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Bertrand Creek Area (Whatcom County)

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**EDB and 1,2-DCP in
Domestic Groundwater Supplies,
Follow-Up Investigation**

**Bertrand Creek Area
(Whatcom County)**

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Abstract

Elevated levels of the pesticides ethylene dibromide (EDB) and 1,2-dichloropropane (1,2-DCP) are present in some domestic groundwater supplies in northwestern Whatcom County. The Sumas-Blaine aquifer is the primary source of drinking water in the area.

Groundwater was initially discovered to be contaminated in 1984 during a statewide EDB investigation.

The Washington State Department of Ecology conducted a more comprehensive study in 1998 which focused on drinking water from 123 private domestic wells in the Bertrand Creek and Meadowdale areas near the City of Lynden. The purpose of the 1998 study was to refine the nature and extent of EDB and 1,2-DCP contamination and determine the fate and transport mechanisms. Alternate water sources were supplied to residents where contamination was documented or suspected.

This report presents results of a 2007 follow-up study that defined the current condition of the aquifer and supplements the data collected in 1998. This was a one-time sampling project that focused on 32 private domestic wells, 19 of which were also sampled in 1998. Samples were also analyzed for the presence of nitrates, which are elevated in groundwater.

The results of this 2007 study indicate that pesticides are still present in groundwater in the Bertrand Creek area where EDB, 1,2-DCP, dibromochloropropane (DBCP), or 1,2,3-trichloropropane (1,2,3-TCP) were detected in 59% of the wells sampled.

EDB and nitrate concentrations were slightly higher in 2007 compared to 1998 results. DBCP and 1,2,3-TCP concentrations were lower in 2007 compared to 1998. During 2007, six wells failed to meet the drinking water standard for EDB, and one well failed to meet the drinking water standard for 1,2-DCP.

Fifteen wells failed to meet the drinking water standard for nitrate. A total of 81% of the wells had higher nitrate concentrations in 2007 than in 1998.

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Executive Summary

The pesticides ethylene dibromide (EDB) and 1,2-dichloropropane (1,2-DCP) are present in some private domestic supply wells in the Sumas-Blaine aquifer at levels higher than the drinking water standard. The Sumas-Blaine aquifer is the primary source of drinking water for the area.

Groundwater was initially found to be contaminated with pesticides in 1984. Since then there have been several studies conducted to determine the extent of contamination, the source, and potential health risks.

EDB is a soil fumigant which was banned by the U.S. Environmental Protection Agency in 1983. EDB is a persistent chemical that remains in the soils and in groundwater for years. 1,2-DCP was introduced as an alternative soil fumigant when EDB was banned.

Beginning in 1986, alternate drinking water supplies were provided to residents whose private wells exceeded a drinking water maximum contaminant level (MCL) for a pesticide. Ecology conducted a comprehensive groundwater well sampling investigation in 1998 to refine the nature and extent of pesticide contamination.

This report presents the results of a 2007 follow-up study conducted by the Washington State Department of Ecology (Ecology) in the Sumas-Blaine aquifer, which is located in northwestern Whatcom County. The Bertrand Creek area, located west of Lynden, was the primary focus of this study.

The study goal was to determine the current state of pesticides in groundwater. This was a one-time sampling of 32 private domestic wells; 19 of which had been previously sampled in the extensive 1998 study by Ecology (O'Herron, 1999a). Residences not receiving an alternate water supply were targeted for this 2007 study.

The results of this 2007 investigation indicate that pesticides are still present in groundwater, where EDB, 1,2-DCP, dibromochloropropane (DBCP), or 1,2,3-trichloropropane (1,2,3-TCP) were detected in 59% of the wells sampled. A total of 22% of these wells failed to meet the drinking water standard for a pesticide. Nitrate contamination of groundwater was also found to be prevalent.

Ecology mailed individual well results along with letters of explanation to the residents as soon as Ecology received the analytical results. Ecology also shared the results with the Whatcom County Health Department. Based on the relatively similar pesticide concentrations detected in private domestic wells in 2007, the Washington State Department of Health risk assessment conclusions made in 2000 (Duff) may still be valid.

Due to the highly permeable soils, the shallow groundwater table, and the historic and continued agricultural land use, the aquifer is vulnerable to pesticide and nitrate contamination.

Presence of Pesticides and Nitrate in Groundwater

- **EDB** remains a contaminant of concern for users of private domestic wells in the Sumas-Blaine aquifer. While EDB concentrations detected in groundwater were slightly higher in 2007 than in 1998, this may not constitute a significant increase since many of the concentrations were detected at very low levels. EDB concentrations have declined dramatically since 1991 when Mayer et al. (1991) found a maximum EDB concentration of 6.17 ug/L compared to the maximum concentration of 0.27 ug/L detected in 2007. EDB concentrations monitored in this 2007 study are consistent with the published EDB degradation rate projections from 16 years ago, which project that EDB will be detectable in groundwater until the year 2012. EDB is still present in approximately 20% of the wells sampled, at concentrations exceeding the drinking water maximum contaminant level (MCL). EDB remains a contaminant of concern for users of private domestic wells in the Sumas-Blaine aquifer.
- **1,2-DCP** is present in almost half of the wells sampled. The concentrations are generally lower than in previous studies; however, one new well sampled exceeded the drinking water MCL. 1,2-DCP remains a contaminant of concern for users of private domestic wells in the aquifer.
- **DBCP** detections in groundwater are low, and concentrations for all wells sampled are below the drinking water MCL. DBCP does not appear to present a widespread concern.
- **1,2,3-TCP** detections in groundwater are low, and concentrations for all wells sampled are below the lifetime health advisory. 1,2,3-TCP does not appear to present a widespread concern.
- **Nitrate** was detected in almost every well sampled, with approximately half of those wells exceeding the drinking water MCL. Nitrate remains a contaminant of concern for users of private domestic wells in the Sumas-Blaine aquifer.

Introduction

Pesticides are present in the Sumas-Blaine aquifer in Whatcom County, Washington. Ethylene dibromide (EDB) was first detected in groundwater in 1984 (Erickson and Norton, 1990). 1,2-dichloropropane (1,2-DCP) was identified during the subsequent 1998 groundwater investigation (O'Herron, 1999a, 1999b). Numerous studies have been conducted to investigate this issue, characterizing the extent of pesticide contamination, as well as examining both the environmental and human health effects.

This study is a follow-up study to the O'Herron work. The objectives of this study are to characterize the current condition of the aquifer by:

- Defining the current concentration of target pesticides in area groundwater.
- Determining the local attenuation rates of EDB and 1,2-DCP.
- Determining which households currently have drinking water not meeting drinking water standards and may therefore be at increased health risk due to pesticide exposure.

This report documents the sampling results of 32 private domestic wells in the Bertrand Creek area. These wells were sampled to assess how the concentration or distribution of pesticides in groundwater has changed since the last formal evaluation in 1998 (O'Herron, 1999a, 1999b). This study was conducted in 2007 as a one-time sampling event. Nitrates were also sampled since Whatcom County has a documented history of groundwater nitrate contamination.

Concerns About EDB and 1,2-DCP in Groundwater

Pesticides and fertilizers are used to promote and maintain the viability and growth of crops. Pesticides are used extensively in Washington State both on a large agricultural scale and a small homeowner scale. Whatcom County is a largely agricultural community with many raspberry, strawberry, blueberry, seed potato, and forage crops. Whatcom County produces 77% of the nation's raspberries. (FAOSTAT, 2010)

EDB and 1,2-DCP are fungicides (nematocides) which were used as soil fumigants to control root worms on raspberries, strawberries, blueberries and seed potato crops. EDB was used from 1940 until 1983, when the Environmental Protection Agency (EPA) banned it from agricultural use due to its carcinogenic properties. EDB is a persistent chemical that remains in the soils and groundwater. 1,2-DCP was introduced as a substitute nematocide when EDB was banned, and has gradually been phased out of use. 1,2-DCP is also used in chemical manufacturing. (O'Herron, 1999a)

The intensive use of agricultural chemicals has unintended consequences, such as migration of pesticides and nutrients into surface water and groundwater. The majority of the rural population relies on private domestic wells for their drinking water. There are potential human health implications for pesticides and nutrients when they exceed the drinking water standards.

The Sumas-Blaine aquifer (Figure 1) spans an area of 150 square miles and is the primary drinking water source for area residents. It is hydraulically connected to the surface waters in the watershed. Due to the highly permeable hydrostratigraphic units, the shallow water table, and the historic and continued agricultural land use, the aquifer is vulnerable, with widespread nitrate contamination and known plumes of pesticide contamination beneath the Meadowdale and Bertrand Creek neighborhoods.

The Sumas-Blaine aquifer has been identified as one of the most severely contaminated aquifers in Washington State (Erickson, 2000). Historic and current groundwater studies indicate that water quality in this area continues to be affected by pesticides and nutrients.

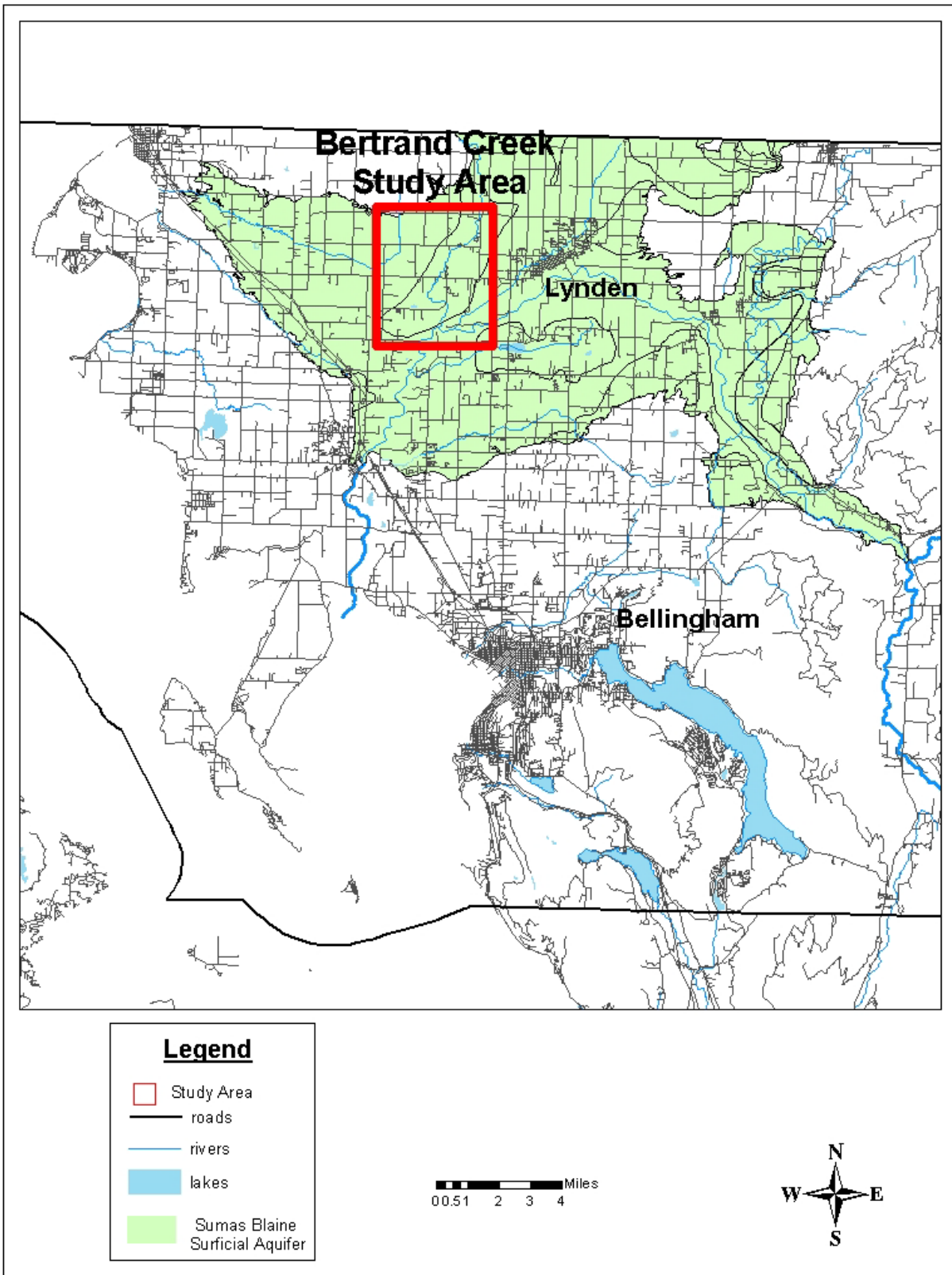


Figure 1. Study area in the Sumas-Blaine aquifer.

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Study Area

The Sumas-Blaine aquifer is located northwest of Bellingham, Washington (Figure 1).

The Bertrand Creek area, west of the City of Lynden, is the primary focus of this investigation. It is one of four EDB contaminated areas identified statewide in 1984 (Erickson and Norton, 1990) and was the focus of further testing in 1998 (O'Herron 1999a, 1999b). A municipal water line was completed in 2001 to serve the homes with EDB and 1,2-DCP contaminated drinking water. Area homes not connected to the water line, along with the still functioning wells from homes using municipal water, were selected for this 2007 follow-up investigation.

The population of Lynden is 11,690. Agriculture, forestry, fishing, and hunting employ 3.6% of the Whatcom County population and produce 2.4% of the county's income. Farming occupies approximately 11% of the county's land base (Washington State, Office of Financial Management, 2010).

The elevation of Lynden is 58 feet above mean sea level. The average annual temperature is 51.6 degrees Fahrenheit (°F), with a high of 90.9°F and a low of 12.7°F. The average annual precipitation at the Clearbrook weather station (6 miles from Lynden) was 45.77 inches per year (NOAA, 2010).

Bertrand Creek Area

The Bertrand Creek area lies three miles to the west of Lynden. There are approximately seven square miles of agricultural land, with the rest primarily light residential development.

Seventy percent of the Bertrand Creek area population uses private domestic wells as their source of drinking water. Twenty percent receive their water from the Berthusen Water Association, and 10% are served by community wells (O'Herron, 1999a).

Raspberries are the predominant crop in the Bertrand Creek area. Blueberries, seed potatoes, cucumbers, and strawberries are also grown in the area. There are two dairies, a nursery, and other small hobby farms.

Meadowdale Area

The Meadowdale area, located northeast of Lynden, is also an area where pesticide contaminated groundwater has been previously identified. However, the Meadowdale area was not included in this study since the residents were connected to the City of Lynden water supply in 1988 and are no longer exposed to pesticide contaminated water.

Land Use

Historically the area was heavily forested. As the dense forests were logged and land was cleared, agriculture became the main economic source for the community. Fertile soils and relatively flat topography make this area a prime spot for agriculture. The transition between forestry and agriculture happened around 1950. Currently the main land uses are agriculture and residential (Cox and Kahle, 1999).

Agriculture is the predominant land use over the Sumas-Blaine aquifer. Grass, corn, raspberries, blueberries, strawberries, and seed potatoes are the main crops grown. Raspberries are a significant agricultural commodity, and Whatcom County is one of the leading dairy producers in Washington State.

