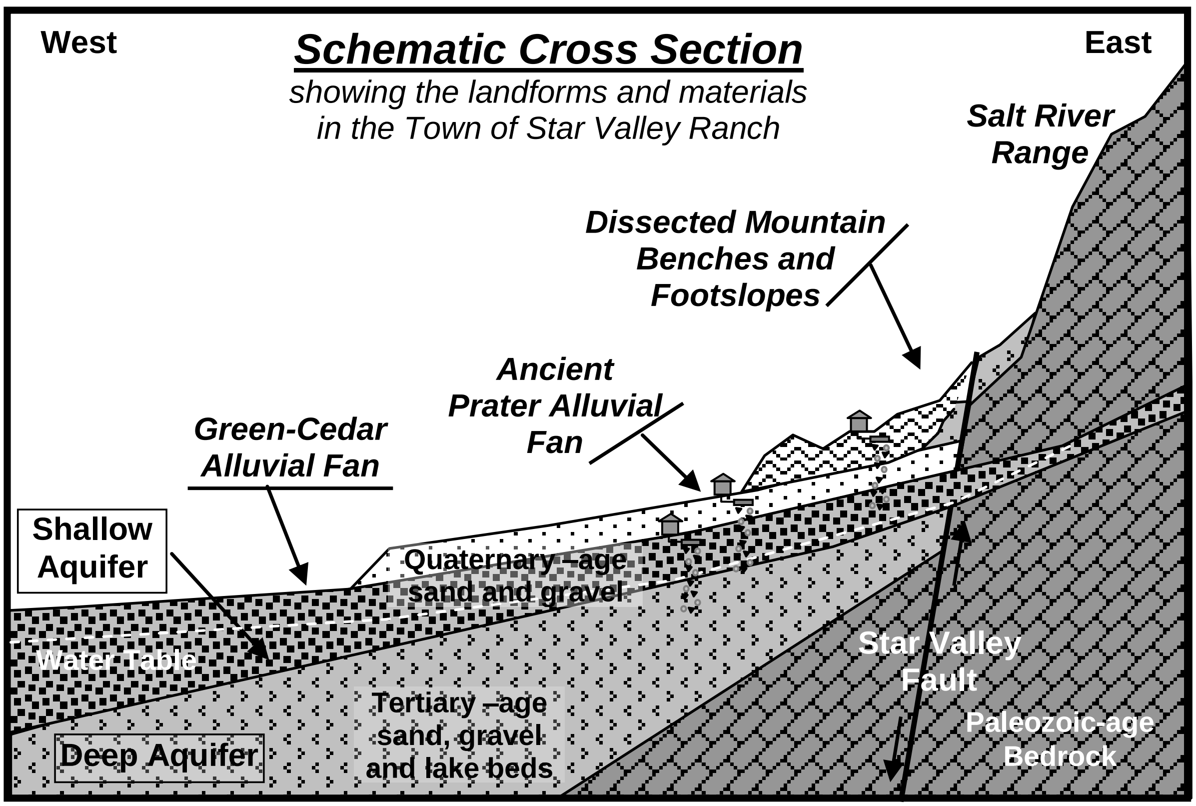
FINAL
ON-SITE WASTEWATER STUDY

FOR THE

TOWN OF STAR VALLEY RANCH, WYOMING

April 28, 2008

Prepared for
Boyd Siddoway, Mayor
Town of Star Valley Ranch



Prepared by
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Boyd Siddoway, Mayor
Town of Star Valley Ranch
P.O. Box 1180
Star Valley Ranch, Wyoming

April 28, 2008

Dear Mayor Siddoway,

I am proud to deliver to you two copies of the final report entitled On-site Wastewater Study for the Town of Star Valley Ranch, Wyoming. The draft report was reviewed by the Water Quality Division of the Wyoming Department of Environmental Quality (WDEQ) and meets WQD Chapter 23 Rules and Regulations as described in the attached letter from Jim O'Connor, dated April 16, 2008.

The report provides the necessary information to assess the potential impact of existing on-site disposal systems on ground water quality as build out continues and to identify those areas within town where this impact is the greatest. Should the Town Council wish to explore other waste water disposal systems to minimize future ground water degradation from on site systems the analysis in this study can be modified to assess future changes in the degree of ground water degradation from the employment of each alternative system. As the quantity and quality of data on the subsurface geology and ground water flow conditions improves, the calculations in this study should be rerun using to new data to better estimate the degree and location of potential ground water degradation.

My study was conducted following accepted procedures in the profession at this time using the public data that were available to me. To the best of my knowledge the findings in the report are consistent with the available data. The report is intended only for the use by the Town as background information for planning. I recognize that other interpretations of the data are possible. I cannot assume responsibility for conclusions reached by others.

If I can provide the Town with additional information and analyses, please do not hesitate to contact me.

Yours Truly

Robert C. Palmquist

Robert Palmquist, PhD
WPG #1347

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER QUALITY DIVISION
510 Meadowview Drive
Lander, Wyoming 82520
(307) 332-3144

April 16, 2008

Boyd Siddoway, Mayor
Town of Star Valley Ranch
P.O. Box 1180
Star Valley Ranch, WY 83127
(307) 883-8696

To The Honorable Mayor Siddoway,

We are in receipt of Dr. Palmquist's wastewater study for the Town of Star Valley Ranch (referenced above). It is my pleasure to respond at this time.

To that end, please find attached the comments from the Water Quality Division. By way of reference, the comments are in response to questions posed in your email of April 3, 2008. Please be advised, the intent of the review is to provide general observations. As the project develops we will be in a better position to address specific proposals.

Should you have questions pertaining to the review or if I can be of assistance in some other fashion, please feel free to contact me at joconn2@state.wy.us or (307) 335-6942. Also available are Mr. Lou Harmon, W/WW Manager, LHARMO@state.wy.us and Ms. Beth Pratt, Manager of the Watershed Management Program, BPRATT@state.wy.us. In the interim, please be assured of our continued support for your project.

Sincerely,
Jim O'Connor
Jim O'Connor

Geological Project Analyst
Groundwater Protection Control Program

Cc: Bauer, Brenda, Town Clerk
Kent Harker, Councilman
Al Redlin, Councilman
Carol Warren, Councilman
Jim Wheeler, Councilman
Gregg Wilkes, Town Administrator
Dr. Robert Palmquist, PhD,
Mark Baron, SW District Engineer
Kevin Frederick, Manager GPC Program
Lou Harmon, Manager W/WW Program
Beth Pratt, Manager WM Program
John Wagner, Administrator WQD
Mark Thiesse, GPC Program Principal

Attachment (1)

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

WATER QUALITY DIVISION
510 Meadowview Drive
Lander, Wyoming 82520
(307) 332-3144

Subject: On-site Wastewater Study for the Town of Star Valley Ranch, Wyoming
by Dr. Robert Palmquist
Lincoln County

Date: April 9, 2008

Reviewer: Jim O'Connor, Environmental Senior Analyst JOC

Project overview: A detailed description of the project is outlined in the report (§1.2; page 1)

At the request of Mr. Boyd Siddoway, Mayor, representing the Town of Star Valley Ranch, the Groundwater Pollution Control Section (GPC) has completed a cursory review of the On-site Wastewater Study for the Town of Star Valley Ranch, Wyoming. The purpose of the request is to outline general goals and milestones as a basis for determining the most effective waste treatment options. To that end, the following items requested in an email dated April 3, 2008 were considered:

#1 Review the wastewater draft document prepared for the town by Dr. Robert Palmquist.

#2 Assist the Town in recommending a plan for the direction and associated milestones for the effective management of the domestic wastewater.

1) **Review the document's data, assumptions and results**

   a) "The applicability of the statistical data and assumptions used in the study", and,
   b) "The probability of the results as presented in the study"

   WW/W & GPC Comments: The geological report is complete in all aspects. The interpretation of the hydrogeological data and conclusions submitted in the report are thorough and sound. This review is in agreement with the method of collection and interpretation of the data. Where the data is not specific or available, the consultant addressed the issue in a clear and reasonable manner. It is appreciated that Dr. Palmquist outlined the process by which he selected various parameters such as hydraulic conductivity and depth to groundwater. (§7.0, page 10)

   As required under WQD Chapter 23 Rules & Regulations for subdivisions, the report provided the hydrogeologic setting as well as information pertaining to water quality and quantity. We are in agreement with the parameters employed and the interpretations of the geologic environment.

   There is agreement with the consultant as to the degree of confinement (confined/semi-confined) and hydraulic conductivity. The consultant clearly identified the complexity of the groundwater flow as depicted in Figure 14. The consultant adequately addressed the impacts to groundwater from the wastewater disposal.

The data as depicted in Figures 13-16 should prove useful to participants involved in the decision making process. For instance, Figure 15 'Discharge length for plats' reveals several down-gradient areas of concern for future planning. These vectors indicate areas that may be impacted by pathogens discharged from leach fields. This type of impact, (e.g. effluent migrating beyond the boundaries of the subdivision) is of great concern to DEQ.

While we are in agreement with the parameters employed in the fate and transport models (Appendices A & B), the data and analysis performed in this study reveal the limitations of the models currently in use. It is the experience of Mr. Lou Harmon, Water/Wastewater Section Manager, that in order to better approximate the nitrate impacts there are more responsive models available. However, even with the limitations the model clearly demonstrates the projected nitrate concentration level at various stages of build-out. In doing so the consultant complied with current guidelines. The attached modeling demonstrated the nitrate concentrations as the each phase progresses to full build-out stage. This information will serve as a platform for group discussion as the project goals are outlined.

c) "The variations or additional data/assumptions that DEQ would suggest"
d) "Any requirements DEQ would have prior to the official finalization of this document"

WW/W & GPC Comments: No additional information is warranted at this stage of the proposal. However, additional data may be required depending upon potential wastewater treatment options exercised in the future. For example, the calculations performed by Dr. Palmquist indicate that the 10.0 mg/L nitrate limit will be exceeded in a number of the subdivision phases as early as the mid-stage of development. The predicted two year time/distance of groundwater travel indicative of potential pathogenic contamination is well beyond the boundaries of several subdivision phases. Consequently, it will be necessary to explore options for mitigating these impacts. Additional requirements will be dictated by the treatment options that are to be implemented may be necessary.

2) Establishment of Direction and Milestones

e) "Work in conjunction with the DEQ to establish a wastewater master plan", and,
f) "Establish implementation milestones"

WW/W & GPC Comments: This review is in agreement that both of the above listed objectives should be vigorously pursued by all concerned parties. We make ourselves available to assist in whatever fashion the town deems appropriate.

Finally, the report has been found to be in proper order and in good standing. The consultant should be commended for the superior quality of work submitted. Furthermore, the town leaders should be commended for their proactive stance to this vital community issue. Any community would benefit greatly by such dedicated individuals.

3) Miscellaneous

WW/W & GPC Comments: There appears to be a minor error concerning the pagination of the report. Please be advised, there is no page 20. However, there are two sheets listed as page 38.

Boyd Siddoway, Mayor
Town of Star Valley Ranch
P.O. Box 1180
Star Valley Ranch, Wyoming

November 15, 2007

Dear Mayor Siddoway,

I am proud to deliver to you two copies of the draft report entitled On-site Wastewater Study for the Town of Star Valley Ranch, Wyoming. The report presents the data, methodology, and findings of my analysis of the potential impacts posed by small on-site wastewater disposal (septic) systems within the Town at different levels of build out. The report consists of text accompanying by a CD (in pocket). The CD contains the Excel© Spreadsheets with the calculations and data.

The study was initiated at your request early this summer to provide information about the potential impacts of the Town on ground water quality. It finds that the septic systems within the Town may cause a degradation of ground water quality beyond the Town boundary but that most shallow ground water will meet USEPA drinking water standards for the constituents of concern (nitrates and virus) at all times,.

The draft delivered here is intended for review and comment. I recommend that at least one copy be delivered to an engineering consulting company for their technical review of methods, assumptions, and data quality with the request that they provide a formal reply for inclusion in the final version of the report. Another review should be conducted by the Town for clarity and editorial refinement.

My study was conducted following accepted procedures in the profession at this time using the public data that were available to me. To the best of my knowledge the findings in the report are consistent with the available data. The report is intended only for the use by the Town as background information for planning. I recognize that other interpretations of the data are possible. I cannot assume responsibility for conclusions reached by others.

I await return of the reviewer's comments to provide you with a final version of the report.

