
Brown’s Crossing	1.5
Salem Street	1
Aldrich Road	0.5
Shawsheen Ave.	0.75

Figure F.2 shows the fraction of total active pump capacity associated with each well from January 1965 through May 1981. Only the Shawsheen Ave and Town Park wells were active over this entire period. The other wells were either activated or deactivated at various points in time (see Sections 2.2.1 and 3.2 for more information). Figure F.3 shows the monthly fraction of the total pump capacity attributed to each well. The monthly pumping rate for each well was then estimated by multiplying the fraction of total capacity of each well from Figure F.3 by the total town-wide supply rates from Figure F.1. The resulting estimated monthly pumping rates are shown in Figure F.4. Note that Figure F.2 through Figure F.4 do not include the Butters Row #2 and Chestnut St. #1A/2 wells because they were both installed after May 1981.

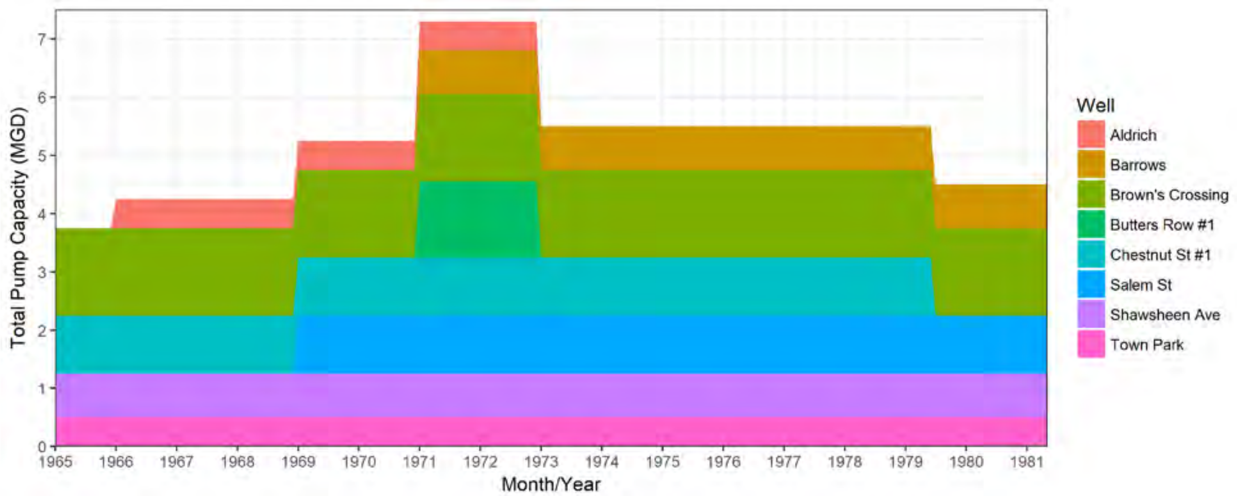

Figure F.2: Total monthly pump capacity contributed from each active well, January 1965 – May 1981.

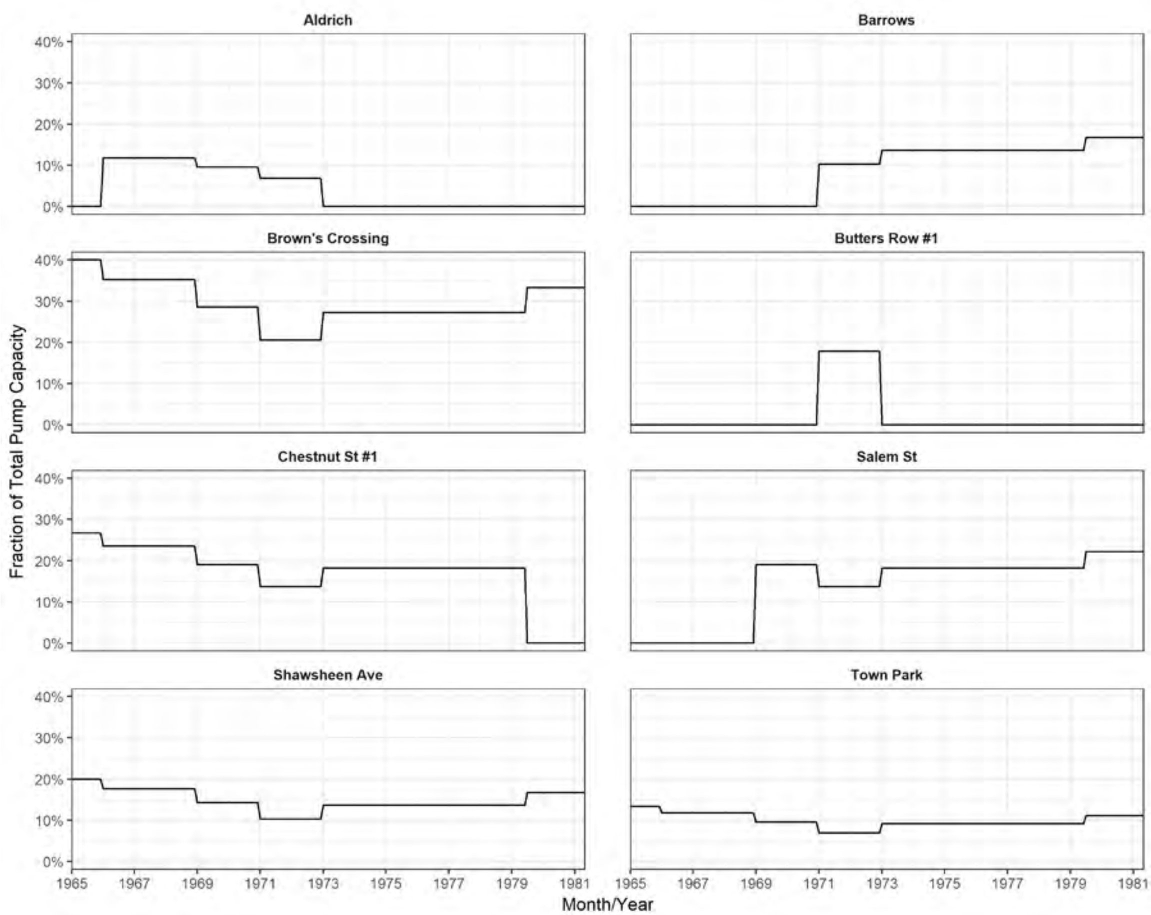

Figure F.3: Fraction of total pump capacity attributed to each well, January 1965 – May 1981.

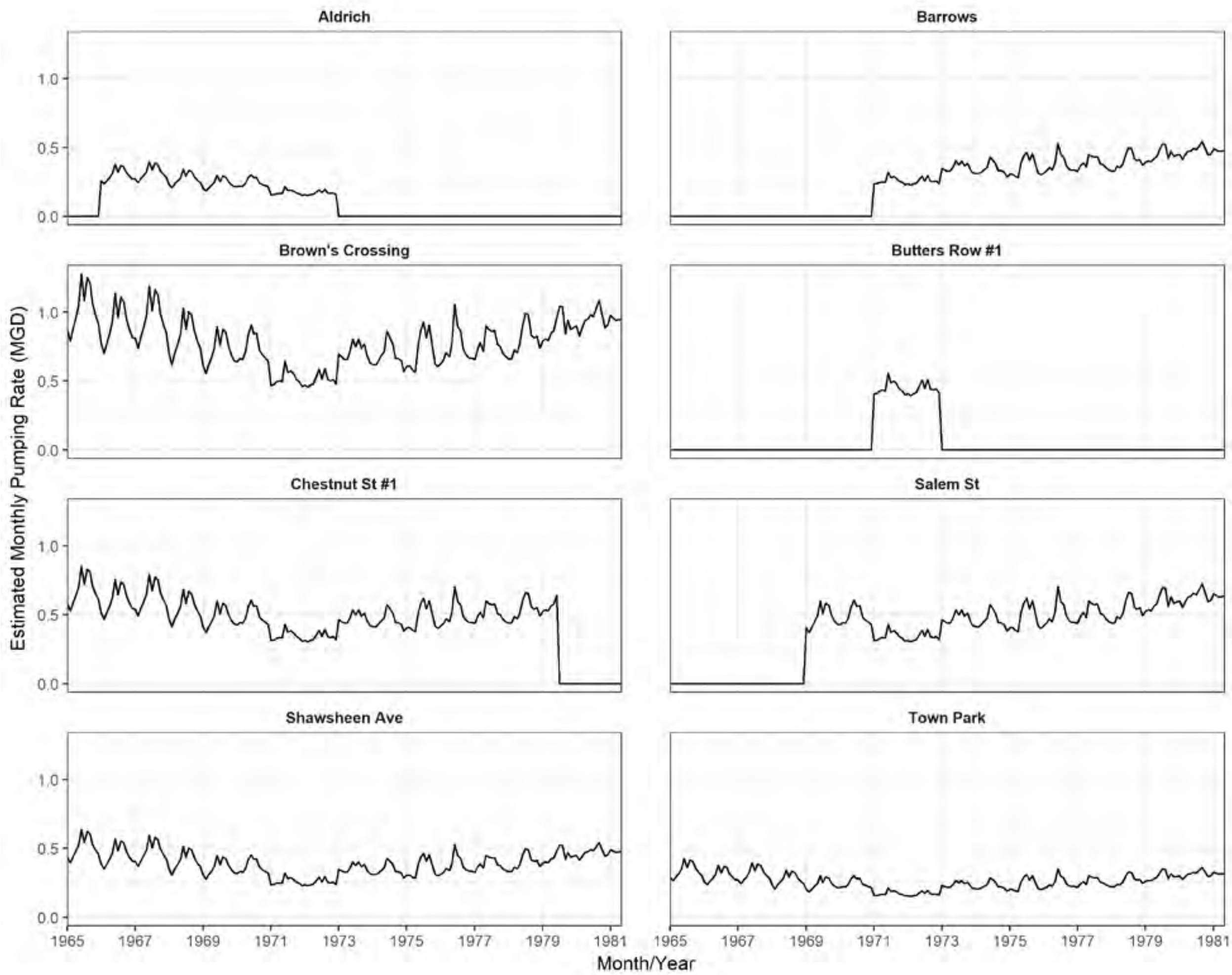

Figure F.4: Estimated monthly pumping rates for each well, January 1965 – May 1981.

F.2 Estimated MMBA Well Pumping Rates: June 1981 – December 1988

In June 1981, the Butters Row WTP began treating all water pumped from the four existing supply wells in the MMB aquifer (the fifth well, Chestnut St #1A/2, was not added until 1992). All other town wells pumped directly into the distribution system. Monthly pumping rates were estimated using a similar method as the previous period, but using additional historical records of total inflow to Butters Row WTP provided by the town Water and Sewer Department. From 1981 through 1983, only the fraction of annual town-wide supply treated at Butters Row WTP was available (39% in 1981, 39% in 1982, and 50% in 1983). For these three years, the total inflow to Butters Row WTP was therefore estimated by multiplying each of those fractions by the monthly town-wide supply rate. Given the total inflow to Butters Row WTP, the total flow from all other wells was computed by subtracting the Butters Row WTP inflow from the total town-wide supply rate.

Figure F.5 shows the total town-wide supply rate, total inflow to Butters Row WTP (sum of pumping from MMB aquifer wells), and total remaining flow associated with the other wells located outside the MMB aquifer.

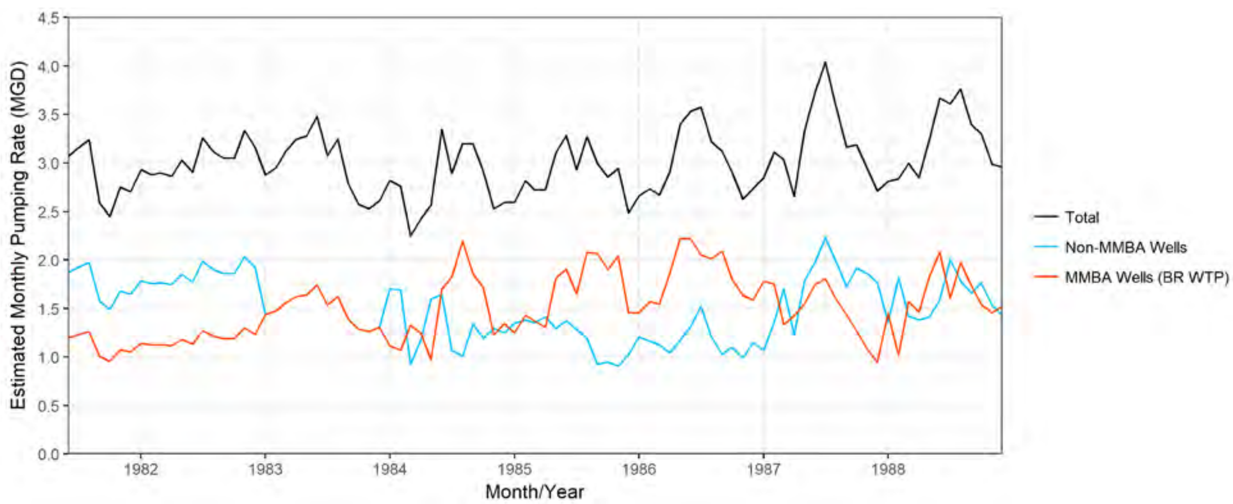

Figure F.5: Total monthly pumping rates from the MMBA wells, non-MMBA wells, and total town-wide supply rate, June 1981 – December 1988

Given the total inflow to Butters Row WTP, the pumping rates for each well in the MMB aquifer were then estimated using the average monthly fraction of total inflow from each well. The monthly fractions of total inflow were estimated by calculating the mean fraction for each month of the year based on meter data of the individual wells from 1989 through 1991 (see Section F.5). The average monthly distribution of inflow to Butters Row WTP from each well during this period was assumed to be representative of the distribution during the previous years (1981 – 1988). Meter data from 1992 or later were not used due to the addition of the Chestnut St. #1A/2 well, which affected the distribution of total inflow among the individual wells.

The monthly pumping rates from the MMB aquifer wells were then estimated by multiplying the average monthly percent of inflow from each well (Figure F.6) by the total inflow to Butters Row WTP (Figure F.5). Figure F.7 shows the estimated monthly pumping rates from each MMB aquifer well from June 1981 through December 1988. Note that these figures do not include the Chestnut St. #1A/2 well, which had not yet been installed.

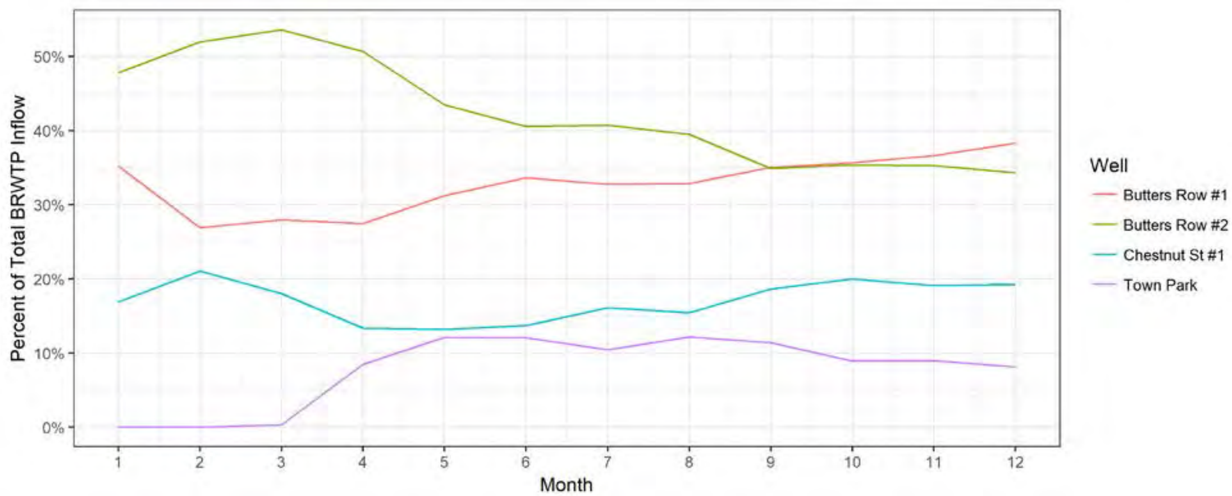

Figure F.6: Average fraction of total inflow to Butters Row WTP from each supply well by month

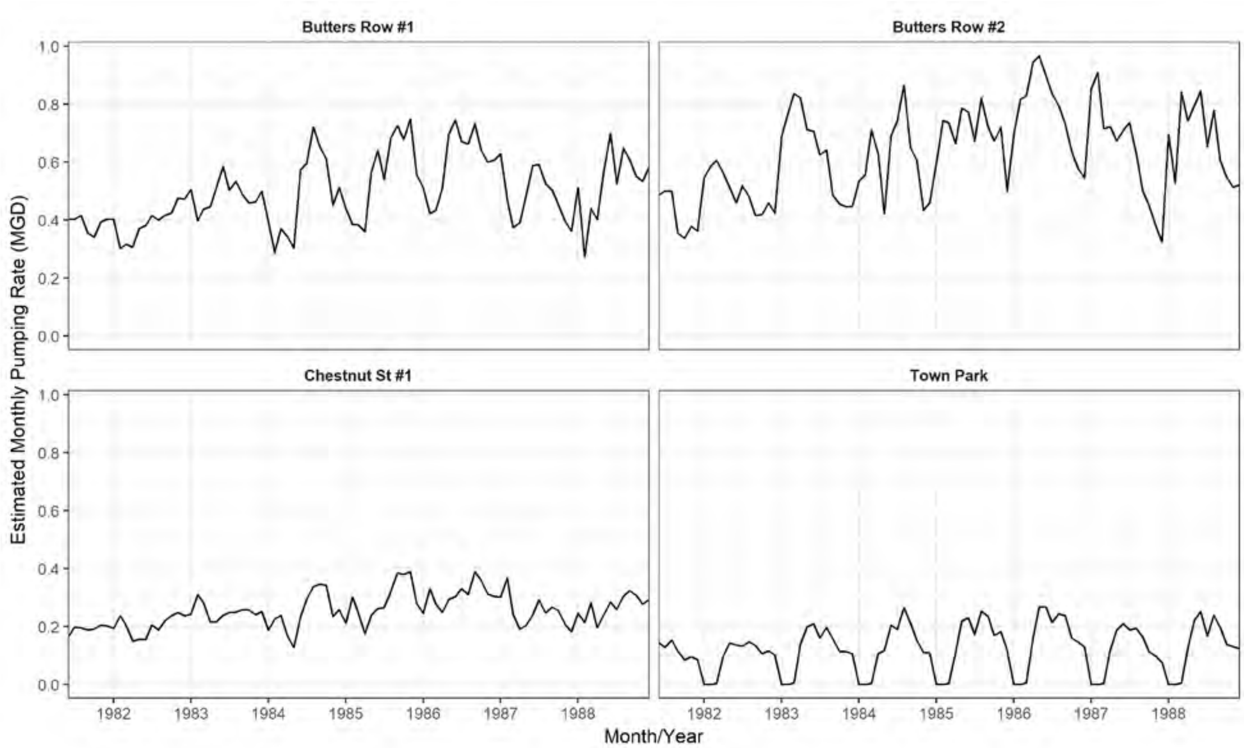

Figure F.7: Estimated monthly pumping rates for supply wells in the MMB aquifer, June 1981 – December 1988

F.3 Estimated Non-MMBA Well Pumping Rates: June 1981 – December 1983

The pumping rates for wells outside the MMB aquifer were estimated using pump capacity ratios from June 1981 through December 1983. During these three years, the active wells outside the MMB aquifer included Barrows, Brown's Crossing, Salem St., and Shawsheen Ave. (the Aldrich well had been closed in 1972). Table F.3 lists the capacity and fraction of total capacity for each of these wells.

Table F.2: Pump capacity and percent of total capacity for non-MMBA wells, 1981 – 1983

Well Name	**Pump Capacity (MGD)**	**% of Total Capacity**
Barrows	0.75	19%
Brown's Crossing	1.5	37%
Salem Street	1	25%
Shawsheen Ave.	0.75	19%
TOTAL	4	100%

The monthly pumping rate for each non-MMBA well was then estimated by multiplying the fraction of total capacity in Table F.3 by the total non-MMBA pumping rate shown in Figure F.5. The resulting estimated monthly pumping rates for the non-MMBA wells from June 1981 through December 1983 is shown in Figure F.8.

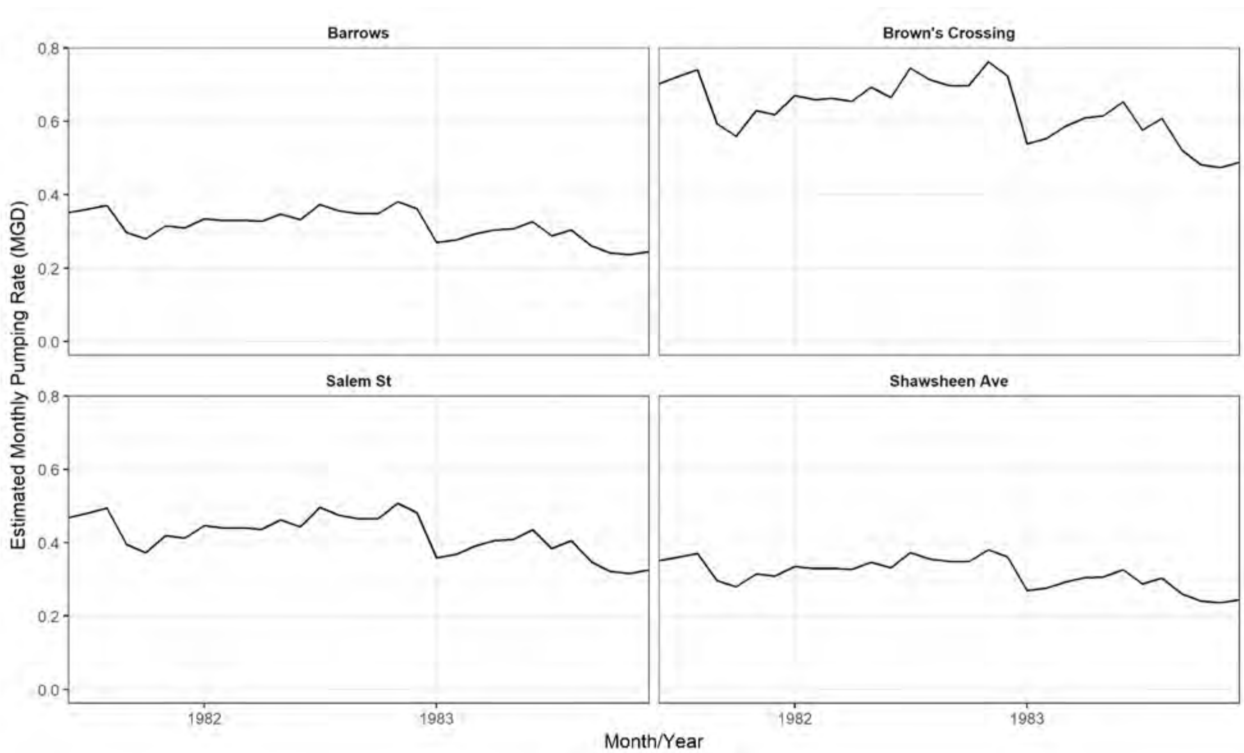

Figure F.8: Estimated monthly pumping rates for non-MMBA wells, June 1981 – December 1983

F.4 Metered Non-MMBA Well Pumping Rates: January 1984 – May 1989

From January 1984 through May 1989, monthly metered data for the non-MMBA wells was obtained from Water Supply Statistics reports by the Massachusetts Dept. of Environmental Quality Engineering, Division of Water Supply, and are shown in Figure F.9.

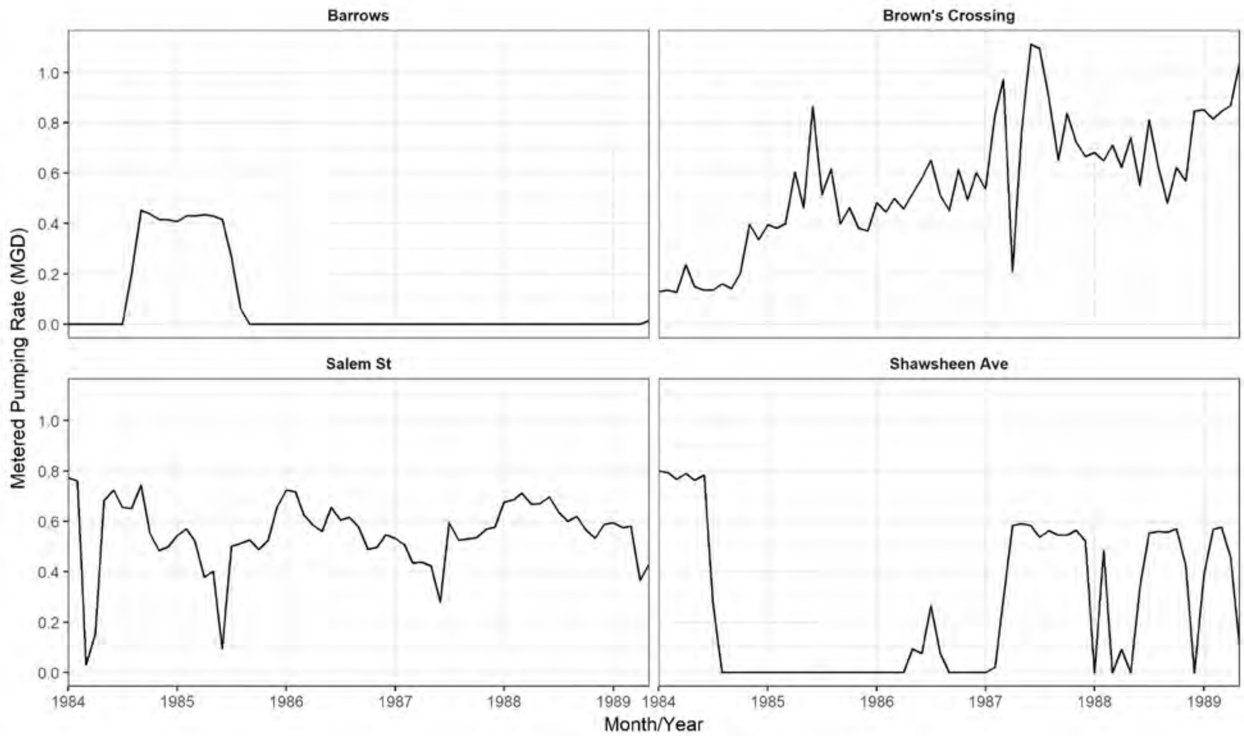

Figure F.9: Metered monthly pumping rates for non-MMBA wells, January 1984 – May 1989

F.5 Metered MMBA Well Pumping Rates: January 1989 – May 2003

From January 1989 through May 2003, metered pumping rates were available for all wells in the MMB aquifer and obtained from MACTEC (2005, Table 3-1). Figure F.10 shows the monthly metered pumping rate for each MMB aquifer well.

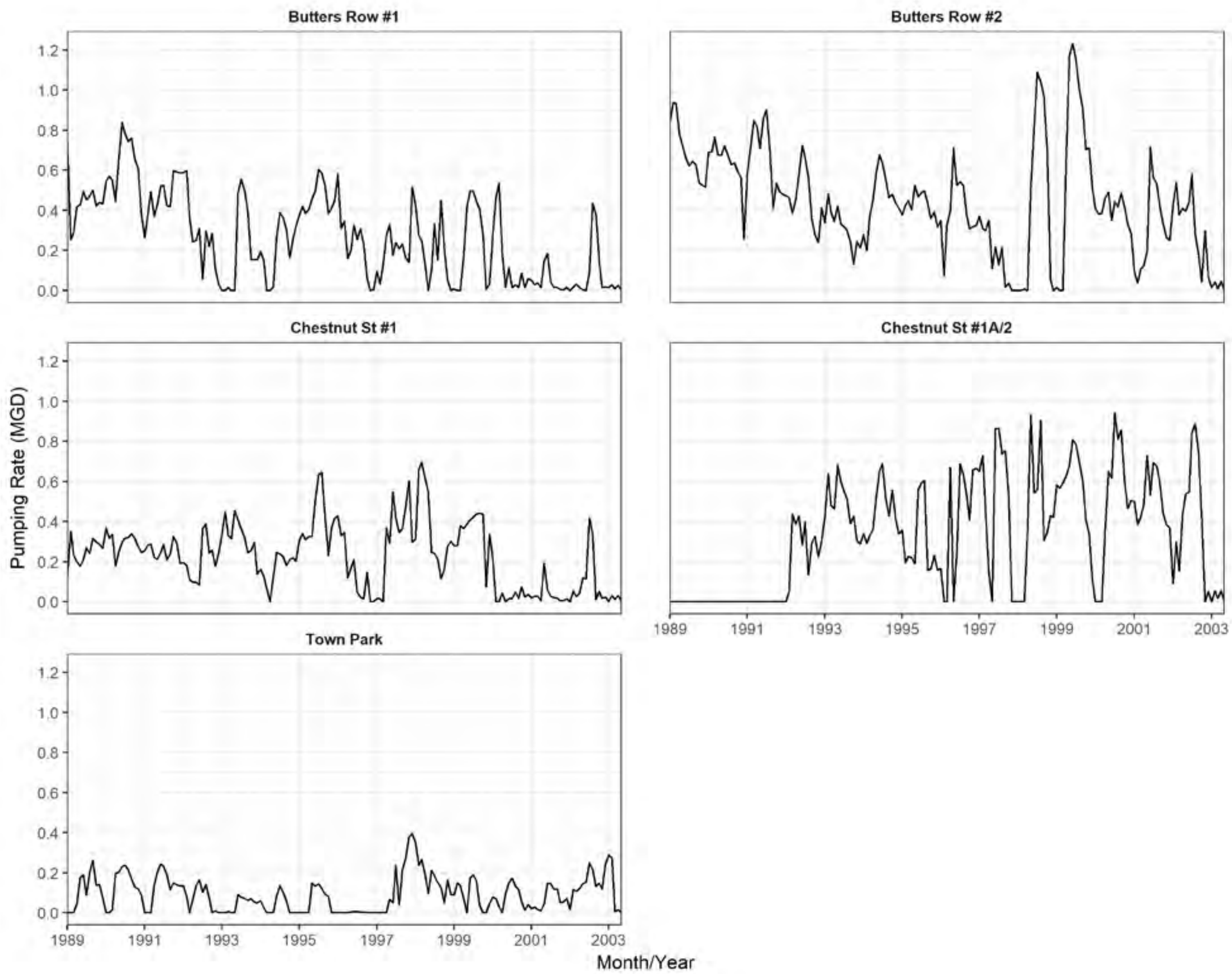

Figure F.10: Metered pumping rates of MMBA wells, January 1989 – May 2003

F.6 METERED FLOWS AT SARGENT WTP: JUNE 1989 – MAY 2003

The Sargent WTP was brought on line in June 1989. Total flow rates at this WTP were obtained from totalizer records provided by the town Water and Sewer Department. Flow rates from the individual wells were not needed because these wells were not used in the ground water model, and because all inflow from those wells was accounted for by the WTP discharge in the water distribution system model. Figure F.11 shows the metered flow rate for Sargent WTP from June 1989 through May 2003.

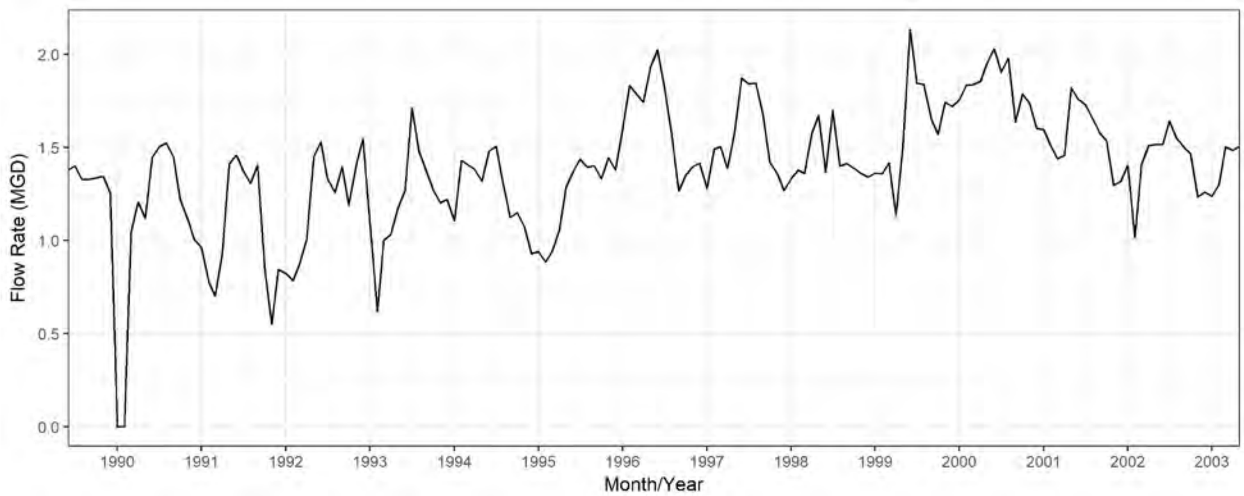

Figure F.11: Total monthly flow rate for Sargent WTP, June 1989 - May 2003

F.7 UNCERTAINTY EVALUATION OF ESTIMATED PUMPING RATES

As described in Sections 6.1.1 and 6.2 of the main report, the pumping rates from supply wells in the MMB aquifer represent a major source of uncertainty in the overall model results, especially during the earlier part of the simulation period. From 1965 to May 1981, historical records were only available for the total town-wide water supply rate. Data on the fraction of total supply obtained from the MMB aquifer was not available until June 1981 (see Section F.2), and pumping rates for the individual wells were not available until 1989 (see Section F.5). Based on the limited data during the earlier period, pumping rates for each well were estimated using the ratio of the pump capacity to the total capacity of all active wells within each month (see Section F.1). Although this method provides reasonable estimates of individual well pumping rates, there is significant uncertainty associated with these estimates because the town likely did not operate the wells in proportion to their capacities. Therefore, the following analysis was performed to estimate the most likely range of total pumping volumes obtained from the MMB aquifer in each month from 1965 to June 1981. That range in total MMBA pumping was then applied equally amongst the pumping rates for the individual MMBA wells.

