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NATURAL RESOURCES &
ENVIRONMENTAL CONTROL
John A. Hughes, Secretary

Ground-water-quality survey of the Indian River Bay watershed, Sussex County, Delaware: Results of sampling, 2001-03

Prepared by

Joshua W. Kasper and Scott A. Strohmeier

Reviewed and approved by

John T. Barndt, P.G.

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Division of Water Resources, Water Supply Section, Ground-Water Protection Branch

State of Delaware
Ruth Ann Minner, Governor

Department of Natural Resources and Environmental Control
John A. Hughes, Secretary

Division of Water Resources
Kevin C. Donnelly, Director

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Ground-water-quality survey of the Indian River Bay watershed, Sussex County, Delaware: Results of sampling, 2001-03

By Joshua W. Kasper and Scott A. Strohmeier

INTRODUCTION

The Indian River Bay (IRB) watershed located in Sussex County, Delaware (Figure 1), contains a coastal lagoon, tidal and non-tidal streams, and ponds that are enriched with nitrogen (N) and phosphorus (P). In accordance with Section 303(d) of the Clean Water Act, the Department of Natural Resources and Environmental Control (DNREC) developed Total Maximum Daily Loads (TMDLs) for N and P discharges in this watershed. The TMDLs address both point- and nonpoint-source discharges and are intended to ensure that surface-water-quality standards are achieved and maintained. The nonpoint-source component of the TMDL requires N and P load reductions of up to 85 and 65 percent, respectively (DNREC, 1998). The nonpoint-source load reductions are among the highest statewide and indicate the significance ground-water discharges and overland flow have on surface-water impairments in the IRB watershed.

Several studies of ground-water quality in Delaware's Inland Bays region, which includes the IRB watershed, have documented the presence of elevated nitrate as nitrogen (hereafter "nitrate") concentrations (Andres, 1991a, 1991b; Denver, 1989, 1993; Ritter and Chirnside, 1982, 1984; Robertson, 1977, 1979). Data on phosphorus in ground water are, however, lacking. Robertson's (1977, 1979) work provided the most areally-extensive assessment of ground-water quality in the IRB watershed and surrounding region; therefore, more than 20 years have passed since a comprehensive assessment of the resource has been conducted. (Andres' (1991a) study also was areally extensive, but it involved portions of Delaware east of 75°15' west longitude.)

The DNREC initiated the study described in this report to assess the current status of ground-water quality in the IRB watershed. DNREC collected samples during 2001-03 from wells completed in the Columbia aquifer, which also is recognized as the unconfined or water-table aquifer in the Coastal Plain of Delaware (Andres, 1987; Talley, 1988). Primary project objectives were to (i) assess and document the current distribution of major ions and nutrients (nitrate as N, ammonia as N, and phosphorus) in the Columbia aquifer and (ii) establish a network of wells that would permit future ground-water sampling and trend analysis.

Figure 1. Map showing the location of the Indian River Bay watershed.

Purpose and scope

This report presents the results from the 2001-03 ground-water sampling effort. The study area is described in terms of land use, hydrogeologic framework, and ground-water recharge potential. Details regarding the well network, sampling methodology, laboratory analytical methods, quality assurance (QA) procedures, and quality control (QC) measures are provided. Data are summarized in tabular format and qualified where appropriate. A general statistical summary of the data is provided. Data are evaluated with respect to Federal standards for drinking water (U.S. EPA, 2004) and surface water (U.S. EPA, 1986). Major-ion chemistry is discussed with geochemical interpretations based largely on the work of others (Hamilton et al., 1993; Andres, 1991a; Denver, 1986, 1989, 1993). Lastly, the occurrence of nitrate and phosphorus are evaluated in terms of spatial distributions, geochemical environment, and recharge-potential setting (Andres et al., 2002).

Acknowledgements

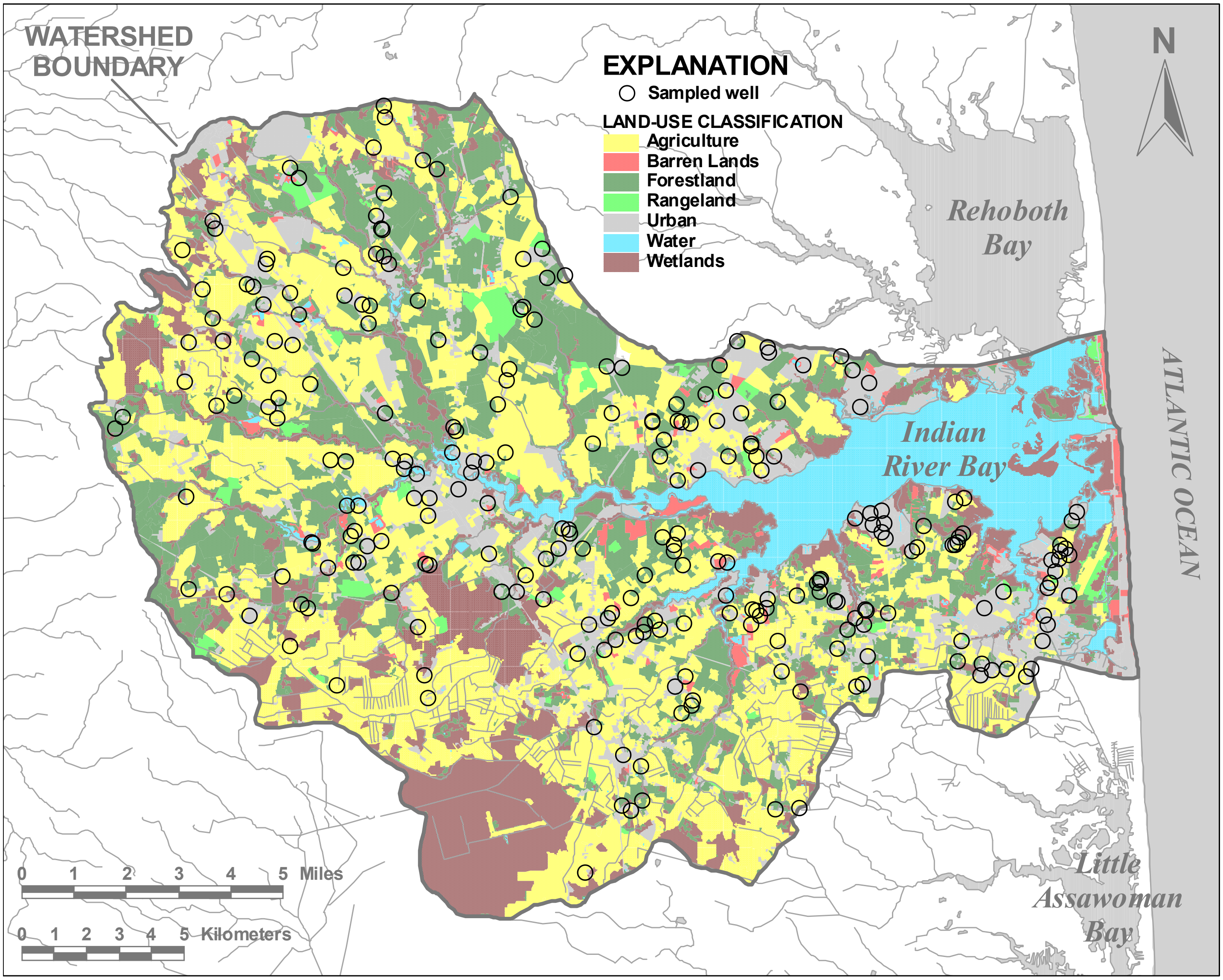
Special thanks are extended to the residents of the IRB watershed who provided access to their properties for the collection of ground-water samples. The following utilities are acknowledged for providing access to public water-supply wells: Long Neck Water Company, Frankford Water, Millsboro Water, Public Water Supply, and Tidewater Utilities, Inc. Scott Blaier (Delaware Department of Agriculture, or DDA) is gratefully acknowledged for providing access to monitoring wells maintained by the DDA for their pesticide monitoring program (see Blaier and Baxter, 2000). The following individuals are thanked for their reviews and comments, which greatly improved the final report: Judith M. Denver (U.S. Geological Survey); Jennifer Volk and Hassan Mirsajadi (both of the DNREC Watershed Assessment Section); and Nicole Miklus and John Barndt (both of the DNREC Water Supply Section). Danielle Hurlock (formerly of the DNREC Water Supply Section) is acknowledged for providing administrative support during many phases of this project. Funding for this project was obtained from the U.S. Environmental Protection Agency (U.S. EPA) through Section 106 of the Clean Water Act.

DESCRIPTION OF STUDY AREA

The IRB watershed encompasses approximately 188 mi^2 in southeastern Sussex County, Delaware (Figure 1). Land-surface elevations range from mean sea level (msl) to approximately 50 ft above msl. Drainage consists primarily of tidal and non-tidal streams, which, in some areas, are interrupted by man-made ponds. An extensive network of drainage ditches exists in the southernmost portion of the study area. The IRB also exchanges water (via tidal processes) with Rehoboth Bay to the north, the Atlantic Ocean to the east, and Little Assawoman Bay to the south. Climate within the region is humid with an average annual rainfall of 46 inches (Johnston, 1976). Net ground-water recharge (recharge minus ground-water evaporation) is approximately 13 in/yr (Johnston, 1976). Population in the study area fluctuates seasonally due to proximity to the Atlantic Ocean and coastal resort areas.

Land Use

Agriculture is the dominant land use in the IRB watershed, covering approximately 37% of the study area based on 1997 estimates (DOSPC, 1999; Figure 2). On the Delmarva Peninsula, most agricultural land is used to grow corn and soybeans for chicken feed (Shedlock et al., 1999; Denver et al., 2004). According to the 2002 Census of Agriculture (USDA, 2004a), over 223 million broiler and other meat-type chickens were sold in Sussex County in 2002. At almost 40 million birds and nearly 379 million dollars in 2002, Sussex County ranked first nationwide in broiler inventory (out of 2,599 counties) and poultry and egg sales (out of 2,918 counties), respectively (USDA, [2004b]). The remaining land use in the study area is 22% forest land, 16% wetlands, 13% urban land, 9% water, 2% range land, and 1% barren land (DOSPC, 1999; Figure 2). A comparison between 1997 and 2002 (DOSPC, 2003) land-use estimates revealed minor reductions in agriculture (-1%) and forest land (-2%), resulting in slight increases in urban land use (+2%) and wetlands (+1%).



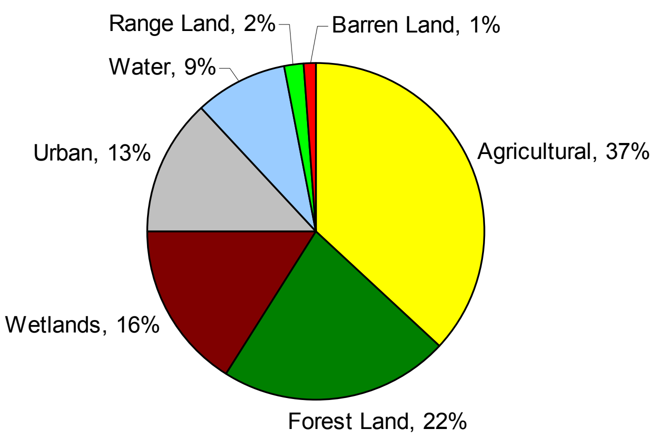


Figure 2. Map of the Indian River Bay watershed showing sample locations and 1997 land-use classifications and pie chart showing areal percentages of 1997 land-use classifications. Digital land-use classification data are from DOSPC (1999).

Hydrogeology

The study area is located within the Atlantic Coastal Plain Physiographic Province, which generally consists of a seaward-dipping wedge of sedimentary rocks. The near-surface sediments of the Coastal Plain form the unconfined hydrologic unit referred to as the Columbia aquifer (Andres, 1987; Talley, 1988). In the study area the Columbia aquifer is a lithologically-complex unit comprised of several lithostratigraphic units including unnamed Holocene-age deposits; the Pleistocene- to Holocene-age Cypress Swamp Formation; the Pleistocene-age Lynch Heights, Scotts Corners, and Omar Formations; the Pliocene-age Beaverdam Formation; and the upper Miocene-age Bethany Formation (Andres and Howard, 2000; Ramsey, 2001; and Andres et al., 2003).

Holocene deposits and the Cypress Swamp, Lynch Heights, Scotts Corners, and Omar Formations form the surficial portion of the Columbia aquifer and are composed of sand, silt, and clay. Each of these units is relatively thin across the study area and considered to be minor components of the Columbia aquifer; their distributions and lithologies, however, affect unsaturated flow and recharge. Fine-grained beds within these formations can serve as leaky confining units in certain locations in eastern Sussex County. The Beaverdam Formation and Bethany Formation subcrop the surficial units and serve as the subsurface portion of the Columbia aquifer (Ramsey and Schenck, 1990). The Beaverdam Formation comprises the bulk of the Columbia aquifer's saturated thickness; lithologies consist of medium to coarse sand with varying amounts of gravel, fine sand, silt, and clay found in discontinuous lenses and layers (Andres, 1991a). The underlying Bethany Formation is predominantly silt containing interbedded fine to coarse sands (Ramsey and Schenck, 1990). Over much of the study area confining beds in the Bethany Formation form the base of the regional surficial aquifer system. Where these beds are absent the sands of the Bethany Formation are hydraulically connected to those of the Beaverdam Formation creating a thick unconfined aquifer. The thickness of the Columbia aquifer is variable across eastern Sussex County, ranging from a minimum of 75 feet to a maximum of over 200 feet (Andres, 1987; Talley, 1988).

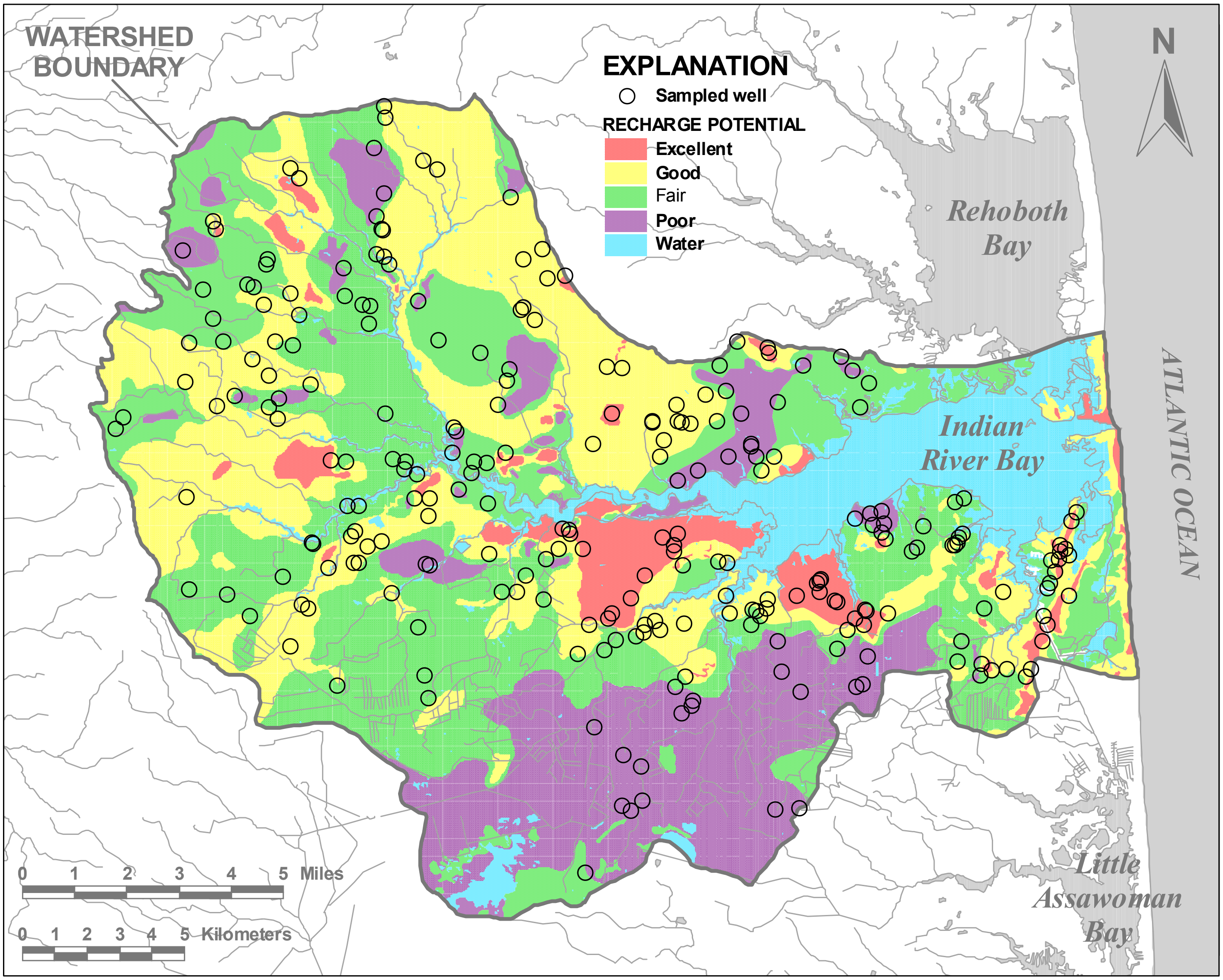
Recharge Potential

Ground-water recharge potential was mapped in Kent and Sussex Counties, Delaware, to characterize the water-transmitting capabilities of the uppermost 20 feet of sediments (Andres, 2004). (Refer to Andres (1991c) for mapping methodology.) Results of the mapping effort indicate the majority of land area, 40%, is classified as "fair" recharge potential (Andres et al., 2002; Figure 3). The remaining land area within the IRB watershed is classified as 33% "good", 21% "poor", and 6% "excellent." According to Andres (2004), the large contiguous areas of fair and poor recharge potential in the southern portion of the study area (Figure 3) reflect the underlying fine-grained deposits of the Cypress Swamp and Omar Formations.

METHODS OF STUDY

Description of well network

The well network consists of 255 wells completed in the Columbia aquifer (Figures 2 and 3). Large-scale maps depicting well locations and local identifiers are provided in Appendix 1. Well details are provided in Appendix 2. As-built construction information is available for a majority of the total well population. Where well construction information was not available, it was based on information noted on the well permit application or otherwise reported by the well owner. Sample depths, which were taken to be the mid point of the well screen, ranged from 6 to 108 ft below ground surface (bgs) with a median depth of 61 ft bgs (Figure 4a). Most of the sample depths (214; 84%) were within the range of 40 to 80 ft bgs (Figure 4b). Shallower (between 0 and 40 ft bgs) and deeper (between 80 and 110 ft bgs) sample depths account for 9 and 7% of the wells sampled, respectively (Figure 4b). Wells are identified by type (domestic, D; public, P; monitor, M; agricultural, A; and commercial, C) in Appendix 2. Definitions of these well types are provided in the "Delaware Regulations Governing the Construction and Use of Wells" (DNREC, 1997). (Note that wells identified as "P" in Appendix 2 include both public and miscellaneous public wells, as defined in the Regulations.) With reference to Figure 4c, domestic wells make up a majority of the well network (200; 78.4%), followed by public wells (22; 8.6%), monitor wells (14; 5.5%), agricultural wells (12; 4.7%), and commercial wells (7; 2.7%).



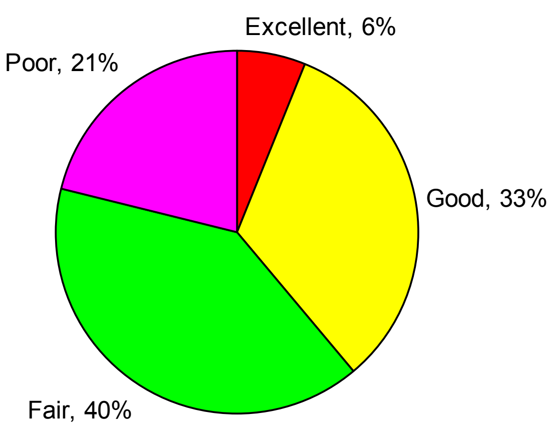


Figure 3. Map of the Indian River Bay watershed showing sample locations and recharge-potential classifications and pie chart showing areal percentages of recharge-potential classifications. Digital recharge-potential data are from Andres et al. (2002).

Ground-water sample collection and laboratory analysis

Ground-water samples were collected as prescribed in the quality assurance project plan (Kasper and McCleary, 2001). Prior to sample collection, all wells were purged to evacuate stagnant water. Water-supply wells such as domestic, public, agricultural, and commercial wells were purged via dedicated pumps, which generally consisted of centrifugal (i.e., “jet”) or submersible pumps; however, some of the higher-capacity public wells were equipped with turbine pumps. For water-supply wells associated with treatment systems, pre-treatment spigots were used for both purging and sample collection. Monitoring wells were purged and sampled using a Whale 921 12-volt DC submersible pump coupled with Tygon tubing.

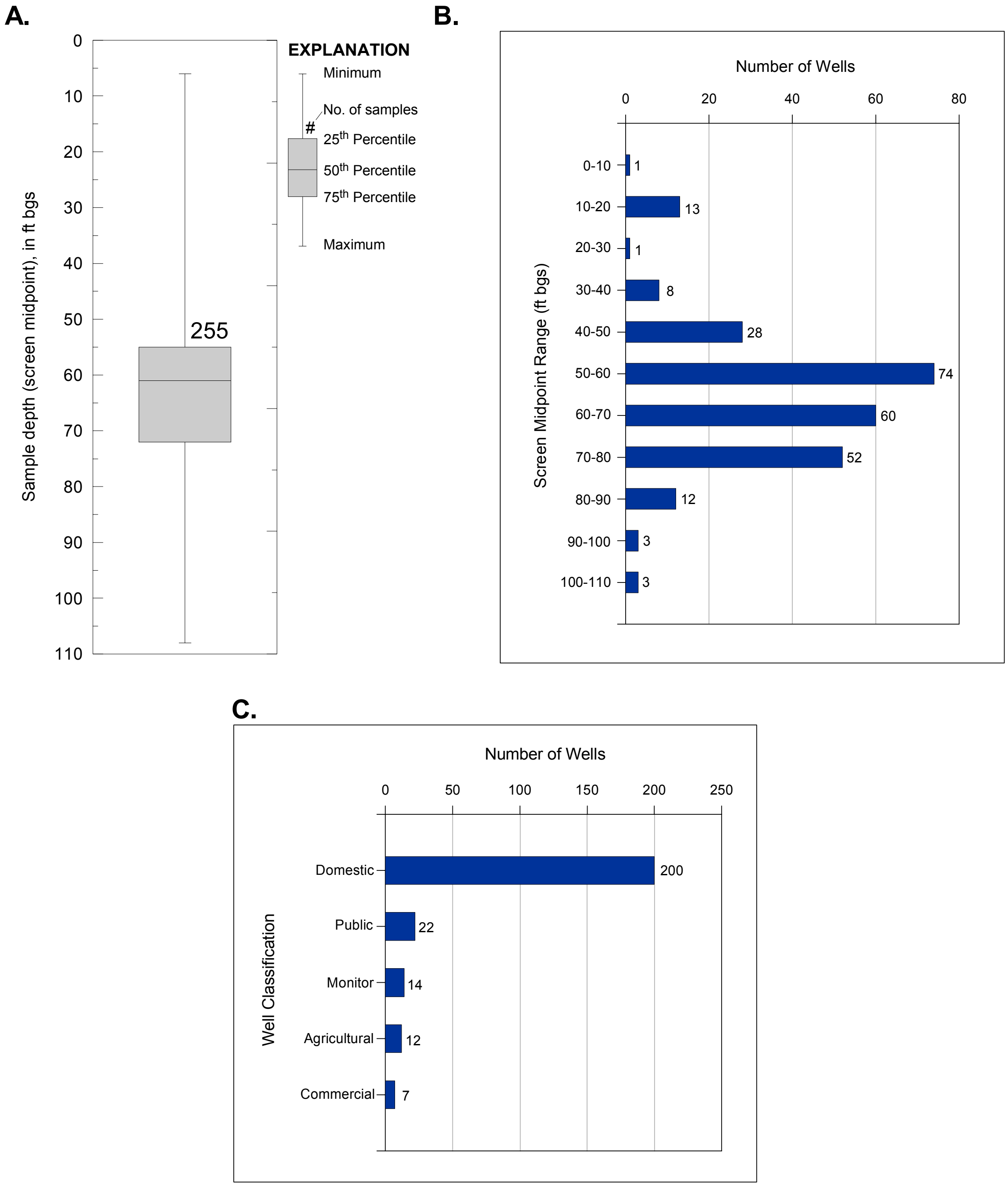


Figure 4. (A) Percentile diagram of sample depth distribution, (B) frequency histogram of sample depth, and (C) frequency histogram of well classification. [ft bgs, feet below ground surface]

A Solinst water-level probe was used to measure depth to water (in feet below top of casing) prior to purging monitoring wells.

Temperature (T), specific electrical conductance (SEC), dissolved oxygen (DO), and the potential for hydrogen (pH) were monitored during well purging and allowed to stabilize prior to sample collection. Prior to February 11, 2002 (42 samples; 16.5% of total), field measurements of T, SEC, and DO were made using a YSI 85 and pH was determined using an Oakton pHTestr2. Beginning on February 11, 2002 and until project completion (213 samples; 83.5% of total), measurements of all field parameters were made using a YSI 556 multi-probe system (MPS). All monitoring equipment used in the field was periodically calibrated or checked against standard solutions. The pH probe on the YSI 556 MPS was replaced in late August 2003 due to apparent probe malfunction noted during a calibration event.

After field parameters stabilized, laboratory-prepared Nalgene sample bottles were filled with discharge water filtered using 0.45-micrometer (-µm) pore-size in-line capsules manufactured by Pall Corporation. Sample bottles for the analysis of calcium (Ca^{2+}), iron (Fe^{2+} for anoxic water and Fe^{3+} for oxic water (Denver, 1986, p. 72)), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}) contained nitric acid (HNO_3) for preservation. Sample bottles for the analysis of phosphorus (P^{3+}) and ammonia as nitrogen (NH_3 as N; "ammonia") contained sulfuric acid (H_2SO_4), also for preservation. Sample bottles for the remaining analyses, namely nitrate plus nitrite as nitrogen (NO_3^{-}+NO_2^{-} as N; "nitrate"), chloride (Cl^{-}), silica as silicon dioxide (SiO_2), sulfate (SO_4^{2-}), and alkalinity as calcium carbonate ($CaCO_3$), contained no preservatives. Dedicated sample bottles were filled for alkalinity analysis; this permits titration of the entire sample volume and is generally recommended when alkalinity is not measured in the field (Deutsch, 1997). Samples were placed in a cooler with ice and a temperature blank and relinquished to the laboratory on the day of collection. Field logs documenting ground-water sampling activities are on file at the DNREC and may be inspected upon request.

Sampling equipment was cleaned via soaking in a solution of tap water (City of Dover) and phosphate-free Liquinox detergent. The cleaning solution was prepared per Liquinox specifications. Subsequent to soaking, the equipment was rinsed with ultra-pure deionized water. (The submersible pump and tubing setup used to sample monitoring wells was cleaned by circulating the Liquinox solution, followed by circulating and rinsing with ultra-pure deionized water.) At each sampling site, the sampling equipment was flushed with raw ground water prior to sample collection.

The geographic coordinates of each well sampled were determined using a Trimble GeoExplorer II hand-held global-positioning system (GPS). The GPS data were differentially corrected using Trimble's GPS Pathfinder Office (version 2.70) software. For wells cut off below grade or otherwise not visible, well locations were approximated based on the location reported by the well owner or on the permit application. Well coordinates (easting and northing in Appendix 2) are in Delaware State Plane, meters (m), North American Datum of 1983 (NAD83).

Laboratory analyses were performed by the DNREC's Environmental Laboratory Section (ELS). Project analytes and the respective analytical methods used by the ELS are summarized in Table 1. Samples collected during and after May 2002 for sulfate analysis were submitted to and analyzed by Lancaster Laboratories, Inc. located in Lancaster, Pennsylvania, to obtain lower quantitation limits. Those data are qualified with an "O" in Appendix 2.

Quality assurance and quality control

Project-specific quality assurance (QA) procedures and quality control (QC) measures are outlined in the quality assurance project plan, or QAPP (Kasper and McCleary, 2001). The ELS also maintains a quality assurance management plan, or QAMP, for laboratory operations (McCleary, 1999). Laboratory QC analyses done in conjunction with the analysis of field samples included method blanks, laboratory duplicates, and spiked duplicates. Laboratory QC reports are on file at the DNREC and may be inspected upon request. Where necessary, the results of laboratory QC are reflected in the data tables by way of qualifier codes.

Field QA procedures involved consistent sample collection and handling procedures and frequent calibration of water-quality meters used to collect field data. Field QC measures included the collection of duplicate samples and equipment blanks. All QC samples were collected, filtered, and preserved as described in the previous section, and analyzed for the twelve parameters listed in Table 1.

Fifteen duplicate samples were collected (one duplicate was collected for approximately every 20 ground-water samples) and analyzed for the twelve laboratory parameters, resulting in a total of 180 pairs of duplicate analyses (Appendix 3). With reference to Appendix 3, duplicate data are evaluated based on relative percent difference (RPD; the absolute difference between two measurements divided by the mean of those measurements). RPD was calculated for 143 of the 180 duplicate pairs. RPD was not calculated for the remaining 37 duplicate pairs because either one or more of the results was not detected above the laboratory quantitation

Table 1. Project analytes, analytical methods, and related information.

[Analytical methods, containers, preservations, and holding times are from EPA (2001); **$CaCO_3$**, calcium carbonate; **N**, nitrogen; **SiO_2**, silicon dioxide; **P**, polyethylene; **G**, glass; **°C**, degrees Celsius; **H_2SO_4**, sulfuric acid; **HNO_3**, nitric acid]

Analyte	Analytical method	Container	Preservation	Holding time
Alkalinity as $CaCO_3$	310.1	P, G	Cool, 4°C	14 days
Chloride	352.2	P, G	None required	28 days
Ammonia as nitrogen	350.1	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days
Nitrate+nitrite as nitrogen	353.2	P, G	Cool, 4°C	48 hours
Phosphorus	365.4	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days
Silica as SiO_2	370.1	P	Cool, 4°C	28 days
Sulfate	375.4	P, G	Cool, 4°C	28 days
Calcium	200.7	P, G	HNO_3 to pH<2	6 months
Iron	200.7	P, G	HNO_3 to pH<2	6 months
Magnesium	200.7	P, G	HNO_3 to pH<2	6 months
Potassium	200.7	P, G	HNO_3 to pH<2	6 months
Sodium	200.7	P, G	HNO_3 to pH<2	6 months

limit or the results were otherwise unavailable (e.g., phosphorus in IRB-006 (dup) was not analyzed).

Overall, RPD was greater than 30% in 14 (9.8%) of the 143 calculations. Analyte-specific RPDs were less than 30% for seven of the twelve analytes, namely chloride, nitrate, silica, sulfate, calcium, magnesium, and sodium. These results generally indicate good reproducibility. The five remaining analytes (alkalinity, ammonia, phosphorus, iron, and potassium) had one or more RPD in excess of 30%. Many of the RPD calculations for these analytes were based on estimated concentrations. Moreover, concentrations of some of the analytes, particularly ammonia, phosphorus, and iron, were very low; as a result, even small differences in absolute concentration can cause large RPD.

