State of Delaware
DELAWARE GEOLOGICAL SURVEY
John H. Talley, State Geologist
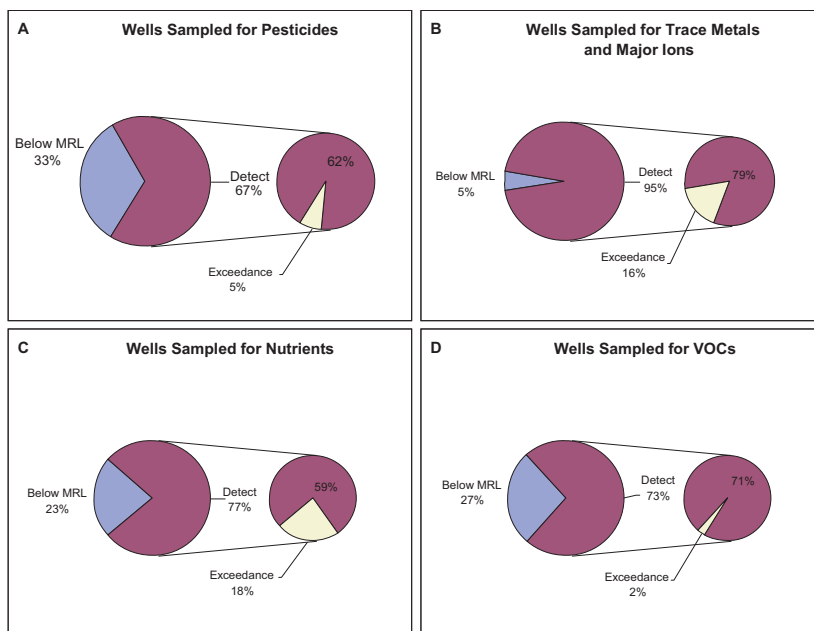
OPEN FILE REPORT NO. 48

RESULTS OF THE DOMESTIC WELL WATER-QUALITY STUDY

By

Vincent Pellerito, Mark P. Neimeister,
Elizabeth Wolff, and A. Scott Andres

A — Wells Sampled for Pesticides: Below MRL 33%, Detect 67%, Exceedance 5%, 62%

B — Wells Sampled for Trace Metals and Major Ions: Below MRL 5%, Detect 95%, Exceedance 16%, 79%

C — Wells Sampled for Nutrients: Below MRL 23%, Detect 77%, Exceedance 18%, 59%

D — Wells Sampled for VOCs: Below MRL 27%, Detect 73%, Exceedance 2%, 71%

University of Delaware
Newark, Delaware
2008

State of Delaware
DELAWARE GEOLOGICAL SURVEY
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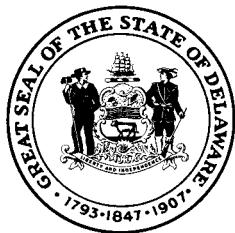
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WATER-QUALITY STUDY

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ABSTRACT

The Delaware Geological Survey conducted a review of existing ground-water quality data collected from shallow (less than 100 feet deep) domestic water-supply wells and small public water-supply wells (serving fewer than 100 residents) to determine the extent to which toxic and carcinogenic compounds are present in the shallow ground water serving domestic water supply wells. These data were generated by several agencies including the Delaware Geological Survey, U.S. Geological Survey, Delaware Department of Natural Resources and Environmental Control, Delaware Division of Public Health Office of Drinking Water, and the Delaware Department of Agriculture Pesticide Management Program.

The results of the review indicate that although pesticides and volatile organic compounds are ubiquitous in shallow ground water throughout the State, concentrations of these compounds rarely exceed maximum contaminant levels. These compounds occur most frequently in wells located in urban/suburban and agricultural areas. The most commonly occurring volatile organic compounds are PCE and chloroform. Atrazine and alachlor are the most commonly detected pesticides. These findings are consistent with findings of surveys of pesticides and volatile organic compounds in the nation's ground water. The frequency of detection of volatile organic compounds and pesticides in shallow domestic and small public wells is less than that found in previous surveys of public water wells in Delaware. Nitrate was detected in a majority of wells sampled and concentrations in excess of the maximum contaminant level occur in nearly 18 percent of wells sampled. Concentrations of nitrate in excess of the maximum contaminant level occur most frequently in wells located in agricultural areas.

A conservative assessment of risk to domestic water-supply wells from contaminants originating from sites of leaking underground storage tanks, landfills, chemical spills, and other sources indicates that a small percentage of wells are at significant risk of contamination originating from these sites. Data collected through DNREC and ODW programs are not adequate to positively document that the at-risk wells have been sampled. Rather, these programs rely on their staff to review water quality data sample by sample, and well by well to ensure that public health is protected.

The data management systems used by DNREC and ODW to store and report ground-water quality data are poorly suited to the task of systematic assessment of the extent to which toxic and carcinogenic compounds are present in the shallow ground water serving domestic water supply wells. Recently, DNREC and ODW have taken the first step to address this issue with the requirement that state-issued well permit numbers will be attached to each and every record of water-well samples collected by these programs. Ideally, all state agencies should manage water-quality data in electronic databases, and, to the maximum extent possible, standardize database design and functionality.

ACRONYM LIST

BDCM	Bromodichloromethane
BFM	Bromoform
BM	Benchmark
BQ	Benchmark Quotient
BRBZ	Bromobenzene
CASRN	Chemical Abstracts Service Registry Number
CDBM	Dibromochloromethane
CFM	Chlorofluoromethane
CLM	Chloromethane
CSF	Contaminated Sites Files web database
DCC	Delaware Cancer Consortium
DCE	1,2-Dichloroethane
DCFM	Dichlorodifluoromethane
DDA	Delaware Department of Agriculture
DDA-PMP	Delaware Department of Agriculture-Pesticide Monitoring Program
DGS	Delaware Geological Survey
DNREC	Delaware Department of Natural Resources and Environmental Control
DPH	Delaware Division of Public Health
DPH-ODW	Delaware Division of Public Health Office of Drinking Water
GIS	Geographic Information System
GW	Ground Water
GWQ	Ground-Water Quality
GWQDB	Ground-Water Quality Database
HBSL	Health-Based Screening Level
LULC	Land Use Land Cover
LUST	Leaking Underground Storage Tank
MCL	Maximum Contaminant Level
MRL	Minimum Reporting Level
MTBE	Methyl tert-butyl-ether
NAWQA	National Water Quality Assessment program
NCODB	National Contaminant Occurrence Database
NWIS	National Water Information System
OXY	o-Xylene
PCE	Tetrachloroethylene
PMP	Pesticide Monitoring Program

PWS	Public Water System		TAME	tert-Amyl Methyl-ether
PXY	p-Xylene		TCFM	Trichlorofluoromethane
QA/QC	Quality Assurance/Quality Control		THM	Trihalomethane
RBCA	Risk-Based Corrective Action		TMB	Tanks Management Branch
SDWA	Safe Drinking Water Act		TOT	Time of Travel
SDWA-UCMP	Safe Drinking Water Act Unregulated Contaminants Monitoring Program		TT ACTL	Treatment Technique Action Level
SDWIS	Safe Drinking Water Information System		UCMR	Unregulated Contaminant Monitoring Rule
SIRB	Site Investigation and Remediation Branch		USEPA	U. S. Environmental Protection Agency
SMCL	Secondary Maximum Contaminant Level		USGS	U. S. Geological Survey
SW	Surface Water		VOC	Volatile Organic Compound
SWAPP	Source Water Assessment and Protection Program		WTE	Water-Table Elevation

INTRODUCTION

This technical report documents both the results of an assessment of ground-water quality data collected in Delaware (Fig. 1) from domestic and public water-supply wells serving populations of less than 100 and an assessment of risk to domestic water-supply wells from known contaminated sites. The data assessment was accomplished with pre-existing data that were compiled from electronic sources distributed through the Internet by the U. S. Geological Survey (USGS), from computer databases obtained from the Delaware Division of Public Health (DPH) and the Delaware Department of Agriculture (DDA), and from documents and digital document images obtained from the Site Investigation and Restoration (SIRB) and Tanks Management (TMB) branches of the Delaware Department of Natural Resources and Environmental Control (DNREC). No new samples were collected as part of this effort. The risk assessment was accomplished by predicting where ground-water flow would transport pollutants from contaminated sites documented in the DNREC's database of contaminated sites.

Previous Assessments

The most recent previous statewide assessments of ground-water quality primarily focused on public water supplies (Ferrari, 2001; DNREC, 2002). These studies occurred after media reports of a small number of well contamination incidents increased public awareness of ground-water contamination. In addition, the National Water Quality Assessment (NAWQA) program of the USGS has conducted several studies over the past 15 years that have evaluated shallow ground-water quality conditions in the region (Hamilton et al., 1993; Senior, 1996; Stackelberg et al., 2001; Denver et al., 2004). Data from these NAWQA studies have been included in a number of nationwide assessments of ground water (Moran et al., 2004; Squillace et al., 2002, 2004; Zogorski et al., 2006) and assessments of state and local ground-water sampling programs (Lapham et al., 2000). Ground-water and domestic water-supply well assessments conducted by the State of Delaware during this time period are limited to specific contaminants (e.g., Blaier and Baxter, 2000; Fischer, 2003) or targeted areas (Andres, 1991; Blaier, 1994; Baxter and Talley, 1996).

These previous statewide and regional assessments have documented the widespread occurrence of contamination in shallow ground water, though with the exception of nitrate, contaminant concentrations rarely exceed public health protection standards such as the U. S. Environmental Protection Agency's (USEPA) maximum contaminant levels (MCL) or other similar action levels. In addition to nitrate, the most common contaminants are part of a class of chemicals

Figure 1. Map of Delaware

known as volatile organic chemicals (VOCs). The occurrences of VOCs in Delaware ground water (Denver et al., 2004) follow trends that are similar to those observed throughout the country (Squillace et al., 2004; Zogorski et al., 2006).

In contrast, a larger number of ground-water quality analyses are conducted in Delaware by consulting firms under the direction of DNREC for watershed studies or in support of assessments of point sources of contamination. The results of these site-specific studies are not published in the peer-reviewed literature. However, considering the numbers of studies and ground-water samples collected during these studies, they have the potential to be a valuable source of information on ground-water quality. Further, it seems reasonable to expect that data resulting from studies of point sources of contamination would show that contaminants occur at higher frequencies and at greater concentrations than data from regional studies of ground-water quality conditions.

Purpose and Scope

This study was conducted at the request of the Environmental Subcommittee of the Delaware Cancer Consortium (DCC) and DPH because of their sense of a concern in the general public that domestic well water may be a contributing cause of the higher incidence rates of certain types of cancers in Delaware. Further, a common perception has been that Delaware ground water is of questionable quality because of a high concentration of polluting industries, agricultural pesticide use, and inadequate public sewage treatment facilities. Because the DGS was aware of the large volume of ground-water quality data collected through State and federal programs, we proposed that as a first step toward evaluating the validity of these concerns, we would compile, evaluate, and assess these existing data. Project design and resources did not allow for collection and analysis of any new samples, though during the course of our project we did attempt to incorporate new data generated by others into our effort.

This study was designed to answer these primary questions:
- What are the overall water-quality conditions in domestic water-supply wells in terms of exceedances of MCLs or Health Based Screening Levels (HBSLs)?
- How does water quality in Delaware domestic water-supply wells compare to water quality in public water supply wells in terms of exceedances of MCLs or HBSLs?
- How does water quality in Delaware domestic water-supply wells compare to water quality in wells nationally in terms of exceedances of MCLs or HBSLs?
- Does proximity of a well to a contaminated site have an effect in terms of exceedances of MCLs or HBSLs?
- Are there any significant gaps in the distribution of sampling points?

Because this study relies on existing water-quality data, we cannot document the occurrence of some contaminants that now are coming to national attention. These include endocrine disrupting compounds, pharmaceuticals, and other organic compounds used in industrial and commercial processes (e.g., perflourooctonoic acid). Assessments of the effects of domestic plumbing and water-treatment systems and well construction practices are also beyond the scope of this study.

METHODS

There are two main parts of the methodology used in this study. The first relates to the acquisition of historic ground-water quality data, development of a database application (GWQDB) to enter, check, manage, and report data, and characterization of those data and the wells from which they were collected. The second part relates to acquisition of information on known and potential point sources of contamination, assessment of relative risk to ground water from these sites, and development of a GIS model for assessing the potential risk to down-flow domestic wells from contaminants transported from those sites through the shallow aquifer.

Data Survey and Data Compilation

A significant effort was devoted to surveying and characterizing historic water-quality data available from digital and paper records from state and federal agencies. Table 1 lists the initial data sources surveyed for the project and their relevance to the project goals. It was from this initial survey that pertinent data sources were chosen and later incorporated into GWQDB based on project rules.

The rules for well and sample metadata were modified from the most recent electronic data deliverable policy established by USEPA (2003a) and adopted by DNREC (2001). They also represent the essential data items for a defensible water-quality database; therefore, they were used to establish necessary fields for database tables. Schematics representing the quality assurance and quality control (QA/QC) logic used by the DGS in its data compilation effort are presented as Appendix I.

Data from seven agencies were collected and characterized (see Appendix II): the U.S. Geological Survey (USGS), Delaware Division of Public Health – Office of Drinking Water (DPH-ODW), Delaware Department of Agriculture – Pesticide Monitoring Program (DDA-PMP), Delaware Geological Survey (DGS), the U.S. Environmental

Protection Agency (USEPA), the Delaware Department of Natural Resources and Environmental Control – Site Investigation and Restoration Branch (DNREC-SIRB) and Tanks Management Branch (DNREC-TMB).

These data resources can be categorized as coming from state or federal sources. The scopes of the water-quality data collection efforts of these different data resources represent either ambient ground-water quality studies or studies of wells possibly impacted by known point-sources of pollution. Handling these differences in scope from the different data sources is addressed later in this report.

Federal Data

Delaware ground-water quality data collected between January 1, 1990 and September 30, 2004 were downloaded from the USGS NWISWeb Water Data website (waterdata.usgs.gov/nwis) in April 2005. Approximately 61,504 analysis results were downloaded from the website as of April 2005. The data were then filtered by pertinent parameter groups "nutrient," "major inorganics," "minor and trace inorganics," "organic" and "radiochemicals." The parameter groups "biological," "information" and "physical property" and data from field analyses were not used.

A total of 22 samples were collected from domestic and small capacity commercial water supply wells in eastern Sussex County as part of the Long Neck Mercury Project (Koterba et al., 2006). This was a joint project conducted by the USGS, DGS, and DNREC. Samples were analyzed for nutrients, major/minor elements and organics. Data were retrieved from the USGS-NWIS site.

Public well water-quality data from the EPA and published results (USEPA, 1999) were also surveyed for this report. EPA data were collected from The Office of Ground Water and Drinking Water website (http://www.epa.gov/safewater/) and are characterized in Table 1.

The EPA STORET Environmental Data System was also considered as a data source. This includes both legacy data from analyses performed before 1998 and modern data beginning from 1999 to present.

State Data: DPH-ODW

Staff of the DPH-ODW provided electronic files containing domestic well sampling results from the Private Well Testing Program for the years 2003 to 2005 (A. Beckel, written communication). These records mainly consist of analyses of nutrients and major/minor elements. Public supply well sampling results were also gathered from the DPH-ODW and included chemical, biological, radiological, trace metal and routine (e.g. nitrates) analyses (A. Beckel, written communication).

State Data: DDA-PMP

Delaware's Ground-Water Monitoring Program for Pesticides included a database of domestic and monitoring well sampling. Domestic well sampling results from 2001 were obtained for this study (G. Stayton, written communication), along with the sampling results from Blaier and Baxter (2000).

State Data: DNREC-SIRB

DNREC-SIRB Contaminated Sites Files (CSF) web database was accessed in order to collect ground-water quality data available for off-site wells impacted by contaminated sites supervised by DNREC-SIRB. A custom query was developed with the help of DNREC-SIRB personnel to identify and gather pertinent documents. Appendix II contains the search criteria and the breakdown of retrieved documents from CSF. Additional information on the status of contamination at these sites was provided by DNREC staff (M. Townshend, written communication).

State Data: DNREC-TMB

DNREC-TMB staff (W. Fischer, written communication) provided spreadsheets containing information on over 600 sites with known or suspected impact to ground water. Of these, 57 sites were known to have impacted water-supply wells. Twelve of these sites were removed from the list because they fell within a public-water-utility franchise area. Paper records for the remaining 45 sites were reviewed at the DNREC-TMB office in New Castle.

Explanation of Data Elements

A complete description of the data elements used in the database development effort can be found in Appendix III. The way these elements are mapped into database tables, relationships, and fields is given as Appendix IV.

In this report we will be using the term *sample* to represent a discrete volume of water collected from an individual well and analyzed by a laboratory. This is in distinction to a *sampling event*, which is essentially the field identifier listed on a sampling Chain-Of-Custody form.

A sample is equivalent to a laboratory sample. A specific analysis method typically is capable of detecting multiple, and, in some cases, dozens or hundreds of analytes in an individual sample. Therefore, a sample may have associated with it numerous records of tested analytes (either detected or not detected) or *analysis results*. Analysis results are unique records of laboratory reported analytes.

Analytical Data Considerations

Analytical results were collated and depicted two ways in this report. First, sample tallies and contaminant detections were reported for specific agencies that collected the data. Secondly, ground-water quality data were combined from several agencies to assess domestic well drinking-water quality for Delaware as a whole. To facilitate comparisons between the different data sources, contaminant assessment levels (see below) were developed for this report.

Minimum Reporting Limits

For a particular analytical method and analyte, a minimum reporting limit (MRL) is the smallest measurable concentration that is statistically reliable (Timme, 1995). Consequently, concentrations below a MRL are considered not detected for the sample. Analyte detections, therefore, are those that were measured above the given MRL.

Laboratory reporting limits for analyses compiled in GWQDB were highly variable. This is particularly the case

Table 1. Overview of Health Project data sources.