Uncertainty in the fraction of total supply obtained from the MMBA wells was estimated by applying the pump capacity methodology that was used from the 1965 to May 1981 period to the later years (1989 – 2000) for which metered pumping rates were available. By comparing the estimated MMBA fractions to those computed from the metered data, we could determine the accuracy of the estimation method and quantify the average range of errors associated with that method. This analysis was performed at annual time steps instead of monthly time steps to exclude additional variability related to the seasonality of pump operations.

Figure F.12 shows the fraction of total annual supply obtained from MMBA wells based on 1) the actual metered data and 2) the estimates derived from pump capacities from 1989 through 2000. The estimated fractions had an overall mean of 57.0% and ranged from 54 to 58%; the metered fractions had a mean of 53.9% and ranged from 37 to 67%. The average estimated fraction was thus slightly higher than that of the metered fractions, but was considered relatively unbiased. However, the metered fractions had a larger range of variability, which is to be expected given that the changes in the estimated fractions only reflect changes in which wells were active over time (i.e., the estimated fractions only change due to the addition or removal of individual wells).

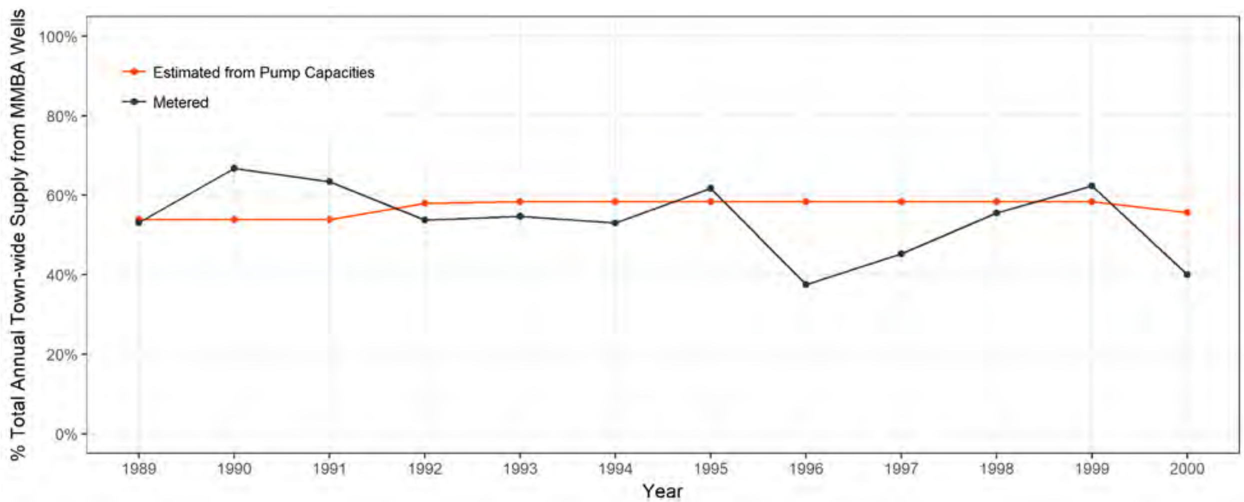

Figure F.12: Annual percent of total supply obtained from MMBA wells based on metered data and the estimates derived from active pump capacities.

Next, the error (also known as the residual) in each year was computed by subtracting the estimated fraction of total supply obtained from MMBA wells from the corresponding metered fraction. Figure F.13 shows the time series of annual error for the estimated fractions. The overall mean error was -3.0% and the standard deviation of the errors was 10.0%.

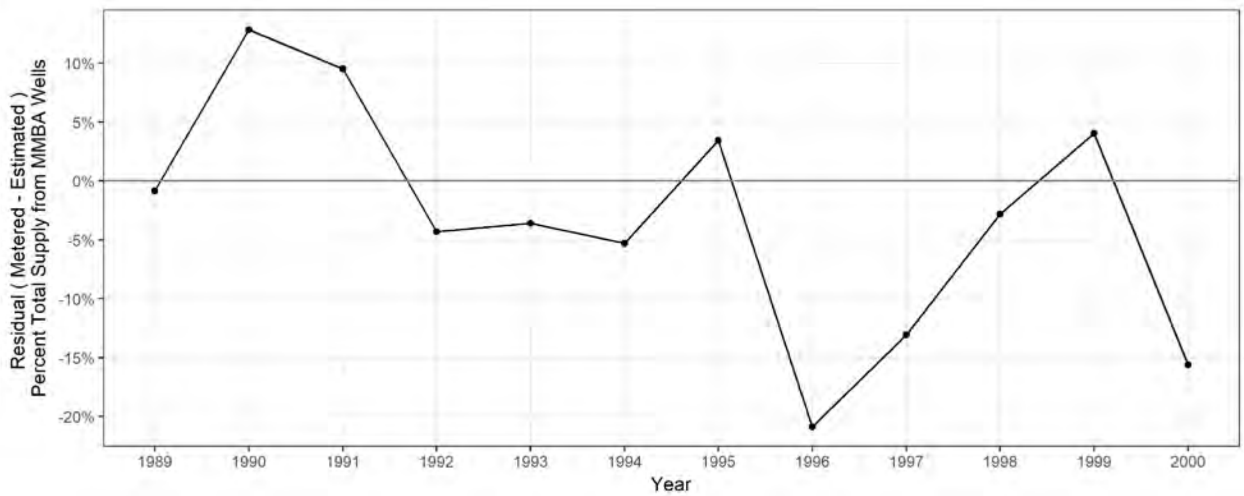

Figure F.13: Annual residuals for the estimated fractions of total supply obtained from MMBA wells

Finally, the standard deviation of the individual errors (10.0%) was divided by the overall mean of the annual metered fractions (53.9%) yielding a relative standard deviation of error equal to 18.5%. The relative standard deviation represents the standard deviation of the error in the estimated fraction of total supply from MMBA wells *relative* to the average of the metered fractions. For the purposes of the uncertainty analysis, this value was rounded up to 20% and considered representative of the relative range in error of the estimated fractions of total supply obtained from MMBA wells during the earlier years (1965 – 1981) for which metered data were not available. The confidence range of monthly pumping rates for the MMBA wells from 1965 through May 1981 were thus computed by multiplying the originally estimated pumping rates by 120% and 80% in each month, which is equivalent to increasing and decreasing the estimated pumping rates by 20%. The final range of estimated pumping rates for the MMBA wells are provided in Section 6.2 of the main report.

F.8 TABULATION OF ESTIMATED PUMPING RATES: JANUARY 1965 – MAY 2003

Table F.3 provides a tabulation the estimated monthly pumping rates for each water supply well and the outflow rate of the Sargent Water Treatment Plant (WTP) from January 1974 through May 2003. From June 1989 through December 2000, pumping rates for the Brown's Crossing, Salem St., and Barrows wells were not estimated because they were included in the Sargent WTP outflow rate; therefore, pumping rates are not shown for these three wells beginning in June 1989. See Section 3.2 for figures of this dataset.

Table F.3: Estimated monthly pumping rates for each water supply well and outflow rate for Sargent WTP, 1965 – 2003

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Jan-1965	0	0	404	0	202	303	0	0	605	0	-
Feb-1965	0	0	366	0	183	275	0	0	550	0	-
Mar-1965	0	0	404	0	202	303	0	0	607	0	-
Apr-1965	0	0	441	0	221	331	0	0	662	0	-
May-1965	0	0	484	0	242	363	0	0	727	0	-
Jun-1965	0	0	592	0	296	444	0	0	889	0	-
Jul-1965	0	0	502	0	251	376	0	0	753	0	-
Aug-1965	0	0	579	0	289	434	0	0	868	0	-
Sep-1965	0	0	561	0	281	421	0	0	842	0	-
Oct-1965	0	0	493	0	246	370	0	0	739	0	-
Nov-1965	0	0	454	0	227	340	0	0	681	0	-
Dec-1965	0	0	426	0	213	320	0	0	639	0	-
Jan-1966	0	0	359	0	180	269	180	0	539	0	-
Feb-1966	0	0	326	0	163	245	163	0	489	0	-
Mar-1966	0	0	360	0	180	270	180	0	540	0	-
Apr-1966	0	0	392	0	196	294	196	0	589	0	-
May-1966	0	0	431	0	216	323	216	0	647	0	-
Jun-1966	0	0	527	0	264	395	264	0	791	0	-
Jul-1966	0	0	447	0	223	335	223	0	670	0	-
Aug-1966	0	0	515	0	257	386	257	0	772	0	-
Sep-1966	0	0	500	0	250	375	250	0	749	0	-
Oct-1966	0	0	439	0	219	329	219	0	658	0	-
Nov-1966	0	0	404	0	202	303	202	0	606	0	-
Dec-1966	0	0	379	0	190	284	190	0	569	0	-
Jan-1967	0	0	376	0	188	282	188	0	564	0	-
Feb-1967	0	0	341	0	171	256	171	0	512	0	-
Mar-1967	0	0	377	0	188	283	188	0	565	0	-
Apr-1967	0	0	411	0	205	308	205	0	616	0	-
May-1967	0	0	451	0	226	339	226	0	677	0	-
Jun-1967	0	0	552	0	276	414	276	0	828	0	-
Jul-1967	0	0	468	0	234	351	234	0	702	0	-
Aug-1967	0	0	539	0	270	404	270	0	809	0	-
Sep-1967	0	0	523	0	262	392	262	0	785	0	-
Oct-1967	0	0	459	0	230	344	230	0	689	0	-
Nov-1967	0	0	423	0	211	317	211	0	634	0	-
Dec-1967	0	0	397	0	198	298	198	0	595	0	-
Jan-1968	0	0	325	0	163	244	163	0	488	0	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Feb-1968	0	0	285	0	143	214	143	0	428	0	-
Mar-1968	0	0	326	0	163	244	163	0	489	0	-
Apr-1968	0	0	355	0	178	267	178	0	533	0	-
May-1968	0	0	390	0	195	293	195	0	586	0	-
Jun-1968	0	0	477	0	239	358	239	0	716	0	-
Jul-1968	0	0	405	0	202	303	202	0	607	0	-
Aug-1968	0	0	466	0	233	350	233	0	699	0	-
Sep-1968	0	0	452	0	226	339	226	0	679	0	-
Oct-1968	0	0	397	0	199	298	199	0	596	0	-
Nov-1968	0	0	366	0	183	274	183	0	549	0	-
Dec-1968	0	0	343	0	172	257	172	0	515	0	-
Jan-1969	0	0	284	0	142	213	142	0	426	284	-
Feb-1969	0	0	258	0	129	193	129	0	386	258	-
Mar-1969	0	0	284	0	142	213	142	0	426	284	-
Apr-1969	0	0	310	0	155	233	155	0	465	310	-
May-1969	0	0	341	0	170	255	170	0	511	341	-
Jun-1969	0	0	416	0	208	312	208	0	625	416	-
Jul-1969	0	0	353	0	176	265	176	0	529	353	-
Aug-1969	0	0	407	0	203	305	203	0	610	407	-
Sep-1969	0	0	395	0	197	296	197	0	592	395	-
Oct-1969	0	0	347	0	173	260	173	0	520	347	-
Nov-1969	0	0	319	0	160	239	160	0	479	319	-
Dec-1969	0	0	299	0	150	225	150	0	449	299	-
Jan-1970	0	0	297	0	148	223	148	0	445	297	-
Feb-1970	0	0	308	0	154	231	154	0	463	308	-
Mar-1970	0	0	304	0	152	228	152	0	457	304	-
Apr-1970	0	0	330	0	165	247	165	0	495	330	-
May-1970	0	0	388	0	194	291	194	0	582	388	-
Jun-1970	0	0	420	0	210	315	210	0	630	420	-
Jul-1970	0	0	390	0	195	293	195	0	586	390	-
Aug-1970	0	0	393	0	196	295	196	0	589	393	-
Sep-1970	0	0	336	0	168	252	168	0	504	336	-
Oct-1970	0	0	321	0	161	241	161	0	482	321	-
Nov-1970	0	0	310	0	155	233	155	0	465	310	-
Dec-1970	0	0	299	0	150	224	150	0	449	299	-
Jan-1971	282	0	217	0	109	163	109	163	326	217	-
Feb-1971	286	0	220	0	110	165	110	165	330	220	-
Mar-1971	297	0	228	0	114	171	114	171	342	228	-
Apr-1971	303	0	233	0	117	175	117	175	350	233	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
May-1971	298	0	229	0	115	172	115	172	344	229	-
Jun-1971	389	0	299	0	149	224	149	224	448	299	-
Jul-1971	337	0	259	0	130	194	130	194	389	259	-
Aug-1971	348	0	267	0	134	201	134	201	401	267	-
Sep-1971	332	0	255	0	128	191	128	191	383	255	-
Oct-1971	309	0	237	0	119	178	119	178	356	237	-
Nov-1971	299	0	230	0	115	172	115	172	345	230	-
Dec-1971	277	0	213	0	107	160	107	160	320	213	-
Jan-1972	284	0	218	0	109	164	109	164	327	218	-
Feb-1972	275	0	211	0	106	158	106	158	317	211	-
Mar-1972	284	0	218	0	109	164	109	164	328	218	-
Apr-1972	290	0	223	0	111	167	111	167	334	223	-
May-1972	319	0	245	0	123	184	123	184	368	245	-
Jun-1972	351	0	270	0	135	203	135	203	405	270	-
Jul-1972	310	0	239	0	119	179	119	179	358	239	-
Aug-1972	355	0	273	0	137	205	137	205	410	273	-
Sep-1972	309	0	237	0	119	178	119	178	356	237	-
Oct-1972	303	0	233	0	116	175	116	175	349	233	-
Nov-1972	308	0	237	0	119	178	119	178	356	237	-
Dec-1972	288	0	222	0	111	166	111	166	333	222	-
Jan-1973	0	0	323	0	162	242	0	242	485	323	-
Feb-1973	0	0	312	0	156	234	0	234	468	312	-
Mar-1973	0	0	304	0	152	228	0	228	456	304	-
Apr-1973	0	0	306	0	153	229	0	229	459	306	-
May-1973	0	0	332	0	166	249	0	249	498	332	-
Jun-1973	0	0	373	0	187	280	0	280	560	373	-
Jul-1973	0	0	347	0	173	260	0	260	520	347	-
Aug-1973	0	0	372	0	186	279	0	279	559	372	-
Sep-1973	0	0	341	0	170	255	0	255	511	341	-
Oct-1973	0	0	357	0	179	268	0	268	536	357	-
Nov-1973	0	0	315	0	158	236	0	236	473	315	-
Dec-1973	0	0	293	0	146	220	0	220	439	293	-
Jan-1974	0	0	288	0	144	216	0	216	432	288	-
Feb-1974	0	0	287	0	143	215	0	215	430	287	-
Mar-1974	0	0	298	0	149	224	0	224	447	298	-
Apr-1974	0	0	316	0	158	237	0	237	474	316	-
May-1974	0	0	330	0	165	247	0	247	495	330	-
Jun-1974	0	0	399	0	199	299	0	299	598	399	-
Jul-1974	0	0	379	0	190	284	0	284	569	379	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Aug-1974	0	0	356	0	178	267	0	267	534	356	-
Sep-1974	0	0	308	0	154	231	0	231	462	308	-
Oct-1974	0	0	307	0	154	230	0	230	461	307	-
Nov-1974	0	0	299	0	150	225	0	225	449	299	-
Dec-1974	0	0	264	0	132	198	0	198	396	264	-
Jan-1975	0	0	281	0	140	211	0	211	421	281	-
Feb-1975	0	0	283	0	142	212	0	212	425	283	-
Mar-1975	0	0	271	0	135	203	0	203	406	271	-
Apr-1975	0	0	261	0	130	196	0	196	391	261	-
May-1975	0	0	356	0	178	267	0	267	534	356	-
Jun-1975	0	0	405	0	203	304	0	304	608	405	-
Jul-1975	0	0	430	0	215	323	0	323	645	430	-
Aug-1975	0	0	377	0	188	283	0	283	565	377	-
Sep-1975	0	0	420	0	210	315	0	315	629	420	-
Oct-1975	0	0	353	0	176	264	0	264	529	353	-
Nov-1975	0	0	291	0	145	218	0	218	436	291	-
Dec-1975	0	0	280	0	140	210	0	210	420	280	-
Jan-1976	0	0	290	0	145	218	0	218	435	290	-
Feb-1976	0	0	304	0	152	228	0	228	456	304	-
Mar-1976	0	0	328	0	164	246	0	246	492	328	-
Apr-1976	0	0	313	0	157	235	0	235	470	313	-
May-1976	0	0	360	0	180	270	0	270	540	360	-
Jun-1976	0	0	490	0	245	367	0	367	735	490	-
Jul-1976	0	0	414	0	207	310	0	310	621	414	-
Aug-1976	0	0	399	0	199	299	0	299	598	399	-
Sep-1976	0	0	337	0	169	253	0	253	506	337	-
Oct-1976	0	0	319	0	160	239	0	239	479	319	-
Nov-1976	0	0	309	0	155	232	0	232	464	309	-
Dec-1976	0	0	308	0	154	231	0	231	463	308	-
Jan-1977	0	0	304	0	152	228	0	228	456	304	-
Feb-1977	0	0	340	0	170	255	0	255	511	340	-
Mar-1977	0	0	360	0	180	270	0	270	540	360	-
Apr-1977	0	0	332	0	166	249	0	249	498	332	-
May-1977	0	0	417	0	209	313	0	313	626	417	-
Jun-1977	0	0	405	0	202	303	0	303	607	405	-
Jul-1977	0	0	397	0	199	298	0	298	596	397	-
Aug-1977	0	0	402	0	201	301	0	301	602	402	-
Sep-1977	0	0	355	0	177	266	0	266	532	355	-
Oct-1977	0	0	348	0	174	261	0	261	523	348	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Nov-1977	0	0	326	0	163	245	0	245	489	326	-
Dec-1977	0	0	313	0	157	235	0	235	470	313	-
Jan-1978	0	0	305	0	153	229	0	229	458	305	-
Feb-1978	0	0	306	0	153	229	0	229	459	306	-
Mar-1978	0	0	337	0	168	253	0	253	505	337	-
Apr-1978	0	0	327	0	164	245	0	245	491	327	-
May-1978	0	0	355	0	177	266	0	266	532	355	-
Jun-1978	0	0	419	0	209	314	0	314	628	419	-
Jul-1978	0	0	461	0	230	346	0	346	691	461	-
Aug-1978	0	0	453	0	226	340	0	340	679	453	-
Sep-1978	0	0	387	0	193	290	0	290	580	387	-
Oct-1978	0	0	375	0	188	281	0	281	563	375	-
Nov-1978	0	0	383	0	191	287	0	287	574	383	-
Dec-1978	0	0	342	0	171	257	0	257	514	342	-
Jan-1979	0	0	366	0	183	274	0	274	548	366	-
Feb-1979	0	0	373	0	186	280	0	280	559	373	-
Mar-1979	0	0	367	0	183	275	0	275	550	367	-
Apr-1979	0	0	391	0	195	293	0	293	586	391	-
May-1979	0	0	402	0	201	301	0	301	602	402	-
Jun-1979	0	0	445	0	222	333	0	333	667	445	-
Jul-1979	0	0	0	0	241	362	0	362	724	483	-
Aug-1979	0	0	0	0	241	362	0	362	724	483	-
Sep-1979	0	0	0	0	195	292	0	292	584	389	-
Oct-1979	0	0	0	0	218	328	0	328	655	437	-
Nov-1979	0	0	0	0	202	304	0	304	607	405	-
Dec-1979	0	0	0	0	206	309	0	309	618	412	-
Jan-1980	0	0	0	0	208	313	0	313	625	417	-
Feb-1980	0	0	0	0	191	287	0	287	574	382	-
Mar-1980	0	0	0	0	206	308	0	308	617	411	-
Apr-1980	0	0	0	0	218	327	0	327	653	435	-
May-1980	0	0	0	0	220	331	0	331	661	441	-
Jun-1980	0	0	0	0	228	341	0	341	683	455	-
Jul-1980	0	0	0	0	224	336	0	336	672	448	-
Aug-1980	0	0	0	0	238	357	0	357	714	476	-
Sep-1980	0	0	0	0	251	377	0	377	754	503	-
Oct-1980	0	0	0	0	229	343	0	343	686	457	-
Nov-1980	0	0	0	0	206	309	0	309	618	412	-
Dec-1980	0	0	0	0	210	315	0	315	630	420	-
Jan-1981	0	0	0	0	227	340	0	340	680	454	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Feb-1981	0	0	0	0	222	333	0	333	666	444	-
Mar-1981	0	0	0	0	218	327	0	327	654	436	-
Apr-1981	0	0	0	0	219	329	0	329	658	439	-
May-1981	0	0	0	0	220	330	0	330	659	440	-
Jun-1981	280	337	114	0	100	244	0	244	488	325	-
Jul-1981	279	348	138	0	89	250	0	250	501	334	-
Aug-1981	289	347	135	0	107	257	0	257	515	343	-
Sep-1981	246	245	131	0	80	206	0	206	412	275	-
Oct-1981	236	235	132	0	59	194	0	194	389	259	-
Nov-1981	273	263	142	0	67	219	0	219	437	291	-
Dec-1981	280	251	141	0	59	215	0	215	429	286	-
Jan-1982	280	379	134	0	0	233	0	233	465	310	-
Feb-1982	210	406	164	0	0	229	0	229	458	305	-
Mar-1982	220	421	141	0	3	230	0	230	460	307	-
Apr-1982	213	393	104	0	66	227	0	227	455	303	-
May-1982	256	357	108	0	99	241	0	241	482	321	-
Jun-1982	265	319	108	0	95	231	0	231	462	308	-
Jul-1982	289	359	142	0	92	259	0	259	518	345	-
Aug-1982	278	334	130	0	103	248	0	248	495	330	-
Sep-1982	290	288	154	0	94	242	0	242	484	323	-
Oct-1982	294	292	165	0	74	242	0	242	484	322	-
Nov-1982	331	319	172	0	81	265	0	265	530	353	-
Dec-1982	328	294	165	0	69	251	0	251	502	335	-
Jan-1983	352	478	169	0	0	187	0	187	375	250	-
Feb-1983	276	533	216	0	0	192	0	192	384	256	-
Mar-1983	304	581	195	0	4	203	0	203	406	271	-
Apr-1983	310	571	151	0	96	211	0	211	423	282	-
May-1983	355	495	150	0	138	213	0	213	427	284	-
Jun-1983	407	491	166	0	146	227	0	227	453	302	-
Jul-1983	350	435	172	0	111	200	0	200	400	267	-
Aug-1983	370	445	174	0	137	211	0	211	422	282	-
Sep-1983	339	338	180	0	110	181	0	181	363	242	-
Oct-1983	319	316	179	0	80	168	0	168	335	223	-
Nov-1983	322	310	168	0	79	165	0	165	329	220	-
Dec-1983	347	311	174	0	73	170	0	170	340	227	-
Jan-1984	273	371	131	0	0	556	0	0	91	537	-
Feb-1984	200	386	156	0	0	552	0	0	94	529	-
Mar-1984	258	493	166	0	3	532	0	0	88	21	-
Apr-1984	237	438	115	0	73	548	0	0	164	107	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
May-1984	210	293	89	0	82	531	0	0	103	474	-
Jun-1984	398	480	162	0	143	544	0	0	94	503	-
Jul-1984	415	516	204	0	132	193	0	0	94	456	-
Aug-1984	500	602	235	0	185	0	0	138	111	453	-
Sep-1984	452	451	240	0	147	0	0	314	98	517	-
Oct-1984	425	421	238	0	106	0	0	304	141	385	-
Nov-1984	313	301	163	0	77	0	0	289	276	336	-
Dec-1984	357	320	179	0	76	0	0	288	233	347	-
Jan-1985	306	415	147	0	0	0	0	284	274	378	-
Feb-1985	268	517	209	0	0	0	0	299	265	396	-
Mar-1985	267	510	172	0	3	0	0	299	277	363	-
Apr-1985	249	460	121	0	77	0	0	302	419	263	-
May-1985	392	547	166	0	152	0	0	299	321	279	-
Jun-1985	445	537	181	0	160	0	0	289	600	67	-
Jul-1985	375	466	185	0	119	0	0	186	358	348	-
Aug-1985	475	571	223	0	176	0	0	43	429	356	-
Sep-1985	504	502	268	0	164	0	0	0	277	366	-
Oct-1985	471	468	264	0	118	0	0	0	321	339	-
Nov-1985	519	500	271	0	127	0	0	0	265	363	-
Dec-1985	387	347	195	0	82	0	0	0	257	457	-
Jan-1986	356	483	171	0	0	0	0	0	336	503	-
Feb-1986	294	568	230	0	0	0	0	0	310	498	-
Mar-1986	301	575	194	0	4	0	0	0	346	436	-
Apr-1986	355	655	173	0	110	0	0	0	318	406	-
May-1986	482	672	204	0	187	65	0	0	361	389	-
Jun-1986	518	625	211	0	186	53	0	0	404	456	-
Jul-1986	467	581	230	0	149	185	0	0	453	420	-
Aug-1986	460	553	216	0	170	54	0	0	356	429	-
Sep-1986	509	507	271	0	165	0	0	0	313	401	-
Oct-1986	446	442	249	0	111	0	0	0	427	340	-
Nov-1986	416	401	217	0	102	0	0	0	343	346	-
Dec-1986	422	378	212	0	89	0	0	0	418	380	-
Jan-1987	437	592	209	0	0	0	0	0	373	370	-
Feb-1987	327	632	256	0	0	15	0	0	579	352	-
Mar-1987	260	497	167	0	3	203	0	0	675	302	-
Apr-1987	272	502	132	0	84	406	0	0	146	304	-
May-1987	336	468	142	0	130	411	0	0	536	293	-
Jun-1987	408	493	166	0	146	406	0	0	773	194	-
Jul-1987	411	511	203	0	131	373	0	0	761	413	-

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Aug-1987	365	439	171	0	135	391	0	0	626	365	-
Sep-1987	350	348	186	0	113	379	0	0	452	368	-
Oct-1987	315	312	176	0	79	379	0	0	581	372	-
Nov-1987	275	265	143	0	67	393	0	0	502	395	-
Dec-1987	252	226	127	0	53	362	0	0	463	401	-
Jan-1988	356	483	171	0	0	0	0	0	473	470	-
Feb-1988	190	367	148	0	0	337	0	0	451	477	-
Mar-1988	306	585	197	0	4	0	0	0	494	494	-
Apr-1988	280	516	136	0	86	63	0	0	434	464	-
May-1988	397	552	167	0	154	0	0	0	514	467	-
Jun-1988	486	586	198	0	174	235	0	0	383	484	-
Jul-1988	365	454	180	0	116	384	0	0	564	443	-
Aug-1988	450	542	211	0	167	389	0	0	435	417	-
Sep-1988	423	421	225	0	137	387	0	0	334	431	-
Oct-1988	382	379	214	0	95	397	0	0	432	393	-
Nov-1988	371	357	193	0	91	297	0	0	395	371	-
Dec-1988	405	363	204	0	86	0	0	0	588	408	-
Jan-1989	518	584	85	0	0	270	0	0	592	414	-
Feb-1989	177	652	243	0	0	395	0	0	566	399	-
Mar-1989	200	648	163	0	0	401	0	0	588	403	-
Apr-1989	290	541	140	0	32	317	0	0	603	254	-
May-1989	298	501	123	0	123	67	0	11	724	300	-
Jun-1989	343	458	147	0	132	0	0	-	-	-	958
Jul-1989	315	431	186	0	62	0	0	-	-	-	973
Aug-1989	328	448	167	0	138	0	0	-	-	-	922
Sep-1989	348	437	220	0	182	0	0	-	-	-	924
Oct-1989	293	373	206	0	96	0	0	-	-	-	928
Nov-1989	306	365	199	0	99	0	0	-	-	-	934
Dec-1989	300	359	185	0	51	0	0	-	-	-	873
Jan-1990	378	479	256	0	0	0	0	-	-	-	0
Feb-1990	396	481	219	0	0	0	0	-	-	-	0
Mar-1990	382	533	233	0	11	0	0	-	-	-	727
Apr-1990	308	469	122	0	136	0	0	-	-	-	839
May-1990	455	469	173	0	142	0	0	-	-	-	779
Jun-1990	583	501	207	0	160	0	0	-	-	-	1005
Jul-1990	546	469	220	0	166	0	0	-	-	-	1044
Aug-1990	515	435	222	0	150	0	0	-	-	-	1059
Sep-1990	530	443	236	0	117	0	0	-	-	-	1006
Oct-1990	456	411	220	0	90	0	0	-	-	-	848

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Nov-1990	423	391	191	0	83	0	0	-	-	-	774
Dec-1990	266	179	171	0	62	0	0	-	-	-	699
Jan-1991	184	402	177	0	0	0	0	-	-	-	669
Feb-1991	268	492	196	0	0	0	0	-	-	-	539
Mar-1991	342	588	199	0	0	0	0	-	-	-	487
Apr-1991	257	568	154	0	96	0	0	-	-	-	645
May-1991	297	493	147	0	142	0	0	-	-	-	981
Jun-1991	362	595	171	0	170	0	0	-	-	-	1014
Jul-1991	365	625	198	0	162	0	0	-	-	-	953
Aug-1991	295	485	145	0	133	0	0	-	-	-	908
Sep-1991	291	284	165	0	80	0	0	-	-	-	976
Oct-1991	416	372	226	0	105	0	0	-	-	-	592
Nov-1991	411	341	204	0	97	0	0	-	-	-	383
Dec-1991	407	334	133	0	93	0	0	-	-	-	586
Jan-1992	409	329	136	0	95	0	0	-	-	-	572
Feb-1992	416	322	126	35	58	0	0	-	-	-	545
Mar-1992	257	268	77	304	0	0	0	-	-	-	608
Apr-1992	169	316	67	270	46	0	0	-	-	-	700
May-1992	174	401	67	297	94	0	0	-	-	-	1007
Jun-1992	215	503	58	197	114	0	0	-	-	-	1062
Jul-1992	40	459	254	276	71	0	0	-	-	-	924
Aug-1992	206	391	269	92	98	0	0	-	-	-	874
Sep-1992	153	248	168	203	51	0	0	-	-	-	970
Oct-1992	197	194	178	226	0	0	0	-	-	-	827
Nov-1992	75	167	123	155	7	0	0	-	-	-	977
Dec-1992	21	288	169	211	0	0	0	-	-	-	1073
Jan-1993	0	235	233	292	0	0	0	-	-	-	759
Feb-1993	0	335	310	443	0	0	0	-	-	-	430
Mar-1993	9	272	231	335	4	0	0	-	-	-	695
Apr-1993	0	241	218	322	0	0	0	-	-	-	717
May-1993	0	293	317	474	0	0	0	-	-	-	815
Jun-1993	338	231	283	416	63	0	0	-	-	-	880
Jul-1993	386	222	252	385	55	0	0	-	-	-	1188
Aug-1993	346	208	223	356	50	0	0	-	-	-	1027
Sep-1993	274	169	169	271	43	0	0	-	-	-	956
Oct-1993	107	91	178	297	49	0	0	-	-	-	883
Nov-1993	107	169	205	212	37	0	0	-	-	-	834
Dec-1993	106	148	96	201	34	0	0	-	-	-	848
Jan-1994	133	193	112	236	42	0	0	-	-	-	769

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Feb-1994	104	138	87	202	17	0	0	-	-	-	993
Mar-1994	0	258	46	230	0	0	0	-	-	-	979
Apr-1994	0	312	0	249	0	0	0	-	-	-	959
May-1994	12	409	86	364	0	0	0	-	-	-	915
Jun-1994	186	471	171	453	59	0	0	-	-	-	1028
Jul-1994	271	442	165	478	95	0	0	-	-	-	1047
Aug-1994	252	384	156	358	70	0	0	-	-	-	906
Sep-1994	209	322	126	297	40	0	0	-	-	-	781
Oct-1994	113	333	146	386	0	0	0	-	-	-	799
Nov-1994	180	303	152	288	2	0	0	-	-	-	746
Dec-1994	222	286	139	235	0	0	0	-	-	-	646
Jan-1995	259	262	211	248	0	0	0	-	-	-	653
Feb-1995	292	296	236	136	0	0	0	-	-	-	614
Mar-1995	268	311	215	157	0	0	0	-	-	-	652
Apr-1995	281	279	225	153	0	0	0	-	-	-	733
May-1995	317	365	227	131	105	0	0	-	-	-	892
Jun-1995	344	325	349	387	93	0	0	-	-	-	952
Jul-1995	420	337	441	409	100	0	0	-	-	-	999
Aug-1995	407	346	449	420	85	0	0	-	-	-	968
Sep-1995	362	302	290	109	65	0	0	-	-	-	974
Oct-1995	266	249	160	114	58	0	0	-	-	-	926
Nov-1995	286	272	258	159	0	0	0	-	-	-	1005
Dec-1995	312	220	289	110	0	0	0	-	-	-	958
Jan-1996	405	242	298	116	0	0	0	-	-	-	1110
Feb-1996	215	51	230	0	0	0	0	-	-	-	1274
Mar-1996	240	228	239	0	0	0	0	-	-	-	1243
Apr-1996	111	275	83	466	0	0	0	-	-	-	1210
May-1996	140	494	118	0	3	0	0	-	-	-	1342
Jun-1996	228	365	146	168	5	0	0	-	-	-	1406
Jul-1996	176	377	33	477	3	0	0	-	-	-	1262
Aug-1996	213	363	16	442	3	0	0	-	-	-	1090
Sep-1996	161	260	10	367	2	0	0	-	-	-	879
Oct-1996	43	213	101	282	2	0	0	-	-	-	939
Nov-1996	0	220	0	456	0	0	0	-	-	-	970
Dec-1996	2	225	2	461	0	0	0	-	-	-	984
Jan-1997	67	258	10	452	0	0	0	-	-	-	888
Feb-1997	22	215	10	507	0	0	0	-	-	-	1035
Mar-1997	90	207	0	310	0	0	0	-	-	-	1045
Apr-1997	189	243	256	103	0	0	0	-	-	-	963