Equipment blanks were collected only when monitoring wells were sampled and a submersible pump was used. Subsequent to equipment cleaning (see previous section), ultra-pure deionized water was circulated through the submersible pump and associated tubing. The discharge was filtered and preserved in the same fashion as ground-water samples collected from monitoring wells. Three equipment blanks were collected for this project; the analytical data are summarized in Appendix 4. Analytes, when detected, were generally found at very low concentrations and reported as estimated values.

Data analysis

Where applicable, results are compared to Primary Maximum Contaminant Levels (PMCLs), Secondary Maximum Contaminant Levels (SMCLs), and Health Advisories (HAs) established by the U.S. Environmental Protection Agency for public water-supply systems (U.S. EPA, 2004). PMCLs are enforceable standards for public water-supply systems, while SMCLs and HAs are non-enforceable standards (U.S. EPA, 2004). Concentrations of hardness (as calcium carbonate, $CaCO_3$; calculated as indicated below) were evaluated with respect to the scale of Love (1962). As there is no drinking-water standard for phosphorus, those results are evaluated with respect to the U.S. EPA's (1986) recommended threshold for preventing excessive plant growth in streams (0.1 mg/L). A dissolved oxygen (DO) concentration of 1 mg/L was used to differentiate between reducing conditions (DO<1 mg/L) and oxidizing conditions (DO≥1 mg/L; Denver et al., 2004).

Piper (1944) diagrams (also known as trilinear diagrams) were used to evaluate the major-ion chemistry of shallow ground water in the IRB watershed. In constructing Piper diagrams, concentrations of major cations and anions are converted to milliequivalents per liter (meq/L) and plotted on separate triangles as percentages of total meq/L; points on the triangular plots are then projected onto a diamond-shaped plot (see, for example, Figure 8). By showing the ionic composition of many samples on a single plot, Piper diagrams can be used to visually discern major trends, groupings, or "hydrogeochemical facies" (Alley, 1993). Data were converted to meq/L and plotted as percentages of total meq/L using Aquachem (version 4.0), a program developed by Waterloo Hydrogeologic, Inc. (WHI, 2003). Note that Aquachem does not plot samples with non-detectable levels of one or more major ion; therefore, only samples with complete chemical analyses are plotted. As previously noted, geochemical interpretations are based largely on the work of others (Hamilton et al., 1993; Andres; 1991a; Denver, 1986, 1989, 1993).

Other methods used to analyze the data included maps and various types of graphs. Maps were used to evaluate the spatial distribution of selected parameters. Graphs included scatter plots, frequency histograms, and percentile diagrams (or box plots). Scatter plots were used to evaluate trends between sets of data. Frequency histograms were used to evaluate distributions of individual parameters. Percentile diagrams were used to evaluate variability in selected parameter concentrations due to factors such as geochemical environment, digital recharge-potential data (Figure 3; Andres et al., 2002), sample depth, and intermediate watersheds mapped by McKenna et al. (in review).

Calculated results discussed in this report include total dissolved solids (TDS) and hardness. TDS (in mg/L) were calculated as follows (after Hounslow, 1995):

$$\text{TDS} = \sum \text{cations} + \sum \text{anions} + \text{silica}$$

Calculated TDS concentrations are qualified with a "C" in Appendix 2. In calculating TDS, it was assumed that alkalinity results are equivalent to concentrations of bicarbonate (HCO_3^-), the dominant carbonate species in local ground water (Hamilton et al., 1993) and a major anion in natural water of the Columbia aquifer (Denver, 1986). Hardness (in mg/L) was calculated as follows (after Hounslow, 1995):

$$\text{Hardness} = \left(\text{Ca (mg/L)} \times \frac{\text{MW CaCO}_3}{\text{AW Ca}}\right) + \left(\text{Mg (mg/L)} \times \frac{\text{MW CaCO}_3}{\text{AW Mg}}\right)$$

where MW $CaCO_3$ is the molecular weight of calcium carbonate (100.088), AW Ca is the atomic weight of calcium (40.08), and AW Mg is the atomic weight of magnesium (24.312). Hardness concentrations were calculated to evaluate general ground-water characteristics and, therefore, are not included in Appendix 2.

RESULTS AND DISCUSSION

Results are presented in three sections: (i) General ground-water quality, (ii) major-ion chemistry, and (iii) nutrient results. Table 2 provides basic statistics for the field and analytical data. With reference to Table 2, note that non-detectable concentrations for all parameters were treated as zeros in the calculations. A frequency histogram of analyte qualification is provided in Figure 5.

General ground-water quality

Ground water in the Columbia aquifer in the IRB watershed is generally dilute. The median concentration of total dissolved solids (TDS) was 77 mg/L; the range was 29.4 to 698 mg/L. TDS concentrations exceeded the U.S. EPA's SMCL (500 mg/L) in only three (about 1%) of the samples.

Table 2. Statistical summary of ground-water-quality data for the IRB watershed, 2001-03.

[**µS/cm**, microsiemens per centimeter at 25 degrees Celsius; **°C**, degrees Celsius; **mg/L**, milligrams per liter; **µg/L**, micrograms per liter]

	Spec. Cond. (µS/cm)	pH	Temp. (ºC)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)	Ammonia as nitrogen, dissolved (mg/L)	Nitrate as nitrogen, dissolved (mg/L)
ALL WELLS (255 samples)								
Maximum	1389.00	7.68	20.02	9.89	147.00	367.00	0.66	43.00
75th Percentile	217.00	5.39	15.50	6.10	10.10	19.50	0.02	11.80
50th Percentile	149.00	5.10	14.72	3.53	7.00	15.00	0.01	6.41
25th Percentile	106.40	4.82	14.31	1.39	3.90	11.00	0.01	1.93
Minimum	41.00	3.51	8.76	0.02	0.00	4.00	0.00	0.00
Mean	180.18	5.11	14.87	3.78	10.23	22.27	0.03	7.73
Variance	22235.29512	0.251611388	1.398874988	7.180987951	244.4153599	1546.61547	0.006208508	48.11339678
Standard Deviation	149.115	0.502	1.183	2.680	15.634	39.327	0.079	6.936
AGRICULTURE WELLS (12 samples)								
Maximum	277.00	5.80	16.29	7.49	42.00	22.00	0.21	16.90
75th Percentile	237.50	5.15	15.50	3.77	11.48	19.25	0.01	14.70
50th Percentile	167.00	5.04	15.21	2.37	5.30	17.00	0.01	4.23
25th Percentile	111.25	4.80	15.06	0.72	3.88	13.50	0.002	1.57
Minimum	69.00	4.42	14.39	0.08	2.00	7.00	0.00	0.01
Mean	165.42	5.04	15.23	3.26	10.57	16.50	0.02	8.53
Variance	4509.537879	0.177238636	0.248990152	4.1861	122.3133333	13.90909091	0.003563091	36.74045455
COMMERCIAL WELLS (7 samples)								
Maximum	342.000	5.350	18.060	7.440	41.900	58.000	0.301	23.400
75th Percentile	259.10	5.14	16.47	5.79	14.20	24.00	0.04	13.47
50th Percentile	148.00	4.89	16.18	4.47	4.20	17.00	0.01	8.24
25th Percentile	126.00	4.75	15.72	0.15	3.10	13.50	0.01	0.08
Minimum	69.00	4.42	14.69	0.08	2.00	7.00	0.00	0.007
Mean	189.886	4.919	16.187	3.407	11.814	22.429	0.058	8.390
Variance	9864.491	0.100	1.094	10.264	229.761	285.952	0.012	86.598
DOMESTIC WELLS (200 samples)								
Maximum	1251.00	7.68	20.02	9.89	129.00	367.00	0.66	43.00
75th Percentile	216.25	5.38	15.48	6.35	10.00	19.00	0.02	12.45
50th Percentile	150.70	5.10	14.70	3.81	7.00	14.00	0.01	7.01
25th Percentile	106.60	4.82	14.22	1.63	3.90	11.00	0.01	2.98
Minimum	41.00	3.51	8.76	0.02	0.00	4.00	0.00	0.00
Mean	170.71	5.10	14.80	4.03	9.13	19.08	0.03	8.31
Variance	14611.5093	0.262378803	1.466697693	6.53530945	209.8883304	1044.66038	0.004044697	43.7519995
MONITOR WELLS (14 samples)								
Maximum	1389.00	6.30	17.80	6.14	147.00	306.00	0.29	25.00
75th Percentile	559.95	5.20	16.80	5.86	10.80	128.25	0.02	8.53
50th Percentile	277.95	4.90	15.35	4.83	3.00	21.50	0.01	2.78
25th Percentile	151.45	4.53	14.70	0.76	0.28	16.50	0.01	0.77
Minimum	105.70	4.30	10.89	0.10	0.00	6.00	0.00	0.00
Mean	423.11	5.00	15.19	3.66	19.11	85.36	0.03	5.39
Variance	155272.2598	0.357969231	4.79836044	6.601698901	1621.216099	12827.78571	0.005556643	49.45999046
PUBLIC WELLS (22 samples)								
Maximum	213.00	6.12	17.82	7.77	69.90	34.00	0.44	8.42
75th Percentile	141.25	5.61	14.75	1.88	12.98	15.75	0.08	6.04
50th Percentile	116.50	5.39	14.58	1.41	8.05	13.00	0.00	2.33
25th Percentile	80.50	5.05	14.39	1.06	6.98	10.25	0.00	0.19
Minimum	51.00	4.64	13.27	0.10	3.90	4.00	0.00	0.00
Mean	116.59	5.35	14.71	1.95	13.89	14.23	0.07	3.35
Variance	1797.205628	0.165184632	0.742850433	3.840564719	244.5574242	55.23160173	0.015810807	9.55279168

Phosphorus, dissolved (mg/L)	Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Calcium, dissolved (μg/L)	Iron, dissolved (μg/L)	Magnesium, dissolved (μg/L)	Potassium, dissolved (μg/L)	Sodium, dissolved (μg/L)	Total Dissolved Solids (mg/L)
0.69	240.00	135.00	49400.00	33200.00	25300.00	12000.00	256000.00	697.62
0.03	20.90	11.70	10650.00	53.30	5355.00	3125.00	12900.00	99.53
0.01	15.80	2.40	5920.00	15.40	3090.00	1970.00	9630.00	76.54
0.00	10.25	0.50	2985.00	0.00	1260.00	1195.00	7215.00	59.36
0.00	1.00	0.00	0.00	0.00	0.00	0.00	3490.00	29.43
0.03	17.40	8.06	7497.49	955.11	3973.07	2384.71	13120.24	93.66
0.004646321	275.5799188	184.9069481	39837598.36	12534329.31	13180116.01	3980867.174	362594758.2	5372.629944
0.068	16.601	13.598	6311.703	3540.385	3630.443	1995.211	19041.921	73.298
0.10	23.00	14.20	16700.00	2640.00	10000.00	4700.00	17000.00	123.16
0.03	19.25	9.75	12350.00	48.38	5965.00	3472.50	13675.00	115.00
0.01	14.95	7.70	5715.00	0.00	4435.00	2795.00	11200.00	97.25
0.01	11.00	3.08	2267.50	0.00	2842.50	2200.00	7967.50	62.54
0.00	6.60	0.00	0.00	0.00	0.00	0.00	4970.00	45.63
0.02	14.10	6.04	7253.33	231.14	4905.00	2740.83	10851.67	81.76
0.000708879	28.59818182	21.86381515	30491533.33	575964.5754	7059954.545	1337953.788	11563178.79	789.1931477
0.204	28.900	37.700	20400.000	12200.000	13800.000	6740.000	21700.000	159.590
0.11	22.60	9.30	10325.00	2645.45	5200.00	4265.00	12850.00	122.10
0.01	15.40	2.70	7160.00	3.30	1430.00	3490.00	9860.00	89.83
0.00	13.65	1.21	5490.00	1.30	1280.00	2160.00	7925.00	73.00
0.00	10.50	0.00	0.00	0.00	0.00	0.00	6320.00	55.76
0.061	18.186	8.774	8455.714	2499.543	4027.143	3297.143	11347.143	99.339
0.009	48.988	189.279	41392728.571	22129095.166	22720557.143	5027723.810	27126690.476	1376.778
0.38	60.00	74.20	28200.00	17100.00	25300.00	11500.00	256000.00	697.62
0.03	19.88	10.60	10725.00	41.50	5425.00	3067.50	12700.00	96.79
0.01	15.80	2.10	6290.00	12.60	3205.00	1890.00	9320.00	76.55
0.00	10.53	0.42	3140.00	0.00	1247.50	1155.00	7110.00	59.57
0.00	3.20	0.00	0.00	0.00	0.00	0.00	3490.00	29.43
0.03	16.59	6.65	7355.41	620.71	3952.77	2268.87	12690.45	86.66
0.001991029	90.22619681	87.19765354	29289805.31	7486487.705	9126582.292	3497258.577	501054756.3	3979.658452
0.07	32.60	135.00	49400.00	12300.00	18900.00	12000.00	123000.00	584.24
0.03	25.43	36.83	20850.00	71.03	10152.50	6975.00	19550.00	272.43
0.02	20.50	25.50	11835.00	36.15	5490.00	2510.00	13200.00	152.03
0.01	2.78	15.20	660.00	0.00	2802.50	1355.00	10550.00	80.72
0.00	1.00	0.00	0.00	0.00	1030.00	0.00	3870.00	54.28
0.02	15.41	33.10	14430.00	1394.99	6741.43	3968.57	27617.14	212.57
0.000266286	148.0745604	1038.863077	229442153.8	12674597.55	25377782.42	13036320.88	1177191822	31041.7538
0.69	240.00	42.40	9410.00	33200.00	4260.00	5150.00	20100.00	365.46
0.05	22.78	6.20	5187.50	1886.00	2612.50	2347.50	9992.50	82.37
0.02	17.85	1.80	3415.00	36.70	1995.00	1995.00	8955.00	66.90
0.00	8.18	1.00	2447.50	16.83	865.75	1305.00	7270.00	53.18
0.00	5.80	0.00	958.00	0.00	293.00	894.00	5560.00	34.53
0.08	27.62	5.78	4205.82	3618.66	1870.36	1945.41	9603.64	86.25
0.03567716	2396.638983	95.05434978	5596824.727	66652788.84	1207019.766	912103.3961	11177624.24	4858.504215

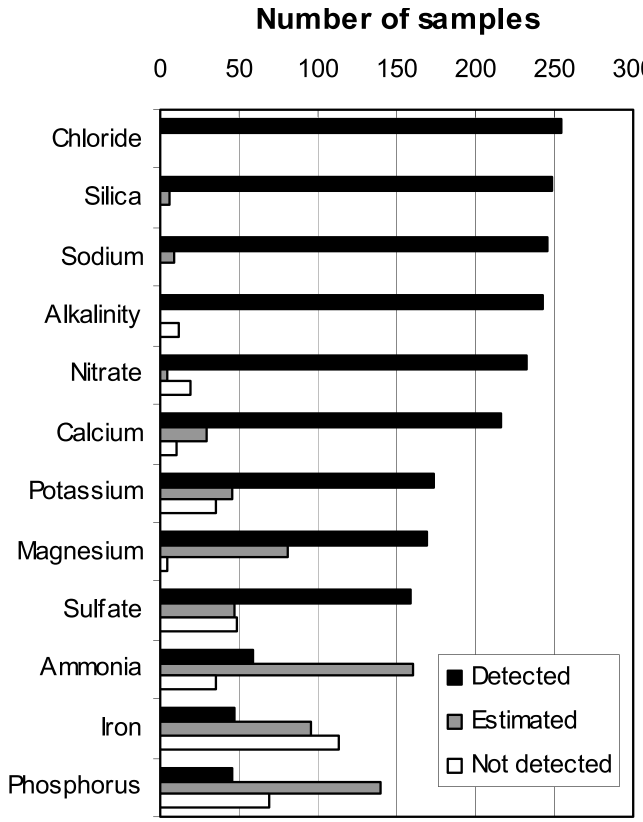


Figure 5. Frequency histogram of project analyte qualification.

Specific electrical conductance (SEC; measured in the field during well sampling) positively correlates with TDS ($R^2 = 0.83$), increasing SEC relates to increasing TDS. SEC ranged from 41 to 1,389 microsiemens per centimeter (µS/cm), with a median value of 149 µS/cm. The median field pH was 5.1 standard units, which indicates slightly acidic conditions. The SMCL range for pH is 6.5 to 8.5. A total of 252 (about 99%) samples had pH values less than 6.5, outside of the SMCL range. Dissolved oxygen (DO) levels measured in the field indicate that oxidizing conditions prevail in the IRB watershed. Field data indicate a median DO concentration of about 3.5 mg/L. Measurements taken at 208 (about 82%) of the well sites showed DO levels greater than or equal to 1 mg/L, which is a general threshold between oxidizing (oxic) and reducing (anoxic) conditions (Denver et al., 2004). DO levels are important because oxidation-reduction reactions are major controls on some chemical constituents in the ground-water system, such as nitrogen and iron (Denver, 1989). DO levels below 1 mg/L (anoxic conditions) are common in poorly-drained areas where soils and (or) underlying geologic materials have high organic-matter content.

Nitrate is the only project analyte with a PMCL (10 mg/L). (Laboratory data are reported as nitrate plus nitrite as nitrogen; however, because nitrite concentrations are usually negligible, results are assumed to be entirely nitrate.) According to the U.S. EPA (2003), infants younger than six months who consume water with nitrate above the PMCL could become seriously ill and, if untreated, may die; symptoms may include shortness of breath or "blue-baby syndrome" (i.e., methemoglobinemia). Some studies indicate there may be other health risks caused by nitrate, such as bladder and ovarian cancers (Weyer et al., 2001) and non-Hodgkin's lymphoma (Ward et al., 1996). Nitrate exceeded the PMCL in 81 (almost 32%) of the samples, the locations of which are shown in Figure 6. Nitrate did not exceed the PMCL in any of the 22 public water-supply wells sampled. The median nitrate concentration was 6.41 mg/L, and the mean was 7.73 mg/L. Nitrate was not detected in 19 (7.5%) of the samples. Details regarding the occurrence and distribution of nitrate are discussed in a later section entitled "nutrient results."

Iron exceeded the SMCL (300 µg/L) in 31 (about 12%) of the samples. The median iron concentration was 15.4 µg/L, which is less than the SMCL. Iron was not detected above the laboratory quantitation limit in 113 (about 44%) of the samples. Elevated iron concentrations are common when DO levels are low. Out of the 31 samples with iron above the SMCL, 24 (about 77%) were associated with DO concentrations below 1 mg/L. Elevated iron is often a problem south of the IRB where soils generally are not well drained and ground water is anoxic; however, iron above the SMCL was also detected in wells in the northwestern portion of the study area (Figure 7). That upland area also is poorly drained, in general. In samples with iron above the SMCL, nitrate was always less than the PMCL.

Chloride concentrations exceeded the SMCL (250 mg/L) in only three (about 1%) of the samples. Elevated chloride levels were accompanied by TDS concentrations in excess of the SMCL (500 mg/L). Two of the samples were collected from shallow monitoring wells (IRB-186 and -024) located along roadways far removed from salt-water bodies, suggesting impacts from road salt. The remaining

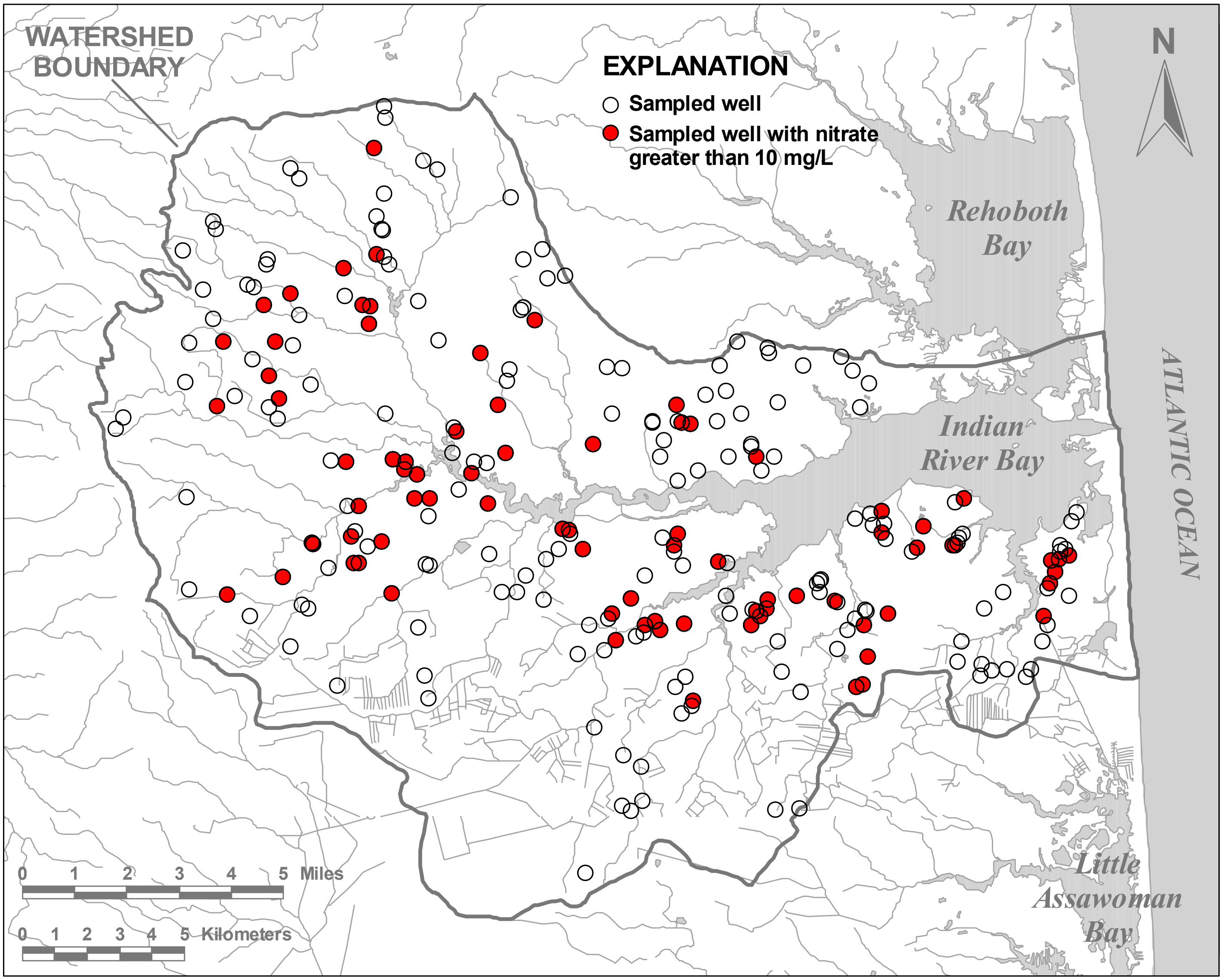


Figure 6. Map showing sampled wells with nitrate concentrations above the Primary Maximum Contaminant Level for public water-supply systems (10 mg/L). [mg/L, milligrams per liter]

sample, taken from a domestic well IRB-078, had the highest chloride concentration (367 mg/L) as well as the highest sodium concentration (256,000 µg/L). Because IRB-078 is located in an unsewered, residential area where salt-water intrusion would be unlikely, the chemistry may suggest impacts from septic-system effluent.

The SMCL for sulfate is 250 mg/L; the HA is 500 mg/L. None of the samples exceeded these values. Sulfate concentrations ranged from non-detectable levels to 135 mg/L. The maximum concentration was detected in a shallow monitor well, IRB-023, which was associated with elevated iron (12,300 µg/L) and DO below 1 mg/L. Median and mean sulfate concentrations were 2.40 and 8.06 mg/L, respectively.

The HA for sodium is 20,000 µg/L. Because sodium is a component of the human diet, elevated concentrations can indicate impacts from sanitary wastewater disposal such as septic-system effluent (Denver, 1989). However, poultry manure, which is often applied to agricultural fields, also has elevated sodium (see Table 3 of Denver, 1986). Sodium exceeded the HA in 26 (about 10%) of the samples. The median sodium concentration was 9,630 µg/L. Most of the elevated sodium concentrations (20 out of 26) were detected in the southern half of the study area.

With respect to the hardness scale of Love (1962), 218 samples (85.5 %) may be characterized as “soft” (<60 mg/L), 34 samples (13.3 %) as “moderately hard” (61 to 120 mg/L), and three samples (1.2 %) as “hard” (121 to 180 mg/L).

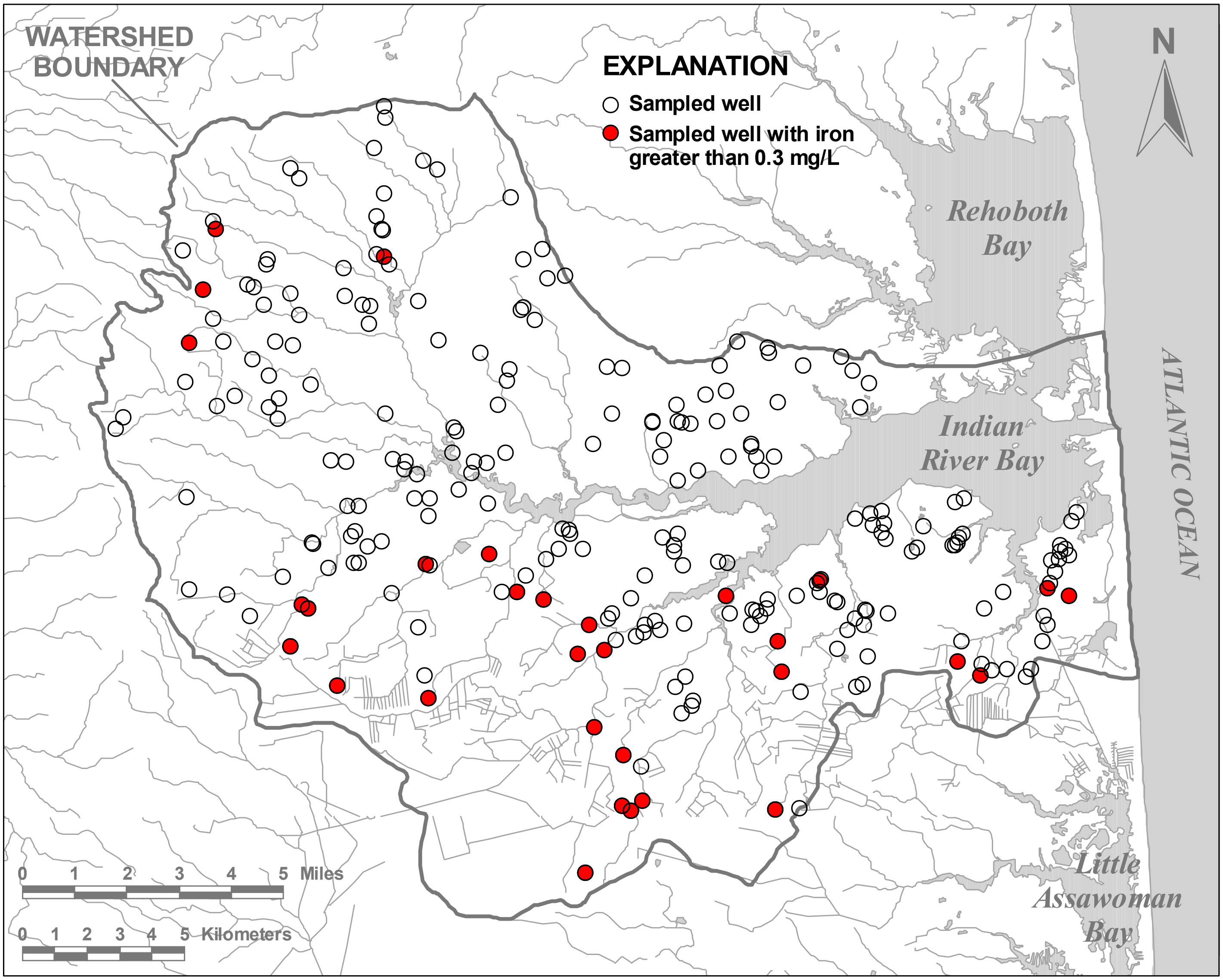


Figure 7. Map showing sampled wells with iron concentrations above the Secondary Maximum Contaminant Level for public water-supply systems (0.3 mg/L). [mg/L, milligrams per liter]

Two of the three wells with hard water were shallow monitoring wells (IRB-024 and -186) with chloride above the SMCL (250 mg/L). The remaining well with hard water (IRB-064) had a sampling interval of 76 ft bgs and the most elevated nitrate concentration (43 mg/L).

Major-ion chemistry

Piper (1944) diagrams are included in Figures 8, 9, and 10 to illustrate the variability of major-ion chemistry of shallow ground water in the IRB watershed. A plot of all samples with complete analyses illustrates overall variability and trends (Figure 8). In general, overall cation composition is either an admixture of major cations (calcium, magnesium, and sodium plus potassium) or dominated by sodium (plus potassium) ions; anions are predominantly comprised of chloride (plus nitrate) ions, although there are many exceptions (Figure 8).

