MODELING NITRATE CONTAMINATION OF GROUNDWATER IN MOUNTAIN HOME, IDAHO USING THE DRASTIC METHOD

by

Jenni Sue Dorsey-Spitz

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DEDICATION

I dedicate this document to my family, who inspired me to work hard and peruse my goals and to my husband, who supported me through all of my adventures.

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I would like to thank my thesis advisor, Dr. John Wilson, for his dedication, mentorship, and support. To my committee members, Dr. Karen Kemp and Dr. Su Jin Lee, thank you for your valuable suggestions and advice that greatly contributed to the success of this thesis. I will be forever grateful to my husband and his unwavering support while I pursed my Master's degree, thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFB	Air Force Base
BPW	Base Production Well
CWA	Clean Water Act
GIS	Geographical Information System
IDEQ	Idaho Department of Environmental Quality
IDW	Inverse Distance Weighting
MCL	Maximum Contaminate Level
MW	Monitoring Well
NPA	Nitrate Priority Area
NPDWR	National Primary Drinking Water Regulations
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NWIS	National Weather Information System
SDWA	Safe Drinking Water Act
SVOC	Semi-Volatile Organic Compounds
TCE	Trichloroethylene
USAF	U.S. Air Force
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

ABSTRACT

Mountain Home Air Force Base (AFB) is located in Elmore County, southwestern Idaho. A regional aquifer is the primary drinking water source for the base residents. While current groundwater quality meets regulatory drinking standards, data collected from the U.S. Geological Survey (USGS) and Mountain Home AFB indicates a significant degradation in quality, particularly nitrate contamination. The purpose of this study was to implement a groundwater model to spatially delineate areas by vulnerability to groundwater contamination risk. The model provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydro-geologic parameters, which can help develop management practices to prevent additional nitrate groundwater contamination in the region. Two Geographical Information System-based groundwater vulnerability models using the DRASTIC method were created using generic, available data and site-specific data. The models were compared to each other, as well as groundwater quality data gathered from 25 wells (16 monitoring wells and 9 base production wells) throughout the study site to validate the model. While the results indicate that the site-specific model is slightly more reliable (56% prediction accuracy), compared to the generic data model (48% prediction accuracy), neither set of model predictions seem good enough to inspire confidence and it is clear that the results produced with the two model runs are not interchangeable. The greatest cause is relative to the small sampling size (n=25) of the wells. The small sample size limits the opportunities to conduct statistical analysis to validate the model outcomes. Additional studies would need to be performed using the same approach, but with larger sample sizes so that the sample size reported here (n=25) would not negatively affect the results.

CHAPTER 1: INTRODUCTION

Groundwater is a valuable resource that provides a source of drinking water to the human population. While 70% of the Earth is covered by water, groundwater only makes up a fraction (0.6%) of all available water on Earth; however, that 0.6% accounts for 98% of the freshwater available for human consumption (Zaporozec and Miller 2000).

Goundwater is stored in aquifers, which not only provides a water source through extraction (e.g., pumped wells), but aquifers also contribute to surface waters such as rivers and lakes (Schwartz and Zhang 2003). Unfortunately, across the globe, groundwater has been significantly degraded by the human population through unsustainable use and contamination (Morris et al. 2003). Significant contamination has been contributed by the disposal of human, animal, and hazardous wastes; byproducts of mining and oil operations; leaks from sanitary sewer lines and septic tanks; and land use operations such as farming (Schwartz and Zhang 2003).

1.1 Motivation

1.1.1 Mountain Home Air Force Base, Idaho

Groundwater supplies 95% of Idaho's drinking water supply. However, some communities, such as the Mountain Home Air Force Base (AFB), rely solely on groundwater due to the dry, arid climates, and lack of surface water availability (IDEQ 2015).

Mountain Home AFB is located in Elmore County, Idaho and has approximately 6,500 base residents. Mountain Home AFB obtains all of its drinking water from the regional aquifer through base production wells (BPWs). Since the establishment of the base in 1942, 11 on-base production wells have been installed to provide drinking water. Of the 11, five wells have been shut down, permanently or temporarily, due to high nitrate concentrations. Currently, the water from two of the base production wells are mixed in order to reduce nitrate levels (ATSDR 2010). In 1985, Mountain Home AFB began working with the U.S. Geological Survey (USGS) to sample and monitor groundwater quality through 16 groundwater monitoring wells (MWs); six of these wells currently exceed the U.S. Environmental Protection Agency's (USEPA) maximum contaminant limit of 10 milligrams per liter for nitrate. Additionally, two of the nine base production wells that are used to provide drinking water also exceed the limit for nitrates. Mountain Home AFB has also been listed as a nitrate priority area by the Idaho Department of Environmental Quality (IDEQ). The purpose of this research was to implement a groundwater model to spatially delineate areas by vulnerability to groundwater contamination. Data from groundwater monitoring wells was used to validate the model.

Identifying high risk areas for groundwater concentration will help with long-term management by identifying the extent of contaminated areas and potential areas susceptible to contamination.

1.1.2 Nitrate Contamination

Nitrate is one of the most common groundwater contaminates in Idaho (IDEQ 2015). Nitrate (NO_3) is the naturally occurring form of nitrogen and is an integral part of the nitrogen cycle in our environment (Figure 1). However, due to the capacity of sandy soils to move elements easily through the soil, nitrate can leach into the groundwater. High concentrations of nitrates, typically specified as a maximum contaminate level (MCL) [MCL > 10 milligrams per liter (mg/L)], are a health risk and may cause *methemoglobinemia* (Blue Baby Syndrome) in infants (USEPA 2013).

Due to the growing number of areas with significant nitrate concentrations in groundwater, the IDEQ has identified and prioritized areas as nitrate priority areas (NPAs). Currently, Mountain Home AFB is ranked #14 out of 32 NPAs in Idaho (IDEQ 2008).

Furthermore, Mountain Home AFB has taken five drinking water production wells offline due to the nitrates exceeding the MCL and posing health risks.

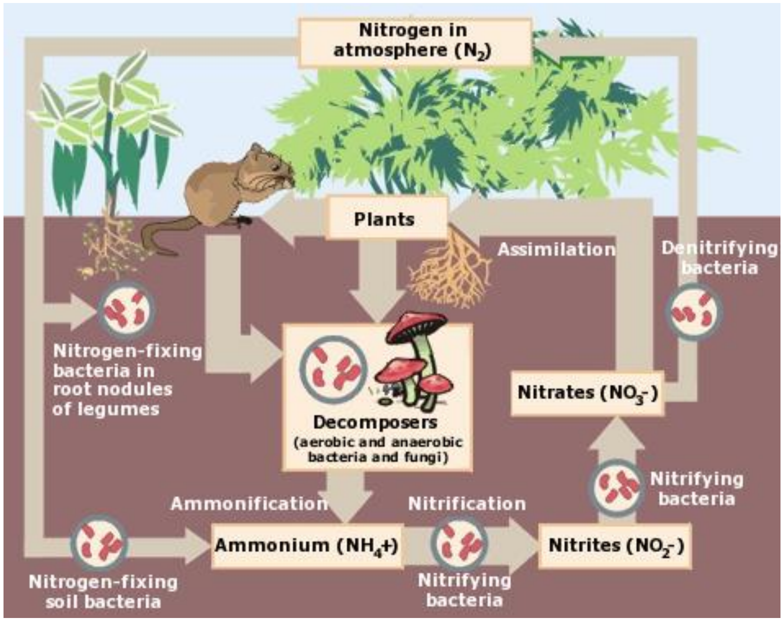

Figure 1. The Nitrogen Cycle, as it occurs on land.
Source: USEPA (2013)

IDEQ works with areas identified as NPAs to implement management strategies and water quality improvement and source protection plans (IDEQ 2014). In order to successfully implement improvement and protection plans, initial data on the location of current and high risk groundwater contamination needs to be identified.

1.1.3 Degraded Groundwater

Mountain Home AFB partnered with USGS in the 1980s to conduct groundwater monitoring and sampling. Sixteen wells around the base are used for monitoring water quality parameters, in addition to water levels. The data show that: (1) Mountain Home AFB groundwater levels are declining at an average of 1.08 feet per year (see Figure 2); (2) nitrate concentrations are increasing in three of the wells, decreasing in three of the wells, and show no consistent trend in the other 11 wells since 1985 to the present-day. Of the 16 MW wells, five exceed the MCL of 10 mg/L for nitrate.

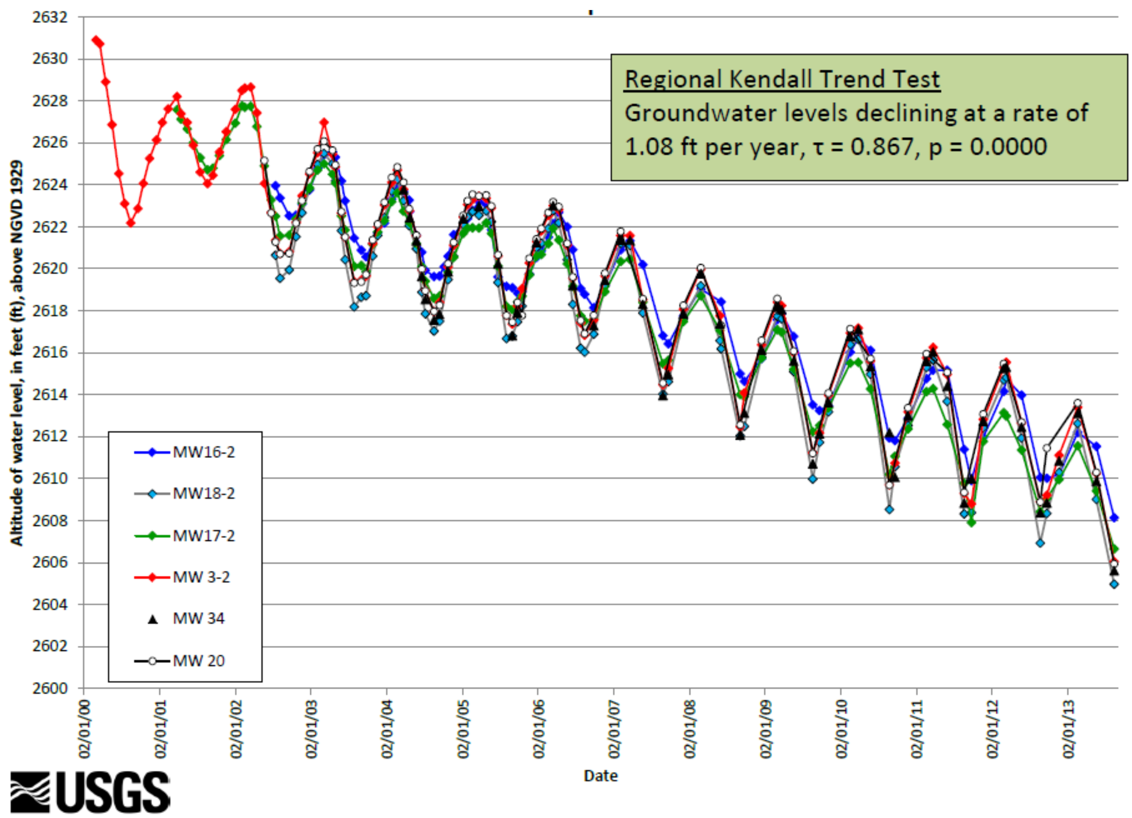

Figure 2. Altitude of water level, in feet (ft), above NGVD 1929 indicating groundwater levels declining at a rate of 1.08 ft per year
Source: Williams (2014)

The declining water table may alter the direction of groundwater movement (Perlman 2014). This change in flow as the water-level continues to decline might also contribute to some areas having greater nitrate concentrations.

1.2 Water Sustainability

The combination of water degradation, declining aquifer levels, and Mountain Home AFB's dependence on the aquifer for drinking water supply drives the need to find one or more solutions. Possible solutions can be identified by using the data to perform analysis, designing a plan to improve and properly manage groundwater quality, and ultimately implementing one or more strategies that lead to the sustainable use of water resources.

1.3 Purpose of this Thesis

Water quality and quantity are long-term and enduring concerns on Mountain Home AFB. While actions such as installing water meters on houses, using reclaimed water for irrigation, and educating the residents on the importance of water conservation have improved conditions, future decisions regarding groundwater protection, well installation, and land management will be informed by the results of monitoring and groundwater modeling.

The purpose of this thesis study was to assess groundwater vulnerability to pollution in the regional, confined aquifer that supplies Mountain Home AFB using the DRASTIC GIS-based groundwater risk assessment model. DRASTIC uses hydro-geological data layers (Depth of water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Connectivity) to assess vulnerability to pollution (Aller et al. 1987). The following objectives were identified in an effort to create a reliable model and demonstrate applications of the DRASTIC Model method:

1. Use available GIS data with DRASTIC to generate vulnerability estimates for the study area and compare predicted results with actual groundwater well observations.
2. Use site-specific and GIS data with DRASTIC to generate vulnerability estimates for the study area and compare predicted results with actual groundwater well observations.

3. Compare the two sets of model estimates to determine whether there is a significant difference between DRASTIC model performance using generic and site-specific data.

1.4 Thesis Organization

The remainder of this thesis consists of four chapters. Chapter 2 describes past studies conducted on Mountain Home AFB and related work incorporating GIS-based groundwater modeling. Chapter 3 summarizes the data and methodology used for this study. Chapter 4 describes the groundwater contamination risk model results, and Chapter 5 summarizes the conclusions that can be drawn from the analysis conducted for this thesis project and presents some suggestions for future work.

CHAPTER 2: RELATED WORK

This chapter starts with a description of the groundwater quality in Idaho, followed by a summary of previous research conducted on Mountain Home AFB. An overview of the human health risks associated with drinking contaminated groundwater, specifically nitrate contamination and of groundwater wells as sources of groundwater contamination are then provided. The chapter closes with a review of GIS-based analyses practices, specifically the DRASTIC Method to develop risk vulnerability models for groundwater contamination.

2.1 Groundwater Quality in Idaho

Approximately 95% of the population in Idaho depends on groundwater as a source of drinking water. The other 5% obtains their drinking water from surface water, including streams, rivers, reservoirs, and springs (IDEQ 2015). Groundwater has many benefits over surface water, such as minimal infrastructure (e.g., water pipes) and better natural protection from contamination and drought (MacDonald, Davies, and Dochartaigh 2002). Nevertheless, groundwater can still become contaminated from sources including human and animal wastes; haphazard disposal of wastes from industrial practices; leaks from storage tanks, pipelines, or disposal ponds; land use activities such as farming and fertilizer applications; and through poorly constructed wells (UNICEF 1999, Schwartz and Zhang 2003).

Federal, state, and local governments have established regulations and guidance to minimize the contamination of waters. The U.S. Federal Clean Water Act (CWA) regulates discharges of pollutants into U.S. waters and establishes quality standards for surface waters (33 U.S.C. §1251 et seq. 1972). Additionally, the Safe Drinking Water Act (SDWA) regulates public water supplies to ensure they are safe; however, the SDWA does not regulate private wells that serve fewer than 25 individuals (USEPA 2014a). In Idaho, a large fraction of the population uses private wells, which are not regulated under the SWDA (IDEQ 2015). Despite Federal regulations established by the CWA and SWDA to control pollutants from entering waters, contamination still occurs through improperly developed and operated private wells and nonpoint pollution sources such as excess fertilizers, herbicides and insecticides from agricultural lands and residential areas; oil, grease and toxic chemicals from runoff; and bacteria and nutrients from livestock, pet wastes, and faulty septic systems (USEPA 2012).