Yours Truly

Robert C. Palmquist

Robert Palmquist, PhD
WPG # 1347

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1.0 INTRODUCTION

1.1 Purpose

This report describes the methods, data, and results of the on-site wastewater (septic assessment) study. The study assessed the potential impacts of septic systems within the Town of Star Valley Ranch (Town). It was conducted for the Town at the request of Mayor Boyd Siddoway. The Town wishes to know if the small on-site waste disposal systems (septic systems) within it pose a threat the ground water quality and public health; and if so, the severity of the potential problems both now (2007) and in the future as build out continues to completion. Should the assessment indicate that ground water quality problems are likely to develop, the Town wishes to be in a position to take appropriate preventative action. Thus the purpose of this study is to determine the nitrate concentration in shallow ground water at different degrees of development (using 10 percent increments), and the viral travel time and distance for the median septic system in each of the Town's 21 subdivisions (plats).

1.2 Background

The Town is located on the western flank of the Salt River Range between the towns of Thayne and Etna in the Star Valley of northern Lincoln County (**Figure 1**). It consists of 21 plats with more than 2000 residential lots encompassing an area of 1,470 acres (2.3 square miles) in parts of eight sections.

The plats were platted between 1970 and 1985 by Leisure Valley Incorporated (LVI) as part of the Star Valley Ranch. Star Valley Ranch was advertised as a resort-retirement community with an emphasis upon golf (9 and 18 hole courses are part of the common areas) with seasonal / retirement living in the mountains of Wyoming. LVI provided community culinary water to all lots and irrigation water to the golf courses and other common area from two springs and two deep wells. Waste disposal is through on-site septic systems. In 1992, the homeowner's association (Star Valley Ranch Association) assumed responsibility for the golf courses, other common areas, roads, and water infrastructure.

The Town of Star Valley Ranch was incorporated in 2006, which at this time, makes it the youngest town in Wyoming, and assumed responsibility for the roads and culinary water supply in 2007. The Town's immediate concerns are the renovation and expansion of the culinary water system and roads. It is anticipated that this task will take approximately ten years to complete. The Town is presently developing a master plan that will influence future growth and distribution of Town infrastructure. A municipal waste disposal system is part of the plan but when it will become necessary is unknown.

The septic assessment is a voluntary, proactive, and unique study. It is voluntary because the Town's plats were filed prior to passage in 2003 of Chapter 23, Wyoming Water Quality Rules and Regulations (Chapter 23). Chapter 23 (section 7) requires an analysis of the impacts of all septic systems within a proposed subdivision and should the analysis show an impact the subdivision application must include a plan to reduce the impact to acceptable levels. The plats within the Town are grandfathered and Chapter 23 does not apply. The septic assessment is proactive because at this time, ground water quality problems are unlikely from the approximately 1000 residences. The study is designed to determine the level of build out at which water quality problems appear. The septic assessment is unique in that; 1) the study is exploratory and attempting to identify and quantify potential water quality problems, 2) it considers 21 plats as a group and therefore includes cumulative impacts of up gradient plats on adjacent down gradient plats, 3) The study covers a large area served by a public water supply and has very few water wells within its boundary, and 4) the analysis does not include the ameliorating effects of enhanced septic systems to reduce nitrate concentrations and viral densities.

1.3 The Assessment

The United States Environmental Protections Agency (USEPA) established drinking water standards for all public water supplies in the US. The standards for the two most common contaminants from septic systems are the concentration of dissolved nitrates and density of virus. USEPA has established a maximum contaminant level (MCL) for nitrate (as measured by nitrogen) at 10 milligrams per liter (mg/l) and for virus at zero. Wyoming in Chapter 23 requires that ground water contaminated by septic systems within a plat must not exceed the nitrate MCLs at its down gradient boundary and that down gradient wells must lay beyond the calculated viral travel distance.

The septic assessment follows the guidelines set forth in Appendices A and B of Chapter 23 to calculate the travel time and distance of viruses and the concentration of nitrate dissolved in the shallow ground water. The Wyoming Department of Environ mental Quality (WDEQ) posts an Excel © Workbook on its website[1] that can be downloaded and used to make the necessary calculations (CD in pocket). The WDEQ spreadsheets are designed for one subdivision and to more readily accommodate the Town's 21 plats and the incremental build out scenarios, they were rearranged and simplified.

1.4 Results

The results indicate that septic systems in some plats will pose a ground water quality problem. Nitrate concentrations will the exceed EPA limit in Plat 10 at 65 percent build out and virus will enter ground water in all plats south of CR # 116. Viral travel distances will extend beyond Town boundaries for Plats 4, 5, 10, 16, 17, 18, and 21. Water quality problems could appear in domestic wells located adjacent to Plats 17, 18, and 21. If the Shallow and Deep Aquifer are separated by a leaky aquitard, public supply wells in the vicinity of the present Airstrip Well #1 could be affected. Hydraulic conductivity and depth to ground water are based on extrapolations and "professional judgment." They should be replaced with better data as they become available.

1.5 Format

The format of this report is similar to those generally submitted to WDEQ in support of a subdivision application. The full report consists of this summary and a Microsoft Excel Workbook © (in pocket) that contains the calculations.

2.0 SUBDIVISION CHARACTERISTICS

The Town consists of 21 plats aligned along the western front of the Salt River range (**Figures 1 and 2**). The plats vary in total area, lot size, amount of common area, and average residential characteristics as shown in **Table 1**.

3.0 SITE CONDITIONS

3.1 Landforms

[1] http://deq.state.wy.us/wqd/www/Permitting/Downloads/Plats/APPENDICESJAN03.xls

Four landforms dominate the Town as illustrated in the schematic diagram on the cover. The *mountain front* along the west flank of the Salt River Range rises rapidly at the eastern town boundary. The Town is sited upon three valley landforms – the highly *dissected footslopes and benches* at the base of the mountain front, the *ancient Prater Creek alluvial fan*, and the *active Green and Cedar Creek alluvial fan* (**Figure 3**). The valley landforms have distinctly different topography, relief, surface materials, soils, and limitations for septic systems. They constitute the physical framework that shapes ground water conditions within the Town.

The highly dissected footslopes and benches (footslopes) lie at the base of the steep mountain front and are composed of remnants of the oldest valley floor and footslopes uplifted along the Star Valley Fault as well as younger alluvial fans and footslopes developed during different episodes of faulting and climate change. The footslopes lie at elevations above 6400 feet and have a local relief of 200 feet.

The ancient Prater Creek Alluvial Fan (ancient Prater fan), which gently slopes westward from the mouth of Prater Canyon, is abruptly terminated by a steep slope along its south margin by the active Green-Cedar alluvial fan. It occurs at elevations between 6200 and 6400 feet and has a local relief of 40 feet. The local relief results from abandoned valleys eroded by streams draining into the Salt River after its abandonment. The ground surface is blanked by wind-blown silt deposits from former ice ages and has been inactive for at least 200,000 years. The natural channel of Prater Creek follows the northern edge of the abandoned fan before turning northwestward to its active fan north of County Road #115.

The active Green-Cedar Alluvial Fan (Green-Cedar fan), which gently slopes westward from the mouth of Cedar Canyon, is the site of active deposition of sandy gravel by the numerous distributaries of Cedar Creek. Its surface is undulating with many shallow channels formed by the shifting channels of Cedar Creek. Green Creek upon leaving its canyon flows through dissected footslopes to abruptly turn south to join the Cedar Creek fan. The Green-Cedar fan lies below an elevation of 6200 feet and has a relief of less than 15 feet.

3.2 Climate

According to the Star Valley Soils report, the climate of Star Valley is classified as a cold climate with humid winters. Local climate data is available from the Bedford meteorological station, which is located a few miles south of the Town of Star Valley Ranch at an elevation of 6240 feet. At Bedford[2] the average annual minimum temperature is 24.3 degrees Fahrenheit (^{o}F) and the average annual maximum temperature is 52.8 ^{o}F. The average annual precipitation is 23.4 inches with from 1.5 to 2.5 inches per month.

The precipitation across the Town site is stratified by an elevation change of 400 feet between Plat 4 on the west and Plat 15 on the east. To better estimate the average annual precipitation for each plat, PRISM[3] data for Wyoming was used. The average annual precipitation for each plat according to PRISM is shown in **Figure 4**.

[2] http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wybed3

[3] PRISM is the acronym for Parameter-elevation Regressions on Independent Slopes Model; http://www.wygisc.uwyo.edu/clearinghouse/climate.html

3.3 Soils

3.3.1 Soil Series

The town site is included in the Soil Survey of Star Valley Area, Wyoming – Idaho, which is available on-line in GIS format.[4] A simplified soil map for the Town showing soils at the series and association levels appears as **Figure 5**. The soils distribution within each plat was determined by intersecting plat boundaries (**Figure 2**) with the soils map (**Figure 5**) within the GIS framework. The summary of the soils within each plat is presented in **Table 2.** The soil characteristics pertinent to septic systems are permeability (**Table 3)**, texture and slope (**Figure 6**) and limitations for septic systems (**Figure 7**). A detailed narrative description of each soil is available in the Star Valley Soil Survey[5]

The soils limitation maps (**Figure 7**) show the distribution of two limitations – pollution and restricted permeability – that are rated as slight to severe. Limitation ratings are described as:

- *Slight:* "…soil properties generally favorable for the rated use… limitations are minor or easily overcome…"
- *Moderate:* "… some soil properties are unfavorable but can be overcome or modified by special planning and design."
- *Severe:* "…soil properties so unfavorable and so difficult to correct or overcome as to require major soil reclamation, special designs, or intensive maintenance."

The pollution limitation arises from the likelihood of septic fluids surfacing on steep slopes particularly in areas with thin soils; it occurs in highly dissected areas along the mountain front and along channels on the Green-Cedar Alluvial Fan. The restricted permeability limitation occurs in fine-grained soils with low percolation rates and in soils with low permeability layers at shallow depth; it coincides with the silty soils on the ancient Prater fan and in isolated higher areas on the Green-Cedar fan.

3.3.2 Percolation Rates

Percolation is the movement of water into the soil from the trenches in the septic drain field. The rate of movement (percolation rate) is measured in minutes per inch. To obtain a septic system permit, Lincoln County requires three percolation tests per parcel with each test consisting of a 30 to 40 inch deep hole around which the soil has been saturated. The water level decline is measured during a specified interval (usually 10 to 15 minutes) and the rate calculated. The slowest rate is to determine loading when six or less holes are used and the average rate when six or more tests more holes are used.

Percolation data were collected from small wastewater facility (septic tank) applications on file in the office of the Lincoln County Planner in Afton. Only those applications received in 2000 or later were used and only when the percolation data were complete and the tests conducted by an individual, or entity, other than the owner. The soils on each parcel were obtained from the soils map (**Figure 5**) and only those parcels with one soil series were retained for analysis. The average observed percolation rate for each soils series are presented in **Table 4**.

[4] http://soildatamart.nrcs.usda.gov/Survey.aspx?State=WY

[5] Soil Survey of Star Valley Area, Wyoming – Idaho. US dept. Ag. Soil Conservation Service, 1976.

The area-weighted percolation rate for each plat was determined by multiplying the area of each soil in a plat by its observed percolation rate and dividing by the total soil area in the plat as shown in **Table 5**.

3.3.3 Depth to Impermeable Layer

The Lincoln County regulations require that the drain field for a small single-family residence must be at least four feet above an impermeable layer. This criterion may not be met in areas mapped as “Stony Lands”, where the soil limitation is cited as “shallowness to bedrock” and in some areas mapped as Robana silt loams and the Robana-Turnerville soils (**Figure 5**). The Star Valley Soils Survey reports that a soil pit in the Robana silt loam, which was located 2.5 miles east of Freedom in the NW corner, Section 36, T32N, R119W, encountered a buried soil at a depth of 72 inches with a silty clay Bt horizon, which could act as a low permeability layer. The soil pit is located on the ancient Prater fan and the buried soil probably underlies large areas of the fan at variable depths.

3.4 Slope of Ground Surface

As indicated by the soils slope map in **Figure 6**, the local ground slopes in the Town range from zero to sixty percent. The regional slope of the land surface westward from the mountain front toward the Salt River varies from 11 to12 percent in Plats 1, 2, 3, 6, 7, and 15 in the northern part of Town to 4 to 5 percent in the southern part of Town.

3.5 Geology

The geology of the Star Valley area consists of two components: the bedrock geology in the Salt River Range and below the unconsolidated sediments of the Star Valley, and the unconsolidated sediments comprising the alluvial fans, terraces, and flood plain forming the floor of the Star Valley.

The generalized geological setting of the Star Valley is described in Seismotectonic Study for the Palisades Dam in 1986.[6] For at least the last 10 million years, Star Valley has been subsiding along the Salt River Fault (**Figure 3**) while the adjacent Salt River Range rose exposing old limestone, sandstone, and shale to erosion. The subsidence caused rivers flowing from the Salt River Range to deposit sandy-gravel in large alluvial fans with the silty sediments deposited in the interspersed lakes and wetlands toward the center of the valley. Similar to the modern land surface, the surface of these ancient alluvial fans probably were cut by numerous active and recently abandoned channels filled with gravel separated by less active surfaces covered with fine sand and silt. Locally large landslides from the mountain front deposited large blocks of limestone upon the fans. These landslide blocks would be subsequently buried by the alluvial sediments.