Samples with nitrate concentrations less than 0.4 mg/L (a threshold used to discern natural water from water affected by human activities; Hamilton et al., 1993) and DO≥1 mg/L are similar to “type II” or sodium-potassium-chloride-bicarbonate-type water as described by Andres (1991a; Figure 9). This water type is the most common natural water type in the unconfined aquifer in coastal Sussex County, Delaware (Andres, 1991a). Samples in Figure 9 with DO≥1 mg/L also have relative ionic compositions

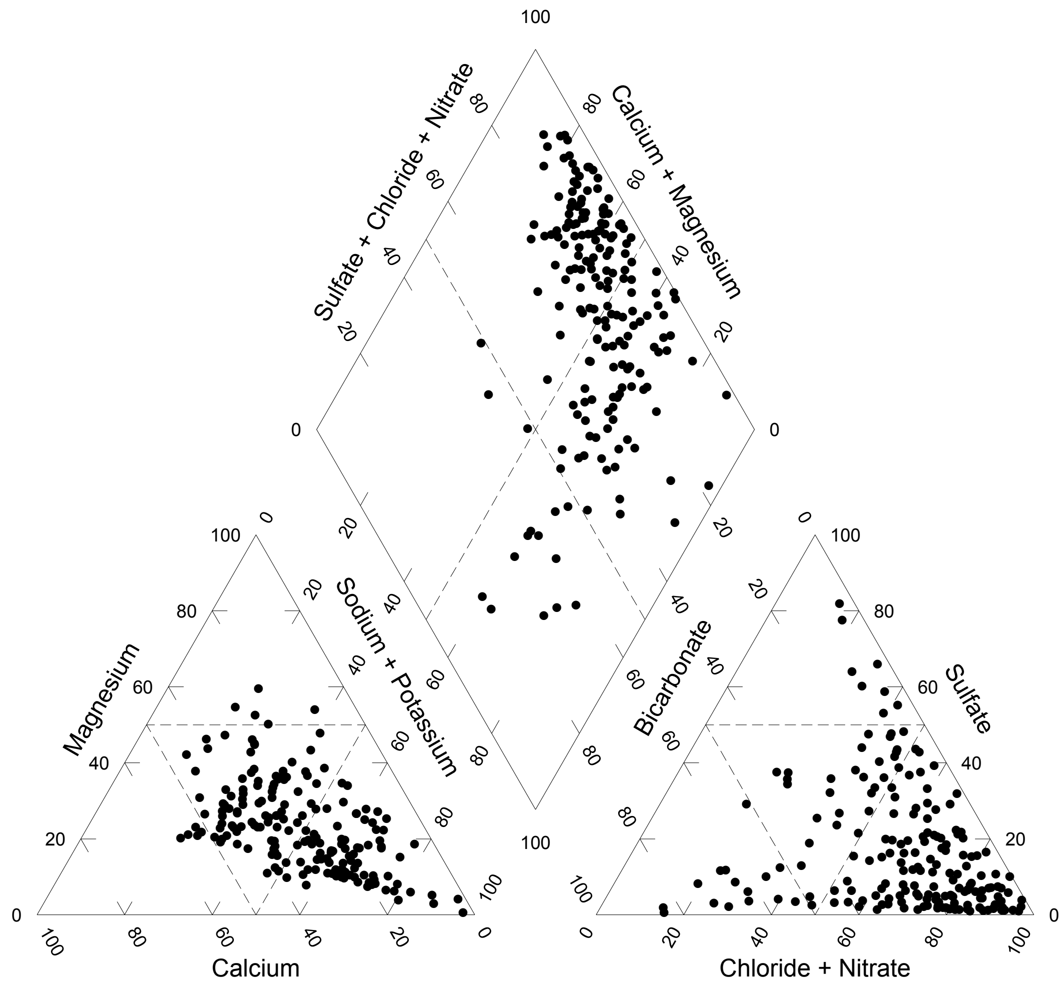


Figure 8. Piper diagram showing major-ion chemistry (as percentages of total milliequivalents per liter or meq/L) for all samples with complete chemical analyses.

similar to natural water samples of Denver (1993; Figure 14 of her report). Specifically, ground-water samples for this study apparently representative of "natural" water under oxidizing conditions include IRB-087, -111, -133, -139, -151, -231, -238, and -258 (Figure 9; Appendix 2). Other samples that may be representative of these conditions, but not plotted in Figure 9 due to incomplete chemical analyses, include IRB-032, -045, -069, and -073 (Appendix 2). Anoxic samples with nitrate concentrations indicative of natural conditions are common in poorly-drained settings in the southern half of the study area, as well as the northwestern portion near the drainage divide.

Ground-water samples with nitrate above the PMCL (10 mg/L) were dominated by calcium, magnesium, and chloride plus nitrate ions (Figure 10). In some samples sodium plus potassium also were dominant ions. The dominance of calcium and magnesium has been attributed to lime applied in agricultural areas (Denver, 1986, 1989, 1993). Sodium and chloride are components of septic-system effluent (due to salt in the human diet) and poultry manure (Denver, 1986, 1989); chloride and potassium are components of potash fertilizer (Shedlock et al., 1999). The grouping of data points in Figure 10 is similar to the "chemical signature" of ground water affected by agricultural activities on Delmarva (see Figure 13 of Hamilton et al., 1993). Chloride (plus nitrate) typically contributed more than 60% total anions in ground water with nitrate concentrations greater than 10 mg/L; conversely, sulfate and bicarbonate anions were typically less

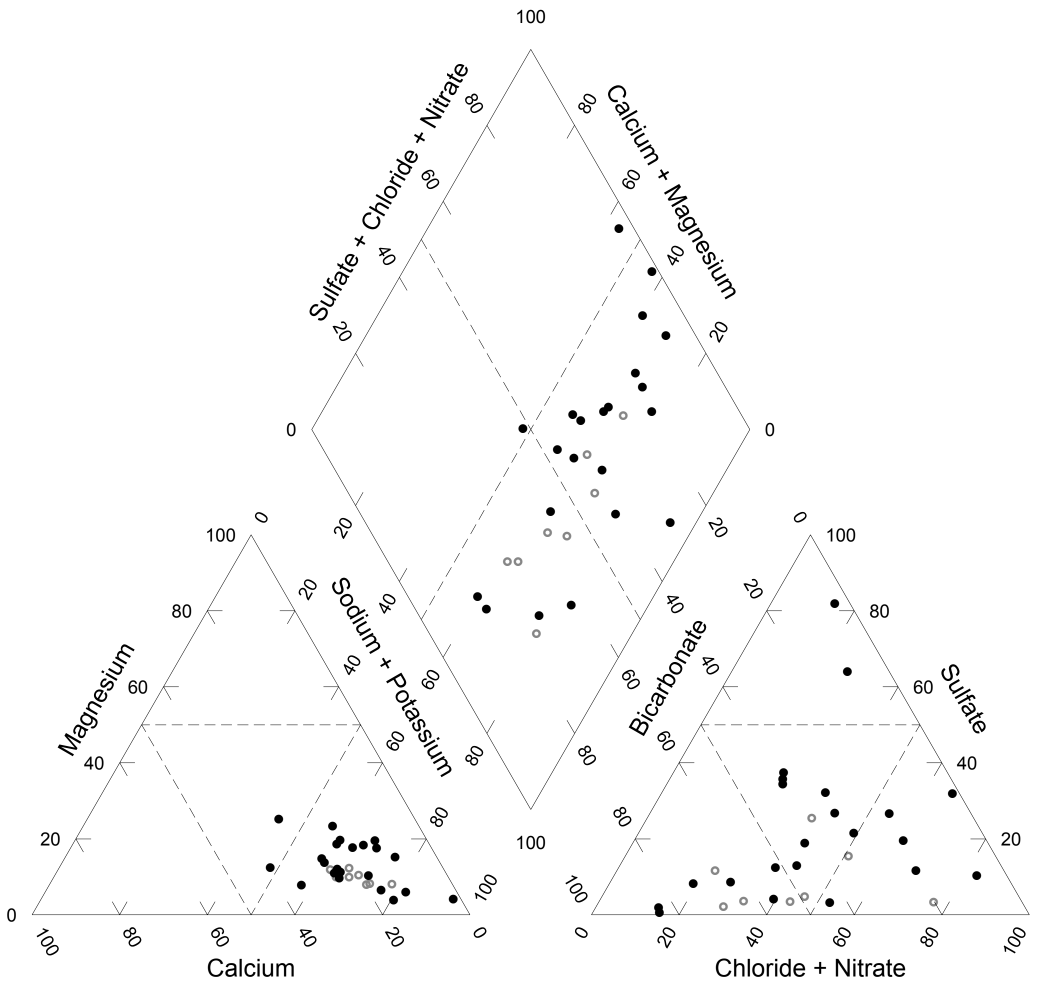


Figure 9. Piper diagram showing major-ion chemistry (as percentages of total milliequivalents per liter or meq/L) for samples with nitrate concentrations less than 0.4 milligrams per liter (mg/L) and complete chemical analyses. Solid black dots denote reducing conditions (dissolved oxygen less than 1 mg/L); gray hollow circles denote oxidizing conditions (dissolved oxygen greater than 1 mg/L).

than 40% of total anions in meq/L. Bicarbonate is consumed in reactions that buffer acidic conditions resulting from the nitrification process (Denver, 1989). In contrast, bicarbonate is a dominant anion in natural ground water (Denver, 1989; Figure 9).

Denver (1989) studied agricultural impacts on ground-water chemistry in the Fairmount area north of the IRB watershed. She reported a positive correlation (Pearson's correlation coefficient = 0.98) between nitrate concentrations and calcium plus magnesium concentrations. On the basis of this relationship she inferred substantial agricultural influence on ground-water quality. The relationship between nitrate and calcium plus magnesium in this study shows similar results (Figure 11). The Pearson's correlation coefficient for these data sets is 0.77. This positive correlation may be indicative of an agricultural influence on ground-water chemistry.

Nutrient results

Sources of nitrogen and phosphorus in the IRB watershed include fertilizer use, manure application, wastewater disposal practices, and atmospheric deposition. On Delmarva, inorganic fertilizer and manure have been estimated to account for more than 95% of the nitrogen input (Denver et al., 2004). Inorganic fertilizer often contains nitrogen in the ammonia form, while manure and septic-system effluent contain nitrogen in the ammonia and organic forms (Denver, 1989). Phosphorus also is

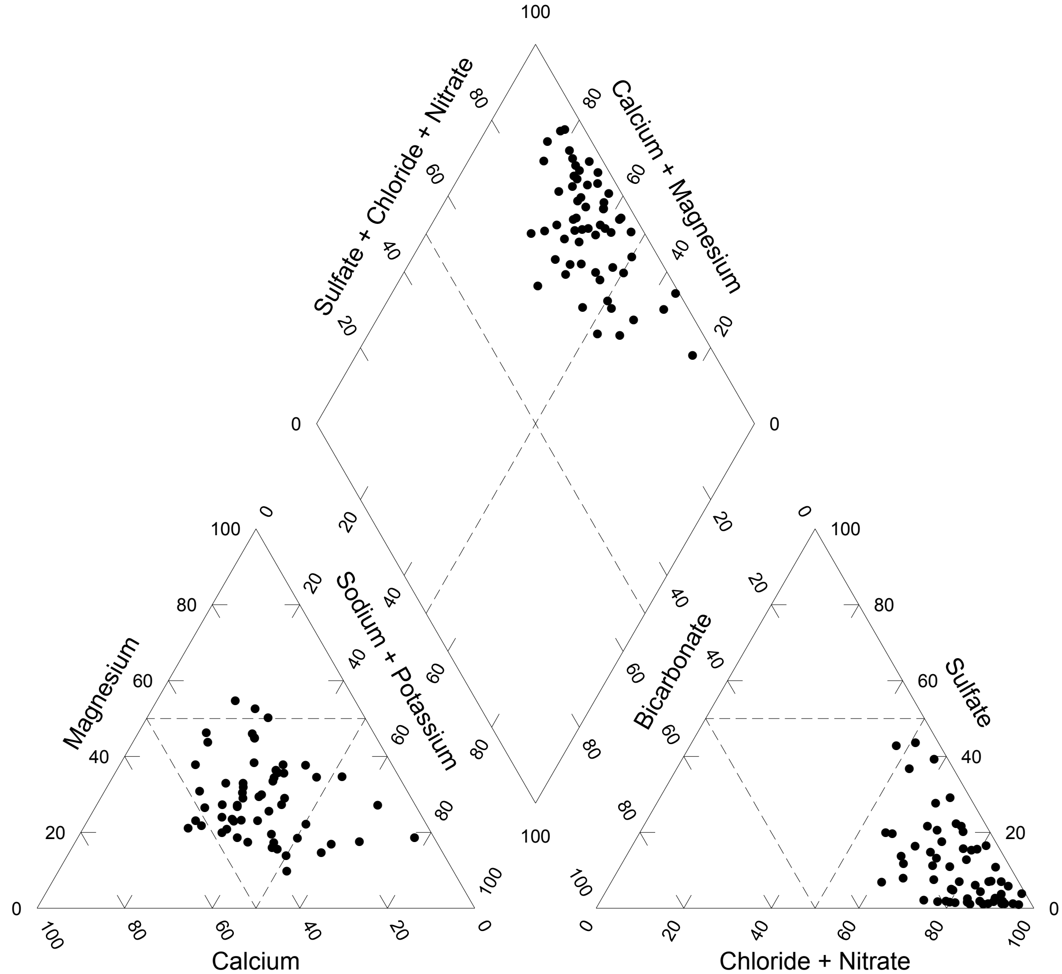


Figure 10. Piper diagram showing major-ion chemistry (as percentages of total milliequivalents per liter or meq/L) for samples with nitrate concentrations greater than 10 milligrams per liter (mg/L) and complete chemical analyses.

a component of fertilizer, manure, and sewage (Denver, 1986). For this project, dissolved concentrations of the following nutrients were measured in ground-water samples: nitrate, ammonia, and phosphorus (see Table 1 for analytical methods). These parameters are discussed individually in the following sections.

Nitrate

Nitrate concentrations ranged from non-detectable levels to 43 mg/L. Median and mean nitrate concentrations were 6.41 mg/L and 7.73 mg/L, respectively. Nitrate data are skewed as indicated by the frequency histogram of nitrate detections (Figure 12).

As noted previously, nitrate is a significant ground-water problem in the IRB watershed, exceeding the PMCL in 81 (almost 32%) of the samples. In 215 (84%) of the samples nitrate exceeded 0.4 mg/L, the threshold between natural water and water affected by human activities (Hamilton et al., 1993). Of the remaining 40 samples with nitrate less than 0.4 mg/L, 12 (30%) were associated with DO concentrations greater than 1 mg/L. Non-detectable nitrate concentrations were reported for 19 (7.5%) of the samples and were associated with low DO concentrations (1.4 mg/L or less). Spatially, nitrate exceeded the PMCL throughout the IRB watershed (Figure 13).

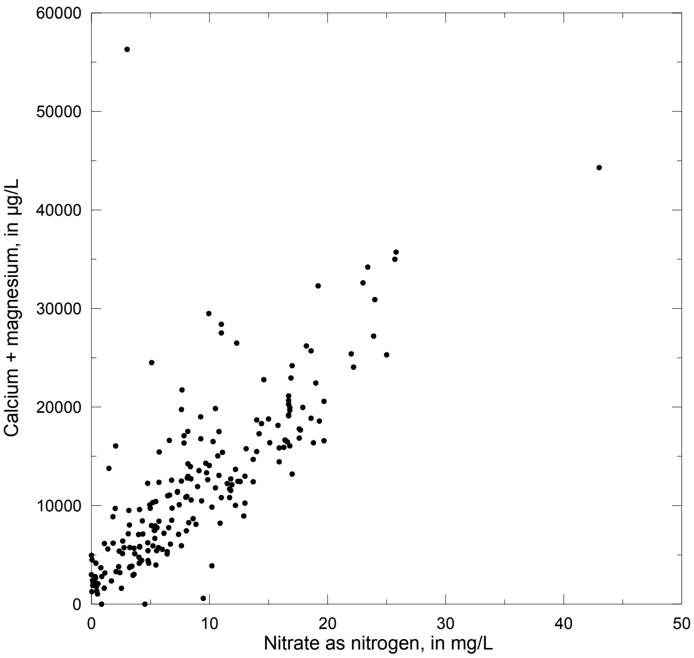


Figure 11. Scatter plot of calcium plus magnesium versus nitrate for samples under oxidizing conditions (dissolved oxygen greater than 1 mg/L). [µg/L, micrograms per liter; mg/L, milligrams per liter]

Lower nitrate concentrations (i.e., concentrations <5 mg/L) were generally most prevalent in the southern portion of the study area, along the drainage divide, and in the Long Neck area. Nitrate data were evaluated with respect to the eight intermediate watersheds of the IRB watershed mapped by McKenna et al. (in review; Figure 14a). (Nineteen sample locations plotted outside the McKenna et al. (in review) delineation and, therefore, were not included in this analysis.) Nitrate exceeded the PMCL in each of these intermediate watersheds (Figure 14b). Watershed "D" (Millsboro Pond southwest) and watershed "B" (Indian River Bay north and Swan Creek) had the highest median nitrate concentrations (9.47 and 6.83 mg/L, respectively). Watershed "D" had the highest percentage of samples with nitrate above the PMCL (48.7%). Watershed "E" (Indian River South and Iron Branch) had the lowest median nitrate concentration (4.53 mg/L), but a large percentage of the samples (29.6%) exceeded the PMCL. Watershed "A" (Indian River Bay north) had the lowest percentage of wells with nitrate above the PMCL (19.1%); that area is served largely by public water-supply wells.

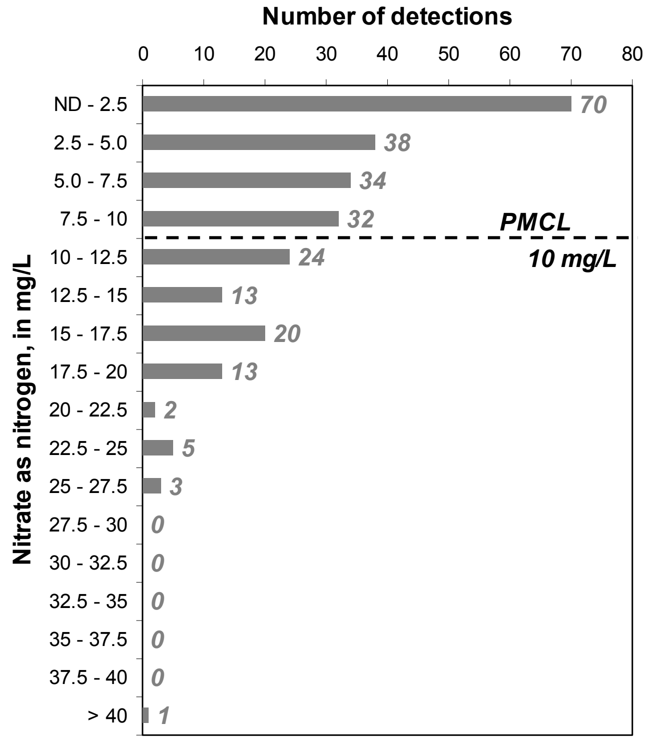


Figure 12. Frequency histogram of nitrate detections. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit; PMCL, Primary Maximum Contaminant Level for nitrate in public water-supply systems (U.S. EPA, 2004)]

Elevated nitrate concentrations were detected at all depths sampled in the Columbia aquifer, with no apparent trend in concentration versus sample depth (Figure 15). Nitrate was most elevated (43 mg/L) in well IRB-064 at a depth of 76 ft below land surface. The nitrate concentration in well IRB-154 (16.6 mg/L), which had a sample depth of 97 ft bgs, was the deepest PMCL exceedence. Sample depths in the 41 to 60 ft bgs range had the highest median nitrate concentration (7.36 mg/L; Figure 16). Sample depths in the 61 to 80 ft bgs range had a median concentration of 6.28 mg/L (Figure 16). Combined, these sample depth intervals comprise 214 samples or 84% of the total well population. Shallower (<40 ft bgs) and deeper (>80 ft bgs) sampling intervals were not well represented by this study (Figure 16). Regardless, median nitrate concentrations for these intervals were as follows: 0 to 20 ft bgs (2.78 mg/L), 21 to 40 ft bgs (4.53 mg/L), and greater than 80 ft bgs (3.90 mg/L).

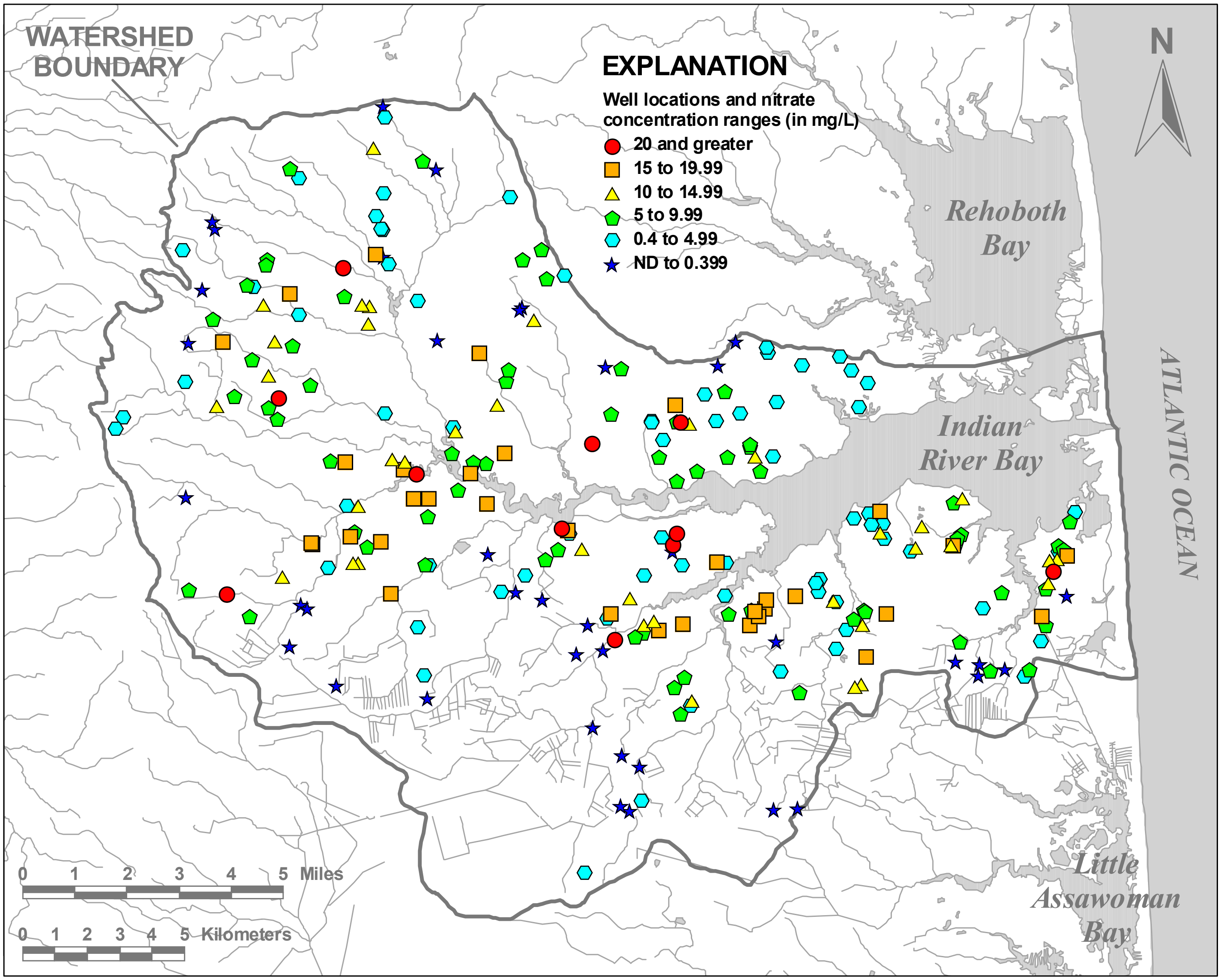


Figure 13. Map showing nitrate concentration ranges. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit]

For ground water with oxidizing conditions (DO≥1 mg/L), the median nitrate concentration was 7.8 mg/L (Figure 17). In contrast, the median was 0.14 mg/L for reducing conditions (DO . These findings are consistent with Denver et al. (2004). Reducing conditions can either prevent the conversion of nitrogen species to nitrate (Shedlock et al., 1999) or cause nitrate to be converted to nitrogen gas (i.e., denitrification; Denver et al., 2004). Where ground water is under oxidizing conditions, nitrate can persist along entire ground-water-flow paths for decades (Andres, 1991a; Shedlock et al., 1999).

Nitrate data were evaluated with respect to digital ground-water recharge potential data (Figure 3; Andres et al., 2002). Nitrate exceeded the PMCL in all recharge-potential categories (Figure 18). Samples from wells in poor recharge-potential settings had the lowest median nitrate concentration (4.78 mg/L) and the smallest percentage of samples with nitrate above the PMCL (21 %). Wells in areas mapped as fair recharge potential had the highest median nitrate concentration (7.98 mg/L) and the largest percentage of samples with PMCL exceedences (37%).

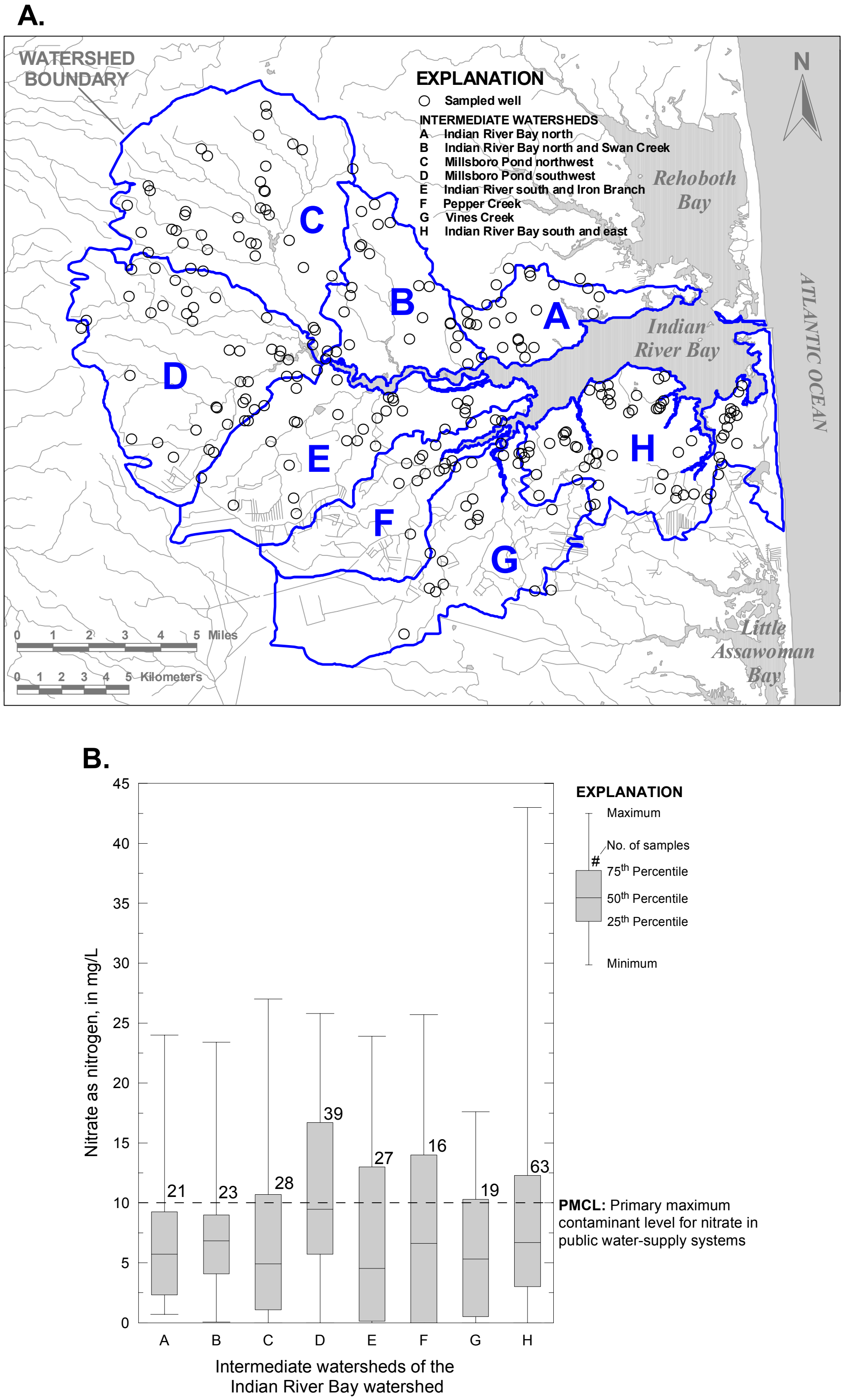


Figure 14. (A) Map of intermediate watersheds of the Indian River Bay watershed (after McKenna et al., in review) and (B) percentile diagram of nitrate distributions for each of those watersheds. [mg/L, milligrams per liter]

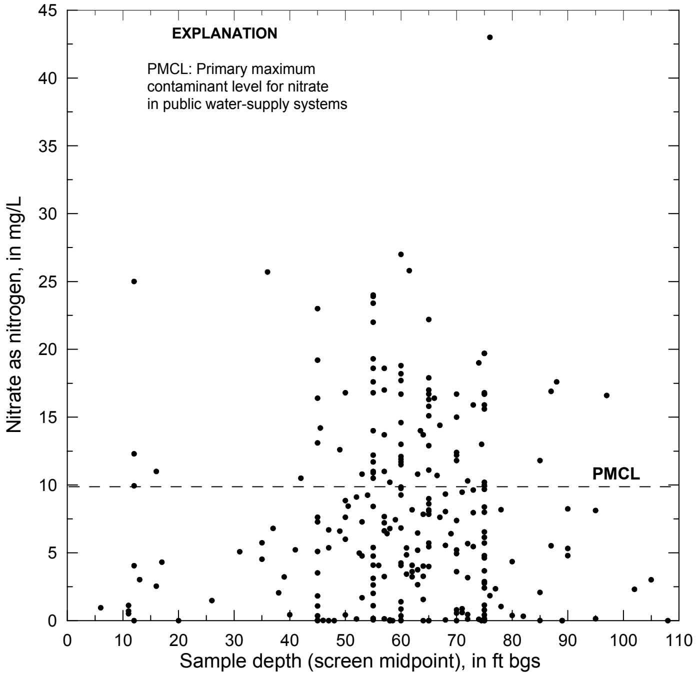


Figure 15. Scatter plot of nitrate versus sample depth. [mg/L, milligrams per liter; ft bgs, feet below ground surface]

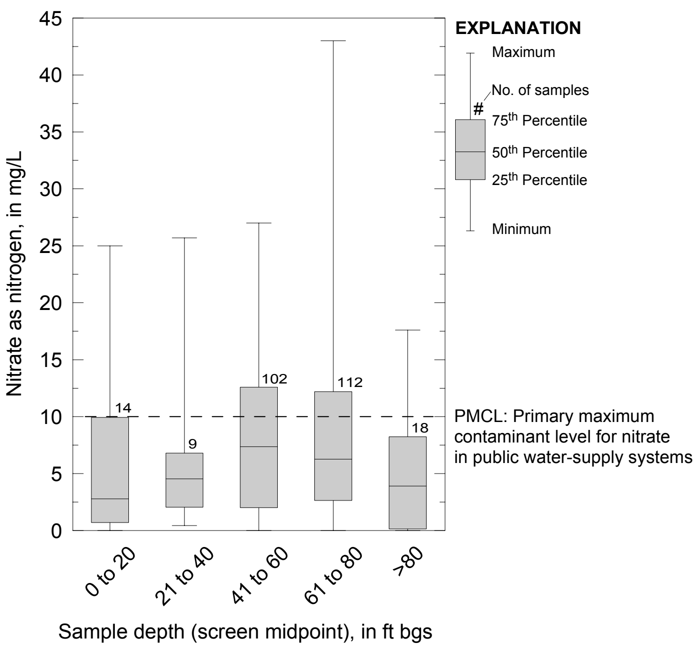


Figure 16. Percentile diagram of nitrate distributions versus sample depth. [mg/L, milligrams per liter; ft bgs, feet below ground surface]

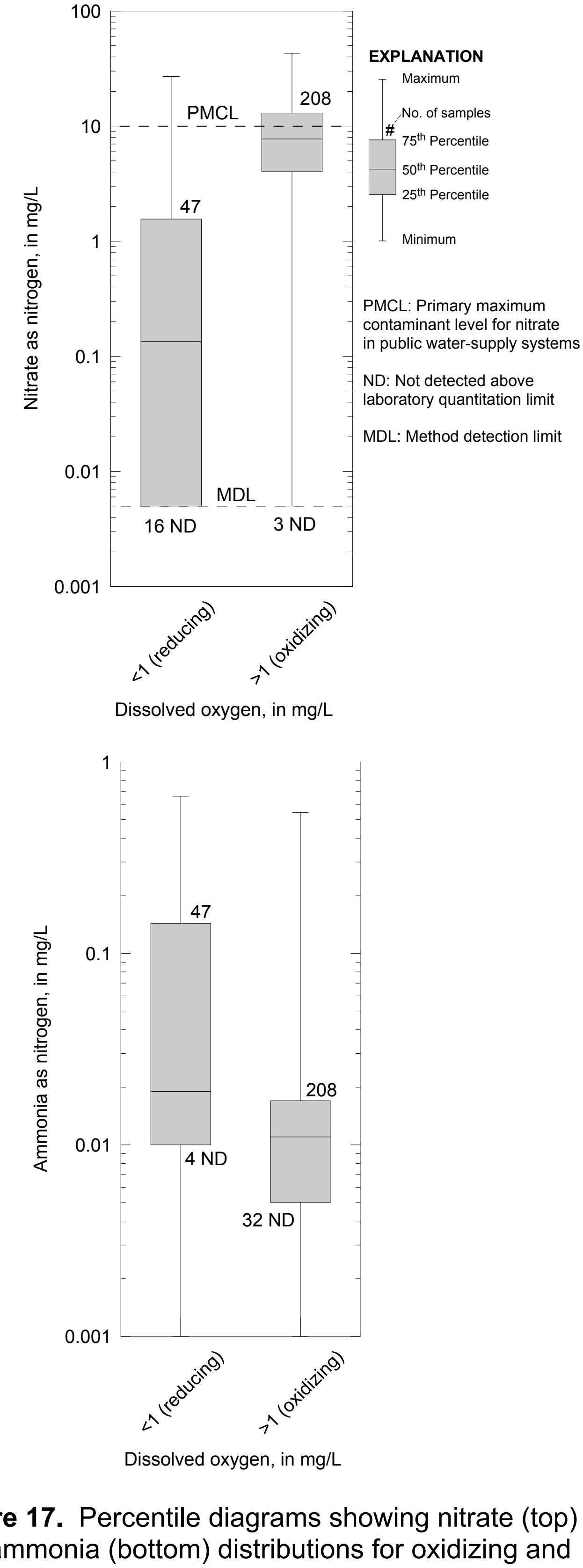


Figure 17. Percentile diagrams showing nitrate (top) and ammonia (bottom) distributions for oxidizing and reducing conditions. [mg/L, milligrams per liter]

For wells in good and fair recharge-potential settings, nitrate exceeded the PMCL in 32% and 31% of the samples, respectively. The median nitrate concentrations for those categories were 5.72 and 5.28 mg/L, respectively. For the nine wells in poor recharge-potential settings with nitrate above the PMCL, ground water was generally under oxidizing conditions (with the exception of IRB-127). These wells likely produce ground water that is recharged in more well-drained settings. For example, well IRB-234, which had the highest nitrate concentration (23 mg/L) of wells in poor recharge areas, is hydrologically downgradient from an extensive area mapped as good recharge potential.