The quality of Idaho's groundwater is affected by human activities as described above and by natural processes. These include chemistry and precipitation, dissolution of organic and mineral substances from vegetation, soil, and rocks as water infiltrates the land surface and percolates through earth materials, and length of time of contact with soil and rocks. These natural factors determine the concentrations of dissolved minerals in groundwater (Yee and Souza 1987). Natural and human factors affecting groundwater quality in Idaho are summarized in Table 1.

Among the natural and human types of contaminants in Idaho (Table 1), arsenic, coliform bacteria, and nitrates are the three most common (IDEQ 2015). Nitrate contamination has the greatest impact on Idaho groundwater quality and is the most widespread. While nitrate, a form of nitrogen, occurs naturally, urban activities are the primary source of additional nitrates. Idaho's groundwater has been significantly degraded and impacted by nitrate contamination, such that 34 areas across Idaho have been identified as NPAs (IDEQ 2015).

IDEQ works with each of the NPAs to restore the degraded groundwater. For each of the NPAs, a groundwater quality improvement and drinking water source protection plan is developed in order to provide information to help prioritize and coordinate water quality related activities (IDEQ 2014).

Table 1. Natural and Human Factors Affecting Groundwater Quality

Natural Factors	
Natural Source	***Types of Contaminant***
Precipitation	Dissolved gases, dust, and emission particles
Infiltration through vegetation, swamps, or soil and rocks (above water table)	Biochemical products, organic materials, color, and minerals
Aquifer rocks	Minerals content (increases with time of contact)
Inter-aquifer mixing of cold water and thermal water	Minerals and gases
Human Factors	
Waste Source	***Types of Contaminant***
Agricultural activities	Fertilizers, pesticides, and herbicides
Mining operations (ore-processing plants	Metallic trace elements and phosphates
Nuclear facilities	Radioactive chemicals, heat, and dissolved solids
Urban activities (storm and sanitary sewers, sewage-disposal plants, cesspools and septic tanks, and sanitary landfills)	Organic materials, dissolved solids, suspended solids, detergents, bacteria, phosphate, nitrate, sodium, chloride, sulfate, metallic trace elements, and others
Industrial facilities (food processors)	Biochemical oxygen demand, suspended solids, sodium, chloride
Geothermal activities	Heat, dissolved solids, fluoride, and metallic trace elements
Hazardous waste- and toxic-waste disposal sites	Toxic metals, hazardous chemicals, and organic compounds

Source: Yee and Souza 1987.

2.1.1 Groundwater Quality in Mountain Home AFB

Mountain Home AFB is ranked #14 out of the 34 NPAs in Idaho due to the substantial nitrate contamination. Groundwater is the primary drinking water source for Mountain Home AFB. Not only is the groundwater quantity important, but so is the quality.

Nitrate levels at Mountain Home AFB have been steadily increasing since initial groundwater monitoring efforts began in the 1980s. In 1994, a base production well was taken out of service due to elevated nitrates above the USEPA's MCL, and the same scenario occurred again in 1997 (ATSDR 2010).

Due to the concern about elevated levels of nitrates across Idaho, the human health risks associated with nitrate contamination, and the rapidly decreasing water levels of the aquifer, Mountain Home AFB has sponsored many studies and reports to address this issue. These studies provide domain knowledge in geology, hydrology, and chemistry, which influences nitrate contamination in the area (Norton et al. 1982; IDEQ 2008; Schwarz and Parliman 2010; IDWR 2013).

In 2010, Schwarz and Parliman took and analyzed groundwater quality data to identify various constituents in the groundwater. The results revealed high amounts of caffeine, which suggested the groundwater was contaminated by leaks from sanitary sewer lines and septic systems (Schwarz and Parliman 2010). Low levels of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and metals have also been detected in the groundwater. During routine drinking water supply sampling, low concentrations of trichloroethylene (TCE) were also detected. Although VOCs, SVOCs, and TCE were detected, none of them exceeded USEPA’s MCLs (ATSDR 2010).

2.2 Nitrate Effects on Human Health

Drinking water standards have been implemented through the SDWA to protect public health. The USEPA has developed the National Primary Drinking Water Regulations (NPDWRs) that set maximum limits for contaminants or naturally occurring constituents in water (i.e., arsenic) to fall below a set limit (Schwartz and Zhang 2003; USEPA 2012). Limits are identified as MCLs.

The MCL for nitrate is 10 mg/L or 10 ppm (USEPA 2014b). Ingestion of water in excess of the MCL for nitrates, in some situations, leads to blue baby syndrome (*Methemoglobinemia*), a condition that affects the body’s ability to transport oxygen from the lungs to the remainder of the body (VanDerslice 2007).

The MCL for nitrates can be traced to a study of 139 cases in Minnesota in 1950 and a survey conducted in 1951 regarding additional cases of *Methemoglobinemia*. While the study found that *Methemoglobinemia* occurred when nitrate levels in infant's water exceeded 10 mg/L, only five of the 214 cases occurred when the level of nitrate was less than 20 mg/L. Nonetheless, the USEPA set the MCL at 10 mg/L since available data was limited and the subpopulation at risk involves infants, so an additional degree of safety was sought in setting the MCL (VanDerslice 2007).

From September 2002 through September 2007, the USEPA investigated the dose-response of nitrate in infants in a nitrate contaminated area in Washington State. The study found that infants, 1-5 months old, who consumed water with nitrate levels above 5 mg/L had significantly and substantially increased risks of having physiologically elevated levels of Methemoglbin. While *Methemoglobinemia* is multi-factorial, it is clear that water containing nitrates is a contributing factor and thus, protecting infants from high nitrates will help to protect them from this potentially fatal disease (VanDerslice 2007).

2.3 Well Development

Groundwater can be contained in a variety of hydrogeological features: confined aquifers, perched aquifers, aquifuges, aquitards, and aquicludes. The most common are confined and perched aquifers.

Aquifers play a key role in supplying water to wells due to their transmission and storage properties. When a pump in a well is turned on, the water level in the well casing is reduced, causing the groundwater in the aquifer to flow towards and into the well (Figure 3). While most of this flow comes from the storage characteristics of the aquifer, the transmissivity is also important since it describes how well the water can move through an aquifer (Schwartz and Zhang 2003).

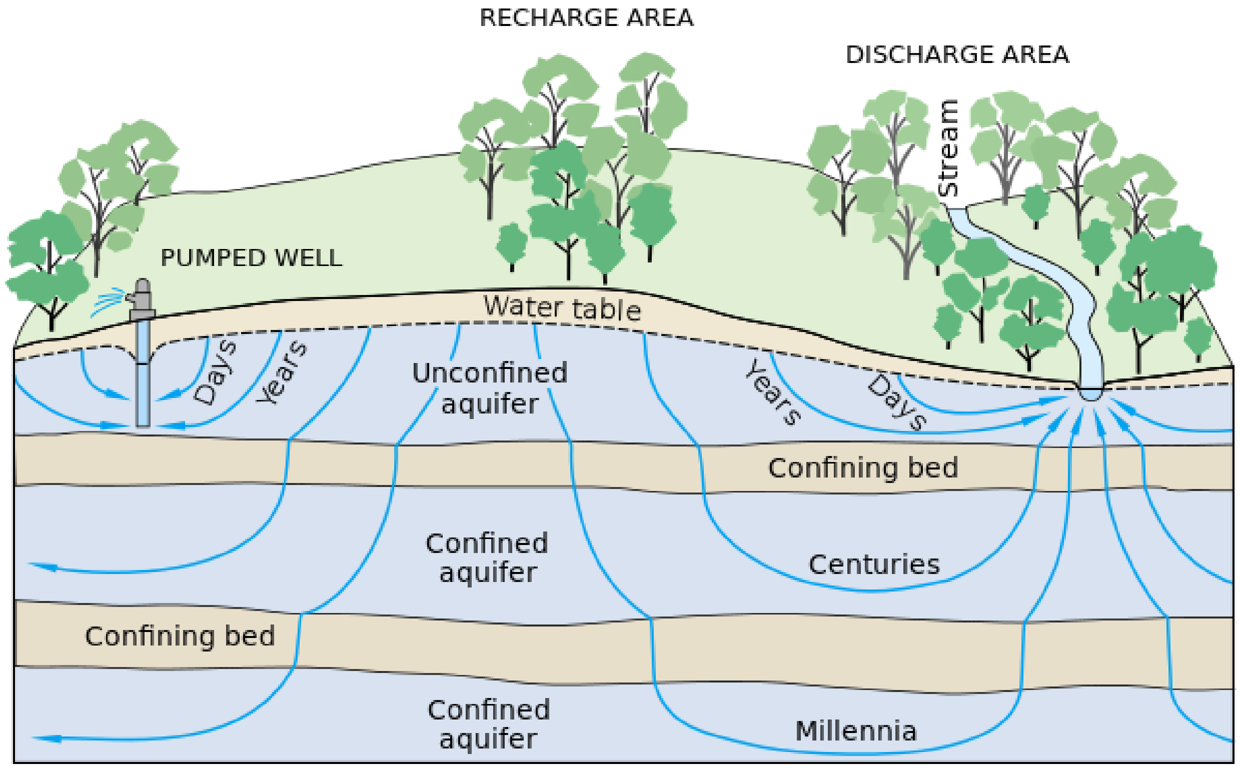

Figure 3. Water infiltrating the subsurface flows through the groundwater system and eventually discharges in streams, lakes, oceans, or is pumped from a well. The residence time in the subsurface can vary from days to thousands of years (Winter et al. 1998).

While wells provide a means of extracting groundwater, they are also susceptible to contamination at the opening on the surface, the piping from groundwater to surface, and the groundwater source (Rural Water Supply Network 2010). Contamination can also occur during the well drilling process since large quantities of drilling water and sometimes chemical additives are added to the subsurface (Barcelona et al. 1985).

As mentioned above in Section 2.1, groundwater can be contaminated from a variety of human and natural sources. The IDEQ has established minimum separation distances in order to protect groundwater contamination and public drinking water systems as described in Table 2.

Table 2. Well Construction Minimum Separation Distances

Separation of Wells from:	**Minimum Separation Distance (feet)**
Existing public water supply well, separate ownership	50
Other existing well, separate ownership	25
Septic drain field	100
Septic tank	50
Drainfield of system with more than 2,500 GPD of sewage inflow	300[a]
Sewer line – main line or sub-main, pressurized, from multiple sources	100
Sewer line – main line or sub-main, gravity, from multiple sources	50
Sewer line – secondary, pressure tested, from a single residence or building	25
Effluent pipe	50
Property line	5
Permanent buildings, other than those to house the well or plumbing apparatus, or both	10
Above ground chemical storage tanks	20
Permanent (more than six months) or intermittent (more than two months) surface water	50
Canals, irrigation ditches or laterals, & other temporary (less than two months) surface water	25

Source: Idaho Administrative Code, IDAPA 37.03.09, "Well Construction Standards Rules"
[a]This distance may be less if data from a site investigation demonstrates compliance with IDAPA 58.01.03, "Individual/Subsurface Sewage Disposal Rules", and separation distances

However, contaminates often times emanate beyond the source and create a plume. A plume of dissolved contaminates can migrate with the flow and create a larger problem. Non-point sources such as fertilizers and point sources including leaking sewer lines can have similar contamination effects on an aquifer due to the mobility of the contaminates and formation of plumes (Schwartz and Zhang 2003).

Groundwater quality data collected from Mountain Home AFB and previous reports suggest nitrate plumes have formed due to non-point (e.g., golf course fertilization) and point contamination (e.g., leaking sewer infrastructure). However, the spatial distribution of the nitrate plumes or areas that are vulnerable to such contamination are unknown (Schwarz and Parliman 2010).

2.4 GIS-based Analysis Methods

The application of GIS to assess groundwater vulnerability to contamination has been successfully practiced since the 1980s (e.g. Merchant 1994, Melloul and Collin 1998, Cameron and Peloso 2001, Al-Adamat, Foster, and Baban 2003, Vias et al. 2005, Baalousha 2006; Jamrah et al. 2007, Sener, Sener, and Davras 2009, Massone, Londono, and Martinez 2010). GIS has been employed to identify and assess groundwater contamination at national, state, and local scales for decades (e.g. Lake et al. 2003, Ceplecha et al. 2004). Many recent studies use interpolation methods for groundwater analyses, the most common being Inverse Distance Weighting (IDW) and kriging. Data collected from monitoring wells is used with one or more of these interpolation methods to produce interpolated layers to analyze the spatial distribution of groundwater quality. Tikle, Saboori, and Sankpal (2012), for example, used IDW and the data contained some data clusters that introduced some errors, suggesting that IDW is sensitive to outliers.

More commonly, studies compare interpolation methods to determine which produces the most accurate results (e.g. Sun et al. 2009, Jie et al. 2013, Taghizadeh-Mehrjardi, Zereiyan-Jahromi, and Asadzadeh 2013). Sun et al. (2009) compared interpolation methods for depth to groundwater in northwest China. Data was collected from 48 observation wells and used to compare IDW, the radial basis function and kriging. They found that simple kriging is the best method since it had the lowest standard deviation between predicted and observed values (Sun et al. 2009).

A more recent study found IDW produced better results compared to kriging or co-kriging (Taghizadeh-Mehrjardi, Zereiyan-Jahromi, and Asadzadeh 2013). The researchers selected IDW and variations of kriging since past research identified kriging to create the best model for groundwater quality parameters, specifically heavy metals. However, the research concluded IDW was the more suitable method of interpolation to estimate groundwater quality variables in Urmia, Iran.

Jie et al. (2013) also compared IDW to kriging and used spatial interpolation to identify the best method. These authors used IDW and kriging and analyzed groundwater depth, salinity, and nitrate values from 90 monitoring wells throughout the Yinchuan, China area. The semi-variation function in ArcGIS was used to determine the optimal interpolation method. By comparing spatial correlation between neighboring observations for each variable through semi-variograms, they were able to determine that both methods offer advantages. IDW is more suitable in areas where neighboring locations play a larger part and the spatial correlation is weak, whereas kriging is more suitable for cases of strong spatial correlation, when the whole trend is being identified (Jie et al. 2013).

IDW and kriging are two of the most common methods; however, the studies revealed that although the tools already offered in Esri's ArcGIS platform offer great convenience, small sampling sizes introduce errors in the results, which can lead to unreliable models (Sun et al. 2009, Tikle, Saboori, and Sankpal 2012, Jie et al. 2013, Taghizadeh-Mehrjardi, Zereiyan-Jahromi, and Asadzadeh 2013).

In situations of small sampling data, or no groundwater monitoring data at all, researchers have taken a different approach where a vulnerability model is first created using site specific geological data and then field verified using either existing or specially acquired groundwater data. Some of the first ideas of assessing groundwater vulnerability to contamination can be traced back to France during the 1960s (e.g., Margat 1968). Since then, several methods for developing vulnerability maps have surfaced, such as CMLS (Nofziger and Hornsby 1986, 1987), DRASTIC (Aller et al. 1987), GOD (Foster 1987), LEACHM (Wagenet and Hutson 1989), AVI (Van Stempvoort, Ewert, and Wassenaar 1993), and SINTACS (Ersoy and Gultekin 2013).