The subsurface geology exerts a strong influence on the rate and direction of ground water flow and on the homogeneity of that flow, that is the level to which the subsurface materials range from homogeneity in permeability to heterogeneity in permeability with higher permeability lenses, ribbons, and strings within a lower permeability matrix. This detailed subsurface geology can only be interpreted from local well logs.

[6] Seismotectonic Study for the Palisades Dam Project, Idaho, Piety, LA, Wood, CK, Gilbert, JD, Sullivan, JT, and Anders, NH, 1986, Seismotectonic Report 86 – 3, US Bureau of Reclamation, Pacific Northwest Region, Geology Branch, Boise Idaho.

3.5.1 Bedrock Geology

Bedrock is exposed along the mountain front, canyons, dissected footslopes east of the Snake River Fault, and in scattered erosional remnants along the Salt River (**Figure 8**). The older bedrock of the mountains consists of Paleozoic[7] age limestone and dolomite with scattered infolded inclusions of shale and sandstone. The limestone and dolomite are major aquifers in the mountains and the source of many springs. Tertiary bedrock is more than 6,000 feet thick in northern Star Valley[8] and consists of the Miocene-Pliocene age Salt Lake Formation and the Pliocene-Pleistocene age Long Spring Formation. The conglomerates of the Salt Lake and Long Spring Formations are cemented by carbonate where limestone gravels dominate and less well cemented where quartzite gravels is more prevalent. According to Weston[9], only the Salt Lake Formation has been identified in the deep well logs for the Towns of Etna, Freedom, and Thayne. It has the following characteristics.

"…. Red/brown sandy mudstone and pebble to cobble conglomerate in zones characterized by alluvial fan and alluvial sediments. In zones characterized by lacustrine [lake] sediments the formation consists of tan to light grey sandy siltstone and light grey very fine- to fine-grained sandstone and interbedded mudstone."

Weston, in their on-going study of the Town's aquifers, produced several cross sections that define the subsurface geology (**Figure 9**). They interpret the unit underlying the Salt lake Formation as an unidentified Paleozoic carbonate. This interpretation is at odds with the generally accepted model of a thick Tertiary age valley fill. Another interpretation is that the "Paleozoic bedrock"is carbonate-cemented gravels belonging to either the Salt Lake or Long Spring Formations.

3.5.2 Unconsolidated Sediments

Unconsolidated sediments mantle bedrock beneath the Star Valley. These sediments are Quaternary in age, underlie the landforms in **Figure 3,** and form the parent materials of the soils in **Figure 6**. The thickness of these deposits ranges from three feet near Thayne to over 250 feet near Etna[9].

4.0 HYDROGEOLOGY

4.1 Water Wells

Ninety five wells occur in the Town area (**Appendix A**, **Figure 10** and **Table 6**). Of these wells, 73 have data recorded for their completion depth and 66 have data recorded for the depth to the top of the main water bearing zone (**Figure 11**). As summarized in **Table 6**, completion depths range from 48 to 664 feet below ground surface (bgs) with a median completion depth of 180 feet; fifty percent of the wells are completed between 136 and 280 feet bgs. The main water-bearing zones (Mwbz) range from 20 to over 663 feet bgs with a

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[7] Geologic time terms; Paleozoic extends from 542 million to 251 million years ago, Tertiary extends from 65 million to 1.8 million years ago; Quaternary extends from 1.8 million to present. Miocene-Pliocene would be an interval of unknown duration around 6 million years ago, and Pliocene – Pleistocene would be an interval of unknown duration around 1.8 million years ago.

[8] Royse, Frank, 1993, An overview of the geologic structure on the thrust belt in Wyoming, northern Utah, and eastern Idaho, in Snoke, AW, Steidmann, JR, and Roberts, SM (eds.) Geology of Wyoming: Geological Survey of Wyoming, memoir No. 5, p. 272 – 311.

[9] Weston Engineering, Inc., March 2007, Well Siting Study for the Star Valley Ranch Level II Water Supply Project.

median depth of 150 feet bgs; fifty percent of the Mwbz lie between 98 and 219 feet bgs. Static water levels (swl) range from -10 to 263 feet above the top of the main water-bearing zone (**Figure 12**). Twenty of the 65 wells with appropriate records have swl at or below the top of the Mwbz and are unconfined. The unconfined conditions occur in each Mwbz zone.

4.2 Aquifers

4.2.1 Shallow Aquifer

The Shallow Aquifer consists of the lower saturated portion of the 500 feet of unconsolidated sediments (Qt) and underlying Tertiary formations (Tsl) in **Figure 9**. The water-bearing portions of the shallow aquifer are loose to weakly cemented gravel and sandy gravel in alluvial fan complexes and occasionally fractures within the cemented units of the Salt lake Formation near Thayne. Sixty-eight of the 73 wells with completion data are completed in the Shallow Aquifer. Most (75%) of the well records indicate an Mwbz above 270 feet bgs (**Table 6**) with most Mwbz between of 100 to 200 feet bgs (**Figure 12**).

The head (height of the swl above the Mwbz) data in **Table 6** indicate that confined and unconfined conditions occur at all depths within the Shallow aquifer. This is reasonable for an alluvial fan complex wherein the coarser gravel lens and ribbons (the Mwbz) can be overlain with a range of materials from silt to sandy gravel. Another possible reason for the scattered unconfined Mwbz is inaccurate records, e.g. rather than measure swl, the driller used the top of Mwbz for both items.

The hydraulic properties (hydraulic conductivity, hydraulic gradient, and effective porosity) of the Shallow Aquifer are inadequately known. The hydraulic conductivity (k) as estimated from the texture of the aquifer (sandy gravel) is between 10 and 100 feet per day[10]. On-site wastewater studies for adjacent plats estimated a hydraulic conductivity of 185.5[11] feet/day and 27[12] feet/day. The depth to ground water and hydraulic gradient are estimated in sections 4.2.1.1 and 4.2.1.2 that follow.

4.2.1.1 Depth to Ground Water. Lincoln County regulations require that the drain field for a small single-family residence must be at least four feet above seasonally high ground water. The “depth to initial ground water” map[13] for Lincoln County indicates that shallow ground water is from 20 to 50 feet bgs throughout Town.

The depth to water beneath the Town must be estimated from the swl in adjacent domestic wells. The measured swl in Mwbz may not be the first ground water encountered by a well but it is the first ground water-bearing zone to have sufficient quantities for use by a residence. The working assumption is that the swl of the Mwbz records the depth to the initial ground water and it is used in this study for “depth to seasonal high ground water” in the Chapter 23 calculations.

The depth to the swl increases from south to north and from east to west (**Figure 13**). The domestic wells south of Town have swl between 68 and181 feet bgs with the easternmost well

[10] Table 2.2 in Freeze, RA and Cherry, JA, 1979, Ground water, Englewood Cliffs, NJ, Prentice-Hall, Inc., 604 p.
[11] Sunrise Engineering, 2003, On-site Waster Study for the Proposed Roberts Subdivision.
[12] Sunrise Engineering, 2007, On-site Wastewater Study for the Proposed North Forty Subdivision.
[13]

having a swl of 235 feet bgs; whereas, the domestic wells northwest of Town have swl between 190 and 400 feet bgs. One domestic well near the middle of Town has a swl of 460 feet bgs. The swl decreases westward from the mountain front where swl of 200 to 400 feet bgs are encountered in contrast to about one mile west where swl of 68 to 190 feet bgs are encountered.

The depth to ground water was contoured (**Figure 13**) using the scattered well data and known topographic breaks. Surface topography is an important control on depth to ground water because it varies more rapidly than the water table. In dissected areas or in plats with variable elevations, the depth to ground water can vary over many tens of feet. Combining the topographic variations with the inaccuracy of well location leads to an error of 20 to 40 feet in depth to water.

The depth to the static water level appears to be controlled by the landforms in **Figure 3**. It increases abruptly across the boundary between the ancient Prater fan and the Green-Cedar fan and it gradually increases eastward as the alluvial fans rise rapidly toward the dissected footslopes along the mountain front (**Figure 8**). These topographically-controlled variations in swl indicate that each subdivision has a different "depth to seasonally high water" in the Chapter 23 calculations.

4.2.1.2 Potentiometric Map. The term "potentiometric" refers to the pressure-controlled elevation to which the static water rises in confined to semi-confined aquifers; in unconfined aquifers, it is known as the "water table." The map consists of lines of equal elevations (equipotential lines or contours). The term potentiometric map is used here because the shallow aquifer is largely confined but in some areas, it is unconfined to semi-confined.

Limited well data are available to clearly define the elevation and slope of the potentiometric surface. The surface shown in **Figure 14** is an approximation based on scattered static water elevations for domestic wells, the elevation of the Salt River Floodplain, and an elevation at the mouth of Cedar Canyon derived from the depth to water map (**Figure 13**). Long segments of contours are uncontrolled by data and are drawn parallel to adjacent somewhat better-controlled contours. The map shows the potentiometric surface has two distinct components separated by County Road 118 – the southern component slopes westward and southwestward away from Cedar Canyon toward the Salt River and is approximately parallel to the topographic contours on the Green-Cedar fan. The northern component slopes steeply to the northwest and cuts obliquely across the topographic contours on the ancient Prater fan.

Ground water flow is perpendicular to the equipotential lines. As shown in **Figure 14**, ground water in the Shallow Aquifer flows westward from its recharge area along the mountain front toward its discharge area along the Salt River – a distance of three to four miles. The contours and flow lines indicate that Cedar Creek is a major recharge source for the Shallow Aquifer with ground water flowing away from the mouth of Cedar Canyon. The Prater alluvial fan, which is located northwest of the ancient Prater fan, appears to be a major discharge area for ground water flowing under the ancient Prater fan.

4.2.2 Deep Aquifer

The deep aquifer is defined here as the saturated portions of the carbonate unit ("Paleozoic Rocks") on the cross sections in **Figure 9**. For the purposes of this analysis the top of the

Deep Aquifer is approximately 500 feet bgs. The only two wells that have Mwbz within this unit are the production wells in the Town of Star Valley Ranch **(Figure 10**) – the Airstrip Well and the Cedar Canyon Well.

5.0 THE ASSESSMENT

5.1 Chapter 23 Requirements

As required in Section 7 of Chapter 23 the specified analyses for determining nitrates levels at the down gradient property line (Chapter 23, Appendix A) and the viral isolation distance between drainfields and property boundaries and surface waters (Chapter 23, Appendix B) were conducted for each of the 21 plats within the Town. Chapter 23, Appendix A presents the equations for a Wehrmann[14] analysis of cumulative nitrate loading and Appendix B presents the equations for the vertical travel time of virus from drain field to water table and the horizontal travel distance of virus from entry into the ground water for the remainder of the two year duration. All spreadsheets are available for download at http://deq.state.wy.us/wqd/www/Permitting/Pages/Subdivision.asp and appear in **Appendix B** of this report. The data required by the Chapter 23 analysis are summarized in **Table 7**.

5.2 Scenarios

The Chapter 23 analysis was conducted for the 21 plats using 10 stages of build out (10 to 100% build out) as summarized in **Table 8**. The build out scenarios use the 2006 subdivision properties (**Table 1**) such median number of bedrooms, median footprint area, median lot area, median drain field area but the number of residences changed with build out (**Table 9**). The hydraulic factors remain constant during build out and are listed in **Table 10.**

5.3 Linkages

The Chapter 23 analyses are designed for a single subdivision. Some of the 21 plats in this study that lie up gradient of their neighbor contribute ambient nitrates to the down gradient neighbors and are thus linked. The linked plats are shown in **Figure 14** with an arrow showing the direction of increasing ambient nitrates.

6.0 RESULTS

The results of the Chapter 23 calculations are summarized in **Table 10**. They indicate that some of the small on-site waste disposal systems within the Town pose a potential water quality problem. Plat 10, which is linked to Plats 9 and 12, is predicted to exceed USEPA nitrate limits by 65 percent build out. In all other plats, the nitrate concentrations remain below 8 mg/l at build out and pose no problems. The vertical travel time for virus to the water table (potentiometric surface) exceeds two years in plats north of County Road #116 where the depth to ground water increases below the ancient Prater alluvial fan and the dissected footslopes. South of CR # 116 on the Green- Cedar alluvial fan, the smaller depth to ground water allows virus to enter to the ground water. Viral travel distances in the Shallow Aquifer are between 262 feet and 2,650 feet down gradient (**Figure 16**). Virus will travel beyond Town boundaries at Plats 4, 5, 10, 16, 17, 18, and 21. Soil limitations (**Figure 7**) are severe in some plats and require special septic system design and installation to minimize health and water quality problems.