Washington State is ranked first in the nation in raspberry production. In 2007 Whatcom County produced over 53,000,000 pounds of raspberries, which is 89% of the raspberries grown in Washington State. (FAOSTAT, 2010; Washington Red Raspberry Commission, 2010)

Whatcom County has over 148,000 acres of agricultural land including 140 dairy farms, 7,200 acres in raspberries, and 2,500 acres in blueberries. Blueberry production is rapidly increasing, comprising 48% of the state's crop. Additionally strawberries, beef cattle, and the greenhouse/ nursery industry are expanding in the area. Whatcom County is leading in farm production in western Washington. Whatcom County is ranked sixth in the state in farm production, and in the top 3% in the United States. (Whatcom Farm Friends, 2010)

British Columbia, Canada, which is north of the study area, shares the same surficial aquifer with Whatcom County. Agriculture is the predominant land use in this part of British Columbia, Canada, with a high concentration of raspberry fields. The B.C. Ministry of Agriculture and Food acknowledges that the combination of agricultural activities is a significant contributor to the high nitrate concentrations in the Sumas-Blaine surficial aquifer (Hughes-Games and Zebarth, 1999).

It is difficult to discern where the sources of pesticides contamination originate. The complex geology, the southern groundwater flow across the international border, and the similar land use in British Columbia make identifying the source of contamination difficult. The amount of time that has passed since EDB was banned and the gradual phased out use of 1,2-DCP also make identification of a specific source difficult.

Hydrogeology

Groundwater is the primary source of drinking water in this area. Over 100,000 people residing over this aquifer, both within the United States and Canada, rely on groundwater as their drinking water source (Mitchell et al., 2000).

The U.S. Geological Survey (USGS) distinguishes four main hydrogeologic units within the project area: the uppermost Sumas aquifer, the Everson-Vashon semiconfining unit, the Vashon semiconfining unit, and the bedrock semiconfining unit (Cox and Kahle, 1999). The wells sampled during this project are all completed in the uppermost Sumas-Blaine aquifer.

The Sumas-Blaine aquifer is the principal aquifer in the Nooksack watershed (WRIA #1). The aquifer is comprised mainly of permeable sand and gravel glacial outwash deposits as well as alluvial deposits from the Nooksack and Sumas Rivers. The aquifer is largely unconfined and shallow, with depth to water commonly less than 10 feet below land surface. These hydrogeologic characteristics create an aquifer which is highly susceptible to contamination from surface activities.

Geology

The study area lies within the Fraser-Whatcom Lowlands, which were formed within part of the Georgia basin. The Georgia basin is a large depression that extends from land into marine waters. The depression was created during the Mesozoic Era by tectonic activity. This tectonic activity also formed the Cascade Mountains and portions of the Pacific Coastline. Substantial sediments were deposited in the basin during the Tertiary Period and accumulated as a result of the rapid weathering of the new mountains.

Within the Sumas-Blaine study area, the Fraser Glaciation had several advances and retreats. With each of these movements, another series of glacial sediments were deposited. There were three main stages of glacial advances and retreats; the oldest was the Vashon Stade, then the Everson Interstade, and then the youngest Sumas Stade. The combined glacial deposits range from 0 and 1500 feet thick over the study area. During the Holocene Epoch, the Nooksack River cut through and eroded the Sumas Formation creating the present-day alluvial flood plain of the Nooksack River Valley (Easterbrook, 1971).

Sumas-Blaine Aquifer

The Sumas-Blaine aquifer is the surficial aquifer and the primary water source for the area. The Sumas-Blaine aquifer extends north into British Columbia, Canada, where the unit is also referred to as the Abbotsford aquifer. The Abbotsford aquifer is hydraulically connected across the international border, and the major groundwater flow direction is south from Canada (Cox and Kahle, 1999). The Sumas-Blaine aquifer continuously underlies a relatively flat glacial outwash plain between the towns of Sumas, Blaine, and Ferndale and the Nooksack River, comprising an area of approximately 150 square miles. The Sumas-Blaine aquifer is unconfined over the extent of the study area.

Lithologic Characteristics

The Sumas-Blaine aquifer is the primary water-producing unit. It is comprised mainly of stratified sand and gravel outwash with minor clay lenses. Fine-grained lenses are more predominant in the Lynden area. The Sumas-Blaine aquifer is a heterogeneous unit which includes glacial outwash sediments and alluvial deposits from the Nooksack and Sumas River systems. There are also isolated lenses of till, fine-grained lacustrine deposits, and peat deposits.

It is a highly productive unconfined aquifer that includes the geologic units of Sumas Outwash, Sumas fine-grained ice-contact deposits, coarse-grained alluvium, fine-grained alluvium, and peat deposits (Cox and Kahle, 1999).

The glacial outwash plains are comprised of unconsolidated sand, silt, and gravel sediments deposited by glacial streams produced during the advancement and retreat of the glaciers. Overall the topography is fairly flat except for the glacial kettle depressions where lakes, marshes, and peat bogs formed. Localized peat deposits are scattered across the area in natural depressions. The area around Wisner Lake, and the area to the east of Fishtrap Creek and south of the international border, have the most significant peat deposits. Over time the Nooksack River has incised the glacial outwash plain 40 to 60 feet, forming the Lynden Terrace near the town of Lynden (Cox and Kahle, 1999).

Hydrogeologic Characteristics

The aquifer thickness ranges from 15 to 80 feet where the Nooksack River has eroded away much of the sand and gravel outwash unit. Depth to groundwater is typically less than 10 feet below land surface (Erickson, 2000). The median hydraulic conductivity was calculated to be 270 feet per day, with a range of 7 to 7,800 feet per day (Cox and Kahle, 1999). The extreme variation in hydraulic conductivities indicates substantial heterogeneity within the units, which is typical of a unit of glacial origin. Cox and Kahle (1999) estimate the hydraulic gradient in the Sumas-Blaine aquifer at about 15 feet per mile or 0.0028 foot per foot. Groundwater flow velocity of two feet per day was determined at a local dairy (Garland and Erickson, 1994).

Generally groundwater within the Sumas-Blaine aquifer flows toward the major river systems and tributaries in the area. The aquifer is in hydraulic connection with surface water and provides baseflows during the summer months (Erickson, 2000). The Nooksack River originates in the Cascade Mountain Range and traverses through the lowlands to the marine waters. The main tributaries are Bertrand, Fishtrap, and Tenmile Creeks. Groundwater naturally discharges to the Nooksack River. Secondary sources of groundwater discharge are groundwater wells and subsurface drains which can alter groundwater flow locally.

The Sumas-Blaine aquifer is mainly recharged by precipitation and irrigation (Tooley and Erickson, 1996), although leachate from on-site sewage systems and manure storage lagoons also contributes to the recharge. Precipitation ranges from 60 inches per year near the international border to 32 inches per year in the southern part of the study area. Recharge rates are affected by precipitation rates, evapotranspiration rates, infiltration rates, and impervious surfaces. Within the study area, the recharge rates are estimated to range from 11 to 45 inches per year (Cox and Kahle, 1999).

Groundwater has a slightly acidic pH with typical values between 5.7 to 6.8 standard units (S.U.). Groundwater is also well oxygenated, with dissolved oxygen values typically greater than 7 mg/L (Cox and Liebscher, 1999). Garland and Erickson (1994) determined that groundwater is a calcium sulfate (CaSO₄) type water.

Everson-Vashon Semiconfining Unit

The Everson-Vashon semiconfining unit lies beneath the Sumas-Blaine aquifer. It is predominantly glaciomarine drift comprised of unsorted gravelly clay and sandy silt. Some lenses of Vashon till have been noted by Cox and Kahle (1999). This unit generally acts as a confining unit, but areas of coarse-grained lenses can produce usable quantities of water. Chloride concentrations and total dissolved solids concentrations are elevated in the deeper wells compared to wells completed in the surficial aquifer. The median hydraulic conductivity value for this unit is calculated to be 81 feet per day. This value is high for fine-grained material and is likely to be biased high, since these values were calculated from specific capacity data from wells, which are normally found in the more productive portions of the aquifer (Cox and Kahle, 1999).

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Pesticide Contamination of Groundwater

History

Groundwater in northwestern Whatcom County has been evaluated for pesticides on several occasions since 1984, and in each case, pesticides have been detected. On the basis of these findings, the Washington State Department of Ecology (Ecology) provided bottled water to affected households from 1986 to 2001. Ecology added a showerhead filtration program in 1999 to 2001 to reduce pesticide inhalation risk during showering. The City of Lynden extended a water line to provide drinking water to households whose wells contained elevated pesticide concentrations. This water line was extended to the Meadowdale area in 1988 and the Bertrand Creek area in 2001. However, not all the affected residents participated in these programs, and many well users potentially remain at risk.

Following is a summary of pesticide use, events, and studies in this area.

- EDB was used as a soil fumigant for crops from 1940 until the 1980s. In Whatcom County, EDB was used on raspberry, strawberry, and seed potatoes. EPA banned EDB in 1983 because it was discovered to be a known animal carcinogen and a probable human carcinogen and it was linked to other health issues. It was also determined that EDB could contaminate groundwater and affect drinking water. (O'Herron, 1999a)
- When EDB was banned, an alternative pesticide 1,2-Dichloropropane (1,2-DCP) was introduced.
- In 1984 EDB was detected in food in western Washington. The EPA and the Washington State Department of Social and Health Services (DSHS) conducted a study looking for contamination. When a well in Skagit County tested positive for EDB, a more extensive study was conducted including Whatcom County. Ninety-six wells were tested, with 14 wells (15%) exceeding the health advisory of 0.02 ug/L. The highest concentrations were detected in Whatcom County. (DSHS, 1985)
- Bertrand Creek and Meadowdale, two areas near Lynden, were included in a 1984 study that identified areas within the state which are contaminated by pesticides. Further investigation delineated the area-wide extent of contamination and determined that EDB and 1,2-DCP were the primary organic contaminants. (Erickson and Norton, 1990)
- In 1985 DSHS published a report documenting their findings and recommending that Ecology conduct a more thorough investigation. DSHS determined that there is a long-term health risk present to those drinking contaminated groundwater. (DSHS, 1985)
- In 1986 Ecology declared two sites in Whatcom County as EDB cleanup sites: the Meadowdale area and the Bertrand Creek area.

- In 1986 Ecology developed a program to supply alternative water sources to those residents whose groundwater was contaminated or suspected to be contaminated.
- In areas where the population was sparse and the distance to the Lynden municipal water supply was too great, extending the water line was cost prohibitive and bottled water was made available as an alternate drinking water source. In 1986 Ecology began supplying bottled water to residents of the Bertrand Creek area (west of Lynden). In 1988, 45 households were supplied with bottled water, and in 1999 the program expanded to include 65 households.
- A pipeline was built in 1988 extending the City of Lynden's water supply to the Meadowdale Water Association to supply water to residents with elevated concentrations of pesticides.
- In 1997 the Washington State Department of Health, Office of Epidemiology, determined that there was a statistically significant greater-than-expected occurrence of acute lymphocytic leukemia in children residing in Whatcom County. Leukemia is a cancer of the bone marrow and blood.

No association between drinking water and elevated leukemia rates were found. This perceived occurrence was identified in children less than 5 years old between the years 1992 and 1994. A survey was conducted to identify possible common exposures in the cancer cluster. The survey considered numerous pathways, including exposure to drinking water contaminated with EDB, 1,2-DCP, and DBCP. The findings of this survey concluded that the ages, races, and genders of the children were consistent with national patterns of leukemia occurrence. Since there was no shared factor among the affected children, it was determined that the childhood leukemia cluster was a random cluster with no identified common cause. The survey ruled out the community's concerns that there was a common exposure from contaminated groundwater. (Johnson et al., 1999)

- In 1998 O'Herron sampled 123 wells both within and outside of the bottled water delivery area. These wells were sampled for EDB, DBCP, volatile organic compounds (VOCs), including 1,2-DCP, hardness, nitrate+nitrite, chloride, calcium, magnesium, sodium, potassium, total coliform bacteria, and field parameters. A small subset of wells near the areas with historical contamination was sampled for additional pesticides and herbicides.
 - *EDB* was detected in 14 out of 123 sampled wells (11%) within the Bertrand Creek area. Eight of these detections exceeded the maximum contaminant level (MCL) of 0.05 ug/L for drinking water. Seventy-five percent (six wells) of these exceedances were along Birch Bay-Lynden Road, east of the Bob Hall Road intersection. Within the same area, another 3 EDB detections occurred, at levels below the MCL, but above the detection limit of 0.02 ug/L. EDB concentrations in this area correlate with the findings of other investigations. Because they found no EDB in neighboring wells to the east, north, and west, O'Herron (1999a) concluded that the EDB plume had not migrated or expanded significantly from the past. A new area of EDB contamination was identified along Willeys Lake Road in two wells almost a mile south of where EDB had been in the past. In Meadowdale, no elevated EDB concentrations were found.

- *1,2-DCP* concentrations exceeded the MCL of 5.0 ug/L in 6 of the 123 wells sampled (5%). Concentrations exceeded the practical quantitation limit (PQL) of 0.25 ug/L at an additional 28 locations. Nineteen of these PQL exceedances were located along the Birch Bay-Lynden Road and the southernmost part of Bob Hall Road, with 21% of these exceeding the MCL. 1,2-DCP also appeared in concentrations above the PQL, but below the MCL, in two wells in the Meadowdale area.
- *Nitrate* was detected in 118 of the 123 wells (96%), with concentrations above the MCL of 10 mg/L in 48 of the total wells sampled (39%).
- *Other Parameters:* Coliform bacteria was present in 78 of the 123 wells (63%), and *E. coli* bacteria was present in 9 of the 78 wells (12%) of those wells testing positive for coliform bacteria. A variety of other chemicals was detected at concentrations below the corresponding MCL. (O'Herron, 1999a)
- In 1998, an EPA investigation failed to identify specific pesticide sources or contamination boundaries. It was determined that the pesticide contamination of groundwater is likely from past agricultural use of soil fumigants.
- In 1999, the Washington State Department of Health conducted a health risk assessment for residents exposed to pesticides in groundwater. (Duff, 2000)
- By 1999, groundwater studies by Ecology, EPA, and USGS showed contamination was more widespread than previously thought. More focused sampling revealed an additional 13 wells in British Columbia exceeded the PQL, and 15% of these wells exceeded the MCL.
- In 1999, Ecology determined that extending a water line from Lynden to Bertrand Creek area households with contaminated wells would be the most reliable and reasonable long-term fix for the problem.
- In 2001, Ecology reached an agreement with the City of Lynden for construction of a water line to serve households in the Bertrand Creek area that had drinking water contaminated with unsafe levels of EDB or 1,2-DCP. Construction of a 5.4 mile water line was completed in 2002. Initially, 50 households were eligible for connection. Not all area households were eligible to connect to the City of Lynden water line; municipal water was available only to manage the public health risk created by EDB and 1,2-DCP. Nitrate, coliform, and other contaminants were not factors considered when determining whether bottled water or connection to the municipal water line would be provided to individual households.
- After the 1999 sampling event, several additional households in the area were found to have EDB and 1,2-DCP contaminated drinking water. Ecology collected additional samples from residential wells, but most of the subsequent sampling results were based on owner collected samples in 2001 and 2002 at residences where owners had chosen not to participate in previous sampling events.

- Beginning in 1999, Ecology also offered showerhead filters to reduce inhalation exposure which occurs during showering (O’Herron, 1999a). This service, along with the bottled water program, was discontinued once the municipal water line was completed in 2002.
- Current fumigant formulations contain minute, if any, levels of 1,2-DCP.
- Other environmental and health studies were conducted by Western Washington University, (Mitchell et al., 2000), USGS (Cox and Liebscher, 1999), Ecology (Larsen, 1996), Black and Veatch (1986), the State Department of Health (Duff, 2000), and the Whatcom County Health Department (2000).