2.4.1 DRASTIC Method

The DRASTIC Method, developed for the USEPA, has become one of the most used methods to distinguish degrees of vulnerability on a regional scale (Merchant 1994, Melloul and Collin 1998, Cameron and Peloso 2001, Al-Adamat, Foster, and Baban 2003, Vias et al. 2005, Baalousha 2006; Jamrah et al. 2007, Sener, Sener, and Davras 2009, Massone, Londono, and Martinez 2010). The DRASTIC Method is named for the seven factors considered in the method: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and hydraulic Conductivity of the aquifer (Aller et al. 1985, Koterba, Banks, and Shedlock 1993, Rupert 1994, Barbash and Resek 1996, USGS 1999, Ersoy and Gultekin 2013).

The DRASTIC Method has been used to show areas of greatest potential for groundwater contamination across the globe. The earliest applications had mixed success, mainly due to their reliance on the uncalibrated DRASTIC Method (e.g. Rupert et al. 1991). However, throughout the years, the method has been improved through calibrating the point rating scheme to measure nitrite plus nitrate as nitrogen concentrations in groundwater and through its integration with GIS. Statistical correlations suggest a linkage between nitrite plus nitrate as nitrogen and land use, soils, and depth to water (Ott 1993, Rupert 1994).

Groundwater vulnerability assessments have been conducted for the region surrounding Mountain Home AFB using the DRASTIC Model (IDEQ 1991, USGS 1999). The Idaho Groundwater Vulnerability Project (IDEQ 1991) used a modified form of the DRASTIC Method to produce a vulnerability map for the Idaho Snake River Plain (Figure 4). The map was designed as a tool for prioritization of groundwater management activities in order to allocate limited resources effectively. The Idaho groundwater vulnerability project also provided justification for future studies (IDEQ 1991).

Furthermore, the vulnerability map was field verified by overlaying water quality data on top of the vulnerability map. All of the wells that had anomalous levels of contaminates were located in areas identified as high or very high risk areas, suggesting a good correlation between the vulnerability map and field data (IDEQ 1991).

However, the project focused on the Idaho Snake River Plain at a scale of 1:250,000, which provides generalized information on a regional scale. The vulnerability assessment does not provide enough information for site-specific locations; therefore, more in-depth studies would need to be performed for site-specific decisions (IDEQ 1991).

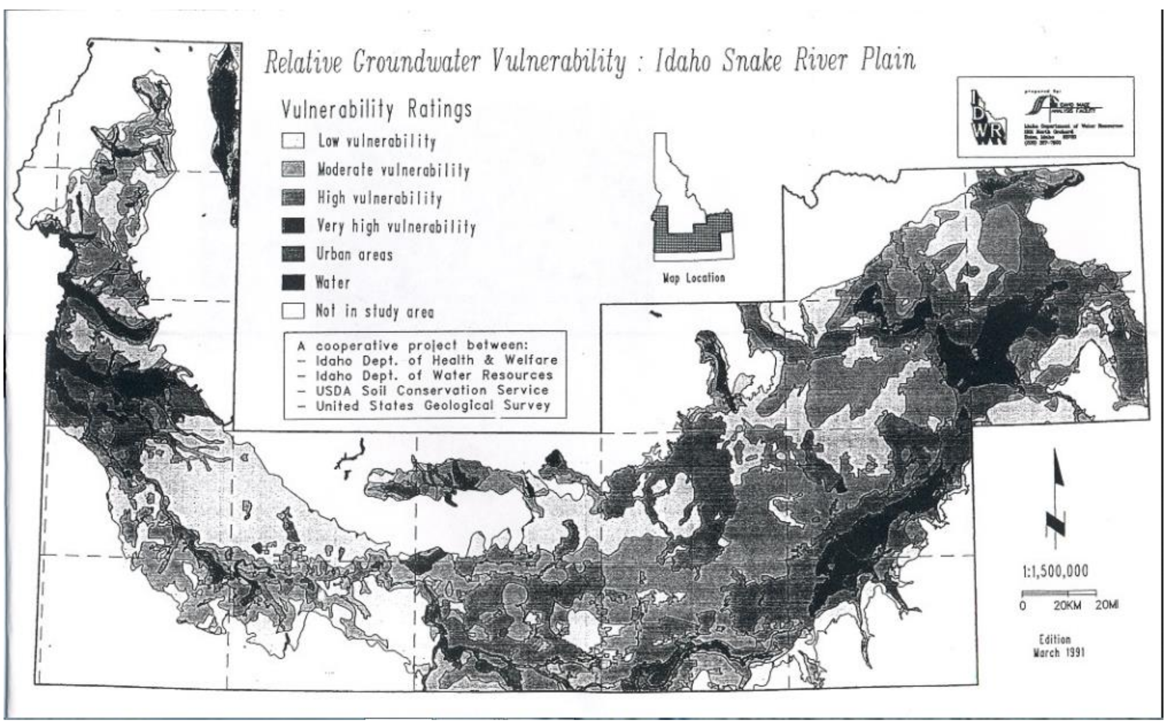

Figure 4. Vulnerability Map of the Idaho Snake River Plain (IDEQ 1991)

Similarly, the USGS (1999) produced a groundwater vulnerability map using the DRASTIC Method for the eastern portion of the Snake River Plain, Idaho (Figure 5). The DRASTIC point rating scheme was calibrated using groundwater quality data and the results indicated a significant correlation between elevated nitrate levels and depth to water, land use, and soil drainage (USGS 1999).

IDEQ (1991) and USGS (1999) have employed the DRASTIC Model to illustrate Idaho's groundwater risk; however, the projects were either at small scales (≤ 1:250,000) and/or did not encompass the Mountain Home AFB area that is the focus of this thesis research project.

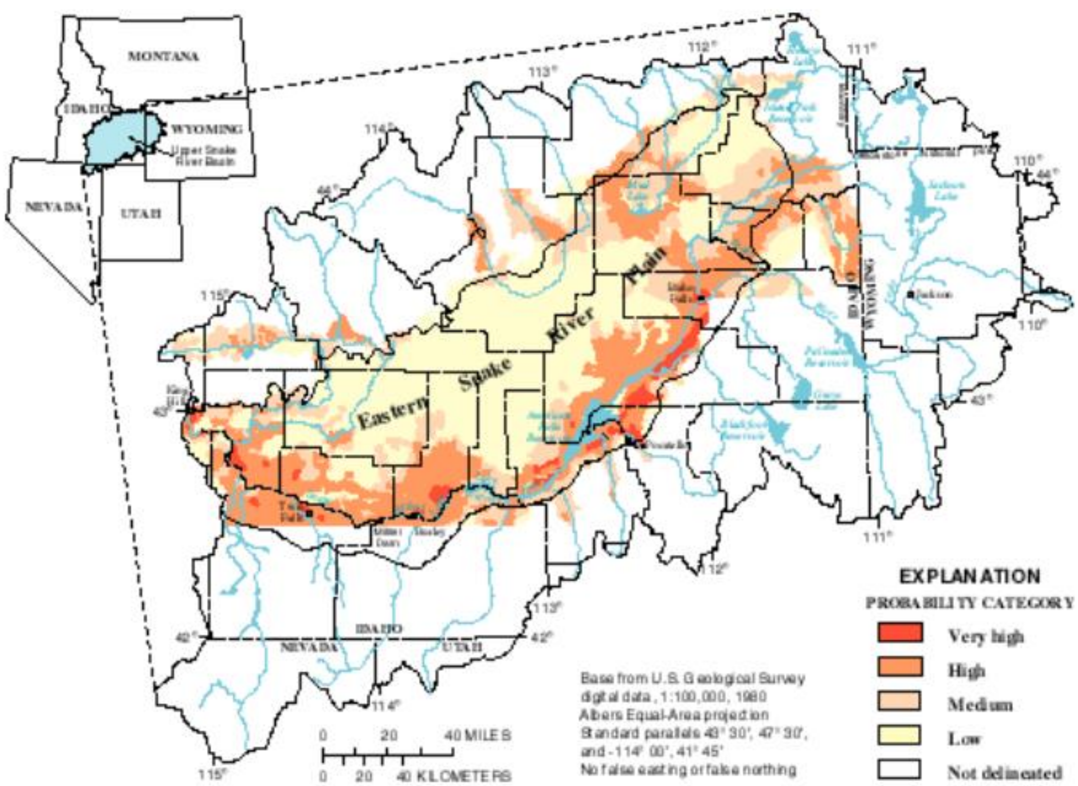

Figure 5. Probability of groundwater contamination by dissolved nitrite plus nitrate as nitrogen for the Eastern Snake River Plain, Idaho (USGS 1999)

CHAPTER 3: METHODOLOGY AND DATA SOURCES

The overarching purpose of this study was to produce a GIS-based groundwater vulnerability model for the Mountain Home AFB using the DRASTIC method. The model provides a basis for evaluating groundwater vulnerability to pollution based on hydro-geologic parameters, which can help guide the development of management practices to prevent additional nitrate groundwater contamination in the region and improve management of water resources. The model was verified using groundwater quality data to illustrate the efficacy of using the DRASTIC method in assessing the vulnerability of the Mountain Home AFB to groundwater contamination.

The remainder of this chapter consists of five sections. The first introduces the Mountain Home AFB study area. The next two sections offer descriptions of the DRASTIC method and the data that were used to implement this method. The final two sections describe how the various factors were combined and how the model predictions were validated using groundwater quality data.

3.1 Study Area

Mountain Home AFB is located in southwestern Idaho in Elmore County, approximately 50 miles southeast of Boise, Idaho and 8 miles southwest of Mountain Home, Idaho. Mountain Home is close to both mountains and high desert landscapes, with vast areas of open space. The 6,844 acres of Mountain Home AFB consists of buildings, roads, and runways, which covers 20-25% of the land (USAF 2012). The remainder of the land includes landscaping, open, undeveloped fields, and partially disturbed areas (Figure 6).

Figure 6. Mountain Home AFB area map.

3.1.1 Climate

Mountain Home AFB is situated in the western portion of the Snake River Plain and receives approximately 12 inches of rain per year. Most of the precipitation falls during late fall to early spring. The semi-arid climate of Mountain Home AFB consists of hot, dry summers with average daily temperatures of 90^{o}F; however, temperatures may reach as high as 109^{o}F during August. During the winter months, the average temperature is 30-35^{o}F (USAF 2012).

3.1.2 Geology and Soils

The Snake River Plain is thought to be an area of crustal rifting that started approximately 16 million years ago and grew southeasterly until about 3 million years ago (USAF 2012). Thick deposits of rhyolites and basalts dominate most of the geology due to early volcanism. Additionally, approximately eight million years ago, the area was covered by a lake called “Lake Idaho”, which has since dried up, leaving thick sedimentary deposits of ash, clays, silts, sands, and gravels (USAF 2012).

The soils on Mountain Home AFB are typical of semi-arid regions, consisting primarily of silt and sandy loam. The soils have poor drainage and lack organic matter, with varying thicknesses, depending on the location of bedrock and hardpans (USAF 2012).

3.2 DRASTIC Method

The DRASTIC method uses seven hydro-geological parameters to assess groundwater vulnerability: (D) depth to groundwater table, (R) net recharge, (A) aquifer media, (S) soil media, (T) topography, (I) impact of vadose zone, and (C) hydraulic conductivity (Table 3).

The input information was obtained from online databases and site-specific borehole, land-use and topography data, and used to develop each DRASTIC parameter. Each of the seven parameters was weighted and rated due to their relative influence on contamination, which ranged from 1 to 5 and 1 to 10, respectively (Tables 3 and 4). Each parameter was multiplied by a multiplier to obtain the weighted value. Then, the products were summed up to calculate the final DRASTIC index (Equation 1), where r = the rated factor and w = the weighted factor. The DRASTIC index (DI) represents the degree of vulnerability and can be used with GIS to produce a vulnerability map that represents the hydrogeological setting (Shirazi et al. 2012):

$$DI = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \qquad (1)$$

where D, R, A, S, T, I, and C are the seven parameters and the r and w subscripts correspond to the rated and weighted factors, respectively.

Table 3. The seven DRASTIC model parameters and their relative weights

Factors	Descriptions	Relative Weights
Depth to Water	Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5
Net **R**echarge	Represents the amount of water which penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants.	4
Aquifer Media	Refers to the saturated zone material properties, which controls the pollutant attenuation processes.	3
Soil Media	Represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward.	2
Topography	Refers to the slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone.	1
Impact of Vadose Zone	Is defined as the unsaturated zone material, it controls the passage and attenuation of the contaminated material to the saturated zone.	5
Hydraulic **C**onductivity	Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system.	3

Source: Babiker et al. (2005)

Table 4. DRASTIC parameters and rating values (adapted from Aller et al. 1987).

Rating	Depth to Water (ft)	Net Recharge (Irrigation)	Aquifer Media	Soil Media	Topo-graphy (%)	Impact of the Vadose Zone	Hydraulic Conductivity (m/day)
10	0 - 5.0	Urban	Karst Limestone	Thin or absent, gravel	0 to 2	Karst Limestone	1.00E+04
9	5.1 - 15.0		Basalt	Sand Stone and Volcanic	2 to 3	Basalt	1000
8			Sand & Gravel	Peat	3 to 4	Sand & Gravel	100
7	15.1 - 30.0	Improved	Massive Sandstone & Limestone	Shrinking and / or aggregate clay / alluvium	4 to 5	Gravel, Sand	10 to 1
6			Bedded Sandstone, Limestone	Sandy Loam, schist, sand, karst volcanic	5 to 6	Limestone, gravel, sand, clay	0.1 - .01
5	30.1 - 50.0	Semi-Improved	Glacial	Loam	6 to 10	Sandy Silt	.01 - .001
4			Weathered Metamorphic / Igneous	Silty Loam	10 to 12	Metamorphic Gravel & Sand	.001 - .0001
3	50.1 - 75.0		Massive Shale	Clay Loam	12 to 16	Shale, Silt & Clay	10E-4 to 10E-5
2	75.1 - 100.0			Muck, acid, granitoid	16 to 18	Silty Clay	10E-5 to 10E-6
1	> 100.1	Un-improved		Non Shrink and Non - aggregated clay	> 18	Confining Layer, Granite	< 10E-6

3.3 Data for DRASTIC Parameters

Several types of data were used to construct two DRASTIC models. The first used generic, publicly available data and the second used site-specific data.

Model 1 relied on generic data that could be gathered from online GIS databases. The data for each parameter is described in more detail in the subsections below. Three considerations guided the choice of these data as follows: (1) the data had to be publicly available; (2) the data had to have been collected or updated within the past five years; and (3) the source must have contained data within the Mountain Home AFB study area itself.

Model 2 used some of these same data sources plus site-specific data obtained primarily from well driller's logs. Mountain Home AFB has partnered with the USGS to collect data on groundwater quality parameters since 1985. Groundwater quality parameters include nitrates and static water levels for 16 different MWs located around the base. Additionally, since nitrate is a NPDWR and regulated by the USEPA, nitrates are sampled at all of the BPWs. Table 5 provides a list of MWs and BPWs with nitrate sampling data available for validating the model outputs. The location of each well has been located with GPS coordinates and provides data on the spatial distribution of nitrates across the base (Figure 7). Furthermore, each well has a well driller's log that indicates the depth of the well and water level. This data has been maintained in a Microsoft Excel spreadsheet, and was used in this thesis research project to populate the attribute table for the feature file. The WGS 84 / UTM Zone 11 N projection with meter as the unit of measure was used for both models.