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
May-1997	229	75	203	0	47	0	0	-	-	-	1096
Jun-1997	122	150	381	600	34	0	0	-	-	-	1301
Jul-1997	166	90	292	602	164	0	0	-	-	-	1279
Aug-1997	145	149	240	511	27	0	0	-	-	-	1283
Sep-1997	161	11	253	523	149	0	0	-	-	-	1168
Oct-1997	113	25	328	369	188	0	0	-	-	-	986
Nov-1997	98	0	419	0	263	0	0	-	-	-	947
Dec-1997	359	0	206	0	275	0	0	-	-	-	882
Jan-1998	296	0	217	0	242	0	0	-	-	-	925
Feb-1998	189	0	458	0	164	0	0	-	-	-	958
Mar-1998	173	6	483	0	185	0	0	-	-	-	946
Apr-1998	92	0	429	239	134	0	0	-	-	-	1095
May-1998	0	354	380	649	68	0	0	-	-	-	1162
Jun-1998	72	566	171	377	147	0	0	-	-	-	950
Jul-1998	230	757	167	387	128	0	0	-	-	-	1181
Aug-1998	105	724	148	628	106	0	0	-	-	-	971
Sep-1998	311	673	80	213	88	0	0	-	-	-	983
Oct-1998	147	486	112	241	35	0	0	-	-	-	964
Nov-1998	36	36	193	299	114	0	0	-	-	-	945
Dec-1998	0	0	209	292	63	0	0	-	-	-	932
Jan-1999	5	10	194	404	61	0	0	-	-	-	947
Feb-1999	0	0	195	393	104	0	0	-	-	-	944
Mar-1999	0	0	263	410	95	0	0	-	-	-	984
Apr-1999	117	456	253	436	50	0	0	-	-	-	789
May-1999	291	814	269	471	0	0	0	-	-	-	1036
Jun-1999	344	856	283	561	120	0	0	-	-	-	1481
Jul-1999	344	797	292	545	131	0	0	-	-	-	1282
Aug-1999	310	698	303	485	112	0	0	-	-	-	1277
Sep-1999	282	632	307	422	28	0	0	-	-	-	1147
Oct-1999	193	488	303	287	0	0	0	-	-	-	1092
Nov-1999	4	494	52	234	0	0	0	-	-	-	1211
Dec-1999	22	363	234	87	32	0	0	-	-	-	1196
Jan-2000	193	285	148	0	56	0	0	-	-	-	1219
Feb-2000	324	264	0	0	49	0	0	-	-	-	1274
Mar-2000	372	267	0	0	22	0	0	-	-	-	1276
Apr-2000	131	322	30	252	0	0	0	-	-	-	1289
May-2000	11	340	0	452	67	0	0	-	-	-	1356
Jun-2000	80	243	10	427	105	0	0	-	-	-	1410
Jul-2000	10	308	10	654	120	18	0	-	-	-	1323

Month	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park	Shawsheen	Aldrich	Barrows	Brown's Crossing	Salem St.	Sargent WTP Outflow
Aug-2000	20	290	33	564	93	0	0	-	-	-	1375
Sep-2000	10	337	11	596	82	4	0	-	-	-	1137
Oct-2000	60	289	51	418	39	31	0	-	-	-	1242
Nov-2000	9	231	16	324	9	24	0	-	-	-	1206
Dec-2000	41	197	26	351	29	33	0	-	-	-	1113
Jan-2001	35	66	13	348	15	101	0	-	-	-	1108
Feb-2001	20	25	18	268	21	279	0	-	-	-	1048
Mar-2001	27	74	20	292	12	249	0	-	-	-	999
Apr-2001	9	86	3	337	7	263	0	-	-	-	1013
May-2001	101	135	132	507	31	344	0	-	-	-	1263
Jun-2001	128	498	40	369	103	356	0	-	-	-	1222
Jul-2001	29	391	18	481	102	385	0	-	-	-	1201
Aug-2001	10	371	14	472	81	359	0	-	-	-	1151
Sep-2001	9	292	12	413	83	293	0	-	-	-	1097
Oct-2001	4	230	3	306	36	238	0	-	-	-	1066
Nov-2001	3	184	3	267	38	191	0	-	-	-	901
Dec-2001	11	174	10	257	50	174	0	-	-	-	916
Jan-2002	0	296	0	63	12	291	0	-	-	-	974
Feb-2002	11	374	37	206	81	338	0	-	-	-	706
Mar-2002	22	262	17	106	74	220	0	-	-	-	978
Apr-2002	9	284	30	299	84	249	0	-	-	-	1050
May-2002	3	274	83	373	101	141	0	-	-	-	1053
Jun-2002	0	308	79	380	106	156	0	-	-	-	1054
Jul-2002	63	404	290	585	174	39	0	-	-	-	1139
Aug-2002	302	195	234	615	151	69	0	-	-	-	1078
Sep-2002	263	125	7	519	91	56	0	-	-	-	1044
Oct-2002	100	30	35	291	103	161	0	-	-	-	1018
Nov-2002	9	207	11	0	83	316	0	-	-	-	856
Dec-2002	13	47	16	36	169	369	0	-	-	-	876
Jan-2003	9	9	0	0	201	400	0	-	-	-	859
Feb-2003	19	29	21	37	188	461	0	-	-	-	903
Mar-2003	6	6	7	11	5	405	0	-	-	-	1044
Apr-2003	18	31	21	37	10	379	0	-	-	-	1030
May-2003	0	0	0	0	0	462	0	-	-	-	1048

G. Records of Water Pipe Construction, 1974 – 1989

Table G.1 lists the historical records of pipe construction from 1974 through 1989. These records were used to modify the pipe network as represented in the water distribution system model (see Section 4.3.1 for more details about this process). The records are based on the Wilmington annual reports from 1974 through 1989.

Table G.1: Records of water pipe construction, 1974 - 1989

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1974	none				Low	High?	?	
1975	Crescent Street (by builder)	277	8	Remove P-498 (300-feet, 8-inch diameter)	High	Low	New	Yes
1975	Presidential Drive (by builder)	750	8	Remove P-769 (900-ft, 8-inch diameter)	High	Low	New	Yes
1975	Roosevelt Road (by builder)	470	6	Remove P-765 (700-ft, 6-inch diameter)	High	Low	New	Yes
1975	Andover Street & Upton Court	10,000	12	Remove P-393 (1,400 ft, 12-inch), P-395 (800 ft, 12-inch), P-844 (1,400 ft, 12-inch), P-416 (1,300 ft, 12-inch), P-845 (1,300 ft, 12-inch), P-402 (2,600 ft, 12-inch) 8,800 feet total - checked against design plans. Connect Jonspin Road main to pre-existing main on Andover Street.	High	High	New	Yes
1975	Canal Street - between dead-ends - part of planned connection between Hillside Way and Nassau Ave. standpipes	750	12	Remove P-818 (900 ft, 12-inch)	Medium	High	New	Yes
1975	Lake Street	600	12	P-619 (700 ft, 12-inch) - This is the same as attributed to 1976. Work on this main between Lake St. and Grove Ave. is described as being underway in 1975 report.	High	High	New	OK
1975	Booster pump at Woburn Street and Industrial Way			Check operation of R-1 and PSV-1 that had been used to represent pump operation - remove check valve and reservoir.	Medium	High	New	
1976	Houghton Road (by developer)	1800	10	Remove P-731 (1900 feet, 10-inch)	High	Medium	New	Yes
1976	Muse Ave.	850	6	Replace P-50 (400 feet, 6-inch) and P-51 (300 feet, 6-inch) with 2-inch diameter pipe. Add junctions J864 and J788 to separate end of Muse from cross-streets.	High	Low	Replacement	Yes
1976	Lake Street	650	12	Remove P-619 (700 feet, 12-inch). Track crossing shown as proposed in 1973 report	High	Low	New	Yes
1977	12-inch "reinforcing" main between storage tanks	?	?	Description is ambiguous. It sounds like it was installed in 1977, however the listed pipes from 1978 indicate that the work occurred then. This is a 12" main starting on Chestnut Street at Butters Row and extending to Canal St. near Nassau Ave. standpipe.	High	High	New	OK

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1978	Salem Street	4,800	12	Remove P-469 (1200 ft), P-463 (400 ft), P-462 (500 ft), P-342 (900 ft), P-456 (1500 ft), P-388 (200 ft), P-441 (total 4,700 ft). Also reconnect local pipes to older main. This section of main is shown as proposed improvement in 1973 report. (confirmed based on design plans)	High	High	New	Yes
1978	Chestnut Street - completion of main between storage tanks started in 1977	3,300	12	Remove P-15 (1700 ft, 12-inch), P-19 (500 ft, 12-inch), P-591 (600 ft, 12-inch), P-20 (700 ft, 12-inch) (total 3,500 ft, 12-inch)	High	High	New	Yes
1978	Burt Road	1,050	12	Remove P-816 (500 ft, 12-inch) P-859 (100 ft, 12-inch), P-815 ft (600 ft, 12-inch) (total 1,200 ft, 12-inch)	High	High	New	Yes
1978	Cross Street	750	12	Remove P-25 (700 ft, 12-inch). Main shown as proposed improvement in 1973 report.	High	High	New	Yes
1978	Harris Street	650	12	Remove P-813 (900 ft, 12-inch)	High	High	New	Yes
1978	Cedar Street	450	12	Remove P-814 (600 ft, 12-inch)	High	High	New	Yes
1978	Canal Street	300	12	Reconnect P-818 so that eastern end joins to 6" pipe at junction J-738 (900 ft, 12-inch)	Medium	High	New	Yes
1978	Burlington Ave	500	12	Remove P-812 (500 feet, 12-inch). This pipe not mentioned in annual report, but it was almost certainly constructed during the installation of 12" main to connect the storage tanks.	High	High	New	Yes
1978	Ballardvale Street (by developer)	450	12	Remove P-404 (1,100 ft, 12-inch)	High	Medium	New	Yes
1979	Mill Road	1,500	8	Remove P-11 (400 ft, 8-inch) and P-12 (1,000 ft, 8-inch)	High	Low	New	Yes
1979	Route #125	3,200	12	Remove P-403 (2900 ft). Shown as proposed improvement in 1973 report.	High	High	New	Yes
1979	Ballardvale Street	1,500	12	Remove lower 1/3 of P-413 (1,500 ft). Based on review of design plans.	High	Medium	New	Yes
1980	Lawrence Street Ext.	252	6	Remove P-289 (800 ft, 6-inch)	High	Low	New	Yes
1980	Birchwood Road	60	8	Remove P-870 (300 ft, 6-inch). Based on length, presume this is a connection to Oakdale Road alleviate dead-end.	Medium	Low	New?	Yes
1980	Miscellaneous streets relaid for sewer reconstruction	775	6	None - location not specified.	Low	High	Replacement?	?

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1981	Main Street (incomplete)	792	10	P-83 (1,100 ft) Southernmost section on Main St. - appears to have been multi-year effor between 1981 and 1982	Medium	Low	New	OK
1981	Lee Street (incomplete)	500	6	P-511 (600 ft). Section constructed in 1982.	High	Low	New?	OK
1981	Ballardvale Street	3000	12	Remove P-414 and shorten P-413 by 2/3 (to 1,500 ft). (Based on design plans.) Possibly P-414 installed later.	High	Medium	New	Yes
1981	Butters Row Treatment Plant online in June			Move Town Park pumping to J-78 and Chestnut Street pumping to J-3. Move node J-3 to location of Chestnut St. outlet, add node J-863 at location of old J-3 and add new pipe P-922				Yes
1982	Lee Street (completed)	150	6	Remove P-511 (600 ft, 6-inch). Also portion constructed in 1981.	High	Low	New?	Yes
1982	Main Street (completed)	210	10	Remove P-83 (1,100 ft) Southernmost section on Main St. - appears to have been multi-year effort between 1981 and 1982. Treat as 1982 construction.	High	Low	New	Yes
1982	Fairmont Avenue	350	6	Remove P-40 (500 ft, 6-inch) - section selected based on new construction at western end of Brand Ave - Presume installed in 1982	High	Medium	New	Yes
1982	Brand Avenue	300	6	Remove P-588 (400 ft, 6-inch) - section selected based on new construction at northern end of Brand Ave and inspection of 1971 and 1988 schematic.	High	Low	New	Yes
1982	Faulkner Avenue	150	6	Could be P-490 (300 feet) northernmost section of Faulkner Ave. (could also be P-1017). According to 1971 and 1988 schematic, Faulkner to south of Beeching served by 12" main. There are isolated mains in model on Faulkner to north, but these are not shown on schematic and were removed in construction of the 1986 model.	Low	Medium	?	OK
1982	Andover Street	300	6	None - not sure which section of Andover this is.	Low	High	?	?
1983	Aldrich Road	571	6	Remove Pipe P-754 (1000 ft) - this is the only 6-inch diameter section on Aldrich Road. Appears to feed homes on Winston Ave.	Medium	Low	New	Yes
1983	Garden Ave.	190	6	Pipe P-519 (300 ft, 6-inch). Replacement for 2-inch main	Medium	Low	Replacement	Yes
1983	Beverly Ave.	310	6	Remove P-570 (400 ft, 8-inch) - also 1984	Medium	Low	New?	Yes

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1983	Woburn Street	30	6	? (is this a repair?)	Low	?		
1983	Blanchard Road	750	8	Remove P-730 (600 ft, 8-inch) - also 1987, assumed installed in 1983 based on construction between 1982 and 1984	Medium	Low	New	Yes
1983	Mozart Ave.	600	8	Remove P-721 (700 ft, 8-inch)	High	Low	New	Yes
1983	Carmel Street	222	8	Remove P-499 (600 ft, 8-inch)	High	Low	New	Yes
1983	West Street Ext.	507	6	None - This is most likely section of West Street to north of Woburn Avenue (unlabeled in google maps). New construction occurred in this area in mid-80's. Main on this section is not explicitly simulated. Consider reducing demand at junction J-112	Low	Low	New?	OK
1984	Palmer Way	1400	8	Remove P-258 (700 feet, 8-inch) and P-259 (600 feet, 8-inch)	High	Low	New	Yes
1984	Douglas Way (Ave.?)	600	8	Remove P-260 (900 feet)	High	Low	New	Yes
1984	Great Neck Drive	500	8	Remove P-143 (600 feet, 8-inch)	High	Low	New	Yes
1984	March Road	400	8	Remove P-99 (300 feet, 8-inch)	High	Low	New	Yes
1984	Elm Street	300	8	Remove P-96 (400 feet, 8-inch) and P-98 (200 feet, 8-inch).	High	Low	New	Yes
1984	Crescent Street	270	8	P-498 or P-520? (already done in 1985) - also some in 1985 and 1987	Low	Low	?	OK
1984	Bay Street	200	8	Remove P-100 (200 feet, 8-inch) and P-101 (600 feet, 8-inch)	High	Low	New	Yes
1984	Faulkner Ave.	200	6	Could be P-490 (300 feet) northernmost section of Faulkner Ave. (could also be P-1017). According to 1971 and 1988 schematic, Faulkner to south of Beeching served by 12" main. There are isolated mains in model on Faulkner to north, but these are not shown on schematic and were removed in construction of the 1986 model.	Low	Medium	unknown	OK
1984	Beverly Ave.	160	6	Remove P-570 (400 feet, 8-inch) already accounted for in 1983 - is this extension	Medium	Low	New	Yes
1985	Flagstaff Road	650	8	Remove P-654 (500 feet, 8-inch)	High	Low	New	Yes
1985	Garden Ave. Extension	252	6	P-666 (300 feet, 6-inch) - also construction in 1986, considered to be installed in 1986.	High	Low	New	OK

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1985	McGrane Road	360	6	None - not explicitly simulated	High	Low	New	OK
1985	Coral Street	350	6	Remove P-500 (300 feet, 6-inch)	High	Low	New	Yes
1985	Cobalt Street	270	8	None - already removed from system	Low	Medium	?	OK
1985	Christine Drive	90	6	None - not explicitly simulated	High	Low	New	OK
1985	Kajin Way	460	8	Remove P-195 (500 feet, 8-inch)	High	Low	New	Yes
1985		20	6					
1985	Cary Street	40	6	None - since only 40-feet of main constructed will leave existing main	High	Low	New	OK
1985	Crescent Street	190	6	Replacement of 2" with 6" at P-520 (600 ft, 2-inch) - section off of Garden Ave- also construction in 1987	Medium	Low	Replacement	OK
1985	Broad Street	212	8	Remove P-495 (300 feet) portion of pipe that fed Coral Street and Gloria Way	High	Low	New	Yes
1985	Boyle Street	600	8	P-678 (500 feet, 8-inch) - assumed served by Fourth Street line constructed in 1987.	Medium	Low	New	OK
1985	Albany Street	550	8	Remove P-680 (500 feet, 8-inch) - also construction in 1987	Medium	Low	New	Yes
1985	Fourth Street	550	8	Remove P-677 (600 ft, 8-inch)	High	Low	New	Yes
1985	Lorin Drive	520	8	Remove P-795 (500 feet, 8-inch)	High	Low	New	Yes
1985	Tomahawk Drive	600	8	Remove P-726 (600 feet, 8-inch)	High	Low	New	Yes
1985	Fairfield Road	175	6	Most likely represents extension to new construction at end of main on Fairfield Road. Reduce length of P-554 by 175 feet.	High	Low	New	Yes
1985	Grand Street	140	6	None - since only 140 feet of 600 foot section - construction of hydrant at end of Grand Street occurred between 1971 and 1988. This is likely this event.	High	Low	New	OK
1985	Jacobs Street	90	6	Remove P-490 (300 ft, 8, inch) and P-489 (400-ft, 6-inch) Length and diameter seem not correct, but this pipe does not exist in 1971. This is only listing, so will attribute entire length to contstruction in this year.	Low	Medium	New	Yes
1986	Pineview Road	140	6	Eastern extension is not explicitly modeled	High	Low		OK
1986	Ballardvale Street	46	6	?	Low	High	New	

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1986		40	8					
1986	Fox Run Drive	970	8	Remove P-231 (800 feet, 8-inch)	High	Low	New	Yes
1986	Bailey Road	505	8	Remove P-732 (700 feet, 8-inch)	High	Low	New	Yes
1986	Fairmont Avenue	233	6	P-40 (500 feet, 6-inch) - installed in 1982	High	Low	New	Yes
1986	Gloria Way	848	8	Remove P-494 (800 feet, 8-inch)	High	Low	New	Yes
1986	Wisser Street	173	6	Remove P-1048 (212 feet, 6-inch) and P-886 (300 feet, 6-inch)	Medium	Low	New	Yes
1986	Morton Road	18	6	None - not explicitly simulated	High	Low	New	OK
1986	St. Paul Street	265	6	Remove P-524 (700 feet, 6-inch)	High	Low	New	Yes
1986	Garden Ave.	94	6	Remove P-666 (300 feet, 6-inch)	Medium	Low	New	Yes
1986	Everett Ave.	425	8	Remove P-572 (400 feet, 8-inch)	High	Low	New	Yes
1986	Marjorie Road	275	6	Remove P-1036 (150 feet, 6-inch) and P-543 (600 ft, 8-inch) based on comparison of 1971 and 1988 schematic.	High	Low	New	Yes
1986	Allston Avenue	240	6	Remove P-491 (400 feet, 6-inch) and P-1017 (130 ft, 6-inch). Longer than reported, however this is not now shown in 1971 schematic.	Medium	Low	New?	Yes
1986	Lloyd Road	100	6	Leave as-is because main on Lloyd Road (P-355) is 800-foot section. This may be 100-foot extension to that main because of new construction at end of block.	High	Low	New	OK
1986	Fifth Avenue	200	8	Remove P-941 (300 feet, 6-inch) and P-650 (200 feet, 6-inch)	High	Low	New	Yes
1986	Reno Road	400	8	Remove P-651 (300 ft, 8-inch) and P-652 (200 ft, 8-inch)	High	Low	New	Yes
1986	Gorham Street	600	8	Remove P-508 (300 ft, 8-inch) and P-510 (300 ft, 8-inch)	High	Low	New	Yes
1986	Chelsea Street	44	6	None - not explicitly simulated				OK
1986	Norfolk Ave.	185	6	Remove P-823 (400 feet), southeast section to east of Nassau Ave.	High	Medium	New	Yes
1986	Newbern Ave	300	6	None - not explicitly simulated, but is connected to removed section on Norfolk Ave.				OK
1986	Plymouth Ave	715	6	Remove P-35 (700 feet)	High	Low	New	Yes
1986	Lee Ave.	450	6	Remove P-172 (400 feet, 6-inch)	High	Low	New	Yes

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1986	Perry Ave.	20	6	None - not explicitly simulated				OK
1986	Ohio Street	1150	8	Remove P-628 (800 ft, 8-inch) and P-629 (700 ft, 8-inch)	High	Low	New	Yes
1986	Cobalt Street	200	6	None - removed previously	Medium	Low	New	OK
1986	Winston Ave.	450	6	None - not explicitly simulated				
1986	Miles Street	250	8	P-1019 is shown as 2-inch diameter pipe on Miles. This may be replacement that was not updated in system model. Leave as 2" diameter.	Medium	Low	Replacement?	OK
1986	Jefferson Road	600	8	Remove P-250 (1,200 feet, 8-inch) shown on schematic as west of Jefferson Road along railroad tracks	High	Low	New	Yes
1986	Research Drive	900	12	None - Research Drive already removed from system map - research drive not accepted as road until 1989	High	Medium	New	OK
1986	Ash Street	300	6	P-97 (500 feet, 6-inch) - 600-ft also installed in 1988 and already removed from model as of 1988.	High	Low	New	OK
1986	Melrose Ave.	100	6	Remove P-77 (400 feet, 6-inch)	High	Low	New	Yes
1987	Research Road	380	12	None - Research Road water main (P-417) already removed in 1988 model - research drive not accepted as road until 1989	High	Medium	New	OK
1987	Fourth Avenue	150	6	Remove P-679 (300 ft, 8-inch) and P-678 (Boyle St) (also listed as 1985 construction)	High	Low	New	Yes
1987	Silverhurst Ave	600	6	None -link at edge of system that is not explicitly modeled.				OK
1987	Lee Street	54	6	Based on length this is most likely connection to Fay Street - not simulated in model	High	Low	New	OK
1987	Appletree Lane	1000	8	Remove P-16 (800 feet, 8-inch)	High	Low	New	Yes
1987	Cobalt Street	228	6	None - removed previously				OK
1987	Research Drive	1200	12	None - Research Road water main (P-417) already removed in 1988 model - research drive not accepted as road until 1989	High	Medium	New	OK
1987	Research Drive	900	12	None - Research Road water main (P-417) already removed in 1988 model - research drive not accepted as road until 1989	High	Medium	New	OK

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1987	Patches Pond Lane	1200	8	Remove P-21 (1200 feet, 12-inch)	High	Low	New	Yes
1987	Towpath Drive	1350	8	Remove P-18 (900 feet, 8-inch)	High	Low	New	Yes
1987	Roosevelt Road	350	8	Southern end - not explicitly simulated	High	Low	New	OK
1987	Dewey Ave.	200	6	Replace P-607 with 2" diameter - southern end of Dewey, north of Wisser St. (120 feet, 8-inch)	Medium	Low	New	Yes
1987	Jefferson Road	400	8	P-250 (1,200 feet, 8-inch) shown on schematic as west of Jefferson Road along railroad tracks - portion of construction occurred in 1986.	High	Low	New	Yes
1987	Albany Street	173	8	Remove P-680 (500 ft, 8-inch)	High	Low	New	Yes
1987	Factory Road	1000	6	Rempve P-918 (472 ft, 6-inch) and P-919 528 ft, 6-inch)	High	Low	New	Yes
1987	Blanchard Road	500	8	P-730 (600 feet, 8-inch) - assumed to be installed in 1983.	High	Low	New	OK
1987	Fall Street	200	6	Fall Street not explicitly simulated	High	Low	New	OK
1987	Crescent Street			P-520? (listed as Fall Street and Crescent Street, however roads not in proximity to each other) (600 feet)	Low	Low	New	OK
1987	Dexter Street	180	8	None - not explicitly simulated	High	Low		OK
1987	Valyn Lane	600	8	Remove P-461 (600 ft, 8-inch)	High	Low	New	Yes
1987	Day Street	450	6	Remove P-323 (400 ft, 8-inch)	High	Low	New	Yes
1988	Research Drive	360	12					
1988	Ohio Street	135	8					
1988	Tracey Circle	700	8					
1988	Ash Street	600	6					
1988	Quail Run	550	8					
1988	Earles Row	1900	8					
1988	Allenhurst Drive	1200	8					
1988	Mather Street	200	8					
1988	Winston Ave.	300	6					
1988	Fenway Road	225	8					

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1988	Rollins Road	225	8					
1988	Blanchard Road	229	8					
1988	Salem Street (Route 62)	950	8					
1988	Woburn Street to WTP	1860	16					
1988	Woburn Street to Easement	5660	16					
1988	Brown's Crossing P.S. to Route 62	1496	12					
1989	Olmstead Avenue	375	6	Not represented in model	High	Low		Yes
1989	Marrietta Avenue	750	8	Remove P-722 (600 feet, 8-inch)	High	Low		Yes
1989	Pearl Court	225	6	Not represented in model	High	Low		Yes
1989	Crystal Road	950	8	Remove P-94 (700 feet, 8-inch)	High	Low		Yes
1989	Whitefield Elms	1650	12	Not represented in model	High	Low		Yes
1989	Andover Street	475	12	Remove P-420 (600 feet, 12-inch)	Medium	Low		
1989	Dunmore Road	300	6	Remove P-826 (400 feet, 6-inch)	High	Low		Yes
1989	Waltham Street	370	6	Not represented in model	High	Low		Yes
1989	Upton Court	240	12	Unknown	Low	?		
1989	Hall Street	123	8	Not represented in model	High	Low		Yes
1989	Dewey Ave.	200	6	Remove P-1018 (122 feet, 6-inch)	Medium	Low		Yes
1989	Naples Road	300	6	Not represented in model	High	Low		Yes
1989	Second Avenue	1275	8	Remove P-686 (300 feet, 8-inch), P-687 (300 feet, 8-inch), P-684 (300 feet, 8-inch), P-685 (300 feet, 8-inch), P-683 (300 feet, 8-inch)	High	Medium		Yes
1989	Dunton Road	234	6	Remove P-863 (500 feet, 6-inch)	Medium	Low		Yes
1989	Clark Terrace	242	6	Remove P-1025 (274 feet, 8-inch)	Medium	Low		Yes
1989	New Hampshire / Rand/ Garvin Road	2100	8	Remove P-643 (500 feet, 8-inch), P-641 (500 feet, 8-inch), P-634 (800 feet, 8-inch), P-631 (200 feet, 8-inch), P-632 (200 feet, 8-inch), P-633 (200 feet, 8-inch), P-630 (200 feet, 8-inch)	High	Low		Yes
1989	Cristo / Vermont Road	700	8	Remove P-635 (500 feet, 8-inch)	High	Low		Yes

Year Installed	Description	Reported Length (feet)	Reported Diameter (inches)	Action Taken and Pipe Properties	Confidence	Importance	New or Replacement	Change Completed
1989	Amherst Road	1500	8	Remove P-709 (1500 feet, 6-inch)	High	Low		Yes
1989	Henry L. Drive	600	8	Remove P-121 (700 feet, 8-inch)	High	Low		Yes
1989	Lynch Road	268	8	Remove P-509 (200 feet, 8-inch)	High	Low		Yes
1989	Buckingham road	450	8	Remove P-740 (400 feet, 8-inch)	High	Low		Yes
1989	Allgrove Estates	900	8	Remove P-145 (300 feet, 8-inch), P-151 (600 feet, 8-inch)	High	Medium		Yes
1989	Cross country for new water tank	3100	12 and 16	Remove P-417 (4000 feet, 12-inch), P-419 (700 feet, 12-inch), P-2003 (300 feet, 16-inch)	High	High		

H. Simulated NDMA Concentrations in the Wilmington Water Supply Wells, 1965 – 2003

Table H.1 lists the simulated NDMA concentration in ng/L for each water supply well located in the Maple Meadow Brook aquifer. These results were generated using the ground water flow and transport model described in Sections 4.1 and 4.2 of the main report. See Section 5.1.4 for figures and discussion of these results.