NAME	AGENCY	FORMAT	PRIORITY*	DATES	DESCRIPTION
NAWQA Potomac aquifer study	USGS	Delimited text file	2	~1990s to 2001	Potomac aquifer survey-domestic, public supply, or monitoring wells.
NAWQA Data Warehouse download	USGS	Delimited text file	3	Oct. 1991 to Jan. 2003	USGS site info (76 sites) and GWQ data. Parameters are Temp., Barometric Pressure, DO, Alkalinity, pH, Bicarbonate, and Specific Conductance.
UCMR List 1 and 2 (1999)	USEPA	Microsoft Excel® PivotTable®	2	1999 to Jan. 2005	Summary (mean, min and max values for detected compounds) and detailed info on sample data collected as part of the Unregulated Contaminants Monitoring Rule (UCMR). Meant to assist informative regulation of a certain contaminant. Designed as a national exposure study which relies on finished water monitoring results. Some untreated source water data included.
UCMR R1&R2 as part of National Contaminant Occurrence Database (NCOD)	USEPA	Delimited text file and Microsoft Excel® PivotTable®	2	1988 to 1992 (R1) 1993 to 1997 (R2)	Unregulated occurence data from monitoring in public sater systems for contaminants not having health-based standards set under the SDWA at the time of the monitoring. DE data only available in round 1.
USEPA Six-year Review as part of NCOD	USEPA	Delimited text file	3	1993 to 1997	Review of regulated contami-nate occurrence for SW and GW. Study consisted of a national cross-section of data from 16 states. DE not included in study.
SDWIS violations from EnviroFacts	USEPA	Microsoft Excel® PivotTable®	3	1993 to July 2004	Reported MCL violations, max and average values for regulated contaminants, for PWS, as given by State agencies.
STORET Legacy Data Center	USEPA	Several delimited text files	2	Early 1900s to 1998	Historical water quality data. Contains raw biological, chemical, and physical data on SW and GW.
STORET Modern	USEPA	Delimited text file	3	~1999 to 2/18/2005	Contains raw biological, chemical, and physical data on SW and GW. DE data for surface water quality.

* Priority or significance as data source; scale from 1 to 3; 1-necessary, 2-secondary priority, 3-likely not necessary

Table 1. (cont.) Overview of Health Project data sources.

NAME	AGENCY	FORMAT	PRIORITY*	DATES	DESCRIPTION
SIRB History notes	DNREC	Microsoft Excel® spreadsheet	1	Up to 5/10/2005	Notes and site histories obtained from Delaware Environmental Navigator as given by Mike Townsend of DNREC.
LUST with Known Ground-Water Impact	DNREC	Microsoft Excel® spreadsheet	1	Up to 2005	Description information for DNREC-TMB leaking underground storage tank sites that are known to have impacted ground water.
TMB data for sites known to have impacted drinking water	DNREC-TMB	Paper Records with some digital files	1	1990 to Present	Analytical data and other documents for drinking water wells sampled in response to a tank spill and/or remediation.
SDWIS-SWAPP database	DE SWAPP	Microsoft® Access database	2	2002 to 1/18/2005	Source Water Assessment Plan database version 3.01; Susceptibility of water systems and detailed PWS and Well info.
DE Pesticide Monitoring Program	DDA-PMP	Microsoft Excel® spreadsheets	1	1998 to Present	GW Monitoring results for Pesticide monitoring program that includes domestic wells.
DGS RI #61	DDA-PMP and DGS	Microsoft Excel® spreadsheet	1	1995 to 1998	Statewide GW monitoring network established to test for pesticides in the unconfined aquifer. Samples collected from 136 wells and analyzed for up to 9 different pesticides.

* Priority or significance as data source; scale from 1 to 3; 1-necessary, 2-secondary priority, 3-likely not necessary

because the data were collected from different agencies using different laboratories, sometimes utilizing different analytical methods (sometimes for the same project). When MRLs were not included along with results, a default laboratory MRL was obtained by the laboratory personnel or the MRL was inferred from the lab report. For example, the "<" values reported from the various laboratories provided an estimate of the MRL. In addition, MRLs were inferred by cross-checking with samples analyzed for the same contaminant, on the same day and utilizing the same laboratory and method (Lapham et al., 2000). For the purpose of assessing the ground-water quality records compiled for this study, analyses listed as less than the laboratory MRL are considered as not detected. However, data collected from USGS NWISWeb occasionally were listed with an E (estimate) qualifier and so were assessed as analyte detections, but the concentrations were not included for any quantitative analyses.

Determination of Assessment Levels for Data Comparisons

One of the difficulties of an investigation that utilizes data from several agencies and laboratories is evaluating results of comparable detection sensitivities. Similar studies have developed assessment levels based on the most frequent MRL for individual analytes (e.g., Lapham et al., 2000, Moran et al., 2002, Moran et al., 2004, Squillace et al., 1999, and Zogorski et al., 2006). A designation of a uniform assessment level, a common reporting threshold for a group of contaminants such as VOCs, is based on the idea that detection frequencies are highly dependent on laboratory MRLs (Lapham et al., 2000). Therefore, applying a censor of a common reporting level facilitates comparisons among compounds and between agencies using similar analytical methods.

In this study, an assessment level of 0.0002 mg/L was chosen for VOC analyses, which retained approximately 81 percent of the VOC analyses compiled in GWQDB (Fig. 2).

This assessment level for VOCs is the same used for national studies of ambient ground-water quality (e.g., Squillace et al., 1999, Lapham et al., 2000, Moran et al., 2004 and Zogorski et al., 2006). For comparisons of pesticide detections, an adequate assessment level was determined to be 0.0001 mg/L because nearly 98 percent of pesticide analyses compiled were reported with this or a lower MRL (Fig. 2). An assessment level of 0.4 mg/L for nitrate represents the natural background level for the Delmarva Peninsula (Denver et al., 2004) and retains nearly 100 percent of nitrate analyses (Fig. 2).

Determination of Detection Frequencies

In assessing domestic well drinking-water quality for Delaware as a whole, detection frequencies or the percentage of samples with contaminant detections were calculated and compared among compounds. Because they impact detection frequencies, it should also be noted that two kinds of non-detections are compiled in GWQDB.

Most non-detections compiled in GWQDB are designated with a "<" reporting limit, which signifies that the contaminant was not detected at the MRL. However, oftentimes non-detects are not reported for each contaminant tested with the analytical method used. In these cases, a non-detect for a specific contaminant is inferred from the analytical method. Only about 4 percent of the records in GWQDB represent this kind of non-detect analysis result. These kinds of non-detect analysis results were considered in determining overall detection frequencies of contaminants.

Determination of Contaminant Exceedances

State and nationally regulated compounds have Maximum Contaminant Levels (MCLs) that are the only enforceable standards and represent the highest allowed concentration of a contaminant in drinking water (USEPA, 2002). Secondary Maximum Contaminant Levels (SMCL) or Treatment Technique Action Levels (TT ACTL) are other standards established by the USEPA by which drinking water can be assessed. In terms of assessing human health, Health Based Screening Levels (HBSL) were developed by the USGS and other agencies to evaluate unregulated contaminants. HBSLs are of particular pertinence to the purposes of this study because they were developed for state- or local-scale water quality assessments (Toccalino et al., 2003). In addition, HBSLs are based on USEPA methodologies for determining cancer classification for carcinogenic contaminants. Discussion on how HBSLs were formulated and how they should be used is described in Toccalino et al. (2003) and Toccalino et al. (2004). Concentrations of chemicals in excess of these values are termed exceedances.

Exceedances of drinking water standards (MCL, SMCL or TT ACTL for lead and copper) or screening levels (HBSL) are assessed separately in this report, as suggested by USGS guidelines on using HBSLs in investigating water-quality data (Toccalino et al., 2005). However, in assessing the data compiled into GWQDB, exceedances are grouped for considering exceedance percentages by groups of contaminants, that is, VOCs, pesticides, metals and inorganic chemicals and nutrients (see Results of Water Quality Investigations).

It is important to note that the pilot study (Toccalino et al., 2004) for utilizing HBSLs for ground-water quality at the state/local level determined that studies assessing contaminants with a human-health context should not censor data to a common reporting level (assessment level) as they could lead to a loss of data relevant to human health. With the assessment levels established for this study, the majority of analysis results censored were for VOCs (see Fig. 2). However, only one contaminant for censored analyses, acrylonitrile (CASRN 107-13-1), was considered a carcinogenic compound. Furthermore, all of the analysis results for acrylonitrile compiled in GWQDB were less than the given reporting limit (non-detect). Therefore, the use of a common reporting limit for VOCs in this report did not censor data pertinent to human health in terms of assessing concentrations
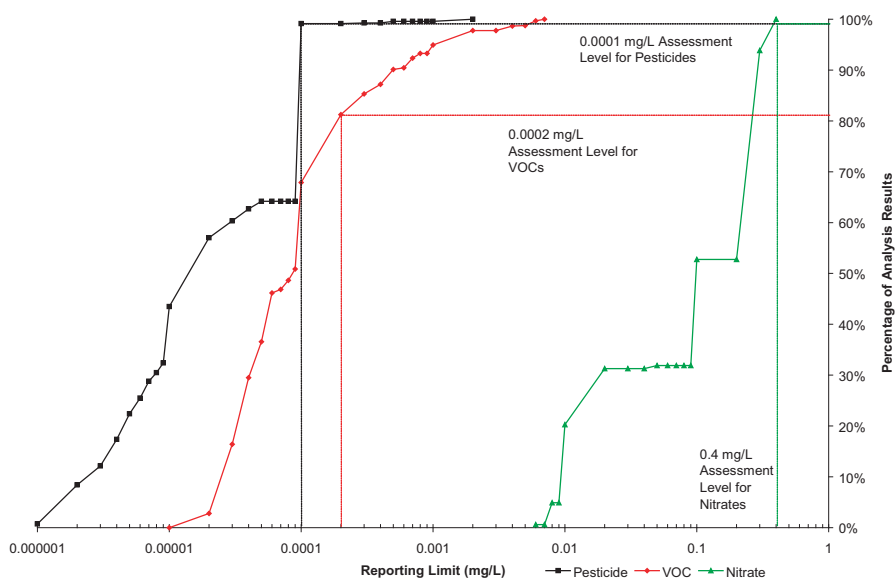

Figure 2. Cumulative occurrence of laboratory MRL as an aid toward development of assessment levels. Three curves (VOC, pesticides and nitrates) are plotted and assessment levels chosen based mainly on a high percentage of analysis results.

of carcinogenic compounds. Furthermore, establishment of assessment levels allowed for comparison of VOC detections and determination of detection frequencies based on a common MRL.

Calculation of Benchmark Quotients for Human-Health Considerations

Toccalino et al. (2003) suggests the calculation of benchmark quotients (BQs) for assessing contaminant concentrations in a human-health context. A human-health benchmark is the water- quality standard used to determine exceedances (e.g., MCL or HBSL). BQs in this report were determined by ascertaining the maximum contaminant concentration for a given well, in a given year, and then dividing this value by the value of its human-health benchmark (i.e., the MCL or HBSL value). Therefore, a single well may have several BQs calculated. Calculated BQs were then plotted to show their distribution along a logarithmic axis. A BQ value of 1 signifies that a maximum contaminant concentration met its human-health benchmark, while a value of 10 signifies that the maximum concentration was a factor of 10 greater than its human-health benchmark.

For the purpose of this report, BQ values of 0.1 or greater are considered potential human-health concerns as suggested by Toccalino et al. (2004), which is consistent with various USEPA practices. Toccalino et al. (2004) further suggests evaluating four other factors besides the magnitudes of BQ values in assessing contaminant concentrations in a human-health context. These are (1) detection frequency of the contaminant, (2) whether the MRL was above its BM, (3) well type and water use, and (4) sources and physiochemical properties of the contaminants. Further information regarding how BQ values should be used and interpreted can be found in Toccalino et al. (2004).

Ground-Water Quality Database Data Requirements and Development

The primary scope of the database development effort was to organize existing drinking water-quality data for shallow domestic wells. However, the design needed to be flexible enough for incorporation of a variety of types of information and for possible future data entry. Data requirements for a database can often be established by surveying existing data collection and reporting forms.

Initial data requirements for GWQDB were determined on the basis of interviews with potential users of the database and water resource professionals. Later, a conceptual model was developed using relational database development techniques and subsequently reviewed by potential users and water resource professionals. In parallel with the conceptual development of the database, QA rules were established to aid in assessing the efficacy of data prior to populating the database.

In a database conceptual model, the defined entities (i.e., tables) and their relationships are portrayed in a graphical form (e.g., as an Entity-Relationship diagram) and used to establish business rules of the database. The database conceptual model was developed using a computer assisted software engineering (CASE) tool, Microsoft Visio® drawing

and diagramming software. Figure 3 diagrams the tables, relationships, and business rules for the core tables in the GWQDB. A written description of all tables, fields, and table relationships is included as Appendix IV of this report.

Development of Rules to Assess Available Water-Quality Data and Metadata

The data compiled in this work were generated by many studies conducted by multiple consulting firms, state agencies, and the USGS. Though there are many similarities between the various studies, the sampling and analytic protocols, methods, and reporting standards have some differences and reflect the programmatic and scientific goals of the various entities and studies. As a result, the inferences and conclusions drawn from these data are limited to the areas where there are commonalities in protocols, methods, and reporting standards between the studies. In addition, our efforts provide information useful for assessing aspects of the data collection, management, and reporting systems employed.

For water- quality data to be most useful for assessing the chemical quality of ground water being pumped from shallow domestic water supply wells a variety of additional information, or metadata, are necessary to assess whether the sample is representative of ground water or is an artifact of the sample collection and analytic processes (Alley, 1993; Mackay and Smith, 1993). In many cases, the metadata requirements are specified in protocols. Sampling protocols describe or reference how samples are collected, stored, and transported to the laboratory. Sampling protocols also specify that other information be recorded regarding date and time of collection, personnel and agency responsible for collection, location and description of the sampling point, and field measurement of sample properties such as temperature, pH, and specific conductance. Analytic protocols describe or reference the laboratory procedures used to measure the concentrations of chemicals in samples and the quality assurance and quality control systems that assure that the laboratory instruments are performing within predefined standards (which includes the detection limits). Reporting protocols describe or reference the quality assurance and quality control (QA/QC) systems that assure that the analytic data are reported accurately and with the appropriate detection limits and precisions. (Alley, 1993; Lapham et al., 2000). Table 2 summarizes the availability of these metadata by agency and program.

Importance of Well Metadata

Throughout Delaware, ground water is being pumped from multiple depths and aquifers. The depth and aquifer being used by a particular well determine the natural chemistry of water pumped from the well and will determine if a well can be contaminated by a pollution source located on or near land surface. Hence, information about the well being sampled is the key element for evaluating ground-water quality data. Information about the well and plumbing systems allows evaluation of the potential affects that construction materials and methods and pumping equipment and plumbing may have on the sample. Missing or ambiguous
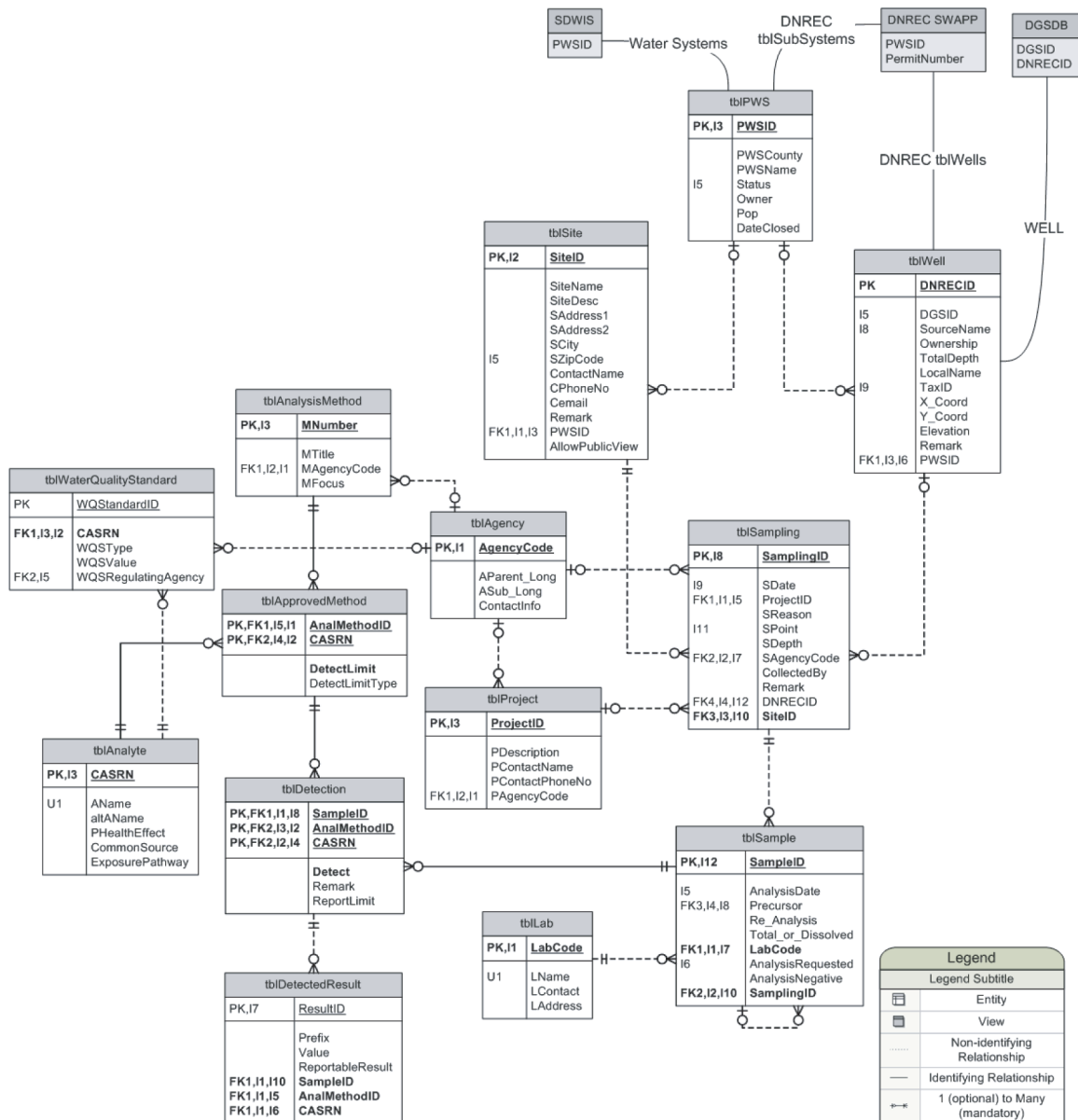
Figure 3. Schematic showing design of core database tables for GWQDB.

well information limits the inferences and conclusions about ground water that can be made from the water- quality data. Well information requirements are sometimes included in the sampling protocol. Information typically collected about wells includes, but is not limited to, depth interval of the screen or open area, well construction materials and sizes, date and method of construction, and pumping and plumbing systems.

In Delaware, well information is available from the State DNREC's well permitting system and database. Beginning in the mid-1970s all water-supply wells installed in Delaware were required to have State-issued well permits and to meet standards regarding construction methods and reporting. Some records are available for wells constructed prior to the permitting system, most frequently for the larger public, industrial, and irrigation supply wells. Since the permitting process was established, almost all wells have been installed by licensed contractors, who also are required to submit well-completion reports containing information

about the methods and materials used for each well. For many years, a key limitation of the database has been that the locations of the permitted wells were not accurately reported. Sometimes, this required significant work to acquire information about wells.