Table 5. Summary of available groundwater quality data from USGS and Mountain Home AFB for 16 MWs and nine BPWs

Base Production Wells (BPWs)			
BPW 1	BPW 2	BPW 4	BPW 6
BPW 8	BPW 9	BPW 11	BPW 12
BPW 13			
Monitoring Wells (MWs)			
MW 3-2	MW 6-2	MW 7-2	MW 11-2
MW 16-2	MW 17-2	MW 18-2	MW 21
MW 22	MW 23	MW 29	MW 30
MW 34	MW 35	MW 36	MW 40

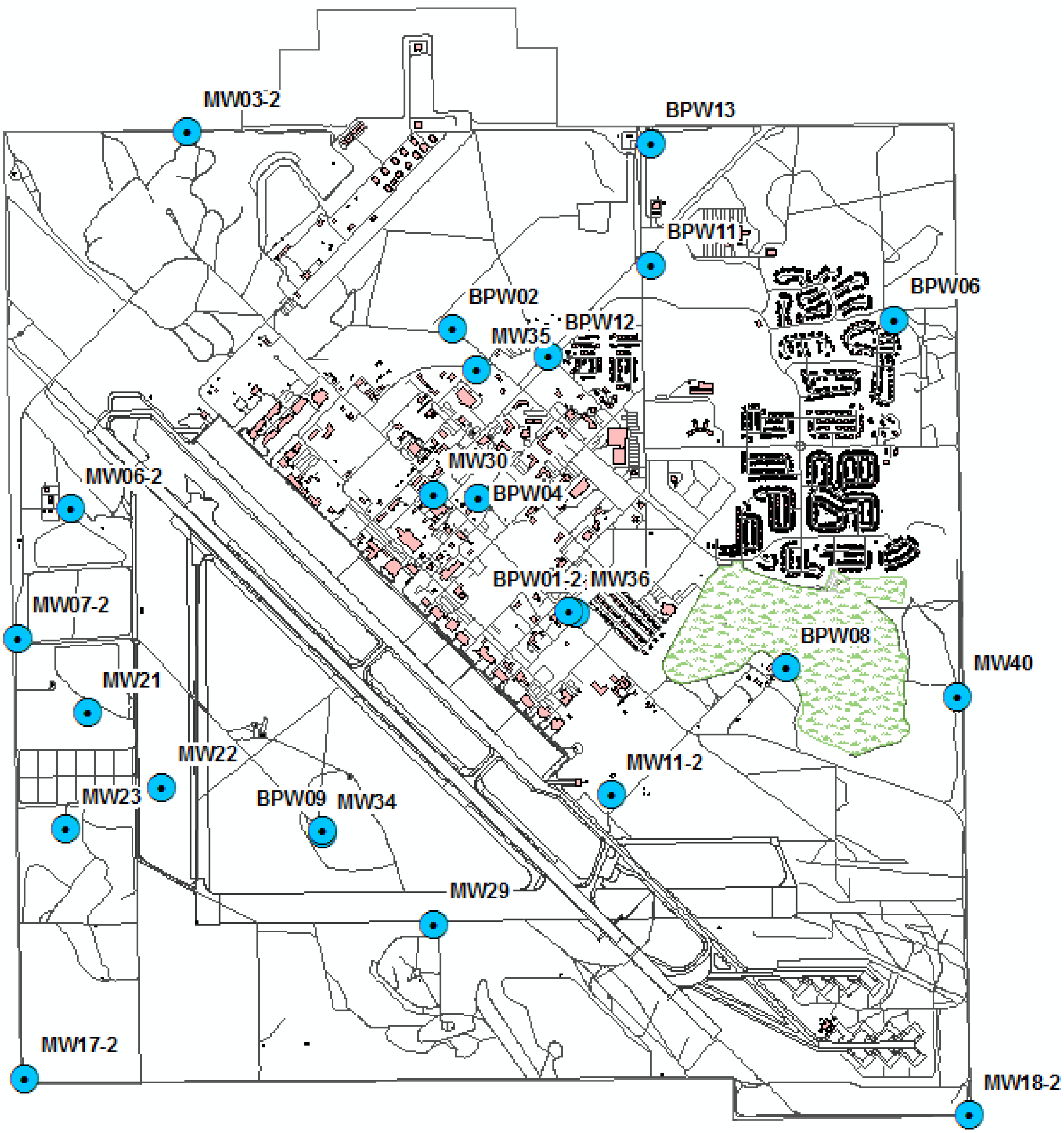

Figure 7. Location of BPWs and MWs, which have been sampled for nitrates on Mountain Home AFB, Idaho. Green area is a golf course within the study area.

3.3.1 Depth to Groundwater

The depth to groundwater for Model 1 was obtained from the USGS National Water Information System (NWIS). NWIS contains data on active well networks, including statistics about groundwater level data. These data were interpolated using the IDW method to create a smooth surface representing the spatial continuity of the groundwater surface for the study area. The IDW was performed on the point data using the default distance parameter (i.e. distance squared), cell size of 20 m, and a limiting search radius to capture at least two other points. This approach ensured that larger weights were assigned to points close to an output pixel and this same procedure was used for every IDW interpolation in this study. Following the IDW, the map was classified into ranges defined by the DRASTIC Model (1-10, with 1 representing minimal impact to vulnerability and 10 representing maximum impact). The deeper the groundwater, the smaller the rating value. Since the groundwater is deeper than 100 feet for the entire year, a rating factor of one was assigned to the entire study area.

The well driller's log data was uploaded into ArcGIS for Model 2. The depth to the water table was obtained from the data and using IDW to interpolate a smooth surface. Similar to Model 1, the groundwater level is greater than 100 feet, so a rating of one was applied to the whole study area for the second set of model runs as well.

3.3.2 Net Recharge

Land use was used as a surrogate for net recharge since Mountain Home AFB does not have any recharge wells and receives little precipitation, so irrigated areas provide the largest amount of recharge in southern Idaho (Rupert et al. 1991).

Esri's ArcGIS Online has a robust database for a variety of data, including the U.S. Land Cover GAP database (USGS 2011). This data layer contained the land cover classification used by the USGS Gap Analysis Program. These data include detailed vegetation and land use patterns for the continental U.S. A total of 590 detailed land use classes in the data set are grouped together into a total of eight general classes, including agricultural, urban/developed, non-forested lands, water, etc. The USA Land Cover GAP data layer was used for Model 1 and reclassified using the DRASTIC Model rating scheme based upon the eight general classes.

Mountain Home AFB has a Geobase Office that maintains all local GIS databases. The land use data are divided into four general categories based upon improvements, specifically irrigation and maintenance: (1) urban/developed (turf lawns, significant amounts of irrigation); (2) semi-improved (established irrigation systems); (3) improved (drip-line irrigation); and (4) unimproved (no irrigation, native landscape). These land-use data were stored as a polygon feature class, so they were converted into raster and then used to assign the rated net recharge (R) factor.

3.3.3 Aquifer Media

The U.S. aquifers data layer was also obtained from Esri's ArcGIS Online database. This US aquifer layer was produced as part of the Ground Water Atlas of the U.S. (USGS 2009) and specifies the areal extent of the principal aquifers, including aquifer media for the Snake River Plain Aquifer on which the Mountain Home AFB is located. The data was imported, clipped to the installation boundary, and used for Model 1. Since the data was in polygon format, it was convert to raster using the Polygon to Raster conversion tool Esri's Spatial Analyst (Version 10.1). The data was then assigned a rating factor in accordance with the DRASTIC Model parameter fields (Table 4).

The drill logs and sampling provided details of the well construction and the subsurface materials that were bored through. Since each well is an individual entity, the data provided information for that particular data point. The well driller's logs were reviewed and the information on aquifer media was uploaded into a well layer. Rating factors were assigned to each well point, depending on the aquifer media and interpolated using IDW to create a smooth surface representative of the aquifer.

3.3.4 Soil Media

Models 1 and 2 used the same data for the soil DRASTIC parameter—the SSURGO database from the United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS 2015). The SSURGO database contains information about soil as collected by the National Cooperative Soil Survey over the past century. This information was imported in digital format into the ArcGIS system and clipped to the installation boundary. The soil media types were then assigned ratings from 1 to 10 according to their permeability (Table 4).

3.3.5 Topography

The topography layer for both Model 1 and Model 2 was constructed using contour elevation data at 5 foot intervals. The data was imported from the Mountain Home AFB Geobase. In order to determine the percent slope, the topography data was converted to a raster (20x20 cell size) using the Topo to Raster Spatial Analyst tool. Once converted, the Slope tool in Spatial Analyst was used to calculate the percent slope. Each percent range was reclassified using the DRASTIC Model rating factors (Table 4).

3.3.6 Impact of Vadose Zone

Similar to the aquifer media, the impact of the vadose zone was obtained from Esri's ArcGIS Online U.S. aquifer layer. The same data was imported and clipped to the installation boundary for use in Model 1. Since the data was in polygon format, it was converted to raster using the

Polygon to Raster conversion tool in Spatial Analyst. The data was then assigned a rating factor in accordance with the DRASTIC Model parameter fields (Table 4).

The procedures used for the aquifer media data obtained from the well driller's logs were used to estimate the impact of the vadose zone data for Model 2. Rating factors were assigned to each well point, depending on the aquifer media and interpolated using IDW to create a surface representative of the vadose zone values.

3.3.7 Hydraulic Conductivity

Unsaturated zone hydraulic properties can be used to estimate the movement of chemicals into the aquifer and are typically obtained from pump tests, slug tests, and constant-head tests. However, these values are sometimes not readily available due to the costs associated with performing the necessary tests to obtain those values. To balance the need for data and lacking information, quasi-empirical models, hydraulic data from similar soils, or typical values for most aquifer material from textbooks or publications were used to predict the unsaturated hydraulic conductivity (Adams and Jovanovic 2005).

Data from the aquifer media were used with Figure 8 to obtain hydraulic conductivity values (Heath 1983). These hydraulic conductivity estimates were then added to the aquifer media attribute table and rated in accordance with the DRASTIC Model (Table 4). The polygon layer was converted to a raster layer using the hydraulic conductivity rating values. The same process was performed for both Models 1 and 2, using the associated aquifer media data for each.

3.4 Aquifer Vulnerability Assessment

Each of the DRASTIC factors was reclassified to incorporate the rated factor in order to calculate the DRASTIC Index (Equation 1). Once each of the layers were prepared, they were combined using the weighted sum overlay function in ArcGIS to combine the layers using the weighted factor. The output of the function was a single cell layer signifying the vulnerability index for the study area.

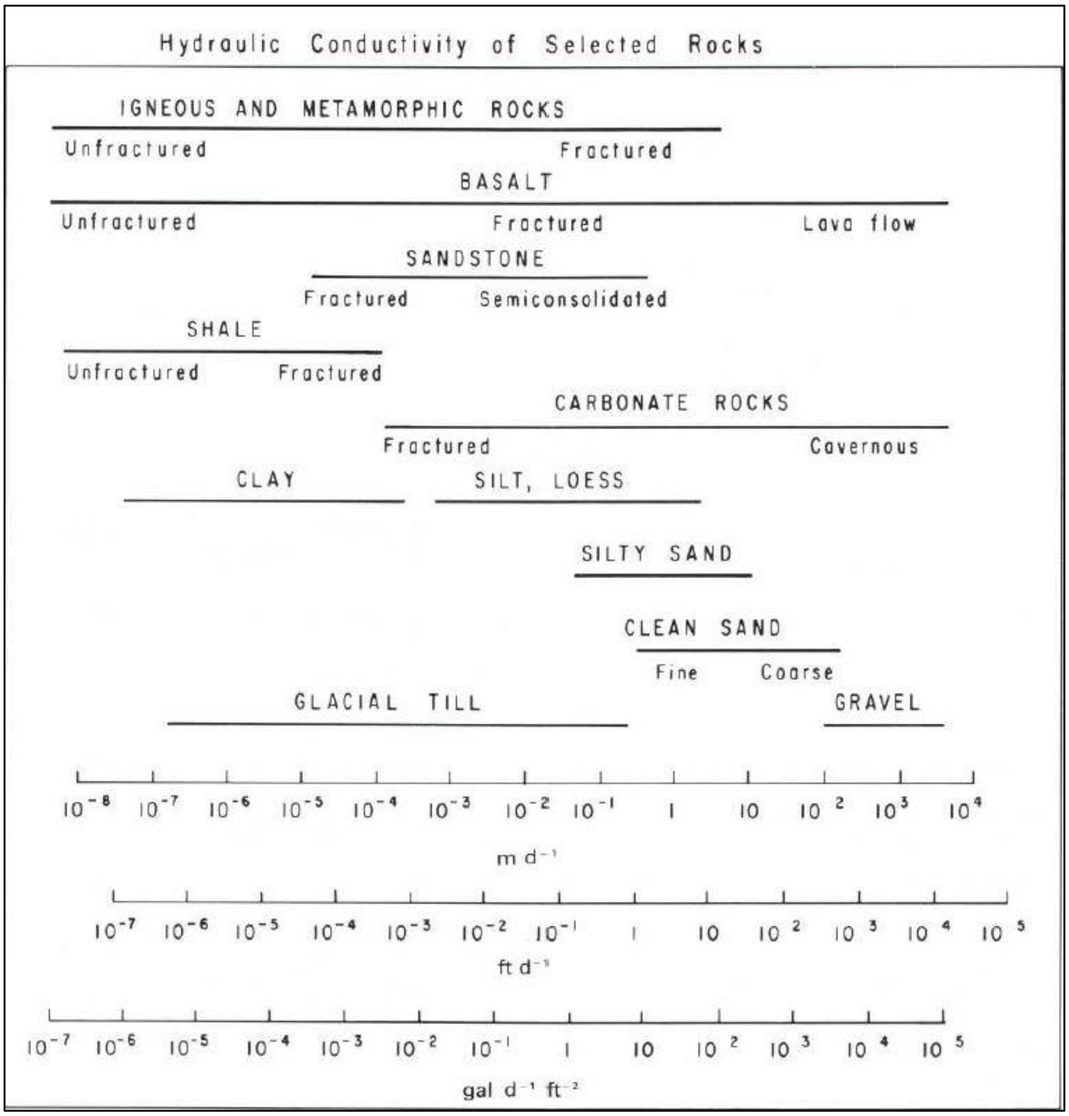

Figure 8. Hydraulic conductivity values for selected aquifer media types.
Source: Heath 1983

The DRASTIC indices were classified into categories based on the mean value of the dataset then renamed based on vulnerability risk: low and high. The indices were assigned a color corresponding to the level of risk and these colors were then used to produce a vulnerability map: green was used to indicate "low" vulnerability and red to indicate "high" vulnerability.

3.5 Model Validation

Two efforts were made to compare the model predictions and to evaluate the efficacy of the two sets of model predictions as follows.

For the first test, the predictions generated with both models were compared to one another to see whether or not the two models tended to produce similar rankings in terms of the vulnerability risk at the 25 locations with monitoring wells (Figure 7).