Chemical Usage

EDB was primarily used as a scavenger for lead in anti-knock gasoline mixtures beginning in the 1920s. The purpose was to prevent the formation of lead deposits from forming in automobile engines. Eighty-three percent of the EDB produced was used in gasoline. Additionally it was used as a solvent for resins, gums, waxes, waterproofing, dyes, pharmaceuticals, and as a fumigant for nematode infestation of crops. (EPA, 2006a) EDB was used on a variety of crops in Whatcom County, including raspberries, seed potatoes, strawberries, and blueberries, until EDB was banned in 1983. EDB is a carcinogen, and EPA has established a MCL for EDB at 0.05 ug/L.

1,2-DCP was used in making lead-free gasoline and in paper coating. It was also used as an insecticide for stored grain and as a soil fumigant for nematodes. 1,2-DCP was substituted for EDB after it was banned. The production of 1,2-DCP declined greatly after Dow Chemical, the only manufacturer, discontinued its production in 1991. (EPA, 2006a) EPA has established a MCL for the 1,2-DCP at 5 ug/L.

DBCP was primarily used as an insecticide against nematodes. It was applied as a soil fumigant for cucumbers, summer squash, cabbage, cauliflower, carrots, snap beans, okra, aster, shasta daisy, lawn grasses, and ornamental shrubs. DBCP was banned in 1985. (EPA, 2006b) EPA has established a MCL for DBCP at 0.2 ug/L.

1,2,3-TCP is a pesticide, but is also used as industrial solvent, paint remover, and cleaner. (ATSDR, 1992). There is no MCL for 1,2,3-TCP, but EPA has established a lifetime health advisory level of 40 ug/L.

Nitrates are primarily manufactured as fertilizers (EPA, 2006b). However, nitrates are also a by-product of human and animal wastes. Nitrate is identified by EPA as a primary drinking water contaminant and has a MCL of 10 mg/L.

Potential Health Effects

The effects to human health from exposure to pesticides depend on the chemical characteristics, dose, duration, route of exposure, and the presence of other chemicals. Additionally, the

individual characteristics of the person exposed have an influence on the personal effects. These characteristics include traits such as age, sex, nutritional status, family traits, life style, and the person's state of health. (ATSDR, 1992)

In 1998 members of the community petitioned for a health assessment of the effects of pesticides present in groundwater. This health assessment was conducted by the Washington State Department of Health (Duff, 2000) under a cooperative agreement from the federal Agency for Toxic Substances and Disease Registry (ATSDR). The findings of this health assessment were released to the community in 1999 and are summarized below (Duff, 2000).

- A public health hazard exists for those residents exposed to pesticides found in drinking water at levels greater than the MCLs.
- Long-term exposure to the maximum level of EDB found in the Sumas-Blaine aquifer during this study creates a low to moderate increase in cancer risk.
- Exposure to the maximum levels of other pesticides detected creates a lower cancer risk.
- There is a low to very low cancer risk where multiple pesticides were detected below the MCL.
- Long-term exposure to pesticides which are detected below the MCL creates a low to very low cancer risk.
- Exposure to the maximum levels of pesticides is not anticipated to create harmful non-cancer health effects.
- Exposure to nitrate concentrations above the MCL could create a health risk for pregnant women and infants.
- Over time, as pesticide concentrations in groundwater decrease, it is anticipated that the cancer risk will also decrease.

Routes of Exposure

There are three ways that humans can be exposed to pesticides in their water: ingestion, inhalation, and dermal absorption. Showering with contaminated water exposes an individual in two ways: (1) through inhalation from VOCs that escape from water into the air, or (2) from dermal exposure as the water touches the skin during showering.

There was concern that residents showering with contaminated water would receive excessive exposure to pesticides. In 2000 the Whatcom County Health Department conducted a carbon filter showerhead study to determine their effectiveness in removing pesticides, and the length of time the filters provide adequate protection before they needed to be replaced. An exposure investigation determined that a carbon filtration cartridge installed in the showerhead is effective in removing EDB and 1,2-DCP to acceptable levels (below the MCL) for three months, before the filter would need to be replaced. (Whatcom County Health, 2000)

Nitrate exposure occurs only through ingestion.

Fate and Transport of EDB

Mayer et al. (1991) monitored 107 wells in Whatcom County for EDB over a 27-month period. They found that 18 wells (17%) contained elevated concentrations of EDB above 0.02 ug/L (1991 standard), with a maximum value of 6.17 ug/L.

Based on their extensive research, Mayer et al. (1991) used a first-order kinetics decay model to determine the projected concentrations of EDB in groundwater.

$$[\text{EDB}] = 1.99e^{-0.00364t}$$

The EDB concentration during the study ranged from 0.94 to 2.29 ug/L. According to this model, it was determined that EDB levels in the aquifer would naturally degrade to 0.02 ug/L by the year 2012, requiring a total of 24 years to degrade in the environment (Mayer et al., 1991).

Mayer's research indicates that a precipitation event can cause a pulse of water entering the aquifer which results in a temporary dilution of the EDB concentrations. After a lag time of one to three months, the EDB concentrations tended to rebound to their prior undiluted level. Mayer also noted that the EDB concentrations varied significantly over the course of the study (0.94 to 2.29 ug/L). This researcher observed that EDB concentrations change very slowly, and the residual EDB binds strongly to the soils, persisting for more than 20 years and causing long-term groundwater contamination.

Pignatello and Cohen (1990) observed fairly rapid degradation of EDB under aerobic and anaerobic soil conditions. However, they also noted that EDB persists in the soils for decades at significantly lower levels, yet still above the MCL.

In a review of multiple EDB studies, Falta (2004) noted that EDB does not appear to completely degrade. EDB was observed to be mobile and persistent in groundwater. Falta cited two drinking water studies where EDB was detected in 0.72% of the public drinking water supply systems tested and another study where EDB was detected in 1.7% of systems. Falta determined that 76% of the public water supply systems impacted was the result of agricultural application of EDB. This is based on (1) the correlation of EDB with the presence of DBCP, which is also a pesticide detected in 76% of the systems; and (2) the presence of 1,2-DCA, which is a gasoline additive detected in 27% of the systems; and (3) the lack of correlation between DBCP and 1,2-DCA.

EDB was banned for agricultural use in 1983, yet it is still present at low levels in groundwater. It seems to degrade in some environments, yet persist under other conditions. The degradation mechanisms are not clearly understood (Falta, 2004).

Methods

During this 2007 study, 32 domestic wells within the Bertrand Creek area were tested for EDB, 1,2-DCP, DBCP, 1,2,3-TCP, and nitrate+nitrite-N. This was a one-time sampling event which included both households that were tested in the 1998 study (O'Herron), as well as 13 households which have never had their water tested before.

Well Selection Process

To assess the potential human health risks associated with exposure to pesticide-contaminated groundwater, only private domestic wells that were currently in use were sampled during this evaluation. This included private domestic wells used for drinking water and water wells used only for irrigation. Individual wells were targeted for sampling based on their prior sampling history and their location to provide a representative areal coverage of current groundwater quality conditions within the study area. Well selection criteria were followed according to the Quality Assurance Project Plan (Redding, 2007).

Monitoring wells were not included as part of this study. While monitoring wells provide a better understanding of aquifer conditions, this study was designed to examine drinking water sources of residents. This approach provides a better basis to determine relative health risk; however, it diminishes the ability to determine plume boundaries and contaminant degradation rates.

Field Sampling

Standard operating procedures for well purging and sampling were used to measure field parameters and to minimize potential changes to water chemistry for laboratory samples. All laboratory-bound samples were collected, preserved, stored, and otherwise managed using accepted procedures for maintaining sample integrity prior to analysis (Ecology, 1993; USGS, various dates).

In addition to the parameters listed in Table 1, all wells were sampled for the following field parameters: temperature, pH, dissolved oxygen, and conductivity.

Thirty-two wells were sampled in a one-time sampling. Samples were collected as close to the wellhead as possible and were obtained prior to any type of water treatment. Samples were collected only while the pump was running in order to minimize contributions from water storage tanks.

Wells were sampled from a faucet with a "Y" fitting. The "Y" adapter allowed the well to be purged while field parameters were constantly measured in a flow cell. This system is advantageous for residences where a storage tank is in place prior to the closest tap. Variable flow controls allow large volumes of water to be purged from the tank, which facilitates the pump cycling on, which then produces water directly from the borehole. One side of the "Y"

was connected to a garden hose, which was used to purge the well and discharge the water to a vegetated area. The other side of the “Y” was connected to a flow cell with a polyethylene hose.

The flow cell houses the pH, temperature, conductivity, and dissolved oxygen probes. The flow cell allows field measurements to be made prior to the water being exposed to the atmosphere. Purging was considered complete, and a sample was taken once two consecutive field measurements, taken at three-minute intervals, were made within the stability criteria established in the project plan (Redding, 2007). Samples were collected from the restricted side of the “Y” adapter after the polyethylene tubing was unhooked from the flow cell. This allowed a sample to be collected from as close to the wellhead as possible while minimizing contact with field equipment and hoses.

After completion of field tests, water samples were collected in pre-cleaned, laboratory-supplied sample containers. The filled sample bottles were labeled and placed in portable coolers filled with ice for short-term storage during transport to Manchester Environmental Laboratory (MEL). The samples were delivered to the Ecology operation center walk-in cooler on the final day of sampling for transport to MEL via laboratory courier.

Analytical Methods

MEL analyzed all samples using the analytical methods described in Table 1.

Table 1. Analytical methods.

Parameter	Analytical Method
EDB	Extracted with hexane, analyzed by capillary gas chromatography with dual column ECD detection (GC/ECD) following EPA SW-846 Method 8011 – modified.
1,2-DCP	EPA method 8260B for volatile organic analysis (VOA).
DBCP	Extracted with hexane, analyzed by capillary gas chromatography with dual column ECD detection (GC/ECD) following EPA SW-846 Method 8011 – modified.
1,2,3-TCP	Extracted with hexane, analyzed by capillary gas chromatography with dual column ECD detection (GC/ECD) following EPA SW-846 Method 8011 – modified.
Nitrate+ nitrite-N	Standard methods 4500NO3I.

Quality Assurance

Laboratory quality assurance samples for this project include duplicate samples, matrix spikes, control standards, surrogates, and blanks. Accuracy is affected by both precision and bias. The targets for analytical precision are briefly described in Appendix C and in more detail in the Quality Assurance Project Plan (Redding, 2007).

Results

The results of this study indicate that pesticides and nitrates are present in groundwater and are impacting private domestic wells. The pesticides EDB and 1,2-DCP, and nitrate+nitrite, were the primary focus of this study. However, since 1,2,3-TCP and DBCP were detected in several of the samples analyzed and have drinking water standards, these compounds are also reported.

Individual well results along with a letter of explanation were sent to residents as soon as the analytical results were received. These results were also shared with the Whatcom County Health Department.

The analytical results are presented in Table A-1 of Appendix A. Field measurements are presented in Table A-2 of Appendix A. Table 2 presents a summary of the sampling results. The data for this project are judged to be acceptable based on the measurement quality objectives described in the Quality Assurance Project Plan (Redding, 2007). The quality assurance results are discussed in Appendix C.

Table 2. Results summary.

Parameter	Detections		MCL Exceedances*		Minimum value	Maximum value	Mean	Units
	#	%	#	%				
EDB	6	19	6	19	0.019	0.270	0.047	ug/L
1,2-DCP	14	44	1	3	0.190	12.00	1.099	ug/L
DBCP	1	3	0	0	0.019	0.071	0.021	ug/L
1,2,3-TCP	4	13	0	0	0.018	0.63	0.121	ug/L
Nitrate	31	97	15	47	0.010	24.5	9.30	mg/L

*1,2,3-TCP has a lifetime health advisory.

Pesticides were detected in 19 of the 32 wells (59%) sampled during this study. The MCL was exceeded for a pesticide in seven wells (22%); six were for EDB and one was for 1,2-DCP. All wells with detected EDB had concentrations which exceeded the MCL. 1,2-DCP was the most commonly detected pesticide with a 44% detection rate (14 wells), but only one well exceeded the MCL. Well #29, which exceeded the MCL for 1,2-DCP, was anomalously high; three times higher than the next highest concentration. This value was reviewed by the project lead, discussed with MEL chemists, and determined to be valid (Westerlund, 2007).

All four pesticides analyzed were detected in at least one of the 32 wells sampled. Four wells (13%) contained multiple pesticides. Thirteen wells (41%) had no detections of pesticides (Figure 17).

Nitrate was detected in 31 wells (97%) with 15 wells (47%) exceeding the MCL.

The following Figures 2 through 6 illustrate the location of the wells and the results of the 2007 sampling.

EDB

EDB was detected in six wells (19%). All six of these detections exceeded the MCL of 0.05 ug/L. Figure 2 illustrates the locations of the groundwater wells impacted by EDB.

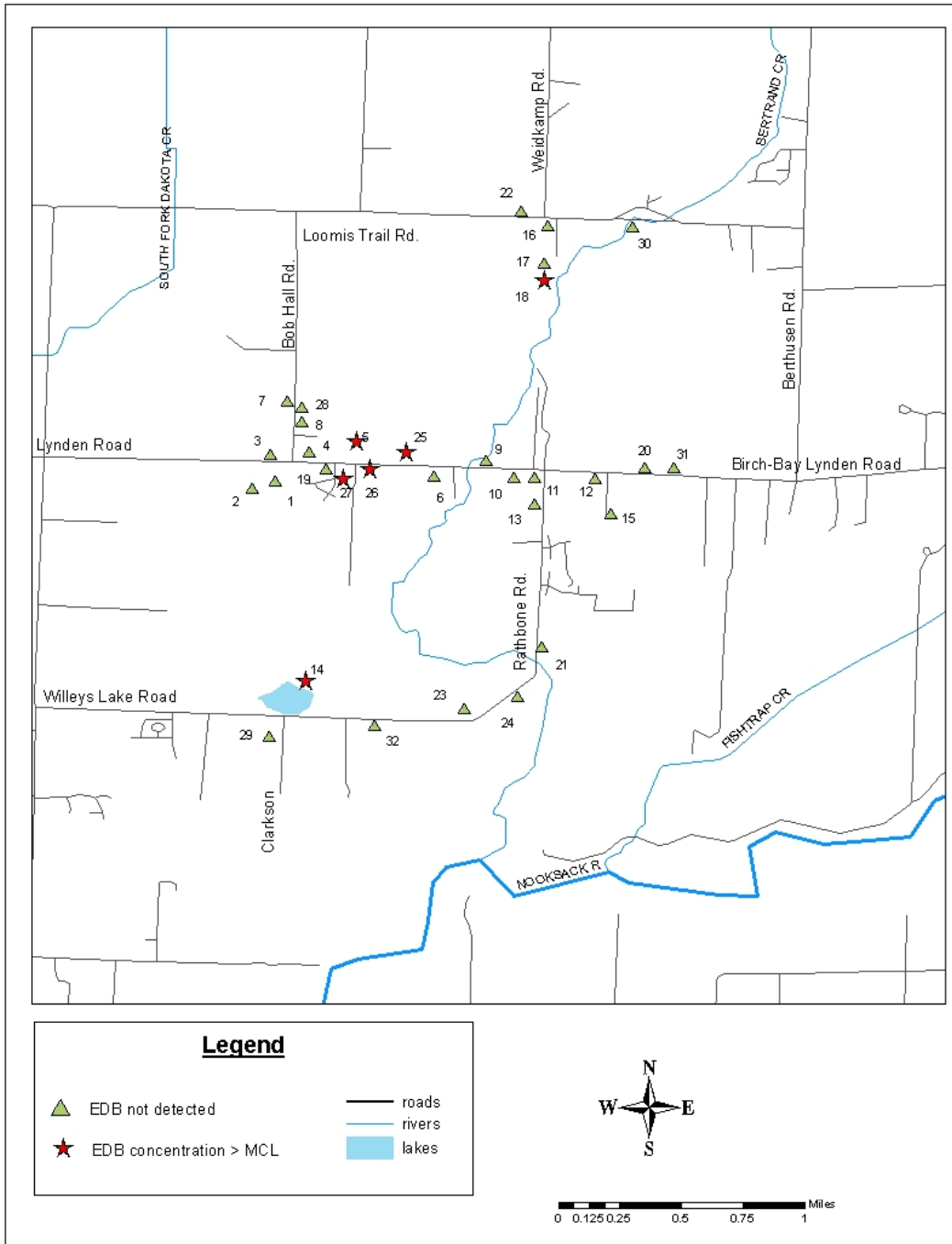


Figure 2. EDB detections in groundwater.