As noted by Andres (1991a), proving the source of nitrate contamination in an individual well is not always possible, because land-use practices at the well head do not always constitute the source. Wells screened at or near the water table, witch generally yield data representative of recently-recharged ground water, are more likely to provide data representative of an overlying land use (Hamilton and Denver, 1990). Ground water that is intercepted by deep unconfined wells is sometimes recharged thousands of feet upgradient of the well and, therefore, is representative of land use at the point of recharge (Andres, 1991a; Denver, 1993; Hamilton and Denver, 1990). In addition, time must be considered. Dunkle et al. (1993) used chlorofluorocarbons (CFCs) to estimate shallow ground-water ages in the Fairmount area, which is immediately north of the IRB watershed. Their results indicate modeled ground-water ages ranging from "modern" (or recently recharged) for shallow wells screened near the water table to almost 30 yrs for deeper wells (up to 102 ft deep). As noted previously, 214 (84%) of the wells sampled for this study had sample depths in the 40 to 80 ft bgs range. Wells in this depth range sampled by Dunkle et al. (1993) had modeled ground-water ages ranging from 8 to 28.8 yrs, with age increasing with depth. Considering these complications, analysis of individual well capture zones using computer models and particle tracking would be necessary to definitively evaluate ground-water travel time and land-use impacts at the point of recharge (see, for example, Christenson and Rea, 1993). Denver et al. (2004) evaluated land use within a 500-m radius of shallow wells sampled in the Delmarva Peninsula,

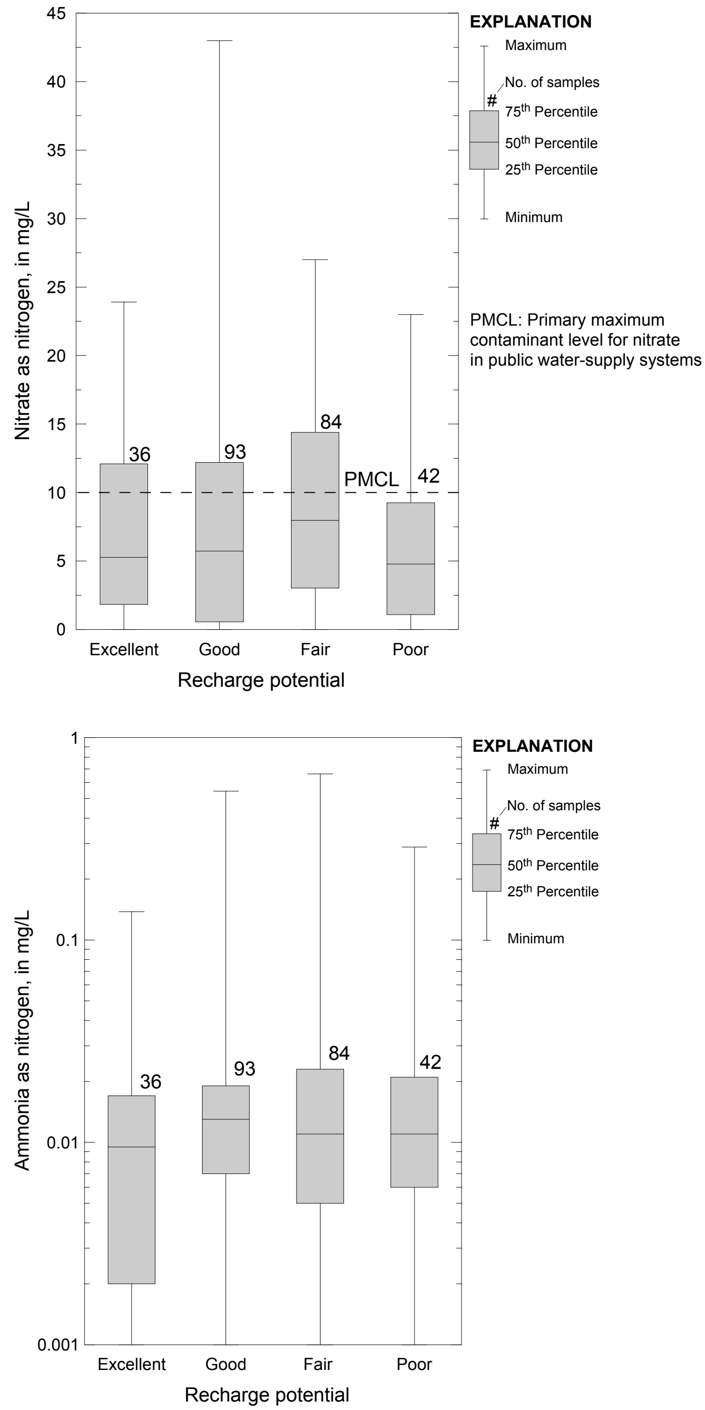


Figure 18. Percentile diagrams showing nitrate (top) and ammonia (bottom) distributions for each recharge-potential setting. Refer to Figure 3 for recharge-potential map. [mg/L, milligrams per liter]

and reported increasing nitrate concentrations with increasing percentages of agricultural land use. Such analyses are beyond the scope of this study.

Ammonia

Ammonia concentrations ranged from non-detectable levels to 0.662 mg/L. Median and mean ammonia concentrations were 0.011 and 0.034 mg/L, respectively. The ammonia data, like the nitrate data, are skewed (Figure 19). Ammonia was not detected above the laboratory quantitation limit in 36 (14%) of the samples (Figures 5 and 19). Estimated values (i.e., values below the quantitation limit but above the method detection limit, or MDL) were reported for 160 (63%) of the samples (Figure 5).

The most elevated ammonia concentration (0.662 mg/L) was detected in well IRB-170 and was associated with anoxic conditions and non-detectable nitrate (Appendix 2). As noted by Denver et al. (2004), ammonia is readily converted to nitrate under oxidizing conditions and, therefore, concentrations are relatively low (<1 mg/L) in the surficial aquifer of the Delmarva Peninsula. Well IRB-170 also had elevated phosphorus (0.145 mg/L). In some instances, elevated ammonia and phosphorus may be attributed to naturally-occurring sources, such as organic-rich sediments in confining beds (Ator et al., 2004). Two other examples of wells with elevated ammonia and phosphorus include wells IRB-174 and -246 (see "Phosphorus" section below). Spatially, the most elevated ammonia concentrations were detected in the southern half of the study area.

In contrast to nitrate concentrations, ammonia concentrations were generally higher under reducing conditions than oxidizing conditions. Specifically, the median ammonia concentrations for reducing and oxidizing conditions were 0.019 and 0.011 mg/L, respectively, and the 75th percentiles were 0.141 and 0.017, respectively (Figure 17). Median ammonia concentrations for each recharge-potential category indicate little variation with respect to recharge-potential setting (Figure 18). Specifically, the median concentrations for each category were: excellent (0.010 mg/L), good (0.013 mg/L), fair (0.011 mg/L), and poor (0.011 mg/L). Wells in excellent recharge-potential settings, however, showed the lowest maximum concentration (0.138 mg/L) and the lowest 25th percentile (0.002 mg/L) of the four categories (Figure 18).

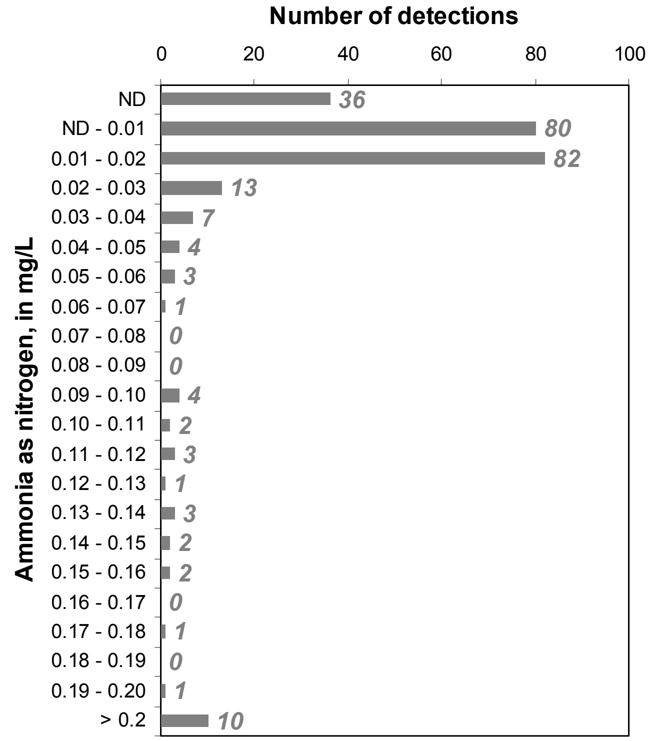


Figure 19. Frequency histogram of ammonia detections. [ND, not detected above laboratory quantitation limit; mg/L, milligrams per liter]

Phosphorus

Phosphorus concentrations ranged from non-detectable levels to 0.688 mg/L. Median and mean phosphorus concentrations were 0.014 and 0.031 mg/L, respectively. The phosphorus data, like the nitrate and ammonia data, are skewed (Figure 20). Phosphorus was not detected above the laboratory quantitation limit in 69 (27%) of the samples (Figure 5). Estimated values were reported for 140 (55%) of the samples (Figure 5).

Twelve (4.7%) of the samples had phosphorus concentrations greater than 0.1 mg/L (Figure 20), a recommended threshold to prevent excessive plant growth in streams (U.S. EPA, 1986). As with the nitrate data, there is no obvious trend in phosphorus with sample depth; however, phosphorus concentrations above 0.1 mg/L were only found at sample depths of 40 ft bgs and greater (Figure 21). The two most elevated phosphorus concentrations were detected at depths of 70 ft bgs and greater.

In contrast with the nitrate data, phosphorus concentrations (like ammonia concentrations) tend to be higher under reducing conditions than oxidizing

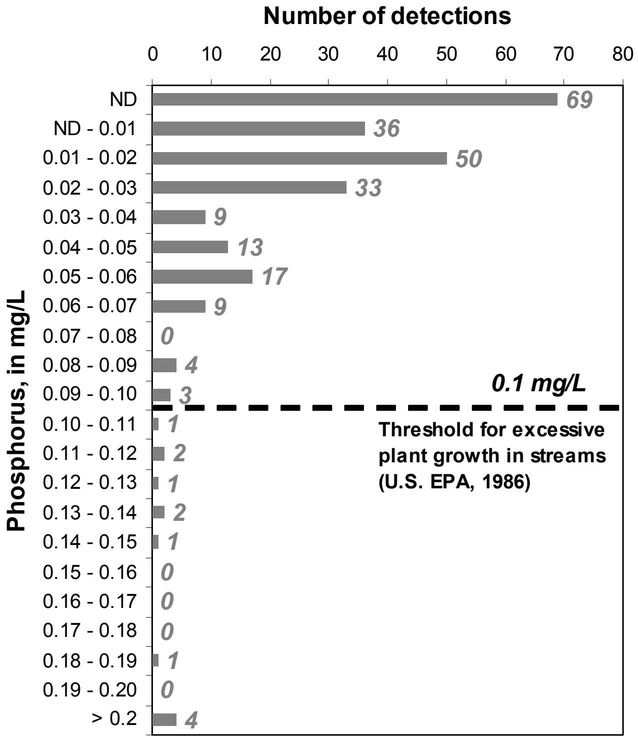


Figure 20. Frequency histogram of phosphorus detections. [ND, not detected above laboratory quantitation limit; mg/L, milligrams per liter]

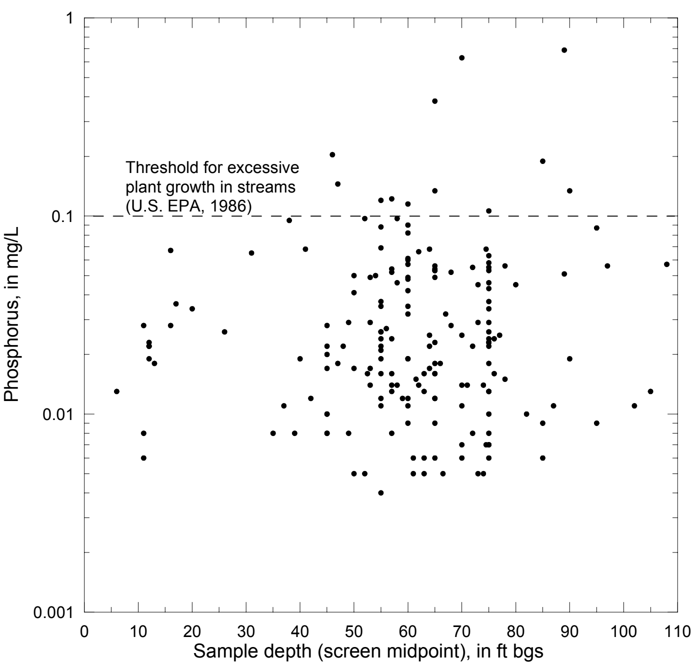


Figure 21. Scatter plot of phosphorus versus sample depth. [Only samples with detected or estimated concentrations shown; mg/L, milligrams per liter; ft bgs, feet below ground surface]

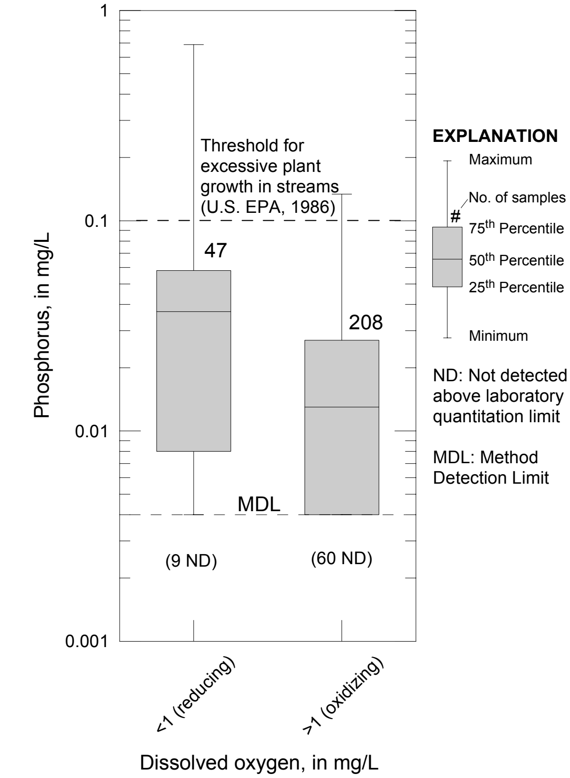


Figure 22. Percentile diagram showing phosphorus distributions for oxidizing and reducing conditions. [mg/L, milligrams per liter]

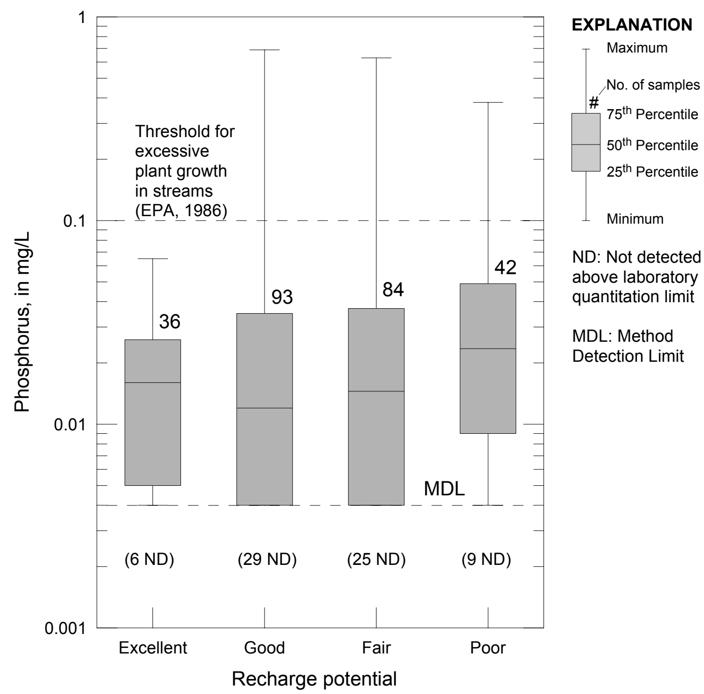


Figure 23. Percentile diagram showing phosphorus distributions for each recharge-potential setting. Refer to Figure 3 for recharge-potential map. [mg/L, milligrams per liter]

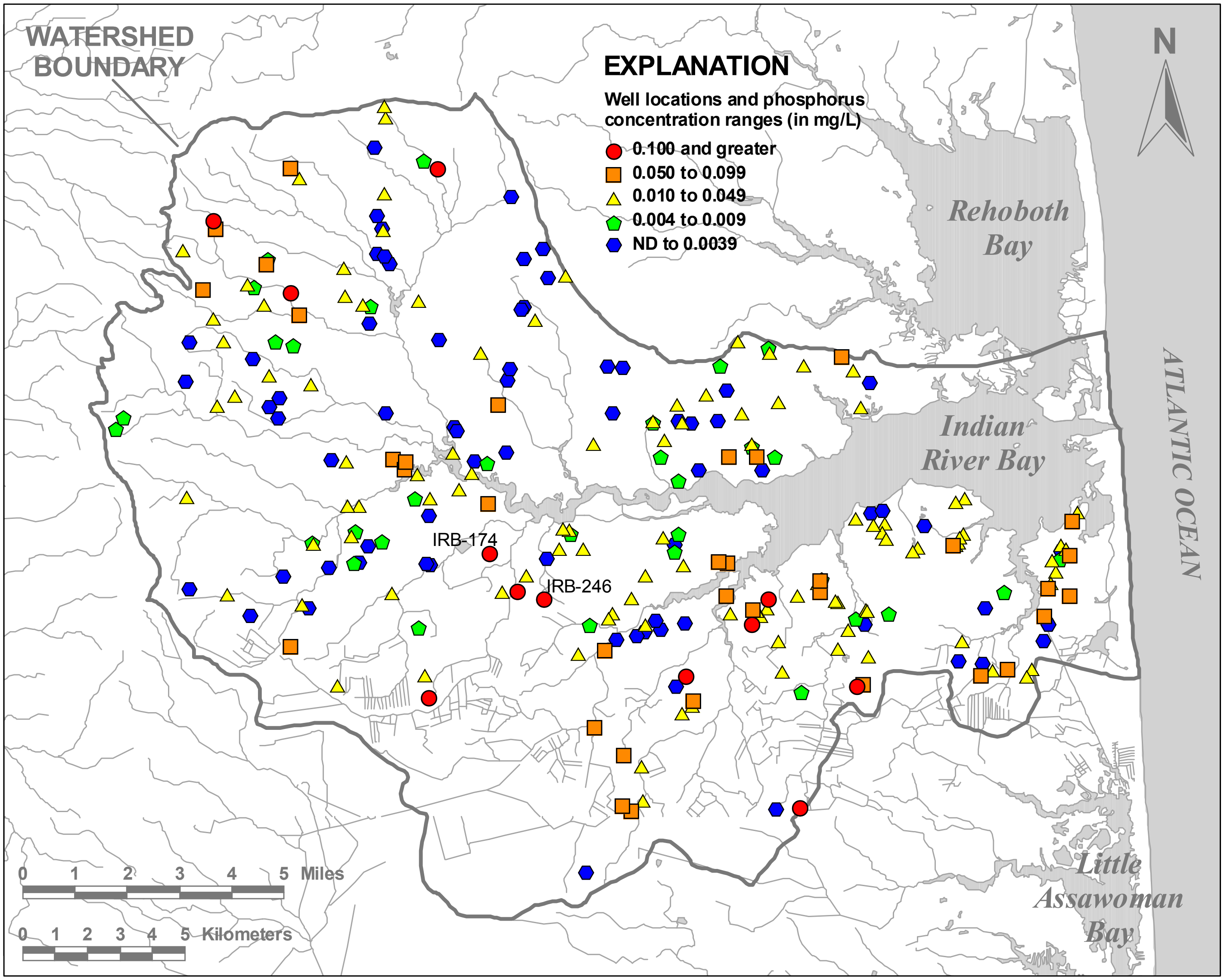


Figure 24. Map showing phosphorus concentration ranges. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit]

conditions. Specifically, the median phosphorus concentrations for anoxic and oxic ground-water conditions were 0.037 and 0.013 mg/L, respectively (Figure 22). Moreover, samples from wells in poor recharge-potential settings had the highest median phosphorus concentration (0.024 mg/L; Figure 23). In excellent recharge-potential settings, phosphorus never exceeded 0.1 mg/L (Figure 23). Again, these findings are in contrast with the nitrate data. Phosphorus results from this study are consistent with those of Denver et al. (2004), who reported phosphorus concentrations above 0.1 mg/L in ground water under reducing conditions. Reducing conditions allow for the dissolution of phosphorus, while oxidizing conditions cause phosphorus to attach to soil particles (Denver et al., 2004).

Concentrations of phosphorus above 0.1 mg/L (red dots in Figure 24) were most prevalent in the southern half of the study area where reducing conditions are prevalent. Specifically, nine of the 12 wells with phosphorus above 0.1 mg/L are located in this region; the three remaining wells are located in the northwestern portion of the study area (Figure 24). This spatial pattern is generally consistent with the iron results (Figure 7). The highest phosphorus concentrations (0.688 and 0.629 mg/L) were detected in wells IRB-174 and –246, respectively (Figure 24). Both wells produce anoxic ground water (DO<1 mg/L), and hydrogen sulfide gas was noted during well sampling. The drillers' logs for both wells also indicate significant clay/silt above the screened intervals. Collectively these data appear to suggest naturally-occurring phosphorus sources.

SUMMARY AND CONCLUSIONS

Field and analytical ground-water data were collected during 2001-03 from 255 wells completed in the Columbia aquifer in the Indian River Bay (IRB) watershed. Total Maximum Daily Loads (TMDLs) developed for this watershed require significant reductions in non-point source nitrogen (N) and phosphorus (P) discharges (up to 85 and 65%, respectively; DNREC, 1998). Samples were analyzed for field parameters (pH, temperature, dissolved oxygen, and specific electrical conductance) and laboratory parameters (major ions, silica, and nutrients). Nutrient analyses included nitrate plus nitrite as nitrogen (nitrate), ammonia as nitrogen (ammonia), and phosphorus.

Data were compared to Federal drinking-water standards for public water-supply systems. The standards included Primary and Secondary Maximum Contaminant Levels (PMCLs and SMCLs, respectively) and Health Advisories (HAs) established by the U.S. EPA (2004). Nitrate was the only project analyte with a PMCL (10 mg/L). Nitrate concentrations exceeded the PMCL in 81 (almost 32%) of the samples. Nitrate did not exceed the PMCL in any of the 22 public water-supply wells sampled. Iron exceeded the SMCL (300 µg/L) in 31 (about 12%) of the samples. Chloride concentrations exceeded the SMCL (250 mg/L) in only three (about 1%) of the samples; elevated chloride levels were accompanied by total dissolved solids (TDS) concentrations in excess of the SMCL (500 mg/L). None of the samples exceeded the SMCL or HA for sulfate (250 mg/L and 500 mg/L, respectively). A total of 252 (about 99%) of the samples had pH values less than 6.5 and, therefore, outside of the SMCL range (6.5 to 8.5). Sodium exceeded the HA (20,000 µg/L) in 26 (about 10%) of the samples.

Results from this study indicate that nitrate is the most significant ground-water-quality issue in the IRB watershed. As such, key findings regarding this contaminant follow:

- Nitrate concentrations ranged from non-detectable levels to 43 mg/L and the overall distribution is skewed. Median and mean nitrate concentrations were 6.41 mg/L and 7.73 mg/L, respectively. Nitrate was not detected in 19 (7.5%) of the samples.
- In most of the samples (84%), nitrate exceeded 0.4 mg/L, a threshold established by Hamilton et al. (1993) to distinguish between natural and human-impacted ground water. Natural ground water, i.e., water with nitrate below 0.4 mg/L, is a sodium-potassium-chloride-bicarbonate-type water, consistent with natural water types reported by Andres (1991a) and Denver (1993).
- Areally, nitrate exceeded the PMCL in parts of the eight intermediate watersheds mapped by McKenna et al. (in review). Of these, intermediate watershed "D" (Millsboro Pond southwest) had the highest median nitrate concentration (9.47 mg/L) and the highest percentage of samples with nitrate above the PMCL (48.7%).
- No obvious trend in nitrate with respect to sample depth (screen midpoint) was identified. Nitrate exceeded the PMCL at virtually all depths sampled.
- Nitrate concentrations were higher under oxidizing conditions (median = 7.8 mg/L) than reducing conditions (median = 0.14 mg/L).
- Nitrate exceeded the PMCL in all four recharge-potential categories (excellent, good, fair, and poor) mapped by Andres et al. (2002). Wells in poor recharge-potential settings had the lowest median nitrate concentration (4.78 mg/L) and the smallest percentage of PMCL exceedences (21%).
- Sources of nitrate contamination were not assessed as part of this study; however, samples with nitrate concentrations above the PMCL have a chemical signature indicative of agricultural impacts (see Figure 14 of Hamilton et al., 1993). This finding is substantiated by the fact that agriculture is, and has been in recent history, the predominant land use in the watershed. Based on 1997 estimates, 37% of the land area in the watershed is used for agricultural purposes. To evaluate the effects of land-use practices on ground-water quality, three-dimensional ground-water modeling in conjunction with particle tracking and historical aerial photographs would

be necessary to evaluate ground-water travel time and land-use impacts at the point of recharge for individual wells (see, for example, Christenson and Rea, 1993).

Ammonia and phosphorus concentrations were generally low and often non detectable. Median concentrations were 0.011 and 0.014 mg/L, respectively; maximum concentrations were 0.662 and 0.688 mg/L, respectively. Twelve (4.7%) of the samples had phosphorus concentrations greater than 0.1 mg/L, the recommended threshold to prevent excessive plant growth in streams (U.S. EPA, 1986). In contrast with the nitrate data, ammonia and phosphorus concentrations tended to be higher under reducing conditions than oxidizing conditions. Moreover, samples from wells in poor recharge-potential settings had the highest median phosphorus concentration. Median ammonia concentrations, however, showed little variation with respect to the four recharge-potential settings. Elevated concentrations of ammonia and phosphorus appear to be associated with naturally-occurring sources.

The ground-water-quality data presented here provide information needed to assess nonpoint-source nitrogen and phosphorus loads from ground water in the IRB watershed. In addition, the data serve as a benchmark for future ground-water-quality studies in the watershed, and perhaps guide more local-scale studies. Finally, the data provide an appraisal of ground-water quality in an aquifer that is utilized extensively for potable water supply.

REFERENCES

Alley, W. M., 1993, Establishing the conceptual framework, *in* Alley, W. M., ed., Regional Ground-Water Quality: New York, Van Nostrand Reinhold, Ch. 2, p. 23-60.

Andres, A. S., 1987, Geohydrology of the northern coastal area, Delaware – Sheet 2, Geohydrology of the Columbia aquifer: Delaware Geological Survey Hydrologic Map Series No. 5, scale 1:24,000.

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

_____ 1991b, Basic ground-water level and chemistry data from the coastal Sussex County, Delaware, ground-water quality survey: Delaware Geological Survey Open File Report No. 33, 31 p.

_____ 1991c, Methodology for mapping ground-water recharge areas in Delaware's Coastal Plain: Delaware Geological Survey Open File Report No. 34, 18 p.

_____ 2004, Ground-water recharge potential mapping in Kent and Sussex counties, Delaware: Delaware Geological Survey Report of Investigations No. 66, 14 p.

Andres, A. S., Duffy, C. A., and Costas, E. M., 2003, Wellhead protection area delineations for the Lewes-Rehoboth Beach area, Delaware: Delaware Geological Survey Report of Investigations No. 65, 23 p.

Andres, A. S., and Howard, C. S., 2000, The Cypress Swamp Formation, Delaware: Delaware Geological Survey Report of Investigations No. 62, 13 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 Product DP 02-01.

Ator, S. W., Denver, J. M., and Brayton, M. J., 2004, Hydrologic and geochemical controls on pesticide and nutrient transport to two streams on the Delmarva Peninsula: U.S. Geological Survey Scientific Investigations Report 2004-5051, 34 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, 23 p.

Christenson, S., and Rea, A., 1993, Ground-water quality in the Oklahoma City urban area, *in* Alley, W. M., ed., Regional Ground-Water Quality: New York, Van Nostrand Reinhold, ch. 24, p. 589-611.

Denver, J. M., 1986, Hydrogeology and geochemistry of the unconfined aquifer, west-central and southwestern Delaware: Delaware Geological Survey Report of Investigations No. 41, 100 p.