For the second test, the two models were individually validated using groundwater quality data obtained from the 25 monitoring wells scattered across the study site (Figure 7).

Both models were overlaid with the well point layer, displaying the average nitrate sampling results for each well. The models were analyzed to determine the prediction accuracy rate.

In order to do so, the vulnerability index values for each model were converted from raster to point values using the Raster to Point conversion tool and the point values were compared with the well point feature class containing the nitrate data and collected into a series of tables: descriptive statistics and model prediction analysis. The data was used to calculate descriptive statistics, including the minimum, maximum, mean, standard deviation, and coefficient of variance. The mean for each model was used to identify the classification break between low and high vulnerability. Values below the mean were classified as low, while anything equal to or greater than the mean was high risk. Nitrate sampling data was classified into low or high risk by the USEPA action level of 5.0 mg/L. The prediction accuracy rate was determined by whether the model successfully identified a low vulnerability area for a low nitrate observation and a high vulnerability area for a high nitrate observation.

Finally, the results from the two models were compared to each other to determine whether there was a significant difference between the models built using the generic and site-specific data using cross-tabulated tables.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter describes the seven DRASTIC parameter maps and the two vulnerability index maps that were developed to represent groundwater contamination risk for Mountain Home AFB, Idaho. The first goal of this project was to create a DRASTIC model using available GIS data from sources such as USGS, ArcGIS Online, etc. The second goal was to create an additional DRASTIC model using site-specific data obtained from well drilling logs. The third goal was to compare the model predictions to the groundwater well observations to determine whether the use of the site-specific data improved the specificity of the model predictions. The following sections detail the results and how this thesis project accomplished the aforementioned goals.

4.1 DRASTIC Parameters

4.1.1 Available GIS Data

The average depth to the water table (D) at Mountain Home AFB is 360 feet, which the rated metric computes to a value of one for the entire study area (Figure 9).

The arid-dry climate and minimal rainfall at Mountain Home AFB means that the net recharge to the groundwater aquifer is more dependent on land use and irrigation applications. The general land cover map reproduced in Figure 10 shows the general land cover types which control the net recharge to the groundwater aquifer on the Mountain Home AFB. The lowest recharge rate (rated value of one) was associated with the non-forested unimproved areas with no maintenance or irrigation systems since the net recharge relies entirely on precipitation (annual > 12in/year). The urban/developed land and other improved areas such as the golf course had relatively higher recharge rates due to the substantial irrigation applications (rated value of 10).

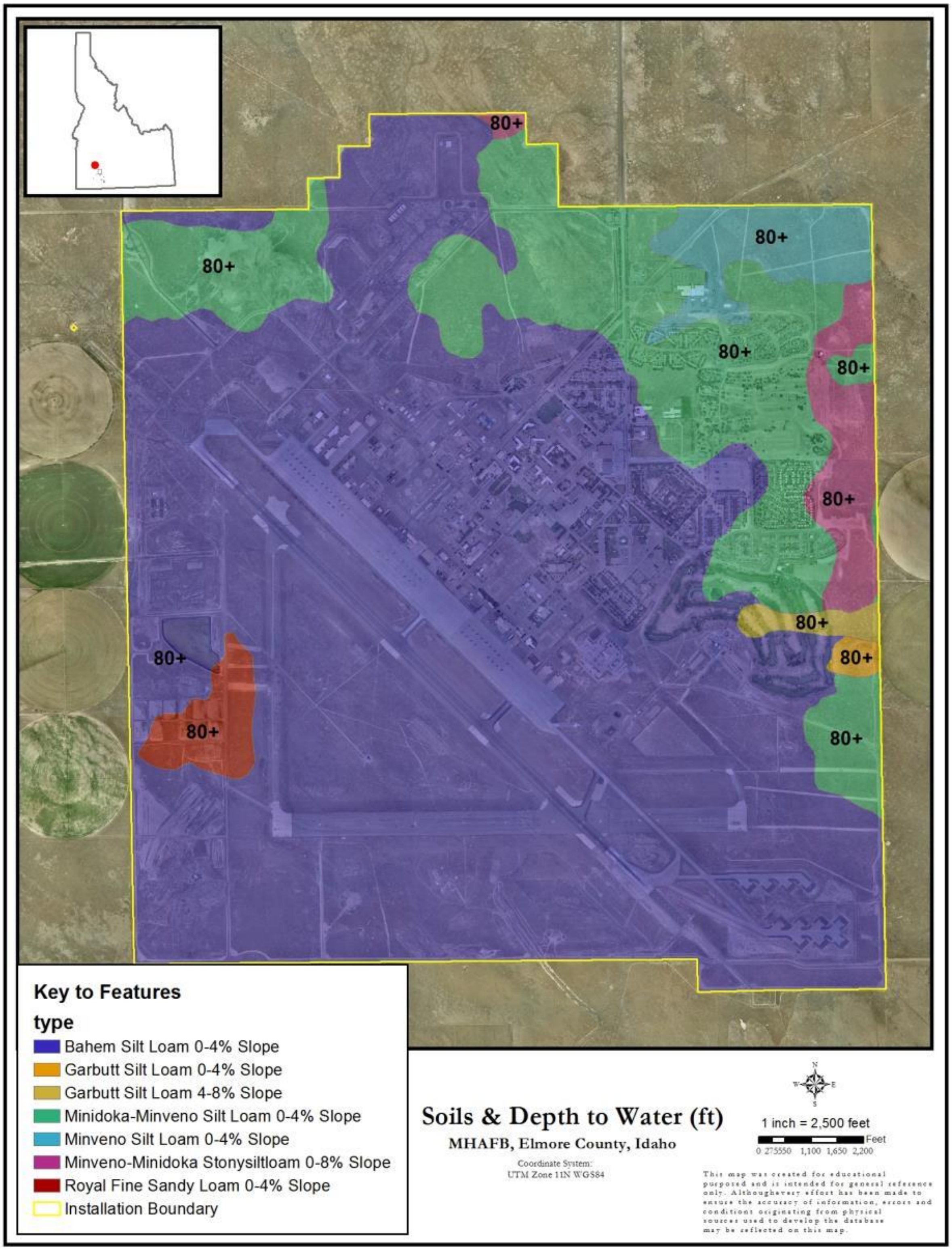

Figure 9. Soil type (symbology) and depth to water in feet (labels) for Mountain Home AFB. The depth to groundwater is greater than 80 feet across the entire study area.

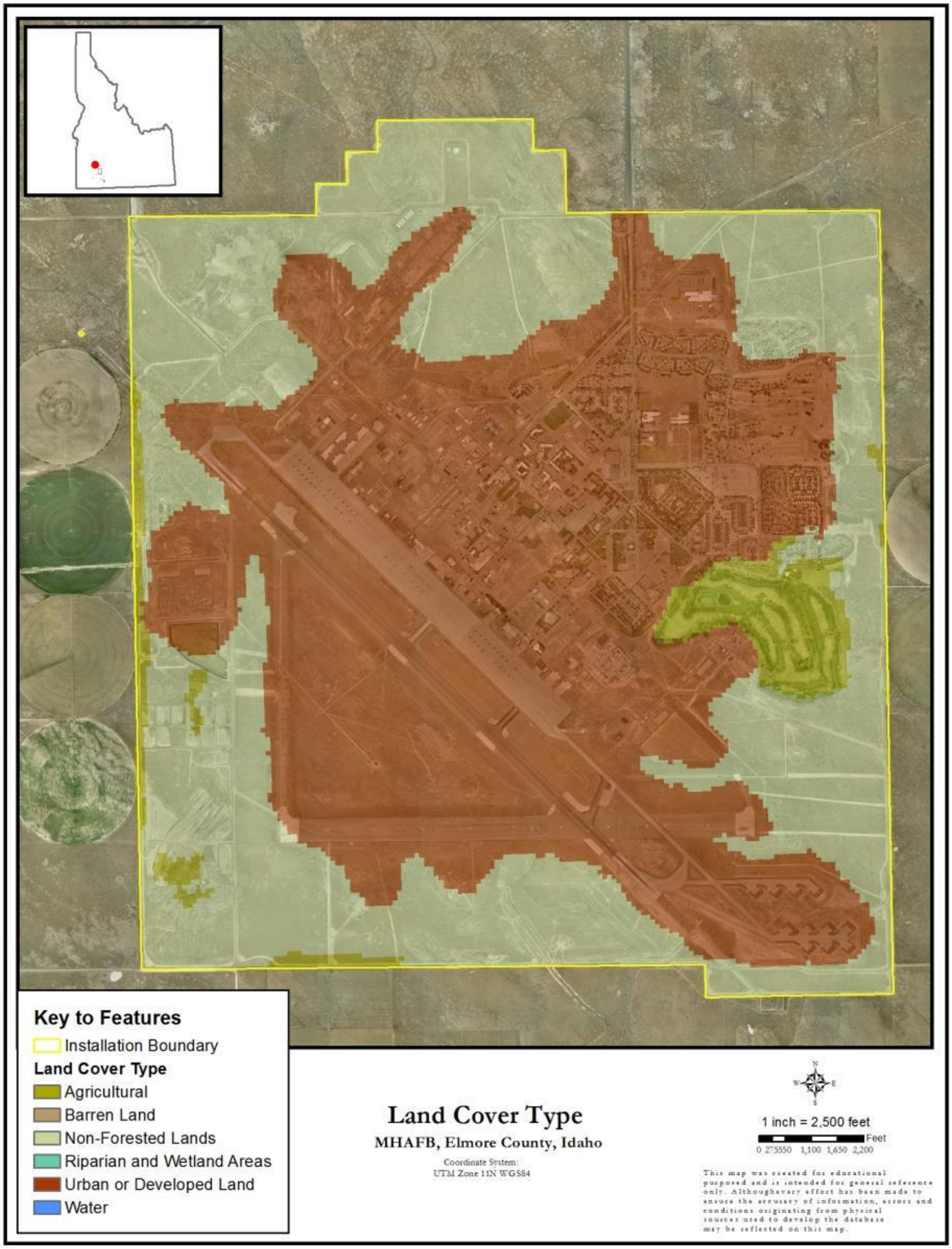

Figure 10. General land cover type, consisting primarily of Urban/Developed Land (red), Agricultural (including the golf course), and Non-Forested Lands.

The aquifer media underlying Mountain Home AFBis primarily metamorphic/igneous with a small section of sand/gravel in the southwest corner of the study area. These media were rated four and eight, respectively (Appendix A, Figure A1).

Soils on Mountain Home AFB are mostly silty loam with the exception of a small area of fine sandy loam (Figure 10). The majority of the study area consists of Bahem silt loam, with a rating of four. Turning next to slope (S), the overall slope is less than 2% across the entire study area, so water is more likely to percolate rather than flow to another location (rating score 10) (Appendix A, Figure A2).

The impact to the unsaturated material in the vadose zone mirrored that of the aquifer media, consisting primarily of grey basalt (rating score 9) and an area of sand and gravel (rating score 8) in the southwest corner (Appendix A, Figure A3).

The hydraulic conductivity of fractured basalt is relatively minimal, with a value of 0.1 m/day (rating score 6); however, sand and gravel transmits flow more quickly, with a value of 100 m/day (rating score 8) (Appendix A, Figure A4).

4.1.2 Site-Specific GIS Data

Starting in the same place and moving through the various inputs in the same order, the reader can see that while more specific measurements of depth to groundwater were obtained from well drilling logs, the overall rating (rating score 1) did not change from the first model since the depth ranges from 350 feet to 432 feet (Appendix B, Figure B1).

Net recharge ranged from one to 10, with the highest rating associated with the urban land use because of irrigation systems (rating score 10) (Figure 11). The remainder of the study area had lower net recharge rates due to the barren land (rating score 1), rangeland (rating score 3), and agricultural land (rating score 7) as a consequence of the types and amounts of irrigation,

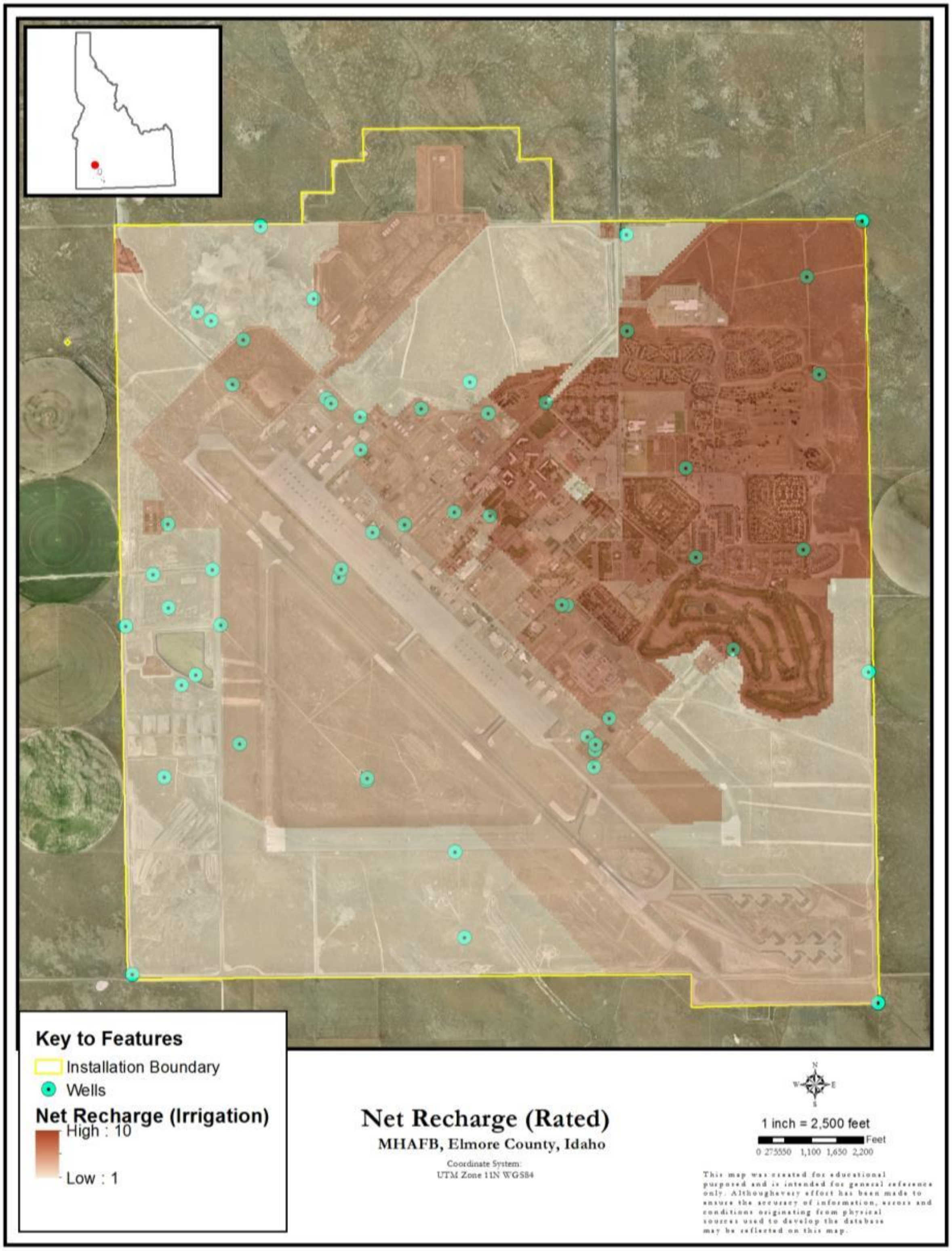

Figure 11. Site-specific land cover type to obtain Rated Net Recharge, ranging from Urban/Developed Land (darker red) to barren, rangeland (white). Wells are depicted in blue.

if any, involved with these land uses. The area with the greatest amount of irrigation use is the golf course, which uses an average of 1 to 2 million gallons of water per day during the growing season (rating score 10).