1,2-DCP

1,2-DCP was detected in 14 wells (44%). One well exceeded the MCL of 5.00 ug/L. Figure 3 illustrates the locations of the groundwater wells impacted by 1,2-DCP.

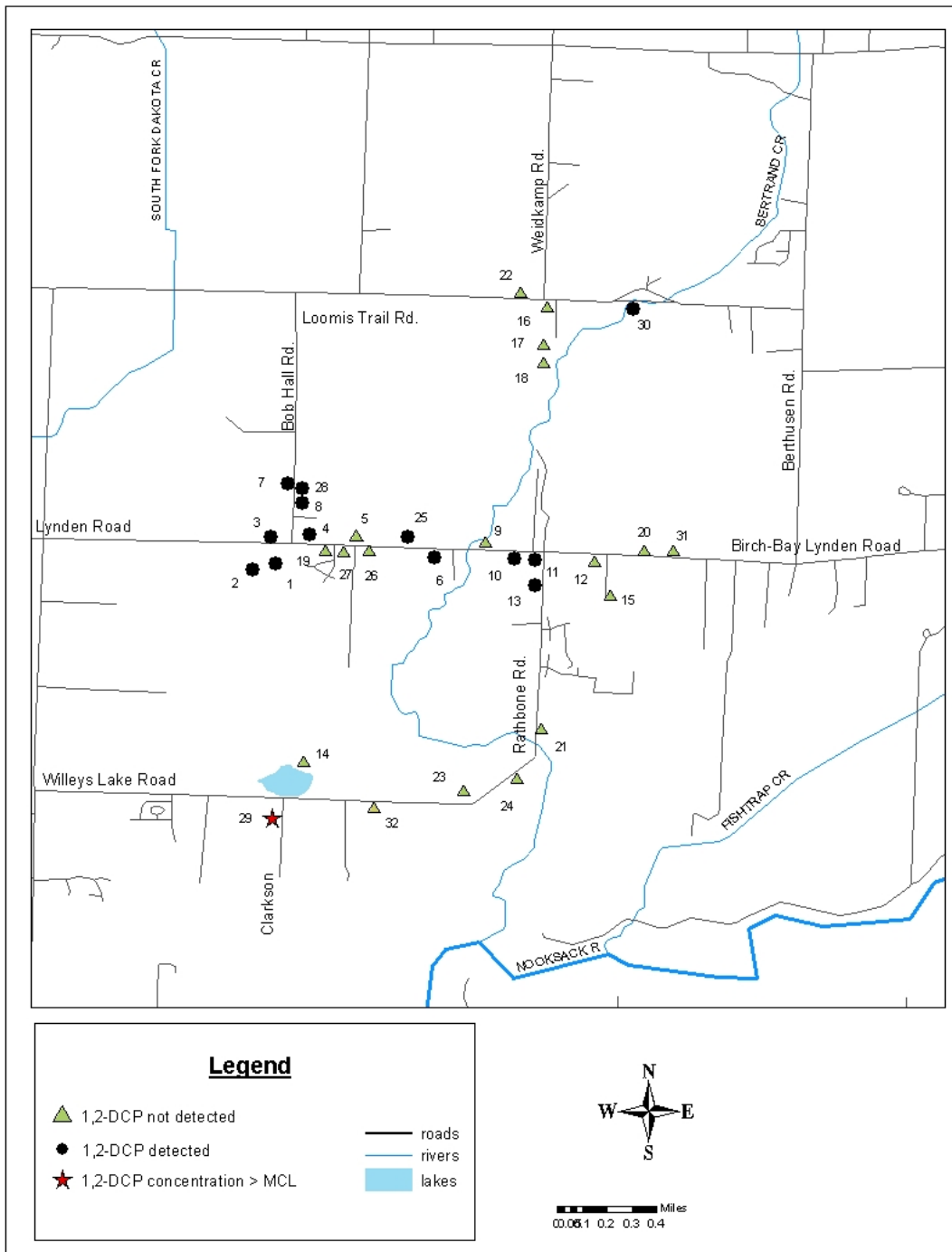


Figure 3. 1,2-DCP detections in groundwater.

DBCP

DBCP was detected in one well. There were no exceedances of the MCL of 0.2 ug/L. Figure 4 illustrates the locations of the groundwater wells impacted by DBCP.

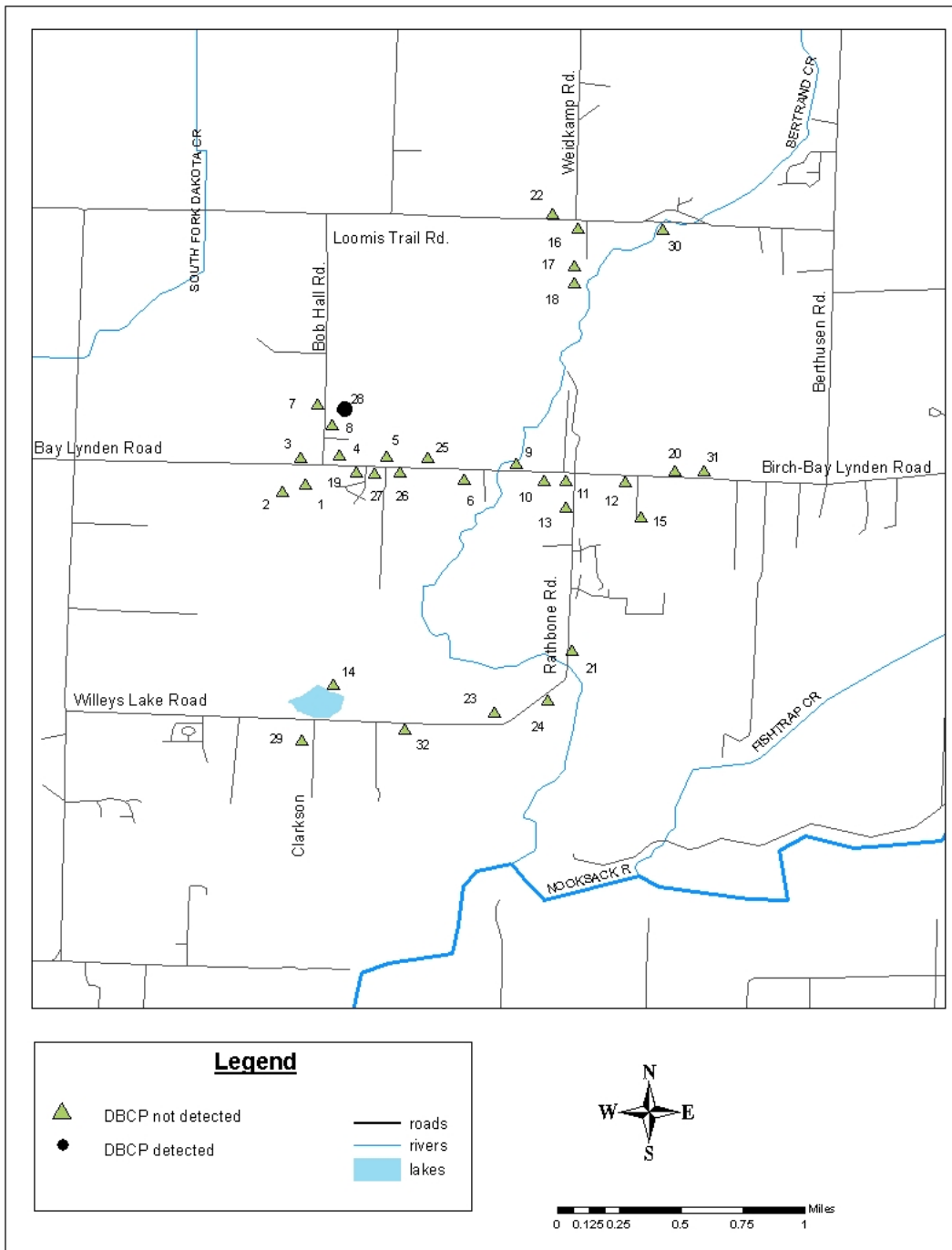


Figure 4. DBCP detections in groundwater.

1,2,3-TCP

1,2,3-TCP was detected in 4 wells (13%). There were no wells which exceeded the EPA lifetime health advisory of 40 ug/L. Figure 5 illustrates the locations of the groundwater wells impacted by 1,2,3-TCP.

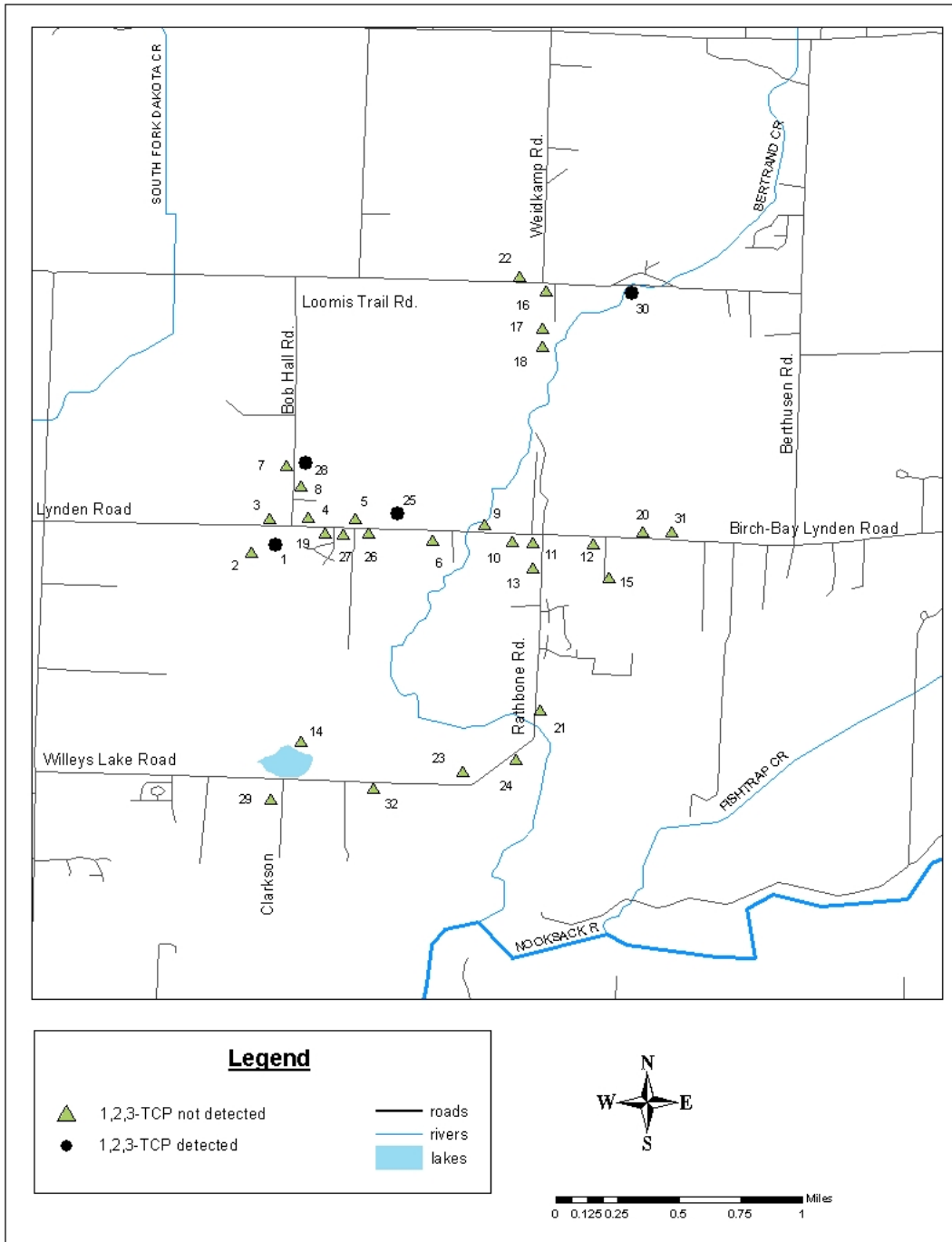


Figure 5. 1,2,3-TCP detections in groundwater.

Nitrate

Nitrate was detected in 31 wells (97%) in 2007, and 15 of these wells (47%) exceeded the MCL of 10 mg/L. Figure 6 illustrates the locations of the groundwater wells impacted by nitrate.

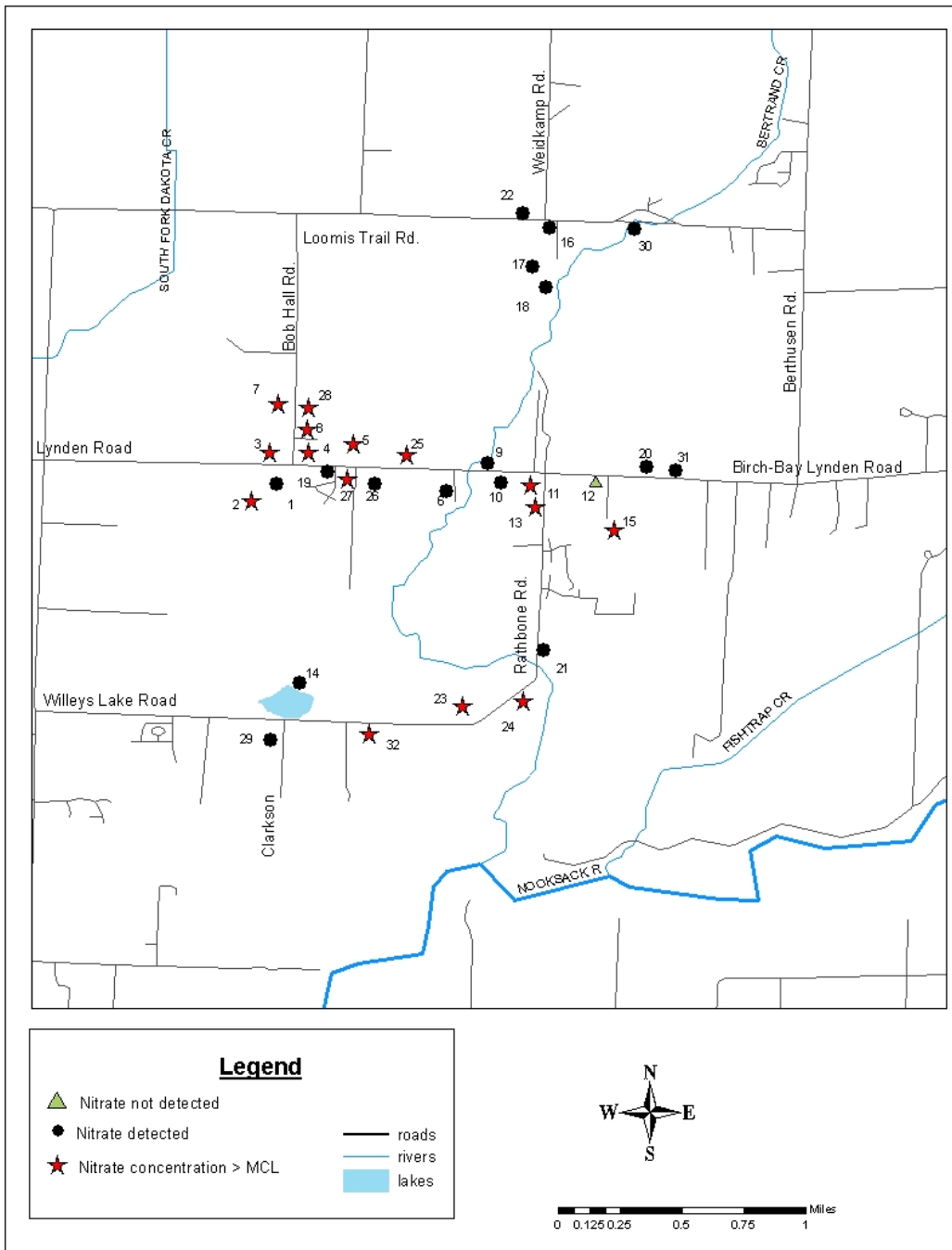


Figure 6. Nitrate detections in groundwater.

