The effects of septic systems on surface water and groundwater quality in two subdivisions in the Gallatin County Local Water Quality District, Montana
by Kerri Rae Fleming

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

Abstract:
The Gallatin Valley has experienced a tremendous increase in rural subdivision growth. Due to the number of individual septic systems, there is growing concern regarding groundwater and surface water contamination. To test whether degradation is occurring from subdivisions specifically, two mature subdivisions with shallow ground water and proximity to water-quality impaired streams were chosen for study.

The shallow ground water was sampled from shallow monitoring wells located up flow, mid flow, and down flow of the subdivision. Deeper ground water was sampled from domestic wells. Both shallow and deep wells were sampled during high water and low water periods. All samples were tested for pH, specific conductivity, temperature, dissolved oxygen, total coliform (if present, then also for E. coli), chloride, total ammonia as nitrogen, nitrate plus nitrite as nitrogen, and total phosphorus. The water-quality impaired streams in the selected subdivisions were also tested for these parameters up flow, mid flow, and down flow of the subdivision.

Nutrient values are well below maximum contaminant levels with no obvious increasing trends or patterns related to septic system flow lines in the surface water or the ground water. Nitrate plus nitrite as nitrogen averaged less than two milligrams per liter in both wells and surface water. Total coliform was present in some wells at both subdivisions, but no E. coli was found to be present, except in one shallow monitoring well. No discemable cumulative septic system influence was found in domestic wells or surface water. Some local areas with higher than average concentrations of nitrate (2.7mg/l) and chloride (18.1 mg/1) were found, which suggests that detailed, site-specific studies may be valuable, rather than regional studies.

Two nitrate models were tested for prediction accuracy, Bauman-Schafer and Hantszche. The Bauman-Schafer model accurately predicted the Middle Creek subdivision area nitrate results and predicted higher than observed nitrate values for the Gardner/Sourdough subdivision area. The Hantszche model attempts to predict an overall degradation and was higher than observed nitrate values for both subdivisions. A phosphorus breakthrough curve model was run which showed no areas of concern when predicting breakthrough times.

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Master of Science

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Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2003

APPROVAL

of a thesis submitted by

Kerri Rae Fleming

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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ACKNOWLEDGMENTS

I would like to gratefully acknowledge Dr. Steve Custer for his support and direction. I also thank Dr. Custer for his excellent advice and assistance with this project. I also would like to thank Dr. Bill Locke and Dr. Chris Brick for their valuable input as well.

This project was funded by an EPA 319 grant administered by the Montana Department of Environmental Quality, a Montana Water Resources Grant (USGS Sec. 104-B), and a Department of Earth Sciences teaching assistantship.

Thanks also go to Dr. Barry Pyle, Dr. Gordon McFeters, the Gallatin County Local Water Quality District, Cyndi Crayton, the Gallatin County Health Department, Tony Rolfes and Jay Brooker with NRCS, and to all the homeowners who participated in the study.

My friends and fellow students also deserve thanks for their help and support. Special thanks go to Ruth O'Neill, Karin Kirk, Stewart Dixon, Rosemary Crebs, Chuck Lindsey, Michael O'Connell, Martha Kaufman, Grace Winer, Garret Slaugenhoup, and Jeff LaRock.

I would also like to gratefully acknowledge my family for their support, with special thanks to my husband, Kevin, to my sister, Lynn, to my sister-in-law, Christy, and to my parents, Raymond and Linda Strasheim.

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ABSTRACT

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INTRODUCTION

The population of Gallatin County has increased by 34.4% to 69,442 from 1990 to 2000 (U.S. Census Bureau, 2002), and much of this new population is on individual well and septic systems. Over 7,000 septic systems are in use in the county (Custer et al., 2000). The cumulative effects of individual septic systems in subdivisions on surface and ground water quality have not been determined in the Gallatin valley. Concerns have been raised regarding water quality because of the increasing number of individual septic systems being installed in the Gallatin County Local Water Quality District (GCLWQD) (Fig. 1).