[14] Wehrmann, HA, 1984, Managing Ground Water Nitrate Quality by Mass Balance Modeling in the Rockton-Roscoe Area, Ilinois. *In* Proceedings of the NWWA Eastern Regional Conference on Ground Water Management, National Well Association, Dublin, Ohio, pp. 558 – 587.

7.0 DISCUSSION

The potential impacts of the results and the quality of data used in the calculations deserve additional discussion. Because the results are no better than the data, data is discussed first.

The hydraulic data used in the Chapter 23 analysis have the greatest potential of being in error. No measured hydraulic conductivities are available for the Shallow Aquifer and estimates based on particle size of the sandy gravel allow an order of magnitude spread (10 to 100 feet/day) for hydraulic conductivity. The hydraulic conductivity used here (25 feet/day) is near the lower limit. A larger hydraulic conductivity would decrease nitrate concentrations and increase viral travel distances.

The “depth to water” and hydraulic gradient estimates are based upon extrapolations from adjacent domestic wells that are screened at different depths within the Shallow Aquifer. Private domestic wells are not allowed within Star Valley Ranch and residences are served by a public water supply. For this reason only the Airstrip Well #1, which is completed in the Deep Aquifer, is located within Town. This lack of domestic wells produces large data gaps in the depth to water (**Figure 13**) and potentiometric (**Figure 14**) maps. These gaps allow alternate interpretations that would affect calculations in the Chapter 23 analysis based on depth to water (viral travel time), hydraulic gradient (viral travel distance and nitrate concentrations), and linkages (ambient nitrates). The interpretations used here are consistent with Cedar Creek being the major recharge source for the Shallow Aquifer beneath the Green-Cedar alluvial fan.

A comparison of data used in this study to that from similar studies in nearby subdivisions indicates similarities in hydraulic conductivity and gradient. Depth to water in the Robert’s subdivision falls within the range of this study because Roberts is also located on the ancient Prater alluvial fan and adjacent dissected foot slopes. The North Forty subdivision is located on an alluvial fan complex and has a depth to water similar to Plats 4 and 5.

Study	Hydraulic Conductivity (ft/day)	Hydraulic Gradient	Depth to Water (ft)
Roberts	185.5	0.028	155
Star Valley Ranch	25	0.010 - 0.034	50 - 425
North Forty	27	0.01	30

The calculated nitrate and viral accedence’s pose different problems. Nitrate concentrations in excess of USEPA limits occur only in Plat 10. The high nitrate ground water is likely to flow northwest from Plat 10 across the Town boundary into the southwest quarter of section 30, which is under consideration for a subdivision. The potential viral travel directions and distances pose potential water quality problems for domestic wells that are completed within the Shallow Aquifer in the Cedar Creek Ranches located southwest of plats 17, 18, and 21; Coleman Hardy Family Estates located west of Plat 20, and; if ground water directions are slightly different, to the Bridger View Subdivision located northwest of plats 4 and 5.

The nitrate and viral problems identified by the Chapter 23 analysis must be considered when locating culinary supply wells within Town. The Shallow Aquifer above Airstrip Well #1 will contain virus as will any well site located in the western part of Town south of CR #118, as extended to the east. The tightness and extend of the aquitard between the Shallow and Deep Aquifers should be a major consideration when selecting a well site in this area.

Tables

Table 1. Characteristics of plats (plats) within the Town of Star Valley Ranch.

Plat maps were provided by the Lincoln County GIS Department in June 2006 as ArcView files accompanied by electronic tables providing parcel use, area, and ownership.

Plat	Date Platted	Number Lots	Areas (acres)								Drain field area (ft^2)	Median Number Bedrooms
			Plat	Lots	Road	Common Area	Forests	Average Lot	Median House Footprint	Est. Av. lawn		
1	01/06/71	86	80	73	6.4	0.0	32	0.85	0.03	0.81	462	2
2	08/05/70	61	60	51	6.2	0.0	24	0.84	0.04	0.80	526	2
3	03/03/71	125	81	69	0.1	0.0	32	0.55	0.03	0.51	789	3
4	06/19/85	14	14	14	0.2	0.0	6	0.96	0.04	0.92	375	2
5	06/30/71	160	66	56	11.2	0.0	27	0.35	0.03	0.31	563	3
6	08/04/71	66	36	79	10.8	38.1	14	1.20	0.04	0.67	714	3
7	08/04/71	117	55	47	7.4	3.7	22	0.41	0.03	0.45	500	2
8	06/30/71	132	55	47	8.0	0.0	22	0.42	0.03	0.88	500	2
9	03/16/76	96	62	51	10.2	5.4	25	0.53	0.04	0.60	423	2
10	03/16/76	100	63	51	10.7	17.6	25	0.51	0.03	0.83	692	3
11	06/04/84	18	16	16	2.2	3.8	6	0.89	0.04	1.49	577	2.5
12	08/03/77	104	62	57	8.0	21.4	25	0.55	0.04	1.06	563	3
13	08/03/77	87	71	58	9.0	10.8	28	0.66	0.04	0.83	600	3
14	08/03/77	88	62	53	11.2	8.3	25	0.61	0.03	0.82	469	2.5
15	09/05/78	79	80	65	8.9	0.0	32	0.82	0.04	0.77	789	3
16	09/05/78	93	95	84	11.9	1.0	38	0.90	0.04	0.89	563	3
17	04/04/79	144	119	87	15.8	50.5	48	0.60	0.04	1.56	563	3
18	04/04/79	188	151	115	22.9	21.6	61	0.61	0.04	1.04	563	3
19	02/04/70	104	80	71	8.1	0.0	32	0.68	0.04	0.64	714	3
20	06/04/84	114	80	64	13.6	0.0	32	0.56	0.03	0.52	563	3
21	06/04/84	68	80	71	8.3	0.0	32	1.04	0.04	0.99	714	3

Table 2. Distribution of soils by plat. The soils map (Figure 5) was intersected by the plat map (Figure 2) in the GIS Arc View program to determine the area of each soil type occurring in the plat. These areas were subsequently used to determine the average percolation rate for the plat.

Plat	Cowdrey clay loam	Greyback gravelly loam	Greyback and Hobacker soils	Greyback - Rooset assoc. - hilly	Hobacker - Osmund gravelly loams	Robana silt loam	Robana - Turnerville Assoc. - undulating	Stony rock land	Thayne loam	Thayne gravelly loam	Willow Creek - Bozeman assoc. -
1				34	14		26	6			
2				1			59				
3							82				1.2
4		15									
5		89									
6				7			55				14.5
7				14			39				
8				11			27				
9				8	13		8		5	29	
10				8			44		16	9	
11				10			6				
12		23			6					60	
13		0	2	1	28	2				38	
14		1	3			24				45	
15	6			10			59				
16		41	2			8			8	38	
17		90	39	11	5	1				5	
18		112	34	2						11	
20						6	54				19.5
21		68	9							3	
22				4			61				23.7

Table 3. Soil characteristics and interpretations related to their capacity for septic drain fields. Included are the soils series located within the boundaries of the Town of Star Valley Ranch. Soil survey data[a] are presented at the soils series and association levels are were interpreted from their physical characteristics.

Soil Name	Parent Material[1]	Horizons[2]	Solum Thickness	B- horizon Thickness	pH	Permeability[2] (in/hr)	Topographic Setting
Cowdry	cl loam	A/Bt	48	17	acid	(<17") 0.6 - 2.0 (17 - 40") 0.06 - 0.2 (>40") 0.2 - 0.6	hillsides
Greyback	vG L Sand	A/B/Cca	18	11	alkaline	(<18") 0.6 - 2.0 (>18") 6.0 - 20	fan
Greyback/ Hobacker	vG L Sand	A/B/Cca	Hobacker 23	Hobacker 0	alkaline	Greyback (<18") 0.6 - 2.0 (>18") 6.0 - 20: Hobacker (<23") 0.6 - 2.0 (>23") 6.0 - 20.0	fan
Greyback/ Rooset	vG L Sand	A/B/Cca	Rooset 30	Rooset 9	alkaline	Greyback (<18") 0.6 - 2.0 (>18") 6.0 - 20: Rooset (0 - 7") 0.6 - 2.0 (>7") 0.2 - 0.6	Foot
Hobacker/ Osmund	G loam	A/C	Osmund 30	Osmund 20	alkaline	Hobacker (<23") 0.6 - 2.0 (>23") 6.0 - 20.0: Osmund (<30") 0.6 - 2.0, (>30") 2.0 - 6.0	fan/foot
Robana	loess	A/Bt/C	60	45	neutral	0.6 - 2.0	uplands
Robana/ Turnerville	loess	A/Bt/C	Turnerville 60	Turnerville 45	neutral		uplands
Stony land	rock	A/C/R	variable	0		Too variable to estimate	mountain slope
Thayne	loam	A/B/Cca	24	12	alkaline	0.6 - 2.0	fan
Thayne GL	G loam	A/B/Cca	above	above	alkaline	(<24") 0.6 - 2.0 (>24") 2.0 - 60.0	fan
Willow Cr	loess	A/Bt/C	37	27	alkaline	0.6 - 2.0	uplands

1 c = clay
G = gravelly
L = loam
V = very

2 A = the mineral horizon at the surface in which the living organisms are the most active and marked by the accumulation of humus.
B = the mineral horizon below the A that is marked by the accumulation of clay, humic acids, and blocky structure.
Bt = Part of the B horizon characterized by clay accumulation and blocky structure.
C = the weathered mineral material immediately below the B.
Cca = Part of the C horizon with accumulations of calcium carbonate.
R = Consolidated rock beneath soil.

Table 4. Summary statistics of soil percolation rates measured within the Town of Star Valley Ranch. The number of percolation observations within each soils unit refers to number of observations. Three observations per site are required by Lincoln County. The County requires that the average value be used when the number of observations exceeds 6.

Soil Series	Number	Percolation Rate			
		(min/in)		(in/hr)	
		Average	Standard Deviation	Average	Standard Deviation
Cowdry cL	3	20.0	0.0	3.0	0.0
Greyback gl	141	4.0	2.8	21.5	11.4
Greyback/Hobacker	6	5.0	0.0	12.0	0.0
Greyback/Hobacker	18	6.4	3.4	12.2	6.8
Hobacker/Osmund	12	9.6	6.4	11.6	10.3
Robana	3	4.8	1.7	13.6	4.0
Robana/Turnerville	18	12.2	6.9	8.6	7.5
Robana/Turnerville	84	12.4	8.5	9.7	11.1
Thayne L	3	4.1	0.9	15.1	3.1
Thayne gl	45	4.4	2.3	17.9	8.5
Willow Creek/Bozeman	9	4.7	1.3	14.0	5.0

Table 5. Distribution of area-weighted average percolation rates by plat. Area-weighted soils distribution in Table 2.

Soil series		Cowdry	Greyback	Greyback - Hobacker	Greyback-Rooset	Hobacker - Osmund	Robana	Robana - Turnerville	Stony Land	Thayne Loam	Thayne gravelly loam	Willow Creek - Bozeman	Area Averaged Percolation Rate		Loading Rate gpdpsf
Percolation Rate		20	4	5	6	10	5	12	12	4	4	5	Min. /inch	feet/day	
Plat	1				215	131		322	69				9.4	0.0009	0.65
	2				8			739					12.3	0.0007	0.57
	3							1,026					12.3	0.0007	0.57
	4		58										4.0	0.0021	0.80
	5		353										4.0	0.0021	0.80
	6				73			243					10.6	0.0008	0.60
	7				88			490					10.9	0.0008	0.60
	8				48			683				68	10.4	0.0008	0.63
	9				51	119		98		22	125		6.7	0.0013	0.71
	10				51			542		66	39		9.0	0.0009	0.65
	11				62								8.6	0.0010	0.65
	12		92			56					263		4.6	0.0018	0.80
	13		1	9	4	265	11				166		6.4	0.0013	0.75
	14		3	13			113				197		4.5	0.0018	0.80
	15	123			66			735					12.2	0.0007	0.57
	16		162	10			40			34	167		4.2	0.0020	0.80
	17		357	196	71	51	3				20		4.6	0.0018	0.80
	18		449	170	11						48		4.3	0.0020	0.80
	20						28	669				92	9.9	0.0008	0.63
	21		272	47							11		4.1	0.0020	0.80
	22				25			749				112	10.0	0.0008	0.63

Table 6. Summary of well characteristics. Summary of characteristics of wells in the vicinity of Star Valley Ranch shown in Figure 10. "All wells" refers to the 66 to 73 wells of the 95 identified wells with recorded data. Mwbz refers to the "main water-bearing zone." The three columns under "Mwbz Zones" present the distribution of Top Mwbz within that depth interval. Head refers to the difference in depth bgs between the static water level (swl) and the top of the Mwbz. A positive value indicates the swl is above the Top of the Mwbz and zero or negative value means the swl is at or below the top of the Mwbz. A positive head is an indication of a confined aquifer and a negative head indicates an unconfined aquifer.

