Driller specific capacity as a measure of aquifer transmissivity and a test of the hydrogeologic units in the Gallatin Local Water Quality District, Gallatin County, Montana

by Stewart Alan Dixon

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

Abstract:
Increased development in the rural areas of Gallatin County, Montana has raised concerns about groundwater resources. Hydraulic properties of geologic units are needed to address groundwater quality and quantity issues. This study uses abundant driller specific capacity data to test whether eleven geologic units commonly thought to be different have statistically different hydraulic character. Aquifer transmissivity was estimated from driller specific capacity using an empirical equation developed from fifty data pairs of transmissivity and specific capacity calculated from single well tests at unscreened or non-perforated wells pumped for one hour. Unscreened or non-perforated wells represent 73% of the wells in the district. Seventy percent of the driller-tested wells in the district were pumped for one hour. Recovery transmissivity and specific capacity are log-linearly related. The best-fit regression is Log T = 1.3562(Log Q/s) + 3.5209, where T = transmissivity expressed in m2/day and Q/s (specific capacity) is in (m3/min)/m with a coefficient of determination, R2, of 0.749. The wells within the district had to be located to be allowed in the database. A test of pumped, airlift, and bailed driller tests showed that bailed tests could not be used. Although there are 7253 wells in the Gallatin Local Water Quality District only 16% (1136) could be located, were unscreened, were tested for one hour, had specific capacity data, and were not bail tested. The data only allowed statistical analysis of the Quaternary - Tertiary hydrogeologic units within the Gallatin Valley. The older units had few located wells or missing or inappropriate data such as short pumping times. A Mann-Whitney statistical analysis of the estimated transmissivity values among identified hydrogeologic units indicates significant difference between neighboring units. The eleven initial Quaternary - Tertiary Hydrogeologic units were recombined into three distinct hydrogeologic units to reflect the results of the statistical analysis. The units are the Quaternary West Gallatin alluvium aquifer, Quaternary small stream and fan aquifer, and the Quaternary-Tertiary basin fill aquifer. The calculated transmissivity values for the distinct Hydrogeologic units utilizing driller reported specific capacity data agree well with published values from aquifer tests in the region, except for the high transmissivity West Gallatin alluvium aquifer. This study demonstrates that driller reported specific capacity data can be used to estimate hydraulic parameters and that the values obtained are in good agreement with hydraulic parameters determined by traditional aquifer pump tests. Driller reported specific capacity is a rich but underused database, which can help characterize aquifers in an area.

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APPROVAL

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Stewart Alan Dixon

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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Date July 17, 2002

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ABSTRACT

Increased development in the rural areas of Gallatin County, Montana has raised concerns about groundwater resources. Hydraulic properties of geologic units are needed to address groundwater quality and quantity issues. This study uses abundant driller specific capacity data to test whether eleven geologic units commonly thought to be different have statistically different hydraulic character. Aquifer transmissivity was estimated from driller specific capacity using an empirical equation developed from fifty data pairs of transmissivity and specific capacity calculated from single well tests at unscreened or non-perforated wells pumped for one hour. Unscreened or non-perforated wells represent 73% of the wells in the district. Seventy percent of the driller-tested wells in the district were pumped for one hour. Recovery transmissivity and specific capacity are log-linearly related. The best-fit regression is Log T = 1.3562(Log $^Q/_S$) + 3.5209, where T = transmissivity expressed in m^2/day and $^Q/_S$ (specific capacity) is in (m^3/min)/m with a coefficient of determination, R^2, of 0.749. The wells within the district had to be located to be allowed in the database. A test of pumped, airlift, and bailed driller tests showed that bailed tests could not be used. Although there are 7253 wells in the Gallatin Local Water Quality District only 16% (1136) could be located, were unscreened, were tested for one hour, had specific capacity data, and were not bail tested. The data only allowed statistical analysis of the Quaternary – Tertiary hydrogeologic units within the Gallatin Valley. The older units had few located wells or missing or inappropriate data such as short pumping times. A Mann-Whitney statistical analysis of the estimated transmissivity values among identified hydrogeologic units indicates significant difference between neighboring units. The eleven initial Quaternary – Tertiary Hydrogeologic units were recombined into three distinct hydrogeologic units to reflect the results of the statistical analysis. The units are the Quaternary West Gallatin alluvium aquifer, Quaternary small stream and fan aquifer, and the Quaternary-Tertiary basin fill aquifer. The calculated transmissivity values for the distinct Hydrogeologic units utilizing driller reported specific capacity data agree well with published values from aquifer tests in the region, except for the high transmissivity West Gallatin alluvium aquifer. This study demonstrates that driller reported specific capacity data can be used to estimate hydraulic parameters and that the values obtained are in good agreement with hydraulic parameters determined by traditional aquifer pump tests. Driller reported specific capacity is a rich but underused database, which can help characterize aquifers in an area.