The Mountain Home aquifer geology is primarily basalt (rating score 9) with occasional intercalated, thin, discontinuous deposits of sand/gravels (rating score 8), mudstone (rating score 7), and shale and clay (rating score 3). The deposits of aquifer media other than basalt occurred predominately on the western portion of the study area and in the northeast corner (Figure B2).

Both DRASTIC models shared the same soils and topography data, and therefore utilized the same rating results for soils (rating score 4) and slope (rating score 10) for the reasons noted earlier.

The impact of the vadose zone varied more than it did for the first model due to the data obtained from the well driller's logs. Similar to the aquifer media, basalt (rating score 9) is the primary media; however, deposits of silt/sand (rating score 5), sand/gravel (rating score 7), and clay (rating score 3) were located throughout the study area (Figure 12). The Mountain Home aquifer is characterized by mixed hydraulic conductivity, ranging from 100 m/day (rating score 8) to 0.0001 m/day (rating score 4) (Appendix B, Figure B3).

4.2 DRASTIC Results

4.2.1 Model 1

The DRASTIC vulnerability index generated with generic, publicly available data ranged from 102 to 138. The values were classified into two categories: low (<118) and high (≥118) risk based on the mean model prediction values (Figure 13).

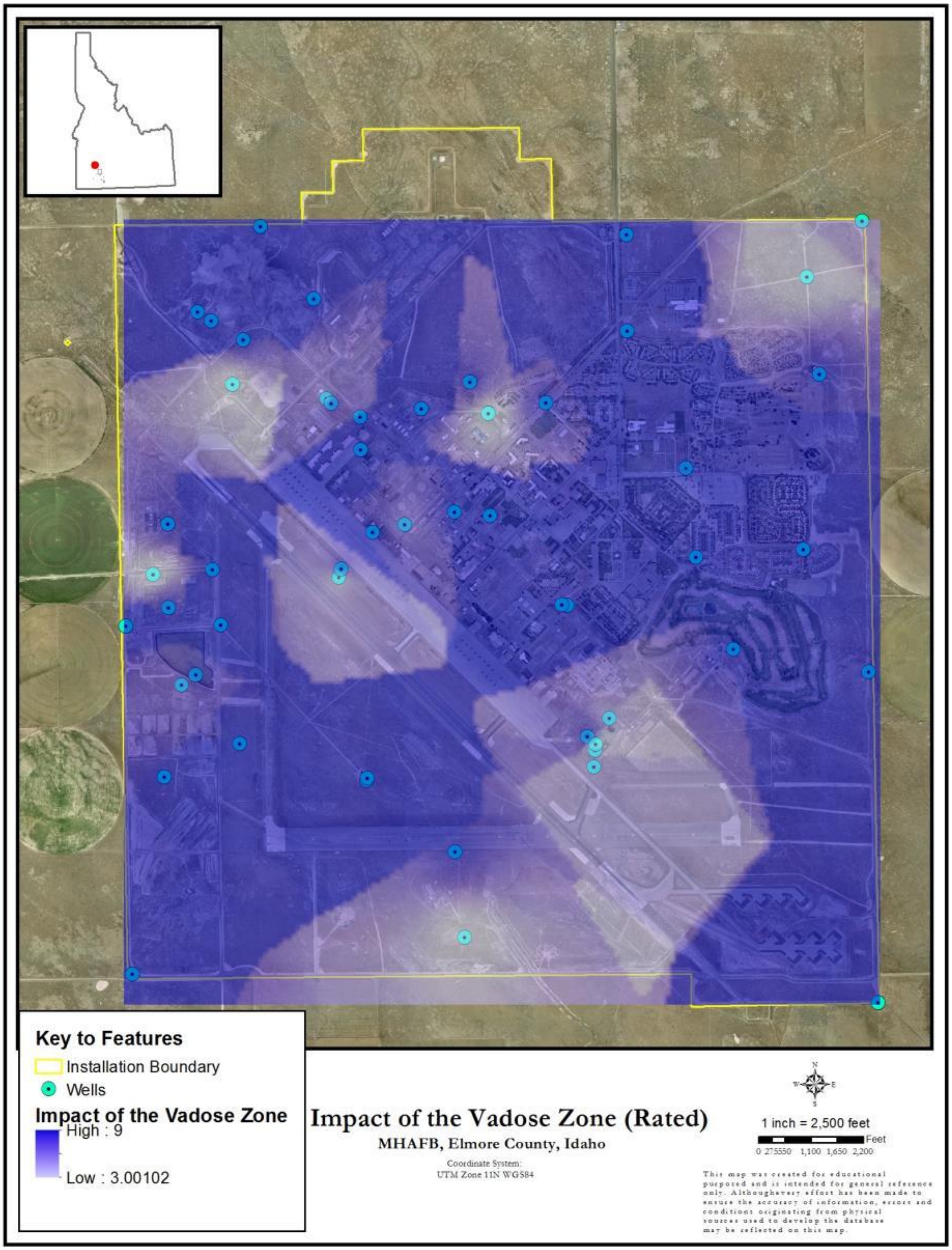

Figure 12. Impact of the Rated Vadose Zone, ranging from 9 to 3. Data obtained from well driller's logs. Wells are depicted in blue.

More than 50% of the DRASTIC aquifer vulnerability map falls into the middle of the vulnerability spectrum, with patches of ‘high’ and ‘low’ vulnerability scattered throughout the Mountain Home AFB (Figure 13). Areas of ‘high’ vulnerability largely correspond to residential lots, the golf course, and the southwest corner of the study area. This result is due to the combination of net recharge (irrigation application rates), aquifer media (sand/gravel aquifer media in the southwest corner) and soil type. Several of the parameters were the same across the entire study area (e.g., depth to water and slope), which resulted in the other parameters having greater influence on the patterns evident in the vulnerability map.

4.2.2 Model 2

The site-specific DRASTIC vulnerability index had a greater range (93 to 159) compared to the first model. The ranges for low and high vulnerability classes were <128 and ≥128, respectively.

The DRASTIC aquifer vulnerability map using site-specific data shows broad areas of ‘low’ to ‘high’ risk (Figure 14). Similar to the previous model, depth to water and slope were assigned the same rating across the entire study area, so other parameters had greater influence on the model results. The ‘high’ vulnerability classes in the north and northeastern portion of the study area are a combination of high irrigation, basalt aquifer media, and fractured basalt vadose zone, which all have high ratings. The ‘moderate’ vulnerability patches were distinguished from the ‘high’ risk areas due to the lower rated aquifer media and vadose zones, and areas of the study area with little to no irrigation and similar hydrogeological properties fell into the ‘low’ vulnerability classification with this particular model.

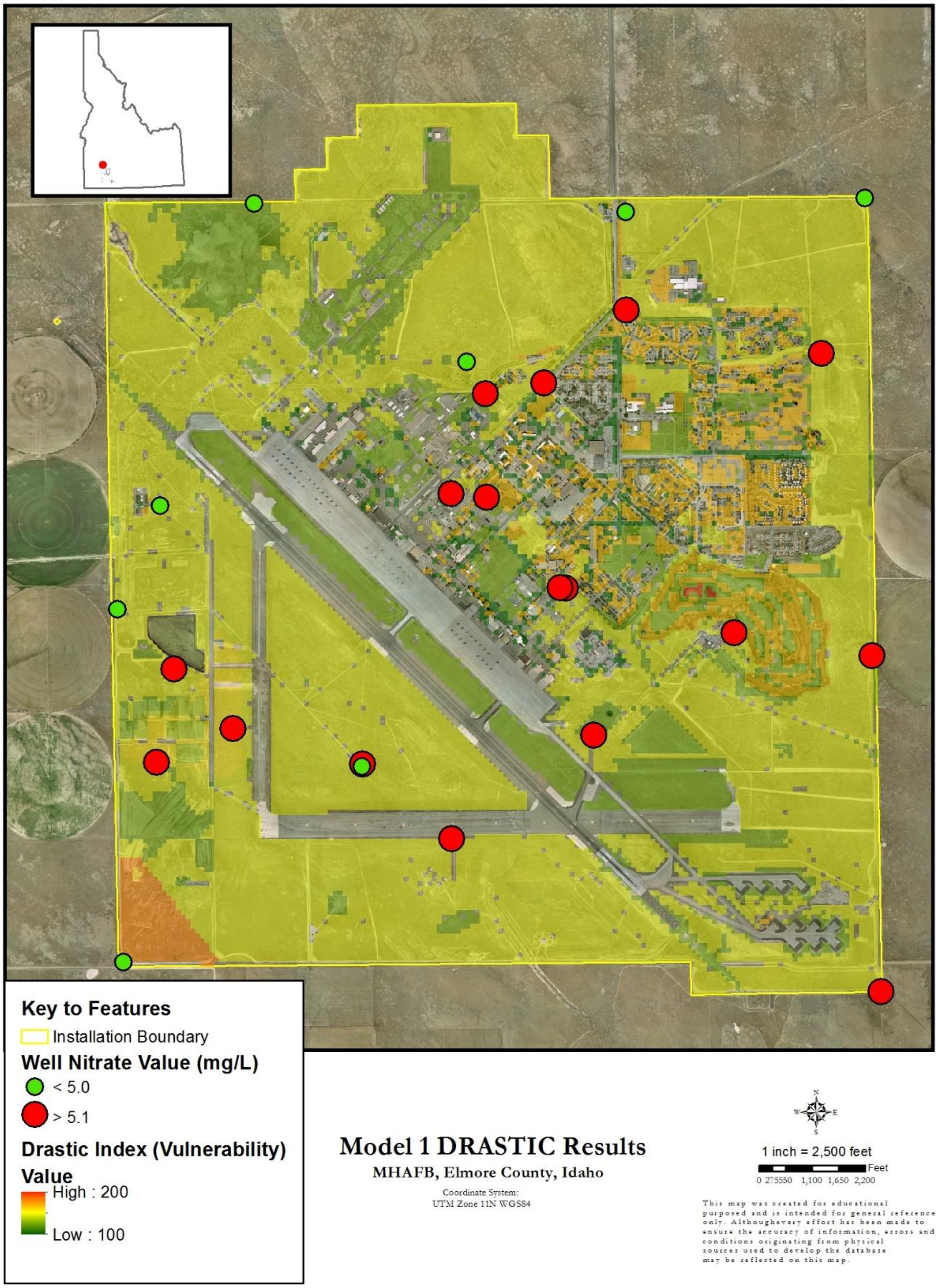

Figure 13. Model 1 – DRASTIC Index of vulnerability for Mountain Home AFB, using generic, publicly available data and overlaid with average nitrate sampling results per well.

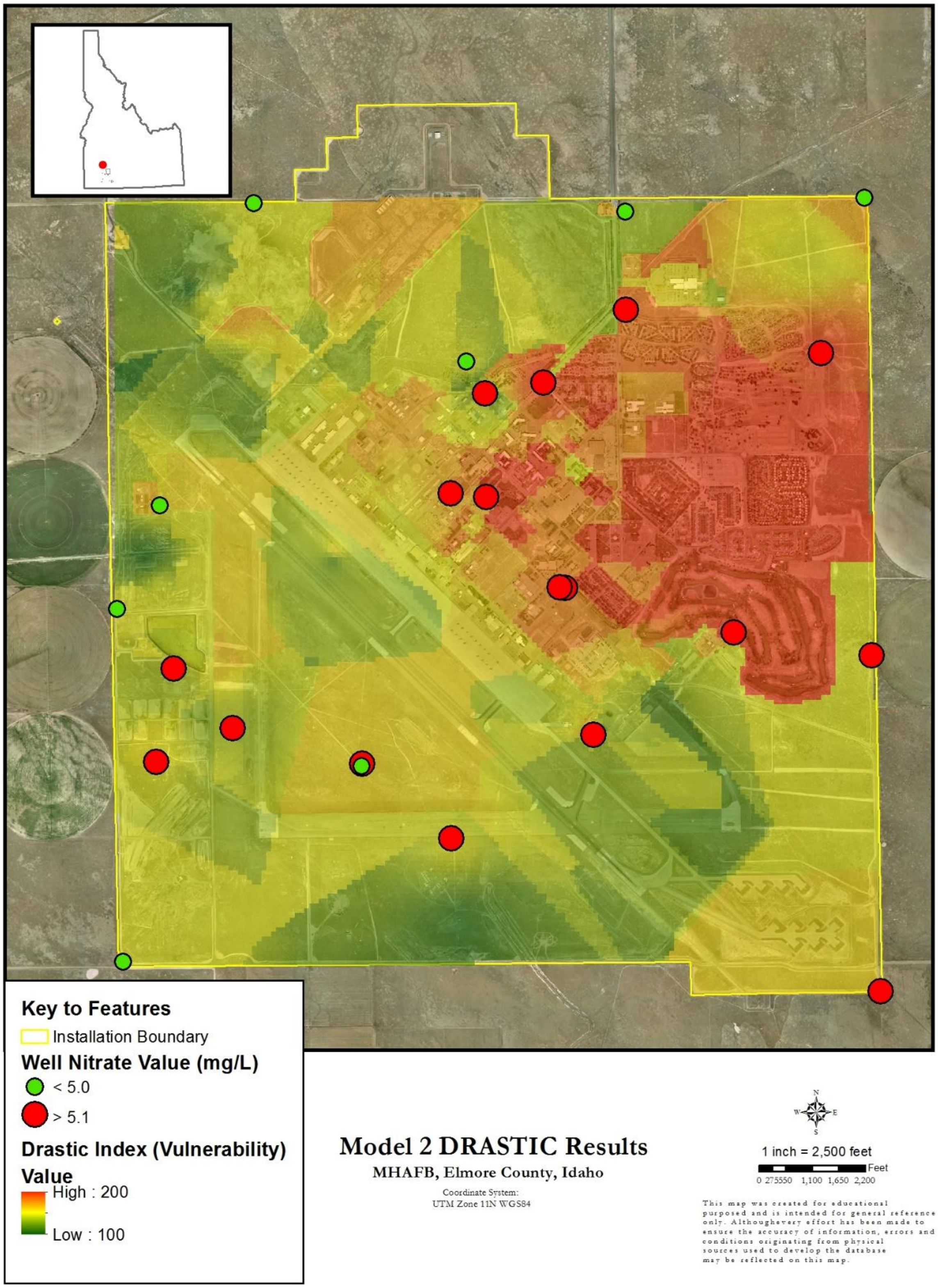

Figure 14. Model 2 – DRASTIC Index of vulnerability for Mountain Home AFB, using site-specific data and overlaid with average nitrate sampling results per well.

4.3 Validation

The descriptive statistics for both of the DRASTIC models and nitrate well observations are depicted in Table 6. In summary, Model 2 had a greater standard deviation (6.9) and coefficient of variation (0.101) compared to Model 1 (3.65 and 0.042, respectively), indicating a greater variance amongst the predicted values. Additionally, the range of Model 1 risk scores was only 36, compared to 66 for Model 2.

