Spatial investigation of ground water nitrate-nitrogen and coliform bacteria in the Gallatin Local Water Quality District, Gallatin County, Montana
by Mary Taylor Greenup

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Rapid growth outside of municipal boundaries in Gallatin County, Montana, has raised concerns over ground water quality. Comprehensive data on ground water quality is needed in order to effectively manage the sustainability of the resource and to protect public health. This study compiled ground water quality data, primarily for nitrate-nitrogen and coliform bacteria in the Gallatin Local Water Quality District (GLWQD). Well locations were plotted within a Geographic Information System (GIS). Then previously cited independent variables were assigned based on spatial location in the GIS. Statistical tests were performed to discern the relationship between ground water nitrate-nitrogen and coliform occurrence and the a priori independent variables. Areas with septic system limitation ratings of shallow soils, insufficient soil percolation rates, and shallow depth to high water table are expected to have an increased risk for bacteria occurrence. The West Gallatin Alluvial aquifer has the lowest levels of both nitrate-nitrogen and coliform bacteria, presumably due to the greatest capacity for dilution. Predictive surfaces of nitrate-nitrogen values were created within GIS using geostatistical methods. An overall lack of presence data for coliform bacteria precluded modeling in GIS, leading to the conclusion that bacterial contamination in the GLWQD is not a regionalized phenomenon. Regional nitrate-nitrogen surfaces created in the GIS revealed that no areas in the GLWQD have a probability greater than 20% for exceeding 10 mg/1. However, areas along the western flanks of the Bridger Range and northern front of the Gallatin Range show a tendency for nitrate-nitrogen levels higher than expected from normal background levels. This pattern corresponds with the Quaternary-Tertiary Basin Fill aquifer. The finding suggests that continual loading of nitrate-nitrogen in these areas may pose future health risks due to limited dilution rates. Findings from this study are not to be used as a substitute for field investigation, nor to draw site-specific conclusions. This water quality database may be useful as a base-line for nitrate-nitrogen and coliform levels in the GLWQD so that managers, scientists, and citizens can make informed decisions regarding ground water quality protection and public health measures.

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APPROVAL

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Mary Taylor Greenup

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Rapid growth outside of municipal boundaries in Gallatin County, Montana, has raised concerns over ground water quality. Comprehensive data on ground water quality is needed in order to effectively manage the sustainability of the resource and to protect public health. This study compiled ground water quality data, primarily for nitrate-nitrogen and coliform bacteria in the Gallatin Local Water Quality District (GLWQD). Well locations were plotted within a Geographic Information System (GIS). Then previously cited independent variables were assigned based on spatial location in the GIS. Statistical tests were performed to discern the relationship between ground water nitrate-nitrogen and coliform occurrence and the *a priori* independent variables. Areas with septic system limitation ratings of shallow soils, insufficient soil percolation rates, and shallow depth to high water table are expected to have an increased risk for bacteria occurrence. The West Gallatin Alluvial aquifer has the lowest levels of both nitrate-nitrogen and coliform bacteria, presumably due to the greatest capacity for dilution. Predictive surfaces of nitrate-nitrogen values were created within GIS using geostatistical methods. An overall lack of presence data for coliform bacteria precluded modeling in GIS, leading to the conclusion that bacterial contamination in the GLWQD is not a regionalized phenomenon. Regional nitrate-nitrogen surfaces created in the GIS revealed that no areas in the GLWQD have a probability greater than 20% for exceeding 10 mg/l. However, areas along the western flanks of the Bridger Range and northern front of the Gallatin Range show a tendency for nitrate-nitrogen levels higher than expected from normal background levels. This pattern corresponds with the Quaternary-Tertiary Basin Fill aquifer. The finding suggests that continual loading of nitrate-nitrogen in these areas may pose future health risks due to limited dilution rates. Findings from this study are not to be used as a substitute for field investigation, nor to draw site-specific conclusions. This water quality database may be useful as a base-line for nitrate-nitrogen and coliform levels in the GLWQD so that managers, scientists, and citizens can make informed decisions regarding ground water quality protection and public health measures.

CHAPTER 1

INTRODUCTION

In the twenty-first century, world population growth is placing increased demands on finite natural resources. Water availability and water quality are of concern. Scientists, managers, and citizens require effective means of evaluating aquifer condition, susceptibility, and sustainability for drinking water needs. This project presents a systematic method of spatially evaluating ground water quality data with respect to physical and cultural variables, and the exploration of the data for patterns of occurrence. This type of information is useful to residents, managers, and scientists in preparing for future population growth and protection of ground water quality.

Montana, like many other states in the Rocky Mountain region has experienced a major influx of population over the last 50 years. Most of this growth has occurred in and around urban areas, where traditional farms and ranches are being converted to subdivisions for single family homes. Gallatin County, Montana, epitomizes this growth trend with nearly all new development occurring beyond municipal limits (Gallatin County Planning Office 1998) (Figure 1). According to the U.S. Census Bureau, the population in Gallatin County has more than tripled from just over 18,000 residents in 1940 to almost 68,000 in 2000. Twenty-five percent of the population has been added since 1990 (Figure 2).