Table H.1: Simulated monthly NDMA concentration (ng/L) for Wilmington water supply wells located in the Maple Meadow Brook aquifer, 1965 – 2003

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Jan-1965	0.0	0.0	0.0	0.0	0.0
Feb-1965	0.0	0.0	0.0	0.0	0.0
Mar-1965	0.0	0.0	0.0	0.0	0.0
Apr-1965	0.0	0.0	0.0	0.0	0.0
May-1965	0.0	0.0	0.0	0.0	0.0
Jun-1965	0.0	0.0	0.0	0.0	0.0
Jul-1965	0.0	0.0	0.0	0.0	0.0
Aug-1965	0.0	0.0	0.0	0.0	0.0
Sep-1965	0.0	0.0	0.0	0.0	0.0
Oct-1965	0.0	0.0	0.0	0.0	0.0
Nov-1965	0.0	0.0	0.0	0.0	0.0
Dec-1965	0.0	0.0	0.0	0.0	0.0
Jan-1966	0.0	0.0	0.0	0.0	0.0
Feb-1966	0.0	0.0	0.0	0.0	0.0
Mar-1966	0.0	0.0	0.0	0.0	0.0
Apr-1966	0.0	0.0	0.0	0.0	0.0
May-1966	0.0	0.0	0.0	0.0	0.0
Jun-1966	0.0	0.0	0.0	0.0	0.0
Jul-1966	0.0	0.0	0.0	0.0	0.0
Aug-1966	0.0	0.0	0.0	0.0	0.0
Sep-1966	0.0	0.0	0.0	0.0	0.0
Oct-1966	0.0	0.0	0.0	0.0	0.0
Nov-1966	0.0	0.0	0.0	0.0	0.0
Dec-1966	0.0	0.0	0.0	0.0	0.0
Jan-1967	0.0	0.0	0.0	0.0	0.0
Feb-1967	0.0	0.0	0.0	0.0	0.0
Mar-1967	0.0	0.0	0.0	0.0	0.0
Apr-1967	0.0	0.0	0.0	0.0	0.0
May-1967	0.0	0.0	0.0	0.0	0.0
Jun-1967	0.0	0.0	0.0	0.0	0.0
Jul-1967	0.0	0.0	0.0	0.0	0.0
Aug-1967	0.0	0.0	0.0	0.0	0.0
Sep-1967	0.0	0.0	0.0	0.0	0.0
Oct-1967	0.0	0.0	0.0	0.0	0.0
Nov-1967	0.0	0.0	0.0	0.0	0.0
Dec-1967	0.0	0.0	0.0	0.0	0.0
Jan-1968	0.0	0.0	0.0	0.0	0.0
Feb-1968	0.0	0.0	0.0	0.0	0.0
Mar-1968	0.0	0.0	0.0	0.0	0.0
Apr-1968	0.0	0.0	0.0	0.0	0.0

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
May-1968	0.0	0.0	0.0	0.0	0.0
Jun-1968	0.0	0.0	0.0	0.0	0.0
Jul-1968	0.0	0.0	0.0	0.0	0.0
Aug-1968	0.0	0.0	0.0	0.0	0.0
Sep-1968	0.0	0.0	0.0	0.0	0.0
Oct-1968	0.0	0.0	0.0	0.0	0.0
Nov-1968	0.0	0.0	0.0	0.0	0.0
Dec-1968	0.0	0.0	0.0	0.0	0.0
Jan-1969	0.0	0.0	0.0	0.0	0.0
Feb-1969	0.0	0.0	0.0	0.0	0.0
Mar-1969	0.0	0.0	0.0	0.0	0.0
Apr-1969	0.0	0.0	0.0	0.0	0.0
May-1969	0.0	0.0	0.0	0.0	0.0
Jun-1969	0.0	0.0	0.0	0.0	0.0
Jul-1969	0.0	0.0	0.0	0.0	0.0
Aug-1969	0.0	0.0	0.0	0.0	0.0
Sep-1969	0.0	0.0	0.0	0.0	0.0
Oct-1969	0.0	0.0	0.0	0.0	0.0
Nov-1969	0.0	0.0	0.0	0.0	0.0
Dec-1969	0.0	0.0	0.0	0.0	0.0
Jan-1970	0.0	0.0	0.0	0.0	0.0
Feb-1970	0.0	0.0	0.0	0.0	0.0
Mar-1970	0.0	0.0	0.0	0.0	0.0
Apr-1970	0.0	0.0	0.0	0.0	0.0
May-1970	0.0	0.0	0.0	0.0	0.0
Jun-1970	0.0	0.0	0.0	0.0	0.0
Jul-1970	0.0	0.0	0.0	0.0	0.0
Aug-1970	0.0	0.0	0.0	0.0	0.0
Sep-1970	0.0	0.0	0.0	0.0	0.0
Oct-1970	0.0	0.0	0.0	0.0	0.0
Nov-1970	0.0	0.0	0.0	0.0	0.0
Dec-1970	0.0	0.0	0.0	0.0	0.0
Jan-1971	0.0	0.0	0.0	0.0	0.0
Feb-1971	0.0	0.0	0.0	0.0	0.0
Mar-1971	0.0	0.0	0.0	0.0	0.0
Apr-1971	0.0	0.0	0.0	0.0	0.0
May-1971	0.0	0.0	0.0	0.0	0.0
Jun-1971	0.0	0.0	0.0	0.0	0.0
Jul-1971	0.0	0.0	0.0	0.0	0.0
Aug-1971	0.0	0.0	0.0	0.0	0.0
Sep-1971	0.0	0.0	0.0	0.0	0.0
Oct-1971	0.0	0.0	0.0	0.0	0.0
Nov-1971	0.0	0.0	0.0	0.0	0.0
Dec-1971	0.0	0.0	0.0	0.0	0.0
Jan-1972	0.0	0.0	0.0	0.0	0.0
Feb-1972	0.0	0.0	0.0	0.0	0.0
Mar-1972	0.1	0.0	0.0	0.0	0.0
Apr-1972	0.1	0.0	0.0	0.0	0.0
May-1972	0.1	0.0	0.0	0.0	0.0
Jun-1972	0.1	0.0	0.0	0.0	0.0
Jul-1972	0.1	0.0	0.0	0.0	0.0
Aug-1972	0.2	0.0	0.0	0.0	0.0
Sep-1972	0.2	0.0	0.0	0.0	0.0
Oct-1972	0.2	0.0	0.0	0.0	0.0
Nov-1972	0.2	0.0	0.0	0.0	0.0
Dec-1972	0.3	0.0	0.0	0.0	0.0
Jan-1973	0.3	0.0	0.0	0.0	0.0
Feb-1973	0.4	0.0	0.0	0.0	0.0
Mar-1973	0.4	0.0	0.0	0.0	0.0

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Apr-1973	0.3	0.0	0.0	0.0	0.0
May-1973	0.3	0.0	0.0	0.0	0.0
Jun-1973	0.4	0.0	0.0	0.0	0.0
Jul-1973	0.4	0.0	0.0	0.0	0.0
Aug-1973	0.5	0.0	0.1	0.0	0.0
Sep-1973	0.5	0.0	0.2	0.0	0.0
Oct-1973	0.5	0.0	0.4	0.0	0.0
Nov-1973	0.5	0.0	0.6	0.0	0.0
Dec-1973	0.6	0.0	0.9	0.0	0.0
Jan-1974	0.5	0.0	1.1	0.0	0.0
Feb-1974	0.5	0.0	1.4	0.0	0.0
Mar-1974	0.5	0.0	1.7	0.0	0.0
Apr-1974	0.5	0.0	2.2	0.0	0.0
May-1974	0.4	0.0	3.1	0.0	0.0
Jun-1974	0.5	0.0	4.8	0.0	0.0
Jul-1974	0.5	0.0	7.4	0.0	0.0
Aug-1974	0.5	0.0	10.7	0.0	0.0
Sep-1974	0.6	0.0	13.8	0.1	0.0
Oct-1974	0.6	0.0	16.9	0.1	0.0
Nov-1974	0.6	0.0	19.1	0.1	0.0
Dec-1974	0.6	0.0	20.4	0.1	0.0
Jan-1975	0.6	0.0	21.3	0.1	0.0
Feb-1975	0.6	0.0	21.9	0.1	0.0
Mar-1975	0.6	0.0	22.1	0.1	0.0
Apr-1975	0.5	0.0	22.6	0.1	0.0
May-1975	0.5	0.0	24.9	0.1	0.0
Jun-1975	0.5	0.0	28.8	0.1	0.0
Jul-1975	0.6	0.0	34.2	0.1	0.0
Aug-1975	0.6	0.0	39.8	0.2	0.0
Sep-1975	0.7	0.0	45.1	0.2	0.0
Oct-1975	0.8	0.0	49.0	0.2	0.0
Nov-1975	0.8	0.0	50.1	0.2	0.0
Dec-1975	0.8	0.0	49.2	0.2	0.0
Jan-1976	0.8	0.0	47.7	0.2	0.0
Feb-1976	0.7	0.0	45.9	0.2	0.0
Mar-1976	0.7	0.0	44.1	0.2	0.0
Apr-1976	0.7	0.0	43.4	0.2	0.1
May-1976	0.6	0.0	44.8	0.2	0.1
Jun-1976	0.7	0.0	49.1	0.2	0.1
Jul-1976	0.7	0.0	54.3	0.3	0.1
Aug-1976	0.8	0.0	60.0	0.3	0.1
Sep-1976	0.9	0.0	64.2	0.3	0.1
Oct-1976	1.0	0.0	66.9	0.3	0.1
Nov-1976	1.1	0.0	67.6	0.3	0.1
Dec-1976	1.1	0.0	67.1	0.3	0.1
Jan-1977	1.1	0.0	66.2	0.3	0.1
Feb-1977	1.1	0.0	65.4	0.3	0.1
Mar-1977	1.1	0.0	64.6	0.3	0.1
Apr-1977	1.1	0.0	64.8	0.3	0.1
May-1977	1.2	0.0	67.6	0.3	0.1
Jun-1977	1.3	0.0	71.9	0.3	0.1
Jul-1977	1.5	0.0	77.2	0.4	0.1
Aug-1977	1.7	0.0	82.6	0.4	0.1
Sep-1977	2.0	0.0	86.4	0.4	0.2
Oct-1977	2.2	0.0	88.4	0.5	0.2
Nov-1977	2.4	0.0	87.5	0.5	0.2
Dec-1977	2.5	0.0	84.6	0.4	0.2
Jan-1978	2.4	0.0	81.1	0.4	0.2
Feb-1978	2.4	0.0	77.5	0.4	0.2

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Mar-1978	2.2	0.0	73.9	0.4	0.2
Apr-1978	2.2	0.0	72.4	0.4	0.2
May-1978	2.2	0.0	73.4	0.4	0.2
Jun-1978	2.3	0.0	77.1	0.4	0.2
Jul-1978	2.5	0.0	83.3	0.4	0.2
Aug-1978	2.9	0.0	89.9	0.5	0.2
Sep-1978	3.3	0.0	94.7	0.5	0.2
Oct-1978	3.7	0.0	97.3	0.5	0.2
Nov-1978	4.1	0.0	97.2	0.5	0.2
Dec-1978	4.3	0.0	95.7	0.5	0.3
Jan-1979	4.5	0.1	93.4	0.5	0.3
Feb-1979	4.6	0.1	90.8	0.5	0.3
Mar-1979	4.6	0.1	87.8	0.5	0.3
Apr-1979	4.6	0.1	86.7	0.5	0.3
May-1979	4.9	0.1	87.8	0.5	0.3
Jun-1979	5.2	0.1	90.8	0.5	0.3
Jul-1979	5.7	0.1	88.5	0.4	0.3
Aug-1979	6.3	0.1	67.6	0.4	0.3
Sep-1979	6.7	0.1	50.5	0.3	0.3
Oct-1979	7.0	0.1	36.4	0.3	0.3
Nov-1979	6.9	0.2	25.3	0.3	0.4
Dec-1979	6.5	0.1	17.0	0.2	0.4
Jan-1980	6.1	0.1	11.4	0.2	0.4
Feb-1980	5.7	0.1	7.9	0.2	0.4
Mar-1980	5.1	0.1	5.3	0.1	0.5
Apr-1980	4.7	0.1	3.7	0.1	0.5
May-1980	4.5	0.1	2.6	0.1	0.6
Jun-1980	4.3	0.1	1.9	0.1	0.6
Jul-1980	4.3	0.1	1.4	0.0	0.6
Aug-1980	4.3	0.1	1.1	0.0	0.6
Sep-1980	4.4	0.2	0.8	0.0	0.7
Oct-1980	4.5	0.2	0.6	0.0	0.7
Nov-1980	4.4	0.2	0.4	0.0	0.7
Dec-1980	4.1	0.2	0.3	0.0	0.8
Jan-1981	3.8	0.1	0.2	0.0	0.8
Feb-1981	3.5	0.1	0.2	0.0	0.9
Mar-1981	3.1	0.1	0.1	0.0	0.9
Apr-1981	2.8	0.1	0.1	0.0	1.0
May-1981	2.6	0.1	0.1	0.0	1.1
Jun-1981	8.4	0.5	0.3	0.0	1.0
Jul-1981	17.4	1.2	1.0	0.0	0.9
Aug-1981	31.7	2.2	1.9	0.0	0.8
Sep-1981	47.3	3.2	2.8	0.0	0.7
Oct-1981	63.0	4.1	3.8	0.0	0.6
Nov-1981	75.9	4.8	4.5	0.0	0.6
Dec-1981	86.8	5.3	4.9	0.0	0.5
Jan-1982	100.6	6.0	4.9	0.0	0.4
Feb-1982	117.1	6.7	5.2	0.0	0.3
Mar-1982	129.3	7.5	5.0	0.0	0.1
Apr-1982	141.5	8.4	4.4	0.0	0.3
May-1982	147.7	9.2	4.2	0.0	0.3
Jun-1982	153.7	9.7	4.0	0.0	0.3
Jul-1982	158.4	10.0	4.1	0.0	0.3
Aug-1982	163.1	10.3	3.9	0.0	0.3
Sep-1982	160.2	10.1	3.8	0.0	0.2
Oct-1982	155.4	9.5	3.7	0.0	0.2
Nov-1982	146.6	8.5	3.4	0.0	0.2
Dec-1982	140.3	7.6	3.0	0.0	0.2
Jan-1983	141.5	6.8	2.7	0.0	0.1

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Feb-1983	153.7	6.8	2.7	0.0	0.1
Mar-1983	157.7	6.8	2.4	0.0	0.0
Apr-1983	163.7	7.3	2.0	0.0	0.1
May-1983	162.2	7.5	1.8	0.0	0.1
Jun-1983	158.4	7.4	1.6	0.0	0.1
Jul-1983	155.4	7.0	1.5	0.0	0.1
Aug-1983	155.6	6.7	1.3	0.0	0.1
Sep-1983	158.8	6.3	1.2	0.0	0.1
Oct-1983	178.4	6.5	1.1	0.0	0.0
Nov-1983	181.1	6.5	1.0	0.0	0.0
Dec-1983	170.2	6.3	0.9	0.0	0.0
Jan-1984	173.5	6.5	0.8	0.0	0.0
Feb-1984	183.3	7.1	0.8	0.0	0.0
Mar-1984	177.2	7.6	0.8	0.0	0.0
Apr-1984	179.9	8.4	0.7	0.0	0.0
May-1984	180.8	9.1	0.6	0.0	0.0
Jun-1984	163.1	8.6	0.6	0.0	0.0
Jul-1984	161.1	8.2	0.6	0.0	0.0
Aug-1984	155.9	7.6	0.6	0.0	0.0
Sep-1984	147.6	6.6	0.6	0.0	0.0
Oct-1984	146.5	5.7	0.5	0.0	0.0
Nov-1984	164.6	5.6	0.4	0.0	0.0
Dec-1984	163.3	5.4	0.4	0.0	0.0
Jan-1985	170.0	5.6	0.4	0.0	0.0
Feb-1985	178.9	6.3	0.4	0.0	0.0
Mar-1985	180.3	7.0	0.4	0.0	0.0
Apr-1985	183.1	7.9	0.3	0.0	0.0
May-1985	166.9	7.9	0.4	0.0	0.0
Jun-1985	158.6	7.5	0.3	0.0	0.0
Jul-1985	160.8	7.4	0.3	0.0	0.0
Aug-1985	152.5	6.8	0.4	0.0	0.0
Sep-1985	144.2	5.9	0.4	0.0	0.0
Oct-1985	140.5	5.2	0.5	0.0	0.0
Nov-1985	132.9	4.4	0.5	0.0	0.0
Dec-1985	133.7	3.9	0.5	0.0	0.0
Jan-1986	138.9	3.8	0.5	0.0	0.0
Feb-1986	150.5	4.1	0.5	0.0	0.0
Mar-1986	154.4	4.4	0.5	0.0	0.0
Apr-1986	155.5	4.9	0.5	0.0	0.0
May-1986	147.7	5.0	0.5	0.0	0.0
Jun-1986	145.1	4.9	0.4	0.0	0.0
Jul-1986	149.3	4.9	0.4	0.0	0.0
Aug-1986	150.9	5.0	0.4	0.0	0.0
Sep-1986	143.9	4.6	0.4	0.0	0.0
Oct-1986	138.6	4.1	0.4	0.0	0.0
Nov-1986	144.9	3.8	0.4	0.0	0.0
Dec-1986	144.2	3.5	0.4	0.0	0.0
Jan-1987	147.6	3.7	0.4	0.0	0.0
Feb-1987	161.2	4.3	0.4	0.0	0.0
Mar-1987	169.0	5.0	0.4	0.0	0.0
Apr-1987	169.5	5.7	0.3	0.0	0.0
May-1987	160.0	6.0	0.3	0.0	0.0
Jun-1987	150.3	5.9	0.3	0.0	0.0
Jul-1987	143.9	5.3	0.3	0.0	0.0
Aug-1987	147.6	5.0	0.3	0.0	0.0
Sep-1987	149.9	4.6	0.3	0.0	0.0
Oct-1987	168.8	4.7	0.2	0.0	0.0
Nov-1987	176.6	4.8	0.2	0.0	0.0
Dec-1987	173.9	5.0	0.2	0.0	0.0

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Jan-1988	163.4	5.1	0.2	0.0	0.0
Feb-1988	180.0	5.8	0.2	0.0	0.0
Mar-1988	169.0	6.3	0.2	0.0	0.0
Apr-1988	171.2	6.9	0.2	0.0	0.0
May-1988	158.0	6.9	0.2	0.0	0.0
Jun-1988	148.4	6.4	0.2	0.0	0.0
Jul-1988	148.3	6.0	0.2	0.0	0.0
Aug-1988	146.9	5.5	0.2	0.0	0.0
Sep-1988	151.4	5.0	0.2	0.0	0.0
Oct-1988	159.2	4.7	0.2	0.0	0.0
Nov-1988	177.8	4.7	0.1	0.0	0.0
Dec-1988	178.7	4.7	0.1	0.0	0.0
Jan-1989	169.9	4.9	0.1	0.0	0.0
Feb-1989	226.4	7.1	0.1	0.0	0.0
Mar-1989	232.0	10.1	0.1	0.0	0.0
Apr-1989	203.9	11.3	0.1	0.0	0.0
May-1989	190.4	11.7	0.1	0.0	0.0
Jun-1989	173.8	11.1	0.1	0.0	0.0
Jul-1989	167.1	10.2	0.1	0.0	0.0
Aug-1989	160.2	9.3	0.2	0.0	0.0
Sep-1989	152.2	8.3	0.2	0.0	0.0
Oct-1989	150.4	7.5	0.2	0.0	0.0
Nov-1989	142.9	6.7	0.3	0.0	0.0
Dec-1989	137.6	5.9	0.3	0.0	0.0
Jan-1990	129.7	4.9	0.4	0.0	0.0
Feb-1990	125.8	4.2	0.4	0.0	0.0
Mar-1990	128.0	3.7	0.4	0.0	0.0
Apr-1990	138.6	3.7	0.3	0.0	0.0
May-1990	129.6	3.4	0.3	0.0	0.0
Jun-1990	121.5	2.9	0.3	0.0	0.0
Jul-1990	119.2	2.4	0.3	0.0	0.0
Aug-1990	124.8	2.1	0.3	0.0	0.0
Sep-1990	139.5	2.0	0.2	0.0	0.0
Oct-1990	150.0	2.1	0.2	0.0	0.0
Nov-1990	150.3	2.2	0.2	0.0	0.0
Dec-1990	152.0	2.3	0.2	0.0	0.0
Jan-1991	173.0	3.0	0.2	0.0	0.0
Feb-1991	165.3	3.7	0.3	0.0	0.0
Mar-1991	156.3	4.3	0.3	0.0	0.0
Apr-1991	170.3	5.2	0.3	0.0	0.0
May-1991	167.4	6.0	0.3	0.0	0.0
Jun-1991	164.2	6.4	0.3	0.0	0.0
Jul-1991	162.1	6.7	0.3	0.0	0.0
Aug-1991	180.6	7.6	0.2	0.0	0.0
Sep-1991	175.8	7.8	0.2	0.0	0.0
Oct-1991	154.1	6.9	0.3	0.0	0.0
Nov-1991	140.5	5.9	0.3	0.0	0.0
Dec-1991	131.1	5.0	0.2	0.0	0.0
Jan-1992	124.6	4.2	0.2	0.0	0.0
Feb-1992	119.0	3.5	0.2	0.0	0.0
Mar-1992	124.0	3.2	0.4	0.1	0.0
Apr-1992	138.8	3.3	0.5	0.2	0.0
May-1992	151.4	3.7	0.9	0.3	0.0
Jun-1992	160.7	4.3	1.2	0.4	0.0
Jul-1992	223.9	6.4	4.6	0.4	0.0
Aug-1992	182.5	7.4	7.3	0.1	0.0
Sep-1992	174.1	7.7	12.3	1.2	0.0
Oct-1992	150.1	7.1	19.0	2.4	0.0
Nov-1992	155.4	7.1	22.7	3.1	0.0

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Dec-1992	180.1	7.8	31.9	4.0	0.0
Jan-1993	187.7	8.4	48.1	5.7	0.0
Feb-1993	186.7	9.0	70.1	10.0	0.0
Mar-1993	175.9	9.6	87.6	13.3	0.0
Apr-1993	172.9	10.6	106.5	16.7	0.0
May-1993	164.1	11.7	137.8	22.2	0.0
Jun-1993	121.0	8.9	156.5	26.4	0.0
Jul-1993	95.4	6.2	169.8	28.4	0.0
Aug-1993	82.2	4.6	176.9	30.1	0.0
Sep-1993	76.0	3.6	168.4	35.9	0.0
Oct-1993	68.2	3.0	174.5	44.0	0.0
Nov-1993	66.4	3.1	180.3	32.8	0.0
Dec-1993	66.6	2.9	163.8	51.8	0.0
Jan-1994	68.8	2.9	162.9	52.5	0.0
Feb-1994	69.1	2.8	155.4	52.5	0.0
Mar-1994	78.4	3.1	137.6	60.2	0.0
Apr-1994	88.1	3.4	101.4	63.7	0.0
May-1994	95.6	4.0	144.6	60.9	0.0
Jun-1994	97.5	4.3	159.6	54.4	0.0
Jul-1994	90.8	4.0	155.2	56.5	0.0
Aug-1994	90.1	3.6	158.0	50.6	0.0
Sep-1994	87.9	3.2	141.9	52.2	0.0
Oct-1994	87.4	3.0	140.7	57.7	0.0
Nov-1994	85.6	2.7	140.6	53.0	0.0
Dec-1994	84.8	2.3	135.3	48.3	0.0
Jan-1995	81.6	2.0	144.8	34.8	0.0
Feb-1995	81.4	1.7	138.8	12.3	0.0
Mar-1995	84.4	1.4	133.4	11.8	0.0
Apr-1995	85.3	1.2	130.2	8.9	0.0
May-1995	91.0	1.1	123.4	5.7	0.0
Jun-1995	87.0	0.9	138.2	21.2	0.0
Jul-1995	80.0	0.6	151.7	17.8	0.0
Aug-1995	76.3	0.5	164.9	19.2	0.0
Sep-1995	81.0	0.4	144.1	4.9	0.0
Oct-1995	89.9	0.3	141.0	6.9	0.0
Nov-1995	94.2	0.3	139.8	6.5	0.0
Dec-1995	92.5	0.2	134.2	4.0	0.0
Jan-1996	89.8	0.2	135.6	4.1	0.0
Feb-1996	84.3	0.1	110.8	2.4	0.0
Mar-1996	91.1	0.1	104.1	1.8	0.0
Apr-1996	97.2	0.2	112.2	54.4	0.0
May-1996	123.0	0.4	107.6	15.0	0.0
Jun-1996	122.8	0.5	119.7	23.8	0.0
Jul-1996	123.9	0.7	75.2	57.0	0.0
Aug-1996	118.7	0.8	58.5	59.0	0.0
Sep-1996	113.4	0.9	48.7	58.3	0.0
Oct-1996	107.4	1.0	85.8	58.8	0.0
Nov-1996	105.4	1.2	55.9	61.6	0.0
Dec-1996	100.0	1.5	61.0	63.2	0.0
Jan-1997	107.9	1.9	72.9	64.6	0.0
Feb-1997	105.0	2.2	81.9	65.8	0.0
Mar-1997	114.1	2.5	72.6	61.3	0.0
Apr-1997	115.6	2.6	135.8	14.0	0.0
May-1997	106.3	2.2	114.3	4.9	0.0
Jun-1997	91.1	2.2	168.0	35.5	0.0
Jul-1997	74.1	1.7	195.7	48.7	0.0
Aug-1997	63.1	1.5	219.5	54.0	0.0
Sep-1997	50.1	0.8	243.0	56.3	0.0
Oct-1997	39.7	0.7	259.1	37.3	0.0

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Nov-1997	34.9	0.5	206.2	6.7	0.0
Dec-1997	42.5	0.3	190.6	4.9	0.0
Jan-1998	45.1	0.2	173.1	2.9	0.0
Feb-1998	43.6	0.2	174.9	3.0	0.0
Mar-1998	41.0	0.1	167.9	2.4	0.0
Apr-1998	34.0	0.1	206.0	7.2	0.0
May-1998	32.2	0.4	225.8	47.7	0.0
Jun-1998	40.7	0.6	214.4	62.1	0.0
Jul-1998	53.6	0.8	195.9	63.1	0.0
Aug-1998	58.2	1.4	175.8	74.5	0.0
Sep-1998	73.2	1.9	144.0	60.9	0.0
Oct-1998	91.3	2.6	139.4	48.8	0.0
Nov-1998	79.5	2.2	145.1	43.3	0.0
Dec-1998	71.5	1.7	154.6	44.3	0.0
Jan-1999	58.2	1.4	165.3	58.1	0.0
Feb-1999	52.8	1.3	176.8	60.4	0.0
Mar-1999	45.6	1.1	193.5	53.7	0.0
Apr-1999	51.4	2.1	201.1	54.2	0.0
May-1999	65.0	2.6	199.3	51.5	0.0
Jun-1999	75.6	2.9	191.6	53.7	0.0
Jul-1999	89.4	3.1	186.6	49.8	0.0
Aug-1999	104.3	3.2	181.6	44.8	0.0
Sep-1999	117.2	3.2	181.7	40.1	0.0
Oct-1999	127.8	3.2	185.5	26.4	0.0
Nov-1999	160.5	4.4	114.4	59.9	0.0
Dec-1999	165.1	5.8	146.0	12.5	0.0
Jan-2000	157.6	6.0	109.9	5.8	0.0
Feb-2000	152.3	5.4	55.4	4.1	0.0
Mar-2000	150.9	4.8	29.5	2.7	0.0
Apr-2000	171.0	5.6	38.4	29.5	0.0
May-2000	182.5	7.2	39.8	46.3	0.0
Jun-2000	175.3	7.9	48.8	54.9	0.0
Jul-2000	159.1	9.5	58.0	64.8	0.0
Aug-2000	147.3	10.8	71.3	72.4	0.0
Sep-2000	137.5	12.6	69.1	76.3	0.0
Oct-2000	130.6	13.3	86.2	79.9	0.0
Nov-2000	122.1	14.2	72.8	76.9	0.0
Dec-2000	121.9	14.9	82.2	76.2	0.0
Jan-2001	114.3	14.3	85.3	76.3	0.0
Feb-2001	108.5	14.1	95.6	75.8	0.0
Mar-2001	113.5	15.1	107.8	73.9	0.0
Apr-2001	116.8	16.5	113.5	75.5	0.0
May-2001	115.9	15.6	166.4	72.4	0.0
Jun-2001	127.4	17.2	156.2	76.6	0.0
Jul-2001	125.0	19.3	145.6	80.4	0.0
Aug-2001	119.5	21.2	144.5	84.0	0.0
Sep-2001	116.4	22.5	140.3	86.2	0.0
Oct-2001	116.3	23.5	121.0	85.1	0.0
Nov-2001	116.9	24.7	111.2	81.9	0.0
Dec-2001	119.1	26.5	120.4	79.4	0.0
Jan-2002	130.4	30.5	81.0	62.4	0.0
Feb-2002	144.6	34.8	131.2	63.4	0.0
Mar-2002	157.3	39.1	121.9	53.3	0.0
Apr-2002	168.6	42.4	137.6	60.5	0.0
May-2002	172.1	44.4	158.1	59.8	0.0
Jun-2002	172.7	45.4	159.4	63.5	0.0
Jul-2002	157.6	43.1	192.5	53.6	0.0
Aug-2002	140.3	32.3	206.7	61.7	0.0
Sep-2002	128.6	23.7	164.0	82.7	0.0

Month/Year	Butters Row #1	Butters Row #2	Chestnut St. #1	Chestnut St. #1A/2	Town Park
Oct-2002	110.1	16.8	152.7	83.5	0.0
Nov-2002	111.6	22.5	99.9	58.0	0.0
Dec-2002	122.0	25.0	83.2	55.5	0.0
Jan-2003	140.2	32.8	63.8	37.9	0.0
Feb-2003	158.1	36.7	88.8	32.7	0.0
Mar-2003	181.9	44.6	91.1	16.9	0.0
Apr-2003	191.2	43.4	114.8	17.4	0.0
May-2003	206.9	49.2	99.5	12.9	0.0
Jun-2003	217.5	53.4	84.0	9.6	0.0
Jul-2003	225.5	56.7	69.2	7.2	0.0
Aug-2003	231.6	59.3	56.4	5.4	0.0
Sep-2003	235.7	61.1	45.1	4.1	0.0
Oct-2003	238.1	61.9	34.8	3.0	0.0
Nov-2003	237.7	61.0	25.8	2.2	0.0
Dec-2003	234.4	58.5	18.4	1.5	0.0

I. WATER QUALITY MONITORING DATA FROM THE WILMINGTON WATER DISTRIBUTION SYSTEM

The data in the tables below derive from records provided by the Wilmington Water Department, except as noted on the last page. A descriptive summary of this data can be found in Appendix D.

AMMONIA NH3 as N (mg/L)																							
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	SARGENT FINISH	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
7/31/75					0.01																	0.16		0.14
4/29/76					0.02																	0.08		0.11
5/26/77					0.01																	0.57		0.15
6/1/78					0.01																	0.06		0.07
5/21/79					0.04																	<0.05		0.09
5/13/81	0.10				0.07																			
4/15/83					0.01																			
6/11/84		0.08		0.03	0.02																			
4/1/86		0.43		0.12	0.06																	0.14		0.22
3/24/87				0.14	0.05																	0.33		0.26
3/25/88		1.38		0.14	0.07																	0.12		0.18
2/13/89		3.20			0.09																	0.19		0.08
4/26/1989																					0.08			
5/30/90	0.56	1.30		0.25	0.03																<0.2	0.13		0.30
3/1/92		2.50		0.30																		0.10	0.10	
9/1/92		2.10		0.35																		0.20	0.10	
1/14/93		3.46		0.52																		0.57	0.19	0.50
2/10/93		3.36		0.51																		0.59	0.15	0.51
3/23/93																								
10/1/93		3.90		0.28																		1.80	0.20	
2/14/94																								
3/1/94		3.80		0.45																		1.00	0.20	
5/1/94		6.20		0.43																		0.90	0.40	
8/1/94		7.90		0.42																		1.10	0.60	
10/1/94		7.70		0.75																		1.30	0.50	
11/1/94		7.10		0.43																		0.60	0.20	
2/14/95		4.70		0.51																		1.20	0.20	
4/1/95				0.52																		1.20	0.20	
6/1/95		4.00		0.20																		4.10	0.25	
10/1/95		4.00		0.49																		2.00	0.00	
1/1/96		5.20		0.27																		1.90		
3/5/96		3.90		0.51																		1.90	0.25	
5/1/96		4.80		0.50																		1.70	0.20	
6/1/96		5.90		0.51																		1.70	0.30	
7/1/96		4.90		0.45																		1.90	0.60	
8/1/96		7.60		0.56																		2.00	0.80	
9/1/96		8.70		0.57																				
10/1/96		7.20		0.40																		1.70	1.10	

AMMONIA NH3 as N (mg/L)

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	SARGENT FINISH	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
11/1/96		7.30		0.46																		1.70	0.75	
12/1/96		9.30		0.47																		1.80	0.75	
1/1/97		8.20		0.39																		1.90	0.75	
2/18/97		6.80		0.46																			0.80	
3/1/97		0.00		0.47																		2.00	0.70	
4/1/97		3.20		0.38																		1.90	0.00	
5/1/97		3.90		0.40																		1.90	0.80	
6/1/97		3.15		0.40																		2.20		
7/1/97		2.30		0.42																				
8/1/97		2.10		0.45																		7.40	1.70	
10/1/97		2.20		0.25																		8.00	3.10	
11/1/97		3.20		0.25																		7.60	0.80	
Dec-97		2.40																				7.10		
1/6/98		2.20																				7.40	1.00	
2/1/98		1.80																				3.60	0.25	
3/1/98		1.90																				3.10	0.20	
4/1/98		3.10																				3.00	0.20	
5/1/98		3.90																				2.90	0.30	
6/1/98		4.20																				3.70	0.20	
7/1/98		3.20		0.25																		3.10	0.20	
8/1/98		3.10		0.55																		3.80	1.50	
9/1/98		3.80		1.55																			0.30	
10/1/98		7.60		0.88																		4.20	1.10	
11/1/98		5.80		0.54																				
12/1/98		6.80		0.65																		4.90	1.20	
1/1/99		6.20		0.95																		1.80	5.10	
2/2/99		3.80		1.48																		4.70	0.30	
3/1/99		0.00		0.80																		0.50	1.20	
4/1/99		5.20		0.58																		6.20	1.10	
5/1/99		4.20		0.61																		6.00	1.10	
6/1/99		4.10		0.60																		4.20	1.20	
7/1/99		3.30		0.59																		8.10	2.00	
8/1/99		4.00		0.50																		12.0	3.70	
9/1/99		8.00		0.54																		15.2	0.00	
10/1/99		6.80		0.78																		10.1	3.20	
11/1/99		6.00		0.90																		9.20		
12/1/99		6.20		0.53																		7.80		
1/1/00		4.90		0.62																				
2/1/00				0.49																				
3/1/00		3.80		0.52																			1.10	
04/04/00	0.91	3.44	2.36	0.69	OFF	1.02	0.10	0.55											0.77			OFF	OFF	OFF