CHAPTER 1

INTRODUCTION

In Gallatin County, Montana, ground water is the major water source for light industrial, agricultural, and domestic water supply in rural areas. Increased development in the rural areas of Gallatin County has raised concerns about potential problems affecting the groundwater resources of the region. Identification and characterization of the hydraulic parameters of the aquifers within the region is needed to help address water quality and quantity issues. For example, the aquifer parameters are needed for septic assessments (Bauman Shafer method (Bauman and Shafer, 1984)) and assessment of aquifer yield potential. There is a need for statistical analysis of hydraulic data to provide perspective regarding central tendency and variation in aquifer parameters. Some of the variation may rise from differences between geologic units. If hydraulic data can be stratified to account for differences then more meaningful characterization will be possible. Expected aquifer units were tested using existing driller reported data. This statistical testing allowed identification of hydraulically distinct geologic units based on the hydraulic properties of the units in the Gallatin Local Water Quality District (GLWQD) (Figure 1).

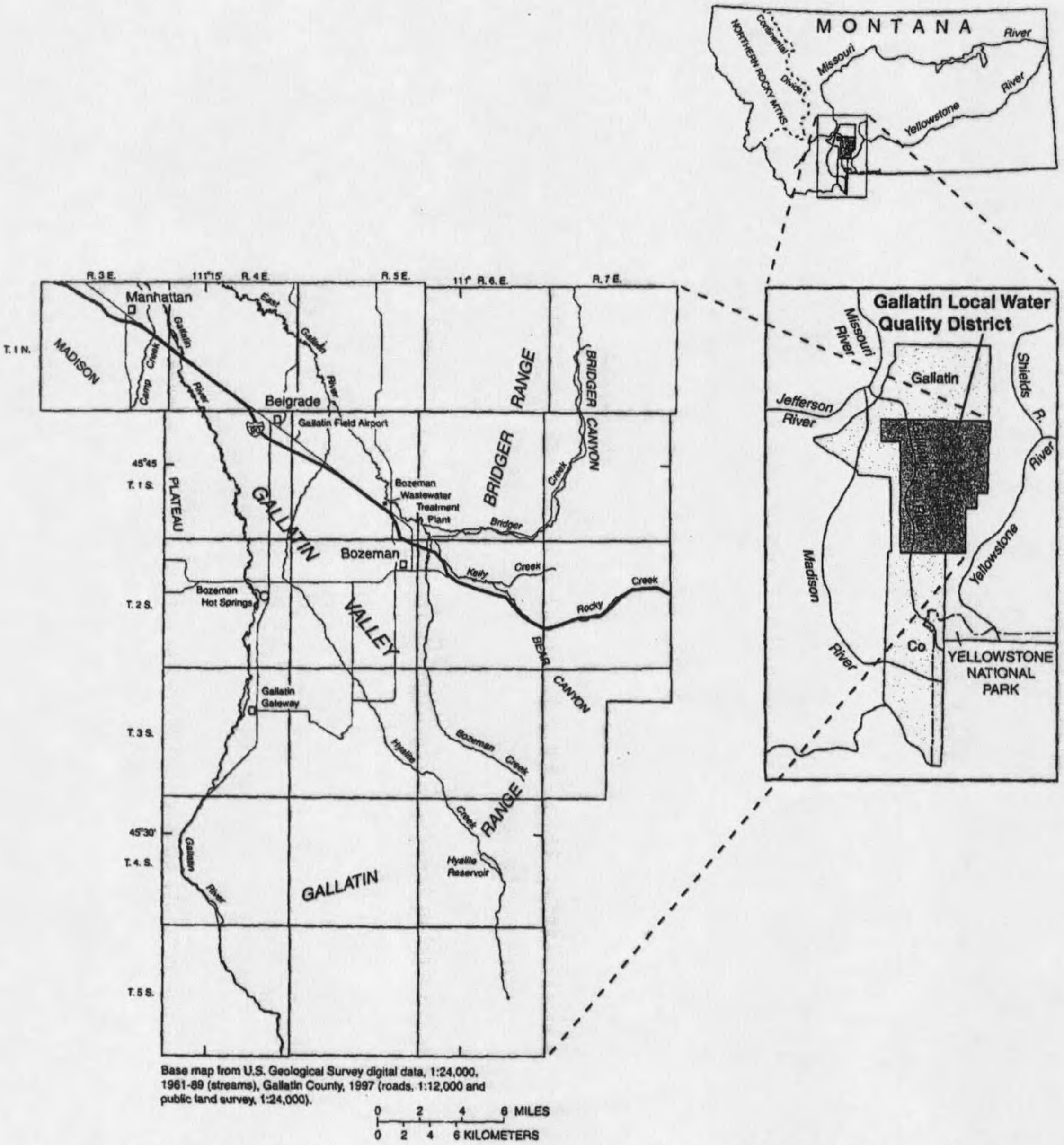

Figure 1: Location of the Gallatin Local Water Quality District, Montana (Kendy, 2001, page 3).

Common aquifer parameters defined during aquifer characterization studies include hydraulic conductivity (K) and transmissivity (T). The hydraulic conductivity of an aquifer is defined as the velocity of water moving through a unit area of a porous medium per unit time. This assumes a unit hydraulic gradient perpendicular to the direction of flow. Hydraulic conductivity is given in units of length divided by time [L/T]; for example in International System of Units (SI) as meters per day (m/day) or in American Practical Units (APU) as gallons per day per square foot (gpd/ft^2) (Driscoll, 1986, Fetter, 1994, Kruseman and de Ridder, 1994). Likewise, transmissivity is defined as the rate of flow through a cross-section of unit width; again, under a unit hydraulic gradient over the saturated thickness of the aquifer (Driscoll, 1986; Fetter, 1994; Kruseman and de Ridder, 1994). Transmissivity is expressed in units of L^2/T, for example in SI units as meters squared per day (m^2/day) or in APU as gallons per day per foot (gpd/ft) (Driscoll, 1986; Fetter, 1994; Kruseman and de Ridder, 1994). Hydraulic conductivity (K) and transmissivity (T) are related by thickness (b): T=Kb.