The system has been greatly improved through the years. Beginning in 1985, all wells were required to have clearly visible well tags showing the well permit number. This allows anyone who is on the site, such as a person collecting a water sample, to easily acquire the well permit number and access the well completion information. Beginning in the mid-1990s increased use of the database, GIS technology, and sharing of tax-parcel data for counties has allowed well permits to be linked to tax parcels and accurate location information to be assigned to all wells permitted since that time. Through individual projects and ongoing programs at the DGS and DNREC, locations have been assigned to over 50,200 of the approximately 96,400 water-supply wells in the DGS database. Efforts are ongoing to assign locations to

Table 2. Data suitability by agency and program.

Program	Data Types	Well Metadata	Sample Metadata	Sample Method	Analytic Metadata	Analytic Method*	Reporting Metadata
USGS	V,M,A,P,R	C	C	C	C	C	C
DDA	P	C	C	C	C	A	C
DPH (PWSP)	M,A,B	N	R	N	C	C	K
DPH (PUB)	V,M,A,P,R	S	U	U	C	C	C
SIRB	V,M,A	R	S	U	C	C	C
TMB	F	R	S	U	C	C	C

PWSP = Private Wells Sampling Program; PUB = public supply wells
Data Types - V - Volatile Organics, M - Metals, A - Anions, P - Pesticides, R - Radionuclides, B - bacteriological, F - petroleum components
*Report card code*s - C- consistently, U - usually, S - sometimes, R - rarely, N - never, K - unknown,
Analytic Method- C - consistent and standard method, A - alternate method

the backlog of older wells that do not have location data. In summary, there are very few obstacles to collection of accurate well data for a vast majority of existing wells.

Modeling Contaminant Flow Paths and Risk Zones

One of the objectives of this study was to assess the spatial relationships between known and potential contaminant sources and water quality in samples collected from wells. Information about locations and types of contaminants associated with known and potential sources of contamination were obtained from files of SIRB CSF database. Sites from SIRB were included in the list of known and potential contaminant sources only where the sites had known or potential ground-water impacts. In addition, known or potential sources from the TMB included those sites where ground-water contamination had been documented, or the sites that were classified as having had leaking tanks (Fig. 4). The SIRB sites determined to have a potential impact on ground-water are those where soil tests yielded positive detections of contaminants. In the following discussion these sites will be referred to as contaminated sites or contaminant sources. Information about the locations and construction details of wells was obtained from the State's water-well permitting database.

As a first step, some of the contaminant sources were removed from the analysis. Because actively used domestic water supply and small public water supply wells are much less likely to be located within public water supply franchise areas, known and potential contaminant sources located more than 1 km inside of the boundaries of public water supply franchise areas were removed from the analysis. The 1 km buffer zone was chosen in the event that contaminants entering the ground in this area could travel to locations outside of the buffer zone and be pumped by domestic wells.

Risk zones for these contaminated sites were delineated by computing distances and directions that a conservative ground-water contaminant from these sites would travel in 10 years. Particle track model predicts a worst case condition with respect to ground-water contamination and risk to wells because the mass of contaminants from any site are not part of the calculation, and reactivity, sorption, or decay characteristics of the contaminants are assumed to be negligible.

For example, this approach is considered worst case in terms of mass in that this approach would consider a site with 10 kg of contaminant to result in the same risk as a site with 100 kg of contaminant. Addition of terms representing contaminant reactivity, sorption, or decay to the calculation will reduce the contaminant concentrations in the aquifer with distance from the contaminant source area.

A 10-year time of travel (TOT) is of intermediate length compared to other risk assessment models (Lytton et al., 2003; Maxwell and Kastenberg, 1999). Delaware uses a five-year TOT for identifying public water supply wellhead protection areas (DNREC, 1990, 1999).

The basic concepts of this approach are illustrated in Figure 5. Contaminated sites are represented as points. Ground-water flow directions and distances from contaminated sites were computed using the Groundwater Darcy Velocity & Particle Tracking tools (ESRI, 2003). The tools compute ground-water flow distances and directions in two-dimensional space (i.e., aquifer of uniform thickness) by solving the equation for flow velocity and direction ($V = dl/dt$):

$$V = (K * i)/n = dl/dt \qquad (1)$$

Where:

V = velocity (l/t)

dl = change in distance (l)

dt = change in time ($t = 10$ years)

K = hydraulic conductivity (l/t)

i = gradient of water table (dimensionless)
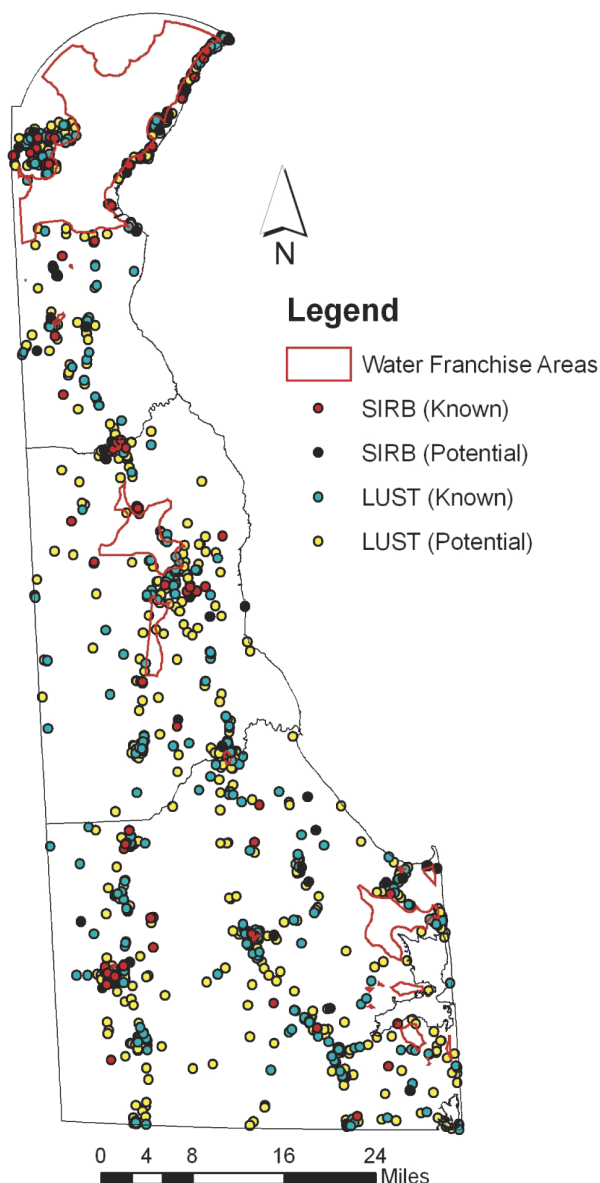
n = porosity (dimensionless)

Figure 4. Map of known and potential sources of ground-water contamination.

Gradient direction (azimuth) and slope (magnitude) were determined with the Spatial Analyst tool (ESRI, 2002) from floating point grids of water-table elevation (WTE). These grids were computed from integer-value minimum WTE grids for Sussex and Kent counties and the coastal plain portion of New Castle County (Andres and Martin, 2004; Martin and Andres, 2005a, b, c). Gridded spatial distributions of hydraulic conductivity (K) and porosity (n) were derived from the digital ground-water recharge potential maps of Kent and Sussex counties (Andres et al., 2002) and statistical relationships between recharge potential and K and n reported by Andres (2004). Table 3 lists the recharge potential classes and the respective K and n values. The averaged K and n value of all recharge potential categories was used in estimating K for the Coastal Plain portion of New Castle County.

The resultant particle tracklines were rotated 5 degrees from the point of origin in both directions from the pathline to account for uncertainty in the flow direction and to approximate diffusion and dispersion in directions perpendicular to flow. The resultant line pairs were then joined into polygons. Buffer zones with logarithmically expanding distances of 30.5, 100, and 305 m were then drawn around each polygon. This was done to compensate for the fact that the sites were simulated as points rather than areas. Internal polygon boundaries were removed with the dissolve tool where the polygons intersected. The buffer zones were then spatially joined to the original points that represent contaminated sites. This allows for the attributes of the contaminated sites (e.g., contaminant types and DNREC program) to be associated with the polygons and their respective buffer areas. An example of the estimated tracklines and appropriate buffers are illustrated in Figure 6.

Risk Assessment Methodology

All domestic wells located within the polygons and buffers were selected from the DGS internal database for further investigation. The wells were flagged with information regarding the polygon and buffer zone in which they were located. Similar to the buffer zones, the selected wells were spatially joined to attributes of the contaminated sites, associating the well with a possible contaminant type and DNREC program.

The selected wells were assigned a risk to ground-water contamination level using the matrix shown in Table 4. The risk matrix accounts for depths of wells and their distances in the down-gradient directions from the contaminated sites, contaminant mobility, derived from the water solubilities of the compounds (Yaws, 1999), and the status of ground-water contamination (known or potential). Values for each risk criterion range from 1-4, with the higher risk assigned the lower value. Risk criteria were totaled for each well and risk to each well was classified high, medium, or low, depending upon this total value.

Modeling Capture Zones

In an effort to evaluate whether there is a correlation between land use land cover (LULC) around sampled wells and observed water quality, "capture zones" were delineated
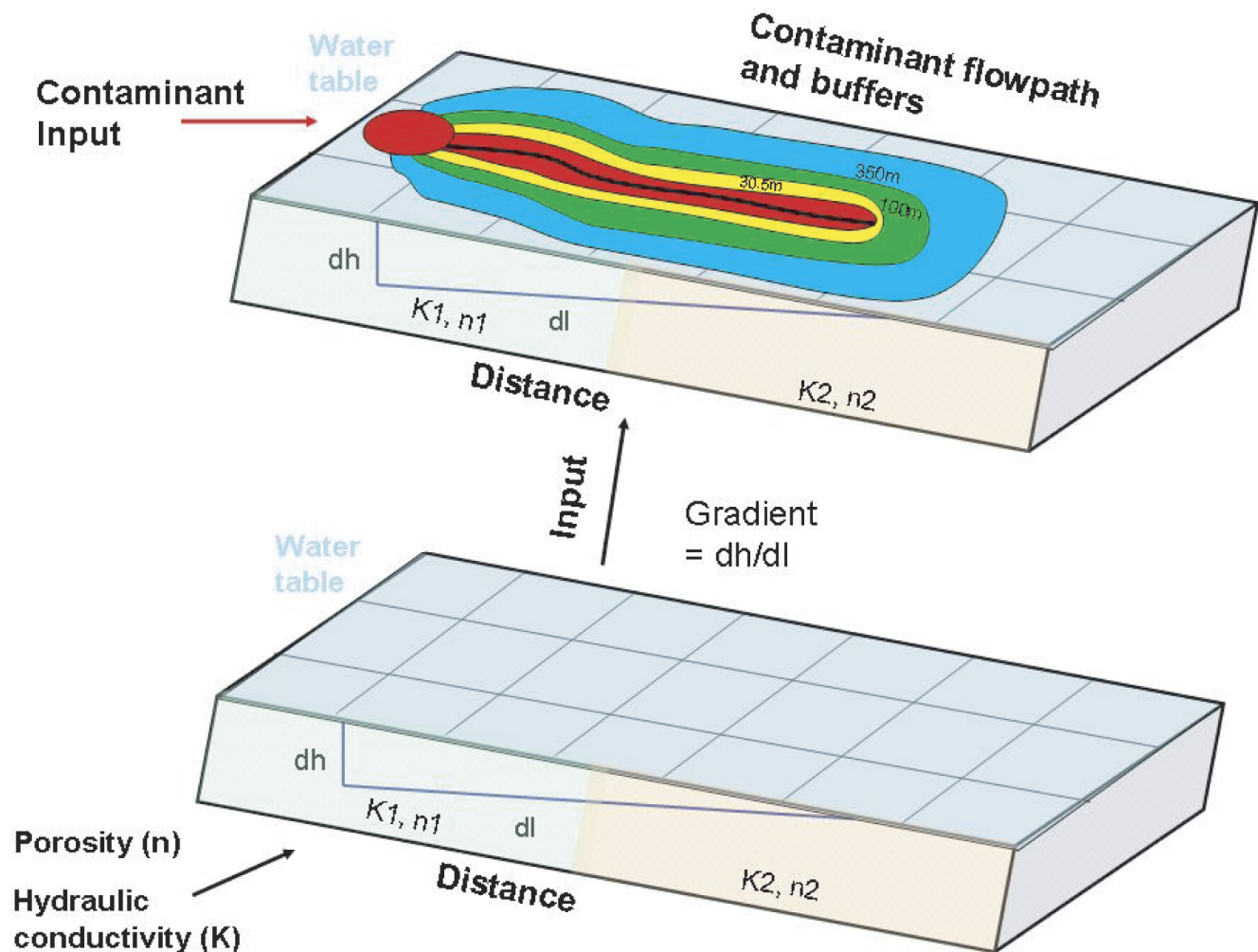
Figure 5. Generalized illustration of contaminant flow-path model.

for those wells where contaminants were detected. The method of creating the capture zones was computed in a similar manner to the risk zone creation process; however, particle track lines were computed in an upgradient direction from the wells. A 100m buffer was applied to each trackline. The capture zones were intersected with 1997 LULC data (www.DataMil.gov). Only the land use types that occupied at least 25 percent of the capture zone were considered in this evaluation. Because LULC often varies significantly over a capture zone, a single well's water chemistry data can

Table 3. Input data for contaminant flow-path modeling. Porosity and hydraulic conductivity values from Andres (2002). Hydraulic conductivity for New Castle County is geometric mean of all recharge classes.

RECHARGE CLASS	POROSITY	HYDRAULIC CONDUCTIVITY (M/DAY)
Excellent	0.34	21.64
Good	0.34	15.54
Fair	0.27	7.32
Poor	0.24	1.52
New Castle County	0.29	9.75

be associated with multiple LULC categories. For example, one well can be associated with two LULC types (agriculture, urban, and suburban) and two contaminant classes (metals and inorganic chemicals, nitrate).

RESULTS OF WATER-QUALITY INVESTIGATION

The results of the study are presented in terms of the main efforts of the study. The first relates to assessment of data sources and the water-quality data. The second is focused on assessment of risk to domestic wells from contaminated sites.

Water-Quality Data and Metadata

Because of the different program goals of the various agencies collecting water-quality data, many sample records were rejected for not meeting project parameters, or the sample metadata did not meet the QA requirements of this study. As mentioned previously, a key QA filter for accepting or rejecting sample records is the presence or absence of construction data for the sampled well.

In some cases, sample records were not used because construction data for the sampled well indicated that the sample was pumped from a confined aquifer and from depths in the
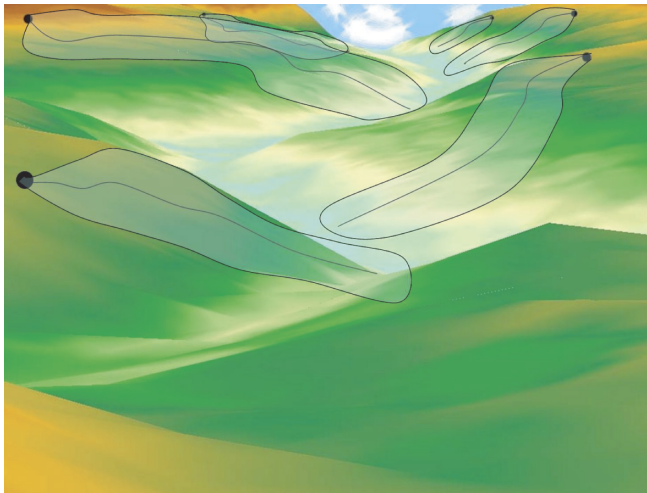
Figure 6. Generalized illustration of flow-path model results. 3-Dimensional scene displaying pathlines, buffers, and WTE (ESRI ArcScene).

unconfined aquifer greater than 100 feet that are much less susceptible to contamination introduced near land surface. However, in most cases, data were rejected because of a lack of adequate well or sample metadata. The end result was that the data were not adequate to address some of the primary questions that we posed.

DNREC-SIRB Data Assessment

The DNREC-SIRB CSF on-line document resource contains tens of thousands of document images on sites investigated by DNREC-SIRB or under the direction of DNREC-SIRB. The supporting metadata permit keyword searching, and this process resulted in retrieval of nearly 4,800 documents. However, because DNREC-SIRB does not maintain a central database that specifically identifies sites known to have impacted ground water, a page by page review of these documents was necessary.

In many instances, individual documents were sections or chapters of whole reports. A vast majority of the documents contained no water chemistry data. After surveying these records for sampling of offsite domestic wells, numerous documents covering investigations at approximately 25 sites were identified as having sampled offsite domestic wells. Several hundred person hours were spent characterizing multiple documents from a total of twelve DNREC-SIRB sites. This, of course, does not represent our complete effort to search the DNREC-SIRB CSF. DNREC-SIRB personnel and project officers were contacted and surveyed to determine if they had any personal knowledge on possible sites of interest. This effort resulted in no additional pertinent information.

Of the project records perused on the DNREC-SIRB CSF web database, 85 domestic wells were identified as having ground-water quality data. We were able to find or match DNREC permit numbers for 14 of those wells. Of those 14, nine have sufficient metadata in the state's well permitting database. Of these nine wells, only three wells were screened in the unconfined aquifer. Following application of QA rules for sample metadata, only two samples were incorporated into the database. Both samples contained no detectable contaminants (Table 5).

An important characteristic of the DNREC-SIRB data is that the sampled wells were not randomly selected from all domestic wells, but rather the well locations are biased by proximity to contaminated sites. This was done by design to assess whether proximity to contaminated sites has an effect on water quality in the shallow aquifer. The number of wells in this dataset would have to be much greater to assess this issue.

DNREC-TMB Data Assessment

A total of 57 sites were selected by DNREC-TMB staff as having known impact to offsite wells. Twelve of those sites were eliminated because they fell within public-water-utility franchise areas. Similar to the experience with DNREC-

Table 4. Decision matrix for assigning risk levels to domestic wells located in risk zones.

VALUE	IMPACT OF CONTAMINATION	WELL SCREEN DEPTH (FEET)	DISTANCE FROM CONTAMINATION	MOBILITY OF CONTAMINANT FX(H_2O SOLUBILITY PPM)
1	Known Ground-Water Impact	Less than or equal to 50'	Well located within the immediate contaminant plume	10^4 - 10^6
2	Potential Ground-Water Impact	Greater than 50' & less than 100'	Well located within the 30.5m buffer of the contaminant plume	10^2 - 10^4
3	N/A	Greater than 100'	Well located within the 100m buffer of the contaminant plume	$0 – 10^2$
4	N/A	N/A	Well located within the 305m buffer of the contaminant plume	N/A

SIRB, site investigations lacked well permit identifiers. Most records contained no information on water use, depth, or owner. Because this experience was similar to DNREC-SIRB CSF records, only a portion of all sites were surveyed. Of the 22 sites surveyed by DGS staff, DNREC-TMB files contained data for 177 wells. Approximately 31 percent or 54 domestic wells were matched with DNREC well permit numbers. Water use and depth requirements of the project narrowed the number of sampled wells compiled for this study to 20.