AMMONIA NH3 as N (mg/L)																								
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	SARGENT FINISH	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
04/11/00	0.27	OFF	1.22	0.62	OFF	0.88	0.29	0.48	0.53	0.02	0.62	0.18	0.01	0.01	ND				0.69			OFF	1.27	OFF
04/18/00	0.72	3.90	1.47	0.72	OFF	0.74	0.22	0.28	0.40	0.12	0.46	0.13	ND	ND	ND				0.51			OFF	1.52	OFF
04/25/00	0.32	OFF	1.23	0.56	OFF	0.53	0.11	0.20	0.28	0.31	0.31	0.04	ND	ND	ND				0.36			4.14	1.38	OFF
05/01/00		2.40																						
05/02/00	0.42	OFF	1.32	0.60	OFF	0.51	0.20	0.34	0.39	0.01	0.08	0.07	0.01	ND	ND				0.16			OFF	1.47	OFF
05/09/00	0.31	OFF	1.24	0.56	OFF	0.43	0.37	0.33	0.31	0.27	0.44	0.04	0.01	NS	ND				0.30			OFF	1.49	0.49
05/16/00	0.45	OFF	1.24	0.68	OFF	0.42	OFF	0.22	0.30	0.28	0.43	0.09	0.04	0.04	0.06				0.42			OFF	1.52	0.67
05/23/00	0.48	OFF	1.35	0.65	OFF	0.44	0.36	0.38	0.47	0.24	0.59	0.10	0.01	0.26	0.14				0.31			OFF	1.49	0.63
05/30/00	0.72	OFF	1.92	0.55	OFF	0.42	0.30	0.31	0.40	0.36	0.51	0.04	ND	0.35	0.34				0.37			OFF	1.61	0.68
6/1/00*	0.92	4.14	2.19	OFF																				
6/2/00**	0.74		1.57																					
06/06/00	0.78	3.32	1.78	OFF	OFF	0.62	0.63	0.47	0.85	0.15	0.82	0.09	0.10	0.39	0.47				0.61	0.62		OFF	1.57	0.67
06/13/00	0.22	OFF	1.29	0.60	OFF	0.39	0.25	0.16	0.26	0.02	0.24	0.04	0.02	0.07	0.09				0.23	0.44		OFF	1.68	0.63
06/20/00	0.36	OFF	1.30	0.63	OFF	0.21	0.08	0.02	0.05	0.25	0.05	0.02	ND	0.01	0.03				0.12	0.28		OFF	1.68	0.59
06/27/00	0.40	OFF	1.26	0.73	OFF	0.33	0.34	0.32	0.40	0.45	0.33	0.08	0.02	0.37	0.22				0.36			OFF	1.62	0.64
06/27/00	BRL		0.40	BRL			BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.00	BRL
07/01/00		7.40																				4.20		
07/05/00	0.40	OFF	1.36	0.85	OFF	0.40	0.32	0.23	0.39	0.43	0.29	0.13	0.06	0.28	0.20				0.38			OFF	1.71	0.67
07/05/00	0.40	OFF	1.36	0.85	OFF	0.40	0.32	0.23	0.39	0.43	0.29	0.13	0.06	0.28	0.20				0.38	0.36		OFF	1.71	0.67
07/05/00	0.30		0.90	0.30		0.40	0.30	0.30	0.30	0.40	BRL	0.30	BRL	0.20	0.20				0.30				1.50	BRL
07/11/00	0.29	OFF	1.39	0.86	OFF	0.38	0.38	0.24	0.45	0.41	0.39	0.01	0.04	0.36	0.30				0.42			OFF	1.73	0.64
07/11/00	0.29	OFF	1.39	0.86	OFF	0.38	0.38	0.24	0.45	0.41	0.39	0.01	0.04	0.36	0.30				0.42	0.35		OFF	1.73	0.64
07/11/00	BRL		BRL	BRL		0.40	0.30	BRL	0.20	0.30	BRL	BRL	BRL	0.30	BRL				0.30				0.40	BRL
07/18/00	0.21	OFF	1.37	0.73	OFF	0.26	0.39	0.27	0.38	0.36	0.35	0.01	0.19	0.38	0.34				0.37	0.44		OFF	1.76	0.52
07/18/00	0.50		1.10	BRL		0.40	0.40	0.30	BRL	0.30	BRL	BRL	BRL	BRL	BRL				0.40				1.00	BRL
07/25/00	0.24	OFF	1.47	0.88	OFF	0.39	0.38	0.22	0.37	0.32	0.39	0.05	0.02	0.21	0.24				0.44	0.40		OFF	1.89	0.59
08/01/00		7.00																						
08/01/00	0.41	OFF	1.49	0.97	OFF	0.29	0.17	0.21	0.32	0.04	0.28	0.04	0.02	0.09	0.08				0.31	0.36		OFF	1.79	0.68
08/08/00	0.34	OFF	1.39	0.94	OFF	0.29	0.16	0.24	0.34	0.35	0.39	0.05	0.04	0.04	0.16				0.26	0.27		OFF	1.75	0.63
08/15/00	0.10	OFF	1.02	0.77	OFF	0.02	0.17	0.16	0.12	0.24	0.22	ND	ND	0.12	0.09				0.22	0.20		OFF	1.71	0.51
08/17/00		5.56																				4.50		
08/22/00	0.14	OFF	1.31	0.77	OFF	0.20	0.04	0.14	0.23	0.03	0.19	0.01	0.17	0.04	0.10				0.16	0.06		OFF	1.61	0.58
08/22/00																								
08/26/00										0.48					0.17									
08/28/00										0.14					BRL									
08/29/00	0.22	OFF	1.38	0.82	OFF	0.20	0.15	0.14	0.28	0.31	0.31	0.08	0.14	0.28	0.17				0.20	0.13		OFF	1.76	0.56
08/29/00	0.40		0.90	0.40		BRL	BRL	0.20	0.40	0.30	0.30	BRL	BRL	0.20	BRL				0.40				1.50	BRL
09/01/00		6.80																						
09/05/00		OFF		0.98	OFF	0.37	0.21	0.23	0.46	0.48	0.37	0.07	0.08	0.34					0.36			OFF	1.98	0.82
09/05/00	BRL		1.10	0.30		BRL	BRL	BRL	0.30	BRL	BRL	BRL	BRL	BRL	0.33				BRL			1.40		BRL
09/06/00	0.25		1.46												0.40									

AMMONIA NH3 as N (mg/L)

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMED.) SCHOOL	MARION ST. (LAST HYDRANT)	SARGENT FINISH	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
09/12/00	ND	OFF	1.29	0.92	OFF	0.43	0.22	0.31	0.53	0.51	0.54	0.10	0.03	0.24	0.10				0.48			OFF	1.95	0.74
09/12/00	0.50		0.30	0.60		0.60	0.70	0.50	0.60	0.60	0.60	BRL	BRL	0.50	BRL				1.10				1.60	0.40
09/19/00	0.49	OFF	1.61	0.90	OFF	0.35	0.20	0.28	0.33	0.05	0.35	0.08	0.02	0.35	0.30				0.19			OFF	2.07	0.68
09/19/00	0.60		1.50	0.70		0.50	0.30	0.30	0.30	BRL	0.30	BRL	BRL	0.30	0.30				0.20				1.90	0.50
09/26/00	0.45	OFF	1.60	0.87	OFF	0.48	0.38	0.32	0.47	0.53	0.52	0.04	0.03	0.46	0.13				0.57			OFF	2.01	0.70
09/26/00	0.20		0.70	0.30	BRL	BRL		BRL	0.20	0.30	0.30	BRL	0.30	BRL	BRL				BRL				1.20	0.20
10/01/00		7.00																				4.70		
10/03/00	0.05	OFF	1.62	1.03	OFF	0.31	0.22	0.30	0.40	0.39	0.50	0.00	0.01						0.27				2.09	0.78
10/03/00	BRL		0.90	0.40		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL						BRL			OFF	1.40	BRL
10/03/00																								
10/04/00														BRL										
10/10/00	0.30		1.10	0.50		BRL	0.40	BRL	BRL	0.50	0.30	BRL	BRL	BRL	0.30				BRL				1.60	BRL
10/17/00	BRL		1.20	0.50		BRL	1.30	BRL	0.30	BRL	BRL	0.20	BRL	BRL	BRL				BRL				1.30	BRL
10/24/00	BRL		0.80	0.40		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				0.90	BRL
10/31/00	BRL		0.70	BRL		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.00	
11/07/00	BRL		BRL	BRL		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				0.50				BRL	0.30
11/14/00	0.50		1.20	0.70		BRL	0.50	BRL	BRL	BRL	0.20	BRL	0.60	BRL	0.40				BRL				1.60	
11/20/00	0.50		1.30	0.60		0.30	BRL	0.20	0.50	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.60	
11/28/00	0.50		1.10			0.30	BRL	BRL	0.30	BRL	0.30	BRL	BRL	BRL	0.30				BRL				1.70	
12/01/00		7.00																				4.60		
12/05/00	BRL		1.20	0.50		BRL	BRL	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.50	
12/11/00	0.90		1.50	0.70		0.30	0.30	0.30	0.30	0.40	0.50	0.30	0.30	0.30	0.80				0.30				0.70	
12/19/00	0.20		1.10	0.70		0.30	0.30	BRL	0.50	BRL	0.20	BRL	BRL	BRL	BRL				BRL				1.40	
12/26/00	0.30		1.40	0.60		0.30	0.30	BRL	BRL	BRL	BRL	0.20	BRL	BRL	BRL				0.40				1.30	
1/2/2001	0.20		0.90	0.40		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	0.20				BRL				1.40	
1/9/2001	0.60		1.20	0.60		0.30	BRL	0.40	0.30	BRL	BRL	BRL	BRL	BRL	BRL				0.20				1.60	
1/16/2001	0.20		0.90	0.30		BRL	BRL	BRL	BRL	BRL	0.20	0.30	BRL	BRL	BRL				BRL				1.40	
1/16/2001																								
1/23/2001	0.30		0.90	0.70	BRL	0.40	0.20	0.30	0.40	0.20	BRL	0.30	0.40	BRL	BRL				0.20				1.60	
1/30/2001	0.30		1.00		0.30	0.40	BRL	4.30	4.20	4.90	BRL	BRL	BRL	BRL	BRL				BRL				1.50	
2/7/2001	0.20		1.10		0.30	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				2.10	
2/13/2001	BRL		0.70		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	1.50	BRL	BRL				BRL				1.50	
2/20/2001																								
2/21/2001	BRL		1.00		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	
2/27/2001	0.30		0.80		0.20	BRL	BRL	BRL	BRL	1.20	BRL	BRL	BRL	BRL	BRL				BRL				1.60	
3/8/2001	0.50		0.80		0.30	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				0.30				1.60	
3/13/2001	0.30		0.90	0.50	BRL	0.20	BRL	0.40	0.20	BRL	0.40	BRL	BRL	BRL	BRL				0.20				1.50	
3/20/2001	0.30		0.80	0.60	BRL	0.30	BRL	0.20	0.30	BRL	0.30	0.20	BRL	BRL	BRL				BRL				1.40	
3/27/2001	BRL		0.70	0.50	BRL	0.20	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.20	
4/3/2001	0.20		0.70	0.40	BRL	BRL	BRL	BRL	0.30	BRL	BRL	BRL	BRL	BRL	BRL				0.30				1.30	
4/10/2001	BRL		0.70	0.40	BRL	BRL	BRL	BRL	0.30	BRL	0.40	BRL	BRL	BRL	BRL				BRL				1.30	
4/17/2001	0.30		0.70	0.30	BRL	BRL	BRL	BRL	0.80	0.20	0.30	BRL	BRL	BRL	BRL				BRL				1.20	
4/24/2001	BRL		0.80	0.40	BRL	BRL	BRL	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.30	

AMMONIA NH3 as N (mg/L)																							
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	SARGENT FINISH	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
5/1/2001	0.40		1.10	0.50	0.30	0.40	0.40	0.40	0.40	0.40	0.50	BRL	BRL	0.30	0.20				0.50				1.50	
5/8/2001	1.70		2.00	2.50	BRL	0.80	0.90	1.00	1.20	1.30	1.10	0.30	BRL	1.20	0.80				0.90			4.60	1.20	
5/15/2001	1.20	3.40	1.50	0.50	0.40	1.10	1.10	1.10	1.10	1.00	1.20	0.60	BRL	0.80	0.80				1.10			5.60	1.80	
5/22/2001	0.80	3.60	1.40	0.60	0.20	0.60	0.60	0.80	0.60	0.70	0.70	0.30	BRL	BRL	0.20				0.40				1.50	0.30
5/29/2001	0.30		2.20	0.50	BRL	0.40	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				0.30				1.60	0.30
6/5/2001	0.30		0.70	0.30	0.30	0.60	0.40	BRL	BRL	BRL	BRL	0.30	BRL	0.30	BRL				BRL				1.60	0.60
6/12/2001	0.40	4.30	1.10	0.70	BRL	0.50	0.40	0.70	0.60	0.50	0.60	BRL	BRL	0.50	0.40				0.40				1.60	0.50
6/19/2001	0.60	4.00	0.60	0.70	BRL	BRL	BRL	0.70	0.70	0.60	BRL	0.30	BRL	0.30	0.40				BRL			5.20		BRL
6/26/2001	0.60		0.90	0.70	0.40	0.50	0.30	BRL	0.30	BRL	0.20	BRL	BRL	0.40	BRL				BRL				1.60	0.40
7/2/2001	BRL	3.70	0.90	BRL	BRL	BRL	BRL	BRL	0.40	0.30	0.30	0.40	BRL	0.40	0.30				BRL					BRL
7/11/2001	BRL		0.50	0.30	BRL	0.30	BRL	BRL	BRL	0.30	0.30	BRL	BRL	BRL	0.20				BRL				1.00	BRL
7/17/2001	BRL		0.50	0.20	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.10	0.20
7/24/2001	0.40		0.70	0.60	0.30	0.30	0.30	BRL	0.20	0.30	0.30	BRL	BRL	0.20	BRL				0.20				1.20	0.40
7/31/2001	BRL		0.90	0.40	BRL	0.40	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.10	0.50
8/7/2001	0.50		0.80	0.70	0.30	0.50	0.30	0.30	0.30	0.30	0.30	BRL	BRL	BRL	0.20				0.30				1.50	0.50
8/14/2001	BRL		0.50	0.30	0.40	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				0.20				1.20	0.60
8/21/2001	BRL		0.70	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.00	0.20
8/28/2001	BRL		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.00	BRL
9/4/2001	0.40		0.80	0.60	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	0.40
9/11/2001	BRL		0.60	0.40	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.30	0.30
9/18/2001	BRL		0.80	0.60	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				0.30				1.30	0.30
9/25/2001	0.50		1.70	0.70	0.30	BRL	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.50	0.50
10/2/2001	BRL		0.80	0.80	BRL	BRL	BRL	BRL	0.20	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.50	0.50
10/9/2001	BRL		0.40	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.10	BRL
10/16/2001	0.50		0.80	0.60	0.30	BRL	BRL	BRL	0.30	0.30	BRL	BRL	BRL	BRL	BRL				0.30				1.50	0.50
10/23/2001	BRL		0.70	0.40	BRL	BRL	0.30	BRL	0.20	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.30	
10/30/2001	0.30		0.70	0.70	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	
11/6/2001	BRL		0.70	0.60	BRL	BRL	BRL	BRL	BRL	0.30	0.20	BRL	BRL	BRL	BRL				BRL				1.30	
11/13/2001	BRL		0.70	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	0.30
11/20/2001	BRL		0.60	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	0.30
11/27/2001	BRL		0.70	0.70	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.70	0.40
12/4/2001	BRL		0.90	0.60	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.60	0.50
12/11/2001	BRL		0.60	0.40	BRL	BRL	BRL	BRL	0.20	0.30	0.30	BRL	BRL	BRL	BRL				BRL				1.40	BRL
12/18/2001	BRL		0.70	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.50	0.20
12/26/2001	0.50		1.20	1.00	0.20	0.40	BRL	0.40	0.30	0.30	BRL	BRL	BRL	0.20	BRL				BRL				1.60	0.50
1/2/2002	BRL		0.90	0.60	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	0.60
1/8/2002	BRL		0.70	0.60	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.40	BRL
1/15/2002	BRL		0.20	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					
1/22/2002	0.30		0.80	0.80	0.30	0.20	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					
1/29/2002	BRL		0.40	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					
2/5/2002	0.30		0.90	0.60	0.40	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.20	

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2/12/2002	BRL		0.20	0.50	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					0.30
2/19/2002	BRL		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					BRL
2/26/2002	1.40		2.00	0.50	BRL	1.30	1.20	0.50	0.40	1.50	1.20	BRL	0.20	0.30	BRL				0.70			5.30	1.40	0.30
3/5/2002	BRL		0.30	0.50	BRL	0.20	BRL	BRL	BRL	BRL	0.20	BRL	BRL	BRL	0.30				0.70					0.40
3/12/2002	BRL		0.40	0.40	BRL	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					0.30
3/19/2002	BRL		BRL	0.70	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					0.30
3/26/2002	0.30		0.80	0.40		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.00	BRL
4/2/2002	0.40		1.20	0.50		BRL	BRL	BRL	BRL	BRL	BRL	BRL	0.30	BRL	BRL				BRL				1.40	0.30
4/9/2002	BRL		1.00	0.50		BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.00	0.40
4/16/2002	BRL		0.50	0.50	0.20	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL					0.50
4/23/2002	BRL		0.50	0.40	BRL	0.30	0.30	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				0.30				1.10	0.30
4/30/2002	0.30		1.20	0.60	BRL	BRL	BRL	BRL	0.30	0.30	BRL	0.20	0.90	BRL	BRL				BRL				1.60	
5/7/2002	BRL		0.70	0.50	BRL	0.20	BRL	BRL	BRL	BRL	0.40	BRL	BRL	BRL	BRL				0.20				1.30	0.50
5/14/2002	BRL		0.50	0.40	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL	BRL				BRL				1.10	0.20
5/21/2002	1.50		2.10	0.50		0.30	1.00	1.00	1.30	1.30	1.40	0.60	BRL	0.40	0.90				0.80			4.60	1.10	0.40
5/28/2002	1.00		1.90	0.40		0.40	0.70			0.70		0.40		0.90	0.40				1.00			4.70	0.80	0.20
6/4/2002	1.10		1.60	0.60		0.60	0.90	1.00	1.10	0.90	1.00	0.50	BRL	0.70	0.70				0.90			4.30	0.90	0.40
6/11/2002	0.90		1.50	0.50		0.60	0.60	0.50	0.60	0.50	0.80	0.20	BRL	0.50	0.30				0.70			3.70	0.90	0.20
6/18/2002	0.60		1.70	0.50		0.70	0.70	0.60	0.90	0.70	0.70	0.30	BRL	0.50	0.40				0.60			3.50	1.00	0.40
6/25/2002	0.30		0.80	0.70	0.30	0.70	0.40	0.30	0.40	0.30	0.30	0.40	BRL	0.30	0.20				0.40				1.30	0.60
7/2/2002	0.11		0.58	0.63	0.09	0.24	0.08	0.03	0.12	0.13	0.07	0.07	ND	0.10	0.06				0.16				1.10	0.36
7/9/2002	1.10		1.80	0.62		0.94	1.00	0.72	0.96	1.10	1.00	0.40	0.03	0.98	0.85				1.00			0.35	0.78	0.28
7/16/2002	1.00		1.60	0.61		1.00	1.00	0.91	1.10	1.10	1.10	0.70	0.06	1.10	0.54				1.00			3.70	0.80	0.44
7/23/2002	1.10	3.30	1.60	0.60		1.30	1.10	0.96	1.20	1.10	1.20	0.91	0.14	1.20	0.99				1.30			3.80	0.89	0.40
7/30/2002	1.10		1.60	0.66		1.10	1.10	0.84	1.10	1.10	1.10	0.64	0.08	0.86	0.74				1.10			4.20	0.85	0.43
8/6/2002	1.80	2.80	2.30	0.62		1.50	1.70	1.40	1.80	1.70	1.80	1.10	0.29	1.70	1.80				1.60			6.10	0.89	0.45
8/13/2002	2.20	2.30	2.60	0.58		1.70	2.00	1.50	2.00	2.20	2.20	1.10	0.14		2.00				1.90			8.10	0.96	0.46
8/15/2002																								
8/16/2002														2.30										
8/20/2002	2.50	2.30	3.20	0.52		2.60	2.90	2.40	2.80	2.80	2.80	1.70	0.20	2.60	2.50				2.80			9.80	0.92	0.42
8/27/2002	1.10	3.52	1.20	0.41		2.30	2.00	1.70	2.10	1.90	2.10	0.99	0.11	2.00	2.10				2.10				1.00	0.35
9/3/2002	1.20	3.59	1.80	0.43		1.50	0.96	0.78	1.00	1.30	1.10	1.20	0.11	0.81	0.62				1.10				1.80	0.40
9/10/2002	1.50	3.55	1.80	0.39		1.40	1.40	1.30	1.60	1.60	1.50	0.73	0.09	1.30	0.52				1.40				2.50	0.37
9/17/2002	1.90	3.84	2.40	0.35		1.50	1.80	1.60	1.80	1.90	1.80	0.55	0.09	1.50	1.00				1.70				3.00	
9/18/2002		2.76																						
9/24/2002	1.80	3.81	4.00	0.36		1.60	1.60	1.50	1.90	1.90	1.30	0.35	0.08	0.74	1.30				1.70					0.36
10/1/2002	2.20		2.60			1.60	2.10	1.70	2.10	0.55	1.90	0.46	ND	0.11	0.70				1.50				3.40	0.35
10/8/2002	2.00		2.60			1.90	1.80	1.80	2.20	0.48	2.20	0.49	0.09	2.10	1.30				1.90				3.40	0.32
10/9/2002												0.80												
10/10/2002		2.10										0.78										10.0		
10/11/2002						1.20						1.00												

AMMONIA NH3 as N (mg/L)																							
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	SARGENT FINISH	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
10/15/2002						0.18	0.08	0.06	0.42	0.09	0.15	0.09	ND	ND	0.06				ND					
10/22/2002	0.51	3.06	0.95		0.11	0.34		0.74	0.66	0.04	0.71	0.48	ND	0.67	0.45								2.00	0.30
10/24/2002							0.62												0.48					
10/29/2002	0.97		1.80	0.30	0.12	0.40	0.47	1.10	1.00	0.84	1.00	ND	ND	0.43	0.09				0.62				3.70	0.37
11/5/2002	ND		0.22	0.41	0.14	0.16	ND	ND	0.02	ND	ND	0.08	ND	ND	0.07				0.06					0.36
11/12/2002	ND	8.04	0.26	0.52	0.12	ND	ND	ND	0.03	ND	ND	ND	ND	0.04	0.02				ND					0.35
11/19/2002	ND		0.31	0.61	0.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.36
11/26/2002	ND		0.30	0.65	0.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.38
12/3/2002	ND		0.30	0.65	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.36
12/10/2002	ND		0.12		0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.35
12/17/2002	ND	8.08	0.13		0.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.36
12/23/2002	ND		0.11		0.08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.31
12/31/2002	ND		0.16		0.12	0.50	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.40
1/7/2003	ND		0.16		0.09	ND	ND	ND	ND	ND	ND	ND	0.04	ND	ND				ND					0.37
1/14/2003	ND	7.98	0.18		0.14	ND	ND	0.03	0.03	ND	ND	0.03		0.05	0.07	0.03	0.02	0.04	0.05					0.41
1/21/2003	ND		0.17		0.10	ND	ND		0.03	ND	ND	0.05		ND	0.04	0.04	ND	ND	0.05					0.38
1/28/2003	0.02		0.14		0.12	ND	ND	ND	0.02	ND	ND	ND		ND	ND	ND	ND	ND	0.04					0.39
2/4/2003	ND		0.16		0.12	ND	0.02	ND	0.03	ND	ND	ND		ND	ND	ND	ND	ND	ND					0.39
2/7/2003		7.31																						
2/11/2003	0.08		0.12		0.11	ND	ND	ND	ND	0.17	0.05	0.05		ND	0.06	ND	0.05	0.07	ND					0.39
2/19/2003	0.04		0.20		0.13	ND	0.03	0.03	ND	ND	ND	ND		0.03	ND	ND	ND	ND	0.05					0.37
2/25/2003	0.04		0.20		0.14	ND	ND	ND	ND	ND	0.03	ND		ND	0.04	ND	0.05	0.04	0.03					0.39
2/26/2003		6.19				0.04	0.05	0.04	0.06	0.04	0.05	0.07		0.05	0.05	0.06	0.07	0.04	0.08					
3/19/2003		5.50																						
4/16/2003		4.55																						

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
7/31/75					1.00																	0.20		0.40
4/29/76					1.00																	0.10		0.50
5/26/77					0.80																	0.10		0.50
6/1/78					0.70																	0.10		0.80
5/21/79					0.70																	0.10		0.30
5/13/81	0.10				0.50																			
4/15/83					1.30																			
6/11/84		<0.05		0.10	0.10																			
4/1/86		<0.1		0.20	1.20																	0.10		0.60
3/24/87				0.20	1.60																	<0.1		0.50
3/25/88		<0.1		0.30	0.60																	0.20		0.70
2/13/89		<0.1			0.70																	0.20		0.50
4/26/1989																					0.27			
5/30/90	0.24			0.29	1.87																0.95	0.16		0.42
2/10/93		0.60		0.50																		0.20	0.40	1.00
3/23/93	0.61																				0.98			
2/14/94	0.88																				1.33			
2/14/95	0.67																				1.52			
3/5/96	0.39																				1.79			
2/18/97	0.39																				1.70			
1/6/98	0.81																				1.30			
2/2/99	0.58																				1.40			
04/04/00	1.70	0.90	0.90	0.90	OFF	1.60	1.40	1.50											1.50			OFF	OFF	OFF
04/11/00	1.30	OFF	0.60	0.90	OFF	1.60	1.50	1.50	1.50	1.30	1.50	1.80	1.30	1.40	1.40				1.40			OFF	0.60	OFF
04/18/00	0.70	0.60	0.40	0.70	OFF	0.80	0.70	0.70	0.60	0.70	0.60	0.70	0.70	0.70	0.70				0.60			OFF	0.30	
04/25/00	1.30	OFF	0.50	0.80	OFF	1.40	1.40	1.30	1.20	1.20	1.20	1.40	1.20	1.30	1.40				1.20			OFF	0.60	OFF
05/02/00	1.10	OFF	0.40	1.00	OFF	0.80	0.90	0.80	0.90	1.10	1.00	0.70	1.20	1.10	0.80				0.90			OFF	0.60	OFF
05/09/00	1.10	OFF	0.80	0.80	OFF	1.20	1.20	1.00	0.90	0.90	1.00	1.20	1.30		1.20				1.00			OFF	0.60	1.00
05/16/00	1.10	OFF	0.50	0.80	OFF	0.60	OFF	0.90	0.90	1.00	1.10	1.10	1.20	1.90	1.20				1.00			OFF	0.50	1.00
05/23/00	1.20	OFF	0.40	0.70	OFF	1.00	1.00	1.10	1.10	1.00	1.10	1.00	1.20	1.00	1.00				1.00			OFF	0.50	0.90
05/30/00	1.40	OFF	0.50	0.80	OFF	1.10	1.10	1.10	1.10	1.10	1.10	1.20	1.40	1.20	1.10				1.10				0.50	0.90
06/06/00	1.20	0.70	0.30	OFF	OFF	1.20	1.20	1.00	1.20	1.20	1.20	1.10	1.20	1.10	0.90				1.10	1.20		OFF	0.30	1.00
06/13/00	0.90	OFF	0.60	0.60	OFF	1.10	1.10	0.90	0.90	1.20	0.90	1.30	1.20	1.00	0.90				0.90	1.10		OFF	0.40	1.00
06/20/00	1.10	OFF	0.50	0.60	OFF	1.00	1.10	0.80	0.80	1.20	0.80	1.00	1.20	1.10	1.00				0.90	1.00		OFF	0.50	1.00
06/27/00	1.00	OFF	0.07	0.08	OFF	1.00	1.00	1.00	1.00	1.10	1.00	1.00	1.00	1.00	0.90				0.90			OFF	0.50	1.00
06/27/00	0.69		0.33	0.46			0.72	0.74	0.72	0.70	0.80	1.00	1.30	0.69	0.81				0.73				0.18	0.61
07/05/00	0.66		0.27	0.39		0.70	0.73	0.80	0.73	0.68	0.67	0.98	1.20	0.78	0.89				0.86	1.10			0.13	0.48
07/11/00	0.63																							
07/11/00			0.23	0.24		0.70	0.67	0.79	0.65	0.63	0.68	1.10	1.20	0.68	0.68				0.65				0.15	0.38
07/18/00																				1.20				
07/18/00	0.67		0.26	0.36		0.78	0.76	0.85	0.72	0.73	0.69	1.30	1.00	0.74	0.71				0.77				0.18	0.50
07/25/00																				1.10				
08/01/00																				0.90				
08/08/00																				1.00				

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMED.) SCHOOL	MARION St.(LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
08/15/00																				0.90				
08/22/00																				1.00				
08/22/00	0.73			0.22		0.69	0.70	0.72	0.63	0.94	0.66	0.89	0.97	0.89	0.79				0.76				0.19	0.33
08/26/00			0.21																					
08/28/00															0.79									
08/29/00																				0.90				
08/29/00	0.60			0.16		0.67	0.64	0.75	0.62	0.60	0.63	0.88	0.97	0.67	0.92				0.72				0.18	0.34
09/05/00			0.20																					
09/05/00	0.72			0.22		0.75	0.85	0.86	0.71	0.71	0.77	1.20	1.10	0.79					0.87				0.14	0.37
09/06/00			0.18												0.82									
09/12/00	0.78			0.27		0.74	0.73	0.83	0.70	0.66	0.68	1.20	1.20	0.94	1.00				0.74				0.17	0.42
09/19/00			0.58																					
09/19/00	0.71			0.21		0.79	0.87	0.89	0.88	1.10	0.84	1.20	1.10	0.82	0.83				0.97				0.18	0.36
09/26/00			0.20																					
09/26/00	0.60			0.21		0.72	0.73	0.85	0.65	0.60	0.61	1.10	1.00	0.74					0.63				0.14	0.36
10/03/00			0.19												0.92									
10/03/00	0.90			0.24				0.86											0.84				0.24	
10/03/00	0.88		0.25			0.83	0.84		0.75	0.79	0.73	1.10	1.10											0.37
10/04/00														0.83										
10/10/00	0.71		0.21	0.21		0.93	0.82	0.94	0.89	0.77	0.91	1.20	1.20	1.00	1.10				0.96				0.23	0.31
10/17/00	1.10		0.18	0.14		0.90	1.10	1.10	1.00	1.10	0.93	1.20	1.10	0.92	0.97				0.93				0.16	0.25
10/24/00	1.30		0.37	0.21		1.10	1.20	1.30	1.20	1.20	1.20	1.40	1.20	1.20	1.20				1.20				0.50	0.30
10/31/00	1.00		0.27	0.25		1.00	1.00	1.00	0.99	0.93	1.00	1.20	0.93	0.93	0.98				1.00				0.32	
11/07/00	0.84		0.32	0.19		0.93	0.86	0.91	0.85	0.84	0.88	1.00	0.84	0.84	0.87				0.88				0.43	0.29
11/14/00	1.10		0.35	0.21		1.10	1.10	1.20	1.10	1.10	1.10	1.30	1.10	1.10	1.10				1.10				0.45	
11/20/00	1.20		0.36	0.22		1.20	1.10	1.20	1.10	1.10	1.10	1.30	1.10	1.10	1.10				1.10				0.48	
11/28/00	1.10		0.32	0.21		1.20	1.20	1.20	1.10	1.20	1.10	1.40	1.40	1.10	1.20				1.20				0.40	
12/05/00	0.98		0.26	0.20		1.00	1.10	1.10	1.00	1.10	1.00	1.20	1.10	1.10	1.10				1.00				0.29	
12/11/00	0.87		0.28	0.29		1.00	1.10	1.10	0.98	0.93	1.00	1.20	1.10	1.10	1.10				0.99				0.31	
12/19/00	0.84		0.31	0.26		0.86	0.97	0.89	0.84	1.00	0.89	0.98	1.00	1.00	1.00				0.93				0.36	
12/26/00	0.89		0.37	0.28		0.82	0.91	0.94	0.84	0.95	0.88	0.96	0.96	0.94	0.92				0.91				0.41	
1/2/2001	0.81		0.33	0.29		0.79	0.80	0.82	0.94	0.84	0.87	0.98	0.98	0.96	0.89				0.89				0.37	
1/9/2001	0.80		0.29	0.23		0.85	0.99	0.92	0.80	1.10	0.84	0.98	1.10	1.10	0.98				0.94				0.34	
1/16/2001	0.76		0.27	0.25		0.80	1.00	0.85	0.77	0.92	0.88	0.95	1.20	1.10	1.00				0.90				0.30	
1/16/2001	0.73																							
1/23/2001	0.95		0.75		0.68	0.63	0.35	0.75	0.64	0.82	0.78	0.90	0.90	0.86	0.85				0.75				1.40	
1/30/2001	1.20		0.80		1.30	0.91	1.10	1.10	1.20	1.00	1.00	1.00	1.00	0.99	1.00				1.10				0.34	
2/7/2001	0.90		0.69		1.00	0.76	0.81	0.90	0.87	0.85	0.83	0.83	0.82	0.81	0.79				0.83				0.30	
2/13/2001	1.40		1.00		1.40	1.40	1.40	1.50	1.50	1.40	1.40	1.50		1.50	1.40				1.40				0.51	
2/20/2001	ND		1.00				1.50	1.50		1.50	1.40		1.50	1.50					1.50				0.48	
2/21/2001					1.50	1.40			1.50			1.50			1.50									
2/27/2001	1.40		0.99		1.50	1.40	1.60	1.50	1.40	1.60	1.40	1.50	1.70	1.60	1.50				1.50				0.46	
3/8/2001	1.20		0.79		1.40	1.30	1.50	1.40	1.50	1.30	1.40	1.50	1.60	1.70	1.50				1.40				0.42	
3/13/2001	1.10		0.81	0.26	1.50	1.20	1.50	0.92	1.10	1.50	1.20	1.40	1.60	1.60	1.50				1.20				0.42	
3/20/2001	1.20		0.97	0.24	1.50	1.30	1.60	1.20	1.20	1.60	1.20	1.40	1.60	1.40	1.50				1.40				0.51	