Septic systems, which are used for wastewater disposal in rural subdivisions, have been shown to affect surface water quality (Ingram, 1993; Weiskel et al., 1996; Grant, 1999) and ground water quality (Yates, 1985; Reneau et al., 1989; Robertson et al., 1991; Aravena et al., 1993; DeSimone and Howes, 1998; Tuthill et al., 1998). Nutrients and microbes that affect the quality of drinking water are the main contaminants of concern. Nitrate is a concern because nitrate can contribute to methemoglobinemia (blue-baby disease) (Cogger, 1988; Avery, 2000). Ammonia and ammonium, part of the nitrogen cycle, can have negative effects on human health when present in large amounts (ATSDR, 2002). Phosphorus causes eutrophication of surface waters, which can negatively affect ecosystems (Cogger, 1988; Zanini et al., 1998). Microbes from septic systems can cause disease, so any indication of septic system effluent in drinking water poses a serious health risk (Cogger, 1988; Ingram, 1993).

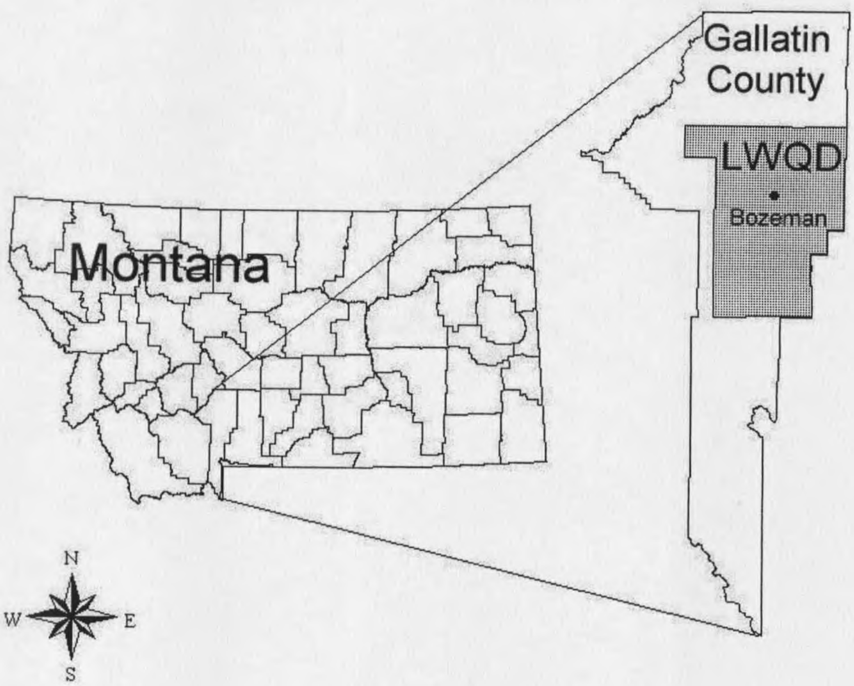

Figure 1. The location of the Local Water Quality District (LWQD) in Gallatin County.

Coliform bacteria are used as indicator microorganisms because they are the most populous bacteria in septic waste and are easy to detect. If *E. coli* is found, the possibility of other disease-causing microorganisms being present is high (NRC, 1977). Diseases caused by septic effluent include hepatitis A, typhoid, and gastroenteritis (Yates, 1985). Viruses can also be found in effluent (NRC, 1977). Viruses are smaller (0.06 microns) than bacteria (0.60 microns) and may sometimes move farther and faster depending upon the interaction between cell surface charge and sediment particle surface charge, although this pattern is not always true (Bales et al., 1995; Sinton et al., 2000). Depending on interactions, viruses may not get filtered out of groundwater as soon as bacteria. Therefore, coliform bacteria may not always be an appropriate indicator of microbial presence or absence (Pyle et al., 1979; Yates et al., 1985; Bales et al., 1995; DeBorde et al., 1998). Since absence of bacteria does not necessarily mean absence of contamination, testing for other indicators of septic influence, such as nutrients and chloride, is important.