Generally speaking, analytical data recovered from DNREC-TMB files met sample metadata requirements; however, the list of tested analytes is limited to gasoline and fuel related compounds. In addition, few of those samples were attributable to a known DNREC well permit number. A total of 435 samples were collected from DNREC-TMB files and only 109 samples remained after attempts to identify a sample with a DNREC well permit number. Of those 109 samples, a total of 48 samples were incorporated into GWQDB that were for wells that met project pertinent parameters, giving approximately 57 analysis results (Table 5).

An important characteristic of the DNREC-TMB data is that the sampled wells were not randomly selected from all domestic wells, but rather the well locations are biased by proximity to contaminated sites. This was done by design to assess whether proximity to contaminated sites has an effect on water quality in the shallow aquifer. The number of wells in this dataset was marginally adequate to assess this issue.

DPH-ODW Data Assessment

Public well ground-water quality data for small public water systems (PWS) (serving <100 persons) included records for over 6,000 samples collected from 1993 to 2005. Sample metadata indicated that nearly 1,400 discreet wells were sampled. This number of wells is not realistic, indicating that multiple identifiers were assigned for the same wells. Linking samples by address and/or well owner and the DPH-ODW identifier for the well matched 133 wells to permit numbers in the DNREC well permitting and Source Water Assessment Program databases. Of those wells, 35 matched project parameters, approximately 3 percent of the original public wells estimate.

The public supply well data (serving <100 persons) obtained from DPH-ODW contained 6,265 sample records. Compliant samples from this dataset, that is, samples that met QA standards, made up about 2 percent (94 samples) of the total samples. Of these 94 compliant samples, 18 are for

organic chemical analysis, 12 for trace metal analysis and 64 for routine (mostly nitrate) analysis.

Domestic well ground-water quality data from 2,800 sampling events of numerous wells generated by the Private Well Sampling Program were also obtained from DPH-ODW staff. These records, collected from 2003 to 2005, contain analyses of a limited suite of inorganic compounds with nitrate being the chemical constituent of interest for this study. DGS staff members were able to match 138 wells to DNREC well permit numbers based on well owner and/or address. Of those 138 matched wells, 27 met project parameters and were included in the GWQDB. These pertinent domestic and public wells produced a total of 122 samples, and 461 analysis results (Table 5).

There were 3,209 domestic well samples collected from DPH-ODW (2003-2005 domestic well data). Less than 1 percent of samples complied with the QA standards for this study or approximately 31 samples. All of these samples were tested for nitrate.

DDA-PMP Data Assessment

Of the domestic wells analyzed for the DDA-PMP, all but two were retained following application of QA standards to DDA-PMP data. These wells also met project parameters as the scope of the DDA-PMP and this study are similar. Domestic well ground-water quality samples in this dataset numbered 321 with 454 total analysis results, representing a date range from 1995 to 1998 and 2001 (Table 5).

USGS-NWIS Data Assessment

A total of 61,504 analysis results were downloaded from the USGS-NWISWeb Water Data website as of April, 2005. Applying project parameters to the USGS data narrowed the pertinent wells in the USGS dataset to 42, producing 108 samples and 3,545 analysis results (Table 5). No records were removed from the USGS-NWIS dataset as a result of failing project QA standards for sample or well data.

EPA Data Assessment

Public well ground-water quality data surveyed for this report were also collected from EPA's Office of Ground Water and Drinking Water website (http://www.epa.gov/safewater/). No data are reported for Delaware PWSs serving less than 100 persons in the Safe Drinking Water Act Unregulated Contaminants Monitoring Program (SDWA-UCMP) for 1999 List 1 and 2 Chemicals. SDWA National Contaminant Occurrence database (NCODB), Round 1 and Round 2 sampling

Table 5. Numbers of wells, samples, and analyses used in this study.

AGENCY	WELLS	SAMPLES	ANALYSIS RESULTS	DATE RANGE
DNREC-SIRB	2	2	2	1990
DNREC-TMB	20	48	57	1999-2005
DPH-ODW	62	122	461	1993-2005
DDA-PMP	83	321	454	1995-1998, 2001
NWIS	42	108	3,545	1990-2005
Total	**209**	**601**	**4,519**	**1990-2005**

(1988-1997) also does not contain data for Delaware PWS serving less than 100 persons. The EPA also performed a six-year review study in 1998 under the SDWA but data in this study did not include Delaware wells.

Ground-water quality data downloaded from the Safe Drinking Water Information System (SDWIS) were compiled from known MCL violations reported by State agencies and, therefore, represent duplicate samples. Furthermore, these data are presented as aggregated concentration values. Therefore, data from the SDWIS were not incorporated into GWQDB and not explicitly considered for this report.

No STORET data were included in the study as only surface-water quality data were available for Delaware.

Data Characterization

Samples from 209 wells are included in this study. Sampled wells are distributed throughout the state (Fig. 7). Varying numbers of samples from these wells were analyzed for four classes of contaminants; pesticides, metals and inorganic chemicals, nutrients, and VOCs (Tables 6A and 6B). Nutrient data include analyses of nitrate-nitrogen, nitrite plus nitrate-nitrogen and ammonia-nitrogen. VOCs also include other organic chemicals not typically considered as a VOC (e.g., MTBE).

Record tallies in Table 6A and 6B are categorized by agency and broken down into detections and non-detections. Non-detections are those analyses that were reported below the MRL. Exceedances are presented in the table and represent concentration exceedances for regulated (MCL) and unregulated compounds (SMCL, TT ACTL or HBSL). Tallies of exceedances are considered separate from totals because they were already included in the number of detections (Tables 6A and 6B). It should be kept in mind that the percentage of wells with detections/non-detections displayed in Table 6B represents data that met all metadata requirements for this study and are not representative of the total data collected from the different agencies. In addition, differences in contaminant class percentages between Tables 6A and 6B are the result of multiple samplings for many wells.

Exceedances - All Contaminant Classes

Concentrations of compounds exceeding primary or secondary MCLs and HBSLs for wells varied by contaminant class (Table 6B and Figs. 8 A-D). For pesticides, approximately 67 percent of wells exhibited detections with 5 percent of those exceeding an MCL or HBSL (Fig. 8A). Approximately 73 percent of wells exhibited VOC detections with concentrations exceeding an MCL or HBSL in about two percent of wells (Fig. 8D). In a recent study of 30 public wells, Ferrari (2001) found none of the sampled wells had exceedances for pesticides or VOCs.

Similarly, approximately 16 percent of metal and inorganic chemical analyses exceeded standards (Fig. 8D). However, many more detections, about 95 percent of trace metal and major ion samples, were recorded for this class of contaminants than for any other in GWQDB (Fig. 8B).

Overall, nitrate makes up the largest proportion of contaminant concentration exceedances in GWQDB with 18 percent of analysis results exceeding the MCL (Fig. 8C).

Pesticides

Pesticides, with herbicides, insecticides, and fungicides as the most common pesticide types, are widely used in Delaware, with the largest quantities used by agriculture (Denver et al., 2004; Blaier and Baxter, 2000). A total of nine pesticides or pesticide degradants were detected (Figures 8 and 9) in two-thirds of the wells sampled (Table 6B). This proportion is lower than for public wells where 90 percent of wells sampled in one study had detectable pesticides or pesticide degradants (Ferrari, 2001). Of the pesticides with a national or state MCL, alachlor, atrazine and simazine constitute the majority of detections for domestic wells compiled into GWQDB (Fig. 9).

Seven of the 124 alachlor detections were at concentrations above the USEPA MCL (0.003 mg/L). Alachlor was detected in 46 wells (Table 7), with 30 wells having alachlor detected in multiple samples. No other regulated pesticides were detected with concentrations above their MCL (Fig. 9). Alachlor had the highest detection frequency at 45 percent (using an assessment level of 0.0001 mg/L) of all analyses and 43 percent of all wells sampled for pesticides (Table 7). Atrazine, metolachlor and simazine also had detection frequencies greater than 10 percent

Figure 7. Location map of sampled wells.

Table 6A. Detection and exceedance tallies of analyses by contaminant and agency for data compiled in GWQDB[a].

ANALYSIS RESULTS	PESTICIDE	METALS AND INORGANICS	NUTRIENTS[b]	VOC[c]	AGENCY TOTAL
USGS-NWIS					
Exceedance[d]	1	2	6	1	10
Detect	14	471	53	45	583
Non-Detect	655	135	45	2,127	2,962
Total	**669**	**606**	**98**	**2,172**	**3,545**
DDA-PMP					
Exceedance[d]	7	0	NA	0	7
Detect	306	8	NA	2	316
Non-Detect	138	0	NA	0	138
Total	**444**	**8**	**NA**	**2**	**454**
DPH-ODW					
Exceedance[d]	4	18	16	0	38
Detect	9	123	55	3	190
Non-Detect	0	210	60	1	271
Total	**9**	**333**	**115**	**4**	**461**
DNREC-TMB					
Exceedance[d]	NA	0	NA	12	12
Detect	NA	4	NA	36	40
Non-Detect	NA	0	NA	17	17
Total	**NA**	**4**	**NA**	**53**	**57**
Class Total	**1,122**	**951**	**213**	**2,231**	**4,517**

NA- Not available

[a] Detect means that the contaminant was found above the lab minimum reporting level, while non-detect means that the contaminant was not found above the lab minimum reporting level.

[b] Comprised of nitrate -nitrogen, nitrite -nitrogen, nitrite plus nitrate, and ammonia analyses.

[c] Includes other organic compounds

[d] Exceedances were not included in analysis result totals because they were already considered as detect.

Table 6B. Detections and exceedance tallies of wells by contaminant and agency for data compiled in GWQDB[a].

WELLS	PESTICIDE	METALS AND INORGANICS	NUTRIENTS[b]	VOC[c]
USGS-NWIS				
Exceedance	1	2	5	1
Detect	5	42	35	17
Non-Detect	17	0	7	3
DDA-PMP				
Exceedance	3	0	NA	0
Detect	65	8	NA	2
Non-Detect	18	0	NA	0
DPH-ODW				
Exceedance	1	13	14	0
Detect	1	33	44	2
Non-Detect	0	3	17	1
DNREC-TMB				
Exceedance	NA	0	NA	6
Detect	NA	3	NA	11
Non-Detect	NA	2	NA	8
CONTAMINANT CLASS PERCENTAGES				
Exceedance	5%	16%	18%	2%
Detect	67%	95%	77%	73%
Non-Detect	33%	5%	23%	27%

NA – Not available

[a] Detect means that the contaminant was found above the lab minimum reporting level, while non-detect means that the contaminant was not found above the lab minimum reporting level.

[b] Comprised of nitrate -nitrogen, nitrite -nitrogen, nitrite plus nitrate, and ammonia analyses

[c] Includes other organic compounds

(Table 7). These four most frequently detected pesticides are commonly found in domestic supply ground water of the Delmarva Peninsula and with similar detection frequencies (Denver et al., 2004). The one exception is alachlor with a higher frequency of detections reported here compared with approximately 5 percent reported in Denver et al. (2004).

Most pesticides are unregulated, yet many of them are listed on the USGS HBSL webpage (http://infotrek.er.usgs.gov/traverse/f?p=HBSL:HOME:1414439475200153466), and have HBSLs to assess human health. The number of pesticides with USGS HBSLs has been growing, from the 78 studied in Toccalino et al. (2004) to the 158 currently on the list (http://infotrek.er.usgs.gov/traverse/f?p=HBSL:HOME:14144 39475200153466). Nonetheless, only five unregulated pesticides with detections were compiled in GWQDB (Fig. 10).

Metolachlor, an agricultural herbicide, is the most frequently detected pesticide that does not have an MCL, with a detection frequency of 26 percent and occurring in 24 wells (Table 7), with 15 wells having metolachlor detected in multiple samples. Dieldrin, an herbicide that has not been used in the United States since 1987 (USEPA, 2003b), was detect-

ed in two samples for two wells, one in November of 1995 and one in June of 2001. Both detections have concentrations exceeding the HBSL of 0.000002 mg/L (Fig. 10).

Combinations of pesticides were common in many samples. The two most commonly co-occurring regulated pesticides, alachlor and atrazine, were detected together in about 15 percent of the total number of wells sampled for pesticides (106 wells). Similarly, the combination of alachlor and metolachlor occurred in 17 percent of the total number of wells sampled for pesticides, while approximately 13 percent of wells detected the three most commonly occurring pesticides, alachlor, atrazine and metolachlor. The next most common combination of pesticides was atrazine and simazine at only 6 percent of wells sampled for pesticides. These percentages of pesticide mixtures are determined for detections based on original MRLs, that is, not based on a common assessment level of 0.0001 mg/L.

The frequencies of these pesticides occurring together are similar to slightly lower than those determined for a national assessment of ground water where approximately 20 percent of 2,227 sites detected two or more pesticides (Barbash
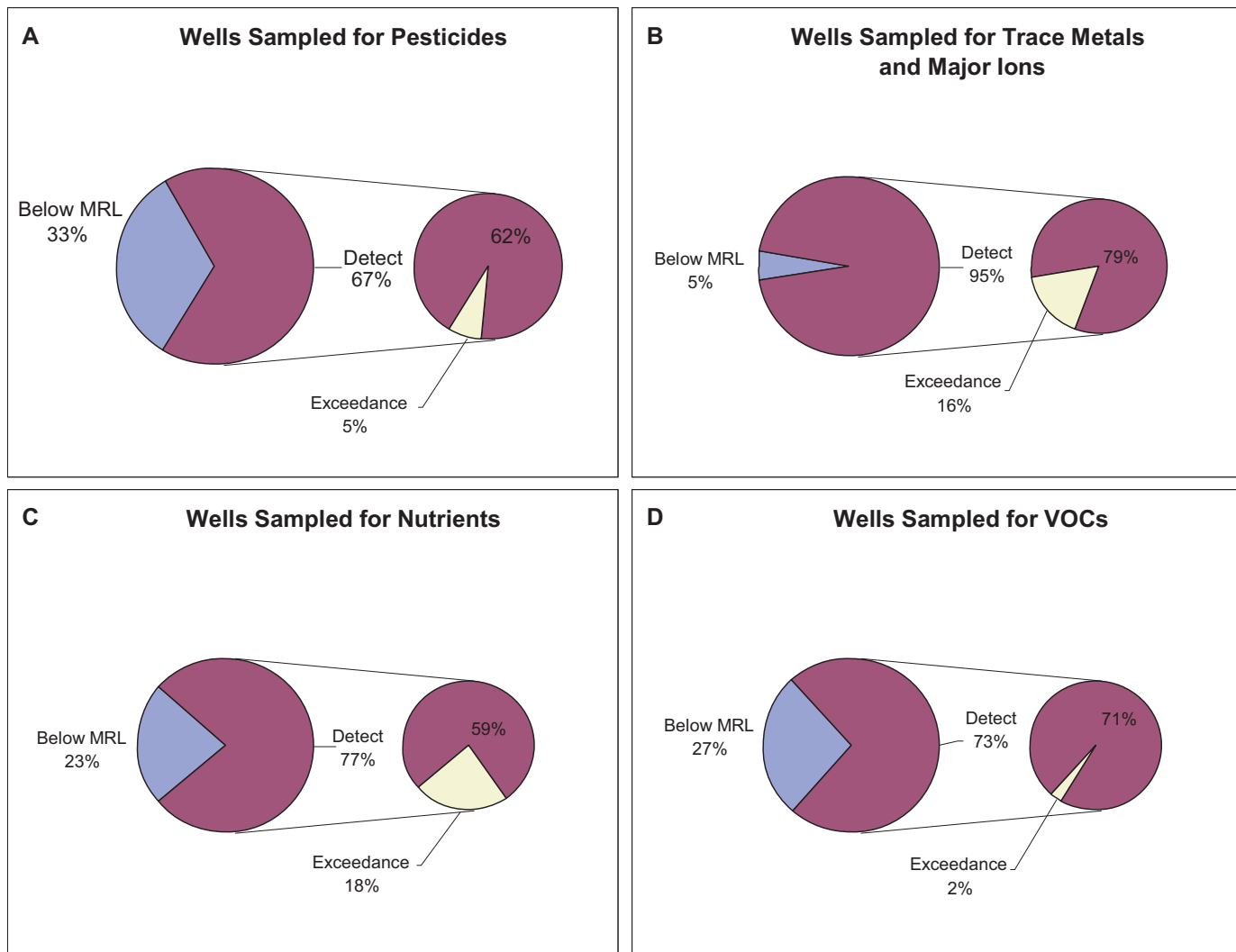

Figure 8. Summary charts of detection and exceedance proportions for sampled wells in terms of contaminant classes. Below MRL refers to non-detections as they represent analyses of contaminants that were not detected above the laboratory minimum reporting limit. Nutrient analysis results include nitrate-nitrogen, nitrite-nitrogen, nitrite plus nitrate-nitrogen and ammonia.

Table 7. Detection frequency for selected contaminants. Regulated (MCL) and unregulated (HBSL) compounds are listed with their water quality standard (benchmark type). Four of the VOCs listed do not currently have a primary, secondary or screening level benchmark type (BM Type).

CONTAMINANT	WELLS	SAMPLES	DETECTION FREQUENCY [a]	BM TYPE	VALUE (mg/L)
VOC					
MTBE 1634-04-4	10	11	18%	MCL	0.01 [c]
Chloroform 67-66-3	4	4	10%	--	--
PCE 127-18-4	2	2	4%	MCL	0.005
TAME 994-05-8	2	2	4%	--	--
BDCM 75-27-4	1	2	4%	--	--
Trichloroethylene 79-01-6	1	1	2%	MCL	0.005
Pesticides					
Alachlor 159752-60-8	46	123	45%	MCL	0.002
Atrazine 1912-24-9	36	83	36%	MCL	0.003
Metolachlor 51218-45-2	24	50	26%	HBSL	0.07
Simazine 122-34-9	8	22	13%	MCL	0.004
Cyanazine 21725-46-2	5	9	6%	HBSL	0.001
Carbofuran 1563-66-2	2	2	1%	MCL	0.04
Dieldrin 60-57-1	b	b	b	HBSL	0.000002
Nutrients					
Nitrate (includes nitrite plus nitrate)	79	99	76%	MCL	10

[a] Detection frequency based on assessment levels: 0.0002 mg/L for VOC, 0.0001 mg/L for Pesticides and 0.4 mg/L for Nitrate.

[b] Only two detections occur, but these were censored because their MRL was above the assessment level. In addition, the HBSL for Dieldrin is much lower than the MRL or the pesticide assessment level.