When compared to the nitrate USEPA contamination limits: below action level (<5.0 mg/L) and above action level (≥5.0 mg/L), above MCL (>10.0 mg/L), the Model 2 vulnerability classes correctly predicted 56% of the USEPA classes, compared to just 48% for Model 1 (Table 7).

Table 6. Descriptive statistics of Model 1, Model 2, and nitrate results from 25 wells.

Statistics Summary			
	Model 1	**Model 2**	**Nitrates**
Min	102	93	0.4
Max	138	159	27.67
Mean	117	127.14	8.66
Std Dev	3.65	12.28	6.9
CoV	0.042	0.101	0.797

The efforts to validate the models was hampered by the relatively small number of observation wells for Mountain Home AFB (n=25), irregular distribution, and the relatively small numbers of unique model scores generated at the locations of these wells (i.e. five unique risk scores for Model 1 and 13 unique scores for model 2) (Table 7).

Table 7. Model prediction results using MW and BPW data to validate the two models. Mean Nitrate color corresponds to USEPA action level (>5.0) standards, while colors correspond to model vulnerability risk classes. False = 0, True =1 for correct values.

Well #	Nitrate Observation	Model 1 Prediction	Accuracy	Model 2 Prediction	Accuracy
MW 16-2	0.4	110	1	139	0
MW 3-2	0.97	110	1	123	1
MW 6-2	1.24	118	0	130	0
BPW 13	1.85	118	0	114	1
MW 17-2	3.16	131	0	123	1
MW 7-2	3.4	118	0	123	1
MW 34	4.57	118	0	131	0
BPW 2	4.87	118	0	122.9	1
BPW 9	5.06	118	0	131	1
BPW 11	5.1	114	0	117.8	0
MW 30	5.47	110	0	139	1
BPW 12	6.1	110	0	139	1
MW 22	6.84	122	1	117	0
MW 23	6.85	122	1	127	0
MW 21	6.99	118	1	114	0
BPW 6	8.62	118	1	158.8	1
BPW 4	8.73	110	0	139	1
MW 18-2	8.8	118	1	131	1
BPW 1	12.97	118	1	147	1
MW 36	13.55	118	1	147	1
MW 40	14.83	118	1	123	0
BPW 8	16.42	110	0	159	1
MW 11-2	18.19	110	0	117.8	0
MW 29	23.77	118	1	123	0
MW 35	27.67	118	1	109	0
		Total	**12**	**Total**	**14**
		Prediction Rate	**48%**	**Prediction Rate**	**56%**

The scores generated with the two models in the cells corresponding to the locations of the 25 observation wells are cross-tabulated in Table 8. These results simply reaffirm what the discerning reader will have already picked up on in Table 7; namely, that the vulnerability rankings produced with the DRASTIC method and the two sets of input data were widely different. For example, the shaded area in the top left-hand corner of Table 8 shows that just two of the five lowest scores generated with Model 1 coincided with the lowest scores from Model 2 (ignoring the difference in the magnitude of the scores for the time being). The results were even worse at the top and more important end in which high risk areas are supposedly found – the shaded cells in the bottom right quadrant shows that none of the three highest risk scores generated with the two models overlapped with one another. Perhaps the most galling of all, the location for which the highest risk was predicted with Model 2 was one of seven monitoring well locations for which Model 1 predicted the least risk.

Table 8. Model predictions in the grid cells corresponding to the locations of the 25 observation wells

Model 2 scores	**Model 1 scores**					**Totals**
	110	**114**	**118**	**122**	**131**	
109			1			**1**
114			2			**2**
117				1		**1**
117.8	1	1				**2**
122.5			1			**1**
123	1		3		1	**5**
127				1		**1**
130			1			**1**
131			3			**3**
139	4					**4**
147			2			**2**
158.8			1			**1**
159	1					**1**
Totals	**7**	**1**	**14**	**2**	**1**	**25**

These results, taken as a whole, show that the predictions generated with the two models are not very similar and therefore not interchangeable. The next test was to compare the model predictions with the nitrate observations at the 25 monitoring wells to see whether or not there were grounds to say that the predictions generated with one of the two models produced more robust results than the model results generated with the other input data.

Table 9 takes a similar approach to the previous summary table and reports unique Model 1 prediction values by nitrate level. The shaded cells in the top-left quadrant of this table show that Model 1 correctly predicted ‘low’ risk at just two of the eight monitoring wells with nitrate levels ≤ 5.0 mg/L and the shaded cells in the bottom-right quadrant show that this particular model predicted ‘high’ risk in none of the seven monitoring wells recording nitrate levels > 10 mg/L. In addition, the large scatter of counts in the first and third rows and middle column of Table 9 shows that Model 1 suggest this model does a poor job of identifying locations with varying levels of risk and the single value in the last row indicates that this model predicted the greatest risk in a grid cell that coincided with a monitoring well with nitrate readings of ≤ 5 mg/L and the cell in the first row and third column indicates that this model predicted ‘low’ risk in two of the seven locations where the nitrate monitoring results pointed to contamination levels > 10 mg/L. Clearly, this particular model, which used generic, publicly available datasets did not do a very good job of predicting groundwater contamination potential.

Table 9. Model 1 predictions compared with nitrate levels sampled at 25 monitoring wells

Model 1 scores	**Nitrate levels (mg/L)**			
	≤ 5	**5-10**	**> 10**	**Totals**
110	2	3	2	**7**
114		1		**1**
118	5	4	5	**14**
122		2		**2**
131	1			**1**
Totals	**8**	**10**	**7**	**25**

Table 10 provides the same comparison using the Model 2 predictions and these results show that this model did a little better, particularly at the top end where the highest contamination levels have been reported. These model predictions predicted 'low' risk for two of the eight monitoring wells reporting nitrate levels ≤ 5 mg/L and 'high' risk for three of the seven monitoring wells reporting nitrate levels > 10 mg/L. However, there are still problems with these model predictions since Model 2 shows a similar large scatter to Model 1 and the lowest relative risk was predicted for one of the seven monitoring wells reporting nitrate levels > 10 mg/L.

These results, taken as a whole, confirm that Model 2 using site-specific data did marginally better than Model 1 which relied exclusively on generic, publicly available data as inputs. However, neither set of model predictions seem good enough to inspire confidence and it is clear that the results produced with the two model runs are not interchangeable. Some suggestions for how to overcome some or all of the aforementioned problems are provided in the final chapter.

Table 10. Model 2 predictions compared with nitrate levels sampled at 25 monitoring wells

Model 2 scores	**Nitrate levels (mg/L)**			
	≤ 5	**5-10**	**> 10**	**Totals**
109			1	**1**
114	1	1		**2**
117		1		**1**
117.8		1	1	**2**
122.9	1			**1**
123	3		2	**5**
127		1		**1**
130	1			**1**
131	1	2		**3**
139	1	3		**4**
147			2	**2**
158.8		1		**1**
159			1	**1**
Totals	**8**	**10**	**7**	**25**

CHAPTER 5: CONCLUSIONS

Mountain Home AFB relies on groundwater to provide drinking water for the residents. Over the years, the groundwater has degraded, both in quantity and quality, which points to the need to find a long-term sustainable water supply solution. Information on areas of high contamination risk would assist in articulating and choosing among those solutions.

This thesis attempted to assess the vulnerability of groundwater to contamination using the DRASTIC method. The method used seven hydrogeological parameters to create a single map that classifies areas by the potential risk: low to high. A variety of data is required in order to create the seven layers that contribute to the final model values. Mountain Home AFB operates much like a small municipality, which includes a Geodatabase office that stores substantial amounts of geospatial data. However, every study area may not have site-specific data available. Since GIS has been used to assess groundwater quality since the 1980s, and on several scales, generic data can be obtained from online sources (Lake et al. 2003, Ceplecha et al. 2004). In addition to determining groundwater vulnerability, this thesis also aimed to compare the results of two models, the first created using generic, publicly available data and the second created with site-specific data, to determine whether or not there was a significant difference between the two models.

The first model (generic data) suggested that most of the study area was at moderate risk to groundwater contamination, with some smaller areas of low and high risk. The low risk corresponded primarily to areas lacking irrigation and silt loam soils. High risk areas were areas characterized by intensive irrigation, sand/gravel aquifer media, and high impact of the vadose zone. When compared to nitrate observation data, Model 1 had a 48% prediction accuracy rate when both model predictions and nitrate observations were divided into ‘low’ and ‘high’ risk classes (Table 7).

The second model (site-specific data) characterized the northeast quadrant of the Mountain Home AFB to be high risk, the perimeter to be low risk, and predicted several moderate risk areas located around the airfield and further afar. Similar to Model 1, irrigation (Net Recharge), the impact of the vadose zone, and aquifer media variables had the greatest influence on the model predictions. When also validated against observation data, Model 2 had a slightly greater prediction rate of 56% when both model and nitrate observations were divided into ‘low’ and ‘high’ risk classes (Table 7).

The results summarized in Tables 8-10 showed that the two models produced different predictions for the grid cells that were coincident with the 25 nitrate monitoring wells and confirmed that the second model did slightly better than the first model.

This assessment suggests that the well driller’s logs that were used to develop several of the DRASTIC parameters, such as depth to water, aquifer media, impact of the vadose zone, and hydraulic conductivity for Model 2 were helpful. However, Model 2 may also contain additional errors since IDW was used to develop raster layers for those parameters. IDW calculates cell values dependent of each other using ≥ 2 nearby observations with the importance of these observations set by the inverse of the distance between the cell and the observation squared. However, the values for the different contributing variables on the Mountain Home AFB some areas may not be directly dependent on each other. For example, the golf course is not native to the area and had to be formally established by new soil, vegetation, excessive irrigation and fertilization, which creates a micro-ecosystem significantly different than the remainder of the study area.

Both models were developed using the GIS techniques first described by Aller et al. (1987), but while the methodology has been standardized, data has significant effects on the production of the final DRASTIC index as illustrated in this study. The DRASTIC method is commonly used to analyze groundwater contamination risk; however, the scale and detail of data used in the model and the accuracy has yet to be analyzed. While this study aimed to expand on that notion, the results and validation encompass a small sample size that could have compromised the study. Additional studies would need to be performed using the same approach, but with larger sample sizes so that the sample size reported here (n=25) would not negatively affect the results (as may have happened here). One popular option, that offers have tried, is to calculate the DRASTIC index for a county, rather than a single facility like the Mountain Home AFB.

Furthermore, the DRASTIC Method evaluates seven hydrogeological parameters; however, previous studies conducted on Mountain Home AFB indicate leaking sewer lines as a potential source of nitrates. Human impacts are not a parameter in the DRASTIC method and therefore, they are not captured in the model. The historical leaking sewers could significantly increase some of the nitrate contamination and values that were used to validate the models, so the validation process could be biased. Future studies will also need to pursue other validation methods outside of human induced contamination or look into including a 'human impact' parameter to the DRASTIC method.

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APPENDIX A: ADDITIONAL DRASTIC PARAMETER MAPS FOR MODEL 1 - GENERIC AVAILABLE DATA

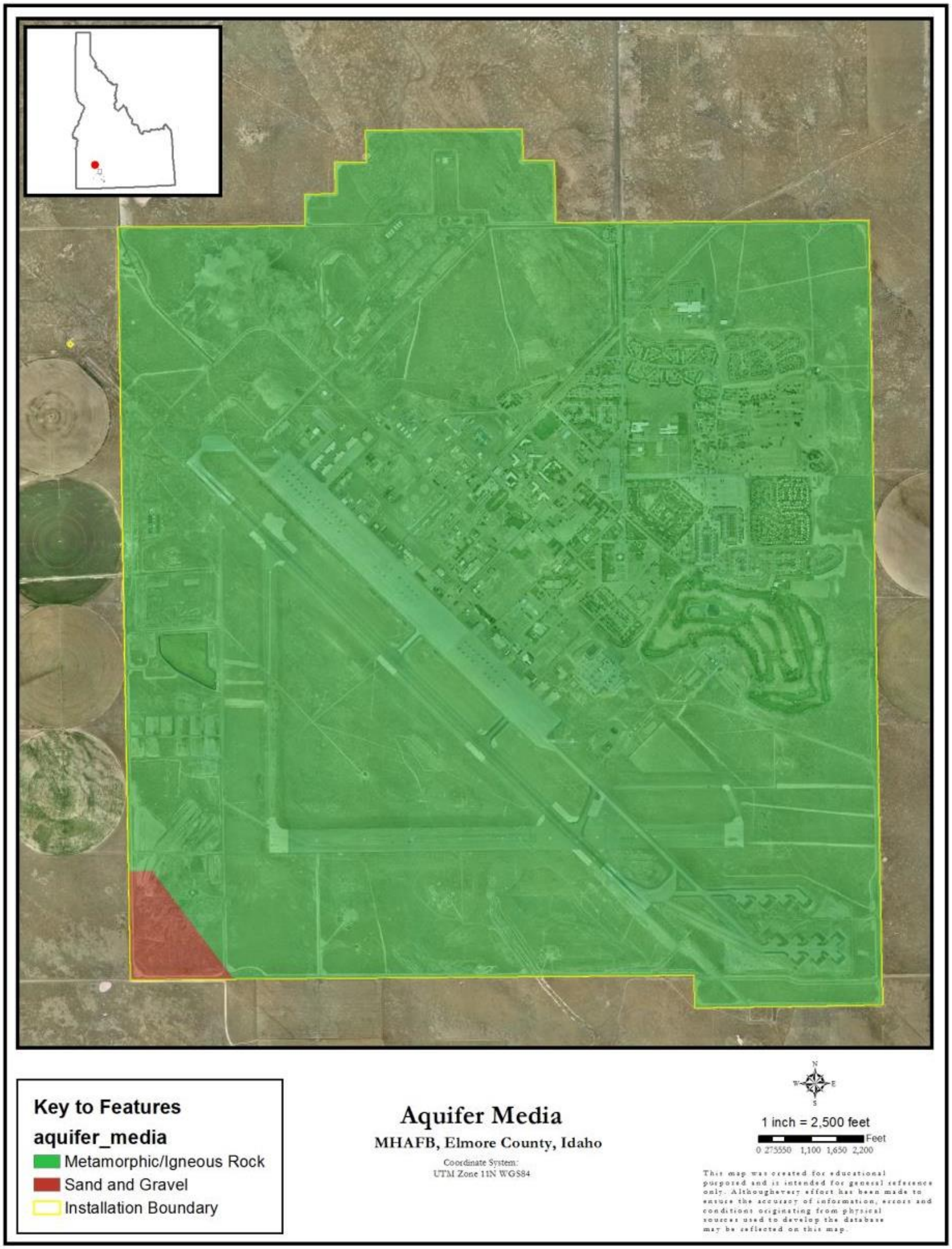

Figure A 1. DRASTIC Parameter Aquifer Media, using generic, available data.

Figure A 2. DRASTIC Parameter Topography (Slope), using contour elevation data.