_____ 1989, Effects of agricultural practices and septic-system effluent on the quality of water in the unconfined aquifer in parts of eastern Sussex County, Delaware: Delaware Geological Survey Report of Investigations No. 45, 66 p.

_____ 1993, Herbicides in shallow ground water at tow agricultural sites in Delaware: Delaware Geological Survey Report of Investigations No. 51, 28 p.

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

Deutsch, W. J., 1997, Groundwater Geochemistry: Boca Raton, Lewis Publishers, 221 p.

DNREC, 1997, Delaware Regulations Governing the Construction and Use of Wells: Department of Natural Resources and Environmental Control Document No. 40-08-95-06-01, 49 p.

_____ 1998, Total maximum daily load (TMDL) analysis for Indian River, Indian River Bay, and Rehoboth Bay, Delaware: Department of Natural Resources and Environmental Control, unpublished report, 3 sections, 2 appendices.

DOSPC, 1999, 1997 land use and land cover data: Delaware Office of State Planning Coordination, available at http://www.stateplanning.delaware.gov/info/lulcdata/lulc.shtml

_____ 2003, 2002 land use and land cover data: Delaware Office of State Planning Coordination, available at http://www.stateplanning.delaware.gov/info/lulcdata/2002lulc.shtml

Dunkle, S. A., Plummer, L. N., Busenburg, E., Phillips, P. J., Denver, J. M., Hamilton, P. A., Michel, R. L., and Coplen, T. B., 1993, Chlorofluorocarbons (CCl_3F and CCl_2F_2) as dating tools and hydrologic tracers in shallow groundwater of the Delmarva Peninsula, Atlantic Coastal Plain, United States: Water Resources Research, v. 29, no. 12, p. 3837-3860.

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 93-90, 87 p.

Hamilton, P. A., and Denver, J. M., 1990, Effects of land use on shallow ground-water quality, Delmarva Peninsula, Delaware, Maryland, and Virginia: Ground Water, v. 28, no. 5, p. 789.

Hounslow, A. W., 1995, Water quality data; analysis and interpretation: New York, Lewis Publishers, 397 p.

Johnston, R.H., 1976, Relation of ground water to surface water in four small basins of the Delaware Coastal Plain: Delaware Geological Survey Report of Investigations No. 24, 56 p.

Kasper, J. W., and McCleary, B. O., 2001 (as revised), Quality assurance project plan for a ground-water-quality survey of the Indian River, Indian River Bay, and Iron Branch watersheds, Sussex County, Delaware: Department of Natural Resources and Environmental Control, unpublished report, 21 p.

Love, S. K., March 22, 1962, Water quality – hardness of water: U.S. Geological Survey Quality of Water Branch Memorandum No. 62.47, 1 p.

McCleary, B. O., 1999, Quality assurance management plan for laboratory and field operations: Department of Natural Resources and Environmental Control, unpublished report, 62 p.

McKenna, T. A., Andres, A. S., and Steck, K., in review, Watershed delineations for Indian River and Rehoboth Bays, Delaware: Delaware Geological Survey Digital Data Product.

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water analyses: American Geophysical Union, Transactions, v. 27, p. 914-923.

Ramsey, K. W., 2001, Geologic map of the Ellendale and Milton quadrangles, Delaware: Delaware Geologic Map Series No. 11, scale 1:24,000.

Ramsey, K. W., and Schenck, S. W., 1990, Geologic map of southern Delaware: Delaware Geological Survey Open File Report No. 32, scale 1:100,000.

Ritter, W. F., and Chirnside, A. E. M., 1982, Ground-water quality in selected areas of Kent and Sussex counties, Delaware: Newark, Delaware, University of Delaware Agricultural Engineering Department, 229 p.

_____ 1984, Impact of land use on ground-water quality in southern Delaware: Ground Water, v. 22, no. 1, p. 38-47.

Robertson, F.N., 1977, The quality and potential problems of ground water in coastal Sussex County, Delaware: Newark, Delaware, University of Delaware Water Resources Center, 58 p.

_____ 1979, Evaluation of nitrate in ground in the Delaware Coastal Plain: Ground Water, v. 17, no. 4, p. 328-337.

Shedlock, R.J., Denver, J.M., Hayes, M.A., Hamilton, P.A., Koterba, M.T., Bachman, L.J., Phillips, P.J., and Banks, W.S.L., 1999, Water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia: Results of Investigations, 1987-91: U.S. Geological Survey Water-Supply Paper 2355-A, 41 p.

Talley, J. H., 1988, Geohydrology of the southern coastal area, Delaware – Sheet 2, Geohydrology of the Columbia aquifer: Delaware Geological Survey Hydrologic Map Series No. 7, scale 1:24,000.

USDA, 2004a, 2002 Census of agriculture – Delaware, state and county data: U.S. Department of Agriculture, National Agricultural Statistics Service, Volume 1, Geographic Area Series Part 8, AC-02-A-8, 246 p.

_____ [2004b], 2002 Census of agriculture county profile – Sussex, Delaware: U.S. Department of Agriculture, National Agricultural Statistics Service, 2 p., accessed on December 12, 2005 at http://www.nass.usda.gov/census/census02/profiles/de/cp10005.PDF

U.S. EPA, 1986, Quality criteria for water, 1986: U.S. Environmental Protection Agency, EPA 440/5-86-001, variously paged.

_____ 2001, Guidelines establishing test procedures for the analysis of pollutants: U.S. Code of Federal Regulations, Title 40, Part 136.3, Identification of test procedures, amended June 18, 2001.

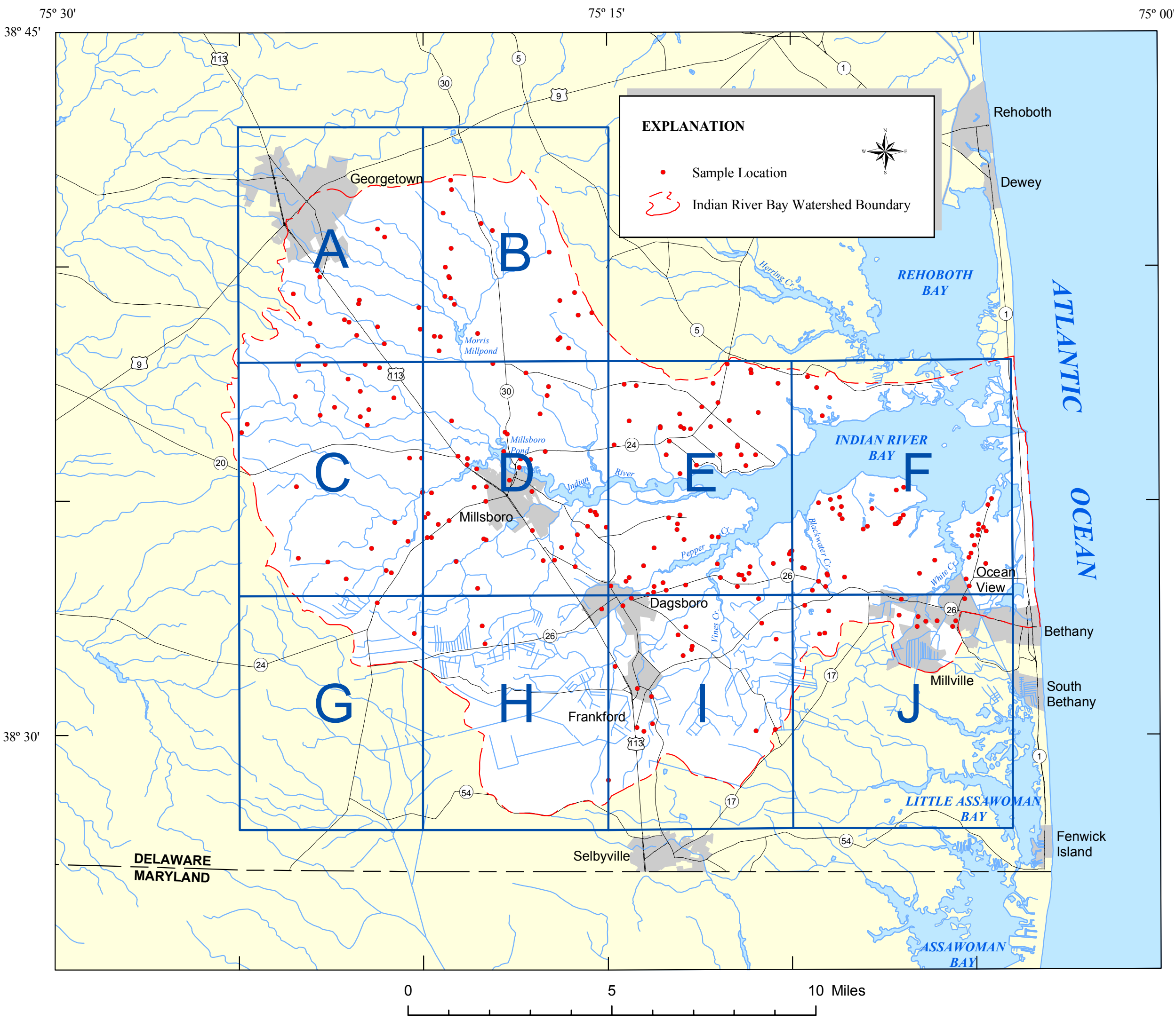
_____ 2004, 2004 edition of the drinking water standards and health advisories: U.S. Environmental Protection Agency, EPA 822-R-04-005, 12 p.

Ward, M. H., Mark, S. D., Cantor, K. P., Weisenburger, D. D., Correa-Villasenor, A., and Zahm, S. H., 1996, Drinking water nitrate and the risk of non-Hodgkin's lymphoma: Epidemiology, v. 7, no. 5, p. 465-471.

Weyer, P. J., Cerhan, J. R., Kross, B. C., Hallberg, G. R., Kantamneni, J., Breuer, G., Jones, M. P., Zheng, W., and Lynch, C. F., 2001, Municipal drinking water nitrate levels and cancer risk in older women: the Iowa women's health study: Epidemiology, v. 11, no. 3, p. 327-338.

WHI, 2003, Aquachem v.4.0 user's manual: Waterloo, Ontario, Canada, Waterloo Hydrogeologic, Inc., 276 p.

Appendix 1. Maps showing locations of wells sampled in grids A thru J.


75° 30'
75° 15'
75° 00'
38° 45'
38° 30'
EXPLANATION
Sample Location
Indian River Bay Watershed Boundary
A
B
C
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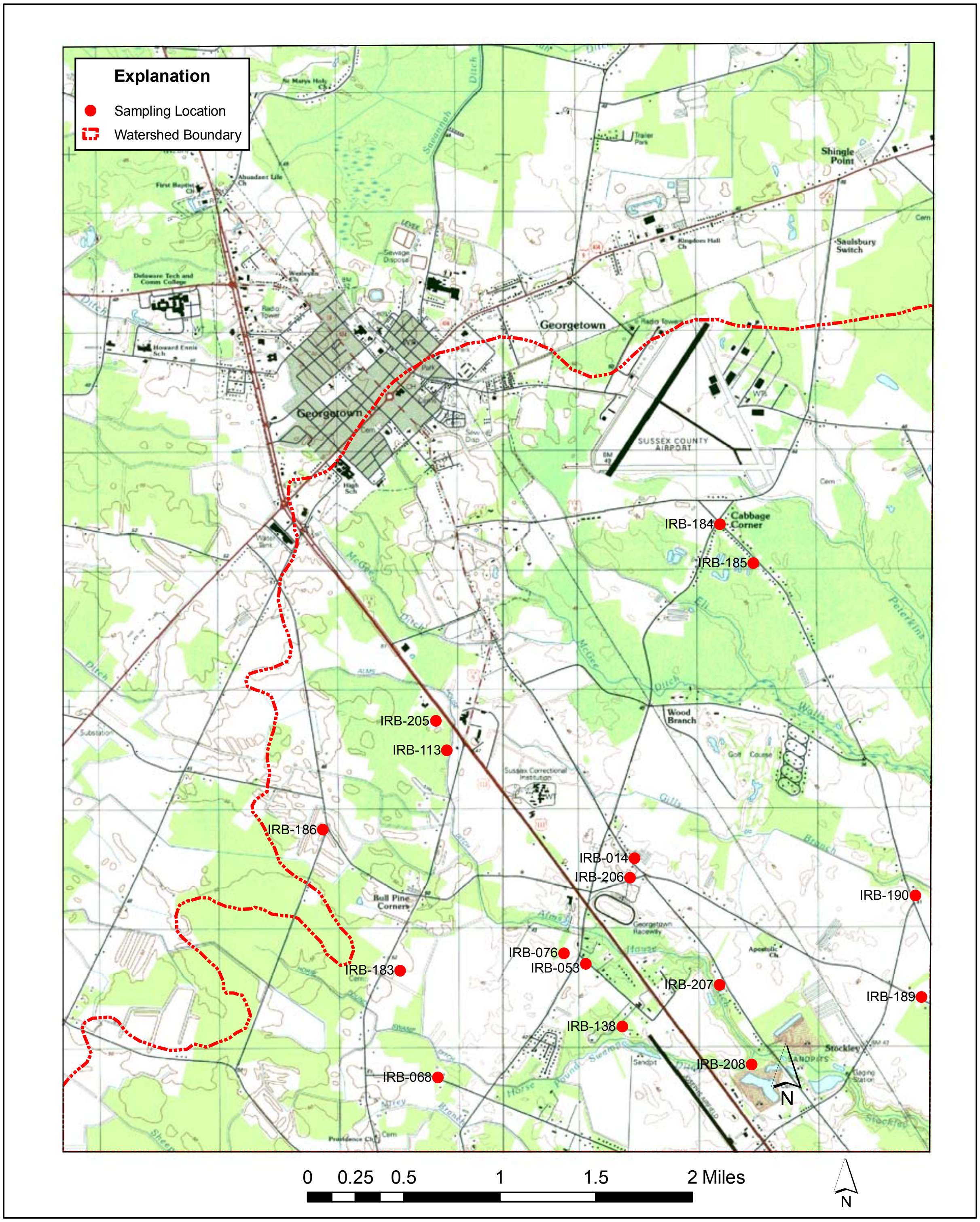
E
F
G
H
I
J
Georgetown
Millsboro
Dagsboro
Frankford
Selbyville
Millville
Ocean View
Bethany
South Bethany
Fenwick Island
Rehoboth
Dewey
REHOBOTH BAY
INDIAN RIVER BAY
LITTLE ASSAWOMAN BAY
ASSAWOMAN BAY
ATLANTIC OCEAN
DELAWARE
MARYLAND
Morris Millpond
Millsboro Pond
0
5
10 Miles

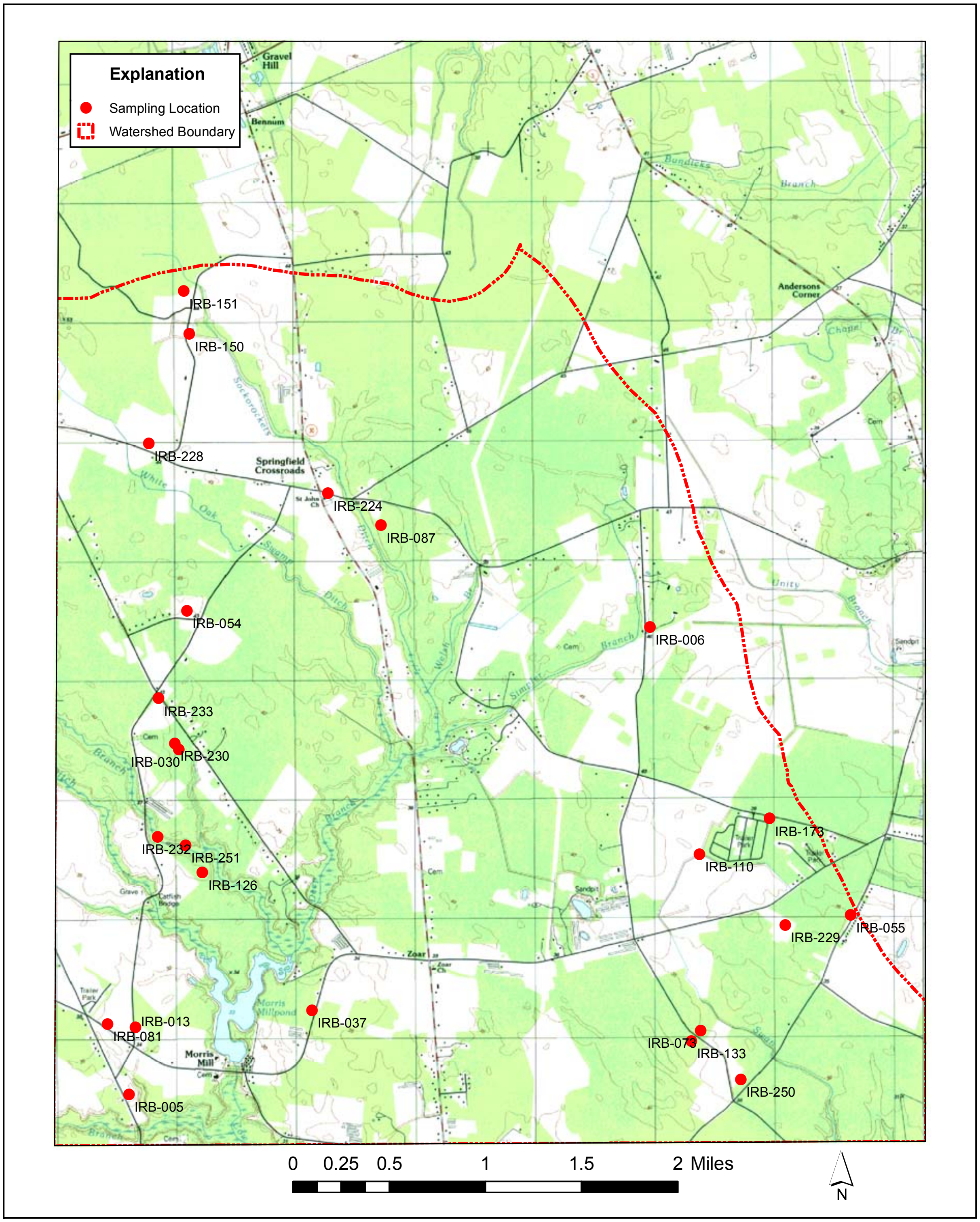
Index Map

Appendix 1. Maps showing locations of wells sampled in grids A thru J. Refer to index map at beginning of Appendix 1 for grid location. (cont.)



Grid A

Appendix 1. Maps showing locations of wells sampled in grids A thru J. Refer to index map at beginning of Appendix 1 for grid location. (cont.)



Grid B

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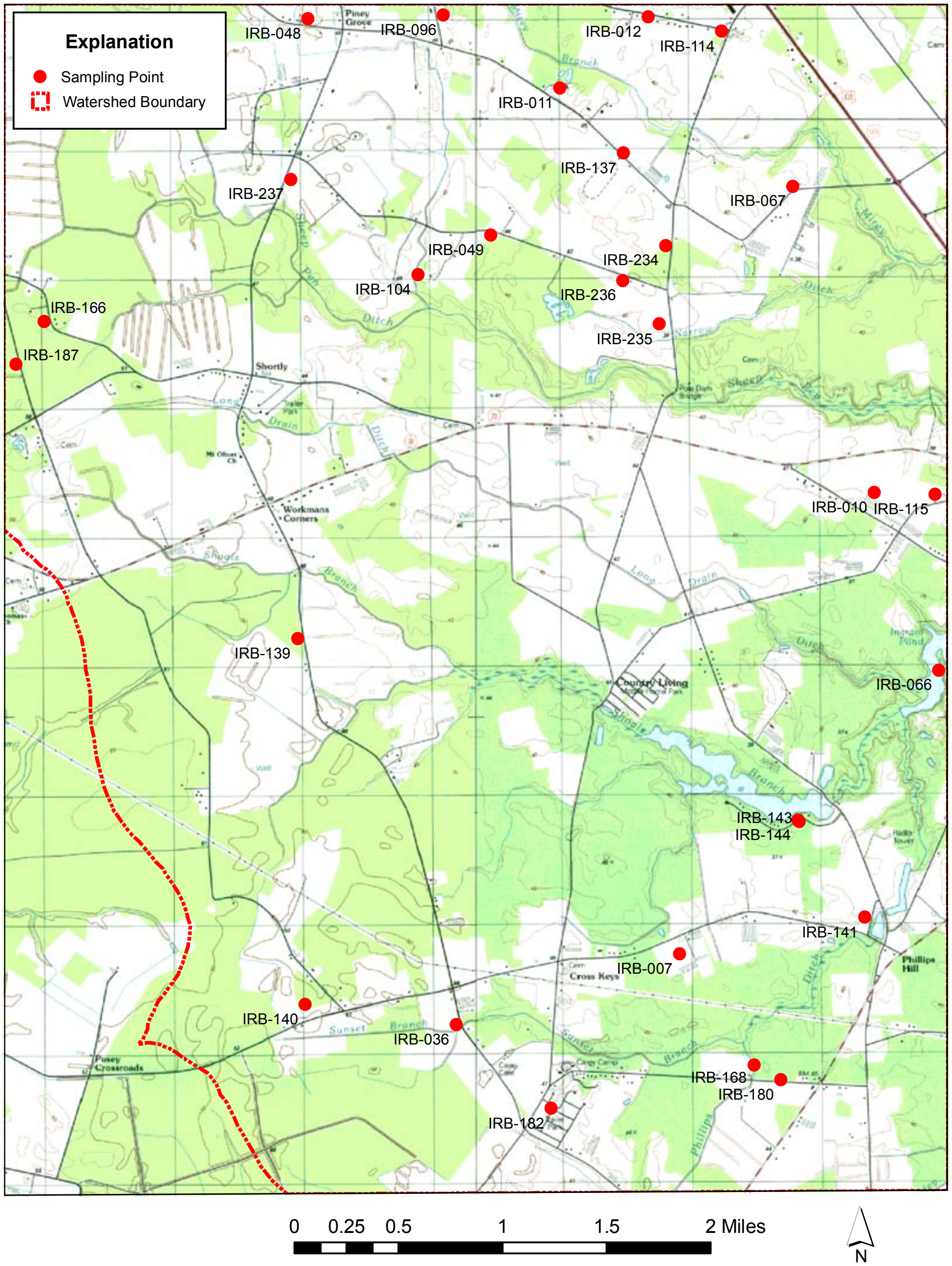

Grid C

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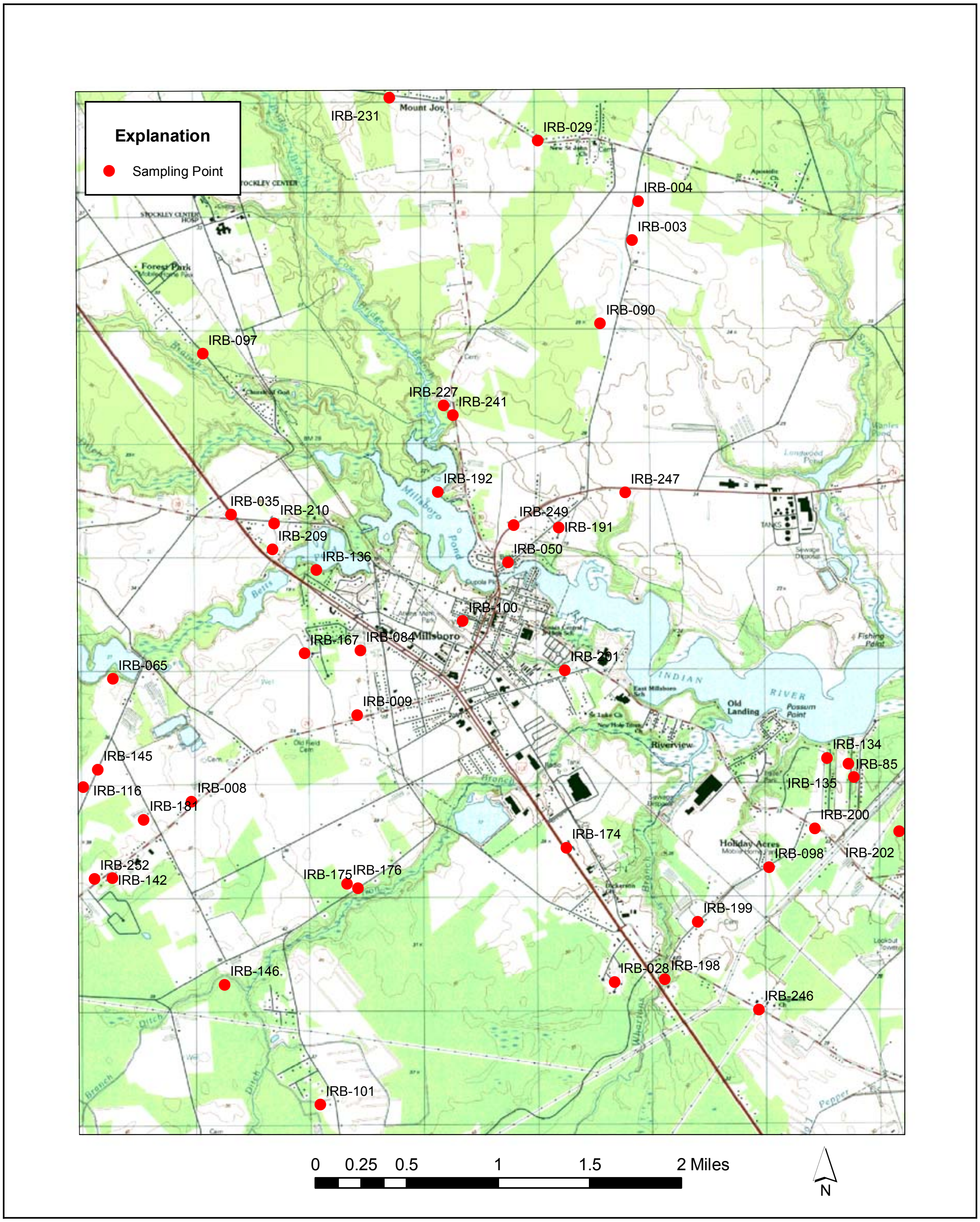

Grid D

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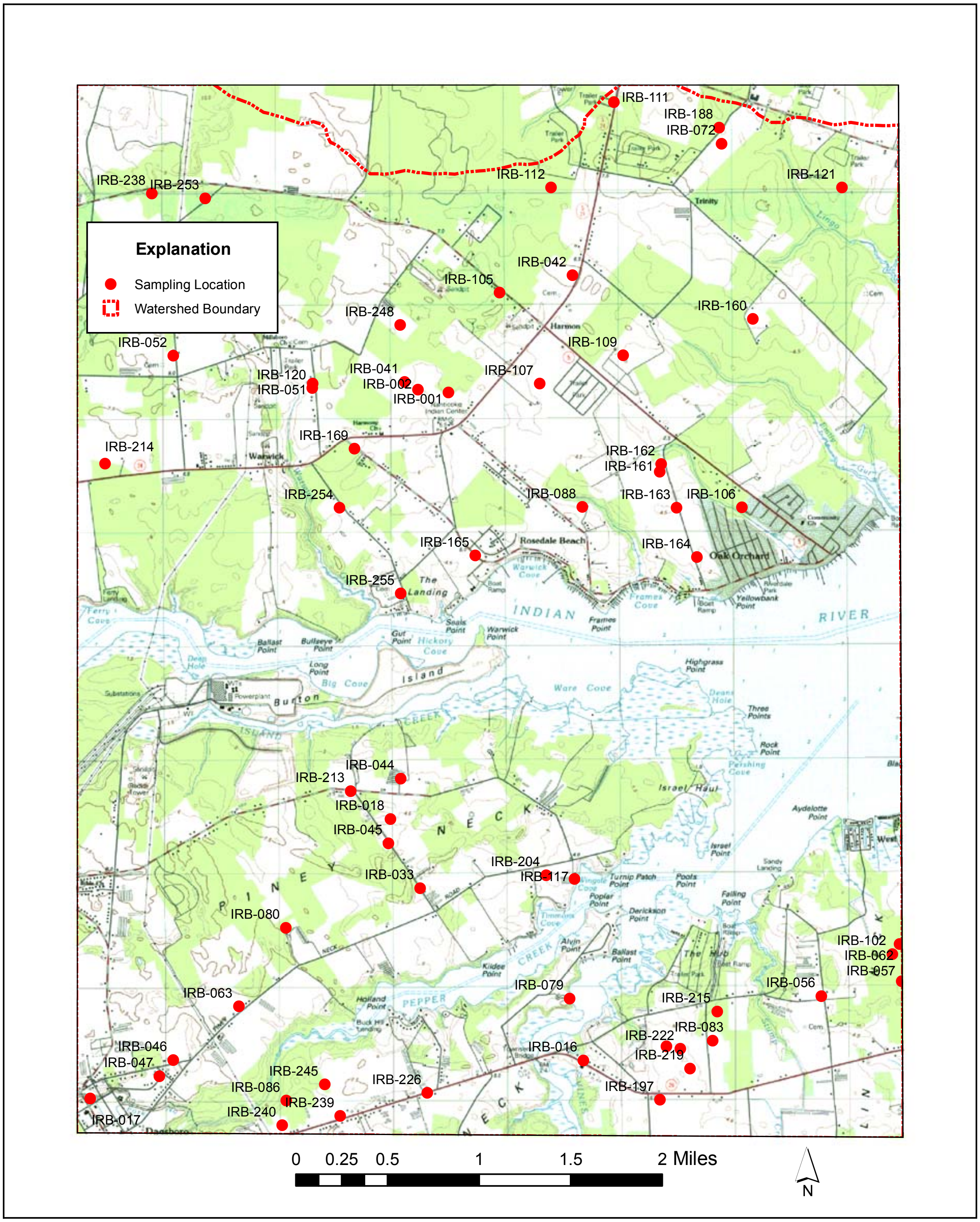