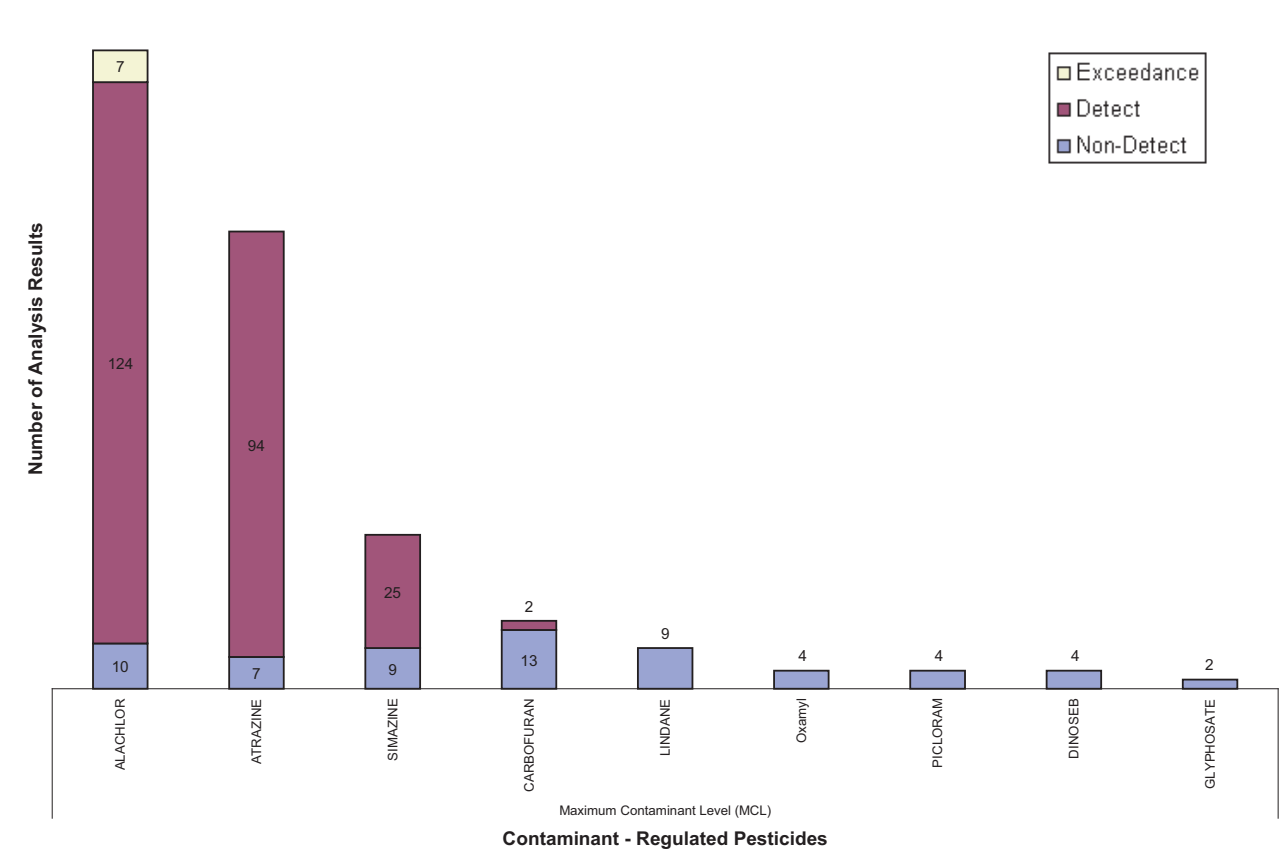[c] MCL for MTBE is established by Delaware (16 Delaware Code, Chapter 1, Section 122 (3))

Figure 9. Majority of analysis results for regulated pesticides, those having an MCL. Analyte tallies were determined from a total of 221 samples analyzed for pesticides and compiled into GWQDB. An exceedance tally is part of the detection tally shown for a specific contaminant.

Figure 10. Majority of analysis results for unregulated pesticides, those having an HBSL. Analyte tallies were determined from a total of 221 samples analyzed for pesticides and compiled into GWQDB. An exceedance tally is part of the detection tally shown for a specific contaminant.
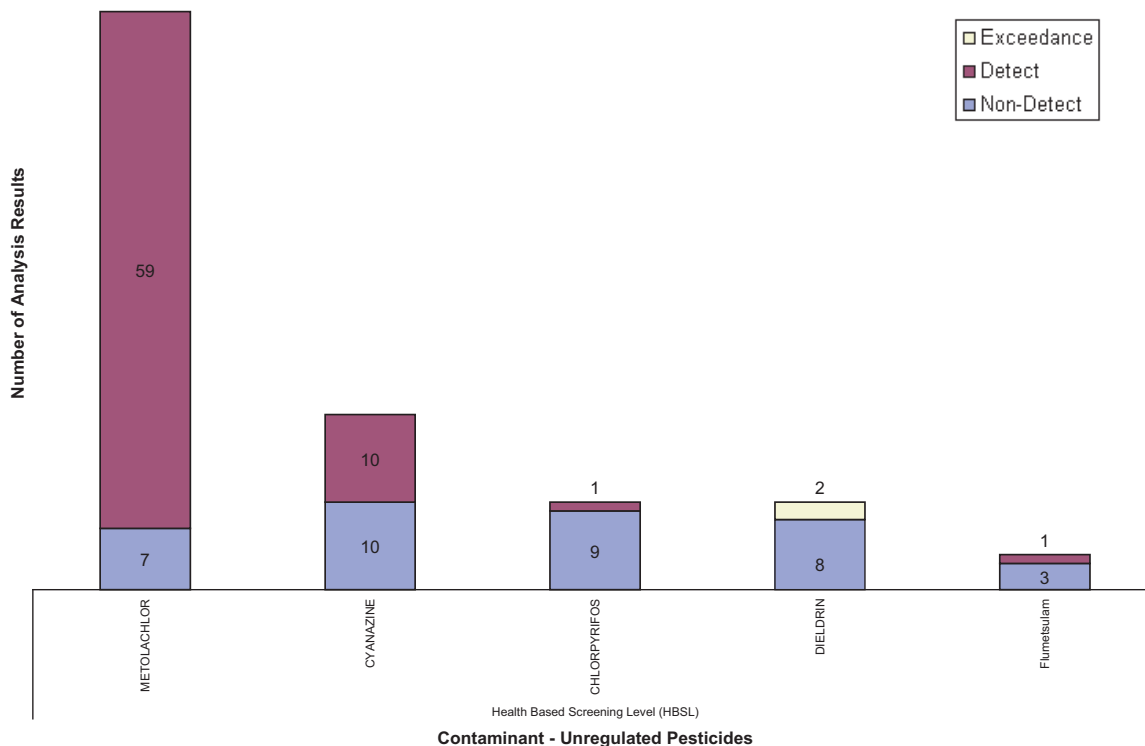
et al., 1999). However, the most frequently occurring of the pesticides in the national assessment found by Barbash et al. (1999), were atrazine, DEA (an atrazine degradate), and simazine. The most commonly occurring pesticides in this study (alachlor, atrazine, metolachlor, and simazine) are consistent with what has been detected in ground water for the Delmarva region (Denver et al., 2004).

When the BQ values of the most frequently detected pesticides are calculated from contaminant concentrations for individual wells (Fig. 11), three pesticides (alachlor, atrazine and simazine) have BQ values that are above 10percent of their benchmark (MCLs). Some alachlor analyses also exceeded their benchmark of 0.002 mg/L (Fig. 11). Metolachlor BQ values did not fall within the range of potential human-health concern (within 10 percent of its BM) even though it was a frequently detected pesticide. Conversely, cyanazine BQ values do occur above 10 percent of its benchmark (Fig.10); however, it was not a frequently detected pesticide (Table 7). The magnitudes of BQ values for alachlor, atrazine, and simazine are of concern particularly because their significant (greater than 10 percent) frequency of detection. However, none of these compounds are considered carcinogenic by the USEPA (as listed in the HBSL database of contaminants http://infotrek.er.usgs.gov/traverse/f?p=169:1:1414439475200153466::NO).

In terms of land use, these frequently detected pesticides are distributed fairly randomly across the state (Fig. 12). Similarly, high magnitude BQ values are not preferentially distributed within the state (Fig. 12).

Trace Metals and Major Ions

Numerous samples were analyzed for trace metals and major ions (i.e., metals and inorganic chemicals) and many detections were recorded (Fig. 13). Most of these metals and major ions are naturally occurring as trace components of rock-forming minerals or sea water, and have the potential to be present at very low concentrations in ground water. Higher concentrations of many of these metals and major ions may indicate contamination. Iron, a naturally occurring chemical in Delaware ground water, was sampled the most frequently with 42 detections compiled into GWQDB; 19 of those detections exceeded the SMCL of 0.3 mg/L (Fig. 13). Lead was also detected in one sample with a concentration greater than the TT ACTL of 0.015 mg/L (Fig. 13). Sampling metadata for this sample are not adequate to determine if the lead was present in the ground water or was a result of sample collection or water system issues.

Nitrate, Nitrite, and Ammonium

A total of 133 nutrient samples were compiled into GWQDB with nitrate and nitrite analyses comprising the majority of these results. Because nitrite is so rarely detected, analyses of nitrite plus nitrate were combined with nitrate analyses. A total of 77 nitrate analysis detections are present in GWQDB with 22 of those detections as exceedances of the nitrate-nitrogen MCL (Fig. 14).

Of all the data compiled in GWQDB, nitrate was detected the most frequently at 76 percent (Table 7). Furthermore,
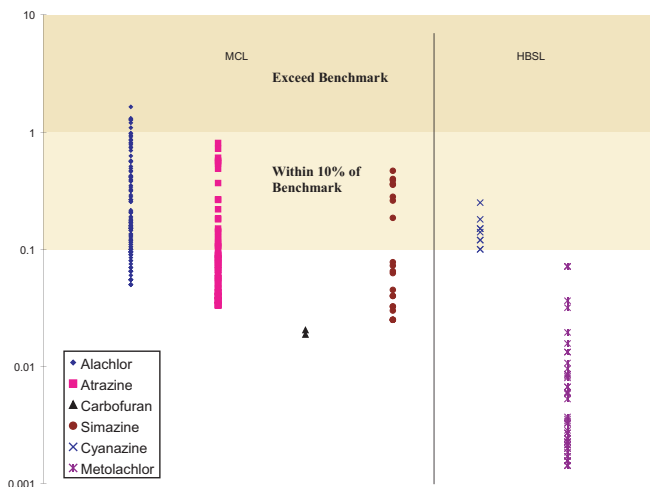
Figure 11. Plot of BQs for selected maximum pesticide concentrations for a given well, in a given year. Therefore, some points may represent multiple samplings of a particular well. Shaded regions denote areas of potential human-health concern. Alachlor, atrazine, cyanazine and simazine all have BQ values within the human-health range of concern (0.1 to 1). Except for a few alachlor analyses (representing three different wells), no detected pesticides exceeded their human-health benchmarks.

nearly 18 percent of sampled wells had nitrate concentrations above the MCL of 10 mg/L (Table 6b).

When these detections are plotted by concentration and well screened interval, it is apparent that high nitrate concentrations occur at all depths within the shallow aquifer (Fig. 15). Figure 15 presents average annual nitrate concentrations for a particular well during a particular year for wells sampled more than once per year. When more than one nitrate analysis existed for a well, an annual mean was plotted along with its standard deviation.

VOCs

VOCs are synthetic compounds that are in wide use throughout the United States (Zogorski, et al., 2006). They do not naturally occur in Delaware ground water, so when detected they indicate ground water has been contaminated by human activities. While only 59 samples in GWQDB were analyzed for VOC and other organic compounds, the suite of analytes tested in these analyses can be numerous. Because of this, VOC analysis results (individual analyte detection/non-detections) make up the majority of analysis results in GWQDB; however most of these are non-detections (Table 6A).

About 70 percent of the domestic wells sampled had one or more VOCs detected (Table 6B). Ferrari (2001) reported that 100 percent of 30 public wells sampled had at least one VOC detected. These ratios are higher than those reported by Zogorski et al. (2006) for domestic and public wells in a national study. Few VOC mixtures occur in this dataset with the exception of MTBE and TAME, which occurred together in nine out of 44 wells sampled in this study. Fewer co-occurrences in this study are thought to result from a smaller overall sample set and an abbreviated list of tested analytes used by DNREC-TMB.
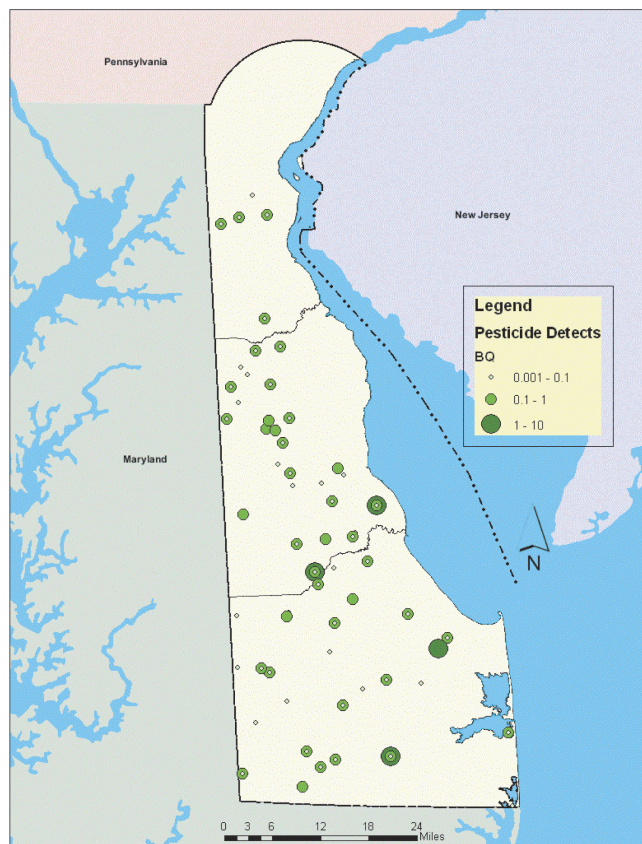
Figure 12. Distribution of most frequently detected pesticides and the range of concentrations expressed as BQs. Overlapping, concentric circles represent multiple, yearly samplings for the same well.

Figure 16 plots individual VOC contaminants compiled in GWQDB and categorizes them by common use. Gasoline compounds, including oxygenates such as MTBE, were detected most frequently. Applying an assessment level of 0.0002 mg/L for VOCs, MTBE had a detection frequency of 18 percent and was detected in ten wells (Table 7). Furthermore, seven wells detected MTBE multiple times, because all of these data were collected from wells located downgradient of petroleum leaks. PCE had a detection frequency of 4 percent and was detected in two wells (Table 7).

The highest VOC detection frequencies were for MTBE, a gasoline oxygenate, at 18 percent and chloroform, a water disinfection byproduct, at 10 percent (Table 7). No national water-quality standards currently exist for these contaminants, although Delaware has established an MCL for MTBE at 0.01 mg/L. The remaining VOC detections to consider are all below 10 percent. These contaminants, PCE (a solvent), TAME (a gasoline oxygenate that often co-occurs with MTBE), BDCM (bromodichloromethane, a disinfection byproduct) and trichloroethylene (a solvent) have detection frequencies of 4, 4, 4 and 2 percent, respectively (Table 7). Only two of these VOC contaminants have MCLs, PCE and trichloroethylene, at 0.005 mg/L.

MTBE contamination of wells is a national issue and is addressed in the 2005 Energy Act. Similarly this has been an ongoing problem in Delaware, with more than 100 wells impacted by MTBE and investigated by TMB (P. Ellis, written

Figure 13. Majority of analysis results for metals and inorganic chemicals (major and minor ions). Analyte tallies were determined from a total 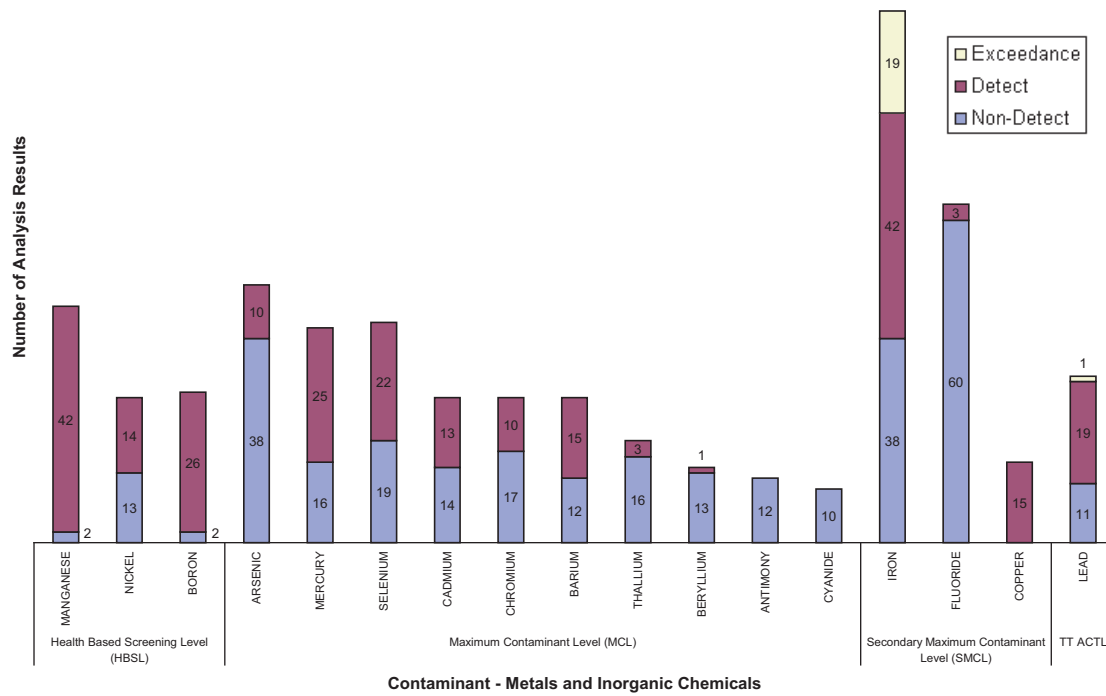of 145 samples analyzed for metals and major/minor ions and compiled into GWQDB. An exceedance tally is part of the detection tally shown for a specific contaminant.

communication). Dozens of wells have been replaced and many more have had treatment systems installed. An accurate count of the number of wells replaced or the number of treatment systems installed is not possible from information available to this study. Six wells (Table 6B) in the GWQDB have MTBE concentrations in excess of the Delaware MCL of 0.01 mg/L (16 Delaware Code, Chapter 1, Section 122 (3)). All of these wells were sampled as part of the DNREC-TMB program and are located near sites with known leaking underground gasoline storage tanks.