Summary Statistics	All Wells					Mwbz Zones (feet bgs)			Head (feet)		
	Well Depth	Static Depth	Mwbz Top	Mwbz Bottom	Head	<100	100 - 300	>300	<100	100 - 300	>300
Number	73	73	66	65	66	19	41	6	19	41	6
Minimum	48	-1	20	48	-10	20	104	345	-9	-10	0
1st Quartile	136	68	97.75	140	0	52.5	132	365	0	0	22.75
Median	180	115	150	180	19.5	68	160	420	15	20	70
3rd Quartile	280	170	219	270	40	90	219	490	23.03	47	143.5
Maximum	664	460	663	664	263	100	300	663	35	231	263

Table 7. Data requirements for the Chapter 23 nitrate and viral travel analyses. The WDEQ spreadsheets that calculate the cumulative nitrate loading and minimum isolation distance are included in Appendix B. The data used to make the calculations in this study are listed under "Source."

Calculation	Required Data	Source
Cumulative Nitrate Loading		
Vi	Gross Area Soil Infiltration	Table 1 Tables 4 and 5
Vs	Number Bedrooms Number of Lots	Table 1
Vb	Hydraulic Conductivity Hydraulic Gradient Discharge Length	Table 8 Table 8 Table 8, Figure 15
Vp	Irrigated lawn Same Aquifer?	Table 1 Figure 9
Co	Ambient Nitrate Well Nitrate	Calculated by incremental growth model
Minimum Isolation Distance Analysis		
Vt	Precipitation Drainfield infiltration Depth to water table	Table 8, Figure 4 Table 8 Table 8
Hd	Hydraulic Conductivity Hydraulic Gradient Effective Porosity	Table 8

Table 8. Hydraulic properties used in the Chapter 23 analyses of cumulative nitrate loading and viral travel time and distance.

Plat	Drain field area (ft^2)	Precipitation (in)	Soil Infiltration Rate (ft/day)	Discharge Length (ft)	Ppt + Drainfield Infiltration (in/yr)	Volumetric Moisture (m:/cm^3)	Effective porosity	Depth to Water (ft)	Hydraulic Conductivity (ft/day)	Hydraulic Gradient
1	462	25	0.0009	2444	405	0.12	0.2	425	25	0.034
2	526	25	0.0007	2411	359			360	25	0.027
3	789	23	0.0007	2345	357			300	25	0.026
4	375	19	0.0021	1151	487			50	25	0.011
5	563	19	0.0021	2539	487			50	25	0.011
6	500	27	0.0008	1811	378			275	25	0.016
7	500	25	0.0008	1384	376			285	25	0.014
8	714	25	0.0008	672	394			310	25	0.014
9	423	25	0.0013	1276	441			225	25	0.014
10	692	23	0.0009	1840	404			200	25	0.015
11	577	25	0.0010	1627	406			225	25	0.014
12	563	23	0.0018	1650	491			225	25	0.015
13	600	25	0.0013	2158	464			225	25	0.016
14	469	23	0.0018	1351	491			180	25	0.015
15	789	25	0.0007	2663	359			400	25	0.024
16	563	22	0.0020	2355	490			160	25	0.014
17	563	24	0.0018	2329	492			175	25	0.014
18	563	24	0.0020	3287	492			160	25	0.016
20	714	23	0.0008	2512	392			250	25	0.021
21	563	21	0.0020	1774	489			100	25	0.017
22	714	25	0.0008	1437	394			275	25	0.017

Table 10. The calculated time and travel distance for viral contamination and for nitrate concentrations at different degrees of build out, Town of Star Valley Ranch, Wyoming. Calculations are based on different degrees of build out for each of the Town's 21 plats. The level of build out that best represents 2007 is shown in bold, underlined type. Some plats are located down gradient from other plats; in these plats the nitrates from up gradient greatly increase the ambient nitrate loading. These "linked plats" are identified in the Plat column by "+ X". Results are derived from calculations based on Appendices A and B of Chapter 23, Wyoming Water Quality Rules and Regulations; the calculations are included on the accompanying CD.

Plat	Virus		Potential Nitrate Concentrations (Co) in Ground water at Different Levels of Build Out									
	Vertical Travel Time (days)[b]	**Horizontal Travel Distance (feet)[c]**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
1	1,098	100	**<u>0.2</u>**	0.3	0.4	0.5	0.7	0.8	0.9	1.0	1.1	1.2
2 + 15	1,051	100	0.4	0.8	**<u>1.1</u>**	1.5	1.8	2.1	2.4	2.6	2.9	3.1
3	881	100	**<u>0.4</u>**	0.8	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.2
4 + 5	107	2,650	1.1	2.0	**<u>2.6</u>**	3.1	3.5	3.8	4.1	4.3	4.4	4.5
5	107	2,650	**<u>1.0</u>**	1.7	2.2	2.6	2.9	3.2	3.4	3.5	3.6	3.7
6	762	100	0.5	0.9	1.3	**<u>1.7</u>**	2.0	2.3	2.7	2.9	3.2	3.5
7 + ½ 8	793	100	1.5	**<u>2.8</u>**	3.7	4.6	5.2	5.8	6.3	6.7	7.0	7.3
8	825	100	**<u>1.6</u>**	2.7	3.6	4.2	4.7	5.1	5.4	5.6	5.7	5.9
9 + ½ 13	535	831	0.9	1.5	**<u>2.1</u>**	2.5	2.9	3.2	3.4	3.6	3.7	3.9
10 + 9 + 12	519	898	2.5	4.5	6.2	**<u>7.6</u>**	8.7	9.7	10.5	11.1	11.7	12.2
11	581	634	0.2	0.3	**<u>0.4</u>**	0.5	0.6	0.8	0.9	1.0	1.1	1.2
12 + ½ 13	480	1,066	1.0	**<u>1.7</u>**	2.3	2.8	3.1	3.4	3.7	3.9	4.1	4.2
13	508	946	0.5	0.9	1.2	**<u>1.5</u>**	1.7	2.0	2.1	2.3	2.4	2.6
14	384	1,474	0.6	1.0	**<u>1.4</u>**	1.6	1.8	1.9	2.0	2.1	2.1	2.2
15	1,168	100	0.3	**<u>0.5</u>**	0.7	0.9	1.1	1.3	1.5	1.7	1.8	2.0
16 + 14	342	1,653	1.4	2.5	**<u>3.3</u>**	4.0	4.5	4.9	5.3	5.5	5.7	5.9
17	372	1,523	0.7	1.2	**<u>1.5</u>**	1.8	2.0	2.1	2.2	2.2	2.3	2.3
18	340	1,659	0.6	**<u>1.0</u>**	1.3	1.6	1.7	1.9	2.0	2.0	2.1	2.1
20	668	262	0.4	**<u>0.8</u>**	1.1	1.4	1.7	1.9	2.2	2.4	2.6	2.8
21 + 18	214	2,197	**<u>1.2</u>**	0.0	2.8	3.3	3.6	3.9	4.1	4.3	4.4	4.5
22 + ½ 8	731	100	**<u>1.3</u>**	2.3	3.1	3.8	4.3	4.7	5.0	5.3	5.5	5.7

a Co = diluted concentration of $NO3^-$ as N leaving the subdivision. It can not exceed 10 mg/L

b VT = vertical travel time in vadose zone. If it does not equal or exceed two years the horizontal travel distance (HD) is calculated.

c HD = horizontal travel distance in ground water during a two year interval.

Figures

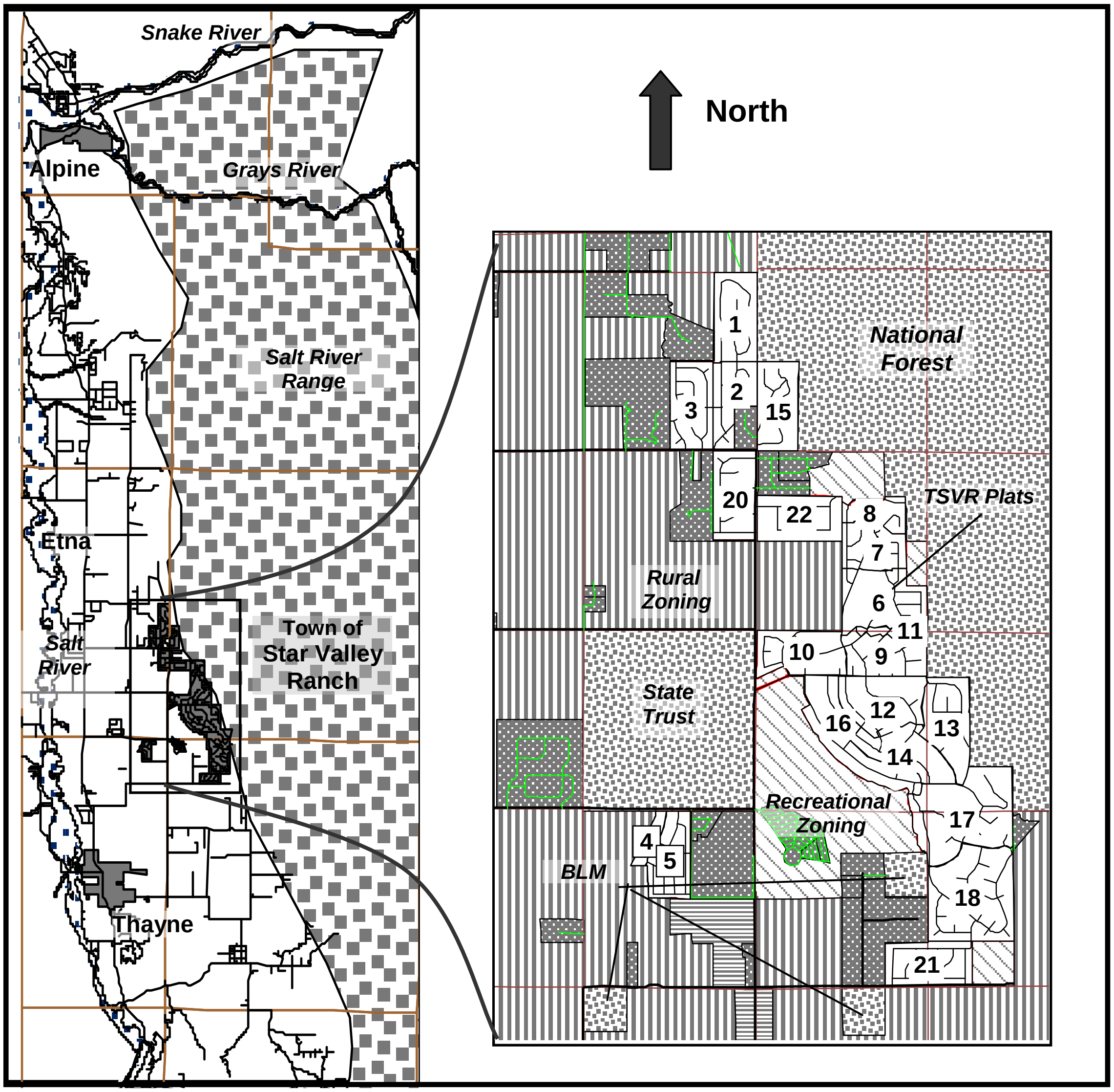

Figure 1. Location Map. The Town of Star Valley Ranch is located in northern or lower Star Valley in western Wyoming. The town contains 12 plats and has within one mile of its western boundary, nine plats and four parcels of public land that are located amid undeveloped lands zoned by Lincoln County as rural or recreational. (Based on Lincoln County GIS maps)