Grid E

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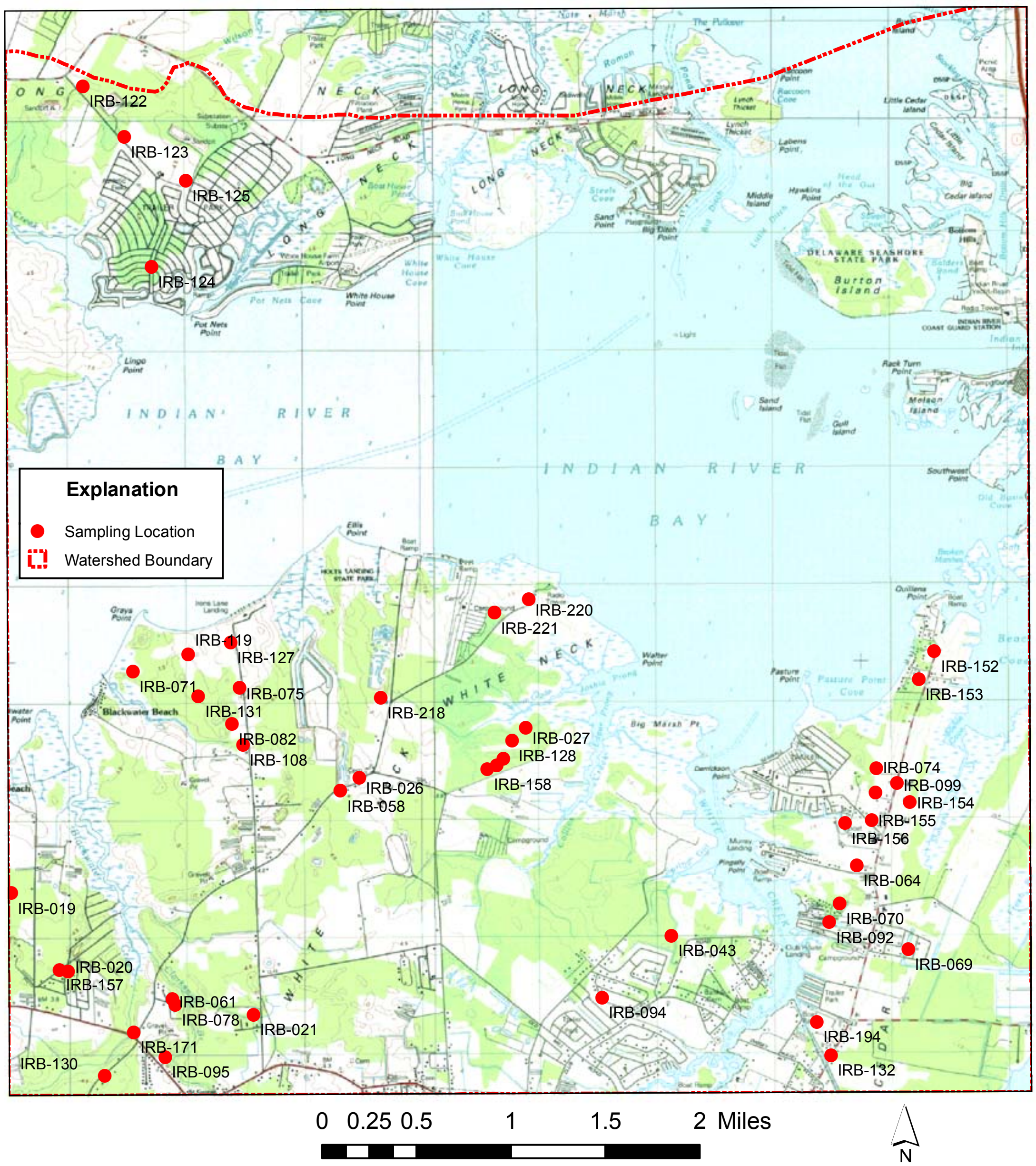

Grid F

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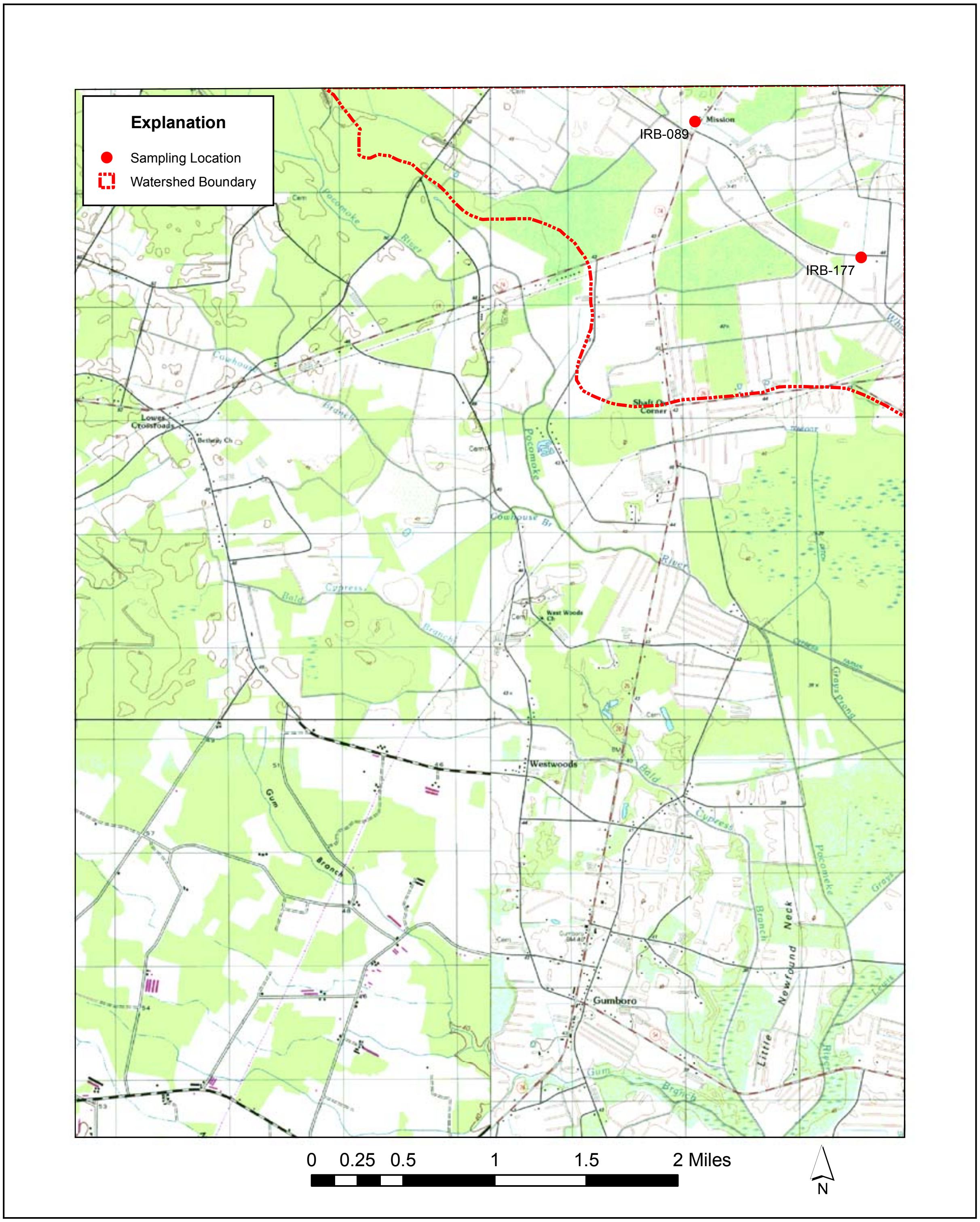
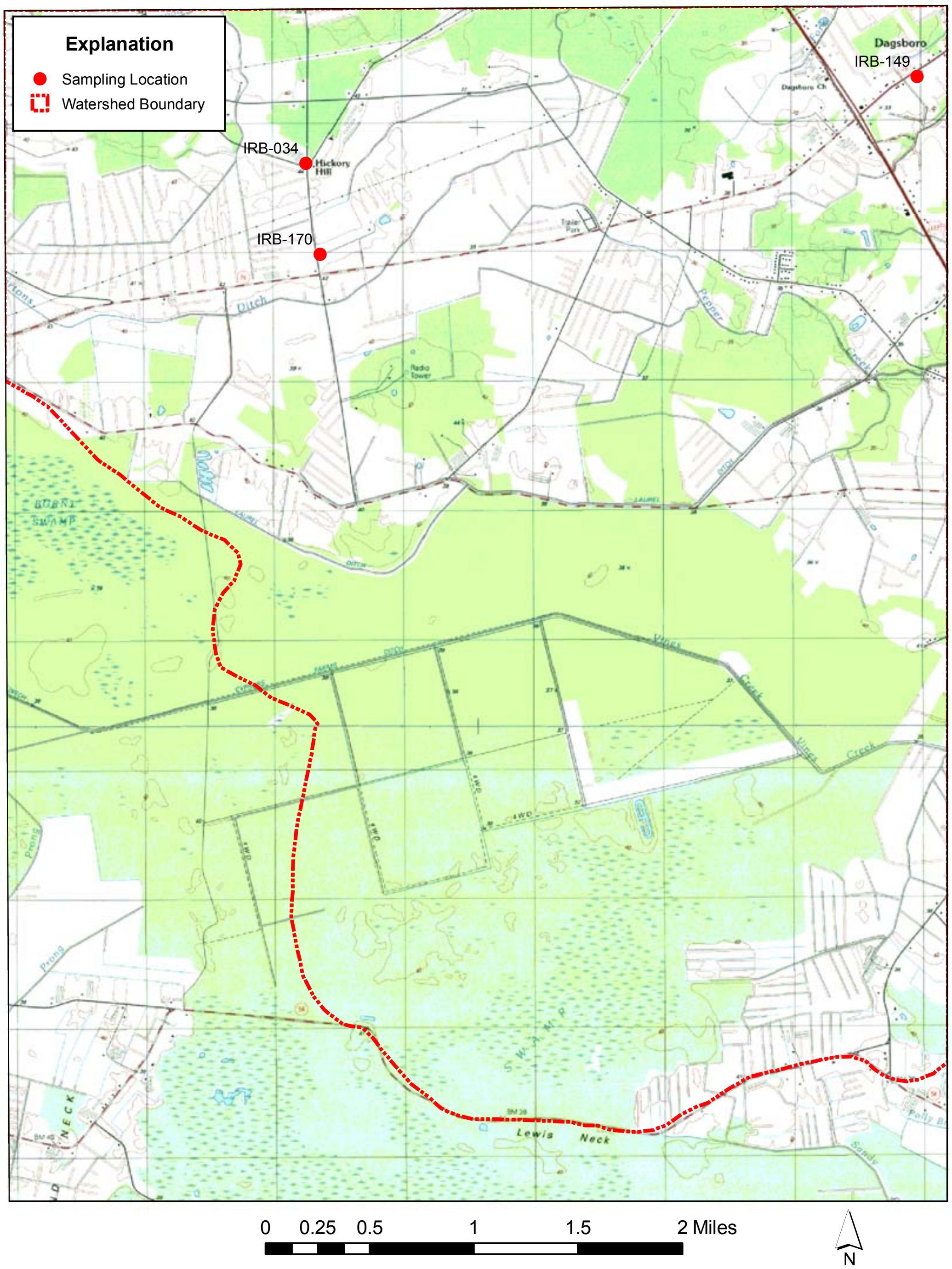


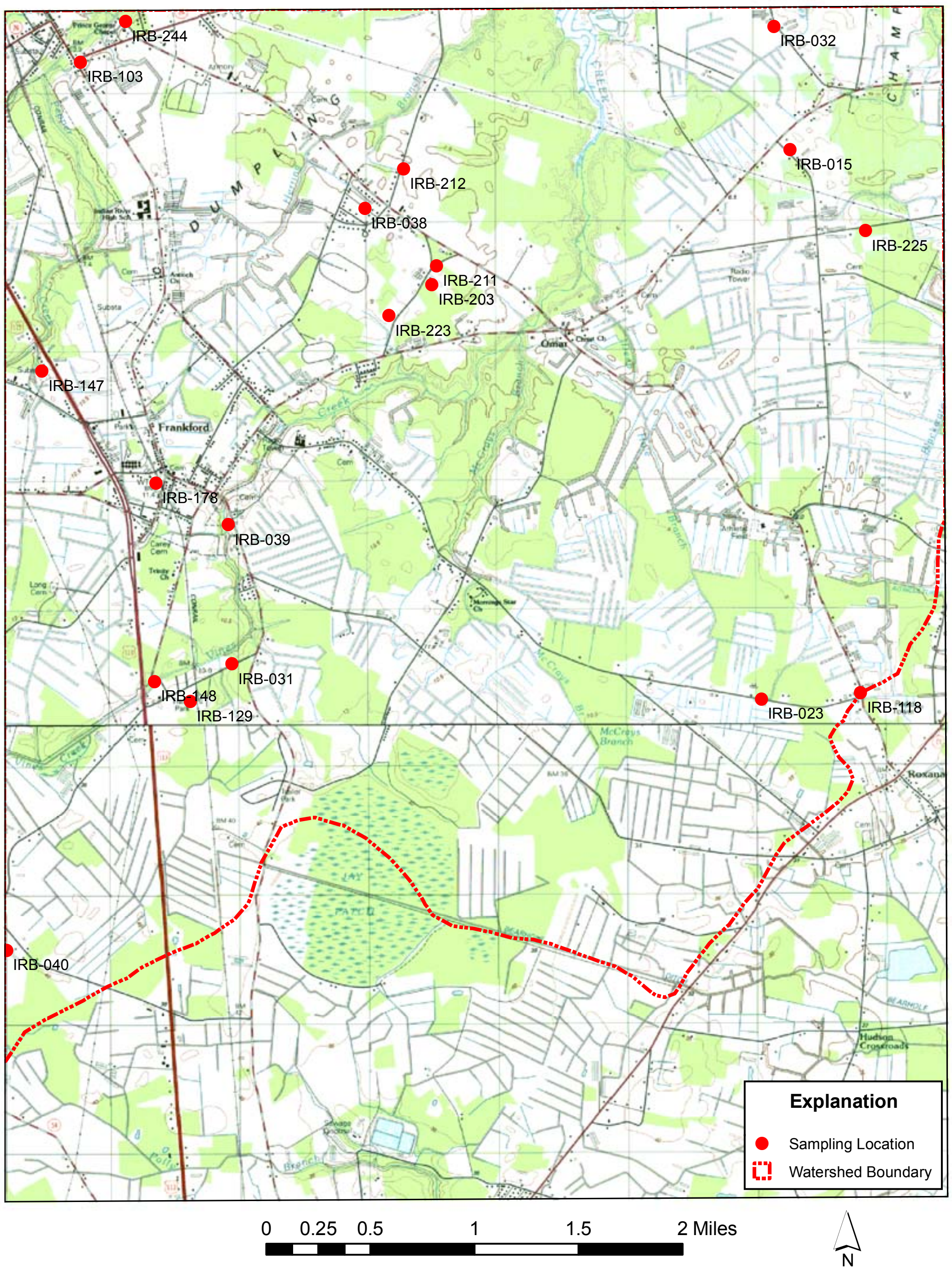
Grid G

Appendix 1. Maps showing locations of wells sampled in grids A thru J. Refer to index map at beginning of Appendix 1 for grid location. (cont.)



Grid H

Appendix 1. Maps showing locations of wells sampled in grids A thru J. Refer to index map at beginning of Appendix 1 for grid location. (cont.)



Grid I

Appendix 1. Maps showing locations of wells sampled in grids A thru J. Refer to index map at beginning of Appendix 1 for grid location. (cont.)

Grid J

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Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03.

[**Easting** and **northing**: Delaware State Plane coordinates in meters (**m**), North American Datum of 1983 (NAD83); **well type**: D, domestic; P, public; M, monitor; A, agricultural; C, commercial; **recharge potential**: E, excellent; G, good; F, fair; P, poor (Andres, 1991c; Andres et al., 2002); **land use**: A, agricultural; U, urban; F, forest land; B, barren land; W, wetland (Delaware Office of State Planning Coordination, 2003); **µS/cm**, microsiemens per centimeter at 25 degrees Celsius; **°C**, degrees Celsius; **mg/L**, milligrams per liter; **µg/L**, micrograms per liter; **U**, analyte not detected above laboratory quantitation limit, quantitation limit is reported; **J**, estimated concentration, value reported is less than quantitation limit and greater than method detection limit (MDL); **O**, analysis outsourced to Lancaster Laboratories, Inc.; **C**, calculated result, see text for details; *****, field duplicate data available, see Table 4; **NA**, not analyzed, "---" reported; **Q,** value outside acceptance limits; **JL**, value is likely underestimated due to matrix effect; **JH**, value likely overestimated due to matrix effect; **V**, analysis performed after holding time expired; **B**, compound not detected substantially (10x) above level reported in the laboratory blanks.]

Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03. (cont.)

Well ID	Easting (m)	Northing (m)	Well Type	Land Use 1997	Land Use 2002	Recharge Potential	Midpoint of screen interval (ft bgs)	Sample Date	Spec. Cond. (µS/cm)	pH	Temp. (ºC)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)		Chloride, dissolved (mg/L)
IRB-001	217830.096	67638.550	D	F	U	G	63.5	11/29/01	226.5	5.70	14.40	6.86	14		17
IRB-002	217564.185	67664.108	D	A	U	G	55	11/29/01	334.8	5.60	14.50	5.79	8		19
IRB-003	212168.273	68963.402	D	A	U	G	50.5	11/29/01	131.4	5.30	14.60	9.46	3		13
IRB-004	212222.267	69303.907	D	A	U	F	65	11/29/01	147.1	5.00	14.70	8.14	3		12
IRB-005	207902.068	70706.395	D	A	U	F	45.5	11/29/01	205.9	4.90	14.70	7.94	2		19
IRB-006	212259.752	74619.135	D	U	U	F	61	11/29/01	106.8	6.40	14.50	4.88	33		7
IRB-007	205239.679	62920.431	D	A	U	F	65	12/03/01	171.4	5.40	14.20	4.29	9		18
IRB-008	208300.081	64021.028	D	U	U	G	74	12/03/01	254.5	5.30	14.80	8.74	29		19
IRB-009	209754.461	64784.711	D	U	U	G	45	12/03/01	141.3	5.30	14.50	3.53	8		10
IRB-010	206745.124	66490.365	D	A	U	E	62	12/03/01	151.4	5.80	14.50	9.89	5		12
IRB-011	204315.932	69616.835	D	U	U	G	57.5	12/03/01	108.7	5.10	14.80	7.70	4		10
IRB-012	204997.097	70170.641	D	U	U	G	66.5	12/03/01	177.7	5.60	14.60	8.02	8		18
IRB-013	207958.384	71268.529	D	A	U	F	74.5	12/03/01	178.9	5.70	14.60	8.55	7		14
IRB-014	204762.309	72732.860	D	A	A	F	75	12/03/01	160.6	5.90	14.70	8.24	10		14
IRB-015	220637.877	59970.851	D	U	U	P	45	12/05/01	101.3	5.10	15.30	4.94	3		9
IRB-016	219015.384	61765.742	D	U	U	G	57	12/05/01	180.7	5.40	15.30	7.46	6		18
IRB-017	214684.996	61431.096	C	U	U	G	57	12/05/01	290.2	4.80	16.20	0.16	2		58
IRB-018	217321.161	63889.682	D	A	U	E	55	12/05/01	306.8	5.30	14.80	8.83	3		20
IRB-019	221846.631	62818.124	D	U	U	E	75	12/06/01	81.8	5.90	13.80	2.87	1	U	11
IRB-020	222331.938	62148.376	D	U	U	E	65	12/06/01	141.6	5.50	14.70	1.22	11		23
IRB-021	223911.715	61782.670	D	W	U	G	65	12/06/01	240.5	5.50	14.40	3.74	7		21
IRB-022	225982.831	63907.793	D	F	U	G	75	12/06/01	250.6	5.10	14.60	5.35	2		18
IRB-023	220417.440	55720.149	M	A	U	P	12	12/13/01	255.6	5.20	16.80	0.54	6		18
IRB-024	222334.782	60686.069	M	U	U	F	13	12/13/01	1067.0	5.80	17.60	6.14	27		296
IRB-025	226157.986	60915.852	M	U	U	F	12	12/13/01	300.3	6.30	17.10	4.85	60		12
IRB-026	224813.932	63801.921	M	U	U	F	12	12/13/01	334.3	5.20	17.80	6.11	6		36
IRB-027	226232.030	64228.063	D	W	U	F	75	12/19/01	149.5	5.40	13.70	3.27	5		18
IRB-028	212015.307	62434.168	D	U	U	F	40	12/19/01	61.0	5.50	15.50	0.20	9		8
IRB-029	211337.170	69840.514	D	U	U	F	75	12/19/01	196.4	5.70	14.00	8.34	6		13
IRB-030	208318.984	73597.518	D	F	F	G	72	12/19/01	51.1	5.80	13.50	6.12	13		5
IRB-031	216326.534	55988.232	M	F	F	P	11	01/02/02	118.9	4.30	16.50	4.81	1	U	10
IRB-032	220514.408	60925.387	M	A	A	P	20	01/02/02	182.8	4.90	15.00	1.40	3		22
IRB-033	217582.331	63279.426	M	A	A	G	17	01/02/02	202.0	4.50	15.50	5.88	1	U	35
IRB-034	209608.862	59860.288	M	U	U	F	12	01/02/02	110.2	4.50	15.20	5.51	1	U	6
IRB-035	208647.115	66547.058	M	U	A	F	16	01/03/02	733.0	4.60	16.80	3.64	3		240
IRB-036	203514.943	62371.933	M	A	A	F	12	01/03/02	355.8	4.70	14.70	5.81	1	U	21
IRB-037	209436.057	71410.684	M	F	F	P	16	01/09/02	105.7	4.90	14.70	6.14	2		18
IRB-038	217353.307	59516.021	D	U	U	F	60	01/17/02	178.4	5.20	14.40	4.68	4		23
IRB-039	216296.614	57066.055	D	U	U	P	75	01/17/02	159.7	5.60	13.90	0.14	23		20
IRB-040	214586.527	53772.095	D	A	A	F	71	01/17/02	237.8	5.10	14.40	0.11	3		24
IRB-041	217446.457	67729.956	D	B	U	G	58	01/17/02	192.2	5.60	13.60	5.06	14		19
IRB-042	218919.515	68671.903	D	U	U	F	75	01/17/02	105.5	5.20	13.70	8.07	3		14
IRB-043	227473.000	62457.400	D	U	U	G	73	02/11/02	119.000	5.26	13.20	8.37	10		14
IRB-044	217411.556	64244.957	D	A	A	E	55	02/11/02	276.000	5.82	14.72	6.69	4		20
IRB-045	217304.091	63675.376	D	U	U	E	52	02/11/02	73.000	5.32	13.68	8.01	8		12

Ammonia as nitrogen, dissolved (mg/L)		Nitrate as nitrogen, dissolved (mg/L)		Phosphorus, dissolved (mg/L)		Silica as SiO_2, dissolved (mg/L)		Sulfate, dissolved (mg/L)		Calcium, dissolved (µg/L)		Iron, dissolved (µg/L)		Magnesium, dissolved (µg/L)		Potassium, dissolved (µg/L)		Sodium, dissolved (µg/L)		Total Dissolved Solids (mg/L)	
0.056		14		0.100	U	12.3		11.2		14100		52.3	J	4590	J	5000	U	12200		99.50	C
0.117		24		0.012	J	16.6		10	U	22000		16.2	J	8900		2290	J	13300		114.24	C
0.152		8.44		0.100	U	8.3		10	U	7640		100	U	2930	J	1620	J	4160	J	49.24	C
0.096		8.99		0.100	U	10.6		10	U	5240		9.7	J	6690		1830	J	4250	J	52.71	C
0.043		14.2		0.100	U	9.7		10	U	9280		18.7	J	8010		1730	J	5850		69.83	C
0.11		3.43		0.100	U	14		10	U	2980	J	100	U	864	J	5000	U	12500		73.88	C
0.115		12.9		0.100	U	16.8		10	U	5600		26.7	J	3340	J	835	J	17400		84.02	C
0.054		19		0.005	J	18.4		10	U	14500		119		7940		1170	J	9300		118.49	C
0.04		7.28		0.100	U	16.4		10	U	6530		20	J	4830	J	1240	J	7150		61.49	C
0.039		8.17		0.100	U	16.5		10	U	10400		9.5	J	3840	J	615	J	6040		62.61	C
0.021		6.42		0.100	U	15.5		10	U	3110	J	41.4	J	2220	J	1980	J	9160		52.45	C
0.139		10.7		0.005	J	23.6		10	U	12100		33.3	J	2940	J	852	J	9110		85.48	C
0.03		13		0.007	J	23.8		10	U	10300		31.7	J	2680	J	1010	J	11600		83.46	C
0.036		9.68		0.007	J	20.1		10	U	11800		16.5	J	2500	J	1200	J	7310		76.65	C
0.008	J	3.52		0.010	J	9.7		15.7		963	J	373		1960	J	1140	J	9200		54.57	C
0.007	J	6.62		0.016	J	18		26.2		5230		100	U	5830		2080	J	11900		99.88	C
0.063		0.135		0.008	J	18.9		37.7		7160		5260		5150		3510	J	21700		159.59	C
0.004	J	23.9		0.100	U	15.7		18.3		12300		31.6	J	14900		5000	U	9290		117.43	C
0.002	J	1.14		0.008	J	22.1		---	NA	2170	J	61.9	J	993	J	884	J	8560		46.92	C
0.002	J	3.99		0.012	J	22		10	U	4910	J	18.3	J	2150	J	906	J	13600		81.59	C
0.005	J	16.3		0.006	J	9.4		11.7		12700		72	J	3210	J	5000	U	18400		99.79	C
0.004	J	16.8		0.010	J	6.4		23.6		8280		13.2	J	11400		2640	J	10400		99.55	C
0.288		0.055	U	0.100	U	18.6		135		9670		12300		4760	J	1730	J	14600		220.95	C
0.003	J	3.02		0.018	J	3.3	J	21.7		37400		66	J	18900		6810		123000		537.22	C
0.012	J	9.94		0.019	J	1.6	J	32.7		23800		100	U	5690		3870	J	11300		160.93	C
0.052		12.3		0.023	J	1.8	J	47.8		21200		35.6	J	5290		12000		12700		155.20	C
0.038		6.54		0.024	J	7.3		10	U,N	3850	J	100	U	3910	J	2000	J	11400		58.06	C
0.002	J	0.434		0.019	J	9.6		10	U,N	638	J	25.2	J	531	J	1060	J	6290		35.60	C
0.003	J	15.9		0.023	J	11.2		10	U,N	11800		100	U	2640	J	2700	J	10200		73.47	C
0.020	U	0.453		0.022	J	27.4		11.7	N	1060	J	22.1	J	260	J	1270	J	5490		65.68	C
0.002	J	0.512		0.028	J	22.4		26.7		0	U	622		1030	J	2590	J	6700		70.58	C
0.029		0.055	U	0.034	J	32.6		38.2		0	U	6350		2990	J	5000	U	13800		119.00	C
0.007	J	4.31		0.036	J	27.7		13.1		0	U	46.9	J	8450		1230	J	13700		103.58	C
0.012	J	4.05		0.022	J	23.9		12.2		2640	J	72.7	J	1510	J	5000	U	3870	J	54.28	C
0.006	J	11		0.067	J	25.7		13.3		17700		100	U	10700		7930		70300		399.70	C
0.005	J	25		0.022	J	26.4		31.9		14000		100	U	11300		7030		12200		148.86	C
0.002	J	2.54		0.028	J	24.6		10	U	0	U	100	U	1610	J	1780	J	8170		58.73	C
0.002	J	9.75		0.100	U	17.2		10	U	8620		45.9	J	4710	J	1850	J	8220		77.40	C
0.019	J	0.033	J	0.046	J	24.6		23.2		484	J	100	U	695	J	5000	U	30000		122.08	C
0.340		0.598		0.100	U	25.8		69.1		10100		14100		6230		1890	J	8470		163.63	C
0.003	J	6.79		0.100	U	17.5		20.4		8440		101		4140	J	5000	U	12500		102.87	C
0.003	J	6.14		0.100	U	8.9		10	U	4600	J	99.6	J	2590	J	2130	J	3960	J	45.42	C
0.002	J	5.46		0.005	J	24.9		10	U	2710	J	100	U	1260	J	5000	U	14200		72.54	C
0.011	J	22		0.004	J	17.2		10	U	15400		62.1	J	10000		5000	U	8770		97.45	C
0.020	U	0.123		0.005	J	14.9		10	U	1340	J	100	U	1000	J	5000	U	8140		45.51	C

Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03. (cont.)