Capture Zone Delineation and LULC

A capture zone is the area within an aquifer that drains to and is captured by a pumping well (DNREC, 1999). Figure 17 illustrates that the majority of wells with detections of VOCs had capture zones that consisted of at least 25 percent urban and suburban LULC. No other LULC type had as high a proportion of wells with detections of VOCs. The association of VOC with urban/suburban LULC is consistent with that found in a national study of VOC occurrence in ground water (Squillace et al., 1999; Moran et al., 2002; Moran et al., 2004; Zogorski et al,. 2006) and could explain the higher detection rate of VOCs in Delaware compared to nationwide. The higher frequency of detection of VOCs in urban/suburban LULC may be attributed to more potential sources and releases of VOCs in addition to structures such as recharge basins and dry wells that serve to quickly route water into the shallow aquifer (Zogorski et al, 2006). Consistent with findings of Denver et al. (2004) for Delaware and of Squillace et al. (2004) for the entire United

States, wells located in areas where agriculture is the prevalent LULC had higher frequencies of detections of herbicides and pesticides than wells in other LULC categories. Forest and wetland LULC types yielded a minimal count of wells with detections.

RESULTS OF CONTAMINANT FLOW PATHS AND RISK ASSESSMENT

Flow Paths and Buffer Zones

The results of the contaminant flow-path modeling experiment are a collection of lines representing the expected ground-water flow paths, and polygons representing uncertainties due to the effects of unknown source area sizes, dispersion, diffusion, and heterogeneity in subsurface conditions. The polygons are buffer zones that increase the area and volume of potentially contaminated ground water. Therefore, they are conservative with respect to protecting the health of people consuming potentially contaminated water originating from contaminated sites.

The 5th, 25th, 75th, and 95th percentiles of the calculated path lengths and buffered zones were computed for the state and its three counties. New Castle County yielded the longest flow paths in all percentiles (Table 8). This is a direct result of the greater water-table gradients and can be attributed to the greater relief of land surface and the water table in that area. Sussex County, conversely, exhibits the shortest flow paths, which can be attributed to the lesser relief of land surface and the water table. As expected, results also show that trends in areas of buffer zones correspond with the trends in path length.
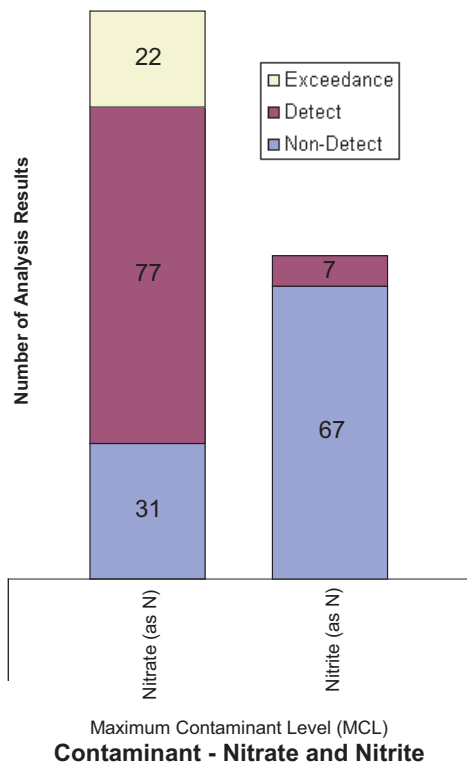
Figure 14. Majority of analysis results for nutrients, nitrate and nitrite. Analyte tallies were determined from a total of 133 samples analyzed for nutrients and compiled into GWQDB. An exceedance tally is part of the detection tally shown for a specific contaminant.
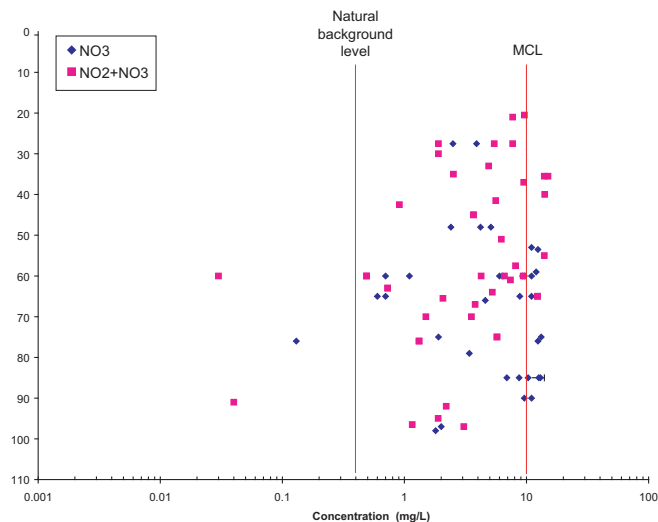
Figure 15. Plot of nitrate concentrations against well screen depth for analyses dating back to 1990. Screen depths represent a calculated midpoint for wells with available screen intervals. Otherwise, total well depths were used. Nitrate concentrations represent year averages for each well sampled. Where a well was sampled for nitrates more than once, a mean value and its standard deviation is plotted. For samples that show $NO_2 + NO_3$, NO_2 (nitrite) represents a small fraction of the total concentration.

Figure 16. Majority of analysis results for VOCs, categorized by use. Analyte tallies were determined from a total of 59 samples analyzed for VOCs and compiled into GWQDB. An exceedance tally is part of the detection tally shown for a specific contaminant.
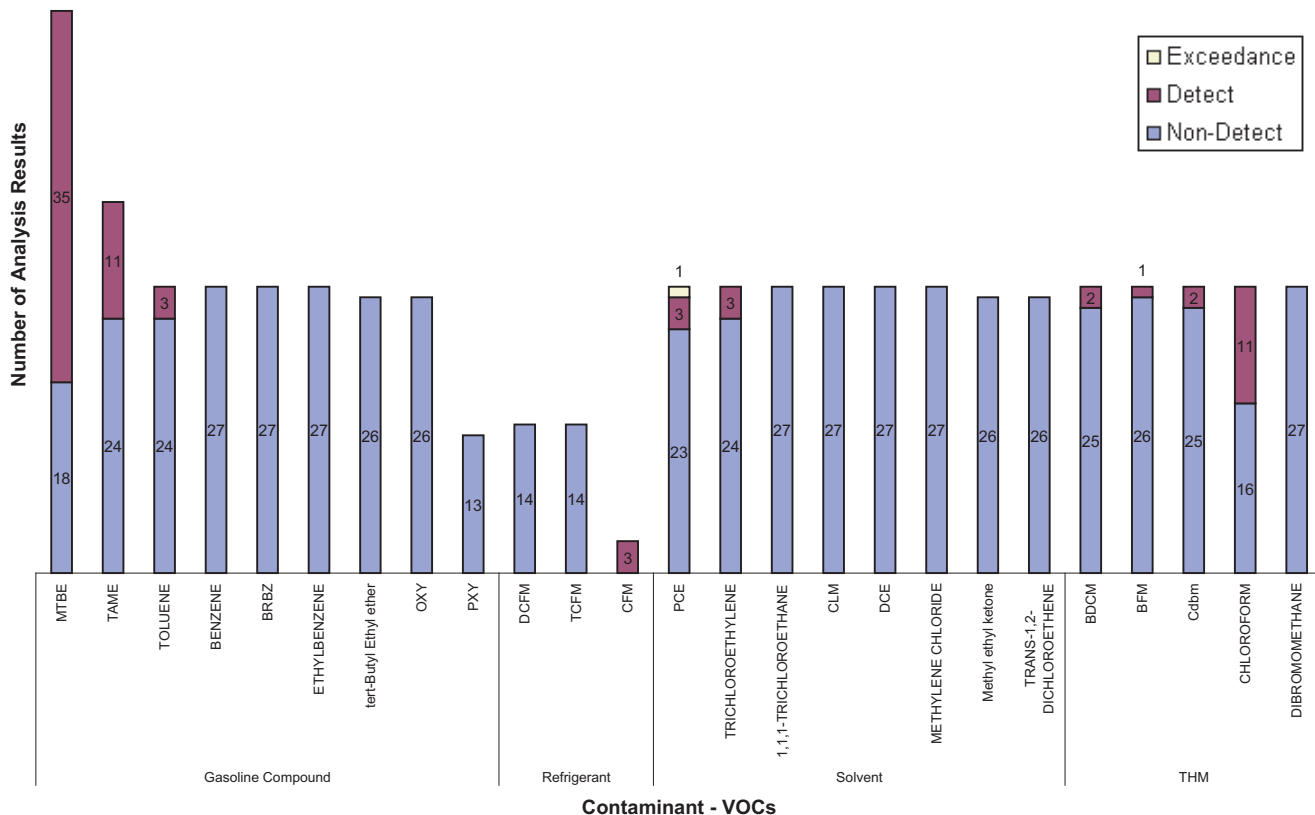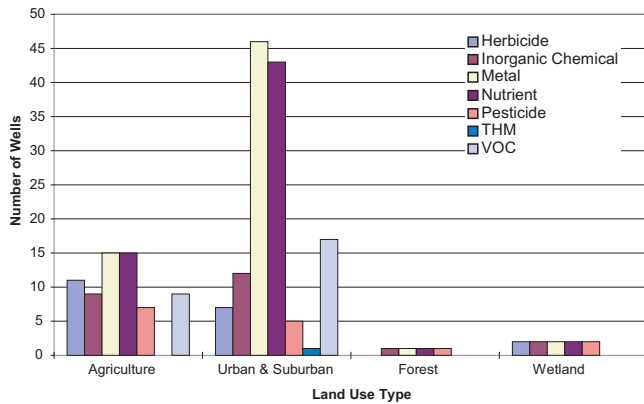
Figure 17. Domestic wells with contaminant detections in modeled capture zones by specific land use/land cover.

Figure 18. Numbers of wells located within modeled risk zones.

Due to the spatial clustering of contaminant source locations and the resultant overlapping of contaminant flow-path polygons and buffers, a number of wells are located within multiple contaminant flow-path areas. Some wells are located within up to seven overlapping polygons (Fig. 18). Of the 34,059 domestic wells in the DGS wells database with location data, 3,051 were located within the modeled contaminant flow-path polygons and buffers. The numbers of wells are 207, 1,195, and 1,649 in New Castle, Kent, and Sussex Counties respectively.

Risk Assessment

Because of the aforementioned uncertainties in modeling contaminant flow, four risk ranking models were developed and tested. These models are qualitative or semi-quantitative in that they assess relative risk of contamination to wells and not a probability of contamination. There are not adequate data on subsurface conditions, the amounts of contaminants, the start and duration of contaminant releases, and precise determination of contaminant source areas to support development of probability-based ranking models, such as the one proposed by Maxwell and Katsenberg (1999). Maxwell and Katsenberg (1999) attempted to predict cancer risk from exposure (ingestion, inhalation, dermal) to contaminated ground water through the use of a coupled ground-water contaminant transport simulator with a carcinogen exposure – cancer risk estimator. They found that uncertainties in exposure to contaminants related to uncertainties in aquifer properties (e.g., hydraulic conductivity, dispersivity) were roughly the same order of magnitude as uncertainties in estimating cancer risk due to human behavior related exposure factors. As a result, the model was unable to improve predictions of cancer risk from exposure to ground-water borne carcinogens over predictions done without considering contaminant transport by ground water.

The four risk ranking models (Table 9) were derived by using different weighting schemes for the four risk criteria (known or potential contamination impact, well depth, distance

Table 8. Statistics on output of the contaminant transport model.

Length of Modeled Contaminant Pathlines (km)								
	Minimum	$5^{th}\%$	$25^{th}\%$	Average	Median	$75^{th}\%$	$95^{th}\%$	Maximum	Count
Delaware	0.000	0.008	0.075	0.217	0.180	0.285	0.602	1.230	1636
New Castle County	0.002	0.045	0.135	0.325	0.270	0.465	0.735	1.230	534
Kent County	0.002	0.033	0.127	0.227	0.285	0.285	0.436	0.628	488
Sussex County	0.000	0.002	0.030	0.114	0.076	0.165	0.337	0.549	614

Area of Modeled Buffer Zones (km^2)								
	Minimum	$5^{th}\%$	$25^{th}\%$	Average	Median	$75^{th}\%$	$95^{th}\%$	Maximum	Count
Delaware	0.00	0.08	5.65	126.60	34.92	291.52	486.80	1295.78	4951
New Castle County	0.00	0.43	10.47	157.78	48.67	293.22	609.21	1295.78	1519
Kent County	0.00	0.18	6.07	124.32	35.43	168.39	494.56	874.89	1218
Sussex County	0.00	0.02	3.57	106.45	29.52	291.46	405.20	676.46	2214

Table 9. Summary of models used in assigning risk.

Method	Description
Model 1.	Wells selected using original matrix and risk level range I.
Model 2.	Wells selected using original matrix but with a new risk level value range II.
Model 3.	Wells selected using matrix criteria; using 4 classes of well depth. (0-50'; 50'-75'; 75'-100'; +100') and risk level range I.
Model 4.	Wells selected using Method 3 with risk level range II.

from source, and contaminant solubility). In Models 1 and 3, the highest risk is assigned only if a well had the lowest value in each of the ranking criteria (Table 4). The highest risk category for models 2 and 4 allowed one of the ranking criteria to have a value of 2. This is expected to increase the number of wells in the highest risk category.

Table 10. Risk level ranges used for categorizing risk.

CLASSIFIED RISK CATEGORIES	RISK LEVEL RANGE I	RISK LEVEL RANGE II
High	4	5
Medium	5 – 10	6 – 8
Low	10+	9 – 12
Negligible	N/A	13+

Model 1 incorporated the original matrix, in which the summed risk values were grouped using the risk level ranges shown in Table 10. In Model 2, the ranges of values in each risk category were modified to more evenly distribute the number of wells between the risk categories (Table 10). Model 2 also included a "Negligible" classification for the wells where the totaled value was larger than a threshold value resulting in an unlikely risk of contamination for the respective well. In Model 3, well screen depth was divided into 4 classes and greater risk was assigned to deeper (75 ft deep) wells. Model 4 combined the risk levels of Model 2 and risk range II (Table 9).

Model 1 yielded the greatest number of wells (2,657) in the medium risk category (Table 11). The other models provided more even distributions of the total number of wells having medium or low risk. Model 4, where a risk level of "negligible" was used, (Model 2 included "negligible"; however no wells totaled within the parameters) resulted in a rel-

atively even spread of wells in risk categories of medium, low or negligible. Model 4 resulted in approximately 50 percent of wells in the medium category and 30 percent and 20 percent of the wells being in the low and negligible risk categories, respectively.

Models 2 and 4 incorporate risk level range II, where the high category risk level range increased to five. The result of this was the number of wells in that category increased roughly 10 times compared to risk level range I (Table 11). However, it should be noted that the number of high risk wells, using all models, totaled to slightly more than 1 percent of all wells located within risk zones. Considering that the number of wells having spatial coordinate data is now more than half of all known wells, we estimate that the total number of wells located in the significant risk zones is between 1 and 2 percent.

CONCLUSIONS

Water quality data from more than 200 wells were characterized in this study. In general, the spatial distribution of wells is adequate to describe overall conditions for the general population of domestic water supply wells. Water quality data are comprised of four general contaminant categories, volatile organic compounds (VOCs), pesticides, metals and major ions, and nutrients.

Known and potential sources of ground-water contamination were catalogued and categorized. The risks the sites pose to water-supply wells were ranked through the use of a conservative contaminant transport model. A small number of domestic wells (1 to 2 percent) are located in areas of significant risk. Although we can not conclusively document the sample data, it appears highly likely that wells in these risk zones have been sampled during DNREC-mandated studies of contaminated sites. As a result, it is unlikely that residents in these areas are consuming contaminated water.

Pesticides and VOCs are frequently found at concentrations much below MCLs or HBSLs. Concentrations of these chemicals above MCLs or HBSLs rarely occur. The herbicides

Table 11. Number of domestic wells in risk categories by model.

Risk Classification	Risk Ranking Model			
	Model 1	Model 2	Model 3	Model 4
High	4	37	3	35
Medium	2,657	1,811	2,160	1,492
Low	390	1,203	888	920
Negligible	N/A	N/A	N/A	604

atrazine and alachlor are the most frequently detected, and alachlor is the only pesticide that occurs above the MCL. Nitrate was detected in more than 75 percent of wells sampled and exceeds the MCL in 18 percent of wells sampled. Of the VOCs, the gasoline-related compounds MTBE and TAME are the most frequently detected; however, this result is biased by the proximity of some wells to known contaminant sources. Of significant concern are the facts that more than 100 wells have been impacted by MTBE and other gasoline-related VOCs, and as a result, dozens of wells have been replaced and dozens of water-treatment systems have been installed.

The frequency of detection of VOCs is greater in public wells than in domestic wells. This is consistent with national trends and is thought to be a result of two main factors: public wells are more frequently located in more densely developed urban/suburban LULC settings than are domestic wells and public wells use higher pumping rates than domestic wells. Greater numbers of contaminants are detected in public wells than are in domestic wells; however, this result may be biased by the reduced number of analytes tested in samples collected for the DNREC-TMB program. The frequency of detection of pesticides is greater in domestic wells. This is consistent with the larger proportion of domestic wells being located in agricultural LULC settings.

Contaminants are frequently found at concentrations much below MCLs or HBSLs and rarely exceed MCLs or HBSLs. The exceedance rate is similar to that in national surveys. The detection rate of VOCs in Delaware is higher than in national surveys. The types of contaminants found in wells are consistent with the LULC of the areas contributing water to the wells. VOCs are most commonly associated with urban/suburban LULC and pesticides and nitrates are most commonly associated with agricultural LULC. This is consistent with national trends.

Water-quality data are not adequate to address this question. A conservative risk assessment model that accounts for locations of wells and contaminated sites and ground-water flow directions indicates that a relatively small number of wells are potentially at risk for contamination due to proximity of a well to a contaminated site. Water quality metadata collected from the State programs responsible for these contaminated sites are not adequate to determine if these at-risk wells have been sampled. The addition of the well permit number to the sampling and analysis records for each and every sample collected for state programs would be an inexpensive way to quickly provide an adequate dataset to address this issue. It is estimated that state-issued tags showing well permit numbers are now present on more than half of all domestic wells.

Following application of data QA/QC rules, the number and distribution of sampling points located in proximity to known contaminated sites are not adequate to the main issues of this study. The addition of the well permit number to the sampling and analysis records for each and every sample collected for state programs would be an inexpensive and effective way to quickly provide an adequate spatial distribution of sampling points.

RECOMMENDATIONS

Considering the similarity of the results of this study compared to those reported studies of public water wells in Delaware and those from national studies, we do not recommend conducting a study at this time that employs random sampling methods for selecting domestic wells to be tested for VOCs, pesticides, metals and major ions, or nutrients. However, given the prevalence of contaminants and ground-water flow conditions in Delaware, we recommend that such a study be conducted at 5-to-10 year intervals, but only in conjunction with efforts to evaluate public water supply wells.