Hydraulic conductivity and transmissivity are ideally calculated from aquifer test data conducted with a pumping well and one or more observation wells in the geologic formation of interest (Driscoll, 1986; Fetter, 1994; Kruseman and de Ridder, 1994). However, there are disadvantages to pumping tests such as nonuniqueness and expense (Freeze and Cherry, 1979). The similarity in drawdown response from a variety of different aquifer types makes prediction of a unique solution of the effects of pumping difficult (Freeze and Cherry, 1979). Also, the expense of installation of test wells and observation piezometers is typically not justified except in those cases where the test wells will eventually serve as water supply production wells (Freeze and Cherry, 1979). Therefore, because of the prohibitive costs of conducting multiple well tests and the abundance of point tests that can provide adequate data, hydrogeologists often use point tests to evaluate hydraulic properties. Specific capacity data is an example of point test data that is frequently used to estimate hydraulic parameters of aquifers.

Specific capacity is chiefly related to the transmissivity of the aquifer with the aquifer storage coefficient, well efficiency, pumping time, and discharge having important influences (Driscoll, 1986; Newcome, 1993; Fetter, 1994). Specific capacity is expressed in units of flow rate (discharge) per length, (Q/L), for example cubic meters per minute per meter of drawdown (m^3/min/m), cubic meters per second per meter (m^3/s/m), or gallons per minute per foot of drawdown (gpm/ft). Specific capacity is determined by dividing the discharge from the well (m^3/minute; m^3/second; gallons/minute) by the amount of water level decline in the well (meters; feet) after a specified pumping time (Driscoll, 1986; Fetter, 1994).

Specific capacity has several advantages for aquifer hydraulic property estimation. Theoretical and empirical relationships between transmissivity and specific capacity have been used to estimate transmissivity from specific capacity data when available (for example; Thomasson et al., 1960; Custer et al., 1991; Razack and Huntley, 1991; Huntley et al., 1992; Mace, 1997). The use of specific capacity data to estimate transmissivity values has become more widespread because of the abundance of specific capacity data from water well logs and the paucity of aquifer pump test data for many areas.

Specific capacity is reported by drillers on the well logs for 52% of the reported wells within the Gallatin Local Water Quality District. However, the specific capacity data are rarely used for aquifer analysis in the GLWQD. The abundance and availability of the specific capacity data of the GLWQD provides an opportunity to examine hydraulic properties of the area aquifers statistically.