Comparative Results (1998/2007)

Nineteen of the 32 wells sampled in 2007 had been sampled in 1998. The remaining 13 of these 32 wells were sampled for the first time for pesticides in 2007.

Figures 7 through 11 compare the subset of 19 wells which were sampled both in 1998 and in 2007. A table comparing the results of the 1998 study to the 2007 study is included in Appendix B, Table B-1.

EDB

In 2007 EDB was detected in four (21%) of the wells which were sampled in 1998. For these same set of 19 wells sampled in both 1998 and 2007, EDB concentrations were the same or slightly greater in four wells in 2007. All of these four wells exceeded the MCL. There were no wells where the concentrations were less in 2007 than in 1998. These four wells are clustered together along Birch-Bay Lynden Road. Figure 7 illustrates the locations of the groundwater wells impacted by EDB.

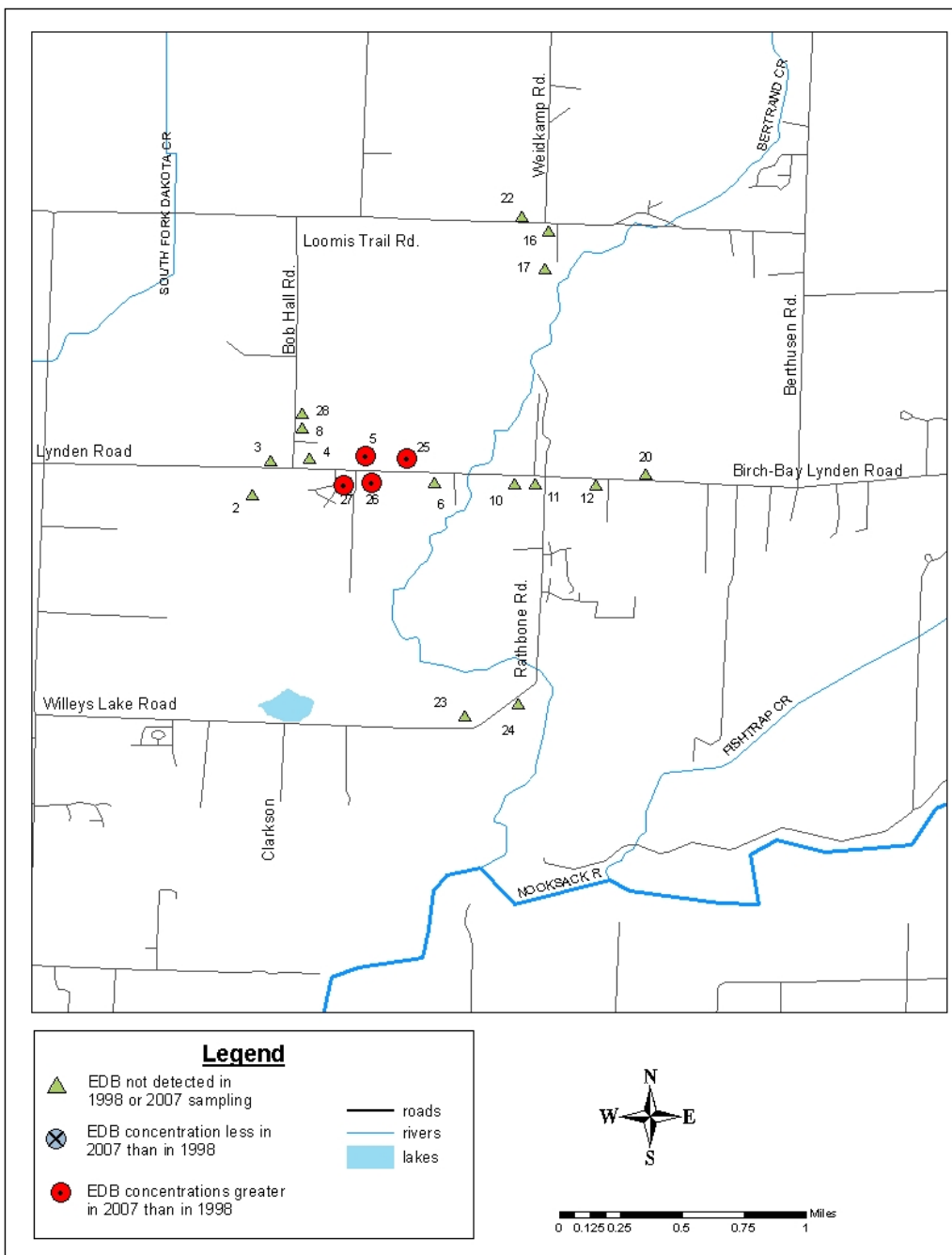


Figure 7. Comparative EDB results from 1998 and 2007 groundwater sampling.

1,2-DCP

1,2-DCP was detected in the same nine wells (47%) in 2007 as in 1998. One well had slightly greater concentrations in 2007 than in 1998. Eight wells (42%) have lower concentrations in 2007 than in 1998. Figure 8 illustrates the locations of the groundwater wells impacted by 1,2-DCP.

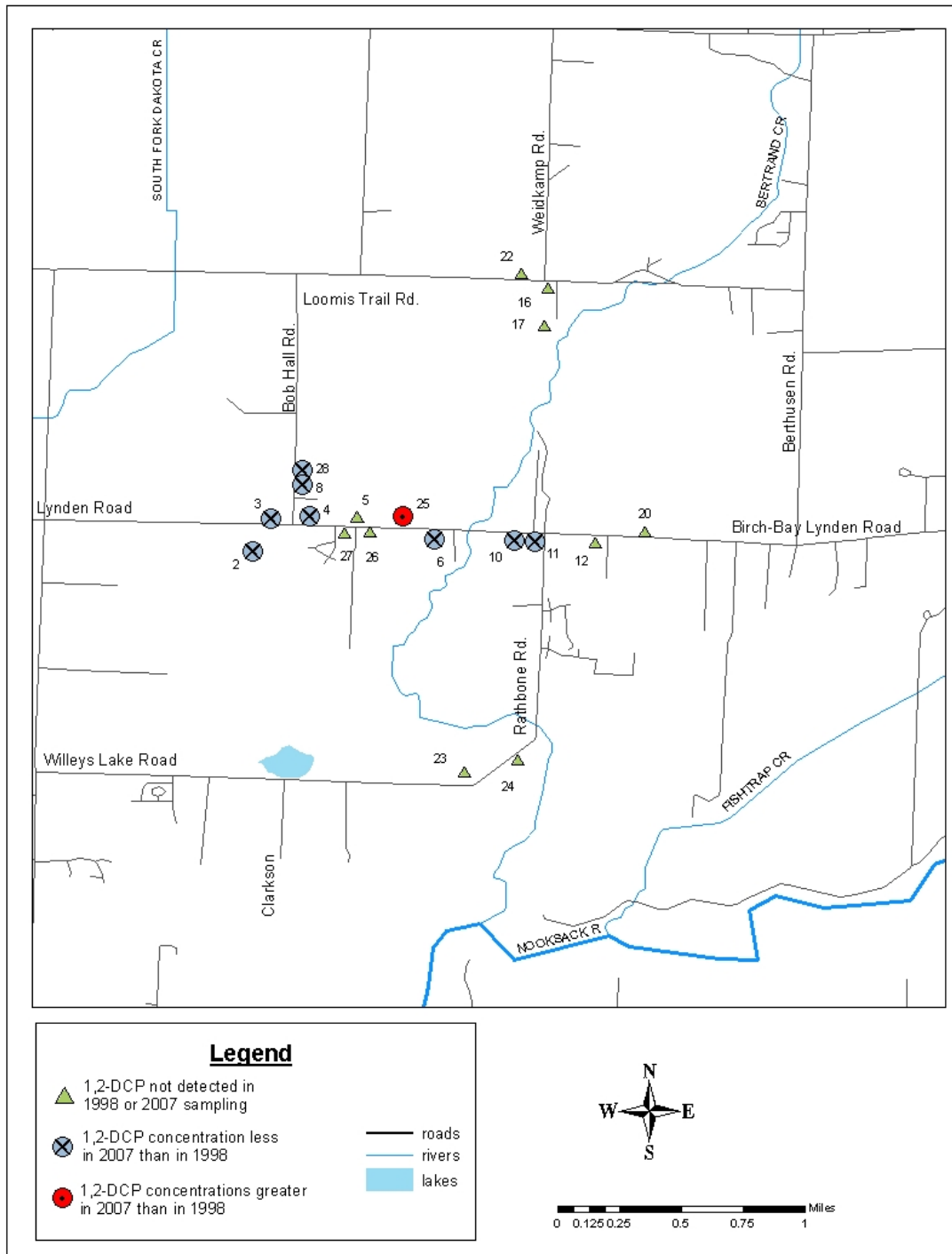


Figure 8. Comparative 1,2-DCP results from 1998 and 2007 groundwater sampling.

DBCP

DBCP was detected in one well in 2007. In 1998 there were two detections. There have never been any wells which have exceeded the MCL of 0.2 ug/L. One well had slightly greater concentrations in 2007 than in 1998, and one well had lower concentrations in 2007. Figure 9 illustrates the locations of the groundwater wells impacted by DBCP.

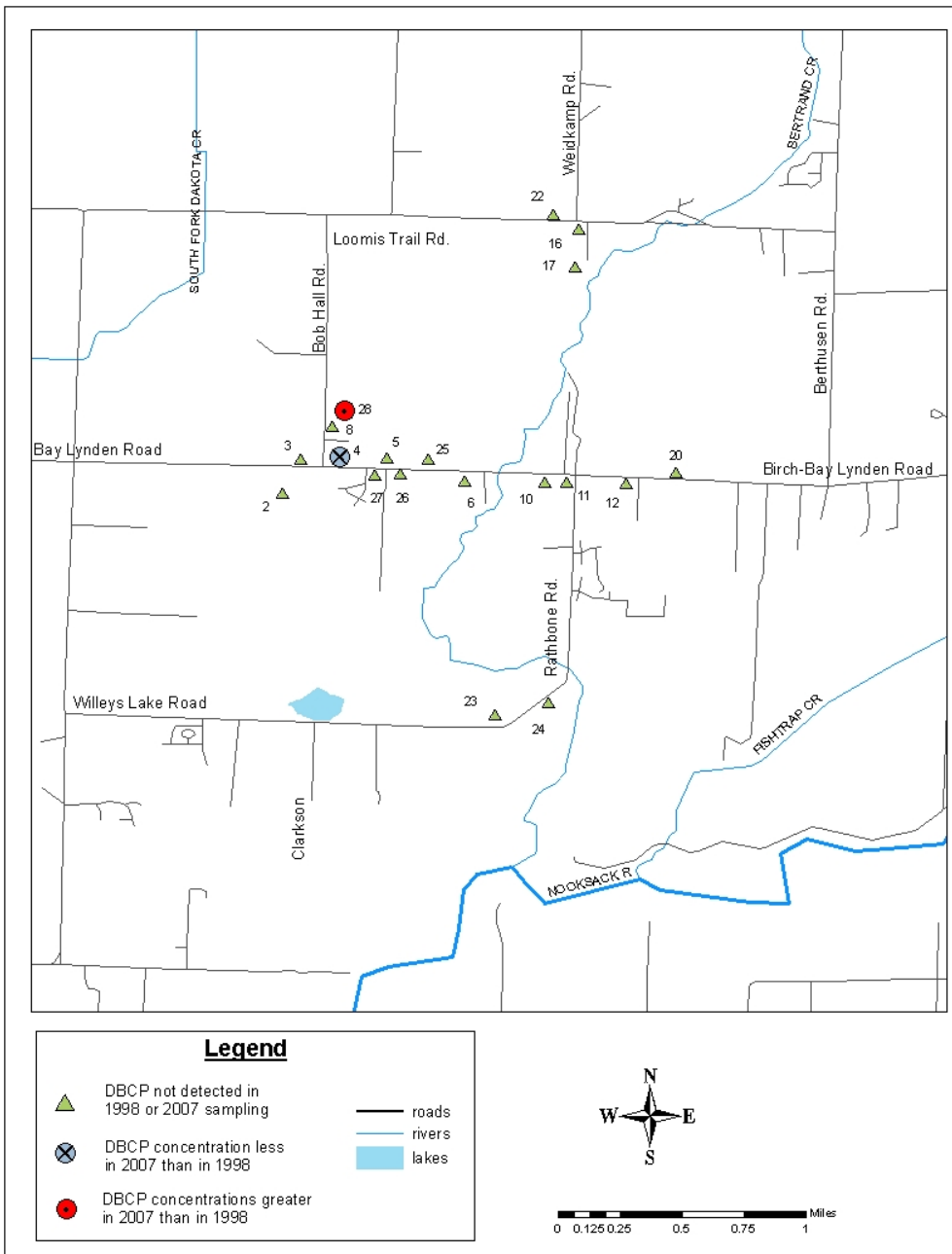


Figure 9. Comparative DBCP results from 1998 and 2007 groundwater sampling.

1,2,3-TCP

1,2,3-TCP was detected in 2 wells (11%) in 2007, which is a decrease from 1998 when there were seven detections (37%). No wells in either year exceeded the EPA lifetime health advisory of 40 ug/L. One well had slightly greater concentrations in 2007 than in 1998, and six wells (32%) had lower concentrations in 2007.