We do not recommend a state-funded study targeted at wells located near known sources of contamination as one or more state programs already are sampling these wells.

From this point forward, well permit numbers should be required elements of the sampling and analysis records for each and every sample collected from wells for all state, county, and local programs.

Programs in DNREC and DPH that collect water quality data should use professionally developed, centralized electronic database applications to manage, analyze, and report these data. The use of collections of paper documents or electronic images of paper documents as the primary means for managing, analyzing, and reporting water quality data should be discontinued as soon as possible.

REFERENCES CITED

Alley, W. M., 1993, General Design Considerations, in: Alley, W. M., ed. Regional Ground-Water Quality: New York, Van Nostrand Reinhold, p. 3-22.

Andres, A. S., 1991, Results of the coastal Sussex County, Delaware ground-water quality survey: Delaware Geological Survey Report of Investigations No. 49, 28 p.

____2004, Ground-water recharge potential mapping in Kent and Sussex counties, Delaware: Delaware Geological Survey Report of Investigations No. 66, 20 p.

Andres, A. S., Howard C. S., Keyser T. A., and Wang L. T., 2002, Digital ground-water recharge potential map data for Kent and Sussex counties, Delaware: Delaware Geological Survey Digital Data Product DP 05-01.

Andres, A. S., and Martin, M. J., 2004, Estimation of the water-table surface for the Inland Bays watershed, Delaware: Delaware Geological Survey Report of Investigations No. 68, 20 p.

Barbash, J. E., Thelin, G. P., Kolpin, D. W., and Gilliom, R. J., 1999, Distribution of major herbicides in ground water of the United States: U.S. Geological Survey Water-Resources Investigations Report 1998-4245, 57 p.

Baxter, S. J., and Talley, J. H., 1996, Design, development, and implementation of a ground-water quality monitoring network for southern New Castle County, Delaware: Delaware Geological Survey Contract Report to New Castle County Department of Public Works, 45 p.

Blaier, S. C., and Baxter, S. J., 2000, The occurrence and distribution of several agricultural pesticides in Delaware's shallow ground water: Delaware Geological Survey Report of Investigations No. 61, 27 p.

Blaier, S. C., 1994, Moores Lake - A study of the effect of pesticide use on ground water in a residential area: Delaware Department of Natural Resources and Environmental Control, 10 p.

Delaware Code, Title 16, Chapter 1, Section 122 (3), 2002, [05/01/02].

Denver, J. M., Ator, S. W., Debrewer, L. M., Ferrari, M. J., Barbaro, J. R., Hancock, T. C., Brayton, M. J., and Nardi, M. R., 2004, Water quality in the Delmarva Peninsula: Delaware, Maryland, and Virginia, 1999-2001: U.S. Geological Survey Circular 1228, 30 p.

DNREC, 1990, State of Delaware Wellhead Protection Program: Delaware Department of Natural Resources and Environmental Control, 40 p.

____ 1999, State of Delaware Wellhead Protection Program annual report and Source Water Assessment and Protection Program status report: Delaware Department of Natural Resources and Environmental Control, 43 p.

____ 2001, Delaware Data Deliverable Model (3DM) Guidance Manual, Version 1.04: DNREC-SIRB, 19 p., http://www.dnrec.state.de.us/DNREC2000/Divisions/AWM/sirb/Misc/3DM%20Guidance%20Manual_v1.pdf

____ 2002, The impact of known and suspected contaminant sources on select public drinking water supplies in Delaware: Delaware Department of Natural Resources and Environmental Control, 81 p.

ESRI, 2002, Spatial Analyst tool, ArcGIS v. 9.2: ESRI, Redlands California.

____ 2003, Groundwater Darcy velocity and particle tracking tool, : ESRI, Redlands California: original link non-functioning, current link: http://webhelp.esri.com/arcgisdesktop/9.1/index.cfm?TopicName=darcy_velocity

Ferrari, M. J., 2001, Occurrence and distribution of selected contaminants in public drinking-water supplies in the surficial aquifer of Delaware: U.S. Geological Survey Open File Report 2001-327, 62 p.

Fischer, W. T. D., 2003, Evaluation of Tertiary-Butyl Alcohol for the development of a drinking water action level in Delaware: Ground Water Monitoring and Remediation, vol. 23, no. 2, p. 56-63.

Hamilton, P. A., Denver, J. M., Phillips, P. J., and Shedlock, R. J.,1993,Water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia — Effects of agricultural activities on, and distribution of, nitrate and other inorganic constituents in the surficial aquifer: U.S. Geological Survey Open-File Report 1993-40, 87 p.

Koterba, M. T., Andres, A. S., Vrabel, J., Crilley, D. M., Szabo, Z., DeWild, J. F., Aiken, G. R., and Reyes-Padro, B., 2006, Occurrence and distribution of Mercury in the surficial aquifer, Long Neck Peninsula, Sussex County, Delaware, 2003-04: U.S. Geological Survey Scientific Investigations Report 2006-5011, 163 p.

Lapham, W. W., Moran, M. J., and Zogorski, J. S., 2000, Enhancements of nonpoint source monitoring of volatile organic compounds in ground water: Journal of the American Water Resources Association, v. 36, no. 6, p.1321-1334.

Lytton, L., Howe, S., Sage, R., and Greenaway, P., 2003, Groundwater abstraction pollution risk assessment: Water Science and Technology, v. 47, no. 9, p. 1-7.

Mackay, D. M., and Smith, L. A., 1993, Organic Contaminants, in: Alley, W. M., ed. Regional Ground-Water Quality: New York, Van Nostrand Reinhold, 634 p.

Martin, M. J., and Andres, A. S., 2005a, Digital water-table data for Sussex County, Delaware: Delaware Geological Survey DP 05-01.

____2005b, Digital water-table data for Kent County, Delaware: Delaware Geological Survey DP 05-03.

____2005c, Digital water-table data for New Castle County, Delaware: Delaware Geological Survey DP 05-04.

Maxwell, R. M., and Kastenberg, W. E., 1999, Stochastic environmental risk analysis: an integrated methodology for predicting cancer risk from contaminated groundwater: Stochastic Environmental Research and Risk Assessment, v. 13, p. 27-47.

Moran, M. J., Lapham, W. W., Rowe, B. L., and Zogorski, J. S., 2002, Occurrence and status of volatile organic compounds in ground water from rural, untreated, self-supplied domestic wells in the United States, 1986-99: U.S. Geological Survey Water-Resources Investigations Report, 2002-4085, 61 p.

____2004, Volatile organic compounds in ground water from rural private wells, 1986 to 1999: Journal of the American Water Resources Association, v. 40, no. 5, p. 1141-1157.

Senior, L. A., 1996, Ground-water quality and its relation to hydrogeology, land use, and surface-water quality in the Red Clay Creek basin, Piedmont physiographic province, Pennsylvania and Delaware: U.S. Geological Survey Water-Resources Investigations Report 96-4288, 122 p.

Squillace, P. J., Moran, M. J., Lapham, W. W., Price, C. V., Clawges, R. M. and Zogorski, J. S., 1999, Volatile organic compounds in untreated ambient groundwater of the United States, 1985-1995: Environmental Science and Technology, v. 33, no. 23, p. 4176-4187.

Squillace, P. J., Moran, M. J. and Price, C. V., 2004, VOCs in shallow groundwater in new residential/commercial areas of the United States: Environmental Science and Technology, v. 38, no. 20, p. 5327-5338.

Squillace, P. J., Scott, J. C., Moran, M. J., Nolan, B.T., and Kolpin, D. W., 2002, VOCs, pesticides, nitrate, and their mixtures in groundwater used for drinking water in the United States: Environmental Science and Technology, v. 36, no. 9, p. 1923-1930.

Squillace, P. J., and Moran, M. J., 2000, Estimating the likelihood of MTBE occurrence in drinking water supplied by ground-water sources in the northeast and mid-Atlantic regions of the United States: U.S. Geological Survey Open File Report, 2000-343, 14 p.

Stackelberg, P. E., Kauffman, L. J., Ayers, M. A., and Baehr, A. L., 2001, Frequently co-occurring pesticides and volatile organic compounds in public supply and monitoring wells, southern New Jersey, USA: Environmental Toxicology and Chemistry, v. 20, no. 4, p. 853-865.

Timme, P., 1995, National Water Quality Laboratory 1995 Services Catalog: U.S. Geological Survey Open-File Report, 1995-352, 112 p.

Toccalino, P. L., Nowell, L. H., Wilber, W., Zogorski, J., Donohue, J., Eiden, C., Krietzman, S. J., and Post, G. B., 2003, Development of Health-Based Screening Levels for Use in State- or Local-Scale Water-Quality Assessments: U.S. Geological Survey Water-Resources Investigations Report, 2003-4054, 31 p.

Toccalino, P. L., Norman, J. E., Phillips, R. H., Kauffman, L. J., Stackelberg, P. E., Nowell, L.H., Krietzman, S.J., and Post, G.B., 2004, Application of Health-Based Screening Levels to Ground-Water Quality Data in a State-Scale Pilot Effort: U.S. Geological Survey Scientific Investigations Report, 2004-5174, 76 p.

Toccalino, P. L., Zogorski, J. S., and Norman, J. E., 2005, Health-Based Screening Levels and their Application to Water-Quality Data: U.S. Geological Survey Fact Sheet, 2005-3059, 2 p.

USEPA, 1999, A Review of Contaminant Occurrence in Public Drinking Water Systems: Office of Water Report, EPA 816-R99-006, 94 p.

____2002, Current drinking water standards: USEPA Office of Water, updated July 2002, accessed October 21, 2002, at http://www.epa.gov/safewater/mcl.html.

____2003a, Electronic Data Deliverable (EDD) Specification Manual, Version 1.1: EPA Region 5, Superfund Division, 74 p.

____2003b, Health Effects Support Document for Aldrin/Dieldrin: USEPA Office of Water, EPA 822-R-03-001, 255 p.

Yaws, C.L., 1999, Chemical Properties Handbook . McGraw-Hill. http://www.knovel.com/knovel2/Toc.jsp?BookID=49&VerticalID=0

Zogorski, J. S., Carter, J. M., Ivahnenko, T., Lapham, W. W., Moran, M. J., Rowe, B. L., Squillace, P. J., and Toccalino, P. L., 2006, Volatile organic compounds in the nation's ground water and drinking-water supply wells: U.S. Geological Survey Circular 1292, 100 p.
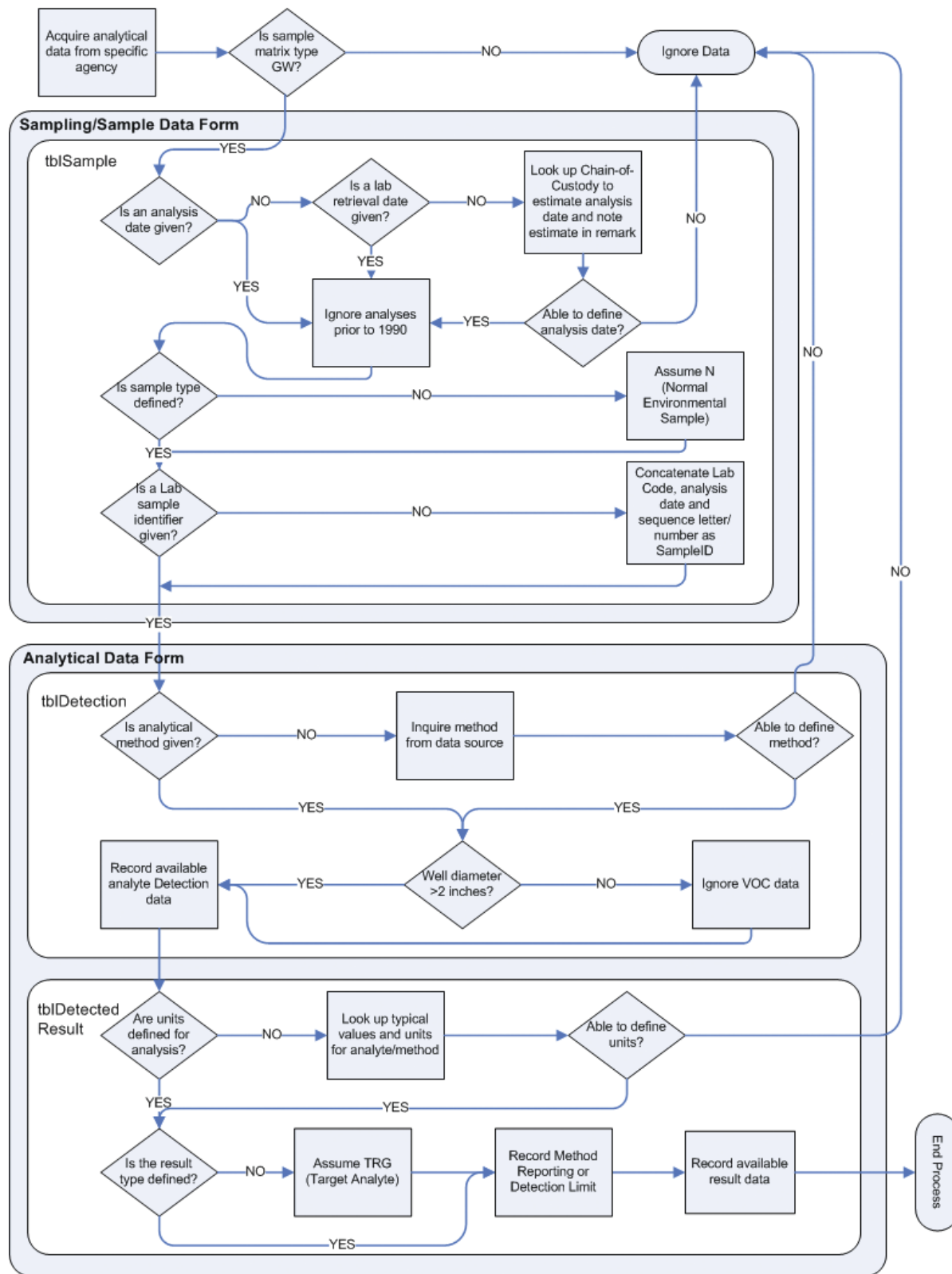
APPENDIX I

QA/QC Rules for Site, Well and Sampling Data

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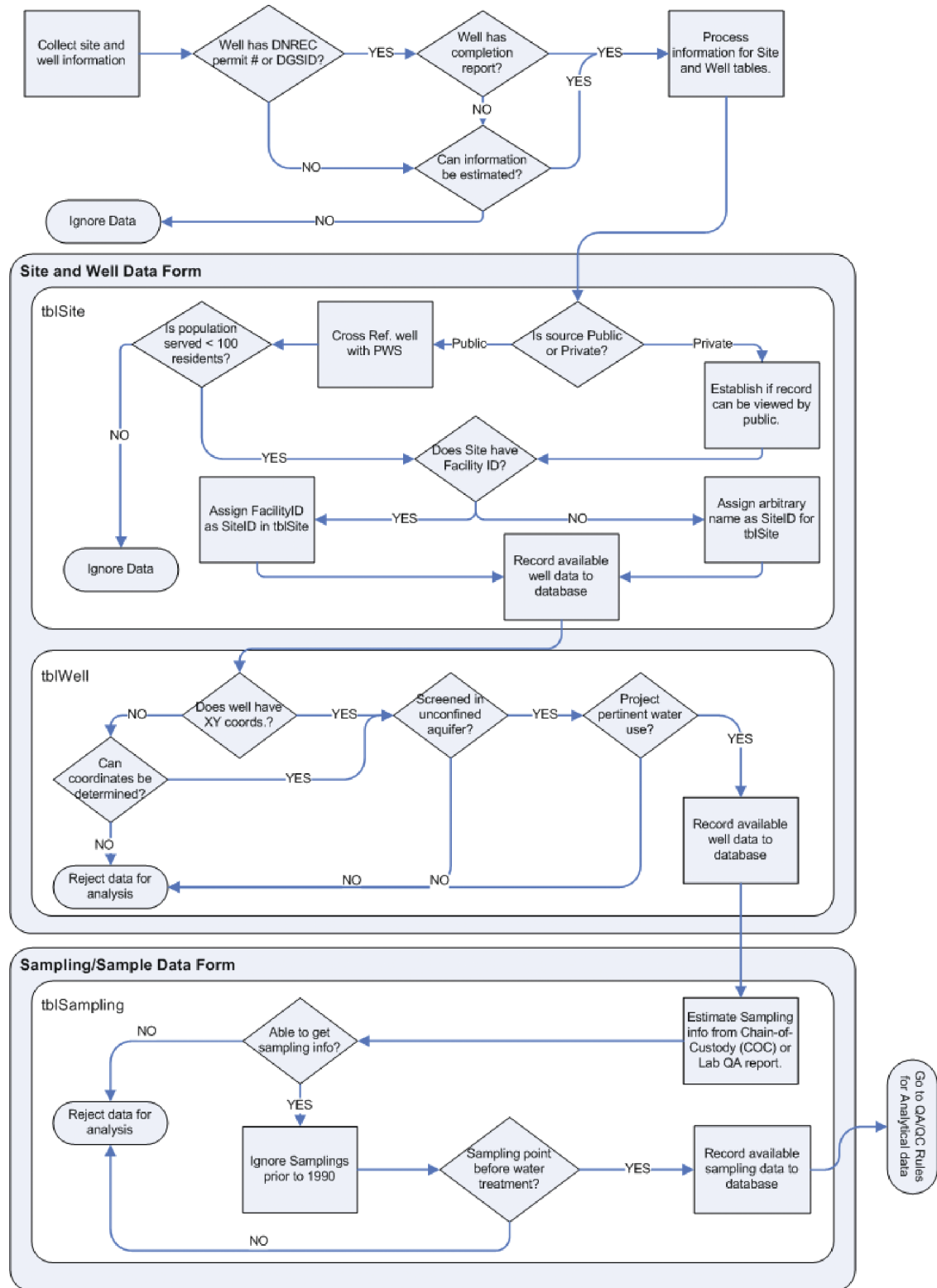
APPENDIX II

QA/QC Rules for Sample and Analytical Data

APPENDIX IV
Database Table and Field Descriptions

Table Name: **tblAgency**

Description: Characterizes the agencies that participate in sampling events and/or originate sampling projects and/or establish analytical methods.

Relationships:
- Sometimes oversees one to many **tblSampling** related from column AgencyCode to column SAgencyCode
- Sometimes oversees one to many **tblProject** related from column AgencyCode to column PAgencyCode
- Sometimes establishes one to many **tblWaterQualityStandard** from column AgencyCode to column WQSRegulatingAgency
- Sometimes originates one to many **tblAnalysisMethod** related from column AgencyCode to column MAgencyCode

Fields:

FieldName	DataType	
AgencyCode	LongString	Short code used to identify particular agencies or agency/sub-agency combinations
AParent_Long	LongString	Long name of parent agency
ASub_Long	LongString	Long name of sub-agency, if sub-agency part of record
ContactInfo	LongString	Address and contact info of agency

Table Name: **tblAnalysisMethod**

Description: Characterizes different laboratory analytical methods used to test for contaminants in aqueous samples. Brief descriptions of the method and its purpose are included.