Well ID	Easting (m)	Northing (m)	Well Type	Land Use 1997	Land Use 2002	Recharge Potential	Midpoint of screen interval (ft bgs)	Sample Date	Spec. Cond. µS/cm)	pH	Temp. (°C)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)
IRB-046	215416.015	61767.786	D	U	U	E	66	02/11/02	218.000	5.00	14.17	5.14	6	20
IRB-047	215292.864	61627.421	D	U	U	E	52.5	02/11/02	183.000	4.82	14.71	5.54	3	21
IRB-048	202369.652	70155.186	D	A	U	G	58.5	02/13/02	41.000	5.52	13.76	0.90	10	5
IRB-049	203781.803	68480.456	D	F	A	P	37	02/13/02	147.000	4.82	14.30	5.11	3	13
IRB-050	211078.729	66126.878	D	U	U	F	60	02/13/02	231.000	5.34	14.24	6.49	5	18
IRB-051	216637.587	67718.026	D	U	U	G	53	02/13/02	124.000	5.55	13.72	6.57	8	14
IRB-052	215414.839	67961.415	D	U	U	E	64	02/13/02	176.000	5.38	13.58	5.00	5	13
IRB-053	204356.784	71847.875	D	F	U	F	63	02/13/02	91.000	5.16	13.25	0.50	10	10
IRB-054	208388.462	74759.734	D	U	U	P	45	02/20/02	67.000	4.59	13.14	7.86	8	4
IRB-055	213938.078	72208.591	D	U	U	G	75	02/20/02	60.000	5.23	12.53	5.52	12	7
IRB-056	221102.782	62331.685	D	U	U	E	45	02/20/02	216.000	5.22	14.26	6.72	5	16
IRB-057	221808.714	62460.964	D	F	U	E	78	02/20/02	85.000	5.22	12.76	0.47	14	9
IRB-058	224652.524	63691.765	D	U	U	F	75	02/20/02	92.000	4.93	13.25	0.29	8	18
IRB-059	227129.883	60042.798	D	U	U	E	65	04/02/02	128.000	3.51	14.95	6.85	4	7
IRB-060	223287.092	60450.822	D	U	U	P	75	04/02/02	242.000	4.40	14.42	5.48	8	18
IRB-061	223220.996	61916.683	D	U	U	E	47	04/02/02	119.000	4.26	15.13	2.04	4	10
IRB-062	221791.372	62789.770	D	U	U	E	75	04/02/02	105.000	5.13	13.87	0.13	21	10
IRB-063	215989.787	62241.808	D	A	A	E	55	04/02/02	561.000	4.01	14.64	6.16	1 U	142
IRB-064	229050.018	63056.435	D	U	U	G	76	04/04/02	448.000	4.91	15.12	2.42	6	31
IRB-065	207607.369	65100.297	D	U	U	F	63	04/04/02	136.000	5.30	14.65	6.18	7	12
IRB-066	207244.820	65116.275	D	F	U	F	75	04/04/02	72.000	5.10	14.55	4.28	11	8
IRB-067	206116.965	68858.490	D	A	A	G	67	04/04/02	119.000	4.82	13.42	3.65	9	12
IRB-068	203119.348	70896.298	P	U	U	F	55	04/04/02	155.000	4.90	14.54	4.79	9	18
IRB-069	229489.344	62341.417	D	U	U	G	74.5	04/22/02	89.000	5.76	15.28	1.30	14	14
IRB-070	228905.733	62731.394	D	U	U	F	64	04/22/02	205.000	5.36	14.77	2.70	10	24
IRB-071	222881.000	64709.700	A	W	W	P	63	04/22/02	94.000	5.23	15.29	3.41	6	18
IRB-072	220229.841	69828.041	D	U	U	E	76	04/22/02	87.000	5.19	14.40	2.50	12	11
IRB-073	212685.000	71242.000	D	F	U	G	58	04/22/02	43.000	5.38	14.03	4.95	9	7
IRB-074	229216.700	63883.254	A	A	A	G	50	05/08/02	164.000	5.00	15.96	2.69	4	19
IRB-075	223792.614	64571.297	A	U	U	P	55	05/08/02	80.000	4.63	15.18	2.75	4	8
IRB-076	204172.885	71938.203	D	A	U	F	53	05/08/02	125.000	4.86	14.41	1.20	6	17
IRB-077	226041.351	63965.534	D	U	U	G	75	05/09/02	183.000	4.74	14.65	1.48	5	18
IRB-078	223245.157	61867.100	D	U	U	E	45	05/09/02	1251.000	5.30	14.89	2.90	10	367
IRB-079	218895.967	62309.287	A	U	U	G	38	05/09/02	170.000	5.80	15.06	2.04	42	17
IRB-080	216402.799	62933.727	D	F	A	E	56	05/09/02	93.000	5.14	13.98	3.57	7	10
IRB-081	207723.449	71294.757	D	A	U	F	53	05/09/02	161.000	5.37	14.72	3.99	11	15
IRB-082	223726.143	64262.539	A	U	U	F	55	06/18/02	160.000	4.38	15.30	2.32	10.1	17
IRB-083	220148.870	61939.022	D	B	U	G	75	06/18/02	247.000	5.00	15.31	3.51	8.6	21
IRB-084	209782.596	65349.074	A	U	U	G	70	06/18/02	233.000	5.10	14.90	3.39	18.3	18
IRB-085	214069.684	64355.290	D	U	U	E	55	06/18/02	221.000	4.83	15.25	2.61	6	16
IRB-086	216406.545	61414.427	D	F	F	G	60	06/18/02	177.000	4.98	15.89	1.73	7.7	17
IRB-087	210009.846	75474.878	D	F	A	G	60	06/19/02	41.000	4.97	14.48	2.23	23.2	7
IRB-088	219004.431	66632.856	D	U	U	P	54	06/19/02	204.000	5.30	15.30	4.25	9.7	16
IRB-089	205468.982	60761.357	D	A	A	G	60	06/19/02	127.000	5.43	16.34	0.19	24.9	12
IRB-090	211888.822	68229.303	D	A	U	G	55	06/19/02	162.000	4.62	15.52	3.57	2.7	12

Ammonia as nitrogen, dissolved (mg/L)		Nitrate as nitrogen, dissolved (mg/L)		Phosphorus, dissolved (mg/L)		Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)		Calcium, dissolved (µg/L)		Iron, dissolved (µg/L)		Magnesium, dissolved (µg/L)		Potassium, dissolved (µg/L)		Sodium, dissolved (µg/L)		Total Dissolved Solids (mg/L)	
0.002	J	16.4		0.018	J	5.9	10	U	11400		100	U	5230		5000	U	11400		76.35	C
0.020	U	4.98		0.016	J	5.9	25.7		3800	J	100	U	5930		5000	U	13500		83.83	C
0.036		0.055	U	0.100	U	9.6	10	U	0	U	668		165	J	5000	U	3960	J	29.43	C
0.004	J	6.8		0.011	J	7.1	12.2		3010	J	100	U	5500		5000	U	3660	J	54.29	C
0.003	J	17.7		0.019	J	18.6	10	U	12800		100	U	4870	J	5000	U	7540		84.53	C
0.544		4.77		0.029	J	21.6	10	U	3150	J	100	U	3080	J	5000	U	7020		62.19	C
0.114		7.84		0.100	U	15.3	24		10400		25	J	5950		5000	U	3490	J	85.12	C
0.003	J	3.75		0.005	J	18.3	10	U	2210	J	100	U	1260	J	5000	U	7000		52.53	C
0.005	J	1.08		0.022	J	18.1	10	U	568	J	65.5	J	1050	J	4560	J	5830		43.28	C
0.005	J	0.418		0.013	J	17.5	10	U	1180	J	100	U	592	J	5000	U	6750		45.46	C
0.004	J	16.4		0.017	J	19.6	10	U	11000		100	U	5660		5000	U	9630		83.31	C
0.005	J	1.04		0.056	J	22.1	10	U	2000	J	100	U	1040	J	5000	U	10000		59.24	C
0.003	J	0.78		0.023	J	12.3	10	U	941	J	100	U	1300	J	5000	U	11300		52.65	C
0.013	J	5.45		0.016	J	15.8	25.1		6120		61.9	J	4290	J	5000	U	6580		74.43	C
0.017	J	19.7		0.034	J	16.5	10	U	11200		42.5	J	5380		1550	J	18600		99.02	C
0.011	J	6.69		0.018	J	21.3	10	U	4820	J	267		1270	J	5000	U	11200		59.58	C
0.138		0.055	U	0.063	J	22.6	18.7		5230		6000		713	J	1600	J	9060		95.10	C
0.018	J	11		0.016	J	8.8	10	U	5620		18.5	J	21900		5660		48500		243.53	C
0.006	J	43		0.016	J	12.2	13.4		19000		25.7	J	25300		5000	U	21500		171.45	C
0.006	J	10.8		0.016	J	14.8	10	U	10800		16.4	J	2260	J	1890	J	9730		69.32	C
0.005	J	2.76		0.043	J	24	10	U	4860	J	16.2	J	870	J	5000	U	7980		59.53	C
0.004	J	7.62		0.032	J	16.1	10	U	9400		100	U	3090	J	5000	U	7400		64.65	C
0.007	J	8.42		0.019	J	17.7	10	U	9410		17.5	J	3310	J	2120	J	9760		77.76	C
0.04		0.055	U	0.068	J	29	10	U	3970	J	2670		978	J	5000	U	4490	J	69.22	C
0.006	J	13.7		0.017	J	17	10	U	10700		100	U	3990	J	5000	U	18300		97.71	C
0.006	J	2.65		0.013	J	15	10	U	5390		15.4	J	1010	J	5000	U	10900		58.98	C
0.006	J	1.84		0.024	J	21	10	U	5030		100	U	1160	J	5000	U	9640		61.70	C
0.006	J	0.051	J	0.100	U	14	10	U	4030	J	21.1	J	469	J	5000	U	4770	J	39.35	C
0.020	U	8.85		0.041	J	11	3.2	O	2990		100	U	5110		2490		13900		70.58	C
0.002	J	2.63		0.037	J	11	8.2	O	1450		100	U	3680		1660		4970		45.63	C
0.006	J	7.28		0.049	J	19	1.8	O	8830		100	U	2600		1650		5640		69.86	C
0.020	U	9.98		0.026	J	12	14.7	O	6620		100	U	7450		2460		12000		88.24	C
0.020	U	5.1		0.028	J	19	11	O	20000		100	U	4510		4980		256000		697.62	C
0.212		2.05		0.095	J	23	7.2	O	12300		2640		3750		3880		9030		123.16	C
0.020	U	4.07		0.027	J	12	4.4	O	2810		100	U	1380		1460		9670		52.82	C
0.020	U	10.8		0.014	J	19	3.2	O	14200		100	U	3310		1410		6290		84.22	C
0.006	J	10.9		0.026	J	11.9	0.86	J, O	3130		72.3	J	5080		3460		12500		75.03	C
0.023		19.7		0.029	J	21.5	2.4	O	13600		100	U	6980		2810		14600		111.24	C
0.007	J	16.7		0.025	J	20.3	3.8	O	14800		100	U	5870		2860		11800		112.46	C
0.009	J	19.3		0.021	J	18.6	0.59	J, O	12500		100	U	6080		4120		9610		92.83	C
0.007	J	11.5		0.032	J	19.5	4.7	O	10600		100	U	1640		3550		14600		90.83	C
0.007	J	0.03	J	0.115		17.2	0.71	J, O	928	J	100	U	331	J	1230		5390		56.14	C
0.006	J	9.25		0.050	J	18.6	24.7	O	15200		100	U	3810		2220		9480		109.02	C
0.094		0.055	U	0.057	J	47.3	21.0	O	1870		14800		647	J	1220		7820		131.71	C
0.007	J	12.2		0.069	J	15	4.9	O	6940		25.3	J	6740		2890		6110		69.58	C

Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03. (cont.).

Well ID	Easting (m)	Northing (m)	Well Type	Land Use 1997	Land Use 2002	Recharge Potential	Midpoint of screen interval (ft bgs)	Sample Date	Spec. Cond. (µS/cm)	pH	Temp. (ºC)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)
IRB-091	229210.595	63678.181	D	U	U	G	72	06/25/02	138.000	4.57	16.14	2.03	3	16
IRB-092	228817.864	62570.220	D	U	U	F	41	06/25/02	140.000	5.52	17.18	0.91	11.7	21
IRB-093	228662.528	60936.035	D	U	U	E	55	06/25/02	104.000	5.11	16.13	3.94	4.7	13
IRB-094	226880.000	61931.200	D	U	U	F	75	06/25/02	154.000	4.88	16.08	0.17	7.1	30
IRB-095	223159.547	61423.397	D	U	U	E	70	06/25/02	159.000	5.57	14.91	2.79	10.3	14
IRB-096	203413.724	70182.941	D	U	U	F	60	06/26/02	243.000	4.45	15.60	1.69	2.8	22
IRB-097	208397.536	67963.219	D	F	U	F	55	06/26/02	84.000	4.87	15.49	2.55	4.9	11
IRB-098	213371.485	63444.650	D	U	U	F	45	06/26/02	415.000	4.52	15.19	1.39	1 U	86
IRB-099	229392.050	63757.126	D	U	U	E	59	07/03/02	217.000	5.09	17.96	2.68	3.3	42
IRB-100	210681.904	65609.096	P	U	U	P	78	07/03/02	166.000	5.61	15.79	1.91	8	13
IRB-101	209430.628	61354.516	A	A	U	F	39	07/03/02	115.000	4.79	15.35	1.72	2.8	14
IRB-102	221725.580	62700.382	D	F	U	E	75	07/10/02	102	5.14	14.39	0.83	11.8	14
IRB-103	215156.892	60648.319	D	U	U	F	65	07/10/02	189	6.26	15.02	0.09	64	12
IRB-104	203218.775	68176.771	D	F	A	G	57	07/10/02	160	4.87	15.17	1.20	3.2	11
IRB-105	218278.507	68519.108	D	U	U	G	50	07/10/02	97	5.32	15.88	0.98	13.2	12
IRB-106	220406.295	66627.570	P	U	U	G	85	07/18/02	63	5.31	14.60	1.66	3.9	7
IRB-107	218631.971	67717.385	P	U	U	F	70	07/18/02	126	5.57	14.39	1.80	9.2	11
IRB-108	223822.927	64084.373	P	U	U	E	90	07/18/02	108	5.48	14.50	1.52	7.2	13
IRB-109	219363.082	67967.546	P	U	U	P	102	07/18/02	75	5.34	14.39	1.23	8.9	8
IRB-110	212675.035	72717.788	P	U	U	G	68	07/24/02	139	4.98	14.33	2.06	7.8	20
IRB-111	219283.108	70192.945	P	U	U	G	82	07/24/02	63	5.32	14.11	1.38	12.6	34
IRB-112	218731.162	69441.932	D	F	F	F	45	07/24/02	78	5.13	14.73	0.33	10.4	10
IRB-113	203193.974	73637.249	P	U	U	E	89	07/24/02	68	5.76	13.95	1.00	13.1	4
IRB-114	205563.017	70057.554	D	A	A	F	35	07/31/02	160	4.85	16.44	1.38	2.1	9
IRB-115	207214.903	66475.278	D	U	U	F	70	07/31/02	201	5.50	14.97	1.40	8	15
IRB-116	207349.529	64150.960	D	A	U	G	60	07/31/02	219	5.21	16.79	1.53	4.8	20
IRB-117	218937.637	63362.135	D	U	U	G	62	07/31/02	119	5.42	15.78	1.23	8	17
IRB-118	221183.387	55765.511	D	U	U	P	65	07/31/02	299	7.18	16.03	0.09	129	12
IRB-119	223356.092	64856.799	A	U	U	P	75	08/01/02	116	5.01	14.80	1.06	6.3	12
IRB-120	216634.508	67677.806	D	A	U	G	60	08/01/02	123	5.35	15.54	1.22	9.9	7
IRB-121	221286.531	69442.352	P	U	U	P	64	08/06/02	97	5.72	15.15	1.31	8.1	13
IRB-122	222455.610	69700.230	P	F	F	F	60	08/06/02	127	5.24	14.06	1.30	13.7	20
IRB-123	222810.792	69270.438	P	U	U	P	77	08/06/02	101	5.44	14.77	1.51	5.3	15
IRB-124	223040.130	68158.977	P	U	U	F	53	08/06/02	68	6.12	14.61	1.44	7.3	10
IRB-125	223334.808	68894.695	P	U	U	F	80	08/06/02	108	5.24	14.70	1.37	7.8	14
IRB-126	208517.971	72564.832	D	U	U	G	62	08/07/02	87	5.52	14.71	1.24	9	7
IRB-127	223715.481	64957.377	A	U	U	P	75	08/07/02	277	5.31	15.06	0.91	15.3	22
IRB-128	226113.198	64120.306	D	F	U	F	75	08/07/02	163	5.19	14.56	1.13	5.8	14
IRB-129	216004.742	55697.762	P	A	U	P	75	11/18/02	51	4.70	14.51	0.10	14.2	7
IRB-130	222644.597	61262.691	D	U	U	G	55	11/18/02	95	5.20	14.10	3.37	17.1	58
IRB-131	223441.019	64497.267	A	U	U	P	75	11/18/02	100	4.56	14.39	6.38	3.5	20
IRB-132	228832.002	61437.290	D	U	U	E	87	11/18/02	106	4.82	14.37	6.36	3.6	15
IRB-133	212607.053	71153.212	D	U	U	G	55	11/20/02	43	4.95	13.82	7.04	10.3	6
IRB-134	213880.947	64405.734	D	U	U	E	65	11/20/02	253	4.36	14.16	5.91	1.8	19
IRB-135	214115.674	64237.074	D	U	U	E	61	11/20/02	107	4.34	15.51	5.12	4.1	18

Ammonia as nitrogen, dissolved (mg/L)		Nitrate as nitrogen, dissolved (mg/L)		Phosphorus, dissolved (mg/L)		Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)		Calcium, dissolved (µg/L)		Iron, dissolved (µg/L)		Magnesium, dissolved (µg/L)		Potassium, dissolved (µg/L)		Sodium, dissolved (µg/L)	Total Dissolved Solids (mg/L)	
0.020	U	3.17		0.100	U	13.1	24.7	O	2150		19.4	J	7360		3890		7130	80.52	C
0.028		5.22		0.068	J	43	0.57	J, O	1570		1140		682	J	5880		18500	109.36	C
0.020	U	3.12		0.100	U	13.4	15.2	O	2680		32.2	J	4460		5150		4940	66.68	C
0.020	U	4.62		0.100	U	14.9	6.0	O	2790		34.8	J	3370		3180		17000	88.99	C
0.020	U	12.4		0.100	U	23.1	4.8	O	9730		100	U	2730		4300		11100	92.46	C
0.023		18.8		0.012	J,V	13.8	0.52	J, O	13300		100	U	3070		7010		17000	98.34	C
0.009	J	4.09		0.100	U,V	18.9	0.50	J, O	3620		26.5	J	2170		2120		6270	53.61	C
0.023		7.62		0.100	U,V	12.9	20.8	O	13000		33	J	6750		10600		47100	204.83	C
0.006	J	7.44		0.012	J	14	5.2	O	4650		36.8	J	5440		5490		19900	107.47	C
0.093		8.18		0.015	J	19.4	17.1	O	8710		16.6	J	4260		5150		9900	93.82	C
0.008	J	3.22		0.008	J	13	14.2	O	4270		40.4	J	3760		2730		6060	64.10	C
0.006	J	2.88		0.022	J	29.2	1.7	O	3190		100	U	827	J	1340		12400	77.37	C
0.098		0.01	U	0.053	J	60	6.9	O	5390		7130		1240		1560		26800	185.17	C
0.007	J	13.7		0.013	J	10.2	0.48	J, O	9080		100	U	3340		4880		7780	63.68	C
0.020	U	0.422		0.017	J	14.6	9.0	O	3870		30	J	1550		1160		9950	65.80	C
0.020	U	2.08		0.006	J	6.5	3.3	O	2440		254		860	J	1470		6720	34.53	C
0.020	U	4.94		0.100	U	8.4	10.0	O	7600		20.6	J	2470		1320		10000	64.95	C
0.020	U	4.79		0.019	J	5.8	1.4	O	3420		30.7	J	2010		2510		9970	50.15	C
0.020	U	2.31		0.011	J	6.1	1.4	O	3090		209		710	J	1490		7570	39.79	C
0.020	U	8.04		0.100	U	18	0.66	J, O	5230		17.7	J	2210		2380		13400	77.74	C
0.020	U	0.323		0.010	J	23.3	2.0	O	2120		42.7	J	670	J	943	J	7890	83.90	C
0.01	J	0.039		0.008	J	15.7	8.6	O	2130		100	U	1270		1250		8030	57.44	C
0.05		0.01	U	0.051	J	39	1.7	O	958	J	5910		293	J	979	J	7170	73.21	C
0.020	U	5.74		0.008	J	12.2	25.2	O	8320		33.1	J	7120		3200		3640	76.56	C
0.020	U	15		0.011	J	17.7	3.0	O	15000		100	U	3790		2810		10000	90.31	C
0.020	U	16.7		0.048	J	17.1	2.7	O	9700		45.8	J	9500		4610		8180	93.38	C
0.020	U	3.61		0.066	J	21.2	1.4	O	4460		100	U	1210		1890		13500	72.34	C
0.012	J	0.01	U	0.380		49.9	8.1	O	0	U	13	J	1000	U	1890		74600	275.90	C
0.020	U	3.67		0.100	U	11.7	3.3	O	2020		100	U	3100		2870		11300	56.26	C
0.006	J	4.07		0.009	J	8.8	12.0	O	6600		100	U	3000		1560		7630	60.58	C
0.020	U	4.02		0.025	J	8.7	1.9	O	3380		55.6	J	1380		1620		10900	53.08	C
0.020	U	1.39		0.061	J	6.2	7.3	O	2430		28.2	J	3170		2430		14600	71.31	C
0.020	U	2.35		0.025	J	6.1	6.4	O	2470		100	U	2910		2760		8660	51.98	C
0.020	U	1.69		0.017	J	19.9	1.9	O	1660		56	J	690	J	1300		8960	53.47	C
0.020	U	4.35		0.100	U	18.8	5.6	O	4060		100	U	3060		1880		9290	68.84	C
0.020	U	4.08		0.100	U	24.4	2	O	4920		100	U	928	J	1680		8250	62.26	C
0.020	U	15.6		0.100	U	16.9	8.6	O	12500		100	U	10000		4700		17000	122.60	C
0.020	U	7.99		0.013	J	17.6	7.6	O	6090		100	U	4750		2850		13100	79.79	C
0.143		0.149		0.058		21.2	1	O	2030		2430		474	J	903	J	5560	55.15	C
0.014	J	1.1		0.035		16.9	3	O	4600		100	U	1550		1500		10900	114.70	C
0.012	J	4.79		0.018	J	7.3	1.5	O	2350		100	U	2070		2720		13600	57.86	C
0.011	J	5.52		0.020	U	7.5	1.9	O	2490		100	U	2930		1330		11700	51.98	C
0.017	J	0.136		0.020	U	8.8	0.64	J, O	1670		100	U	441	J	1170		5060	34.23	C
0.02		22.2		0.016	Q	8.8	0.5	J, O	16500		100	U	7550		5180		13000	94.57	C
0.016	J	4.85		0.006	J	8.4	2.2	O	1730		100	U	2420		3150		12100	56.97	C

Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03. (cont.)

Well ID	Easting (m)	Northing (m)	Well Type	Land Use 1997	Land Use 2002	Recharge Potential	Midpoint of screen interval (ft bgs)	Sample Date	Spec. Cond. (µS/cm)	pH	Temp. (ºC)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)
IRB-136	209396.756	66058.470	D	U	W	F	61.5	11/20/02	315	4.86	14.34	6.38	8.6	25
IRB-137	204806.119	69114.350	D	U	U	G	42	11/20/02	180	5.10	14.44	6.41	10.3	14
IRB-138	204660.325	71322.267	D	U	U	G	55	11/20/02	140	4.48	13.96	5.92	5.7	10
IRB-139	202288.004	65358.902	D	W	U	G	80	12/02/02	65	5.04	13.58	1.74	21.2	5
IRB-140	202345.548	62529.395	D	F	U	F	63	12/02/02	108	4.39	13.89	5.24	3.3	12
IRB-141	206671.492	63202.533	D	U	U	G	70	12/02/02	44	4.86	14.11	3.40	11.8	4
IRB-142	207604.758	63349.517	D	U	U	G	60	12/02/02	147	4.38	12.31	3.61	4.9	11
IRB-143	206166.915	63944.709	D	U	U	F	65	12/02/02	211	4.63	13.79	5.81	3.6	15
IRB-144	206156.240	63953.775	D	U	U	F	75	12/02/02	204	4.84	14.24	5.99	4	15
IRB-145	207475.062	64304.058	D	A	U	G	70	12/02/02	92	4.58	13.72	4.69	7.3	10
IRB-146	208590.160	62410.405	D	F	U	G	57	12/02/02	204	4.80	12.41	4.46	7.1	13
IRB-147	214857.732	58255.768	D	U	U	P	64	12/12/02	124	5.62	14.99	0.17	20.9	10
IRB-148	215726.336	55855.994	P	W	U	P	75	12/12/02	160	4.90	14.64	0.21	6.6	13
IRB-149	214330.103	60531.144	D	U	U	G	58	12/12/02	129	4.75	14.76	0.71	10.1	21
IRB-150	208407.770	77076.484	D	U	U	G	62	12/12/02	83	4.89	13.65	3.06	9.7	9
IRB-151	208359.731	77437.016	D	A	A	G	74	12/12/02	64	4.65	14.43	1.50	11.9	8
IRB-152	229712.304	64885.516	D	U	U	E	26	01/07/03	205	5.12	17.53	4.25	5	37
IRB-153	229580.929	64646.085	D	U	U	E	31	01/07/03	228	4.13	15.63	3.08	1 U	38
IRB-154	229504.627	63595.745	D	U	U	G	97	01/07/03	232	5.11	14.82	3.82	3.2	20
IRB-155	229176.720	63440.742	D	U	U	E	85	01/07/03	172	4.89	13.79	3.79	2.9	19
IRB-156	228949.926	63415.701	D	U	U	G	58	01/07/03	159	4.54	14.39	3.95	1.8	15
IRB-157	222255.563	62164.711	D	U	U	E	60	01/08/03	239	4.68	13.87	0.97	8.8	32
IRB-158	225902.397	63877.162	D	U	U	G	75	01/08/03	156	4.71	14.20	2.91	3.4	16
IRB-159	228306.631	60065.615	D	U	U	G	57	01/08/03	323	5.37	15.52	2.25	11.1	48
IRB-160	220504.027	68285.485	D	U	U	F	60	01/14/03	144	5.46	8.76	7.53	12.2	39
IRB-161	219683.398	66940.364	D	A	U	P	65	01/14/03	145	5.00	11.82	4.32	7.3	9
IRB-162	219698.870	67007.724	D	U	U	P	65	01/14/03	172	5.03	13.88	2.94	10.6	12
IRB-163	219832.888	66625.398	D	A	A	P	65	01/14/03	179	5.42	14.04	4.58	3.9	8
IRB-164	220012.679	66189.498	D	U	U	G	50	01/14/03	119	5.26	14.60	3.28	5.7	10
IRB-165	218065.557	66203.586	D	U	U	P	65	01/14/03	187	5.44	14.22	3.25	10.4	14
IRB-166	200328.777	67813.551	D	U	U	F	70	03/17/03	64	6.71	13.57	2.55	21.3	5
IRB-167	209290.869	65325.823	D	U	U	F	45	03/17/03	313	5.42	13.67	4.09	9.6	24
IRB-168	205815.196	62057.895	D	F	F	G	48	03/17/03	50	5.27	12.99	0.22	9	6
IRB-169	217006.099	67144.878	D	A	U	G	45	03/17/03	126	4.82	14.70	2.49	3.9	13
IRB-170	209718.286	59156.659	D	A	A	F	47	03/19/03	93	4.81	14.64	0.20	19.5	12
IRB-171	222890.481	61633.458	D	U	U	E	50	03/19/03	116	4.78	13.29	2.96	8.7	12
IRB-172	226815.645	60231.001	D	U	U	G	55	03/19/03	106	4.22	14.38	0.11	8.3	20
IRB-173	213260.930	73015.330	P	U	U	G	70	03/24/03	142	4.64	13.27	6.09	6.9	16
IRB-174	211592.698	63616.533	P	U	U	G	89	03/24/03	175	5.62	14.65	0.20	69.9	9
IRB-175	209761.188	63260.529	D	F	U	P	35	03/24/03	115	4.17	14.66	2.99	4	10
IRB-176	209665.466	63298.276	D	U	U	P	73	03/24/03	135	4.53	14.05	0.85	4.6	12
IRB-177	206926.941	59566.144	D	A	A	F	75	03/24/03	149	5.19	14.41	0.13	34.7	17
IRB-178	215739.056	57388.645	P	U	U	P	108	03/26/03	213	5.60	15.49	0.40	27.8	33
IRB-179	228185.218	59825.998	D	U	U	G	105	03/26/03	247	4.69	14.59	0.16	5	11
IRB-180	206023.957	61945.967	D	F	U	G	45	04/02/03	60	5.09	15.07	0.14	6.1	14

Ammonia as nitrogen, dissolved (mg/L)		Nitrate as nitrogen, dissolved (mg/L)		Phosphorus, dissolved (mg/L)		Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)		Calcium, dissolved (µg/L)		Iron, dissolved (µg/L)		Magnesium, dissolved (µg/L)		Potassium, dissolved (µg/L)		Sodium, dissolved (µg/L)	Total Dissolved Solids (mg/L)	
0.014	J	25.8		0.015	J	20.5	0.58	J, O	28200		100	U	7520		4290		12800	133.32	C
0.013	J	10.5		0.012	J	17.7	8.6	O	15800		100	U	4050		2720		7810	91.51	C
0.016	J	10.5		0.011	J	8.3	0.44	J, O	6830		100	U	4970		4820		7300	58.89	C
0.01	J	0.379		0.045		30.3	3.6	O	3250		54.3	J	906	J	894	J	8470	74.11	C
0.011	J	6.46		0.020	U	15.4	1.5	O	7480		115		3520		3510		4100	57.40	C
0.015	J	0.556		0.020	U	10.3	1.1	O	1700		100	U	368	J	902	J	6210	36.95	C
0.032		11.7		0.020	U	8.2	0.37	J,O	7980		100	U	2830		3420		12700	63.13	C
0.018	J	17.9		0.023		6.6	0.42	J,O	12900		27.4	J	7060		5840		9020	78.41	C
0.018	J	16.7		0.007	J	7.8	0.37	J,O	15400		100	U	4880		4810		8890	77.88	C
0.02	J	5.21		0.007	J	7.7	0.82	J,O	4010		100	U	1900		1730		8480	47.18	C
0.014	J	17		0.014	J	6.9	0.63	J,O	10000		25.4	J	3200		4340		21300	83.52	C
0.152		0.01	U	0.068		16.1	20	O	3200		9440		1710		983	J	9920	92.47	C
0.231		0.01	U	0.053		24.9	42.4	O	4280		7510		2560		2210		13700	117.44	C
0.121		0.01	U	0.046		26.4	13.8	O	2710		5810		1980		1600		12700	96.27	C
0.015	J	3.23		0.014	J	21.1	0.53	J,O	3010		100	U	701	J	2360		9260	58.92	C
0.017	J	0.098		0.014	J	23.3	1.1	O	1930		100	U	475	J	1420		7390	55.64	C
0.014	J	1.48		0.026		8.9	15	O	9150		13.1	J	4630		3060		12300	96.57	C
0.017	J	5.08		0.065		7.1	20.5	O	3550		56.3	J	4420		2460		24600	105.85	C
0.015	J	16.6		0.056		14.2	10.2	O	8560		40.3	J	7900		2440		13300	96.51	C
0.01	J	11.8		0.009	J	15.7	0.95	J,O	7180		168		4360		2740		10400	75.22	C
0.008	J	10.2		0.014	J	12	5.2	O	1100		100	U	2790		2600		20300	71.01	C
0.011	J	12.1		0.049		23.6	1.5	O	9000		100	U	3790		2660		23400	116.91	C
0.011	J	10.2		0.055		16.3	1.4	O	6610		100	U	3230		3090		12100	72.40	C
0.012	J	7.67		0.024		12.6	18.1	O	12000		32.5	J	9740		8610		19700	147.59	C
0.014	J	0.857		0.042		11.4	1	O	0	U	100	U	1000	U	1000	U	31600	96.11	C
0.021		5.72		0.009	J	18.3	17.8	O	8950		55.1	J	3410		1910		8680	81.16	C
0.05		7.84		0.049		17.1	17.7	O	12100		225		4990		2420		7630	92.70	C
0.01	J	11.1		0.056		19.6	16	O	12100		100	U	3300		1670		8920	84.66	C
0.012	J	7.62		0.020	U	21.7	3.4	O	4750		100	U	1180		1620		12300	68.28	C
0.011	J	8.16		0.020	U	19.6	17.1	O	12500		207		5030		1530		9290	97.83	C
0.011	J	0.794		0.006	J	30.7	0.87	J,O	2970		16.3	J	722	J	1280		7050	70.72	C
0.01	J	19.2		0.008	J	18.2	14.7	O	21400		100	U	10900		3420		7450	128.89	C
0.013	J	0.01	U	0.022	J	9.9	3.9	O	1130		1140		170	J	1330		5950	38.56	C
0.011	J	1.82		0.020	J	6.1	25.4	O	4820		100	U	4050		1750		7040	67.91	C
0.662		0.01	U	0.145		19.3	5.2	O	2940		5660		999	J	963	J	6940	74.31	C
0.017	J	6		0.005	J	9.4	1.5	O	4360		23.8	J	1200		1530		11800	56.54	C
0.017	J	0.055		0.020	U	7.4	4.6	O	1530		129		1480		1220		13200	57.93	C
0.016	J	7.38		0.020	U	8.1	0.65	J,O	5060		100	U	2020		2250		8950	57.33	C
0.436		0.01	U	0.688		240	0.45	J,O	2910		33200		918	J	894	J	7060	365.46	C
0.017	J	4.53		0.040	U	18.1	9.9	O	0	U	100	U	1000	U	1000	U	20300	66.85	C
0.022		9.63		0.040	U	30.8	0.36	J,O	5450		961		2190		2200		10700	78.91	C
0.148		0.059		0.037	J	50.5	8	O	5890		11900		1130		1480		7400	138.24	C
0.195		0.01	U,JL	0.057		32.1	19.5	O	7020		10200		1980		2890		20100	154.84	C
0.019	J	3.01		0.013	J	24.3	74.2	O	12200		15.3	J	7400		8010		12700	157.87	C
0.019	J	0.01	U,JL	0.040	U	11.5	6	O	932	J	393		788	J	992	J	5380	46.10	C

Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03. (cont.)