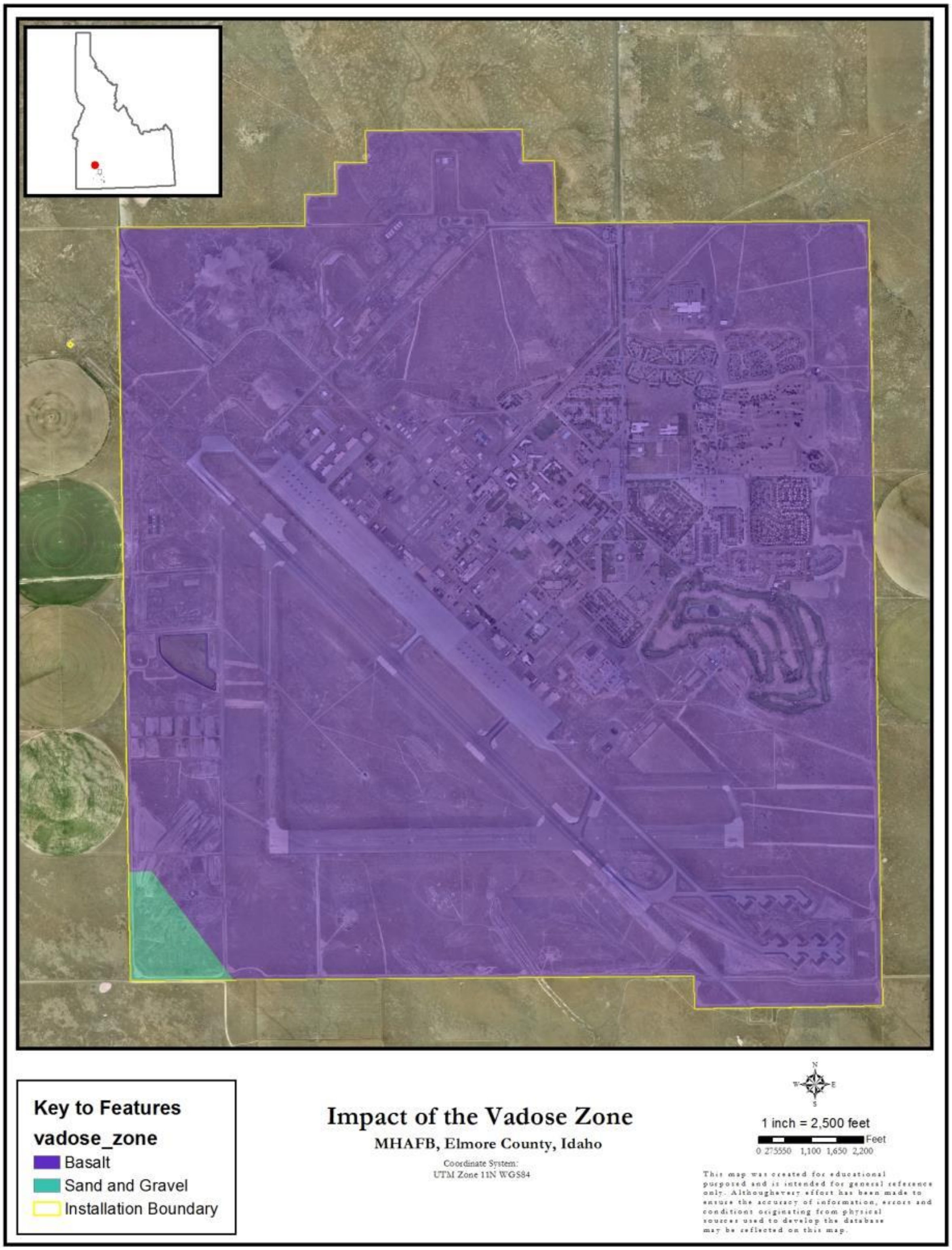

Figure A 3. DRASTIC Parameter Impact of the Vadose Zone, using generic, available data.

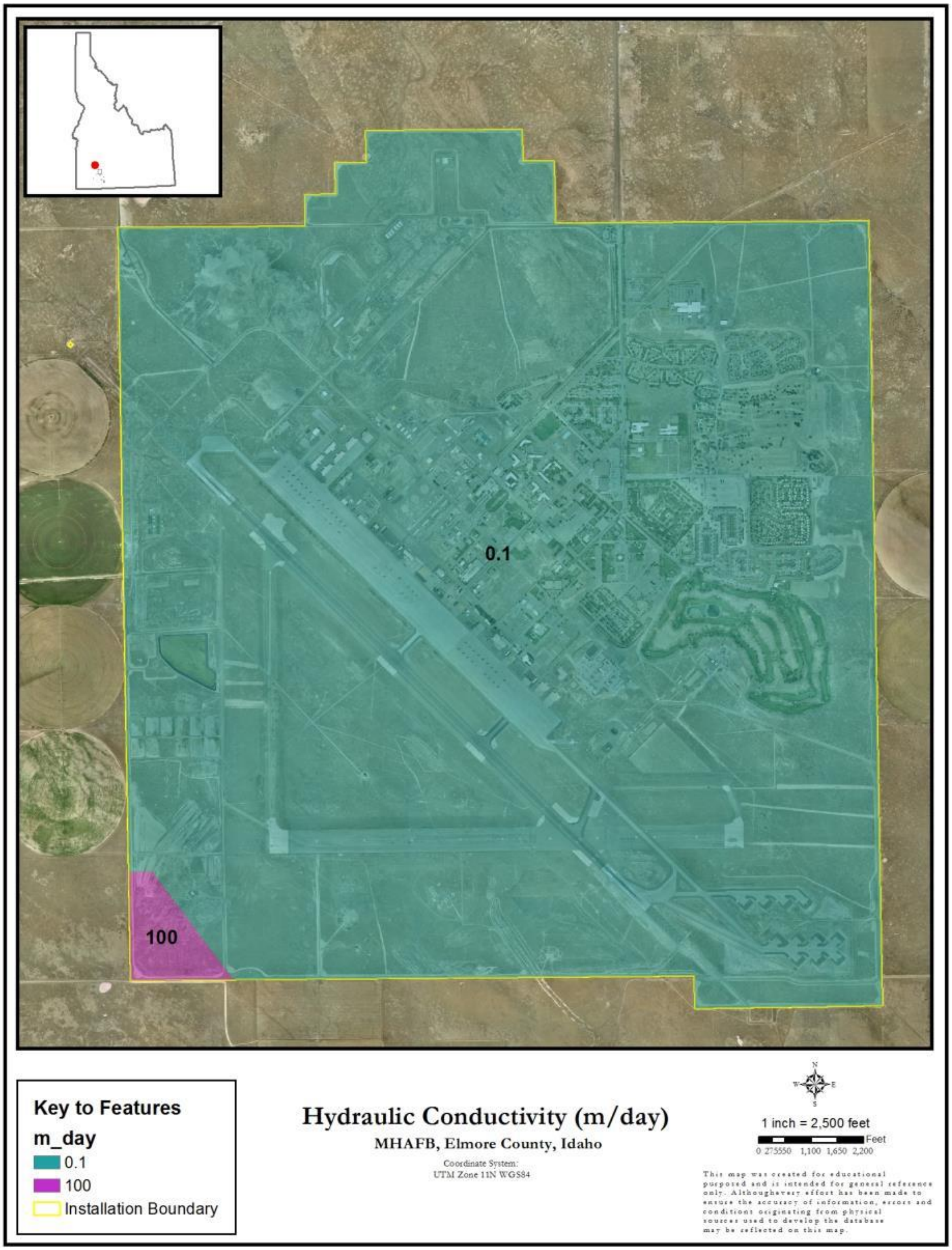

Figure A 4. DRASTIC Parameter Hydraulic Conductivity, using generic, available data.

APPENDIX B: ADDITIONAL DRASTIC PARAMETER MAPS FOR MODEL 2 - SITE-SPECIFIC DATA

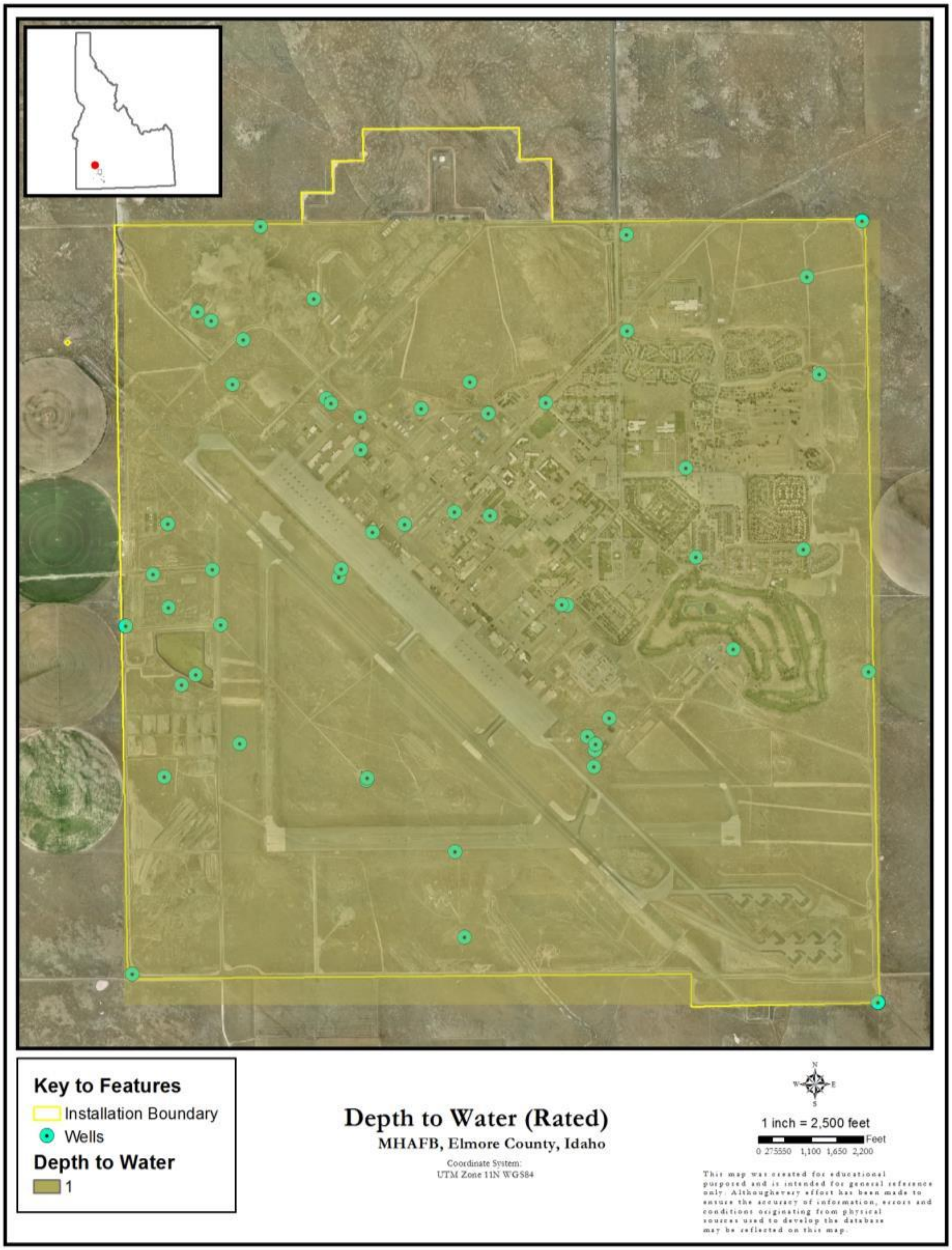

Figure B 1. Rated DRASTIC Parameter Depth to Water, using site-specific data.

Figure B 2. Rated DRASTIC Parameter Aquifer Media, using site-specific data.

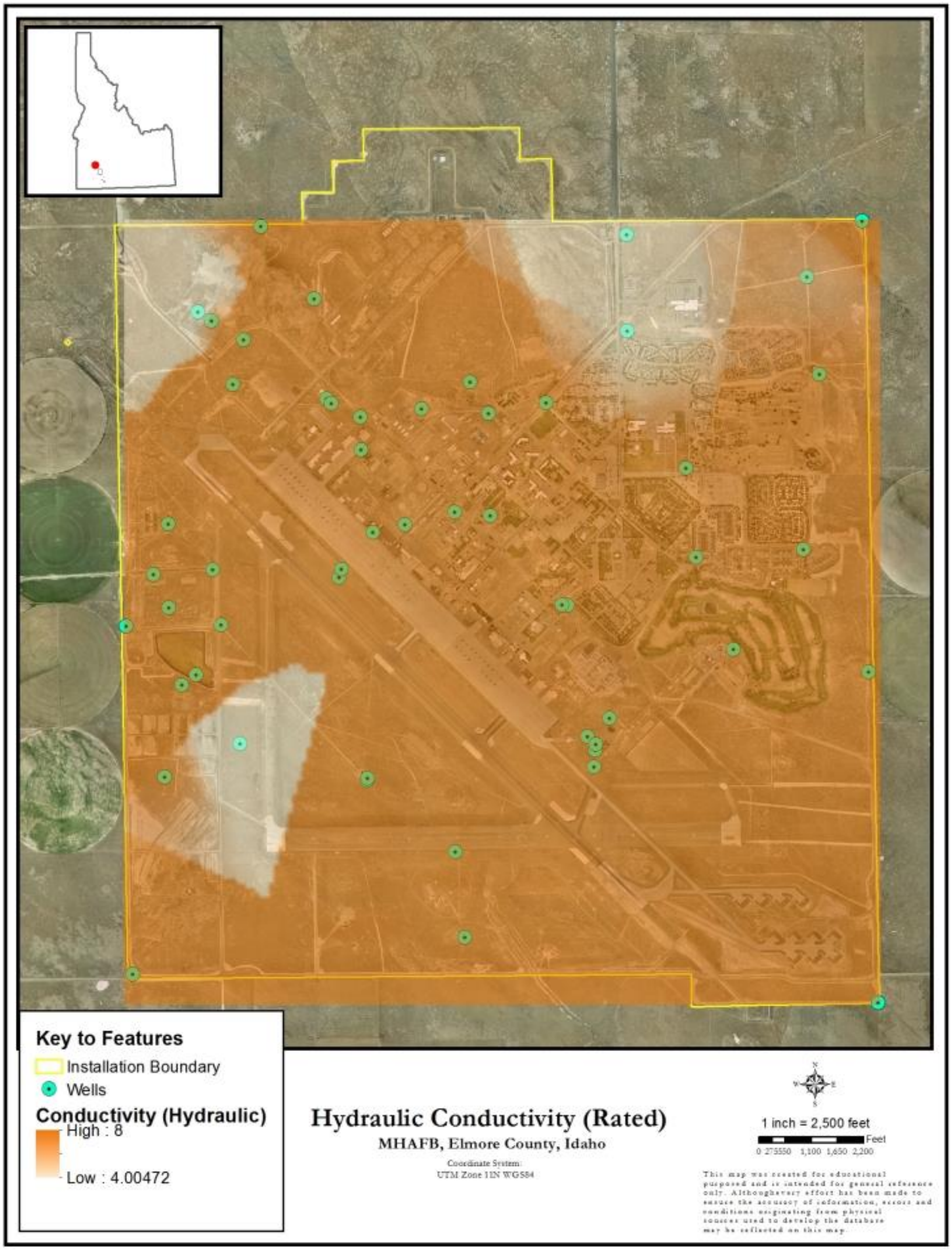

Figure B 3. Rated DRASTIC Parameter Hydraulic Conductivity, using site-specific data.