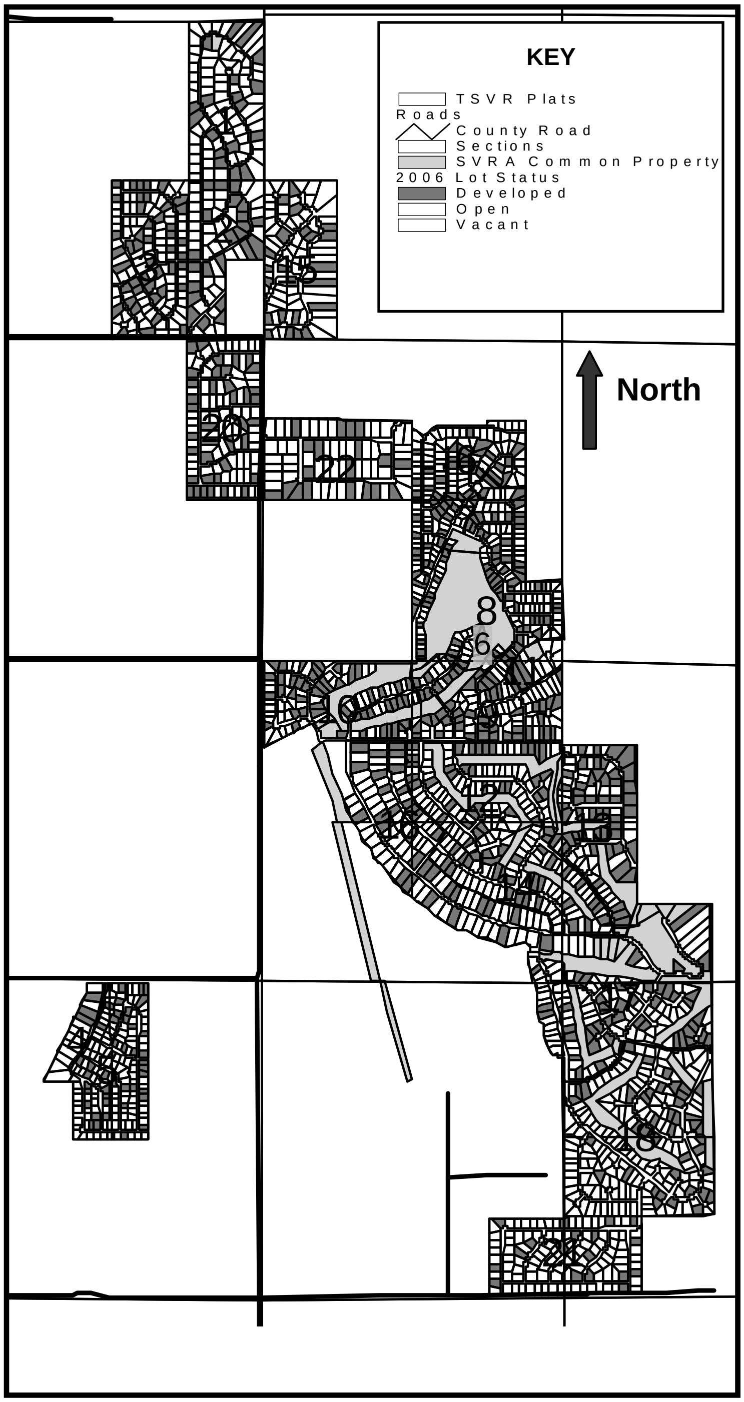

Figure 2. Development Status – 2006. This map shows the distribution of developed lots and common grounds owned by the Star Valley Ranch Association in 2006 and is a more detailed version of the blowup in **Figure 1**. The variations in plat area, median lot area, median residence foot print and number of bedrooms, and other development statistics appear in **Table 1.** (Based on data from the Lincoln County Assessor.)

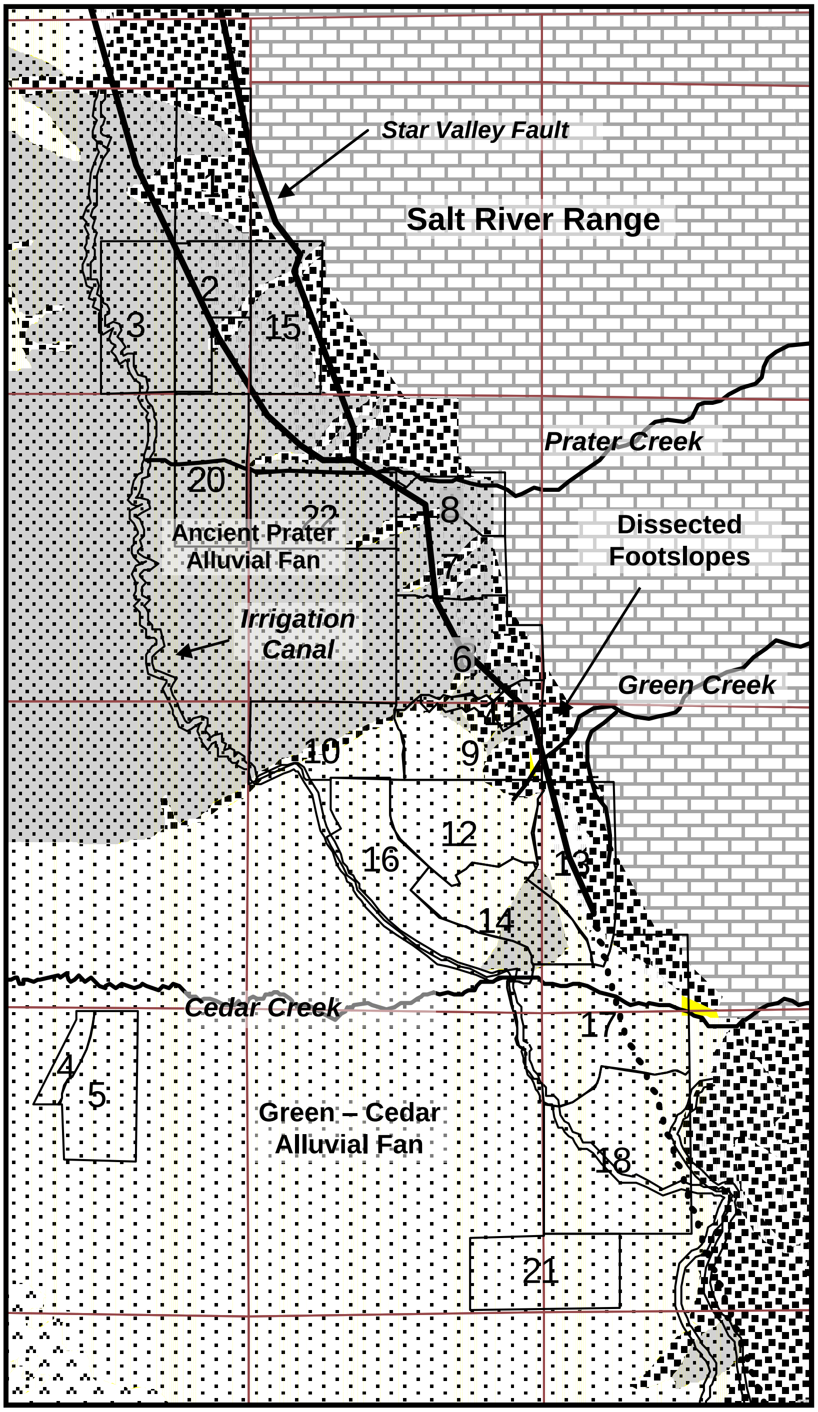

Figure 3. Landforms. The landforms consist of the bedrock slopes of the Salt River Range, highly dissected area at the base of mountains, the active alluvial fans of Green and Cedar Creeks and the ancient, now relic, alluvial fans of Prater Creek. The Star Valley Fault, along which the Star Valley Range was uplifted, approximately separates the alluvial fans from the hilly foot slopes of the mountains. (Data from the digitized versions of Star Valley Soil Survey and the Geologic Map of Wyoming)

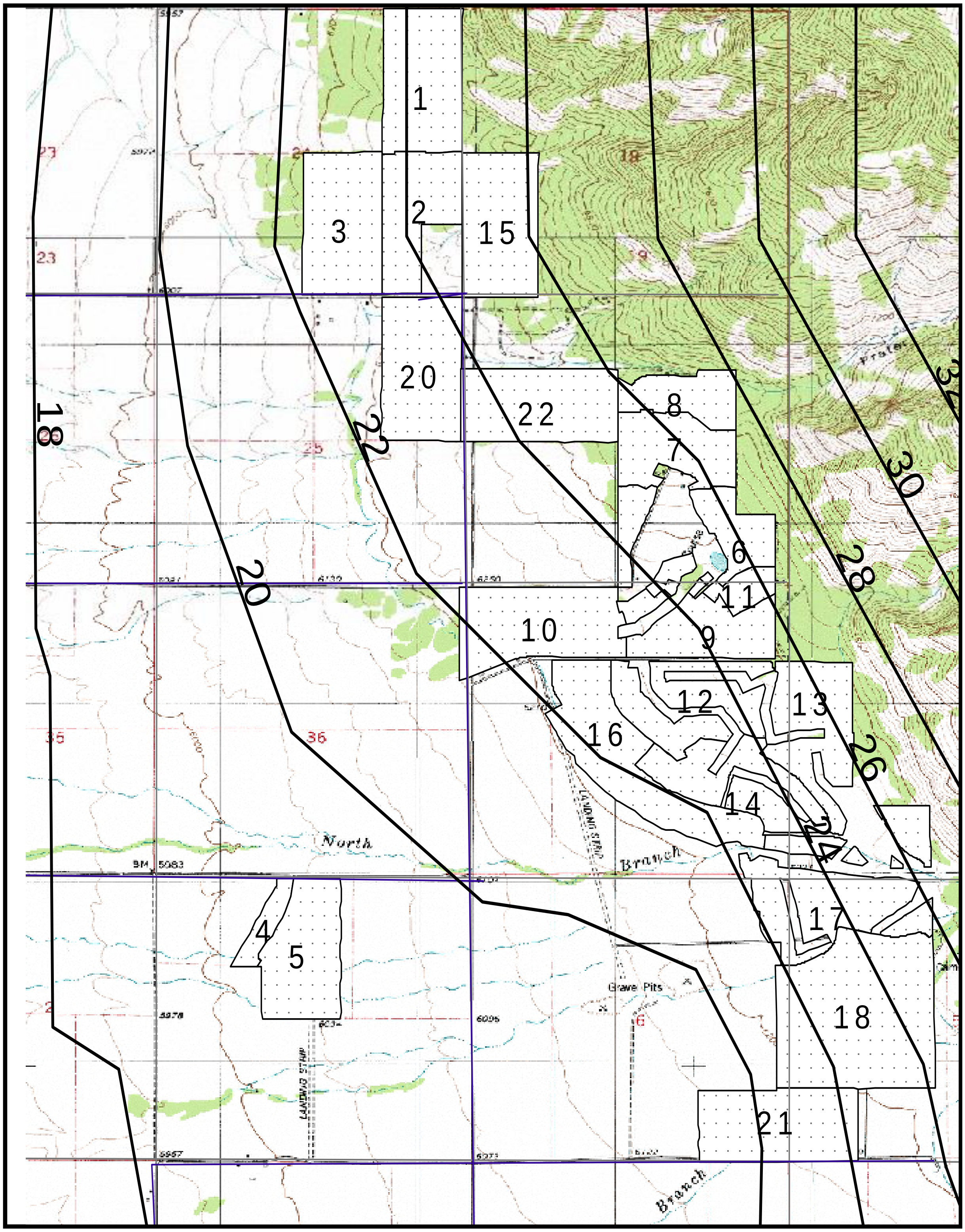

Figure 4. Average annual precipitation in the plats of the Town of Star Valley Ranch. The precipitation contours are developed by the PRISM model to interpolate precipitation data between meteorological stations. Average annual precipitation in Town ranges from a low of 19 inches in Plat 4 to a high of 28 inches in part of Plat 8.