Local historical data on nutrients and chloride can be found in published research. The hydrogeology of the Gallatin valley was first investigated by Hackett and others (1960). This report includes a small section on water quality. Only one well was found in the valley with excessively high chloride, and a shallow well near a barn had a very high nitrate concentration (110 mg/l nitrate), otherwise nitrate concentrations were low (Hackett et al., 1960).

No indications of septic problems were found in the next major study of the area done to revalidate the 1960 findings (Dunn, 1978). Only a small increase in total dissolved solids was found, which was thought to indicate increased leaching as more land became irrigated farmland (Dunn, 1978). One well, located in a farming area with no septic systems, had a large increase in nitrate concentration (4.2 mg/l to 14 mg/l) that was thought to be a locally severe case of leaching in the subsurface (Dunn, 1978).

The results from the Dunn (1978) study were mirrored in the next study of the Gallatin valley's water quality by Slagle (1995). Water quality was good overall, with nitrate concentrations ranging from 0.1-4.5 mg/l (Slagle, 1995). The higher nitrate concentrations (2.0-4.5 mg/l) were all from north-northwest of Bozeman, which is more developed. Slagle (1995) proposed that the increased concentrations, though not detrimental, may be from septic systems or increased fertilization.

No indications of widespread water quality problems were found in the most recent study of the water quality in the Gallatin valley (Kendy, 2001). High nitrates (10 and 13 mg/l) were found in two of the ninety-six wells sampled. One well was affected by livestock waste or septic system effluent, based upon the nitrogen isotope data. The rest of the wells averaged less than three milligrams per liter (Kendy, 2001). One subdivision was sampled more intensely, and two wells were sampled from two subdivisions. Domestic septic-system effluent was determined not to be a major source of nitrate to ground water, rather fertilizers and soil organic nitrogen probably contribute most of the groundwater nitrate (Kendy, 2001).

Nitrate levels were measured in wells in Montana and combined with a geographic information system to identify correlations between average nitrate concentrations in each county, probability of greater than ten milligrams per liter of nitrate concentrations, geographic, climatic, geologic, and land-use practices (Bauder, Sinclair, and Lund, 1993). In Gallatin County, the groundwater nitrate concentration average was 1.7 mg/l (sample size 175) with two samples higher than ten milligrams per liter (Bauder, Sinclair, and Lund, 1993). Higher nitrate concentrations were correlated with soil and physiographic properties, climatic conditions, and land-use practices (Bauder, Sinclair, and Lund, 1993).

A study of two individual septic system drainfields in the Bozeman area found that nitrate was the only pollutant that migrates significant distances in the ground water, with a predicted increase of 2.4 mg/l per lot (Peavy, 1978). Chloride was also found to be elevated in the ground water resulting from septic influence, but numbers were not high enough to cause concern (Peavy, 1978). Both of these constituents are negative ions that do not interact easily with soil particles.

Five subdivisions with individual well and septic systems in southwestern Montana were studied for effects on water quality (Peavy et al., 1980). No indications of septic system influence were found in the domestic well samples or in the installed shallow monitoring well samples, even though sites with porous materials over high ground water were picked. Groundwater dilution was listed as the main reason for seeing no contaminants. Low flow from many of the septic systems was another reason cited for lack of contamination. Most of the systems built for families were being used by retired couples, who generate less wastewater. Since the subdivisions chosen were fairly new and not completely developed, monitoring over time for changes was recommended (Peavy et al., 1980).