Relationships:
- Always originated by one and only one **tblAgency** related from column MAgencyCode to column AgencyCode
- Sometimes partially identifies one or many **tblApprovedMethod** from column MNumber to column AnalMethodID

Fields:

FieldName	DataType	
MAgencyCode	LongString	Name of agency that established the analysis method
MFocus	LongString	More specific information on what the method tests
MNumber	LongString	The official method number or a compiler assigned number if un-numbered
MTitle	LongString	Description of analysis method

<u>Table Name:</u> **tblAnalyte**

<u>Description:</u>   Characterizes a collection of analytes that are contaminants tested for in water quality samples. Ancillary information on sources and health effects of specific contaminants are sometimes provided.

<u>Relationships:</u>
- Sometimes partially defines one or many **tblApprovedMethod** from column CASRN to column CASRN
- Sometimes has one or many **tblWaterQualityStandard** from column CASRN to column CASRN
- Sometimes classified as one and only one **Dictionary_AnalyteType** from column AType to column Choice

<u>Fields:</u>

FieldName	DataType	
altAName	LongString	Alternate analyte name. Only space for one alternative name given
AName	LongString	Name of analyte
AType	LongString	Contaminant category of analyte
CASRN	LongString	PK tblAnalyte,Chemical Abstract Service Registration Number (CASRN#) - CAS Registry Numbers are used in reference works, databases, and regulatory compliance documents by many organizations around the world to identify substances with a standardized name
CommonSource	Memo	Common sources of contaminant in drinking water as listed on EPA's website (http://www.epa.gov/safewater/mcl.html#mcls), ATSDR's website (http://www.atsdr.cdc.gov/), CDC NIOSH pocket guide or references therein
ExposurePathway	LongString	Inhalation, ingestion or contact
PHealthEffect	Memo	Potential health affects attributed to ingesting water contaminated with analyte as listed on EPA's website (http://www.epa.gov/safewater/mcl.html#mcls)

Table Name: **tblApprovedMethod**

Description: Stores an approved analyte/method combination used by regulatory agencies/laboratories to analyze water quality. An analyte (i.e., contaminant) is detected using a specific analytical method and an analytical method is approved to analyze a certain suite of contaminants.

Relationships:
- Always is partially identified by one and only one **tblAnalysisMethod** from column AnalMethodID to column MNumber
- Always is partially identified by one and only one **tblAnalyte** from column CASRN to column CASRN
- Sometimes partially identifies one or many **tblDetection** from columns AnalMethodID and CASRN to columns AnalMethodID and CASRN
- Always contains one and only one **Dictionary_Units** from column DetectLimitUnit to column Choice

Fields:

FieldName	DataTy	
AnalMethodID	LongString	PK combo; FK tblAnalysisMethod
CASRN	LongString	PK combo; FK tblAnalyte
DetectLimit	DoublePrecision	Method detection limit of method/analyte combination. Based on instrument sensitivity, etc
DetectLimitType	LongString	Type of detection limit used by the analytical laboratory (MRL=Minimum Reporting Limit; PQL=Potential Quality Limit; etc)
DetectLimitUnit	LongString	Concentration units of the detection limit

Table Name: **tblApprovedMethod**

Description: Stores an approved analyte/method combination used by regulatory agencies/laboratories to analyze water quality. An analyte (i.e., contaminant) is detected using a specific analytical method and an analytical method is approved to analyze a certain suite of contaminants.

Relationships:
- Always is partially identified by one and only one **tblAnalysisMethod** from column AnalMethodID to column MNumber
- Always is partially identified by one and only one **tblAnalyte** from column CASRN to column CASRN
- Sometimes partially identifies one or many **tblDetection** from columns AnalMethodID and CASRN to columns AnalMethodID and CASRN
- Always contains one and only one **Dictionary_Units** from column DetectLimitUnit to column Choice

Fields:

FieldName	DataType	
AnalMethodID	LongString	PK combo; FK tblAnalysisMethod
CASRN	LongString	PK combo; FK tblAnalyte
DetectLimit	DoublePrecision	Method detection limit of method/analyte combination. Based on instrument sensitivity, etc
DetectLimitType	LongString	Type of detection limit used by the analytical laboratory (MRL=Minimum Reporting Limit; PQL=Potential Quality Limit; etc)
DetectLimitUnit	LongString	Concentration units of the detection limit

Table Name: **tblDetection**

Description: Records whether a specific analyte, measured using a specific method, was detected in a particular sample. This table does not record the actual result of the analysis, only if an analyte was detected or not. Allows for the recording on non-detects for specific analyte/method combinations.

Relationships:
- Always partially identified by one and only one **tblSample** from column SampleID to column SampleID
- Always partially identified by one and only one **tblApprovedMethod** from columns AnalMethodID and CASRN to columns AnalMethodID and CASRN
- Sometimes characterized by one and only one **Dictionary_MethodLimitType** from column ReportLimitType to column Choice
- Sometimes characterized by one and only one **Dictionary_Units** from column ReportLimitUnit to column Choice

Fields:

FieldName	DataType	
AnalMethodID	LongString	combo PK; FK tblApprovedMethod
CASRN	LongString	combo PK; FK tblApprovedMethod
Detect	LongString	Was analyte detected in sample above the MRL?
Remark	LongString	Comment on the result, for example, if result represents mean, min or max value
ReportLimit	DoublePrecision	Method Reporting Limit (MRL) given by the lab for the analyte tested
ReportLimitType	LongString	Type of reporting limit used by the analytical laboratory (MRL=Minimum Reporting Limit; PQL=Potential Quality Limit; etc)
ReportLimitUnit	LongString	Concentration units of reporting limit
SampleID	LongString	combo PK; FK tblSample

Table Name: **tblWaterQualityStandard**

Description: Stores regulatory standards for drinking water, such as EPA's maximum contaminant level (MCL).

Relationships:
- Always contains standard of one and only one **tblAnalyte** from column CASRN to column CASRN
- Always characterized by one and only one **Dictionary_Units** from column WQSUnit to column Choice
- Sometimes characterized by one and only one **tblAgency** from column WQSRegulatingAgency to column Choice

Fields:

FieldName	D	
CASRN	LongString	FK tblAnalyte
WQSRegulatingAgency	LongString	Regulating agency that set water quality standard
WQSStandardID	Integer	Unique ID for water quality standard
WQSType	LongString	Name or type of water quality standard
WQSUnit	LongString	Concentration or measurement units
WQSValue	DoublePrecision	Numeric value of water quality standard
WQSNote	LongString	Notes on water quality standard

Table Name: **tblLab**

Description: Stores and characterizes Delaware certified laboratories. Laboratory names and contact information are recorded whenever a lab is entered in the database, not as a complete list of certified labs in Delaware.

Relationships:
- Sometimes analyzes one or many **tblSample** from column LabCode to column LabCode

Fields:

FieldName	DataType	
LabCode	LongString	PK tblLab
LAddress	LongString	Full address of laboratory
LContact	LongString	Name of person who is the lab contact
LName	LongString	Name of water quality laboratory

Table Name: **tblProject**

Description: Stores and characterizes project information that funds and/or performs sampling events.

Relationships:
- Sometimes overseen by one and only one **tblAgency** from column PAgencyCode to column AgencyCode
- Sometimes manages one or many **tblSampling** from column ProjectID to column ProjectID

Fields:

FieldName	DataType	
PAgencyCode	LongString	Agency responsible for project
PContactName	LongString	Name of project contact person
PContactPhoneNo	Integer	Project contact phone number
PDescription	LongString	Description of parent project of sampling event
ProjectID	LongString	PK tblProject

Table Name: **tblPWS**

Description: Stores and characterizes the Public Water Systems (PWS) for Delaware. A PWS is defined as a water system providing piped water for public consumption and has at least 15 service connections or regularly serves at least 25 individuals. The water supply used by a system may be all ground water, all surface water, or a combination of both.

Relationships:
- Sometimes supplies one or many **tblSite** related from column PWSID to column PWSID
- Sometimes is the source of one or many **tblWell** related from column PWSID to column PWSID
- Sometimes is characterized by one and only one **Dictionary_SizeCat11** from column SizeCat11 to column Choice
- Sometimes is characterized by one and only one **Dictionary_PWSType** from column PWSType to column Choice

Fields:

FieldName	DataType	
DateClosed	Date	If PWS is no longer in use, the date of closure
Owner	LongString	Owner type
Pop	Integer	Count of population served
PWSCounty	LongString	Primary county where water system resides
PWSID	LongString	PK tblPWS
PWSName	LongString	Common name of water system
PWSType	LongString	Water system type
SizeCat11	LongString	Size category based on average daily population served
Status	LongString	Status of the water system (active or closed)

Table Name: **tblSample**

Description: Stores and characterizes samples, ground water or otherwise, collected for a particular sampling event. Samples may or may not have analytical results related to them but the absence of analytical results implies a sample that was non-detect. A field to record sample non-detects is included.

Relationships:
- Always is a result of one and only one **tblSampling** from column SamplingID to column SamplingID
- Always is analyzed by one and only one **tblLab** from column LabCode to column LabCode
- Sometimes partially defines one or many **tblDetection** from column SampleID to column SampleID
- Sometimes is a sub-sample of one or many **tblSample**, representing recursion, from column SampleID to column Precursor
- Sometimes is characterized by one and only one **Dictionary_STypeCode** from column STypeCode to column Choice

Fields:

FieldName	DataType	
AnalysisDate	Date	Date/Time sample was created/analyzed
AnalysisNegative	Boolean	Did analysis of sample produce no analyte detections above MRL?
AnalysisRequested	LongString	A general title of the analysis requested for a particular sample
LabCode	LongString	ID code assigned to a particular laboratory, FK tblLab
Precursor	LongString	Name of sample that is the source of a new sub-sample (i.e. new record). Used when a sample is created from another sample
Re_Analysis	LongString	Does this sample represent a lab replacement sample?
SampleID	LongString	PK tblSample; The name of a distinct sample
SamplingID	LongString	FK tblSampling
STypeCode	LongString	Type of sample (e.g. field sample,split, field blank, duplicate, etc.) using EPA Region V specified codes. See Dictionary_STypeCode for code descriptions
Total_or_Dissolved	LongString	T for total (unfiltered) or D for dissolved (filtered)

Table Name: **tblSampling**

Description: Stores and characterizes sampling events executed for collecting water quality samples. A sampling event unites a site of interest (tblSite) with a specific well (tblWell) and/or project (tblProject).

Relationships:
- Always pertains to one and only one **tblSite** from column SiteID to column SiteID
- Sometimes pertains to one and only one **tblWell** from column DNRECID to column DNRECID
- Sometimes produces one or many **tblSample** from column SamplingID to column SamplingID
- Sometimes is managed by one and only one **tblProject** from column ProjectID to column ProjectID
- Sometimes is overseen by one and only one **tblAgency** from column SAgencyCode to column AgencyCode

Fields:

FieldName	DataType	
CollectedBy	LongString	Name of person who performed the sampling event
DNRECID	LongString	FK tblGWSource
ProjectID	LongString	FK tblProject
Remark	LongString	Comment on sampling event
SAgencyCode	LongString	Agency performing the sampling
SamplingID	LongString	PK tblSampling; Sampling event identification.
SDate	Date	Date/Time of sampling event
SDepth	DoublePrecision	Sampling depth below top of casing for wells
SiteID	LongString	FK tblGWSource
SPoint	LongString	Place or point from which sample was collected (e.g. post-treatment, etc)
SReason	LongString	Reason for sampling event

Table Name: **tblSite**

Description: Stores and characterizes site information, including contact person information. Sites may or may not have sampling events stored in the database. Often site identification (SiteID) uses the unique ID from another agency.

Relationships:
- Sometimes has one or many **tblSampling** from column SiteID to column SiteID
- Sometimes part of one and only one **tblPWS** from column PWSID to column PWSID

Fields:

FieldName	DataType	
AllowPublicView	LongString	Yes or no (True or False) on whether record can be viewed by public. Default is yes
Cemail	LongString	Contact email
ContactName	LongString	Name of Contact person
CPhoneNo	Integer	Contact phone number
PWSID	LongString	FK tblPWs
Remark	LongString	Comment on site
SAddress1	LongString	Site address part 1
SAddress2	LongString	Site address part 2 Default to null if not necessary
SCity	LongString	City where site is located
SiteDesc	LongString	General description of site
SiteID	LongString	PK identifier for a site. May be SIRB site code
SiteName	LongString	Name of site. For SIRB sites please use the short name given in Delaware's 3DM Guidance Manual, Appendix Table 7-11
SZipCode	LongString	Postal zip code of site

Table Name: **tblWell**

Description: Stores and characterizes, with minimal ancillary data, wells located in Delaware. Minimal well information stored because records can be linked by well ID (DNRECID) to more complete well database (e.g., DGS WELL database).

Relationships:
- Sometimes has one or many **tblSampling** from column DNRECID to column DNRECID
- Sometimes part of one and only one **tblPWS** from column PWSID to column PWSID
- Sometimes is characterized by one and only one **Dictionary_CoordSystem** from column CoordSystem to column Choice
- Sometimes is characterized by one and only one **Dictionary_Datum**, Category Horizontal, from column Datum_H to column Choice
- Sometimes is characterized by one and only one **Dictionary_Datum**, Category Vertical, from column Datum_V to column Choice

Fields:

FieldName	DataType	
CoordSystem	LongString	Coordinate system used to plot X,Y points (e.g. UTM meters, State Plane meters, etc)
Datum_H	LongString	Geographic datum used for horizontal map coordinates
Datum_V	LongString	Geographic datum used for vertical map coordinates
DGSID	LongString	DGS well identifier
DNRECID	LongString	DNREC well permit number
Elevation	DoublePrecision	Height of source above reference surface, usually mean sea level
LocalName	LongString	Local name of well
Ownership	LongString	Public or private
PWSID	LongString	FK tblPWSID
Remark	LongString	Remark on well construction or other information
SourceName	LongString	Common name given to water source
TaxID	LongString	City Lot and Block identification of well
TotalDepth	Integer	Total depth of well
X_Coord	DoublePrecision	Coordinate along the X cartesian axis (i.e., along the same axis as Longitude, Easting, etc)
Y_Coord	DoublePrecision	Coordinate along the Y cartesian axis (i.e., along the same axis as Latitude, Northing, etc)

Table Name: **Dictionary_AnalyteType**

Descriptions: Dictionary for analyte classes stored in the database and used to categorize analytes in **tblAnalyte**.

Relationships:
- Sometimes categorizes one or many **tblAnalyte** from column Choice to column AType

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of analyte
Description	Memo	Description of analyte type

Table Name: **Dictionary_CoordSystem**

Descriptions: Dictionary for types of coordinate systems used to locate wells.

Relationships:
- Sometimes locates one or many **tblWell** from column Choice to column CoordSystem

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of coordinate system
Description	Memo	Description of coordinate system type

Table Name: **Dictionary_Datum**

Descriptions: Dictionary for types of data (datum) used to locate wells. Both horizontal and vertical data are stored in this dictionary table.

Relationships:
- Sometimes locates one or many **tblWell** from column Choice and Category to column Datum_H
- Sometimes locates one or many **tblWell** from column Choice and Category to column Datum_V

Fields:

FieldName	DataType	
Category	LongString	Category of datum (i.e. horizontal for geographic position or vertical datum for elevation)
Choice	LongString	Look-up value or code for type of datum
Description	Memo	Description of datum used

Table Name: **Dictionary_LabQualifier**

Descriptions: Dictionary for types of laboratory qualifiers used to modify a laboratory result. A standard set of laboratory qualifiers are stored in this dictionary table.

Relationships:
- Sometimes qualifies one or many **tblDetectedResult** from column Choice to column LabQualifier

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for lab qualifiers as per EPA Region 5 Electronic Data Deliverable Valid Values Appendix
Description	Memo	Description of lab qualifiers as per EPA Region 5 Electronic Data Deliverable Valid Values Appendix

Table Name: **Dictionary_MethodLimitType**

Descriptions: Dictionary for types of laboratory method limits. Method limits often represent the minimal quantity tested or reportable by particular method/laboratory.

Relationships:
- Sometimes characterizes one or many **tblDetection** from column Choice to column ReportLimitType

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of reporting limit
Description	LongString	Description of reporting limit type

Table Name: **Dictionary_PWSType**

Descriptions: Dictionary for types of PWS (CWS, NTNCWS, TNCWS).

Relationships:
- Sometimes characterizes one or many **tblPWS** from column Choice to column PWSType

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of PWS
Description	Memo	Description of PWS type

Table Name: **Dictionary_ResultTypeCode**

Descriptions: Dictionary for types of result types, as specified by EPA Region 5, EDD standards and adopted by the Delaware Data Deliverable Model.

Relationships:
- Sometimes characterizes one or many **tblDetectedResult** from column Choice to column ResultTypeCode

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of result as per EPA Region 5 Electronic Data Deliverable Valid Values Appendix
Description	Memo	Description of result type as per EPA Region 5 Electronic Data Deliverable Valid Values Appendix

Table Name: **Dictionary_SizeCat11**

Descriptions: Dictionary for types of size categories as defined for size category 11.

Relationships:
- Sometimes characterizes one or many **tblPWS** from column Choice to column SizeCat11

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of size category based on population
Description	Memo	Description of size category

Table Name: **Dictionary_STypeCode**

Descriptions: Dictionary for type of sample collected, as specified by EPA Region 5, EDD standards and adopted by the Delaware Data Deliverable Model.

Relationships:
- Sometimes characterizes one or many **tblSample** from column Choice to column STypeCode

Fields:

FieldName	DataType	
Choice	LongString	Look-up value or code for type of sample, as per EPA Region 5 Electronic Data Deliverable Valid Values Appendix
Description	Memo	Description of sample type code, as per EPA Region 5 Electronic Data Deliverable Valid Values Appendix

<u>Table Name:</u>   **Dictionary_Units**

<u>Descriptions:</u>   Dictionary for type of units stored for laboratory results, method limits and/or drinking water standards.

<u>Relationships:</u>
- Sometimes characterizes one or many **tblApprovedMethod** from column Choice to column DetectLimitUnit
- Sometimes characterizes one or many **tblDetection** from column Choice to column ReportLimitUnit
- Sometimes characterizes one or many **tblDetectedResult** from column Choice to column Units
- Sometimes characterizes one or many **tblWaterQualityStandard** from column Choice to column WQSUnit

<u>Fields:</u>

FieldName	DataType	
Choice	LongString	Look-up value or code for type of units used for analytical results
Description	Memo	Description of unit code