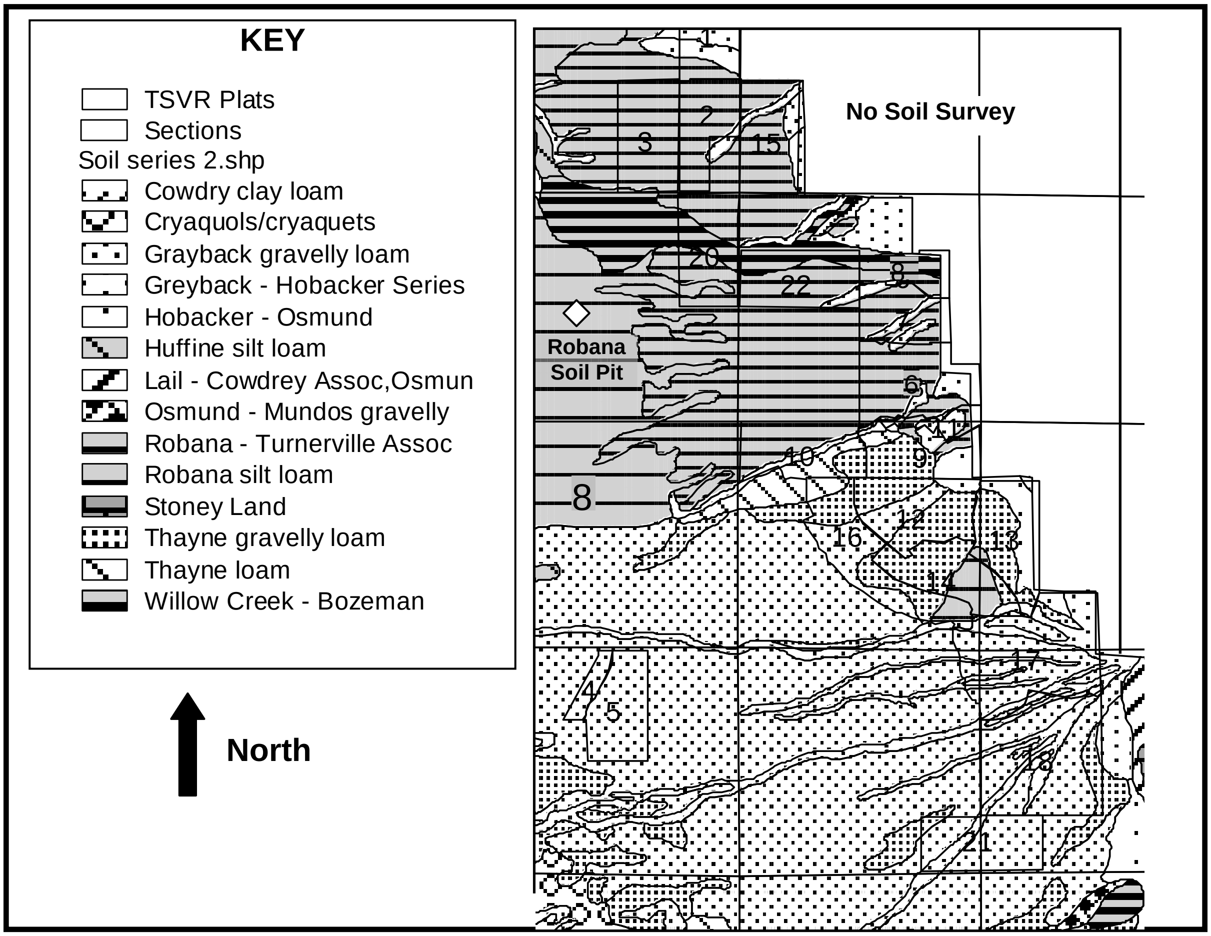

Figure 5. Soils of Star Valley Ranch. This map is a simplified portion of the digitized soils map of Star Valley, Wyoming in that soils are shown at the series /association level with slope variants omitted. The location of soils pit in the Robana silt loam is shown by the white polygon. (Data derived from the digitized Soil Survey of Star Valley Area, Idaho – Wyoming)

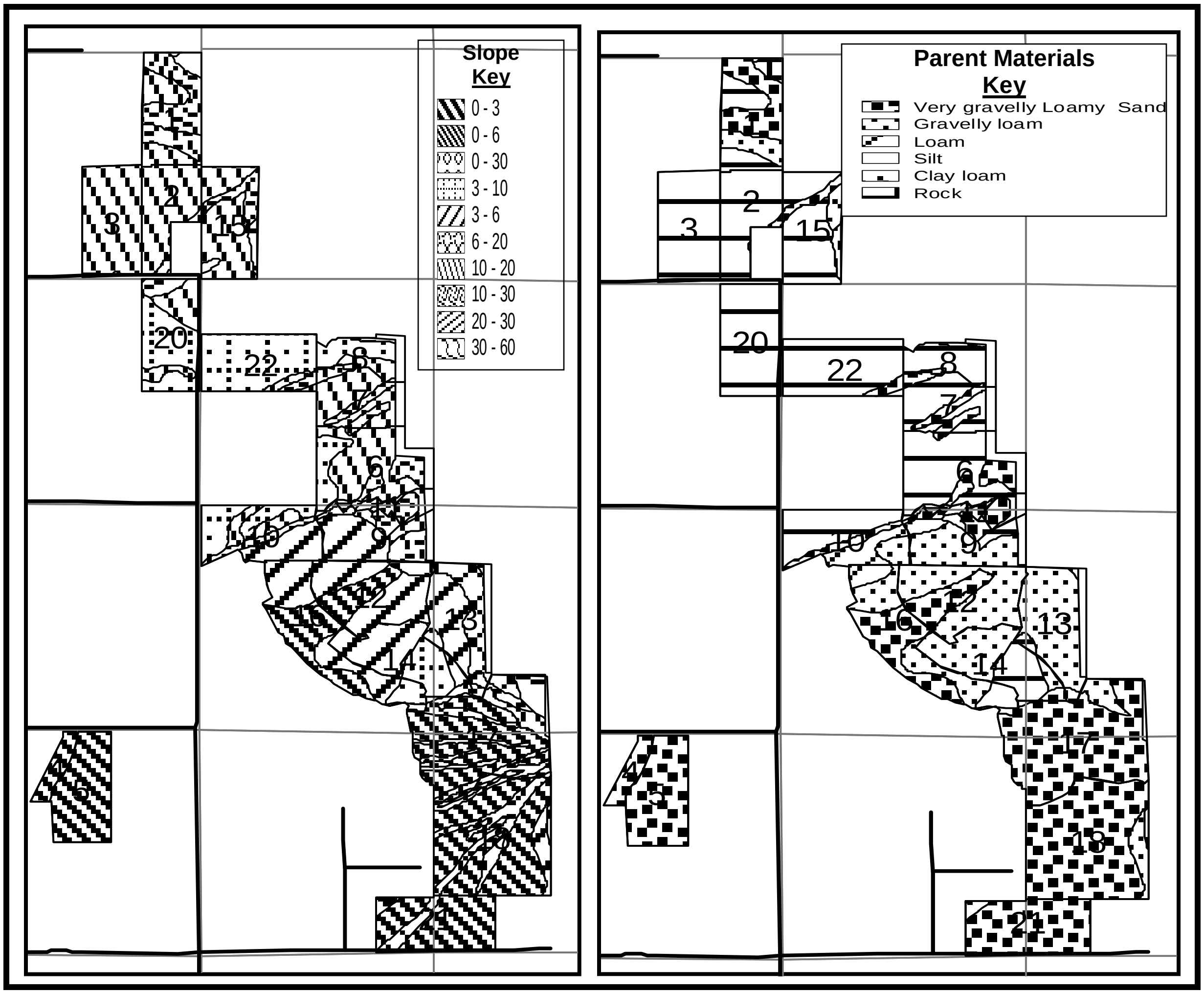

Figure 6. Surface slope and parent materials. Surface slopes and parent materials for the soils underlying the plats on Star Valley Ranch. (Data derived from the digitized Soil Survey of Star Valley Area, Idaho – Wyoming)

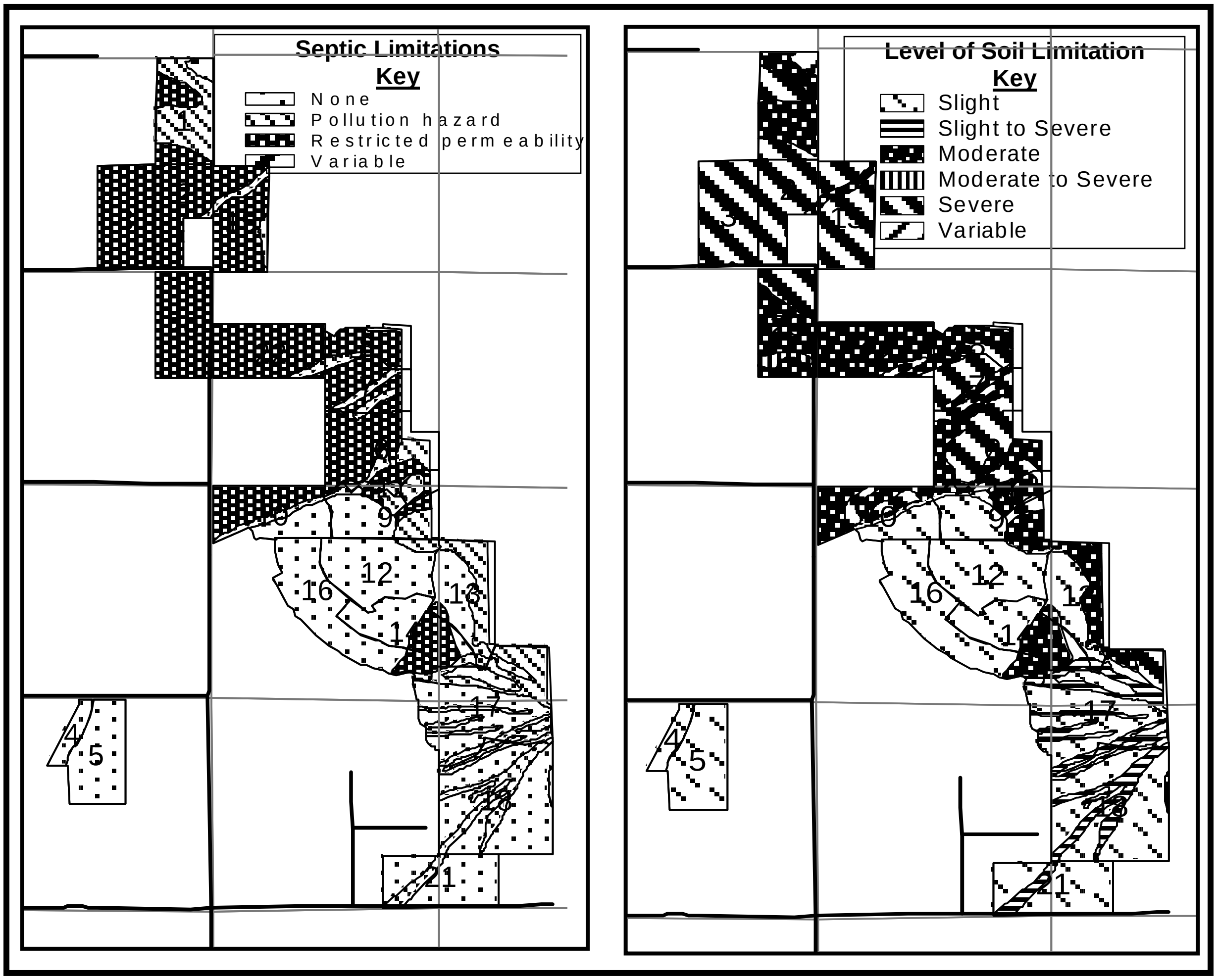

Figure 7. Soil limitations for septic systems. Limitations for installation and operation of septic systems as interpreted from soil properties. (Data derived from the digitized Soil Survey of Star Valley Area, Idaho – Wyoming)

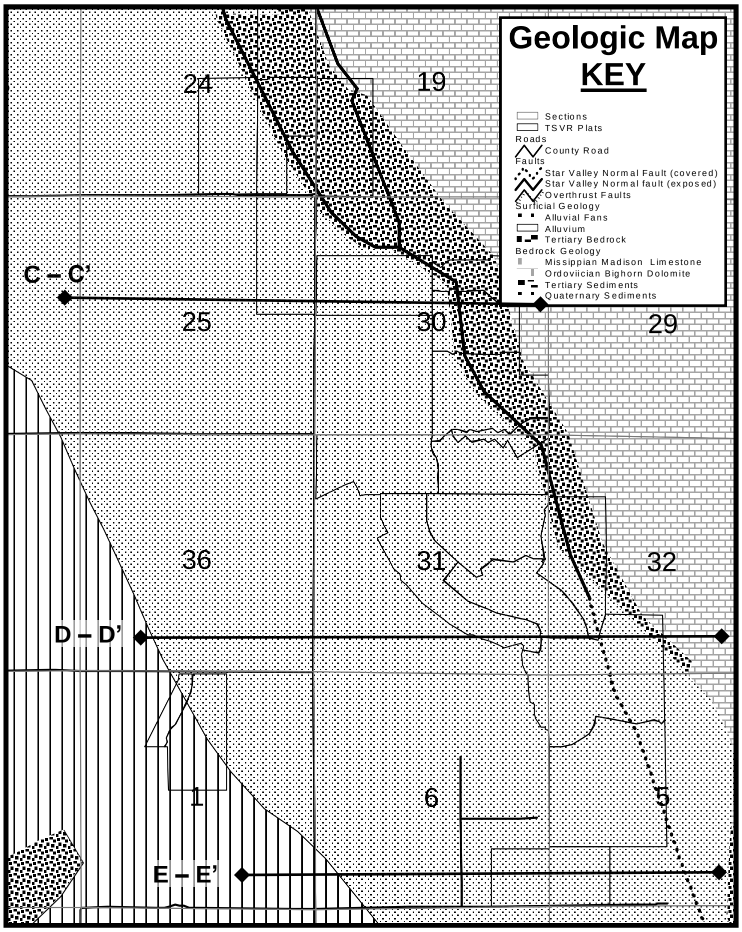

Figure 8. Geologic map of the Town of Star Valley Ranch. The Salt River Range to the east of town is composed of Ordovician-Mississippian age limestone and dolomite with some older sandstone and shale units. The limestone-dolomite was down faulted and probably underlies the Tertiary age sediments in the valley. Slivers of Tertiary valley fill are up lifted with the older bedrock on the east side of the Star Valley Fault. Cross-sections C-C' through E-E' appears in **Figure 9**. (Map modified from the Bedrock Geological Map of Wyoming and the Surficial Geological Map of Wyoming:)