Study Objectives

The project was undertaken to test whether geologic units within the GLWQD that are commonly believed to be different are statistically different based on the hydraulic properties of the units. This will result in the identification and characterization of hydraulically distinct units. Specific capacity will be used to provide information on expected hydraulic characteristics and the variations in these characteristics for the various geologic stratigraphic units. Although a great deal of information exists in the form of static water levels, pumping rates, pumping water levels, pumping times, lithologic logs, and some aquifer test data, the data is not in a format that allows quick assessment of hydraulic properties for a particular area or aquifer. To test whether or not the geologic units of the GLWQD are similar, the following procedure was used:

1. identify expected distinct hydrogeologic units;
2. verify location of wells within the GLWQD;
3. derive an empirical equation that relates specific capacity to transmissivity using field tested specific capacity-transmissivity data pairs;
4. use derived equation to calculate transmissivity for the test hydrogeologic units using existing available specific capacity data;
5. statistically test units to determine whether transmissivity values are different;
6. combine units that fail to be statistically different; and
7. develop both a hydrogeologic map and hydrogeologic column for the GLWQD that reflects the results of the statistical analysis.

Study Area

The Gallatin Local Water Quality District (GLWQD) covers most of northern Gallatin County (Figure 1). The area encompasses roughly 2100 square kilometers (800 square miles). The study area is bounded on the east by the Gallatin County-Park County line; the northern boundary is Township 1 North, Ranges 3 East to 7 East; the western boundary is Townships 1 South to 5 South, Range 4 East, except near Manhattan where the western boundary extends into Township 1 North, Range 3 East (Figure 1). The southern boundary of the study area is along Township 5 South Ranges 4 East to 6 East.

General Geology

Precambrian through Mesozoic bedrock underlies Cenozoic alluvial deposits and borders the majority of the Gallatin Valley (Hackett et al., 1960; Kendy and Tresch, 1996). Although the rock units found in the surrounding mountains make up the majority of the lithostratigraphic units within the GLWQD, the Cenozoic basin-fill and alluvial deposits found in the Gallatin Valley cover a large part of the GLWQD and underlie the area of the GLWQD where most people live. The most prolific aquifers in the GLWQD are Cenozoic deposits. Cenozoic basin-fill ranges in thickness from 0 to 2000 m. (0 to 6000 ft.) (Hackett et al., 1960; Davis et al., 1965; Noble et al., 1982; Vuke et al., 1995). The Gallatin Valley basin-fill includes Tertiary Bozeman Group, Older alluvium (Quaternary-Tertiary?), Quaternary alluvial fan deposits, Quaternary glacial outwash (?) deposits, and alluvium deposited by rivers and streams during the Quaternary (Hackett et al., 1960; Robinson, 1963; Glancy, 1964; Hughes, 1980; Custer et al., 1991; Hay, 1997) (Figure 2). The majority of the domestic wells in the GLWQD are completed in sediments that have been interpreted either as Tertiary Sixmile Creek, Madison Valley Formation, or overlying Quaternary Units (Hackett et al., 1960; Kuenzi and Fields, 1971; Hughes, 1980; Custer et al., 1991; Vuke et al., 1995).

The Gallatin Valley is a north-trending intermontane basin near the edge of the Northern Rocky Mountains (Hackett et al., 1960; Kendy and Tresch, 1996) (Figure 2). The valley is the eastern extension of the Three Forks structural basin (Robinson, 1963) and covers approximately 1330 square kilometers (520 square miles) (Hackett et al., 1960; Kendy and Tresch, 1996). The Gallatin Valley was formed as the compressional tectonic regime of the region was replaced by an extensional tectonic regime "around 46 Ma to 15 Ma" (Lageson, 1989).

Mountainous areas such as the Bridger Range, Gallatin Range and Madison Range cover the remaining half of the land area within GLWQD. The southern part of the GLWQD includes Madison and Gallatin Ranges (Figure 2). The Madison and Gallatin Ranges consist of complexly deformed Archean metamorphic rock (3 billon years before present); amphibolite, schist, gneiss, and basic dikes) (Mogk, 1992), Paleozoic and Mesozoic sedimentary rocks that are overlain locally by Eocene volcanic flows, and volcaniclastic debris (McMannis and Chadwick, 1964; Chadwick, 1969; Hiza, 1994) of the Absaroka Volcanic Supergroup (Smedes and Prostka, 1972).