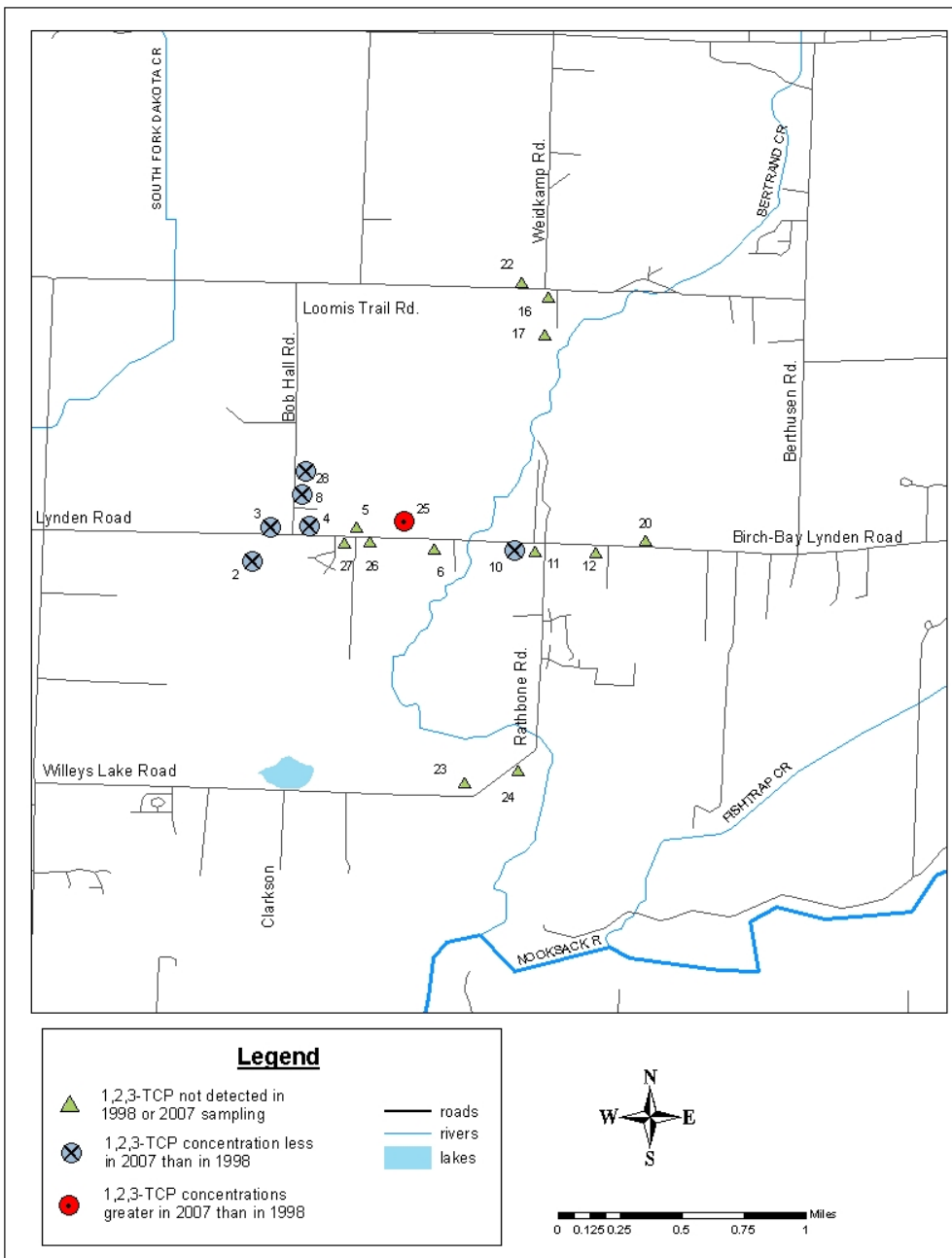


Figure 10. Comparative 1,2,3-TCP results from 1998 and 2007 groundwater sampling.

Nitrate

Sixteen wells were sampled for nitrate in both 1998 and 2007. Nitrate was detected in 15 of the 16 wells (94%) in 2007, and 10 of these wells (63%) exceeded the MCL of 10 mg/L. This is an increase from 1998 when five wells (31%) exceeded the MCL. Thirteen wells (81%) had greater concentrations in 2007 than in 1998, and three wells (19%) had lower concentrations in 2007.

Figure 11 illustrates the locations of the groundwater wells impacted by nitrate.

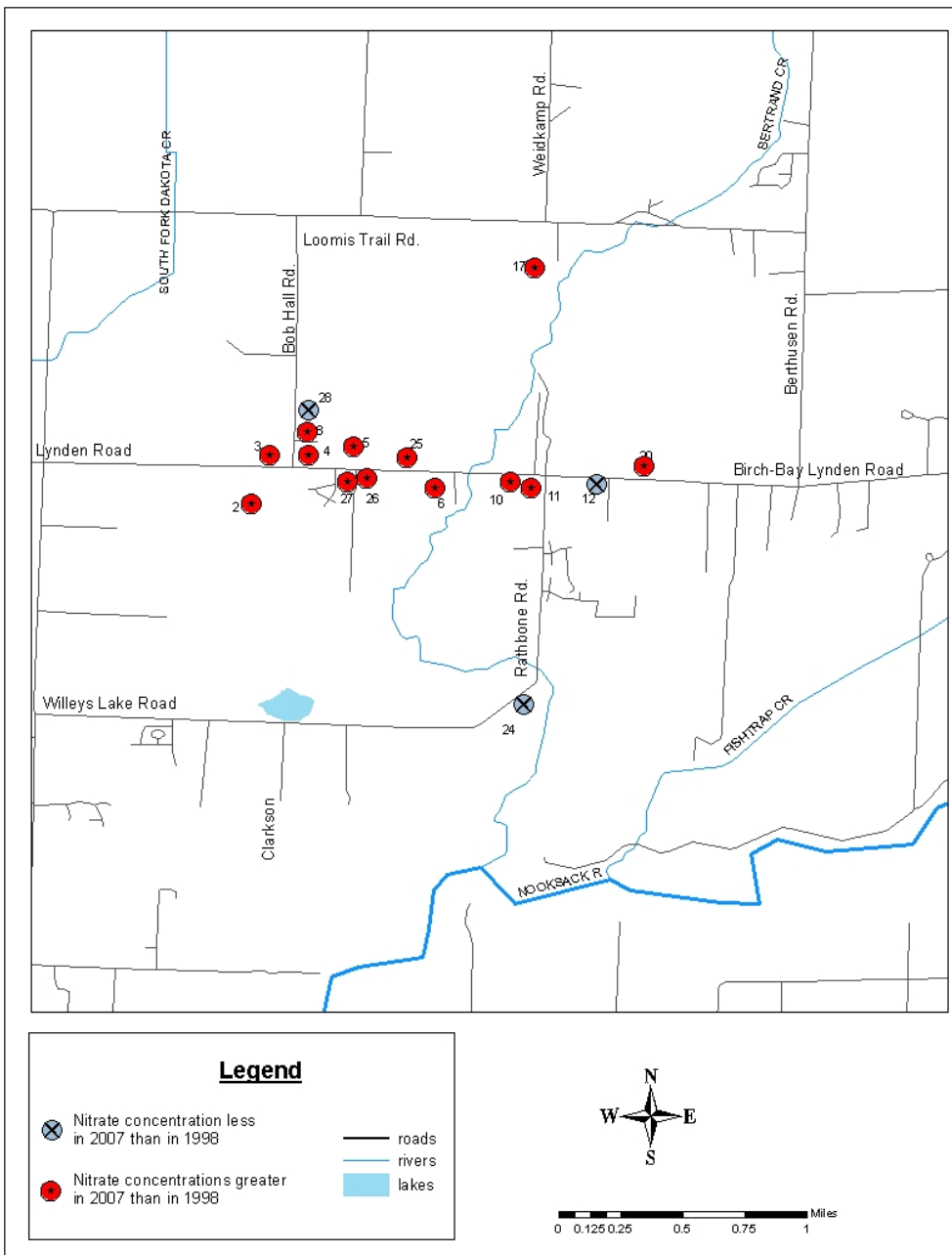


Figure 11. Comparative nitrate results from 1998 and 2007 groundwater sampling.

Comparative Summary Statistics

The data were also evaluated in a number of ways to try to determine the current state of groundwater. The data collected during this 2007 study were compared to the results of the 1998 study conducted by O'Herron to determine if water quality concentrations were higher, lower, or the same. This analysis considered the following for each of the four pesticides and nitrates:

- Frequency of detections (Figure 12).
- Number of wells exceeding the MCL (Figure 13).
- Number of wells that had higher concentrations (Figure 14).
- Maximum concentrations (Figure 15).
- Mean concentrations (Figure 16).

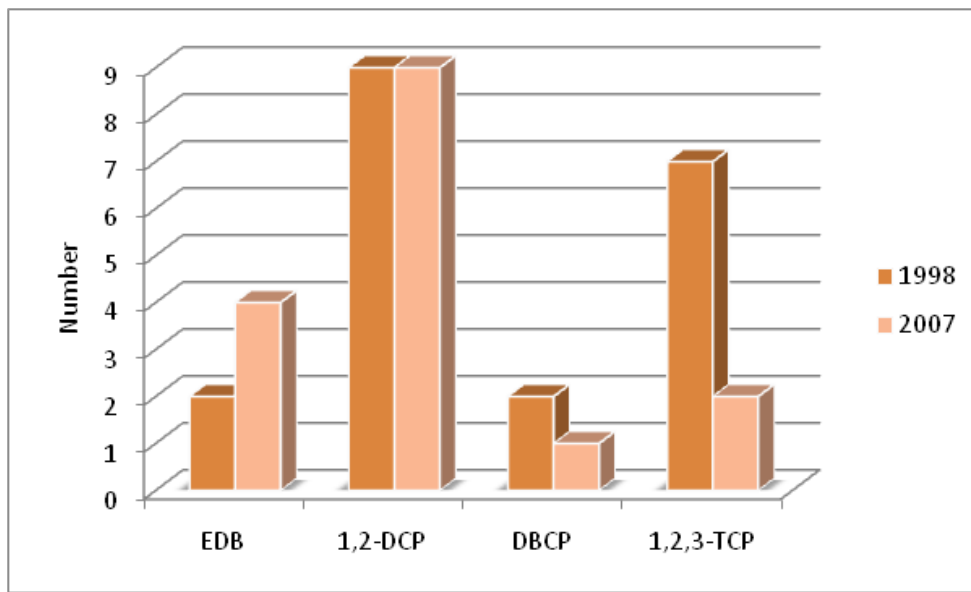


Figure 12. Number of pesticide detections comparing 1998 and 2007 results.

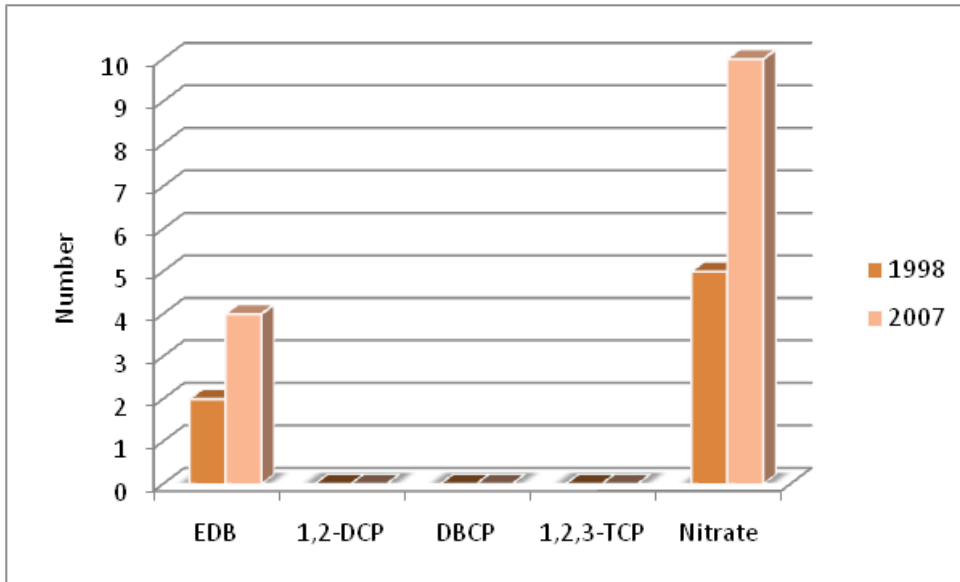


Figure 13. Number of wells exceeding an MCL for a contaminant comparing 1998 and 2007 results.

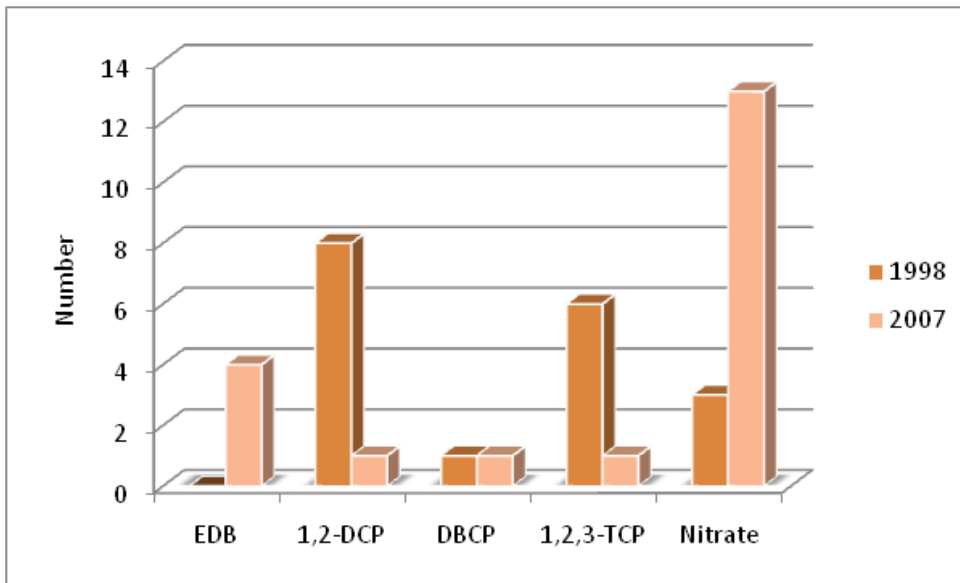


Figure 14. Number of wells that had higher concentrations comparing 1998 and 2007 results.

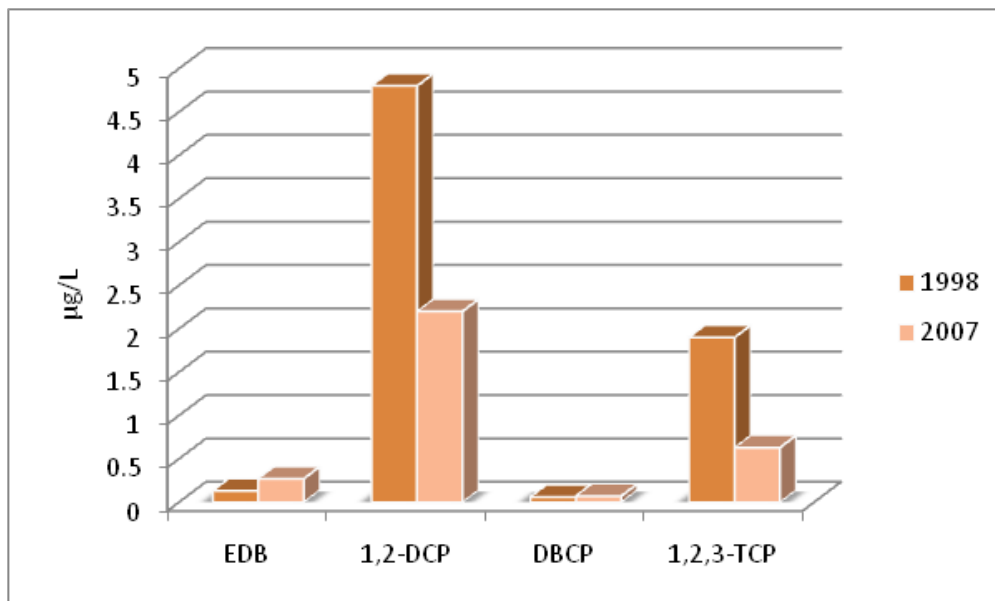


Figure 15. Maximum study concentrations comparing 1998 and 2007 results.