NITRATES NO3 as N (mg/L)																							
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
3/27/2001	1.20		0.96	0.23	1.40	1.20	1.40	1.20	1.20	1.40	1.20	1.30	1.80	1.70	1.70				1.40				0.59	
4/3/2001	1.10		0.77	0.27	1.30	1.20	1.20	1.10	1.10	1.80	1.10	1.20	1.90	1.60	1.60				1.20				0.44	
4/10/2001	0.94		0.63	0.29	1.10	0.99	1.50	0.93	0.92	1.60	0.93	1.10	1.80	1.40	1.50				1.10				0.43	
4/17/2001	0.68		0.46	0.21	0.76	0.76	1.00	0.76	0.70	1.40	0.71	0.82	1.50	1.10	1.30				0.86				0.31	
4/24/2001	0.75		0.50	0.23	0.84	0.85	1.10	0.79	0.92	1.40	0.82	0.98	1.70	1.60	1.30				1.10				0.32	
5/1/2001	0.85		0.67	0.26	1.00	0.97	1.10	0.91	0.97	0.88	0.92	1.10	1.50	1.10	1.20				1.10				0.39	
5/8/2001	0.67		0.50	0.24	1.10	0.42	0.89	0.83	0.78	0.70	0.74	1.20	1.60	0.78	0.98				0.88			ND	0.39	
5/15/2001	0.75	0.04	0.48	0.21	0.97	0.78	0.79	0.73	0.75	0.67	0.66	0.89	1.60	0.70	0.90				0.74			ND	0.31	
5/22/2001	0.72	ND	0.38	0.27	0.92	0.76	0.76	0.68	0.70	0.73	0.68	0.97	1.50	0.76	0.95				0.73				0.27	0.85
5/29/2001	0.81		0.37	0.30		0.80	0.79	0.85	0.85	1.40	0.80	0.96	1.40	0.86	1.30				0.80				0.22	0.69
6/5/2001	0.80		0.35	0.30	0.61	0.81	0.77	0.81	0.80	0.76	0.82	0.94	1.30	0.92	0.80				0.79				0.22	0.55
6/12/2001	0.61	0.03	0.33	0.35	0.50	0.68	0.68	0.58	0.60	0.62	0.56	0.96	1.30	0.62	0.70				0.64				0.20	0.53
6/19/2001	0.51	0.05	0.25	0.32	0.40	0.60	0.53	0.53	0.52	0.47	0.53	0.82	1.10	0.99	0.76				0.57			ND		0.43
6/26/2001	0.69		0.33	0.29	0.47	0.83	0.87	0.80	0.81	0.76	0.78	0.97	1.40	0.95	0.98				0.94				0.19	0.42
7/2/2001	0.88	ND	0.24	0.33	0.41	0.69	0.85	0.85	0.77	0.80	0.83	0.75	1.30	0.75	0.80				0.78					0.43
7/11/2001	0.70		0.27	0.29	0.37	0.73	0.71	0.77	0.75	0.72	0.73	0.80	1.20	0.96	0.81				0.78				0.18	0.36
7/17/2001	0.91		0.35	0.22	0.54	0.90	0.91	0.90	0.94	0.91	0.91	0.95	1.40	0.94	1.10				1.00				0.20	0.29
7/24/2001	0.82		0.37	0.25	0.55	0.84	0.88	0.83	0.84	0.83	0.83	0.93	1.30	0.83	0.95				0.84				0.23	0.33
7/31/2001	0.83		0.35	0.26	0.67	0.86	0.84	0.85	0.86	0.86	0.84	0.93	1.40	0.88	1.00				0.86				0.21	0.25
8/7/2001	0.83		0.40	0.30	0.77	0.90	0.84	0.83	0.87	0.81	0.86	1.00	1.30	0.90	0.89				0.88				0.19	0.31
8/14/2001	1.00		0.32	0.26	0.68	0.91	0.93	0.95	0.96	1.50	0.91	1.00	1.60	0.92	1.10				0.95				0.18	0.25
8/21/2001	0.87		0.31	0.13	0.58	0.89	0.90	0.89	0.90	0.91	0.89	1.00	1.30	0.91	1.10				0.94				0.17	0.18
8/28/2001	0.32		0.89	0.13	0.57	0.87	0.92	0.87	0.88	0.88	0.89	0.92	1.30	0.85	1.00				1.10				0.19	0.17
9/4/2001	0.91		0.33	0.15	0.64	0.92	0.92	0.93	0.92	0.91	0.94	1.00	1.40	1.00	1.10				0.97				0.18	0.19
9/11/2001	0.74		0.27	0.16	0.54	0.78	0.76	0.76	0.77	0.74	0.74	0.88	1.20	0.79	0.84				0.77				0.13	0.19
9/18/2001	0.27		0.68	0.18	0.55	0.72	0.71	0.73	0.70	0.67	0.68	0.81	1.10	0.70	0.80				0.69				0.12	0.20
9/25/2001	0.96		0.39	0.11	0.75	0.93	1.00	0.98	0.96	1.30	0.97	1.10	1.40	0.99	1.30				1.00				0.23	0.13
10/2/2001	0.91		0.36	0.14	0.73	0.93	0.95	0.93	0.90	1.00	0.90	1.00	1.30	0.99	1.20				0.97				0.20	0.18
10/9/2001	1.00		0.41	0.15	0.95	1.00	1.10	1.10	1.00	1.00	1.00	1.20	1.60	1.20	1.40				1.20				0.19	0.21
10/16/2001	0.98		0.36	0.13	0.88	0.94	1.00	1.30	0.96	0.98	0.97	1.10	1.40	1.10	1.20				1.00				0.17	0.14
10/23/2001	1.10		0.44	0.17	0.95	1.00	1.20	1.10	1.00	1.20	1.00	1.10	1.50	1.10	1.20				1.10				0.26	
10/30/2001	1.00		0.46	0.18	0.93	1.00	1.20	1.10	1.00	1.00	1.00	1.10	1.50	1.20	1.30				1.10				0.26	
11/6/2001	1.10		0.51	0.14	0.95	1.10	1.30	1.20	1.10	1.10	1.20	1.30	1.60	1.20	1.40				1.30				0.34	
11/13/2001	1.10		0.46	0.11	0.99	1.10	1.20	1.20	1.10	1.10	1.10	1.30	1.60	1.30	1.50				1.10				0.30	0.11
11/20/2001	1.20		0.47	0.01	1.00	1.10	1.20	1.20	1.10	1.10	1.10	1.30	1.50	1.30	1.40				1.30				0.31	0.18
11/27/2001	1.10		0.51	0.17	1.00	1.10	1.30	1.20	1.10	1.10	1.10	1.20	1.20	1.10	1.50				1.20				0.29	0.13
12/4/2001	0.93		0.38	0.17	0.81	0.89	1.00	0.91	0.89	0.90	0.86	0.93	1.20	0.90	1.10				0.96				0.24	0.19
12/11/2001	0.88		0.39	0.21	0.85	0.89	0.93	0.88	0.82	0.90	0.82	0.95	0.87	1.00	1.00				0.96				0.25	0.23
12/18/2001	0.95		0.43	0.21	0.88	1.00	1.00	1.00	0.96	1.00	1.00	1.00	1.30	1.10	1.30				1.10				0.33	0.25
12/26/2001	0.83		0.39	0.19	0.79	0.84	1.10	0.82	1.00	0.88	0.99	1.10	1.40	0.88	1.30				1.10				0.27	0.20
1/2/2002	0.84		0.38	0.16	0.72	0.89	0.96	0.92	0.86	0.88	0.85	0.98	1.30	0.97	1.10				1.00				0.28	0.17
1/8/2002	0.96		0.39	0.16	0.77	0.95	1.20	0.99	0.96	0.92	0.92	1.10	1.40	1.00	1.30				1.10				0.30	0.16
1/15/2002	0.87		0.50	0.15	0.70	0.94	1.20	0.85	0.89	1.20	0.92	0.99	1.40	1.40	1.20				1.10					
1/22/2002	0.88		0.24	0.21	0.75	1.00	1.20	0.87	0.90	1.40	0.95	1.00	1.50	1.50	1.30				1.10					
1/29/2002	0.90		0.52	0.22	0.76	0.97	1.40	0.96	0.93	1.40	0.96	1.00	1.60	1.60	1.30				1.00					

NITRATES NO3 as N (mg/L)

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
2/5/2002	0.92		0.43	0.20	0.75	0.93	1.00	0.86	0.85	0.95	0.91	0.97	1.60	1.60	1.40				0.98				0.40	
2/12/2002	0.97		0.39	0.15	0.68	0.90	0.99	0.87	0.78	1.10	0.87	0.92	1.60	1.50	1.20				1.10					0.10
2/19/2002	0.83		0.43	0.19	0.73	0.87	1.10	0.88	0.91	1.60	0.91	0.92	1.60	1.60	1.30				1.10					0.14
2/26/2002	0.60		0.27	0.20	0.74	0.65	0.59	0.70	0.67	0.58	0.60	0.91	0.74	0.72	0.84				0.67			ND	0.38	0.15
3/5/2002	0.77		0.42	0.19	0.63	0.74	1.20	0.81	0.83	1.40	0.84	0.87	1.40	1.40	1.10				0.85					0.17
3/12/2002	0.80		0.44	0.23	0.72	0.80	1.30	0.83	0.90	1.40	0.83	0.89	1.50	1.50	1.30				1.00					0.22
3/19/2002	0.82		0.46	0.17	0.62	0.82	1.30	0.83	0.94	1.20	0.90	0.89	1.40	1.50	1.30				0.99					0.06
3/26/2002	1.00		0.32	0.13		0.82	1.00	0.83	0.98	1.20	0.83	0.86	1.40	1.40	1.20				0.98				0.34	0.07
4/2/2002	1.10		0.33	0.22		0.89	1.30	1.40	1.30	1.40	0.90	0.95	1.50	1.30	1.30				1.20				0.37	0.13
4/9/2002	0.79		0.22	0.12		0.73	1.10	0.84	0.89	1.10	0.78	0.81	1.10	1.10	1.00				0.91				0.24	0.11
4/16/2002	0.66		0.35	0.14	0.40	0.84	1.10	0.78	0.82	1.30	0.65	0.93	1.30	1.30	1.20				1.10					0.17
4/23/2002	0.51		0.24	0.19	0.31	0.64	0.60	0.60	0.52	0.64	0.54	0.74	1.10	0.54	0.71				0.65				0.28	0.18
4/30/2002	0.64		0.27	0.17	0.32	0.63	0.76	0.72	0.96	0.82	0.89	0.82	1.40	0.80	1.20				0.90				0.26	
5/7/2002	0.87		0.35	0.21	0.46	0.91	0.88	1.10	0.86	0.87	0.90	1.00	1.80	0.90	1.20				1.00				0.35	0.23
5/14/2002	0.89		0.24	0.09	0.41	0.86	1.20	0.87	0.85	0.85	0.85	1.00	1.70	0.90	1.40				0.96				0.23	0.08
5/21/2002	0.71		0.19	0.17		0.83	0.90	0.88	0.82	0.72	0.71	0.98	1.60	1.40	0.87				0.96			ND	0.36	0.22
5/28/2002	0.83		0.17	0.18		0.81	0.92	0.77	0.72	0.77	0.80	0.99	1.60	0.71	1.20				0.71			ND	0.28	0.24
6/4/2002	0.08		0.18	0.24		0.78	0.76	0.68	0.73	0.73	0.72	0.98	1.60	0.77	0.89				0.66			ND	0.27	0.29
6/11/2002	0.69		0.15	0.23		0.81	0.80	0.86	0.79	0.73	0.70	1.10	1.70	0.91	1.20				0.76			ND	0.28	0.28
6/18/2002	0.81		0.20	0.27		0.77	0.83	0.94	0.78	0.71	0.73	1.20	1.70		1.40				0.87			ND	0.27	0.31
6/25/2002	0.70		0.28	0.26	0.34	0.75	0.69	0.70	0.69	0.70	0.70	0.85	1.50	0.71	1.50				0.75				0.25	0.29
7/2/2002	0.73		0.30	0.25	0.38	0.80	0.77	0.80	0.76	0.73	0.72	0.91	1.70	0.73	1.00				0.80				0.23	0.26
7/9/2002	0.63		0.14	0.21		0.68	0.65	0.87	0.69	0.63	0.66	1.20	1.60	0.66	0.80				0.67			ND	0.20	0.24
7/16/2002	0.68		0.14	0.22		0.70	0.71	0.86	0.71	0.68	0.69	1.00	1.60	0.70	1.20				0.70			ND	0.22	0.20
7/23/2002	0.58	ND	0.15	0.22		0.62	0.64	0.80	0.58	0.55	0.58	0.86	1.40	0.59	0.75				0.60			ND	0.22	0.18
7/30/2002	0.83		0.23	0.26		0.72	0.73	0.81	0.72	0.67	0.72	1.10	1.50	0.85	0.95				0.73			ND	0.34	0.14
8/6/2002	0.50	ND	0.16	0.22		0.59	0.70	0.75	0.54	ND	0.55	0.98	1.30	0.54	0.52				0.65			ND	0.32	0.19
8/13/2002	0.56	ND	0.21	0.25		0.69	0.66	0.91	0.58	0.56	0.58	1.20	1.50		0.64				0.64			ND	0.42	0.24
8/15/2002														0.59										
8/20/2002	0.62	ND	0.26	0.28		0.70	0.69	0.95	0.62	0.60	0.62	1.20	1.50	0.62	0.74				0.63			ND	0.57	0.28
8/27/2002	0.73	0.60	0.33	0.26		0.76	0.80	0.97	0.75	0.82	0.74	1.30	1.60	0.78	0.77				0.73				0.54	0.30
9/3/2002	0.81	ND	0.28	0.37		0.88	0.95	1.10	0.87	0.78	0.82	1.20	1.60	0.98	1.20				0.92				0.40	0.15
9/10/2002	0.68	ND	0.28	0.40		0.85	0.82	0.90	0.74	0.70	0.71	1.50	1.60	0.93	1.10				0.80				0.38	0.31
9/17/2002	0.83	ND	0.29	0.47		0.84	0.81	0.99	0.78	0.81	0.81	1.60	1.60	0.86	1.10				0.81				0.39	
9/24/2002	0.90	ND	0.13	0.43		0.91	0.90	1.00	0.81	0.83	1.10	1.50	1.60	1.40	1.10				0.86					0.37
10/1/2002	1.10		0.40			1.10	1.10	1.40	1.20	1.40	1.20	1.60	1.50	1.50	1.40				1.30				0.40	0.40
10/8/2002	1.20		0.43			1.10	1.20	1.30	0.87	1.60	0.96	1.70	1.60	0.86	1.20				1.00				0.45	0.48
10/9/2002												1.30												
10/10/2002		ND										1.40										ND		
10/11/2002						1.20						1.30												
10/15/2002						0.58	1.40	1.30	0.88	1.50	0.76	1.00	1.50	1.50	1.40				1.00					
10/22/2002	1.10		0.74		0.66	0.85	1.30	1.10	1.20	1.50	1.10	1.20	1.50	1.10	1.30				1.20				1.00	0.31
10/29/2002	1.10		0.67	0.64	0.74	1.10	1.30	1.10	1.10	1.20	1.10	1.20	1.60	1.30	1.50				1.30				0.80	0.29
11/5/2002	0.72		0.49	0.34	0.63	1.00	0.75	0.81	0.82	0.73	0.84	0.95	1.60	1.10	1.40				0.96					0.30
11/12/2002	0.68		0.41	0.26	0.54	0.91	0.66	0.71	0.68	0.69	0.75	0.89	1.50	0.92	1.10				0.79					0.29

NITRATES NO3 as N (mg/L)																							
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
11/19/2002	0.69		0.38	0.29	0.49	0.85	0.91	0.73	0.70	0.70	0.76	0.79	1.50	0.82	1.20				0.75					0.18
11/26/2002	0.66		0.38	0.33	0.49	0.77	0.67	0.64	0.75	0.65	0.67	0.75	1.50	1.00	1.00				0.73					0.21
12/3/2002	0.65		0.39	0.29	0.49	0.68	0.81	0.62	0.66	1.10	0.65	0.72	1.50	1.20	0.80				0.72					0.27
12/10/2002	0.55		0.40		0.46	0.63	0.84	0.56	0.76	0.57	0.58	0.61	1.40	1.40	0.89				0.83					0.24
12/17/2002	0.54		0.39		0.44	0.57	1.20	0.54	0.67	1.40	0.59	0.58	1.40	1.40	1.00				0.72					0.24
12/23/2002	0.58		0.44		0.50	0.58	0.65	0.58	0.58	0.58	0.59	0.60	1.60	0.83	0.91				0.86					0.28
12/31/2002	0.59		0.46		0.56	0.60	1.60	0.58	0.62	0.61	0.60	0.62	1.60	0.65	0.98				0.59					0.27
1/7/2003	0.66		0.47		0.50	0.59	0.71	0.58	0.69	1.30	0.64	0.58	1.60	1.10	1.10				0.81					0.29
1/14/2003	0.56		0.43		0.54	0.55	0.84	0.55	0.62	1.50	0.56	0.60		1.50	1.20	0.60	0.60	0.92	0.64					0.27
1/21/2003	0.60		0.47		0.52	0.58	1.00	1.00	0.83	1.50	0.66	0.58		1.60	1.10	0.58	0.58	0.94	1.10					0.30
1/28/2003	0.57		0.45		0.50	0.58	0.98	0.60	0.65	1.20	0.60	0.57		1.60	1.20	0.60	0.58	1.10	1.00					0.26
2/4/2003	0.55		0.43		0.47	0.56	0.88	0.55	0.58	1.20	0.58	0.56		1.60	1.00	0.56	0.56	1.10	0.62					0.26
2/7/2003		<0.5																						
2/11/2003	0.53		0.47		0.50	0.57	0.86	0.58	0.56	1.00	0.63	0.56		1.70	0.65	0.56	0.57	1.00	0.58					0.25
2/19/2003	0.45		0.45		0.50	0.39	0.70	0.47	0.28	0.92	0.42	0.54		0.39	0.63	0.34	0.39	0.80	0.49					0.28
2/25/2003	0.52		0.46		0.53	0.37	0.70	0.51	0.56	1.50	0.58	0.45		1.50	0.81	0.46	0.37	0.98	0.75					0.20
2/26/2003						0.46	1.00	1.10	0.46	0.14	0.61	0.53		1.30	0.98	0.66	0.36	1.20	1.10					
3/19/2003						0.13	0.99	0.63	0.56	1.20	0.80	0.71		1.30	1.10	0.60	0.62	1.10	1.10		1.30			
7/6/2004	0.40		0.37	0.35	0.36	0.38	1.10	0.84	0.41	1.10	0.49	0.39		0.99	1.10	0.39	0.38	0.79	0.95					
12/21/2004	0.47					0.59	0.66	0.98	0.98	1.00	0.68	0.60		1.00	1.00	0.35	0.69	0.99	0.94					
1/19/2005	0.52					0.77	1.20	1.20	0.86	1.20	1.20	0.63		1.20	1.20	0.28	0.83	1.00	1.20					
4/12/2005	0.34					0.40	0.43	0.47	0.35	1.50	1.20	0.42		1.00	1.20	0.17	0.41	0.88	1.20					
7/19/05																								
12/6/05																								
1/6/2006						0.48	0.94	0.50	0.63	1.10	0.72	0.53		1.20	0.96	0.41	0.48	0.94	1.10					

NITRITES NO2 as N (mg/L)

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
7/31/75					<0.0005																	<0.0005		0.001
4/29/76					<0.0005																	<0.0005		<0.0005
5/26/77					<0.0005																	<0.0005		<0.0005
6/1/78					0.001																	0.004		0.004
5/21/79					<0.0005																	0.002		0.001
5/13/81	<0.0005				0.001																			
4/15/83					0.001																			
6/11/84		0.007		0.002	0.003																			
4/1/86		0.004		<0.002	0.004																	<0.002		<0.002
3/24/87				0.007	0.006																	0.003		0.005
3/25/88		0.012		0.003	<0.002																	<0.002		0.007
2/13/89		0.01			<0.002																	0.002		0.008
4/26/1989																					<0.002			
5/30/90	<0.002			0.008	0.006																<0.002	0.04		0.012
2/10/93		nd		nd																		nd	ND	ND
3/23/93	<0.01																				<0.01			
3/5/96	<0.05																				<0.05			
2/2/99	<0.02																				<0.02			
04/04/00	0.003	ND	ND	0.001	OFF	0.200	0.006	0.199											0.042			OFF	OFF	OFF
04/11/00	0.006	OFF	0.001	0.001	OFF	0.017	0.012	0.158	0.009	0.004	0.026	0.012	0.001	0.001	0.002				0.038			OFF	0.001	OFF
04/18/00	0.004	0.001	0.001	0.003	OFF	0.017	0.009	0.136	0.009	0.011	0.015	0.009	0.002	0.001	0.003				0.038			OFF	0.001	
04/25/00	0.002	OFF	ND	0.001	OFF	0.015	0.009	0.130	0.006	0.029	0.034	0.007	0.003	0.001	0.001				0.029			OFF	0.005	OFF
05/02/00	0.002	OFF	0.001	0.001	OFF	0.012	0.009	0.091	0.016	ND	0.022	0.009	ND	0.002	0.003				0.019			OFF	0.002	OFF
05/09/00	0.001	OFF	0.005	0.002	OFF	0.005	0.006	0.046	0.008	0.012	0.023	0.005	ND	NS	0.002				0.006			OFF	0.006	0.002
05/16/00	0.005	OFF	0.002	ND	OFF	0.003	OFF	0.045	0.003	0.008	0.005	0.002	0.002	0.001	0.018				0.005			OFF	ND	ND
05/23/00	0.003	OFF	ND	ND	OFF	0.004	0.006	0.083	0.003	0.015	0.016	0.012	0.002	0.005	0.018				0.014			OFF	0.001	0.002
05/30/00	0.003	OFF	ND	0.001	OFF	0.007	0.004	0.100	0.005	0.005	0.021	0.008	0.001	0.007	0.020				0.015			OFF	ND	0.002
06/06/00	0.003	ND	ND	OFF	OFF	0.006	0.009	0.151	0.012	0.011	0.023	0.016	0.003	0.015	0.023				0.018	0.014		OFF	ND	ND
06/13/00	0.001	OFF	ND	0.002	OFF	0.004	0.003	0.076	0.005	0.002	0.011	0.004	0.001	0.013	0.014				0.007	0.012		OFF	0.001	0.002
06/20/00	0.001	OFF	ND	0.003	OFF	0.007	0.001	0.002	0.001	0.012	0.002	0.003	0.001	0.002	0.003				0.001	0.009		OFF	0.001	0.002
06/27/00	0.003	OFF	0.001	0.001	OFF	0.006	0.004	0.050	0.004	0.003	0.008	0.010	0.004	0.014	0.019				0.011			OFF	ND	ND
06/27/00	BRL		BRL	BRL			BRL	0.070	BRL	BRL	BRL	BRL	BRL	0.030	0.020				0.020				BRL	BRL
07/05/00																				0.010				
07/05/00	BRL		BRL	0.020		BRL	BRL	0.110	BRL	BRL	BRL	0.020	BRL	BRL	0.020				BRL				BRL	BRL
07/11/00	BRL																							
07/11/00			BRL	BRL		BRL	BRL	0.130	BRL	0.030	0.040	BRL	BRL	0.040	0.040				0.030				BRL	BRL
07/18/00																				0.010				
07/18/00	BRL		BRL	0.360		0.020	BRL	0.050	BRL	BRL	0.020	BRL	0.020	0.030	0.070				0.030				BRL	BRL
07/25/00																				0.018				
08/01/00																				0.015				
08/08/00																				0.007				
08/15/00																				0.900				

NITRITES NO2 as N (mg/L)																								
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
08/22/00																				1.000				
08/22/00	ND			ND		ND	ND	0.060	ND	ND	ND	ND	ND	ND	ND				ND				ND	ND
08/26/00			ND																					
08/28/00															0.020									
08/29/00																				0.900				
08/29/00	ND			0.050		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.060				0.070				ND	ND
09/01/00																								
09/05/00			ND																					
09/05/00	ND			0.030		0.030	ND	0.070	0.020	0.020	0.040	ND	ND	0.030					0.030				0.020	0.030
09/06/00			0.030												0.030									
09/12/00	ND			ND		0.030	0.020	0.070	ND	0.030	0.030	ND	ND	ND	0.030				0.020				ND	ND
09/19/00			0.050																					
09/19/00	0.020			ND		0.040	ND	0.100	ND	ND	0.020	ND	ND	0.030	0.040				0.020				ND	ND
09/26/00			1.000																					
09/26/00	ND			ND		0.030	0.040	0.090	ND	ND	0.030	ND	ND	0.030	0.040				ND				ND	ND
10/03/00			ND																					
10/03/00	ND			ND		0.030	0.030	0.090	ND	ND	0.030	ND	ND						0.040				ND	ND
10/03/00			ND																					
10/04/00														BRL										
10/10/00	ND		ND	ND		0.070	ND	0.070	ND	ND	0.030	ND	ND	ND	0.040				ND				ND	ND
10/17/00	ND		ND	0.030		0.130	ND	ND	ND	ND	0.050	ND	ND	ND	0.030				ND				ND	ND
10/24/00	ND		ND	0.020		0.180	ND	0.060	ND	ND	0.090	ND	ND	ND	0.030				0.020				ND	0.020
10/31/00	ND		ND	ND		0.130	ND	0.030	ND	ND	0.070	ND	ND	ND	ND				ND				ND	
11/07/00	ND		ND	0.020		0.100	ND	0.030	ND	ND	0.080	ND	ND	ND	0.020				ND				ND	ND
11/14/00	ND		ND	ND		0.070	ND	0.040	ND	ND	0.030	ND	ND	ND	ND				ND				ND	
11/20/00	ND		ND	ND		0.050	ND	ND	ND	ND	0.040	ND	ND	ND	ND				ND				ND	
11/28/00	ND		ND	ND		0.040	ND	0.040	ND	ND	0.050	ND	ND	ND	ND				ND				ND	
12/05/00	ND		ND	ND		0.030	ND	0.050	ND	ND	0.040	ND	ND	ND	ND				ND				ND	
12/11/00	ND		ND	ND		ND	ND	0.050	ND	ND	0.040	ND	ND	ND	ND				ND				ND	
12/19/00	ND		ND	ND		ND	ND	0.030	ND	ND	ND	ND	ND	ND	ND				ND				ND	
12/26/00	ND		ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND				ND	
1/2/2001	ND		ND	ND		ND	ND	0.040	ND	ND	0.020	ND	ND	ND	ND				ND				ND	
1/9/2001	ND		ND	ND		ND	ND	0.060	ND	ND	0.030	0.020	ND	ND	ND				ND				ND	
1/16/2001	ND		ND	ND		0.200	ND	0.070	ND	ND	0.030	0.040	ND	ND	ND				ND				ND	
1/23/2001	ND		ND		ND	0.030	ND	0.050	ND	ND	ND	ND	ND	ND	ND				ND				ND	
1/30/2001	ND				ND	ND	ND	0.020	ND	ND	ND	0.040	ND	ND	ND				ND				ND	
2/7/2001	ND		ND		ND	ND		ND	ND	ND	ND	0.040	ND	ND	ND				ND				ND	
2/13/2001	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND		ND	ND				ND				ND	
2/20/2001	ND		ND				ND	ND		ND	ND		ND	ND					ND				ND	
2/21/2001					ND	ND			ND			ND			ND									
2/27/2001	ND		ND		ND	ND	ND	0.030	ND	ND	ND	ND		ND	ND				ND				ND	
3/8/2001	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND				ND	
3/13/2001	ND		ND	ND	ND	ND	ND	0.050	ND	ND	ND	0.030	ND	ND	ND				0.030				ND	

NITRITES NO2 as N (mg/L)																							
DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
3/20/2001	ND		ND	0.020	ND	ND	ND	0.030	ND	ND	ND	0.090	ND	ND	ND				ND				ND	
3/27/2001	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.080	ND	ND	ND				ND				ND	
4/3/2001	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.080	ND	ND	ND				ND				ND	
4/10/2001	ND		ND	ND	ND	ND	ND	0.020	ND	ND	ND	0.090	ND	ND	ND				ND				ND	
4/17/2001	ND		ND	0.020	ND	ND	ND	0.030	ND	ND	0.020	0.120	ND	ND	ND				0.050				ND	
4/24/2001	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.100	ND	ND	ND				ND				ND	
5/1/2001	ND		ND	ND	ND	ND	ND	0.300	ND	ND	0.020	0.090	ND	ND	ND				ND				ND	
5/8/2001	ND		ND	ND	ND	ND	0.020	0.050	0.030	ND	0.080	0.440	ND	ND	0.030				0.030			ND	ND	
5/15/2001	ND	0.020	ND	0.020	ND	0.020	ND	0.040	0.020	ND	0.030	0.170	ND	0.020	0.030				0.030			ND	ND	
5/22/2001	ND	ND	ND	ND	ND	ND	ND	0.030	ND	ND	ND	0.150	ND	ND	ND				ND				ND	ND
5/29/2001	ND		ND	ND		ND	ND	ND	ND	ND	ND	0.120	ND	ND	ND				ND				ND	ND
6/5/2001	ND		ND	0.030	ND	ND	ND	ND	ND	ND	ND	0.100	ND	ND	ND				ND				ND	ND
6/12/2001	ND	ND	ND	ND	ND	ND	ND	0.030	ND	ND	0.020	0.130	ND	ND	ND				ND				ND	ND
6/19/2001	ND	ND	ND	ND	ND	ND	ND	0.040	0.020	ND	0.030	0.140	ND	ND	0.030				0.030			ND		ND
6/26/2001	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.080	ND	ND	ND				ND				ND	ND
7/2/2001	ND	ND	ND	ND	ND	0.020	ND	0.030	ND	ND	0.030	0.070	ND	0.020	0.030				0.030					ND
7/11/2001	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.050	ND	ND	ND				ND				ND	ND
7/17/2001	ND		ND	0.020	ND	ND	ND	0.030	ND	ND	ND	0.050	ND	ND	ND				ND				ND	ND
7/24/2001	ND		ND	ND	ND	ND	ND	0.030	ND	ND	ND	0.050	ND	ND	ND				ND				ND	ND
7/31/2001	ND		0.040	0.020	ND	ND	ND	0.040	ND	ND	ND	0.030	ND	ND	ND				ND				ND	0.050
8/7/2001	ND		ND	ND	ND	ND	ND	0.050	ND	0.020	ND	0.060	ND	ND	ND				ND				ND	ND
8/14/2001	ND		ND	ND	ND	ND	ND	0.040	ND	ND	ND	ND	0.050	0.040	ND				ND				ND	ND
8/21/2001	ND		ND	0.020	ND	0.020	ND	0.070	ND	ND	ND	0.020	ND	ND	ND				ND				ND	ND
8/28/2001	ND		ND	ND	ND	0.080	ND	0.050	ND	ND	ND	ND	ND	ND	ND				ND				ND	ND
9/4/2001	ND		ND	ND	ND	0.070	ND	0.050	ND	ND	0.030	0.030	ND	0.020	0.020				0.020				ND	ND
9/11/2001	ND		ND	ND	ND	0.070	ND	0.070	ND	ND	0.040	0.020	ND	ND	0.030				ND				ND	ND
9/18/2001	ND		ND	ND	ND	0.110	ND	0.100	ND	ND	0.050	0.030	ND	0.040	0.040				0.020				ND	ND
9/25/2001	ND		ND	0.020	ND	0.110	0.020	0.090	0.020	ND	0.070	ND	ND	ND	0.030				0.030				ND	0.020
10/2/2001	ND		ND	0.020	ND	0.120	ND	0.050	0.030	ND	0.060	ND	ND	0.030	0.040				0.040				ND	ND
10/9/2001	ND		ND	ND	ND	0.020	ND	0.090	0.030	ND	0.070	ND	ND	ND	0.040				0.030				ND	ND
10/16/2001	ND		ND	ND	ND	0.140	ND	0.030	0.020	ND	0.080	ND	ND	ND	0.050				0.030				ND	ND
10/23/2001	ND		ND	ND	ND	0.200	ND	0.020	0.020	ND	0.700	ND	ND	0.030	0.040				0.030				ND	
10/30/2001	ND		ND	ND	ND	0.180	ND	0.030	0.040	ND	0.060	ND	ND	ND	0.020				0.020				ND	
11/6/2001	ND		ND	ND	ND	0.150	0.050	0.030	0.030	ND	0.060	ND	ND	ND	0.020				ND				ND	
11/13/2001	ND		ND	ND	ND	0.120	0.070	0.040	0.030	ND	0.070	ND	ND	ND	ND				0.020				ND	0.020
11/20/2001	ND		ND	ND	ND	0.100	ND	0.050	0.040	ND	0.070	ND	ND	0.040	ND				ND				ND	ND
11/27/2001	ND		ND	ND	ND	0.050	ND	ND	ND	ND	0.040	ND	ND	ND	ND				ND				ND	ND
12/4/2001	ND		ND	ND	ND	0.040	ND	ND	0.030	ND	0.030	ND	ND	ND	ND				ND				ND	ND
12/11/2001	ND		ND	ND	ND	0.040	0.020	ND	ND	ND	0.070	ND	ND	ND	ND				ND				ND	ND
12/18/2001	ND		ND	0.020	ND	ND	ND	0.050	0.040	ND	0.050	0.020	ND	ND	ND				ND				ND	ND
12/26/2001	ND		ND	ND	ND	ND	ND	ND	0.020	ND	0.070	ND	ND	ND	ND				0.030				ND	ND
1/2/2002	ND		ND	ND	ND	0.030	ND	0.050	ND	ND	0.030	ND	ND	ND	ND				ND				ND	ND
1/8/2002	ND		ND	ND	ND	0.020	ND	0.030	0.020	ND	0.040	ND	ND	ND	ND				ND				ND	ND

NITRITES NO2 as N (mg/L)