Well ID	Easting (m)	Northing (m)	Well Type	Land Use 1997	Land Use 2002	Recharge Potential	Midpoint of screen interval (ft bgs)	Sample Date	Spec. Cond. (µS/cm)	pH	Temp. (ºC)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)		Chloride, dissolved (mg/L)
IRB-181	207880.228	63860.859	D	U	U	G	75	04/02/03	148	4.62	14.64	3.41	9.4		17
IRB-182	204248.411	61721.986	P	U	U	F	69	04/02/03	101	4.76	14.77	3.67	5.3		11
IRB-183	202805.539	71792.510	D	U	U	F	95	04/14/03	107	5.12	14.63	0.09	41.4		5
IRB-184	205477.466	75530.031	D	U	U	G	57	04/14/03	217	4.19	14.32	0.02	9		26
IRB-185	205758.080	75204.575	D	U	U	G	64	04/14/03	76	4.57	13.75	0.11	14.1		9
IRB-186	202156.396	72969.590	M	A	A	P	6	04/16/03	1389	5.74	12.53	0.16	147		306
IRB-187	200111.776	67480.976	M	F	F	F	11	04/16/03	628	4.34	11.58	0.19	1.1		159
IRB-188	220209.030	69970.892	M	U	U	E	11	04/16/03	141	5.02	10.89	0.10	12.4		16
IRB-189	207163.094	71570.655	D	U	U	F	73	04/23/03	135	4.89	14.02	0.19	11.4		11
IRB-190	207110.373	72421.299	D	A	U	F	60	04/23/03	318	4.92	14.18	0.17	3		19
IRB-191	211523.048	66432.416	D	U	U	F	61	04/23/03	134	4.89	14.89	3.86	8		17
IRB-192	210461.826	66745.080	D	U	U	P	68	04/23/03	109	5.21	14.74	3.24	10.8		8
IRB-193	226777.954	59851.077	D	U	U	F	68	04/28/03	323	4.92	15.06	0.16	9.6		82
IRB-194	228709.669	61721.553	D	U	U	G	65	06/24/03	235	5.40	15.80	3.11	6.2		18
IRB-195	223137.162	59583.806	D	U	U	P	57	06/24/03	162	4.40	15.93	7.49	1.2		14
IRB-196	222928.646	59535.086	D	A	U	P	55	06/24/03	167	4.17	15.84	3.72	1.1		19
IRB-197	219687.515	61420.556	D	B	U	F	65	06/24/03	270	5.15	15.88	5.01	7.1		20
IRB-198	212458.160	62458.829	C	U	W	G	46	06/25/03	127	5.20	16.18	0.13	41.9		14
IRB-199	212743.838	62965.917	D	U	U	F	55	06/25/03	112	4.83	15.52	4.70	6.1		11
IRB-200	213774.764	63786.515	D	U	U	G	65	06/25/03	133	4.59	16.64	6.65	2.8		25
IRB-201	211576.658	65178.098	D	U	U	F	50	06/25/03	227	4.82	16.20	4.16	5.7		16
IRB-202	214516.172	63762.265	D	F	B	E	60	06/25/03	173	4.19	15.13	7.21	1	U	15
IRB-203	217871.459	58924.928	D	F	F	P	55	07/01/03	150	4.74	16.09	4.08	2.8		21
IRB-204	218687.680	63393.980	D	B	U	F	65	07/01/03	232	5.32	15.81	6.48	7.6		19
IRB-205	203101.639	73882.298	C	U	U	G	85	07/02/03	69	4.89	16.74	0.08	23		7
IRB-206	204727.698	72571.661	D	U	U	F	60	07/02/03	157	4.74	15.85	7.91	3.4		14
IRB-207	205474.709	71672.270	D	U	U	G	57	07/02/03	228	4.54	14.96	7.22	1.3		16
IRB-208	205743.558	71005.531	D	F	F	F	60	07/02/03	92	4.78	15.38	1.54	10.4		7
IRB-209	209011.898	66238.164	D	U	W	F	55	07/02/03	259	4.60	15.44	7.94	3.3		21
IRB-210	209026.177	66465.912	D	U	W	F	60	07/02/03	244	4.90	16.14	6.16	3.2		22
IRB-211	217905.555	59070.457	D	U	U	P	72	07/15/03	208	4.35	15.92	9.04	1	U	20
IRB-212	217652.156	59820.820	D	A	A	G	90	07/15/03	133	4.80	15.81	1.27	5.3		18
IRB-213	216974.020	64132.874	D	A	U	E	71	07/15/03	82	4.89	17.19	5.17	9.6		12
IRB-214	214817.298	67013.341	C	F	F	G	55	07/15/03	342	4.42	14.69	7.44	4.2		27
IRB-215	220187.870	62194.209	D	U	U	G	75	07/16/03	237	5.65	20.02	2.94	7.3		16
IRB-216	219745.630	61889.620	D	A	U	F	52	07/16/03	156	5.21	17.26	6.66	4.2		14
IRB-217	227572.647	60057.046	D	U	U	G	58	07/22/03	119	6.08	15.14	0.06	14.1		19
IRB-218	224994.343	64487.489	A	A	A	F	67	07/22/03	225	5.06	16.29	4.90	4.3		16
IRB-219	219951.675	61693.379	D	A	U	F	73	07/22/03	222	5.37	15.61	2.93	7.4		15
IRB-220	226254.715	65328.736	D	A	U	F	70	07/31/03	260	4.87	16.41	2.94	3.9		39
IRB-221	225962.132	65212.105	D	F	F	F	60	07/31/03	296	4.57	14.31	1.88	7.7		54
IRB-222	219865.948	61869.328	D	A	U	F	65	07/31/03	263	4.82	16.57	6.10	3.9		22
IRB-223	217537.834	58685.309	D	U	U	P	49	07/31/03	320	7.68	15.32	4.80	88.3		20
IRB-224	209567.697	75742.097	D	A	U	G	72	07/31/03	96	5.55	15.45	5.26	8.5		9
IRB-225	221221.570	59343.234	D	W	A	P	75	08/12/03	169	5.11	15.10	2.60	4.9		15

Ammonia as nitrogen, dissolved (mg/L)		Nitrate as nitrogen, dissolved (mg/L)		Phosphorus, dissolved (mg/L)		Silica as SiO_2, dissolved (mg/L)		Sulfate, dissolved (mg/L)		Calcium, dissolved (µg/L)		Iron, dissolved (µg/L)		Magnesium, dissolved (µg/L)		Potassium, dissolved (µg/L)		Sodium, dissolved (µg/L)		Total Dissolved Solids (mg/L)	
0.017	J	5.72		0.040	U	9.8		2.1	O	5920		100	U	2490		2990		10800		66.24	C
0.02		6.41		0.040	U	9.3		1	O	3410		100	U	1680		2110		6670		46.90	C
0.104		0.144		0.087		55.9		0.85	J,O	2370		15100		613	J	829	J	6280		128.68	C
0.01	J	7.21		0.052		22.5		18.8	O	12000		100	U	3590		2680		15500		117.34	C
0.020	U	1.56		0.022	J	20.8		0.7	J,O	3500		100	U	823	J	1110		8050		59.67	C
0.011	J	0.949		0.013	J	1	J	45.6	O	49400		36.7	J	10600		2430		21200		584.24	C
0.016	J	1.12		0.006	J	3.5	J	24.3	O	19800		100	U	8810		7140		64800		289.59	C
0.02	J	0.705		0.008	J	2.6	J	20.9	O	6410		100	U	2740		1020		10300		73.10	C
0.007	J	7.96		0.045		21		0.42	J,O	6650		146		1580		2020		13300		75.53	C
0.007	J	27		0.019	J	9.4		0.83	J,O	21900		100	U	8610		4440		8940		103.15	C
0.020	U	5.36		0.005	J	12.2		1.9	O	5730		100	U	1760		2870		11300		66.13	C
0.013	J	5.55		0.028	J	13.5		0.83	J,O	6130		100	U	1630		2080		7460		56.02	C
0.172		0.052		0.052		22		13.7	O	4510		17100		4490		1930		28700		184.31	C
0.007	J	15.8		0.053		15.5		8.5	O	11800		16.1	J	6340		2420		13200		97.84	C
0.012	J	11		0.054		17.9		2	O	7020		59.8	J	3790		1820		10100		68.96	C
0.01	J	11.7		0.120		16.9		2.1	O	6450		20.5	J	5240		2420		8500		73.56	C
0.014	J	16.7		0.134		21.2		5.4	O	15800		100	U	5330		1980		14100		107.76	C
0.301		0.015		0.204		28.9		1.0	U,O	3960		12200		1310		1210		7690		111.69	C
0.017	J	2.01		0.024	J	15.9		19.9	O	7180		259		2530		1390		4610		70.92	C
0.013	J	8.61		0.012	J	6.8		0.5	J,O	5710		58.7	J	2960		2470		9500		64.43	C
0.012	J	16.8		0.050		10.3		2.8	O	14200		22.3	J	5740		3610		10800		86.03	C
0.009	J	13		0.035	J	5.1		0.48	J,O	4940		225		5310		4770		10600		59.47	C
0.008	J	4.76		0.022	J	12.6		41.7	O	6550		100	U	5710		2070		5710		102.93	C
0.01	J	15.1		0.054		19.8		2.2	J,O	13100		21	J	3280		3520		15900		99.59	C
0.011	J	0.007	J	0.189		26.3		2.7	J,O	0	U	100	U	1000	U	1000	U	13000		72.21	C
0.013	J	9.85		0.060	B	13.2		2.4	J,O	10200		100	U	2430		3550		5730		64.83	C
0.011	J	18.6		0.122		14.8		1.0	U,O	13400		193		5460		4150		10500		84.54	C
0.009	J	4.25		0.090		27.2		1.5	J,O	3590		12.2	J	856	J	1970		9340		66.22	C
0.011	J	18.6		0.088		12.6		1.0	U,O	15000		100	U	10700		3060		5610		89.97	C
0.01	J	14.6		0.082		14.5		3.1	J,O	17100		57	J	5680		3390		8200		91.92	C
0.02	J	10.3		0.055		13.7		13.2	O	5700		100	U	10800		3430		6070		83.28	C
0.015	J	5.32		0.134		24.2		8.7	O	5500		100	U	1980		2120		11900		83.17	C
0.013	J	0.878		0.014	J	17.8		4.3	J,O	2150		100	U	659	J	1410		8920		57.74	C
0.016	J	23.4		0.026	J	15.4		15.2	O	20400		100	U	13800		6740		6320		132.50	C
0.017	J	16.7		0.106		24.6		5.9	O	14500		100	U	4610		2060		11600		103.39	C
0.019	J	9.11		0.097		21.6		5.8	O	9610		100	U	3940		1940		6220		76.54	C
0.014	J	0.01	U	0.097		25.6		11.3	O	0	U	100	U	1000	U	158	J	20700		90.97	C
0.012	J	14.4		0.040	U	6.6		13.2	O	9140		100	U	9180		3140		8060		84.03	C
0.015	J	15.9		0.029	J	10.3		6.4	O	12000		100	U	3850		2290		15100		88.28	C
0.006	J	12.2		0.014	J	10.8		2.4	O	3430		100	U	6590		5310		26400		110.05	C
0.006	J	9.26		0.011	J	13.4		1.4	O	9040		100	U	7740		4800		24600		131.96	C
0.006	J	17		0.018	J	23.4		12.6	O	16200		100	U	8000		2900		10600		116.62	C
0.006	J	6.6		0.029	J	12.5		15.3	O	7540		100	U	9080		2830		41200		203.39	C
0.005	J	5.68		0.008	J	18.6		0.63	J,O	4690		100	U	1050		1680		8370		58.21	C
0.017	J	8.38		0.006	J	6.3		10.2	O	8360		54.9	J	5600		1810		8870		69.50	C

Appendix 2. Well details and ground-water-quality data for the IRB watershed, 2001-03. (cont.)

Well ID	Easting (m)	Northing (m)	Well Type	Land Use 1997	Land Use 2002	Recharge Potential	Midpoint of screen interval (ft bgs)	Sample Date	Spec. Cond. (µS/cm)	pH	Temp. (ºC)	Dissolved oxygen (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)
IRB-226	217644.394	61478.967	D	U	U	G	55	08/12/03	247	4.49	16.06	1.91	3.9	16
IRB-227	210511.972	67508.473	D	A	U	F	75	08/12/03	71	4.70	14.27	5.18	8.1	8
IRB-228	208070.086	76157.864	D	U	U	P	60	08/27/03	148	4.92	15.84	9.87	1 U	12
IRB-229	213391.049	72126.169	D	U	U	G	47	08/27/03	112	5.67	15.97	7.46	9	13
IRB-230	208287.240	73647.540	D	U	U	G	70	08/27/03	72	5.27	15.47	7.01	6.5	8
IRB-231	210036.854	70216.961	D	U	U	F	45	09/09/03	51	5.50	15.02	1.66	13.9	5
IRB-232	208143.680	72864.470	D	F	U	F	55	09/09/03	200	5.43	15.09	5.89	6.4	12
IRB-233	208151.682	74022.256	D	A	U	F	57	09/09/03	80	5.41	15.49	7.52	7.9	10
IRB-234	205132.750	68401.884	D	U	U	P	45	09/10/03	314	5.45	15.52	8.65	6.8	15
IRB-235	205084.232	67794.106	D	U	U	G	71	09/10/03	138	5.31	16.13	7.04	5.3	12
IRB-236	204802.391	68129.561	D	U	U	F	65	09/10/03	145	5.20	14.91	8.69	3.8	13
IRB-237	202235.454	68912.429	D	A	A	G	64	09/10/03	72	4.97	15.78	4.03	4.6	9
IRB-238	215225.524	69390.652	D	F	U	G	60	09/10/03	50	5.35	15.40	6.43	6.6	7
IRB-239	216880.246	61277.923	C	U	U	G	88	09/16/03	228	4.70	18.06	6.30	3.8	21
IRB-240	216373.370	61194.050	C	U	U	G	68	09/16/03	148	5.35	15.53	4.47	5.4	17
IRB-241	210593.923	67421.019	D	U	U	P	70	09/16/03	160	5.00	14.83	6.34	2.1	15
IRB-242	226076.296	60289.384	D	F	U	F	55	09/17/03	126	5.71	15.02	0.18	25.9	22
IRB-243	216144.732	61094.596	C	A	A	F	90	09/17/03	125	5.07	15.91	5.27	2.4	13
IRB-244	215503.654	60961.910	D	U	U	F	36	09/17/03	416	4.88	15.58	1.98	2.5	42
IRB-245	216743.953	61555.119	D	F	U	G	55	09/24/03	240	4.95	15.70	7.35	1.9	28
IRB-246	213282.233	62191.298	P	U	U	F	70	09/24/03	134	6.00	14.55	0.21	46.9	11
IRB-247	212108.623	66741.043	D	A	A	F	60	09/24/03	430	5.06	14.88	8.52	3.6	74
IRB-248	217406.473	68234.630	A	A	A	G	87	09/24/03	251	5.64	15.23	7.49	10.2	17
IRB-249	211127.643	66452.287	P	U	U	F	60	09/25/03	125	5.52	17.82	7.77	6	13
IRB-250	213019.840	70830.468	D	F	U	G	45	09/25/03	181	4.79	14.28	8.62	1 U	12
IRB-251	208378.729	72792.462	D	F	F	G	72	09/25/03	54	5.35	14.56	1.66	8.3	6
IRB-252	207446.535	63341.433	D	U	U	G	49	09/30/03	176	4.85	16.34	5.30	2.1	15
IRB-253	215695.758	69345.528	D	U	U	G	55	09/30/03	106	5.27	15.30	7.35	3.1	7
IRB-254	216873.810	66624.034	D	U	U	G	63	09/30/03	141	5.38	14.65	7.72	6.2	16
IRB-255	217411.613	65870.493	D	A	A	P	95	09/30/03	168	5.69	14.80	6.64	7.7	14

Ammonia as nitrogen, dissolved (mg/L)		Nitrate as nitrogen, dissolved (mg/L)		Phosphorus, dissolved (mg/L)		Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)		Calcium, dissolved (µg/L)		Iron, dissolved (µg/L)		Magnesium, dissolved (µg/L)		Potassium, dissolved (µg/L)	Sodium, dissolved (µg/L)	Total Dissolved Solids (mg/L)	
0.213		17.6		0.040	U	6.4	5.3	O	9690		100	U	8090		11500	9890	88.58	C
0.014	J	2.41		0.040	U	4.7	0.76	J,O	2550		100	U	651	J	1840	6630	35.66	C
0.01	J	11.9		0.040	U	4.2	0.39	J,O	7700		37.7	J	4420		3000	5140	48.80	C
0.015	J	5.37		0.040	U	5.6	0.51	J,O	5310		33.1	J	1360		1960	8750	50.91	C
0.014	J	3.61		0.040	U	16.1	0.84	J,O	2140		15.7	J	882	J	1590	7250	46.94	C
0.049		0.353		0.040	U	8	0.75	J,O	2130		100	U	504	J	1220	5500	37.41	C
0.014	J	16.8		0.040	U	20.1	0.49	J,O	12900		30.8	J	3160		3160	11700	86.75	C
0.017	J	3.25		0.040	U	16.1	0.65	J,O	4060		18.5	J	1690		2020	4820	50.53	C
0.024		23		0.040	U	15.6	23.8	O	18800		41.8	J	13800		3340	6830	127.04	C
0.025		9.47		0.040	U	18.1	1.4	O	507	J	108		78	J	5340	20500	72.83	C
0.023		8.08		0.040	U	15.8	6.6	O	6620		100	U	4310		3910	7180	69.32	C
0.025		3.27		0.040	U	16.8	0.45	J,O	2640		100	U	1160		3300	4500	45.75	C
0.018	J	0.349		0.040	U	15.3	2.9	O	1580		100	U	548	J	1090	5000	40.39	C
0.008	J	17.6		0.040	U	12.1	0.72	J,O	11600		30.9	J	5250		5020	12700	89.83	C
0.009	J	9.33		0.040	U	15.2	3.4	O	9050		3.3	J	1430		3110	9860	73.79	C
0.009	J	11.8		0.040	U	14.3	0.36	J,O	7290		100	U	5420		3060	6360	65.70	C
0.137		0.165		0.040	U	14.8	1.8	O	4160		4340		1250		1580	11600	87.73	C
0.020	U	8.24		0.040	U	10.5	1.7	O	7020		2.6	J	1250		3490	8160	55.76	C
0.020	U	25.7		0.040	U	8.9	14.8	O	23000		10.5	J	12000		7160	18100	154.17	C
0.01	J	14		0.040	U	7.5	5.8	O	7180		40.6	J	8300		4760	14900	92.39	C
0.359		0.01	U	0.629		53.8	1.0	U,O	3730		19600		883	J	1030	7690	145.62	C
0.01	J	18.2		0.040	U	9.5	1.1	O	12400		20.5	J	13800		7040	31100	170.77	C
0.011	J	16.9		0.011	J	21.5	8.4	O	16700		5.6	J	6250		2380	11100	110.46	C
0.011	J	6.83		0.040	U	14.4	1.4	O	7110		12	J	2630		2160	6760	60.31	C
0.011	J	13.1		0.010	J	3.2	4.9	O	7370		17	J	8400		3740	3780	56.53	C
0.016	J	0.113		0.040	U	24.4	5.5	O	1500		816		395	J	1130	6080	54.25	C
0.014	J	12.6		0.008	J	13.1	2.3	O	7350		28.7	J	5090		3630	8570	69.79	C
0.013	J	5.39		0.040	U	8.4	11.2	O	4860		5.4	J	3080		1190	5030	49.27	C
0.012	J	5.19		0.006	J	13.1	11.1	O	7250		100	U	3060		1650	8700	72.27	C
0.008	J	8.12		0.009	JH	10.2	14	O	9310		6.1	J	3490		1850	10200	78.89	C

Appendix 3. Summary of duplicate data for the IRB watershed, 2001-03.

[Refer to Appendix 2 for explanation of abbreviations and qualifier codes.]

Well ID	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)	Ammonia as nitrogen, dissolved (mg/L)	Nitrate as nitrogen, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Calcium, dissolved (µg/L)	Iron, dissolved (µg/L)	Magnesium, dissolved (µg/L)	Potassium, dissolved (µg/L)	Sodium, dissolved (µg/L)
IRB-006 (Dup)	6	7	0.139	3.10	--- NA	11.3	<10 U	2530 J	<100 U	871 J	865 J	13000
IRB-006	33	7	0.110	3.43	<0.100 U	14.0	<10 U	2980 J	<100 U	864 J	<5000 U	12500
Mean	19.5	7.0	0.1245	3.265	--- NA	12.65	--- NA	2755	--- NA	867.5	--- NA	12750
Absolute difference	27	0	0.029	0.33	--- NA	2.7	--- NA	450	--- NA	7	--- NA	500
Relative percent difference	138%	0%	23.3%	10.1%	--- NA	21.3%	--- NA	16.3%	--- NA	0.8%	--- NA	3.9%
IRB-014 (Dup)	10	13	0.097	13.0	0.005 J	20.2	<10 U	11800	<100 U	2500 J	1590 J	7290
IRB-014	10	14	0.036	9.68	0.007 J	20.1	<10 U	11800	16.5 J	2500 J	1200 J	7310
Mean	10.0	13.5	0.0665	11.34	0.006	20.15	--- NA	11800	--- NA	2500	1395	7300
Absolute difference	0	1	0.061	3.32	0.002	0.1	--- NA	0	--- NA	0	390	20
Relative percent difference	0%	7.4%	91.7%	29.3%	33.3%	0.5%	--- NA	0%	--- NA	0%	28%	0.3%
IRB-020 (Dup)	14	23	<0.02 U	3.39	0.010 J	21.7	<10 U	4770 J	24 J	2120 J	672 J	13100
IRB-020	11	23	0.002 J	3.99	0.012 J	22.0	<10 U	4910 J	18.3 J	2150 J	906 J	13600
Mean	12.5	23.0	--- NA	3.690	0.011	21.85	--- NA	4840	21.15	2135	789	13350
Absolute difference	3	0	--- NA	0.60	0.002	0.3	--- NA	140	5.7	30	234	500
Relative percent difference	24.0%	0%	--- NA	16.3%	18.2%	1.4%	--- NA	2.9%	27%	1.4%	29.7%	3.7%
IRB-030 (Dup)	13	6	<0.02 U	0.460	0.052 J	28.0	10.0 N	5000 U	<100 U	265 J	1040 J	5650
IRB-030	13	5	<0.02 U	0.453	0.022 J	27.4	11.7 N	1060 J	22.1 J	260 J	1270 J	5490
Mean	13.0	5.5	--- NA	0.4565	0.037	27.7	10.85	--- NA	--- NA	262.5	1155	5570
Absolute difference	0	1	--- NA	0.007	0.030	0.6	1.7	--- NA	--- NA	5	230	160
Relative percent difference	0%	18.2%	--- NA	1.5%	81.1%	2.2%	15.7%	--- NA	--- NA	1.9%	19.9%	2.9%
IRB-042 (Dup)	3	14	0.003 J	5.95	<0.100 U	9.2	<10 U	5550	31.6 J	2610 J	2510 J	4110 J
IRB-042	3	14	0.003 J	6.14	<0.100 U	8.9	<10 U	4600 J	99.6 J	2590 J	2130 J	3960 J
Mean	3.0	14.0	0.0030	6.045	--- NA	9.05	--- NA	5075	65.6	2600	2320	4035
Absolute difference	0	0	0.000	0.19	--- NA	0.3	--- NA	950	68	20	380	150
Relative percent difference	0%	0%	0%	3.1%	--- NA	3.3%	--- NA	18.7%	103.7%	0.8%	16.4%	3.7%
IRB-047 (Dup)	3	21	0.002 J	4.95	0.022 J	6.2	26.2	3380 J	<100 U	6000	<5000 U	13100
IRB-047	3	21	<0.02 U	4.98	0.016 J	5.9	25.7	3800 J	<100 U	5930	<5000 U	13500
Mean	3.0	21.0	--- NA	4.965	0.019	6.05	25.95	3590	--- NA	5965	--- NA	13300
Absolute difference	0	0	--- NA	0.03	0.006	0.3	0.5	420	--- NA	70	--- NA	400
Relative percent difference	0%	0%	--- NA	0.6%	31.6%	5.0%	1.9%	11.7%	--- NA	1.2%	--- NA	3%
IRB-058 (Dup)	6	18	0.005 J	0.854	0.020 J	11.0	<10 U	<5000 U	<100 U	1220 J	<5000 U	11100
IRB-058	8	18	0.003 J	0.780	0.023 J	12.3	<10 U	941 J	<100 U	1300 J	<5000 U	11300
Mean	7.0	18.0	0.0040	0.817	0.022	11.65	--- NA	--- NA	--- NA	1260	--- NA	11200
Absolute difference	2	0	0.002	0.074	0.003	1.3	--- NA	--- NA	--- NA	80	--- NA	200
Relative percent difference	28.6%	0%	50.0%	9.1%	14.0%	11.2%	--- NA	--- NA	--- NA	6.3%	--- NA	1.8%
IRB-074 (Dup)	6	19	0.005 J	9.88	0.061 J	10	3.2 O	3000	<100 U	5250	2600	14200
IRB-074	4	19	<0.02 U	8.85	0.041 J	11	3.2 O	2990	<100 U	5110	2490	13900
Mean	5.0	19.0	--- NA	9.365	0.051	10.5	3.2	2995	--- NA	5180	2545	14050
Absolute difference	2	0	--- NA	1.03	0.020	1	0.0	10	--- NA	140	110	300
Relative percent difference	40.0%	0%	--- NA	11.0%	39.2%	9.5%	0%	0.3%	--- NA	2.7%	4.3%	2.1%
IRB-099 (Dup)	3.1	38	0.007 J	7.47	0.017 J	12.7	5.1 O	4790	46.9 J	5630	8970	21600
IRB-099	3.3	42	0.006 J	7.44	0.012 J	14.0	5.2 O	4650	36.8 J	5440	5490	19900
Mean	3.20	40.0	0.0065	7.455	0.015	13.35	5.15	4720	41.85	5535	7230	20750
Absolute difference	0.2	4	0.001	0.03	0.005	1.3	0.1	140	10.1	190	3480	1700
Relative percent difference	6.2%	10.0%	15.4%	0.4%	34.5%	9.7%	1.9%	3.0%	24.1%	3.4%	48.1%	8.2%
IRB-120 (Dup)	7.9	9	<0.02 U	4.07	<0.100 U	8.7	12.1 O	6560	<100 U	2940	1530	7480
IRB-120	9.9	7	0.006 J	4.07	0.009 J	8.8	12.0 O	6600	<100 U	3000	1560	7630
Mean	8.90	8.0	--- NA	4.07	--- NA	8.75	12.05	6580	--- NA	2970	1545	7555
Absolute difference	2.0	2	--- NA	0.00	--- NA	0.1	0.1	40	--- NA	60	30	150
Relative percent difference	22.5%	25.0%	--- NA	0%	--- NA	1.1%	0.8%	0.6%	--- NA	2%	1.9%	2%
IRB-140 (Dup)	2.9	12	0.013 J	6.78	<0.02 U	15.5	1.5 O	7470	<100 U	3180	3470	3740
IRB-140	3.3	12	0.011 J	6.46	<0.02 U	15.4	1.5 O	7480	115	3520	3510	4100
Mean	3.10	12.0	0.0120	6.62	--- NA	15.45	1.5	7475	--- NA	3350	3490	3920
Absolute difference	0.4	0	0.002	0.32	--- NA	0.1	0.0	10	--- NA	340	40	360
Relative percent difference	12.9%	0%	16.7%	4.8%	--- NA	0.6%	0%	0.1%	--- NA	10.1%	1.1%	9.2%
IRB-160 (Dup)	12.5	34	0.016 J	0.787	<0.02 U	10.9	1.1 O	<1000 U	87.5 J	<1000 U	247 J	32600
IRB-160	12.2	39	0.014 J	0.857	0.042	11.4	1.0 O	<1000 U	<100 U	<1000 U	<1000 U	31600
Mean	12.35	36.5	0.0150	0.822	--- NA	11.15	1.05	--- NA	--- NA	--- NA	--- NA	32100
Absolute difference	0.3	5	0.002	0.070	--- NA	0.5	0.1	--- NA	--- NA	--- NA	--- NA	1000
Relative percent difference	2.4%	13.7%	13.3%	8.5%	--- NA	4.5%	9.5%	--- NA	--- NA	--- NA	--- NA	3.1%
IRB-187 (Dup)	<1 U	157	0.069	1.13	<0.04 U	3.8 J	25.3 O	20200	<100 U	9000	7120	66000
IRB-187	1.1	159	0.016 J	1.12	0.006 J	3.5 J	24.3 O	19800	<100 U	8810	7140	64800
Mean	--- NA	158.0	0.0425	1.125	--- NA	3.65	24.8	20000	--- NA	8905	7130	65400
Absolute difference	--- NA	2	0.053	0.01	--- NA	0.3	1.0	400	--- NA	190	20	1200
Relative percent difference	--- NA	1.3%	125%	0.9%	--- NA	8.2%	4.0%	2.0%	--- NA	2.1%	0.3%	1.8%
IRB-212 (Dup)	5.7	17	0.013 J	4.94	0.022	23.9	8.7 O	5400	<100 U	2030	2120	11900
IRB-212	5.3	18	0.015 J	5.32	0.134	24.2	8.7 O	5500	<100 U	1980	2120	11900
Mean	5.50	17.5	0.0140	5.13	0.078	24.05	8.7	5450	--- NA	2005	2120	11900
Absolute difference	0.4	1	0.002	0.38	0.112	0.3	0.0	100	--- NA	50	0	0
Relative percent difference	7.3%	5.7%	14.3%	7.4%	144%	1.2%	0%	1.8%	--- NA	2.5%	0%	0%
IRB-239 (Dup)	3.0	22	0.008 J	17.3	<0.04 U	15.0	0.69 J,O	11500	19.5 J	5190	4880	12500
IRB-239	3.8	21	0.008 J	17.6	<0.04 U	12.1	0.72 J,O	11600	30.9 J	5250	5020	12700
Mean	3.40	21.5	0.0080	17.45	--- NA	13.55	0.705	11550	25.2	5220	4950	12600
Absolute difference	0.8	1	0.000	0.3	--- NA	2.9	0.03	100	11.4	60	140	200
Relative percent difference	23.5%	4.7%	0%	1.7%	--- NA	21.4%	4.3%	0.9%	45.2%	1.1%	2.8%	1.6%

Appendix 4. Summary of equipment blank data for the IRB watershed, 2001-03.

[Refer to Appendix 2 for explanation of abbreviations and qualifier codes.]

Equipment Blank ID	Alkalinity as $CaCO_3$ (mg/L)	Chloride, dissolved (mg/L)	Ammonia as nitrogen, dissolved (mg/L)	Nitrate as nitrogen, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Silica as SiO_2, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Calcium, dissolved (µg/L)	Iron, dissolved (µg/L)	Magnesium, dissolved (µg/L)	Potassium, dissolved (µg/L)	Sodium, dissolved (µg/L)
EB-1	<1 U	<1 U	0.002 J	0.029 J	0.024 J	<5 U	<10 U	<5000 U	<100 U	<5000 U	982 J	1640 J
EB-2	<1 U	<1 U	0.004 J	<0.055 U	0.038 J	21.8	<10 U	<5000 U	56.7 J	<5000 U	<5000 U	708 J
EB-3	<1 U	<1 U	0.014 J	<0.01 U	0.022	<5 U	<10 U	753 J	<100 U	<1000 U	<1000 U	<1000 U