Most family homes and businesses developing outside of the incorporated areas in Gallatin County rely on wells for drinking water and septic systems for on-site waste removal. The increasing dependence of Gallatin County residents on ground water has led managers, scientists, and residents to investigate the status of ground water quality in the region. There is interest in determining whether growth and land use are impacting ground water quality in the region, and identifying areas at risk for experiencing ground water quality problems.

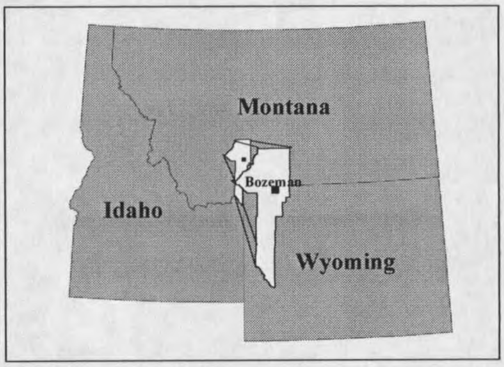

Figure 1. Gallatin County, Montana.

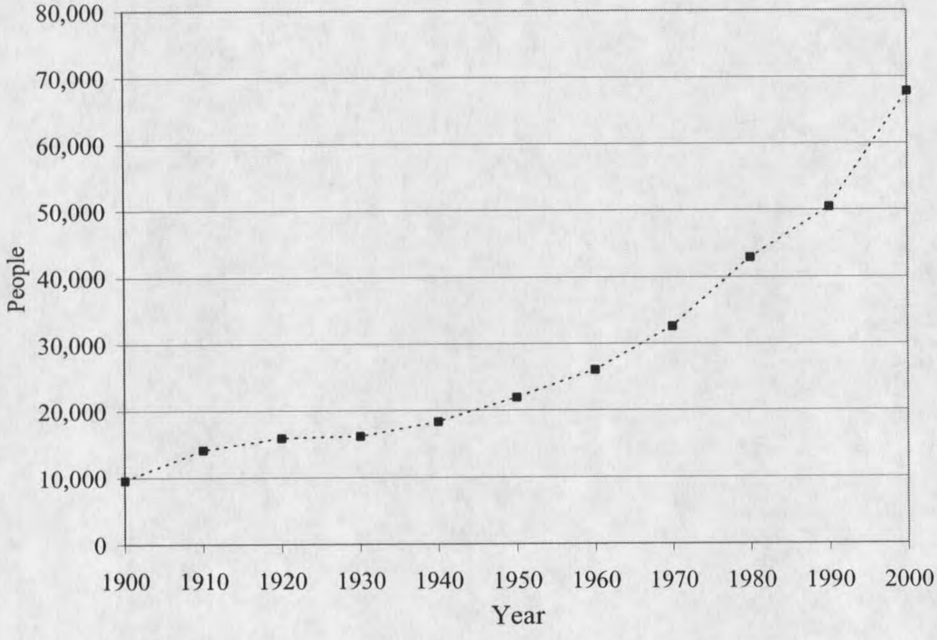

Figure 2. Population Growth in Gallatin County, Montana 1900 to 2000.

Nitrate and coliform bacteria are commonly measured ground water quality properties in Gallatin County. Increased knowledge of ground water nitrate and coliform levels in Gallatin County will provide insight into the possibility of ground water quality degradation. A water quality database with accurately located data can be coupled with a Geographic Information System (GIS), to query the database for spatial relationships with suspected associated variables. GIS investigative modeling for potential ground water health hazards should also be performed.

Nitrate is a danger to infants when the digestive system converts nitrate, NO_3^-, to nitrite, NO_2^-. At high levels, the hemoglobin of red blood cells are converted by nitrite to methemoglobin, which results in the loss of the blood's ability to carry oxygen (Jasa et al. 1998). Methehemoglobia is thought to be induced when nitrate-nitrogen levels in drinking water reach 10 milligrams per liter (mg/l) or higher (Jasa et al. 1998; EPA 2001). Infants, and the elderly with intestinal disorders, are particularly susceptible to this deadly form of oxygen deprivation, often referred to as 'blue-baby syndrome'. Some documented causes of elevated nitrates in ground water include both point sources (confined stock lots, faulty septic systems) and nonpoint sources (fertilized lawns and farmland, soil organic nitrogen, and naturally occurring nitrogen in substrates).

In addition to nutrients, well owners often test for coliform bacteria as indicators of ground water quality. Although most strains of coliform bacteria do not cause sickness, the presence of the bacteria is thought to signal favorable survival conditions for harmful organic pathogens (ReVelle and ReVelle 1988; Skipton et al. 1998; GLWQD 2001). If coliform are cultivated during a water quality test, the colonies are differentiated to determine the proportion, if any, of fecal coliform. Fecal coliform occurrence is presumed to indicate contamination from the feces of warm-blooded mammals, likely associated with point sources (EPA 2001; GLWQD 2001). Because of its origin, fecal coliform presence is thought to raise the risk of the existence of other viruses or protozoa like hepatitis and giardia (Wireman and Job 1998). The human health standard for fecal coliform is less than 1 per 100 milliliters (ml) (EPA 2001; MT DEQ 2001a). The elderly, infants, and those with comprised immune systems are most vulnerable to intestinal bacteria infections. Naturally occurring colonies, faulty well construction, and leaking septic systems are some known sources of coliform bacteria in ground water.