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
1/15/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.040	ND	ND				0.020					
1/22/2002	ND		0.040	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					
1/29/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					
2/5/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND				ND	
2/12/2002	ND		ND	ND	ND	ND	ND	ND	0.020	ND	ND	ND	ND	0.040	ND				ND					ND
2/19/2002	ND		ND	ND	ND	0.020	0.020	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.020
2/26/2002	ND		ND	ND	ND	ND	ND	0.090	ND	ND	0.040	ND	0.020	0.030	0.040				ND			ND	ND	ND
3/5/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.090	ND	ND	0.030				0.050					ND
3/12/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.030	ND	ND	ND				ND					ND
3/19/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.040	ND	ND	ND				ND					0.020
3/26/2002	ND		ND	ND		ND	ND	ND	ND	ND	ND	0.030	ND	ND	ND				ND				ND	ND
4/2/2002	ND		ND	ND		ND	ND	0.020	ND	ND	0.020	0.060	ND	ND	ND				ND				ND	ND
4/9/2002	ND		ND	ND		ND	ND	0.060	ND	ND	0.040	0.140	ND	ND	ND				ND				ND	ND
4/16/2002	ND		ND	ND	ND	ND	ND	0.030	ND	ND	ND	0.080	ND	ND	ND				ND					ND
4/23/2002	ND		ND	ND	ND	ND	ND	0.040	0.030	ND	0.040	0.180	ND	ND	0.040				ND				ND	ND
4/30/2002	ND		ND	ND	ND	ND	ND	0.030	ND	ND	0.020	0.120	0.020	ND	ND				ND				ND	
5/7/2002	ND		ND	0.020	ND	ND	ND	0.080	ND	ND	0.030	0.080	ND	0.020	ND				ND				ND	0.020
5/14/2002	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	0.060	ND	ND	ND				ND				ND	ND
5/21/2002	ND		ND	0.030		ND	ND	0.090	ND	0.020	0.020	0.070	ND	ND	0.030				0.030			ND	ND	0.030
5/28/2002	ND		ND	ND		ND	0.040	0.120	0.040	0.030	0.050	0.120	ND	0.030	0.030				0.030			ND	ND	ND
6/4/2002	ND		ND	ND		ND	ND	0.030	0.030	0.020	0.040	0.120	ND	0.020	0.020				0.050			ND	ND	ND
6/11/2002	ND		ND	ND		0.040	0.040	0.110	0.030	0.020	0.040	0.150	ND	0.030	0.020				0.050			ND	ND	ND
6/18/2002	ND		ND	ND		0.030	0.030	0.110	0.030	ND	0.040	0.170	ND	0.030	0.030				0.030			ND	ND	ND
6/25/2002	ND		ND	ND	ND	ND	ND	0.020	ND	ND	ND	0.100	ND	ND	ND				ND				ND	ND
7/2/2002	ND		ND	ND	ND	ND	ND	0.016	ND	ND	0.013	0.100	ND	0.024	ND				ND				ND	ND
7/9/2002	0.023		0.017	0.017		0.023	0.022	0.120	0.090	0.024	0.033	0.110	ND	0.021	0.028				0.037			ND	ND	ND
7/16/2002	0.028		0.011	0.022		0.030	0.033	0.110	0.051	0.045	0.046	0.120	ND	0.043	0.026				0.045			ND	ND	0.018
7/23/2002	0.017	0.013	ND	ND		0.021	0.024	0.110	0.026	0.016	0.028	0.130	ND	0.025	0.022				0.033			ND	ND	0.015
7/30/2002	0.016		0.019	0.016		0.028	0.032	0.098	0.032	0.020	0.034	0.170	ND	0.041	0.023				0.039			ND	ND	0.013
8/6/2002	ND	0.016	ND	ND		0.017	0.012	0.210	0.025	0.013	0.026	0.170	ND	0.026	0.032				0.030			ND	0.012	0.011
8/13/2002	ND	0.012	ND	0.015		0.066	ND	0.280	0.025	ND	0.035	0.240	ND		0.037				0.051			ND	ND	0.016
8/15/2002														0.012										
8/20/2002	0.018	ND	0.012	0.014		0.047	0.025	0.280	0.030	0.017	0.044	0.540	ND	0.026	0.033				0.038			ND	ND	0.015
8/27/2002	0.023	0.013	0.021	0.020		0.052	0.043	0.230	0.034	0.036	0.048	1.000	ND	0.018	0.043				0.040				0.012	0.017
9/3/2002	0.012	ND	ND	0.011		0.032	0.022	0.150	0.020	ND	0.031	0.140	ND	0.015	0.025				0.032				ND	0.017
9/10/2002	0.015	0.013	0.012	0.013		0.040	0.030	0.170	0.032	0.030	0.040	0.290	ND	0.034	0.026				0.035				0.011	0.015
9/17/2002	0.014	ND	ND	ND		0.037	0.020	0.140	0.027	0.021	0.047	0.420	ND	0.032	0.026				0.031				0.013	
9/24/2002	0.014	ND	0.013	ND		0.042	0.039	0.280	0.027	0.052	0.056	0.610	ND	0.054	0.036				0.036					0.012
10/1/2002	0.020		0.014			0.016	0.021	0.330	0.030	0.048	0.068	1.100	ND	0.011	0.046				0.045				0.011	0.016
10/8/2002	0.016		ND			0.050	0.055	0.370	0.039	0.026	0.081	1.300	ND	0.039	0.058				0.066				ND	0.012
10/9/2002												1.100												
10/10/2002		0.014										1.000										0.011		
10/11/2002						0.270						0.390												

NITRITES NO2 as N (mg/L)

DATE	BUTTERS ROW FINISH	BUTTERS ROW #1	BUTTERS ROW RAW	BUTTERS ROW #2	SHAWSHEEN AVE. Well	HILLSIDE (WAY) TANK	NASSAU TANK	DEMING WAY	900 MAIN ST.	634 MAIN ST.	333 BURLINGTON AVE.	27 HILLSIDE WAY	21 JONES AVE.	14 FAIRMONT AVE.	5 RHODE ISLAND RD.	91 MARION STREET	25 MILL ROAD	21 OX BOW DRIVE	WEST (INTERMEDIATE) SCHOOL	MARION ST. (LAST HYDRANT)	Sargent Finish	CHESTNUT ST.	CHESTNUT ST. 1A	TOWN PARK
10/15/2002						0.460	0.160	0.110	0.093	ND	0.190	0.540	ND	ND	0.100				0.140					
10/22/2002	ND		ND		ND	0.110	0.018	0.047	0.025	ND	0.044	0.036	ND	0.017	0.045				0.042				ND	0.017
10/24/2002																								
10/29/2002	0.012		ND	ND	ND	0.086	ND	0.056	0.019	0.026	0.035	0.058	ND	0.017	0.034				0.020				ND	0.014
11/5/2002	ND		ND	ND	ND	0.100	ND	0.019	ND	ND	ND	0.074	ND	ND	0.061				ND					0.017
11/12/2002	ND		0.011	0.017	ND	0.047	ND	ND	ND	ND	ND	0.077	ND	0.013	ND				ND					0.016
11/19/2002	ND		0.015	0.020	ND	ND	ND	ND	ND	ND	ND	0.015	ND	ND	ND				ND					0.019
11/26/2002	ND		0.011	0.014	ND	ND	ND	ND	ND	ND	ND	0.011	ND	ND	ND				ND					0.015
12/3/2002	ND		0.014	0.014	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.015
12/10/2002	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.015
12/17/2002	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.016
12/23/2002	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND				ND					0.016
1/14/2003	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	0.011	ND					0.018
1/21/2003	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND					0.014
1/28/2003	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND					0.014
2/4/2003	ND		0.011		ND	ND	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND					0.014
2/11/2003	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND					0.016
2/19/2003	ND		ND		ND	ND	ND	ND	ND	ND	ND	ND		0.029	ND	ND	ND	ND	ND					0.016
2/25/2003	0.014		ND		ND	0.091	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND					0.011
2/26/2003						BDL	BDL	BDL	BDL	BDL	BDL	BDL		BDL	BDL	BDL	BDL	BDL	BDL					
3/19/2003						<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01			
4/6/2004	<0.01																							
7/6/2004	ND		ND		ND	ND	0.016	ND	ND	0.031	0.013	ND		0.014	ND	ND	ND	0.014	ND					
1/19/2005	ND					ND	ND	ND	ND	ND	ND	ND		ND	ND	0.190	ND	0.014	ND					
4/12/2005	ND					ND	ND	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND					
7/19/05	<0.01					<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					
12/6/05	<0.01					<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01			
1/6/2006						<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	0.020	<0.01	<0.01	0.020	<0.01					

Total Trihalomethanes (THM) (ug/L)								
Date	90 Industrial Way	End of Chestnut St. (#414)	30 Industrial Way	2 Industrial Way	47 Marion St.	9 Burt Road	18 Allen Park Dr.	Avco - ?? Progress Way
11/24/82	40	11	40	40	6.5	4.6	9.3	49
6/10/83	51		52	43	8.6	13	7.7	47
9/12/83	98		92	74	16		34	102
11/10/83	107		73	83				90
5/8/84	63		60	59			nd	61
8/22/84	29		29	26			7.8	26
2/5/85	8	12	22	5	4	9	3	9
4/4/85	68	8	66	62	8	2	nd	67
7/12/85	75	12	55	50	10	10	12	90
11/7/85	36	10	30	37	9	8	12	38
2/3/86	7	10	5	7	9	9	8	7
4/30/86	6.5	7.8	7.1	5.9	2.3	5.6	7	7
7/31/86	8.8	11.2	7	7	7.6	7.7	5.5	8.1
12/2/86	1.7	6						
12/16/87	1	3.8						
12/12/88	<1.0	<1.0						
10/16/90	2.4	0.6						
8/21/91	1.2	<0.5						
3/23/93	12.9	7.7						
5/19/93	14.8	8.6						
11/10/93	1.2	0.9						
2/14/94	1.9	<0.5						
6/22/94	0.9	1.6						
8/23/94	1.9	1.7						
11/22/94	4.7	2.3						
2/13/95	2.4	0.5						
5/23/95	<0.5	3.4						
9/11/95	<0.5	2						
3/5/96	4.8	1.2						
4/2/96	2.6	2.6						
8/6/96	2	2						
10/1/96	9.5	1						
1/7/97	4	1.6						
4/2/97	5	2						
7/1/97	3	1						
10/7/97	7	1.5						
1/6/98	4.5	2						
4/7/98	5	1						
7/7/98	6	0.9						
10/6/98	12	2						
2/2/99	4	1						
4/6/99	9	1						
7/6/99	6	1						
10/5/99	5	1						
1/4/00	10	3						
4/4/00	7	3						

Total Trihalomethanes (THM) (ug/L)									
Date	90 Industrial Way	End of Chestnut St. (#414)	30 Industrial Way	2 Industrial Way	47 Marion St.	9 Burt Road	18 Allen Park Dr.	Avco - ?? Progress Way	
7/5/00	30	19							
10/3/00	24	23							
1/16/01	22.4	16.1							
4/17/01	16	6.7							
7/2/01	16	15.8							
10/2/01	22	29							
1/8/02	21	20							
4/2/02	28	14							
7/2/02	26	12							
10/1/02	9.6	3.7							
11/13/02	46	58							
1/7/03		97							
3/4/03	83	33							
4/1/03	18	24							
7/1/03	72	23							
10/7/03	60	200							
2/3/04	60	94							
4/6/04	39	76							
7/6/04	57	85							
10/19/04	80	93							
1/4/05	110	76							
4/5/05	86	72							
8/16/05	31	130							
11/1/05	8.3	48							
1/6/06	59	41							

Trichloroethene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	11 Weber St.
2/7/79								nd			nd									
11/25/80						nd *	1.6	3.4	nd		nd									
1/9/81							nd													
1/16/81	1.4																			
9/21/81									nd											
12/1/81	1.5																			
12/7/81	1.1																			
12/14/81	3.3																			
12/14/81(d)	3.3																			
1/7/82	0.8																			
1/7/82 (d)	0.8																			
1/13/82	2.4																			
2/22/82	0.3																			
3/1/82	0.2																			
3/8/82	0.4																			
3/15/82	0																			
3/22/82	0																			
3/29/82	0.8																			
4/5/82	0.5																			
4/16/82	0																			
4/26/82	0.1																			
5/3/82	0.2																			
5/10/82	0.2																			
5/17/82	0.2																			
5/24/82	0.1																			
6/1/82	0.1																			
6/7/82	0.3																			
6/7/82 (d)	0.2																			
6/14/82	0.8																			
6/14/82 (d)	0.5																			
6/21/82	1																			
6/28/82	0.3																			
7/6/82	0.4																			
7/12/82	0.3																			
7/19/82	0.3																			
7/26/82	0.2																			
8/2/82	0.4																			
8/12/82	0.5																			
8/16/82	0.5																			
8/23/82	0.5																			
8/30/82	0.7																			
9/7/82	0																			
9/13/82	0.7																			

Trichloroethene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	11 Weber St.
9/20/82	0																			
9/27/82	1																			
10/4/82	0.8																			
10/11/82	5.3																			
10/18/82	1.2																			
10/25/82	2.2																			
1/3/83	2.5																			
5/16/83	3.6																			
9/6/83	21																			
9/6/83 (d)	20																			
9/14/83	14	518	18																	
9/14/83 (d)	15	529			20		nd													
10/4/83	12	570	45		12		nd													
10/11/83	12	620	42		12		nd													
10/19/83	11																			
10/25/83	12																			
2/16/84													26				2.5			
4/11/84													2							
5/15/84	nd																			
6/11/84	nd																			
12/12/84	21																			
1/1/85	18																			
1/4/85	20	491	438		26		201													
3/1/85	18																			
4/1/85	12																			
4/4/85												15	1.7	15	15	11	5.8			
4/29/85			32		13		<1.0													
8/1/85	27	206	8																	
8/1/85 (d)	25				11		nd													
8/7/85										<1										
10/31/85	19	180	4.9																	
11/19/85	27	178	5		13		nd													
11/19/85 (d)	22		6		12															
2/1/86	13	139			11		nd													
2/11/86		130	11		15		nd													
3/3/86	13	147	11		7.4		nd													
3/3/86 (d)	17		11																	
4/29/86	9.8	96	2.8		12		<1													
6/1/86	9.4	73	1		9.6		nd													
7/14/86	11	68	1.9		11		<1													
7/31/86												9.4	8.6	9.8	8.6	7.6	9			
9/9/86	14	108	0.5		21		nd													
10/23/86	18	240	<1		20		<1													
1/30/87	22	138	21		25		nd													

Trichloroethene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	11 Weber St.
2/1/87	14	97	8.6		17		<1													
5/5/87	8.8	54	3.4		9.7		<1													
6/1/87	8.5	52	2.6		11		<1													
7/7/87	<1	51	2		25		<1													
11/1/87	0.6	165	21		18		1.2													
2/8/88	<1	39	2		9		<1													
3/16/88									<2	<2	<2									
5/17/88	<1																			
7/11/88	<1	17	<1		8.4		<1													
8/1/88	nd	22	nd		4.5		nd													
9/7/88	0.6									nd	nd									
9/29/88									nd											
10/28/88	1.4	26	1.4		6.2		<1													
3/17/89	0.8																			
8/22/89	nd	7.7	0.2																	
8/22/89 (d)		7.3	0.5	nd	5.2		1.3													
3/30/90	nd																			
7/1/90	0.2	7.5	nd		6.2		3.2													
7/1/90 (d)		nd			nd		nd													
7/1/90 (d)					nd															
10/22/90	nd			nd																
3/5/91	nd			nd																
5/3/91	nd			nd																
7/17/91	<0.1	4.6	0.2		2	1.6														
8/21/91	nd			nd *																
8/12/92																		<1	<1	
11/13/92				nd *																
4/1/93		nd *	nd	nd *	nd *	nd *														
9/13/93		4.6	0.1		3.2	4.1														
2/14/94		nd *	nd	nd	nd *	nd *														
2/14/95		nd *	nd	nd *	nd *	nd *														
2/21/95		1.3 s	nd		nd *	5														
3/5/96	nd	1.4 c	0.5	nd *		6.6														
3/27/96					1	nd														
8/8/96		nd *	nd *		nd *	nd *														
10/1/96		nd *	nd *		nd *	nd *														
1/7/97		nd *	nd *	nd *	nd *	nd *														
4/2/97		nd *	nd *		nd *	nd *														
7/1/97		nd *	nd *		nd *	nd *														
10/6/98	nd	nd *	nd *		nd *	nd *														
1/6/98		nd *	nd *	nd *	nd *	nd *														
4/7/98		nd *	nd *		nd *	nd *	nd *													
7/7/98		nd *	nd *	nd *	nd *	nd *	nd *													
2/2/99		nd *	nd *	nd *	nd *	nd *	nd *													

Trichloroethene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	11 Weber St.
4/6/99		nd *	nd *		nd *	nd *	nd *													
7/6/99		nd *	nd *		nd *	nd *	nd *													
10/5/99		nd *	nd *		nd *	nd *	nd *													
1/4/00		nd *	nd *	nd	nd *	nd *	nd *													
4/4/00		nd *	nd *	nd	nd *	nd *	nd *													
7/5/00		nd *	nd *	nd	nd *	nd *	nd *													
10/3/00		nd *	nd *		nd *	nd *	nd *													
1/16/01		nd *	nd *	nd *	nd *	nd *	nd *													
4/17/01		nd *	nd *		nd *	nd *	nd *													
7/2/02	nd	nd *	nd *		nd *	nd *	nd *													
10/2/01		nd *	nd *		nd *	nd *	nd *													
1/8/02		nd *	nd *	nd *	nd *	nd *	nd *													
4/2/02		nd *	nd *		nd *	nd	nd *													
9/15/02																				nd
10/1/02	nd																			
10/8/02		nd	nd		1.1	0.5														

* = Composite sample; d = duplicate sample

Tetrachloroethylene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	12 Weber St.
11/25/80						nd *				1.4										
1/9/81							nd													
1/16/81	0																			
9/28/81									nd											
12/1/81	0																			
12/7/81	0																			
12/14/81	0																			
12/14/81 (d)	0																			
1/7/82	0.6																			
1/7/82 (d)	0																			
1/13/82	0																			
2/22/82	0.1																			
3/1/82	0																			
3/8/82	0																			
3/15/82	0																			
3/22/82	0																			
3/29/82	0																			
4/5/82	0																			
4/16/82	0																			
4/26/82	0.5																			
5/3/82	0																			
5/10/82	0																			
5/17/82	0																			
5/24/82	0																			
6/1/82	0																			
6/7/82	0																			
6/7/82 (d)	0.1																			
6/14/82	0.1																			
6/14/82 (d)	0.1																			
6/21/82	0.6																			
6/28/82	0.8																			
7/6/82	0.9																			
7/12/82	0																			
7/19/82	0																			
7/26/82	0																			
8/2/82	0																			
8/12/82	0																			
8/16/82	0																			
8/23/82	0																			
8/30/82	0																			
9/7/82	0																			
9/13/82	0																			
9/20/82	0																			
9/27/82	0																			
10/4/82	0																			
10/11/82	0																			
10/18/82	0																			

Tetrachloroethylene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	12 Weber St.
10/25/82	0																			
1/3/83	nd																			
5/16/83	nd																			
9/6/83	0.2																			
9/6/83 (d)	0.1																			
9/14/83	nd	3.4	nd																	
9/14/83 (d)	nd	3.3			nd		nd													
10/4/83	3.7	3.7	nd		nd		nd													
10/11/83	nd	5.1	nd		nd		nd													
10/19/83	nd																			
10/25/83	nd																			
6/11/84	nd																			
12/12/84	nd																			
1/4/85	nd	5	4.4		nd		1.2													
10/31/85	<1	1.2	nd																	
11/19/85	nd	2	nd		nd		nd													
11/19/85 (d)	nd		nd		nd															
2/11/86		1.3																		
4/29/86	<1	<1	<1																	
7/14/86	<1	<1	<1																	
7/31/86												<1	<1	<1	<1	<1	<1			
10/29/86	nd	0.75	nd		nd		nd													
1/30/87	nd	1.3	0.1		0.1		nd													
7/7/87	<1	<1	<1		<1		<1													
2/8/88	<1	<1	<1		<1		<1													
3/16/88									<2	<2	<2									
8/1/88	nd	nd	nd		nd		nd													
9/7/88	nd									nd	nd									
9/29/88									nd											
10/28/88	<1	<1	<1		<1		<1													
3/17/89	nd																			
8/22/89	nd	nd	nd																	
8/22/89 (d)		nd		nd	nd		nd													
3/30/90	nd																			
7/1/90	0.1		0.4																	
7/1/90 (d)		2.9			0.4		0.2													
7/1/90 (d)					0.2															
10/22/90	nd			nd																
3/5/91	nd			nd																
5/3/91	nd			nd																
7/17/91	<0.1	<0.1	<0.1		<0.1	<0.1														
8/21/91	nd			nd *																
8/12/92																		<1	<1	
11/13/92				nd *																
4/1/93		nd *	nd *	nd *	nd *	nd														
9/13/93																				
2/14/94		nd *	nd *	nd	nd *	nd *														
2/14/95		nd *	nd	nd *	nd *	nd														

Tetrachloroethylene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	12 Weber St.
2/21/95		nd	nd		nd	nd														
3/5/96	nd	nd	0.7	nd *		1.2														
3/27/96					nd	nd														
8/8/96		nd *	nd *		nd *	nd *														
10/1/96		nd *	nd *		nd *	nd														
1/7/97		nd *	nd *	nd *	nd *	nd														
4/2/97		nd *	nd *		nd *	nd														
7/1/97		nd *	nd *		nd *	nd														
10/6/98	nd	nd *	nd *		nd *	nd														
1/6/98		nd *	nd *	nd *	nd *	nd														
4/7/98		nd *	nd *		nd *	nd	nd *													
7/7/98		nd *	nd *	nd *	nd *	nd	nd													
2/2/99		nd *	nd *	nd	nd *	nd	nd													
4/6/99		nd *	nd *		nd *	nd	nd													
7/6/99		nd *	nd *		nd *	nd	nd													
10/5/99		nd *	nd *		nd *	nd	nd													
1/4/00		nd *	nd *	nd *	nd *	nd	nd													
4/4/00		nd *	nd *	nd	nd *	nd	nd													
7/5/00		nd *	nd *	nd	nd *	nd	nd													
10/3/00		nd *	nd *		nd *	nd	nd													
1/16/01		nd *	nd *	nd	nd *	nd	nd													
4/17/01		nd *	nd *		nd *	nd	nd													
7/2/02	nd	nd *	nd *		nd *	nd	nd													
10/2/01		nd *	nd *		nd *	nd	nd													
1/8/02		nd *	nd *	nd	nd *	nd	nd													
4/2/02		nd *	nd *		nd *	nd	nd													
9/15/02																				nd
10/1/02	nd																			
10/8/02		nd	nd		nd	nd														

* = Composite sample; d = duplicate sample

1,1 Dichloroethene (ug/L)

Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	13 Weber St.
11/25/80						nd *														
1/9/81							nd													
1/16/81	2.6																			
9/28/81									nd											
12/1/81	0																			
12/7/81	0																			
12/14/81	0																			
12/14/81 (d)	0																			
1/7/82	0																			
1/7/82 (d)	0																			
1/13/82	0																			
2/22/82	0																			
3/1/82	0																			
3/8/82	0																			
3/15/82	0																			
3/22/82	0																			
3/29/82	0																			
4/5/82	0																			
4/16/82	0																			
4/26/82	0																			
5/3/82	0																			
5/10/82	0																			
5/17/82	0																			
5/24/82	0																			
6/1/82	0																			
6/7/82	0																			
6/7/82	0																			
6/14/82	0																			
6/14/82 (d)	0																			
6/21/82	0																			
6/28/82	0																			
7/6/82	0																			
7/12/82	0																			
7/19/82	0																			
7/26/82	0																			
8/2/82	0																			

1,1 Dichloroethene (ug/L)

Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	13 Weber St.
8/12/82	0																				
8/16/82	0																				
8/23/82	0																				
8/30/82	0																				
9/7/82	0																				
9/13/82	0																				
9/20/82	0																				
9/27/82	0																				
10/4/82	0																				
10/11/82	0																				
10/18/82	0																				
10/25/82	0																				
1/3/83	nd																				
5/16/83	nd																				
9/6/83	nd																				
9/6/83	0.1																				
9/14/83	nd	nd	nd																		
9/14/83 (d)	nd	nd			nd		nd														
10/4/83	nd	nd	nd		nd		nd														
10/11/83	nd	nd	nd		nd		nd														
10/19/83	nd																				
10/25/83	nd																				
6/11/84	nd																				
12/12/84	nd																				
1/4/85	nd	1	2.8		nd		0.6														
2/11/86		1.3																			
4/29/86	<1	<1	<1		<1		<1														
6/1/86																					
7/14/86	<1	<1	<1		<1		<1														
7/31/86												<1	<1	<1	<1	<1	<1				
10/23/86							<1														
7/7/87	<1	<1	<1		<1		<1														
11/1/87																					
2/8/88	<1	<1	<1		<1		<1														
3/16/88									<2	<2	<2										
7/11/88		<1																			
8/1/88	nd	nd	nd		nd		nd														

1,1 Dichloroethene (ug/L)																					
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	13 Weber St.
9/7/88	nd									nd	nd									
9/29/88									nd											
10/28/88	<1	<1	<1		<1		<1													
3/17/89	nd																			
8/22/89				nd																
3/30/90	nd																			
10/22/90	nd			nd																
3/5/91	nd			nd																
5/3/91	nd			nd																
8/21/91	nd			nd *																
8/12/92																		<1	<1	
11/13/92				nd *																
4/1/93		nd *	nd *	nd *	nd *	nd *														
9/13/93																				
2/14/94		nd *	nd *	nd *	nd *	nd *														
2/14/95		nd *	nd *	nd *	nd *	nd *														
2/21/95		nd	nd		nd	nd														
3/5/96	nd	nd	nd	nd		nd														
3/27/96					nd	nd														
8/8/96		nd *	nd *		nd *	nd *														
10/1/96		nd *	nd *		nd *	nd *														
1/7/97		nd *	nd *	nd *	nd *	nd *														
4/2/97		nd *	nd *		nd *	nd *														
7/1/97		nd *	nd *		nd *	nd *														
10/6/98	nd	nd *	nd *		nd *	nd *														
1/6/98		nd *	nd *	nd *	nd *	nd *														
4/7/98		nd *	nd *		nd *	nd *	nd *													
7/7/98		nd *	nd *	nd *	nd *	nd *	nd *													
2/2/99		nd *	nd *	nd *	nd *	nd *	nd *													
4/6/99		nd *	nd *		nd *	nd *	nd *													
7/6/99		nd *	nd *		nd *	nd *	nd *													
10/5/99		nd *	nd *		nd *	nd *	nd *													
1/4/00		nd *	nd *	nd *	nd *	nd *	nd *													
4/4/00		nd *	nd *	nd *	nd *	nd *	nd *													
7/5/00		nd *	nd *	nd *	nd *	nd *	nd *													
10/3/00		nd *	nd *		nd *	nd *	nd *													
1/16/01		nd *	nd *	nd	nd *	nd *	nd *													

1,1 Dichloroethene (ug/L)

Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	13 Weber St.
4/17/01		nd *	nd *		nd *	nd *	nd *													
7/2/02	nd	nd *	nd *		nd *	nd *	nd *													
10/2/01		nd *	nd *		nd *	nd *	nd *													
1/8/02		nd *	nd *	nd	nd *	nd *	nd *													
4/2/02		nd *	nd *		nd *	nd *	nd *													
9/15/02																				nd
10/1/02	nd																			
10/8/02		nd	nd		nd	nd														

* = Composite sample; d = duplicate sample

1,2-Dichloroethene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	14 Weber St.
11/25/80						0.9 * c														
1/9/81							nd													
1/16/81	1.7																			
9/28/81									nd											
12/1/81	0																			
12/7/81	0																			
12/14/81	0																			
12/14/81 (d)	0																			
1/7/82	0																			
1/7/82 (d)	0																			
1/13/82	0																			
2/22/82	0																			
3/1/82	0																			
3/8/82	0																			
3/15/82	0																			
3/22/82	0																			
3/29/82	0																			
4/5/82	0																			
4/16/82	0																			
4/26/82	0																			
5/3/82	0																			
5/10/82	0																			
5/17/82	0																			
5/24/82	0																			
6/1/82	0																			
6/7/82	0																			
6/7/82 (d)	0																			
6/14/82	0																			
6/14/82 (d)	0.1																			
6/21/82	0.1																			
6/28/82	0.2																			
7/6/82	0.2																			
7/12/82	0.2																			
7/19/82	0.1																			
7/26/82	0																			
8/2/82	0.6																			
8/12/82	0																			
8/16/82	0																			
8/23/82	0																			
8/30/82	0																			
9/7/82	0																			
9/13/82	0																			
9/20/82	0																			
9/27/82	0																			
10/4/82	0																			
10/11/82	0																			
10/18/82	0																			

1,2-Dichloroethene (ug/L)																				
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	14 Weber St.
10/25/82	0																			
1/3/83	nd																			
5/16/83	1.1																			
9/6/83	2.6																			
9/6/83 (d)	2.8																			
9/14/83	1.4	26.2	5.6																	
9/14/83 (d)	1.7	25.8			0.5		nd													
10/4/83	0.9	26	6.5		nd		nd													
10/11/83	1.1	29	6.8		nd		nd													
10/19/83	0.6																			
10/25/83	0.6																			
6/11/84	nd																			
12/12/84	4.1																			
1/4/85	4.4	25.3	58.3		2		27													
4/1/85			13																	
4/6/85												3.4		3.5	4	2.7				
8/1/85	9.5																			
10/31/85			nd																	
11/19/85	6.5	37.7	26.7		0.2		nd													
11/19/85	6.8		21.5		nd															
2/11/86		36	18		<1															
3/3/86	3.8	53.7	17.8		nd		nd													
3/3/86	3.8		14.4																	
4/29/86	3.6	33	13		<1		<1													
7/14/86	6.2	38	14		<1		<1													
7/31/86												4.6	4.8	5.6	4.6	3.6	4.6			
10/23/86	14	83	11		2.1		<1													
10/29/86	5.04	49.97	10.08		nd		nd													
1/30/87	12.4	49.8	23.7		0.7		nd													
5/5/87	4.1	36	11		<1															
7/7/87	<1	53	16		1		<1													
11/1/87																				
2/8/88	2.8	48	15		1		<1													
3/16/88									<2	<2	<2									
5/17/88	6.5																			
7/11/88	9.3	82	18																	
8/1/88	6.1	86.2	11.6		nd		nd													
9/7/88	10									nd	nd									
9/29/88									nd											
10/28/88	9.4	93	13		1.5		<1													
3/17/89	3.7																			
8/22/89	nd	64.4	19.8																	
8/22/89 (d)		67		nd	0.5		0.4													
3/30/90	2.9																			
7/1/90	5.1		14.9																	
7/1/90 (d)		48.1			2.2		2.1													
7/1/90 (d)					1.1															
10/22/90	3.7			nd																

1,2-Dichloroethene (ug/L)																					
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	14 Weber St.
3/5/91	nd			nd																
5/3/91	4.8			nd																
7/17/91	3.7	88.7 c	18		1 c	<0.1 c														
8/21/91	2.5			nd *																
8/12/92																		1 t	1	
11/13/92				nd *																
4/1/93		0.9 *c	0.9 *c	nd *	0.9 *c	0.9 *c														
9/13/93																				
2/14/94		nd *	nd *	nd *	nd *	nd *														
2/14/95		3.8 *c	3.8 *c	nd *	3.8 *c	3.8 c														
2/21/95		22.2 s	6.7 c		2.1 c	3.6 c														
3/5/96	1.5	18.6 c	2.3 c	nd *		6.9 c														
3/27/96					1.9 c	1 *c														
8/8/96		3 *c	3 *c		3 *c	3 *c														
10/1/96		3 *c	3 *c		3 *c	3 *c														
1/7/97		2 *c	2 *c	nd *	2 *c	2 *c														
4/2/97		2 *c	2 *c		2 *c	2 *c														
7/1/97		1 *c	1 *c		1 *c	1 *c														
10/6/98	1	2 *c	2 *c		2 *c	2 *c														
1/6/98		2 *c	2 *c	nd *	2 *c	2 *c														
4/7/98		2 *c	2 *c		2 *c	2 *c	2 *c													
7/7/98		nd *	nd *	nd *	nd *	nd *	nd *													
2/2/99		0.7 *c	0.7 *c	nd *	0.7 *c	0.7 *c	0.7 *c													
4/6/99		0.6 *c	0.6 *c		0.6 *c	0.6 *c	0.6 *c													
7/6/99		1 *c	1 *c		1 *c	1 *c	1 *c													
10/5/99		2 *c	2 *c		2 *c	2 *c	2 *c													
1/4/00		1 *c	1 *c	nd *	1 *c	1 *c	1 *c													
4/4/00		0.8 *c	0.8 *c	nd *	0.8 *c	0.8 *c	0.8 *c													
7/5/00		0.6 *c	0.6 *c	nd *	0.6 *c	0.6 *c	0.6 *c													
10/3/00		0.8 *c	0.8 *c		0.8 *c	0.8 *c	0.8 *c													
1/16/01		0.6 *c	0.6 *c	nd	0.6 *c	0.6 *c	0.6 *c													
4/17/01		nd *	nd *		nd *	nd *	nd													
7/2/02	nd	0.8 *c	0.8 *c		0.8 *c	0.8 *c	0.8 *c													
10/2/01		nd	nd *		nd *	nd *	nd													
1/8/02		nd	nd *	nd	nd *	nd *	nd													
4/2/02		nd	nd *		nd *	nd *	nd													
9/15/02																				2.2
10/1/02	2.1																			
10/8/02		7 c	0.61 c		11 c	7.3 c														
* = Composite sample; d = duplicate sample																				
c = 1,2-DCE as cis- ; t = 1,2-DCE as trans-; s = 1,2-DCE as sum of cis- and trans-																				

1,1-Dichloroethane (ug/L)																		
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant
11/25/80							3.4		2.6									
1/9/81						nd												
1/16/81	0																	
9/28/81								nd										
12/1/81	0																	
12/7/81	0																	
12/14/81	0																	
12/14/81 (d)	0																	
1/7/82	0																	
1/7/82 (d)	0																	
1/13/82	0																	
2/22/82	0																	
3/1/82	0.1																	
3/8/82	0																	
3/15/82	0																	
3/22/82	0																	
3/29/82	0																	
4/5/82	0																	
4/16/82	0																	
4/26/82	0																	
5/3/82	0																	
5/10/82	0																	
5/17/82	0																	
5/24/82	0																	
6/1/82	0																	
6/7/82	0																	
6/7/82 (d)	0																	
6/14/82	0.1																	
6/14/82 (d)	0																	
6/21/82	0																	
6/28/82	0																	
7/6/82	0																	
7/12/82	0																	
7/19/82	0																	
7/26/82	0																	
8/2/82	0																	
8/12/82	0																	
8/16/82	0																	
8/23/82	0																	
8/30/82	0																	
9/7/82	0																	
9/13/82	0																	
9/20/82	0																	
9/27/82	0																	
10/4/82	0																	
10/11/82	0																	
10/18/82	0																	