The Department of Environmental Quality (DEQ) has suggested reexamination of subdivisions studied by Peavy et al. in 1980 to determine if ground-water quality has been degraded below and down flow of subdivisions and to determine whether the Bauman-Schafer and phosphorus breakthrough methods currently used for subdivision review and non-degradation assessment reasonably predict impacts of development on ground-water quality. While the DEQ's proposed reexamination is interesting, the original research wells are gone, homeowner cooperation is not assured, and the study areas would require significant travel. An alternative is to examine groundwater below 1970's-vintage subdivisions in the Gallatin County Local Water Quality District (GCLWQD) (Fig. 1) that are known to show elevated nutrients or coliform. Such a study could be used to answer several important questions of interest both to the State of Montana and the GCLWQD.

Purpose and Scope

Two subdivisions were selected, one with a coarse-grained substrate and one with a fine-grained substrate. Water quality was checked in these subdivisions for indicators of septic contamination, which fall into two categories, microbiological and nutrients plus chloride. Total coliform bacteria can indicate microbiological contamination. If total coliform bacteria are present, then *E. coli* is checked for in the same sample. Nutrients (nitrate, ammonia, and phosphate) and chloride are common byproducts of domestic septic systems and are good indicators of septic contamination (Cogger, 1988). Although chloride is not a nutrient, from this point on the word nutrients will be defined as nitrate, ammonia, phosphorus, and chloride for brevity.

We hypothesized that, in the fine-grained subdivision, higher nutrient concentrations would be found due to lower volumetric dilution, but that coliform bacteria would be lower due to enhanced filtration. On the other hand, the coarser-grained substrate would have more dilution of the nutrients and higher microbiological numbers due to the lack of filtration. The term substrate particle size will be used to encompass both the aquifer grain size and the unsaturated grain size.

Microbiological and nutrient data was collected from the domestic wells and installed shallow monitoring wells. Shallow ground water is closer to possible contamination sources, so a vertical concentration gradient may exist. Furthermore, deeper domestic wells may be isolated from septic contamination by hydrogeologic barriers or be on different flow paths than shallow systems (Fig. 2). To test these possibilities, shallow wells were placed up flow, mid flow, and down flow in each subdivision for microbiological and nutrient sampling. The up flow wells provided a background nitrate concentration for the shallow ground water. The mid flow wells were placed directly down flow of a septic system, as close to the system as possible, to see if any septic influence could be found. The down flow wells were placed on flow lines with the most septic systems to see if cumulative impacts from septic systems could be found in the ground water leaving the subdivision.