Purpose of Project

There are historic as well as current ground water quality records for wells in the Gallatin Valley. Public funded studies have resulted in the establishment of baseline data for the Gallatin Local Water Quality District (GLWQD). The possibility of establishing a larger ground water quality monitoring network exists with inclusion of accurately located private well data. The purpose of this project is to create and spatially investigate a large ground water nitrate-nitrogen and coliform bacteria dataset with representation across the GLWQD. Such knowledge will provide a better understanding of ground water quality within the GLWQD. This information is valuable from the perspective of public health and planning for future growth.

Hackett et al. (1960) with the United States Geological Survey (USGS), began the first, and to date, the most comprehensive evaluation of the ground water resources in the

Gallatin Valley in the early 1950's. During the late 1970's, D. Dunn (1978) attempted to recreate Hackett et al.'s (1960) water quality investigation for a local commission, the Blue Ribbons of the Big Sky Country Areawide Planning Organization. Scientists, S. Slagle (1995a) and E. Kendy (2001) conducted the most recent USGS ground water quality research in the GLWQD.

Another public entity, the state of Montana, also monitors ground water quality in the GLWQD. The Montana Department of Public Health and Human Services (DPHSS), maintains a large database of water quality tests preformed across the state. Unfortunately, the DPHSS has made little effort to collect sample site information, which renders the data virtually useless for this type of study. The Montana Department of Environmental Quality (MT DEQ), monitors water quality for Public Water Supply Systems (PWSS). And the Montana Bureau of Mines and Geology's Ground Water Information Center (GWIC), stores readily accessible ground water quality data for public use.

Although public ground water quality data for the GLWQD exists, the largest USGS monitoring network includes only 101 wells of an estimated 10,000 or more. As for state records, the GWIC database contains less than 100 records for ground water quality in the GLWQD. Over half of GWIC's water quality records for the GLWQD are from the USGS monitoring network wells. Other GLWQD well water quality records in the GWIC database may be located at scales too coarse for the study analysis.

In order to create a more comprehensive well water quality monitoring network for the GLWQD, data should be assembled from public studies and a local private company, Montana Microbiological Services (MMS). MMS has been analyzing and digitally collecting site-specific nutrient and bacterial information for PWSS and private wells within the GLWQD since the mid 1990's. The assimilation of accurately located, public and private ground water quality data enables the building of a robust database for the GLWQD.

Wells in the GLWQD associated with water quality records for nitrate-nitrogen and coliform bacteria information will be located within a GIS. Patterns will be explored as well as relationships with previously cited independent variables. Statistical correlations will be examined between ground water nitrate-nitrogen and coliform bacteria and independent variables of septic system limitation ratings, housing density, proximity to land application of wastes, farming methods, well depth, and hydrogeology. Predictive GIS modeling of regional ground water quality in the GLWQD will also be conducted. The research results and GIS models may have value to homeowners, regulators, and scientists seeking to better understand the relative risk of groundwater contamination in the GLWQD and may provide insight for developing strategies to reduce these risks.

Study Area

The Gallatin Local Water Quality District is located in Gallatin County, southwestern Montana (Figure 1). The semiarid climate and mountainous landscape of the GLWQD reflects its placement east of the Continental Divide in the Northern

Rockies. The borders of the GLWQD conform to that of the county along its eastern margin and to Montana Public Land Survey System (PLSS) townships in all other directions. Altogether the GLQWD ranges from Township 1 North to Township 5 South, and Range 3 East to Range 7 East (Figure 3). The boundaries were chosen to encompass the areas of fastest growth in the county, the lands surrounding Bozeman and Belgrade.

There are over 2,000 square kilometers (km^2) in the GLWQD. This includes the central Gallatin Valley, portions of the Bridger and Gallatin ranges, and a small section of the Madison Range and Plateau. The Gallatin River and its tributaries shape the broad plains of the valley, carrying water from the highlands and draining ultimately into the Missouri River. The river system is a significant source of water in this semi-arid environment and an important component in the recharge and discharge of alluvial aquifers in the valley.

The climate of the GLWQD is influenced by high elevations (1,240 m to 3,350 m), northern latitude (45° 21' to 45° 52'), and its location east of the divide in the Northern Rockies (-100° 47' to -111° 24'). Temperature and precipitation gradients exist between the mountains and the valley. Annual precipitation can range from less than thirty-six centimeters in the northwestern part of the GLWQD to over one-hundred centimeters in the high peaks of the Bridger and Gallatin ranges (Custer et al. 1996; Western Regional Climate Center 2002). Winter temperatures are usually below freezing, with cold spells and snow storms possible anytime of the year. Summers are mild, yet temperatures in July and August are commonly around 30°C. Most of the area's precipitation is received April through June, in the form of snow and spring rains.