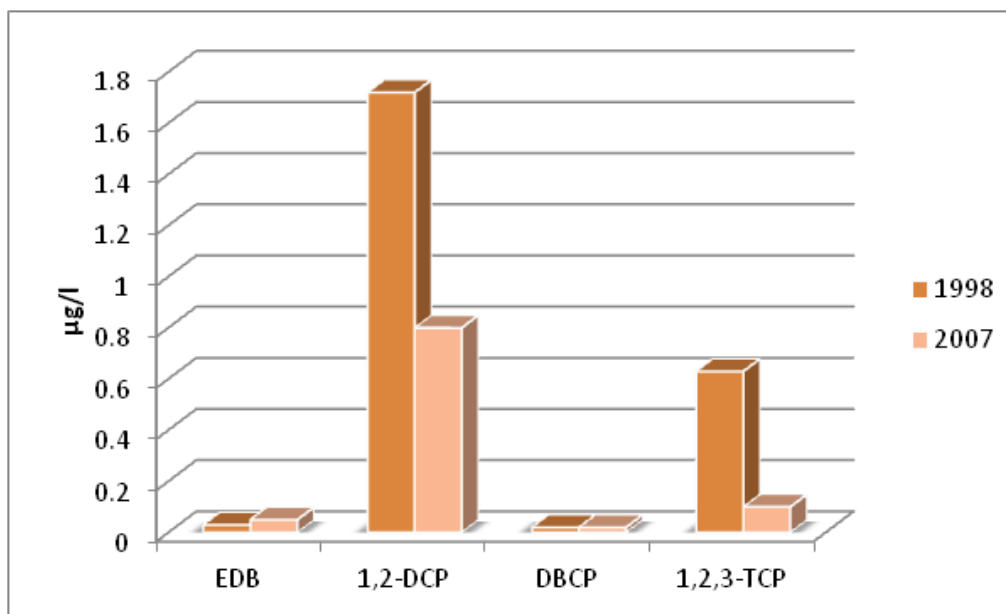


Figure 16. Mean study concentrations comparing 1998 and 2007 results.

New Wells Sampled in 2007

Table 3 presents a summary of the pesticide detections in the new wells sampled in 2007. Of the 13 new wells, seven wells (54%) contained pesticides. Two wells contained multiple pesticides, and three wells (23%) exceeded the MCL.

Table 3. Pesticide detections in the new wells sampled in 2007.

Well ID	EDB	1,2-DCP	DBCP	1,2,3-TCP
1	N/D	detected	N/D	detected
7	N/D	detected	N/D	N/D
9	N/D	N/D	N/D	N/D
13	N/D	detected	N/D	N/D
14	EDB > MCL	N/D	N/D	N/D
15	N/D	N/D	N/D	N/D
18	EDB > MCL	N/D	N/D	N/D
19	N/D	N/D	N/D	N/D
21	N/D	N/D	N/D	N/D
29	N/D	1,2-DCP > MCL	N/D	N/D
30	N/D	detected	N/D	detected
31	N/D	N/D	N/D	N/D
32	N/D	N/D	N/D	N/D

N/D = non detected.

Discussion

Data analyses considered concentrations of the four pesticides and nitrate, well locations, compliance with drinking water standards, and correlation with other contaminants. These analyses also compared the 19 wells sampled in both 1998 and 2007. Pesticides were not detected in 13 of the wells (41%) sampled during this 2007 study. The location of these wells is illustrated in Figure 17.

EDB

Currently there are wells which have EDB concentrations greater than the MCL of 0.05 ug/L. Additionally four of the wells (21%) sampled in 1998 and 2007 had the same or greater concentrations in 2007 (Table 4). Figure 7 illustrates that the location of these wells are clustered together along Birch Bay-Lynden Road.

Table 4. EDB concentrations (ug/L) in groundwater samples, 1998 and 2007.

Well ID	1998	2007
5	0.130	0.130
25	0.120	0.270
26	0.020	0.130
27	0.014	0.120

The rise in EDB concentrations since 1998 could be attributed to several factors:

- The increased concentrations detected in these four wells are very small, ranging from 0 to 0.15 ug/L. The variations in EDB concentrations are typical of the variability that occurs with low EDB concentrations, similar to subsurface observations made by Pignatello and Cohen (1990).
- The concentration is affected by the relative timing of sample collections with respect to precipitation events.
- The EDB plume is naturally migrating south in groundwater.
- It is highly unlikely that this is a result of a new or continued source of pesticide, since it was determined that the presence of EDB in groundwater is the result of residue from legal applications prior to being banned in 1983 (O'Herron, 1998a).
- Overall the EDB concentrations have declined dramatically since pesticide contamination was first detected in groundwater in the 1980s.

One well had detectable concentrations of both EDB and 1,2-DCP in 1998 and 2007 (Table B-1, Appendix B). This may indicate different fate and transport mechanisms based on the chemical characteristics. Or there could have been a lag time between when EDB was used and when 1,2-DCP was used, since 1,2-DCP was substituted for EDB when EDB was banned in 1983.

EDB concentrations can also be compared to the results presented by Mayer et al. (1991) since their work was also conducted in the Sumas-Blaine aquifer. Using a first-order kinetics decay model to determine the projected concentrations of EDB in groundwater for the year 2007, this model estimates the 2007 concentration to be 0.055 ug/L, which is relatively close to the mean EDB concentration of 0.047 ug/L monitored in this 2007 study.

1,2-DCP

Wells which had detectable concentrations of 1,2-DCP in 1998 were the only wells in 2007 which also had detectable concentrations of 1,2-DCP. One well had greater concentrations in 2007 compared to 1998, and eight wells had lower concentrations in 2007.

1,2-DCP appears to be negatively correlated with EDB but positively correlated with 1,2,3-TCP. More wells had detected 1,2-DCP when EDB concentrations were below detection levels. There is only one well, #25, which had detectable concentrations of both EDB and 1,2-DCP. 1,2-DCP was always detected whenever 1,2,3-TCP was detected.

DBCP

DBCP was detected in one well, #28, in 2007 and two wells in 1998. The DBCP concentration in well #28 was greater in 2007 than the concentration reported in 1998. There were no wells which exceeded the MCL in either study.

1,2,3-TCP

1,2,3-TCP was detected in fewer wells in 2007 than in 1998. There were no wells which exceeded the EPA lifetime health advisory in either 1998 or 2007. The majority of wells with detectable levels of 1,2,3-TCP showed lower concentrations in 2007 than in 1998.

There were four wells with detections of 1,2,3-TCP in 2007, and well #25, had a slightly greater concentration in 2007 than in 1998.

Nitrate

Nitrate concentrations in the aquifer appear to be consistent with the increasing trend reported in Redding (2008). Sixty-three percent of the wells sampled exceeded the nitrate MCL of 10 mg/L in 2007.

Eighty-one percent of the 16 wells that were tested in both this 2007 study and the 1998 study had higher nitrate concentrations in 2007. The mean nitrate concentration increased from 7.6 mg/L in 1998 to 9.5 mg/L in 2007.

Comparative Summary Statistics (1998/2007)

Of the 19 wells sampled in both 1998 and 2007:

- There were more detections in 2007 than in 1998 for EDB. There were fewer detections in 2007 for DBCP and 1,2,3-TCP (Figure 12).
- There were more wells which exceeded the MCL for EDB and nitrate in 2007 than in 1998 (Figure 13). There were no wells which exceeded the MCL for 1,2-DCP, DBCP, or the lifetime health advisory for 1,2,3-TCP.
- In 21% of wells, EDB concentrations were higher in 2007 than in 1998 (Figure 14).
- The maximum concentration of EDB detected during the 2007 study was slightly greater than in 1998 (Figure 15). The maximum concentration was greater in the 1998 study for 1,2-DCP and 1,2,3-TCP.
- Mean EDB and nitrate concentrations were higher in the 2007 study than in 1998 (Figure 16).
- Mean 1,2-DCP and 1,2,3-TCP concentrations were lower in the 2007 study than in 1998 (Figure 16).
- At least one pesticide MCL was exceeded in 21% of the wells sampled in 2007 (Figure 17) and in 11% of the wells sampled in 1998.
- The nitrate MCL was exceeded in 63% of the wells sampled in 2007 and in 31% of the wells sampled in 1998.
- Eighty-one percent of the wells had greater nitrate concentrations in 2007 than in 1998 (Figure 14).

Study Limitations

Although it was included as a goal of this project, it was not possible to delineate the areas of the aquifer which are still contaminated by pesticides. The well selection was limited to the Bertrand Creek area and the willingness of residents to participate in this study. The Meadowdale area was excluded since the residents are no longer drinking contaminated groundwater. Additionally, the wells selected for sampling are not adequately distributed across the aquifer to make this type of delineation. All wells sampled were private domestic wells; none were monitoring wells.

The study was actually designed to: (1) determine where there is a potential human health risk for the residents using groundwater, and (2) track groundwater concentration trends over time.

Pesticide occurrence maps were developed to determine the areal distribution of contaminants (Figures 2 – 5 and Figure 17). While these maps are useful in determining relative areas of concern, they cannot be used to delineate precise plumes of groundwater contamination. This is due to the limited number of wells sampled and their relative proximity to roads.

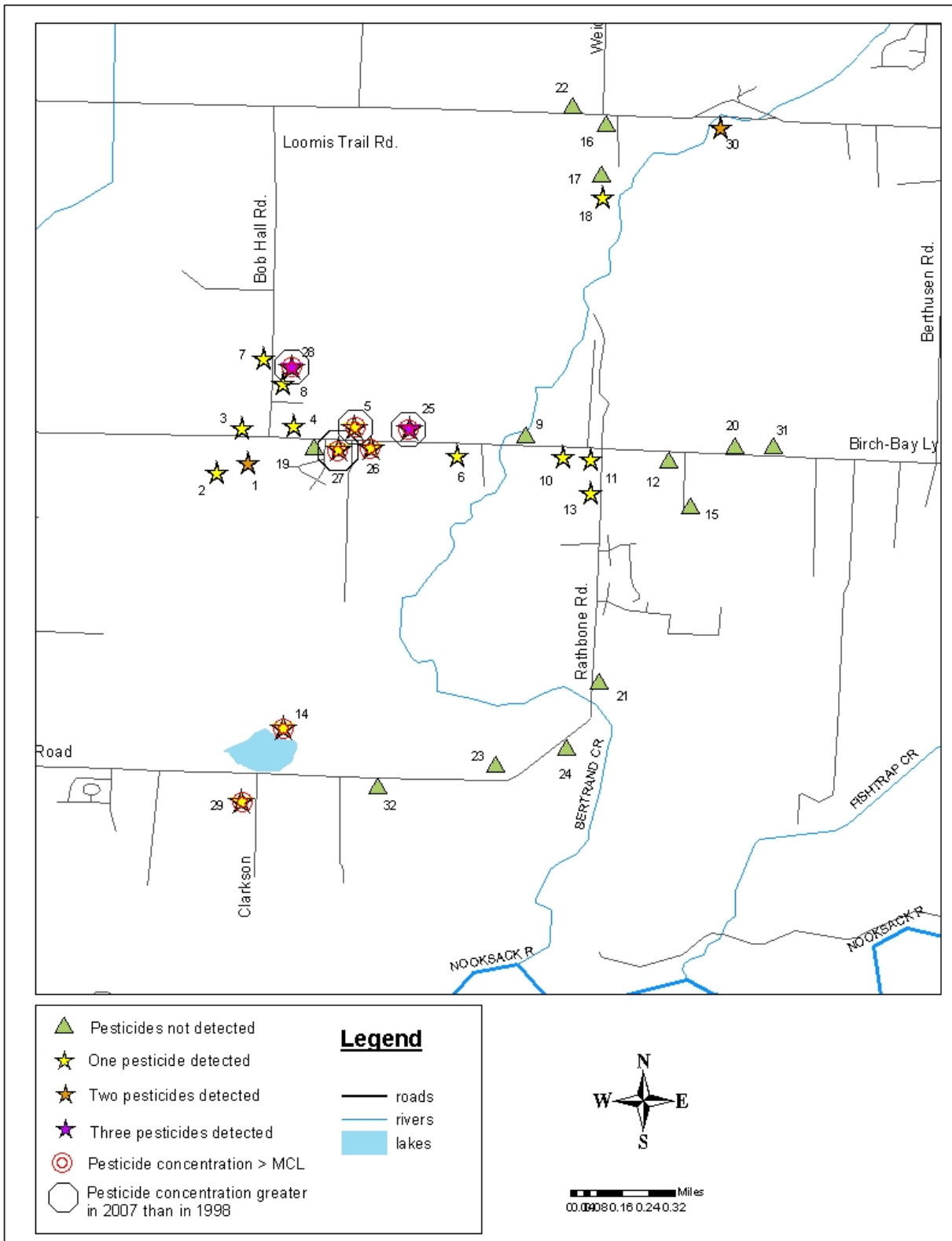


Figure 17. Pesticide occurrence.

Conclusions

Pesticides are still present in groundwater within the Bertrand Creek study area. EDB and 1,2-DCP were the primary focus of this study; however, 1,2,3-TCP and DBCP were also detected. There were detections for one or more of these four pesticides in 59% of the 32 wells sampled. Twenty-two percent of the wells exceeded a maximum contaminant level (MCL) for a pesticide. Table 5 summarizes the findings of this study.

Table 5. Contaminants present in groundwater.

EDB	While EDB concentrations detected in groundwater were higher in 2007 than in 1998, this may not constitute a significant increase since many of the concentrations were detected at very low levels. EDB concentrations have declined dramatically since 1991 when Mayer et al. (1991) found a maximum EDB concentration of 6.17 ug/L, compared to the maximum concentration of 0.27 ug/L detected in 2007. EDB concentrations monitored in this 2007 study are consistent with the published EDB degradation rate projections from 16 years ago, which project that EDB will be detectable in groundwater until the year 2012. EDB is still present in approximately 20% of the wells sampled, at concentrations exceeding the drinking water maximum contaminant level (MCL). EDB remains a contaminant of concern for users of private domestic wells in the Sumas-Blaine aquifer.
1,2-DCP	1,2-DCP is present in almost half of the wells sampled. The concentrations are generally lower than in previous studies; however, one new well sampled exceeded the drinking water MCL. 1,2-DCP remains a contaminant of concern for users of private domestic wells in the aquifer.
DBCP	DBCP detections in groundwater are low, and concentrations for all wells sampled are below the drinking water MCL. DBCP does not appear to present a widespread concern.
1,2,3-TCP	1,2,3-TCP detections in groundwater are low, and concentrations for all wells sampled are below the lifetime health advisory. 1,2,3-TCP does not appear to present a widespread concern.
Nitrate	Nitrate was detected in almost every well sampled, with approximately half of those wells exceeding the drinking water MCL. Nitrate remains a contaminant of concern for users of private domestic wells in the Sumas-Blaine aquifer.

Overall, these results indicate that EDB and nitrate concentrations were higher in 2007 than in 1998, and DBCP and 1,2,3-TCP were lower in 2007 than in 1998.

A total of 54% of the 13 wells that had never been sampled previously had detected levels of pesticides, and 23% contained pesticide concentrations which exceeded a MCL. This raises concern that there may be additional residents who are unknowingly drinking water with elevated concentrations of pesticides.

Based on the relatively similar pesticide concentrations detected in private domestic wells in 2007, the Washington State Department of Health risk assessment conclusions made in 2000 (Duff) may still be valid.

Recommendations

To protect public health, as well as manage and assess groundwater and drinking water contamination, the following recommendations are made:

- Continue monitoring domestic supply wells for EDB, 1,2-DCP, and nitrate. All wells where a pesticide did not meet a drinking water standard should be monitored. Monitoring should be conducted every five years for the wells listed in Table 6.

Table 6. Recommended well sampling locations and rationale for future monitoring.

Well ID	Rationale
1	1,2-DCP and 1,2,3-TCP detected.
5	EDB concentration > MCL.
13	Elevated 1,2-DCP.
14	EDB concentration > MCL.
18	EDB concentration > MCL.
25	EDB, 1,2-DCP, and 1,2,3-TCP detected; EDB concentration > MCL.
26	EDB concentration > MCL.
27	EDB concentration > MCL.
28	1,2-DCP, DBCP, and 1,2,3-TCP detected.
29	1,2-DCP concentration > MCL.
30	1,2-DCP and 1,2,3-TCP detected.