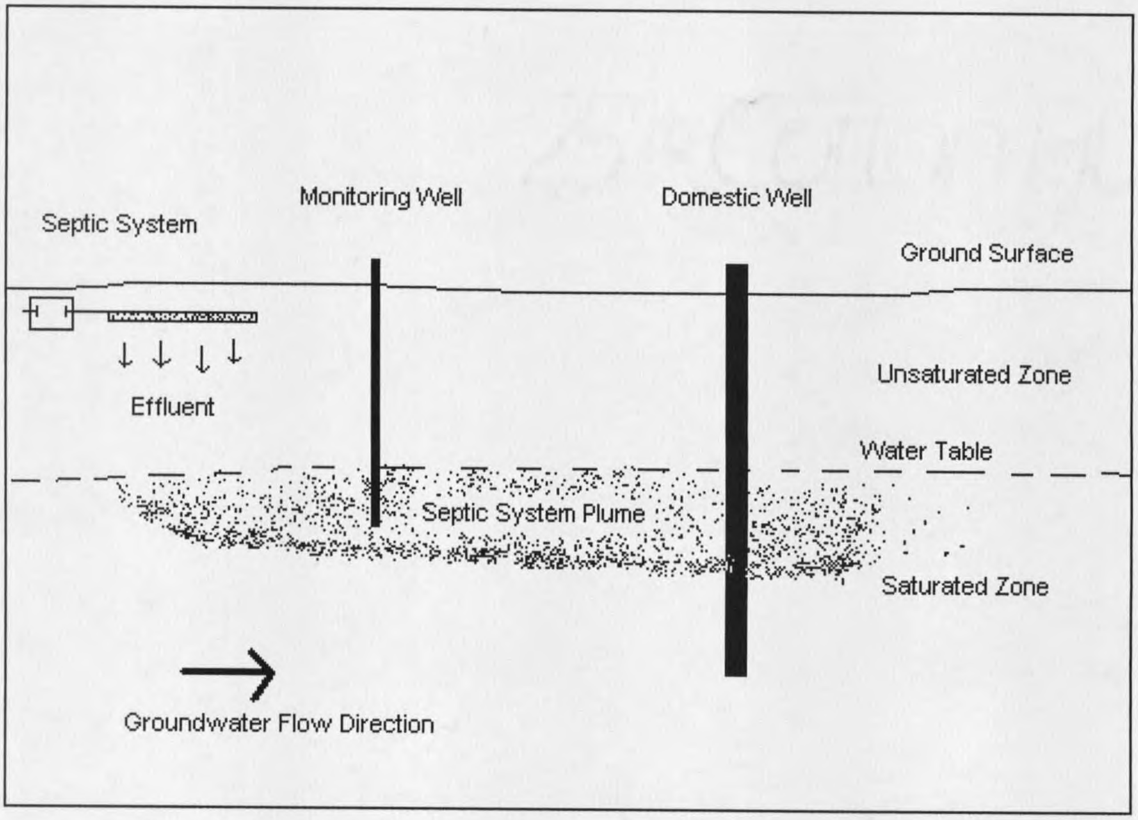

Figure 2. Cross-sectional diagram illustrating relationship of wells and septic systems to the water table.

The streams by each subdivision were also sampled up flow, mid flow, and down flow for microbes, nutrients, and chloride. If the ground water is being degraded by septic systems in subdivisions, then the streams may also be affected if this degraded ground water reaches the streams.

Once all the sampling data were collected, the numbers were compared to popular models used to estimate nitrate levels and phosphorus breakthrough curves. The predictions generated by these models were compared against the actual data collected in each subdivision.

Objectives of Study

The objective of this study is to assess the impact of septic systems on surface water and groundwater quality in mature subdivisions. The following questions will be addressed.

1) What nutrient and total coliform loads are carried by streams in the study area that have been identified as water-quality impaired?
2) What nutrient and total coliform loads enter and leave the subdivision area via the ground water?
3) Is the groundwater used for domestic water supply below subdivisions contaminated with nutrients and/or microbes?
4) Is the shallow ground water contaminated with nutrients and/or microbes?
5) If contaminated wells are found, are the wells on a flow line that contains one or more septic systems?
6) Is the source of microbial contamination discernible?

7) Is the contamination level and type (nitrate, chloride, phosphate, ammonia, and total coliform bacteria) dependent on the texture of the sediments below the subdivision?

8) Do nutrient and microbial levels below subdivisions differ seasonally?

9) Do the Bauman-Schafer nitrate model and the phosphorus breakthrough model accurately predict observed concentrations below mature subdivisions?

Location of Study

The criteria for subdivision selection (Table 1) were based on the hypotheses to be tested. First, the subdivisions had to be next to a stream designated as a water-quality impaired stream by the U.S. Environmental Protection Agency's (EPA) Total Maximum Daily Load (TMDL) process (Montana DEQ, 1998). All of the water quality impaired streams in the GCLWQD were highlighted and then the subdivisions that fit the required

Table 1. Rank of criteria for subdivision selection.

Rank	Criteria
1	Discharge of subdivision ground water to nearby water-quality impaired stream
2	Depth to ground water between two and fifteen meters
3	Mature subdivision (early 1970's to early 1980's)
4	No subdivisions on septic systems up flow
5	Public water supply present down flow
6	Different substrates between subdivisions for comparison (coarse-grained versus fine-grained)
7	Previous history of ground water contamination by nutrients or microbes
8	Permission from homeowners to conduct study

proximity standard for the study were identified on a map with all of the subdivisions listed. This requirement for surface water proximity allowed testing of the hypothesis that ground water from subdivisions might be affecting the water quality of the nearby streams.