1,1-Dichloroethane (ug/L)																		
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Town Park Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant
10/25/82	0																	
1/3/83	nd																	
5/16/83	nd																	
9/6/83	nd																	
9/6/83 (d)	nd																	
9/14/83	nd	0.7	nd															
9/14/83 (d)	nd	0.5			nd	nd												
10/4/83	nd	0.6	nd		nd	nd												
10/11/83	nd	0.9	nd		nd	nd												
10/19/83	nd																	
10/25/83	nd																	
6/11/84	nd																	
11/19/85	nd	0.7	0.2		nd	nd												
11/19/85	nd		0.2		nd													
2/11/86		1																
3/3/86	nd	0.5	nd		nd	nd												
3/3/86	nd		nd															
4/29/86	<1	<1	<1		<1	<1												
7/14/86	<1	<1	<1		<1	<1												
7/31/86												<1	<1	<1	<1	<1		
8/1/86											<1							
10/23/86						<1												
7/7/87	<1	<1	<1		<1	<1												
2/8/88	<1	<1	<1		<1	<1												
3/16/88								<2	<2	<2								
7/11/88		1.2	<1															
8/1/88	nd	nd	nd		nd	nd												
9/7/88	nd								nd	nd								
9/29/88								nd										
10/28/88	<1	<1	<1		<1	<1												
3/17/89	nd																	
8/22/89				nd														
3/30/90	nd																	
10/22/90	nd			nd														
3/5/91	nd			nd														
5/3/91	nd			nd														
7/17/91																		
8/21/91	nd			nd *														
8/12/92																	<2	<1
11/13/92				nd *														

* = Composite sample; d = duplicate sample

1,2-Dichloroethane (ug/L)

Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	16 Weber St.
2/7/79								nd				nd									
11/25/80						nd *															
1/9/81							nd														
1/16/81	1.5																				
9/28/81										nd											
12/1/81	0																				
12/7/81	0																				
12/14/81	0																				
12/14/81 (d)	0																				
1/7/82	0.2																				
1/7/82 (d)	0																				
1/13/82	0																				
2/22/82	0.1																				
3/1/82	0																				
3/8/82	0																				
3/15/82	0																				
3/22/82	0																				
3/29/82	0																				
4/5/82	0																				
4/16/82	1.1																				
4/26/82	0																				
5/3/82	0																				
5/10/82	0																				
5/17/82	0																				
5/24/82	0																				
6/1/82	0																				
6/7/82	0																				
6/7/82 (d)	0																				
6/14/82	0																				
6/14/82 (d)	0.2																				
6/21/82	0.3																				
6/28/82	0.2																				
7/6/82	0.2																				
7/12/82	0.2																				
7/19/82	0.2																				
7/26/82	0																				
8/2/82	0																				
8/12/82	0																				
8/16/82	0.2																				
8/23/82	0.3																				
8/30/82	0.3																				
9/7/82	0																				
9/13/82	0																				
9/20/82	0																				
9/27/82	0.5																				
10/4/82	0.2																				
10/11/82	0.4																				

1,2-Dichloroethane (ug/L)

Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	16 Weber St.
10/18/82	0.4																				
10/25/82	0.4																				
1/3/83	1.2																				
5/16/83	nd																				
9/6/83	nd																				
9/6/83 (d)	nd																				
9/14/83	nd	0.1	nd																		
9/14/83 (d)	nd	nd			nd		nd														
10/4/83	nd	0.1	nd		nd		nd														
10/11/83	nd	0.2	nd		nd		nd														
10/19/83	nd																				
10/25/83	nd																				
6/11/84	nd																				
12/12/84	nd																				
1/1/85																					
4/29/86	<1	<1	<1		<1		<1														
7/14/86	<1	<1	<1		<1		<1														
7/31/86														<1	<1	<1	<1	<1			
8/1/86													<1								
10/23/86							<1														
7/7/87	<1	<1	<1		<1		<1														
2/8/88	<1	<1	<1		<1		<1														
3/16/88										<2	<2	<2									
9/7/88	nd										nd	nd									
9/29/88										nd											
10/28/88	<1	<1	<1		<1		<1														
3/17/89	nd																				
8/22/89				nd																	
3/30/90	nd																				
10/22/90	nd			nd																	
3/5/91	nd			nd																	
5/3/91	nd			nd																	
8/21/91	nd			nd *																	
8/12/92																			<1	<1	
11/13/92				nd *																	
4/1/93		nd *	nd *	nd *	nd *	nd *															
2/14/94		nd *	nd *	nd	nd *	nd *															
2/14/95		nd *	nd *	nd *	nd *	nd *															
2/21/95		nd	nd		nd	nd															
3/5/96	nd	nd	nd	nd *		nd															
3/27/96					nd	nd															
8/8/96		nd *	nd *		nd *	nd *															
10/1/96		nd *	nd *		nd *	nd *															
1/7/97		nd *	nd *	nd *	nd *	nd *															
4/2/97		nd *	nd *		nd *	nd *															
7/1/97		nd *	nd *		nd *	nd *															
10/6/98	nd	nd *	nd *		nd *	nd *															
1/6/98		nd *	nd *	nd *	nd *	nd *															

1,2-Dichloroethane (ug/L)																					
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant	16 Weber St.
4/7/98		nd *	nd *		nd *	nd *	nd *														
7/7/98		nd *	nd *	nd *	nd *	nd *	nd *														
2/2/99		nd *	nd *	nd *	nd *	nd *	nd *														
4/6/99		nd *	nd *		nd *	nd *	nd *														
7/6/99		nd *	nd *		nd *	nd *	nd *														
10/5/99		nd *	nd *		nd *	nd *	nd *														
1/4/00		nd *	nd *	nd *	nd *	nd *	nd *														
4/4/00		nd *	nd *	nd *	nd *	nd *	nd *														
7/5/00		nd *	nd *	nd *	nd *	nd *	nd *														
10/3/00		nd *	nd *		nd *	nd *	nd *														
1/16/01		nd *	nd *	nd	nd *	nd *	nd *														
4/17/01		nd *	nd *		nd *	nd *	nd *														
7/2/02	nd	nd *	nd *		nd *	nd *	nd *														
10/2/01		nd *	nd *		nd *	nd *	nd *														
1/8/02		nd *	nd *	nd	nd *	nd *	nd *														
4/2/02		nd *	nd *		nd *	nd *	nd *														
9/15/02																					nd
10/1/02	nd																				
10/8/02		nd	nd		nd	nd															

* = Composite sample; d = duplicate sample

1,1,1-Trichloroethane (ug/L)																						
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant		17 Weber St.
11/25/80						nd *		2.1			19											
1/9/81							nd															
1/16/81	0																					
9/28/81										nd												
12/1/81	2.5																					
12/7/81	0.9																					
12/14/81	0																					
12/14/81 (d)	0																					
1/7/82	0																					
1/7/82 (d)	0																					
1/13/82	0																					
2/22/82	0																					
3/1/82	0																					
3/8/82	0																					
3/15/82	0																					
3/22/82	0																					
3/29/82	0																					
4/5/82	0																					
4/16/82	0																					
4/26/82	0																					
5/3/82	0																					
5/10/82	0																					
5/17/82	0																					
5/24/82	0																					
6/1/82	0																					
6/7/82	0																					
6/7/82 (d)	0																					
6/14/82	0.5																					
6/14/82 (d)	0																					
6/21/82	0.4																					
6/28/82	0																					
7/6/82	0																					
7/12/82	0																					
7/19/82	0																					
7/26/82	0																					
8/2/82	0																					
8/12/82	0																					
8/16/82	0																					
8/23/82	0																					
8/30/82	0																					
9/7/82	0																					
9/13/82	0																					
9/20/82	0																					
9/27/82	0																					
10/4/82	0																					
10/11/82	0																					
10/18/82	0																					

1,1,1-Trichloroethane (ug/L)																						
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant		17 Weber St.
10/25/82	0																					
1/3/83	nd																					
5/16/83	nd																					
9/6/83	nd																					
9/6/83 (d)	0.1																					
9/14/83	nd	3.3	nd																			
9/14/83 (d)	nd	3			nd		nd															
10/4/83	nd	3	nd		nd		nd															
10/11/83	nd	nd	nd		nd		nd															
10/19/83	nd																					
10/25/83	nd																					
6/11/84	nd																					
12/12/84	nd																					
1/4/85	nd	4	5.5		nd		nd															
4/6/85																		1.1				
10/31/85	nd	2.3																				
11/19/85	nd	3.1	nd		nd		nd															
11/19/85 (d)	nd		nd		nd																	
2/11/86		2.4																				
3/3/86	nd	2	nd		nd		nd															
3/3/86	nd		0.1																			
4/29/86	<1	1.7	<1		<1		<1															
7/14/86	<1	2	<1		<1		<1															
7/31/86														<1	<1	<1	<1	<1				
8/1/86													<1									
10/23/86							<1															
10/29/86	nd	1.72	nd		nd		nd															
1/30/87	nd	0.5	nd		nd		nd															
7/7/87	<1	<1	<1		<1		<1															
2/8/88	<1	<1	<1		<1		<1															
3/16/88										<2	<2	<2										
7/11/88		<1																				
8/1/88	nd	nd	nd		nd		nd															
9/7/88	nd										nd	nd										
9/29/88										nd												
10/28/88	<1	<1	<1		<1		<1															
3/17/89	nd																					
8/22/89				nd																		
3/30/90	0.5																					
10/22/90	nd			nd																		
3/5/91	nd			nd																		
5/3/91	nd			nd																		
8/21/91	1.6			2.9																		
8/12/92																			<1	<1	<1	
11/13/92				nd *																		
4/1/93		nd *	nd *	nd *	nd *	nd *																
2/14/94		nd *	nd *	nd	nd *	nd *																
2/14/95		nd *	nd *	nd *	nd *	nd *																

1,1,1-Trichloroethane (ug/L)																						
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Barrows Well	Barrows Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	End of Marion St.	Compugraphic	Burt Road	End of Chestnut St.	Allen Park Drive	Ferno Forge	Hillside Way Storage Tank	Cross St. Hydrant		17 Weber St.
2/21/95		nd	nd		nd	nd																
3/5/96	nd	nd	nd	nd *		nd																
3/27/96					nd	nd																
8/8/96		nd *	nd *		nd *	nd *																
10/1/96		nd *	nd *		nd *	nd *																
1/7/97		nd *	nd *	nd *	nd *	nd *																
4/2/97		nd *	nd *		nd *	nd *																
7/1/97		nd *	nd *		nd *	nd *																
10/6/98	nd	nd *	nd *		nd *	nd *																
1/6/98		nd *	nd *	nd *	nd *	nd *																
4/7/98		nd *	nd *		nd *	nd *	nd *															
7/7/98		nd *	nd *	nd *	nd *	nd *	nd *															
2/2/99		nd *	nd *	nd *	nd *	nd *	nd *															
4/6/99		nd *	nd *		nd *	nd *	nd *															
7/6/99		nd *	nd *		nd *	nd *	nd *															
10/5/99		nd *	nd *		nd *	nd *	nd *															
1/4/00		nd *	nd *	nd *	nd *	nd *	nd *															
4/4/00		nd *	nd *	nd *	nd *	nd *	nd *															
7/5/00		nd *	nd *	nd *	nd *	nd *	nd *															
10/3/00		nd *	nd *		nd *	nd *	nd *															
1/16/01		nd *	nd *	nd *	nd *	nd *	nd *															
4/17/01		nd *	nd *		nd *	nd *	nd *															
7/2/02	nd	nd *	nd *		nd *	nd *	nd *															
10/2/01		nd *	nd *		nd *	nd *	nd *															
1/8/02		nd *	nd *	nd *	nd *	nd *	nd *															
4/2/02		nd *	nd *		nd *	nd	nd *															
9/15/02																						nd
10/1/02	nd																					
10/8/02		nd	nd		nd	nd																

* = Composite sample; d = duplicate sample

Benzene (ug/L)														
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	Compugraphic	Ferno Forge	Hillside Way Storage Tank	18 Weber St.
11/25/80						nd *								
2/16/84												6.3		
4/6/85											4.2			
3/16/88								<2	<2	<2				
7/11/88	nd													
9/7/88	nd								nd	nd				
9/29/88								nd						
3/17/89	nd													
8/22/89				nd										
3/30/90	nd													
7/1/90	nd													
10/22/90	nd			nd										
3/5/91				nd										
5/3/91	nd			nd										
7/17/91	nd													
8/21/91	nd			nd *										
8/12/92													<1	
11/13/92				nd *										
4/1/93		nd *	nd *	nd *	nd *	nd *								
9/13/93														
2/14/94		nd *	nd *	nd	nd *	nd *								
2/14/95		nd *	nd *	nd *	nd *	nd *								
2/21/95		nd	nd		nd	nd								
3/5/96	nd	nd	nd	nd *		nd								
3/27/96					nd	nd								
8/8/96		nd *	nd *		nd *	nd *								
10/1/96		nd *	nd *		nd *	nd *								
1/7/97		nd *	nd *	nd *	nd *	nd *								
4/2/97		nd *	nd *		nd *	nd *								
7/1/97		nd *	nd *		nd *	nd *								
10/6/98	nd	nd *	nd *		nd *	nd *								
1/6/98		nd *	nd *	nd *	nd *	nd *								
4/7/98		nd *	nd *		nd *	nd *	nd *							
7/7/98		nd *	nd *	nd *	nd *	nd *	nd *							
2/2/99		nd *	nd *	nd *	nd *	nd *	nd *							
4/6/99		nd *	nd *		nd *	nd *	nd *							
7/6/99		nd *	nd *		nd *	nd *	nd *							
10/5/99		nd *	nd *		nd *	nd *	nd *							
1/4/00		nd *	nd *	nd *	nd *	nd *	nd *							
4/4/00		nd *	nd *	nd *	nd *	nd *	nd *							
7/5/00		nd *	nd *	nd *	nd *	nd *	nd *							
10/3/00		nd *	nd *		nd *	nd *	nd *							
1/16/01		nd *	nd *	nd *	nd *	nd *	nd *							
4/17/01		nd *	nd *		nd *	nd *	nd *							
7/2/02		nd *	nd *		nd *	nd *	nd *							
10/2/01		nd *	nd *		nd *	nd *	nd *							
1/8/02		nd *	nd *	nd *	nd *	nd *	nd *							

Benzene (ug/L)														
Date	Butter's Row TP Finish	Butter's Row Well #1	Butter's Row Well #2	E.H. Sargent TP Finish	Chestnut St. Well	Chestnut St. Well 1A-2	Town Park Well	Salem St. Well	Shawsheen St. Well	Brown's Crossing Well	Compugraphic	Ferno Forge	Hillside Way Storage Tank	18 Weber St.
4/2/02		nd *	nd *		nd *	nd	nd *							
9/15/02														nd
10/8/02		nd	nd		nd	nd								
* = Composite sample														

Notes on sources and some minor changes/differences in recorded data:

1,2-DCE :
at times, only listed as 1,2-DCE, other times listed as cis- or trans-, included as a sum of the two isomers, but often only one was measurable (noted in row when known)

Composite samples:
(a) called Butters Row WTP, but composite taken of the following sites:
3342000-03G Chestnut St. Well
3342000-04G Town Park Well
3342000-07G Butters Row Well #1
3342000-09G Butters Row Well #2
3342000-10G Chestnut St. Well 1A-2

(b) called Sargent WTP, but composite is:
3342000-01G site
3342000-02G site
3342000-08G site

composites did not always have "Manifold" marked, but did list all sites
so, perhaps "composite" is not always a composite? Almost all values ND, and only detected compound (cis-1,2-DCE) was very near detection limit, far below MCL

1/8/02: Sampled water sent to lab to be analyzed for pesticides, PCBs, etc.

Butter's Row WTP and Sargent GWTP, all analytes at reporting limit - did not include these results in table

Some of the Butter's Row Finish TCE readings (only TCE) were from a hand-written sheet. These were also only given as months, and have a default date of the first of the month. These readings are averages of all samples measured over the month reported. Mostly these occur in early dates.

Ammonia concentrations data for many dates between March 1986 - December 2000:

Taken from "US EPA New England Superfund Records and Information Center, document #247741 Comprehensive Response Action Transmittal Form and Phase 1 completion statement" by GEI Consultants.

Values of Ammonia concentration and sampling dates were estimated from figures in document:

Butter's Row Wells 1 and 2: Figure 2-2, p. 78 and 179 in report
Chestnut Street Wells: Figure 2-1, p. 80 of 179 in report.

Since no exact date could be determined from scale of graph, date assumed to be first of month. In some cases, dates were already entered and these were used.

Compugraphic = 90 Industrial Way

Ferno Forge = 30 Industrial Way

J. Estimated Industrial/Commercial Water User Demands

Water consumption by industrial/commercial users accounts for a significant fraction of the total water usage in Wilmington. From 1985 through 1995, SEA (1996) reports that annual industrial usage ranged from 546 to 1,201 gallons per minute (gpm), which accounted for 26 to 53% of total usage. Preliminary modeling results also showed that the spatial distribution of contaminated water originating from Butters Row Water Treatment Plant (WTP) was sensitive to the magnitude and location of industrial user demands. Therefore, time histories of water demands for the largest industrial users were reconstructed over the study period (1974 – 2000) using historical records obtained from the town Water and Sewer Division.

The process began with a dataset provided by the town's Water and Sewer Division containing the average consumption rates from 2002 through 2015 for the 100 largest industrial and commercial users. Based on this list, we identified the billing addresses of the top 20 customers, which together accounted for 90% of the total industrial/commercial usage over that period. Project staff then visited the Water and Sewer Division archives to collect historical meter card data and billing records for each of these customers. Because these records were only available in non-digital formats (paper, microfiche), the level of effort required to collect historical records for all years and all customers exceeded the resources available for this project. Therefore, we focused on gathering a representative sample of available data with which we could estimate usage rates over the entire study period.

Table J.1 lists annual and quarterly usage rates based on historical meter card and billing records for each address corresponding to the largest 20 industrial/commercial users. The usage column represents the average rate in gallons per minute (gpm) over the corresponding period. Some rows represent the average rate over one or two years, while others are for a single quarter. Also, some rows are included to indicate the year when a meter was installed thus representing the earliest possible year of usage at that address. This table also indicates the region of town in which each address is located (Northern, Town Center, Eastern, and Southern). Because the location of each industrial/commercial user impacts the model simulation, effort was made to ensure that the data within each region was sufficiently representative. Note that one of the data points listed in Table J.1 was determined to be the result of a data entry error or some other issue. The average usage from 1977 to 1978 for 1 Burlington Rd (Sweatheart Plastics) of 542 gpm (0.78 million gallons per day, MGD) was found to be unrealistic as it would represent a significant fraction of the total town-wide usage attributed to a single user. After consulting staff from Water and Sewer Department staff who confirmed out suspicion, that data point was excluded from further analysis.

Table J.1: Quarterly and annual industrial/commercial water usage by billing address.

Billing Address	Company	Year (Qtr)	Usage Rate (gpm)	Notes	Region
200 Ballardvale Street	Compugraphic	1983	0.0	Meter installed	Northern
		1984	6.9	Meter card data	Northern
		1989-1990	7.8	Meter card data	Northern
		1992 (4)	7.2	Billing records	Northern
		1993 (4)	6.2	Billing records	Northern
		1994 (1)	6.8	Billing records	Northern
		1994 (2)	6.9	Billing records	Northern
		1994 (3)	6.7	Billing records	Northern
		1994 (4)	7.2	Billing records	Northern
		1995 (1)	6.6	Billing records	Northern
		1995 (2)	5.0	Billing records	Northern
		1995 (3)	10.7	Billing records	Northern
		1995 (4)	5.2	Billing records	Northern
		1996 (1)	6.3	Billing records	Northern
		1997 (2)	5.2	Billing records	Northern
		1998 (4)	5.6	Billing records	Northern
		1999 (4)	4.5	Billing records	Northern
251 Ballardvale Street	Charles River Lab	1980	55.4	Meter card data	Northern
		1981-1982	73.6	Meter card data	Northern
		1983-1984	95.2	Meter card data	Northern
		1985	95.2	Meter card data	Northern
		1992 (4)	16.5	Billing records	Northern
		1993 (4)	10.8	Billing records	Northern
		1994 (1)	8.2	Billing records	Northern
		1994 (2)	8.5	Billing records	Northern
		1994 (3)	19.1	Billing records (higher quarterly due to lawn service)	Northern
		1994 (4)	8.9	Billing records	Northern
		1995 (1)	6.3	Billing records	Northern
		1995 (2)	8.4	Billing records	Northern
		1995 (3)	18.3	Billing records (higher quarterly due to lawn service)	Northern
		1995 (4)	5.4	Billing records	Northern
		1996 (1)	9.3	Billing records	Northern
		1997 (2)	9.1	Billing records	Northern
		1998 (4)	18.8	Billing records (higher quarterly due to lawn service)	Northern
		1999 (4)	6.8	Billing records	Northern
330 Ballardvale Road	Hans Kissle	1997-1998	8.7	Meter card data	Northern
		1992 (4)	0.4	Billing records	Northern
		1993 (4)	7.6	Billing records	Northern
		1994 (1)	8.0	Billing records	Northern
		1994 (2)	10.6	Billing records	Northern
		1994 (3)	7.4	Billing records	Northern
		1994 (4)	17.8	Billing records	Northern
		1995 (1)	8.2	Billing records	Northern
		1995 (2)	8.3	Billing records	Northern
		1995 (3)	22.0	Billing records	Northern
		1995 (4)	8.1	Billing records	Northern
		1996 (1)	9.2	Billing records	Northern

Billing Address	Company	Year (Qtr)	Usage Rate (gpm)	Notes	Region
		1997 (2)	15.9	Billing records	Northern
		1998 (4)	19.4	Billing records	Northern
		1999 (4)	7.6	Billing records	Northern
1 Burlington Road	Sweetheart Plastics	1977-1978	542.9	all meters/lines; 2.75M cf from boiler line card; **Data point excluded from further analysis**	Town center
		1978-1982	47.6	all meters/lines; boiler card showing only 50,000 cf	Town center
		1983-1986	34.6		Town center
		1990 (2-4)	11.6	Meter card data	Town center
		1989 (4)	27.2	Meter card data	Town center
		1992 (4)	1.7	Billing records	Town center
		1993 (4)	1.5	Billing records	Town center
		1994 (1)	2.1	Billing records	Town center
		1994 (4)	2.3	Billing records	Town center
		1995 (1)	2.8	Billing records	Town center
		1995 (2)	0.9	Billing records	Town center
		1995 (3)	1.6	Billing records	Town center
		1995 (4)	3.3	Billing records	Town center
		1996 (1)	2.5	Billing records	Town center
		1997 (2)	1.0	Billing records	Town center
		1998 (4)	0.5	Billing records	Town center
		1999 (4)	5.6	Billing records (ownership changed)	Town center
		1998-2000	0.0	Closed	Town center
50 Fordham Road	General Electric	1971	0.0	Earliest record is 1971 repair order	Eastern
		1979-1980	109.1		Eastern
		1983	45.9	Notes unclear; 1983-1984 could be higher than shown	Eastern
		1984	43.3		Eastern
		1985	19.9		Eastern
		1989-1990	17.3	Meter card data	Eastern
		1992 (4)	18.2	Billing records	Eastern
		1993 (4)	14.7	Billing records	Eastern
		1994 (1)	13.4	Billing records	Eastern
		1994 (2)	11.8	Billing records	Eastern

Billing Address	Company	Year (Qtr)	Usage Rate (gpm)	Notes	Region
		1994 (3)	16.0	Billing records	Eastern
		1994 (4)	13.4	Billing records	Eastern
		1995 (1)	9.3	Billing records	Eastern
		1995 (2)	10.3	Billing records	Eastern
		1995 (3)	13.3	Billing records	Eastern
		1995 (4)	8.9	Billing records	Eastern
		1996 (1)	9.3	Billing records	Eastern
		1997 (2)	9.3	Billing records	Eastern
		1998 (4)	13.5	Billing records	Eastern
		1999 (4)	6.8	Billing records	Eastern
100 Fordham Road	Volkswagon	1977-1978	10.4		Eastern
		1982	13.0		Eastern
		1983	16.5		Eastern
		1984	16.5		Eastern
		1985	13.0		Eastern
		1992 (4)	0.0	No billing records found for this quarter	Eastern
		1993 (4)	0.0	No billing records found for this quarter	Eastern
		1994 (1)	0.0	No billing records found for this quarter	Eastern
		1994 (2)	0.0	No billing records found for this quarter	Eastern
		1994 (3)	0.0	No billing records found for this quarter	Eastern
		1994 (4)	0.0	No billing records found for this quarter	Eastern
		1995 (1)	1.2	Billing records	Eastern
		1995 (2)	5.3	Billing records	Eastern
		1995 (3)	17.0	Billing records	Eastern
		1995 (4)	5.0	Billing records	Eastern
		1996 (1)	2.6	Billing records	Eastern
		1997 (2)	1.6	Billing records	Eastern
		1998 (4)	10.8	Billing records	Eastern
		1997-1998	13.0	Meter card data	Eastern
		1999 (4)	4.3	Billing records	Eastern
350 Fordham Road	Dynamics Research (Plant 2)	1984	17.3	Meter card data	Eastern
	MA Carpenter's Union	1992 (4)	0.1	Billing records	Eastern
		1994 (1)	0.2	Billing records	Eastern
		1994 (4)	0.2	Billing records	Eastern
		1995 (1)	0.2	Billing records	Eastern
		1995 (2)	0.3	Billing records	Eastern
		1995 (3)	0.2	Billing records	Eastern
		1995 (4)	0.2	Billing records	Eastern
		1998 (4)	0.1	Billing records	Eastern
60 Concord Street	Dynamics Research	1984	19.0	Meter card data	Eastern
		1989-1990	13.0	Meter card data	Eastern
		1992 (4)	11.7	Billing records	Eastern
		1993 (4)	9.6	Billing records	Eastern
		1994 (1)	7.6	Billing records	Eastern

Billing Address	Company	Year (Qtr)	Usage Rate (gpm)	Notes	Region
		1994 (2)	5.4	Billing records	Eastern
		1994 (3)	2.2	Billing records	Eastern
		1994 (4)	2.3	Billing records	Eastern
		1995 (1)	2.3	Billing records	Eastern
		1995 (2)	3.1	Billing records	Eastern
		1995 (3)	2.7	Billing records	Eastern
		1995 (4)	1.9	Billing records	Eastern
		1996 (1)	2.8	Billing records	Eastern
		1997 (2)	2.1	Billing records	Eastern
		1998 (4)	3.0	Billing records	Eastern
		1997-1998	19.0	Meter card data	Eastern
		1999 (4)	2.5	Billing records	Eastern
51 Eames Street	Olin Chemical/Surface Coatings/ Raffi Swan	1983	0.2		Southern
		1984	60.6		Southern
		1986-1987	1.7		Southern
		1988-1998	0.3		Southern
100 Eames Street	Surface Coatings (Raffi and Swanson)	1977-1978	27.7		Southern
		1981-1982	32.9		Southern
		1983-84	27.7		Southern
		1985	22.5		Southern
		1999-2000	1.7		Southern
		2001-2002	1.7		Southern
45 Industrial Way	Keene Smithcraft	1968	0.0	Meter installed	Southern
		1977-1980	19.0		Southern
		1981	24.2		Southern
		2001-2002	34.6		Southern
24 Industrial Way, Woburn	Lipton Pet	1977	142.9	In Woburn, but received Wilmington water	Southern
		1978	0.0	Plant closed in 1978	Southern
65 Industrial Way	Compugraphic	1976	11.3		Southern
		1977-1979	11.3		Southern
		1980	11.3		Southern
		1982-1983	20.8		Southern
	AGFA	1997-1998	1.7		Southern
80 Industrial Way	Compugraphic	1978	21.6		Southern
		1979-1980	19.9		Southern
		1982-1984	43.3		Southern
90 Industrial Way	Compugraphic	1977	0.0	Meter installed	Southern
		1978-1981	4.3		Southern
		1982	3.9		Southern
		1983-1984	3.5		Southern
1 Jewel Drive	Altron/Sanmina	1975	0.0	Original site plans	Southern
		1979	17.3		Southern
		1981-1984	17.3	1984 - plans for an addition found	Southern
		1986	86.6		Southern
		1997-1998	155.8		Southern
		2001-2002	100.4		Southern

Billing Address	Company	Year (Qtr)	Usage Rate (gpm)	Notes	Region
201 Lowell Street	Avco Reseach Development (Now Textron)	1958	0.0	Meter installed	Southern
		1976	102.2		Southern
		1977	108.2		Southern
		1978	147.2		Southern
		1979	164.5		Southern
		1980	259.7		Southern
		1983	233.8		Southern
		1984-1985	173.2		Southern
730 Main street	Polyvinyl Chemicals	1965	0.0	Building plans	Southern
		1977-1978	6.9		Southern
		1979-1980	6.1		Southern
		1981	5.2		Southern
		1982	69.3	Noted large increase between 1981-1982	Southern
	ICI Resins/Zeneca	1997-1998	69.3		Southern
		2001-2002	30.3		Southern
850 Main Street	Abcor	1968	0.0	Original site plans	Southern
		1977	17.3		Southern
	Koch Membrane	1997-1998	17.3		Southern
		2001-2002	34.6		Southern
804 Woburn Street	Analog Devices	1978	65.8		Southern
		1979	86.6		Southern
		1983-1984	103.9		Southern
		2001-2002	259.7		Southern
829 Woburn Street	Analog Devices	1978-1980	39.0		Southern

Using the historical quarterly and annual usage data in Table J.1, we then constructed time histories of the average annual usage rates for each billing address. For instances where there more than one quarter of historical data were recorded in a single year for a given address, the average annual rate for that year was computed as the mean of the quarterly usage rates. For years in which no data were recorded for a given user, the annual usage rate was estimated by linearly interpolating between the nearest two years with data. For some users, no data were available near the start or end of the simulation period. In these cases, the first or last annual usage rate was extended to cover the period of missing data (e.g. for 1 Burlington Rd, the usage rate for 1978 was assigned to all years between 1974 to 1977). Figure J.1 shows the final interpolated annual-average usage rates for each billing address along with the historical quarterly and annual rates listed in Table J.1.

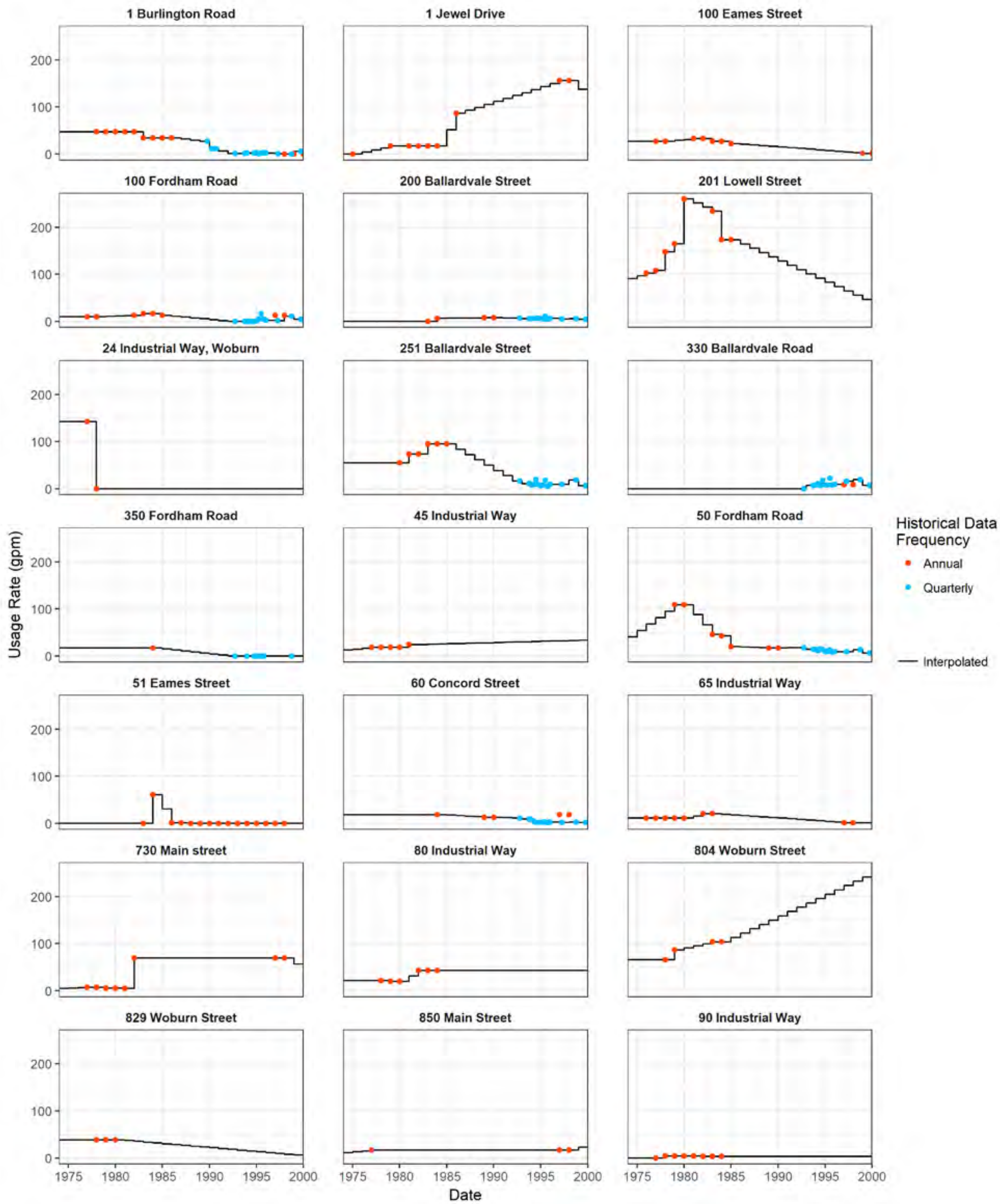

Figure J.1: Historical and interpolated industrial/commercial usage by billing address, 1974 – 2000.