- This study was not a comprehensive study. Not all the wells in the area were sampled. Residents who have pesticides detected in their wells, or are concerned about the presence of pesticides in their drinking water, should have their water tested.
- Continue to educate residents about the current state of groundwater, the potential health effects, and options available to them.
- Continue to support the alternative drinking water program for qualifying households.
- Monitor additional private drinking water wells in the area where groundwater sampling has not previously occurred but where pesticides may impact drinking water sources.
- The Washington State Department of Health should evaluate the 2007 data to determine if the 2000 health risk assessment conclusions are still valid.

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Appendices

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Appendix A. Groundwater Quality Results

Table A-1. 2007 Groundwater concentrations for pesticides and nitrates.

Well ID	EDB		1,2-DCP		DBCP		1,2,3-TCP		NO ₃	
	ug/L		ug/L		ug/L		ug/L		mg/L	
1	0.020	u	1.90		0.020	u	0.340	j	7.65	
2	0.020	u	1.30		0.020	u	0.046	j	14.25	
3	0.020	u	1.10		0.020	u	0.091	j	16.2	
4	0.020	u	1.70		0.020	j	0.180	u	10.1	
5	0.130		0.20	u	0.020		0.020	u	11.9	
6	0.020	u	1.30		0.020	u	0.020	j	0.504	
7	0.020	u	1.70		0.020	u	0.390	j	16.5	
8	0.020	u	1.90		0.019	u	0.200	uj	13.1	
9	0.020	uj	0.20	u	0.020	j	0.020	j	4.15	
10	0.019	u	2.20		0.019	uj	0.190	j	5.02	
11	0.020	u	1.80		0.020	u	0.018	u	11.8	
12	0.020	u	0.20	u	0.020	u	0.020	j	0.01	
13	0.020	u	4.10		0.020	u	0.290	j	17.5	
14	0.063		0.20	u	0.020	u	0.020	u	6.54	
15	0.020	u	0.20	u	0.020	u	0.020	u	13.8	
16	0.020	u	0.20	u	0.020	u	0.020	u	3.93	
17	0.020	u	0.20	u	0.020	u	0.020	u	6.4	
18	0.098		0.19	j	0.021	u	0.072	j	4.86	
19	0.020	u	0.20	u	0.020	u	0.020	u	7.78	
20	0.020	u	0.20	u	0.020	u	0.020	u	3.005	
21	0.020	u	0.20	u	0.020	u	0.020	u	6.84	
22	0.020	u	0.20	u	0.020	u	0.020	u	8.58	
23	0.020	u	0.20	u	0.020	u	0.020	u	21.5	
24	0.020	u	0.20	u	0.020	u	0.020	u	10.7	
25	0.270		1.04		0.020	u	0.625	e	12.45	
26	0.130		0.20	u	0.020	u	0.020	u	9.38	
27	0.120		0.20	u	0.020	u	0.020	u	15.6	
28	0.020	u	0.92		0.071		0.270		11.3	
29	0.020	u	12.00	j	0.020	u	0.020	u	3.08	
30	0.020	u	0.78		0.020	u	0.300		3.14	
31	0.020	u	0.20	u	0.020	u	0.020	u	6.55	
32	0.020	u	0.20	u	0.020	u	0.020	u	24.5	

Bold = detection.

Red and *italics* = standard exceedance.

u = value below the detection limit.

j = contaminant positively identified, value is approximate.

uj = contaminant is not detected at or above the estimated value.

e = estimated value.

Table A-2. Field Measurements.

Well ID	pH	Temperature	Electrical Conductivity	Dissolved Oxygen
	Std units	° C	µmhos/cm	mg/L
1	5.88	10.3	177	8.83
2	6.38	8.9	314	3.08
3	5.7	8.5	292	8.47
4	5.63	10.2	188	9.75
5	5.96	7.2	318	3.87
6	6.2	10	184	4.28
7	5.66	8.7	274	9.93
8	5.54	8.1	305	4.86
9	6.12	9.2	121	9.18
10	6.43	10.6	132	10.05
11	5.94	10.8	258	8.06
12	7.27	10.2	329	0.03
13	5.87	11.1	265	9.39
14	6.38	8.1	174	9.26
15	2.79	10.5	206	9.6
16	5.86	10.2	95	8.82
17	6.28	9.9	240	6.87
18	6.21	9.8	167	6.41
19	6.37	5.2	237	8.02
20	6.25	8.8	132	8.16
21	5.91	11.8	260	7.97
22	5.71	8	191	10.12
23	6.02	9.5	323	9.52
24	6.23	10	202	8.52
25	5.64	10.7	281	9.84
26	6.07	10.8	260	7.11
27	5.75	12.8	337	5.23
28	5.45	9	234	3.52
29	6.45	7.6	165	9.45
30	6.01	8.2	159	9.8
31	6.34	8.1	324	2.71
32	5.46	8.9	387	8.8

Appendix B. Comparison of Groundwater Quality Results to 1998 Study Results

Table B-1. Groundwater concentrations comparing 2007 and 1998 results for the 19 wells sampled in both years.

Well ID	EDB		1,2-DCP		DBCP		1,2,3-TCP		NO ₃	
	2007	1998	2007	1998	2007	1998	2007	1998	2007	1998
	ug/L		ug/L		ug/L		ug/L		mg/L	
2	0.020	0.020	1.30	1.9	0.020	0.02	0.046	0.26	<i>14.25</i>	8.72
3	0.020	0.020	1.10	2.6	0.020	0.02	0.091	1.1	<i>16.2</i>	<i>13.1</i>
4	0.020	0.020	1.70	4.3	0.020	0.046	0.180	1.5	<i>10.1</i>	7.37
5	<i>0.130</i>	<i>0.130</i>	0.20	0.25	0.020	0.02	0.020	0.25	<i>11.9</i>	8.94
6	0.020	0.020	1.30	3.5	0.020	0.02	0.020	0.25	0.50	0.29
8	0.020	0.020	1.90	3.9	0.019	0.0086	0.200	1.9	<i>13.1</i>	9.06
10	0.019	0.020	2.20	4.8	0.019	0.02	0.190	0.89	5.02	3.41
11	0.020	0.020	1.80	4.6	0.020	0.02	0.018	0.15	<i>11.8</i>	7.9
12	0.020	0.010	0.20	0.25	0.020	0.01	0.020	0.5	0.01	0.19
16	0.020	0.010	0.20		0.020	0.01	0.020	0.5	3.93	
17	0.020	0.010	0.20	0.25	0.020	0.01	0.020	0.5	6.4	5.36
20	0.020	0.010	0.20	0.25	0.020	0.01	0.020	0.5	3.01	1.14
22	0.020	0.010	0.20	0.14	0.020	0.01	0.020	0.5	8.58	
23	0.020	0.010	0.20	0.25	0.020	0.01	0.020	0.5	<i>21.5</i>	
24	0.020	0.010	0.20	0.25	0.020	0.01	0.020	0.5	<i>10.7</i>	<i>16.3</i>
25	<i>0.270</i>	<i>0.120</i>	1.04	0.77	0.020	0.02	0.625	0.59	<i>13.1</i>	<i>12.45</i>
26	<i>0.130</i>	0.020	0.20	0.25	0.020	0.02	0.020	0.25	9.38	4.97
27	<i>0.120</i>	0.014	0.20	0.25	0.020	0.02	0.020	0.25	<i>15.6</i>	<i>10.7</i>
28	0.020	0.020	0.92	2.4	0.071	0.058	0.270	1	<i>11.3</i>	<i>11.7</i>

Bold = detection.

Red and *italics* = standard exceedance.

Shaded = greater concentration in 2007 than in 1998.

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Appendix C. Quality Assurance and Quality Control

Quality Assurance

Table C-1. Field duplicate data.

Well ID	Sample number	EDB	RPD	1,2-DCP	RPD	DBCP	RPD	1,2,3-TCP	RPD	NO ₃	RPD
		ug/L	%	ug/L	%	ug/L	%	ug/L	%	mg/L	%
14	07054143	0.081	57.143	<0.20	N/A	<0.020	N/A	<0.020	N/A	6.82	8.563
	07054144	0.045		<0.20		<0.020		<0.020		6.26	
16	07054145	<0.020	N/A	<0.20	N/A	<0.020	N/A	<0.020	N/A	3.8	6.616
	07054146	<0.020		<0.20		<0.020		<0.020		4.06	
25	07064156	0.270	0.000	0.98	11.538	<0.020	N/A	0.620	1.600	13.1	10.442
	07064157	0.270		1.10		<0.020		0.630		11.8	
30	07064162	<0.020	N/A	0.76	5.128	<0.020	N/A	0.300	0.000	3.25	7.006
	07064163	<0.020		0.80		<0.020		0.300		3.03	

RPD = relative percent difference.

NO₃ = nitrate.

N/A = not applicable.

Bold = detected concentrations.

Shaded = exceeds the measurement quality objective (MQO).

Duplicates

Field duplicate samples were used to measure the precision of the entire sampling and analytical process. Field duplicates are two samples collected from the same location at the same time. The duplicates were submitted as blind samples to the laboratory. Differences in the concentrations can be the result of natural heterogeneities in the aquifer, sample collection procedures, variances in the sample containers, preservation methods, or the analytical procedure. Duplicate samples were collected from 13% of the wells sampled.

Laboratory duplicates were used to estimate analytical precision. This entails analysis of duplicate aliquots from a single sample container. Analytical duplicates run by the laboratory are typically used with one of the field duplicates to estimate total and analytical variability from the same sample. The relative percent difference (RPD) is a tool to measure the variability between samples. This is the ratio of the difference of the duplicate results and the mean of the duplicate results expressed as a percentage. The RPD is used to measure analytical precision; the lower the RPD, the more precise the results are (Lombard and Kirchmer, 2004).

Blanks

Method blanks determine bias due to laboratory contamination. This is an analytical tool performed by the laboratory to measure the theoretical concentration of zero. The blanks are prepared and analyzed along with the samples to measure any impacts to the samples from the analytical process.

Control Samples

Laboratory control samples, or check samples, are samples prepared with a known concentration of an analyte prepared independently of the calibration standards. This type of quality control is used to verify the analytical precision, and to determine the level of bias due to calibration (Lombard and Kirchmer, 2004).

Matrix Spikes

Matrix spikes are a process of adding a known amount of an analyte to a portion of one of the submitted samples. Matrix spike recoveries indicate bias due to interference from elements in the sample matrix.

Surrogate Standard

A surrogate standard is a type of spike added to each sample in a known amount at the beginning of the analytical process. The surrogate compound is not expected to be present in the sample, but is similar to one of the target analytes.

Field Quality Control Procedures

The data quality assurance performance requirements are described in the Quality Assurance Project Plan (Redding, 2007). The following protocols were used to maintain quality control during field sampling:

- All field meters were calibrated in accordance with manufacturer's instructions and according to the regulatory requirements, at the beginning of the sampling day and again at midday. Fresh, commercially prepared standards were used for calibration.
- All non-dedicated sampling equipment (Y-fittings and tubing connectors) were cleaned between wells. Equipment decontamination consisted of an initial washing in a mild solution (0.02%) of phosphate-free detergent followed by a de-ionized water rinse.
- Sampling equipment and materials were selected based on their compatibility with the parameters of interest to prevent bias in sample results.
- Sampling teams employed a "clean hands/dirty hands" approach to sample collection. One sampler was responsible for filling and handling the sample bottles at each site. The designated sampler wore a pair of clean sampling gloves prior to touching and/or opening bottles, filters, tubing, and other equipment that could potentially come into contact with the sampled water.

- Four field duplicate samples were collected at a ratio of one duplicate for every 8 samples (13% duplicates) and submitted to the laboratory blind.
- Standardized field forms were used to track and describe all field procedures, to record field parameters and sample identification numbers, and to describe any necessary deviations from the planned purging and sampling procedure described here.

Analysis of all samples was performed within the method's established holding times.

Field Duplicates

Sample numbers 07054143 and 07054144 are field duplicates for EDB. The RPD for these values is 57%, which exceeds the measurement quality objective (MQO) of +/-30%. The closer the values are to the reporting limit, the greater the variability. Therefore, with values close to the detection limit, the RPD is a less precise tool for measuring error. (Westerlund, 2007). All other quality assurance parameters were within the acceptable range.

Laboratory Quality Control Procedures

Manchester Environmental Laboratory routine quality control procedures (method blanks, duplicates, matrix spikes, and check standards) were used to demonstrate laboratory precision and accuracy. These procedures determine if the project MQOs were met. Precision can be estimated from duplicate and check standards, duplicate sample analysis, and duplicate spiked sample analyses. Bias was estimated from matrix spikes, matrix spike duplicates, and check standards. Recoveries from check standards provide an estimate of bias due to calibration. Mean percent recoveries of spiked sample analyses provide an estimate of bias due to interference.

Instrument Calibration

The calibration of the instruments was acceptable according to laboratory standards. Instrument calibrations and checks were performed in accordance with the appropriate method. All initial and continuing calibration checks were within control limits.

Laboratory Duplicates

The laboratory duplicates were within the acceptable range of 0% to 20% RPD.

Blanks

No analytically significant levels of target analytes were detected in the method blanks associated with these samples.

Concentrations of contaminants in the travel blank were less than detection limits for all parameters analyzed.

Matrix Spikes

Matrix spike recoveries were conducted for nitrate+nitrite and were within the acceptable limits.

Control Samples

The laboratory control sample recoveries for all target analytes were within the acceptable limits.

Surrogates

EDB: All of the surrogate recoveries were within the current control limits, except sample 07054138. This sample was qualified with a “UJ”, which indicates that the analyte was not detected at or above the reported estimated value. Additionally, sample 07054138 had no surrogate recovery. This was attributed to a laboratory spiking error during the extraction. This sample was qualified with a “UJ”, which indicates that the analyte was not detected at or above the reported estimated value.

1,2-DCP: All of the surrogate recoveries were within the current control limits, except the following:

- 07014155
- 07014159
- 07014161
- 07014164
- 07014165

All samples were reanalyzed a second time with similar high results. Only sample 07014161 was qualified with a “J”, which indicates the analyte was positively identified and the value is an approximate concentration. All other samples were below the detection limit.

Estimated values

Sample numbers 07064156 and 07064157 (which are duplicates) were reported as estimated values for 1,2,3-TCP. These samples were outside the projected concentration range (detection limit to 0.5 ug/L). These samples were qualified with an “E” to indicate that the values are estimated. The laboratory estimates these values conservatively, meaning that they are probably greater than the reported values of 0.62 ug/L and 0.63 ug/L, but it is unknown how much higher. (Westerlund, 2007)

Appendix D. Glossary, Acronyms, and Abbreviations

Glossary

Exceeded criteria: Failed to meet criteria.

Groundwater: Water in the subsurface that saturates the rocks and sediment in which it occurs. The upper surface of groundwater saturation is commonly termed the water table.

Nutrients: Substances such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pesticide: A pesticide is any substance or mixture of substance intended for preventing, destroying, repelling, or mitigating any pest. Pests include nuisance microbes, plants, fungus, and animals.

Plume: Describes the three-dimensional concentration of particles in the water column (for example, a cloud of sediment).

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

1,2,3-TCP	1,2,3-trichloropropane
1,2-DCP	1,2-dichloropropane
DBCP	Dibromochloropropane
Ecology	Washington State Department of Ecology
EDB	Ethylene dibromide
EPA	U.S. Environmental Protection Agency
MCL	Maximum contaminant level
PQL	Practical quantitation limit
USGS	U.S. Geological Survey
VOC	Volatile organic compounds
WRIA	Water Resource Inventory Area