High water table produces short filtration distances and so is more susceptible to contamination (Reneau et al., 1989). A deep water table is less likely to become contaminated because nutrients and microbes are more likely to be removed or adsorbed in the vadose zone. Furthermore, monitoring wells were to be installed by hand due to budget constraints, so shallow depth to water (less than ten meters) was used as the second criterion. Because deep groundwater depths have a longer flow path, nutrients and microbes may be diluted/removed. The shallow wells are expected to have a higher probability of showing contamination. Depth to ground water for each listed subdivision was estimated from published reports (Hackett et al., 1960; Slagle, 1995) and data from the Ground Water Information Center (GWIC) (Montana Bureau of Mines and Geology, 1998).

The third factor was based on the hypothesis that if septic system influence on water quality is to be found, success would be more likely in mature subdivisions that have had homes with septic systems for at least twenty years. Peavy et al. (1980) studied nine subdivisions less than two years old around the state for septic system influence on ground water, found no septic system effects, and recommended that mature subdivisions be studied in the future because problems would have more time to develop. Mature subdivisions also have a higher probability of septic system failure and groundwater quality degradation in response to poor septic system maintenance. Mature subdivisions are more likely to represent the groundwater condition as developments mature in the valley. Septic system permit dates were used to identify the relative ages of subdivisions. The age was also assessed from preliminary data in a Department of Revenue database (Custer et al., 2000).

The fourth criterion is that no subdivisions on individual septic systems are located up flow of the candidate subdivisions. Ideally, water quality up flow of the candidate subdivisions would be at background levels. This criterion ensures that any changes in water quality down flow are due to the subdivision. The Gallatin County Planning subdivision map was again used to check this factor. Field reconnaissance was also used to ensure that no subdivisions were developed immediately up flow.

The fifth criterion is that the candidate subdivisions are up flow of a public groundwater supply. DEQ was interested to see if the study sites affected community water supplies.

The sixth criterion relates to substrate particle size. One of the hypotheses of the study is that a difference in contamination patterns might exist between different substrates. Two substrates were tested, one finer-grained and one coarser-grained. Both well logs (GWIC; GVLWQD) and soil data (NRCS) were used along with geologic maps (Hackett et al., 1960; Slagle, 1995) to determine the texture of the substrate. A study done using pump-test data from drillers' logs was also used to determine differences in aquifer substrate by statistically comparing transmissivity estimated from driller specific capacity from different geohydrologic units (Dixon, 2002). The candidate list was divided into two groups (one coarse-grained and one fine-grained). One subdivision was chosen from each group.

The seventh factor was evidence of historic nutrient or microbiological contamination at the candidate subdivision. Contamination could be evidence which supports septic system influence.

Finally, homeowner permission was a factor. This criterion couldn't really be researched prior to subdivision selection. In the end, the candidate subdivisions, in coarse-grained and fine-grained classes, were rank ordered so that if owner permissions were denied, another subdivision candidate was available.

Once all of the relevant data was collected for the candidate subdivisions, the list was split into two groups based on substrate grain size, and everything was presented at a selection meeting. Summary information was sent out with a letter to all the involved persons, and a meeting time and place was set up in Helena, Montana, so the subdivisions could be rank ordered. Selection was based on consensus of present personnel, including representatives from GCLWQD, DEQ, DPHHS, and MSU. The subdivision data for candidate subdivisions is in Appendix A.

Two subdivision areas were chosen for study in the Gallatin County LWQD. The Middle Creek study area represents the coarser-grained substrate, and the Gardner Park/Sourdough study area represents the finer-grained substrate (Fig. 3). The Middle Creek Subdivision is in the northeast and northwest quarters of the northwest quarter of section thirteen in range four east and township two south. The Gardner Park portion of the second subdivision area is in the northwest and southwest quarters of the northeast quarter of section thirty in range six east and township two south. The Sourdough portion of the second subdivision area is in the northwest and southwest quarters of the southeast quarter of section thirty in range six east and township two south.