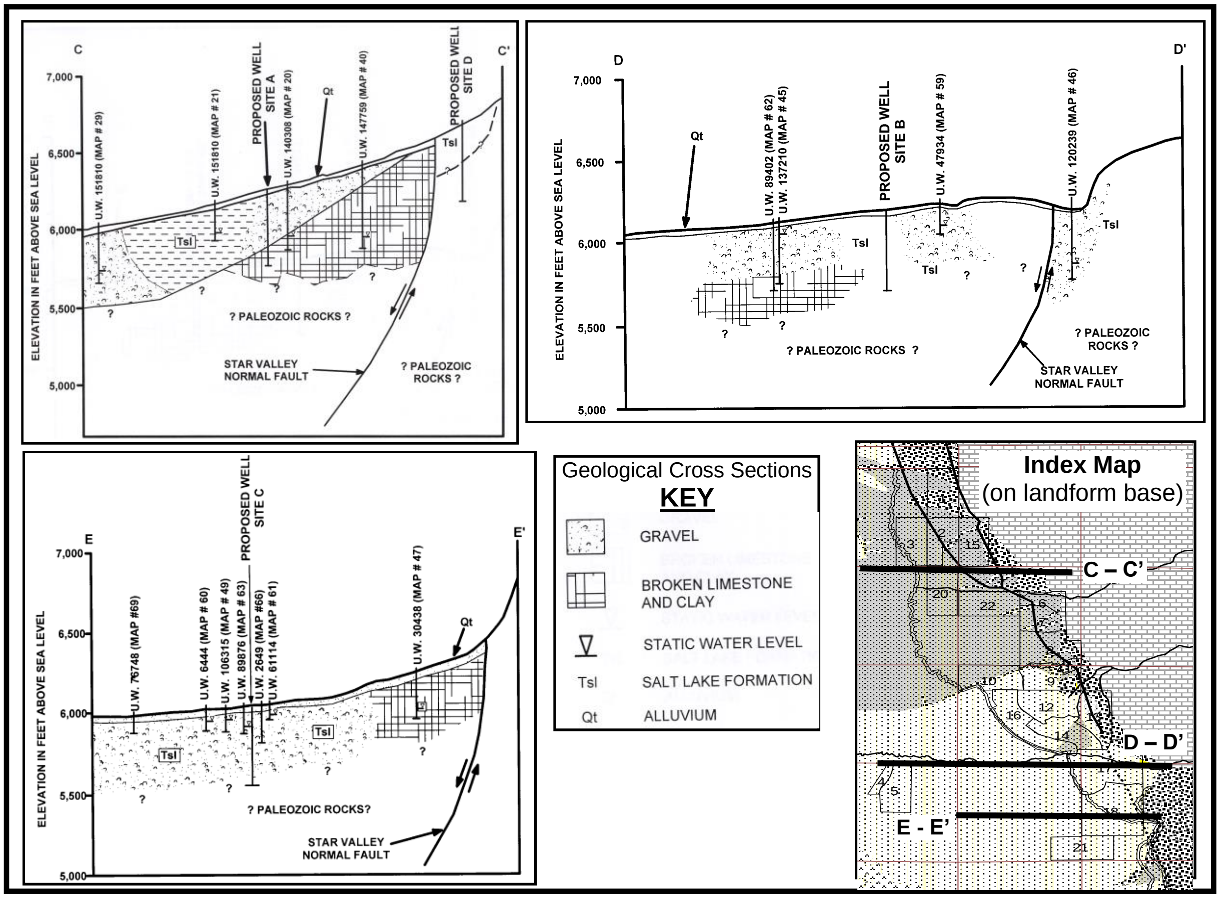

Figure 9. Geologic Cross-Sections. Three geologic cross-sections based on interpretation of well logs adjacent to the Town of Star Valley Ranch. (Cross-sections and interpretation from Weston[5])

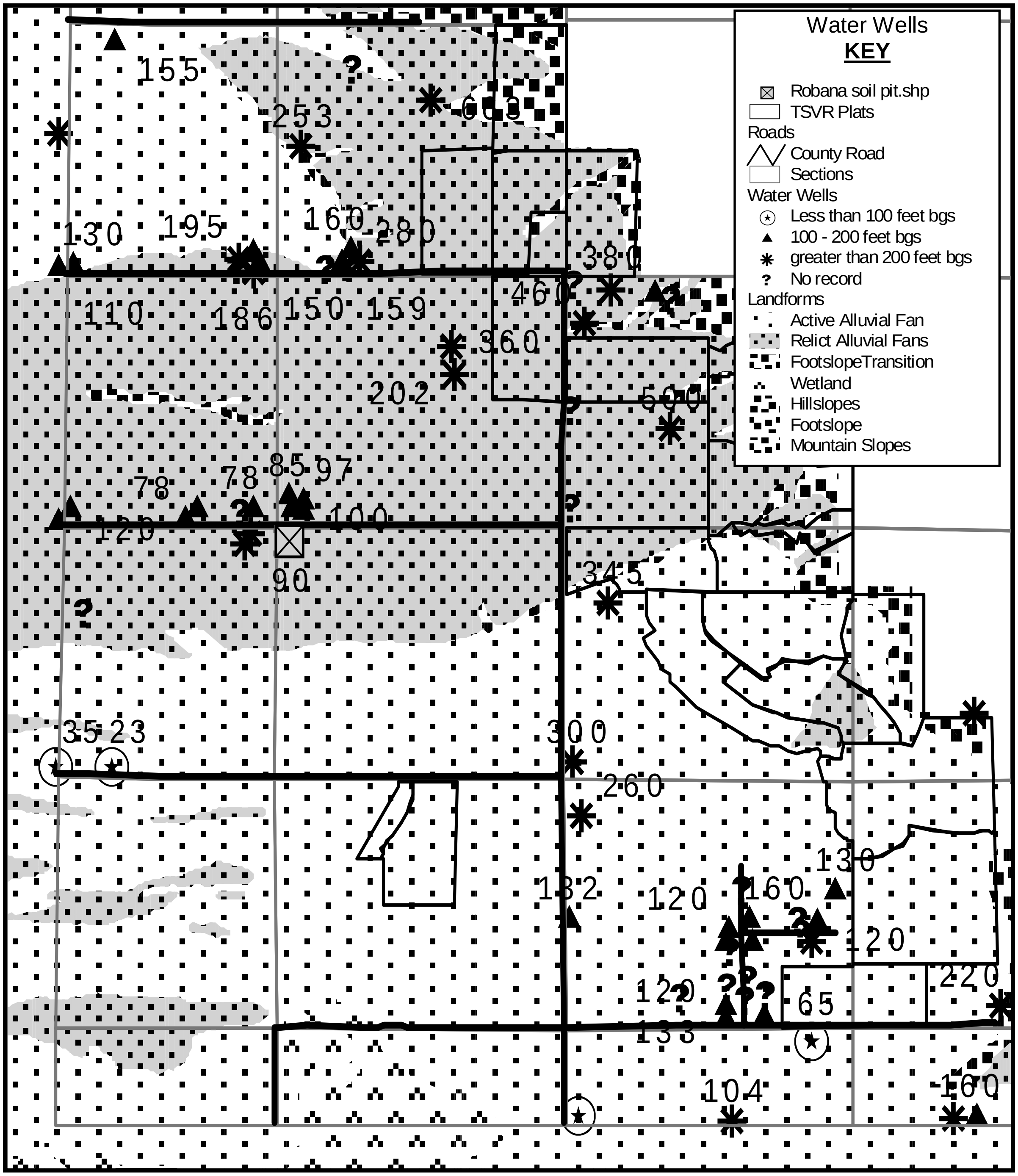

Figure 10. Distribution of water wells in the vicinity of the Town of Star Valley Ranch. The numbers next to the well symbol is the depth below ground surface (bgs) of the top of the main water-bearing zone (Mwbz). A Mwbz beginning at less than 100 feet bgs is susceptible to contamination in the Shallow Aquifer. Plat numbers in **Figure 2**. Well descriptions appear in Appendix A.

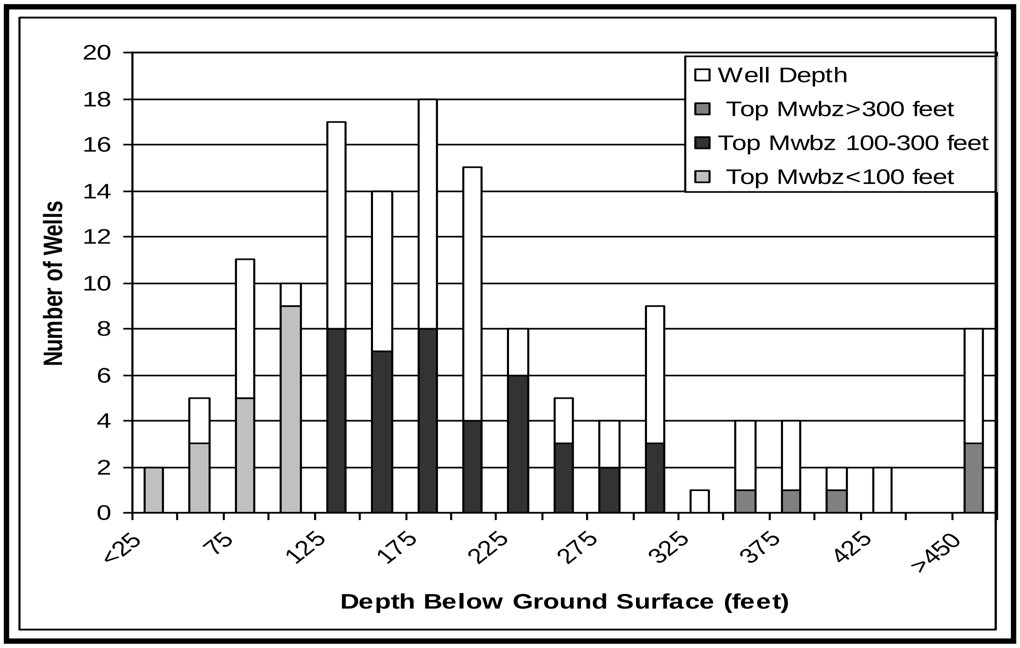

Figure 11. Depth Distribution of water wells in the vicinity of the Town of Star Valley Ranch. This histogram shows the distribution of completion depth of water wells and the distribution of depth to the top of the main water bearing zones (Mwbz). (data from Appendix A)

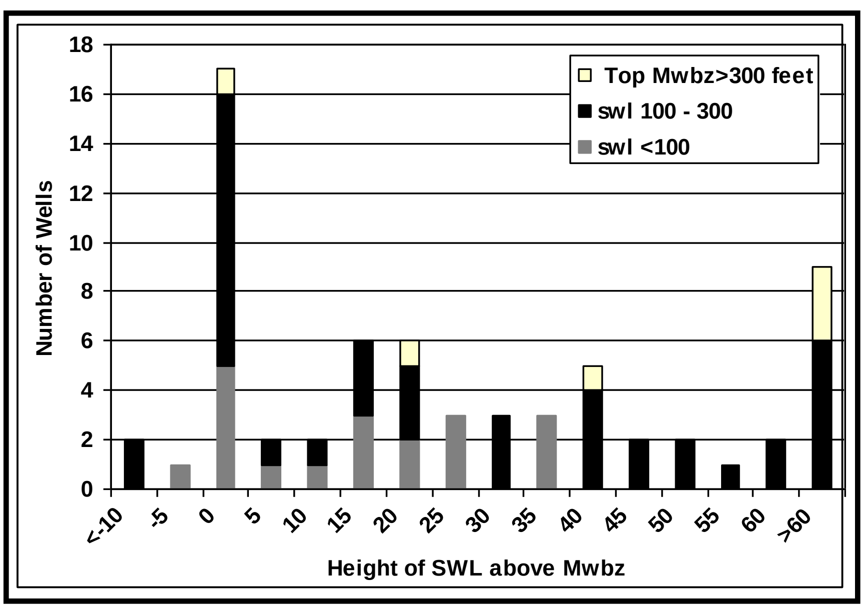

Figure 12. Height of static water level (swl) above the top of the main water-bearing zone (Mwbz) by Mwbz. The depth to the Mwbz was subtracted from the depth to swl to determine their relationship. A swl above the top of the Mwbz indicates that the water is under pressure and rising toward the surface; this condition is typical of a confined aquifer. When the swl is at or below the top of the Mwbz (zero or a negative value), the aquifer is unconfined. (Data from Appendix A)

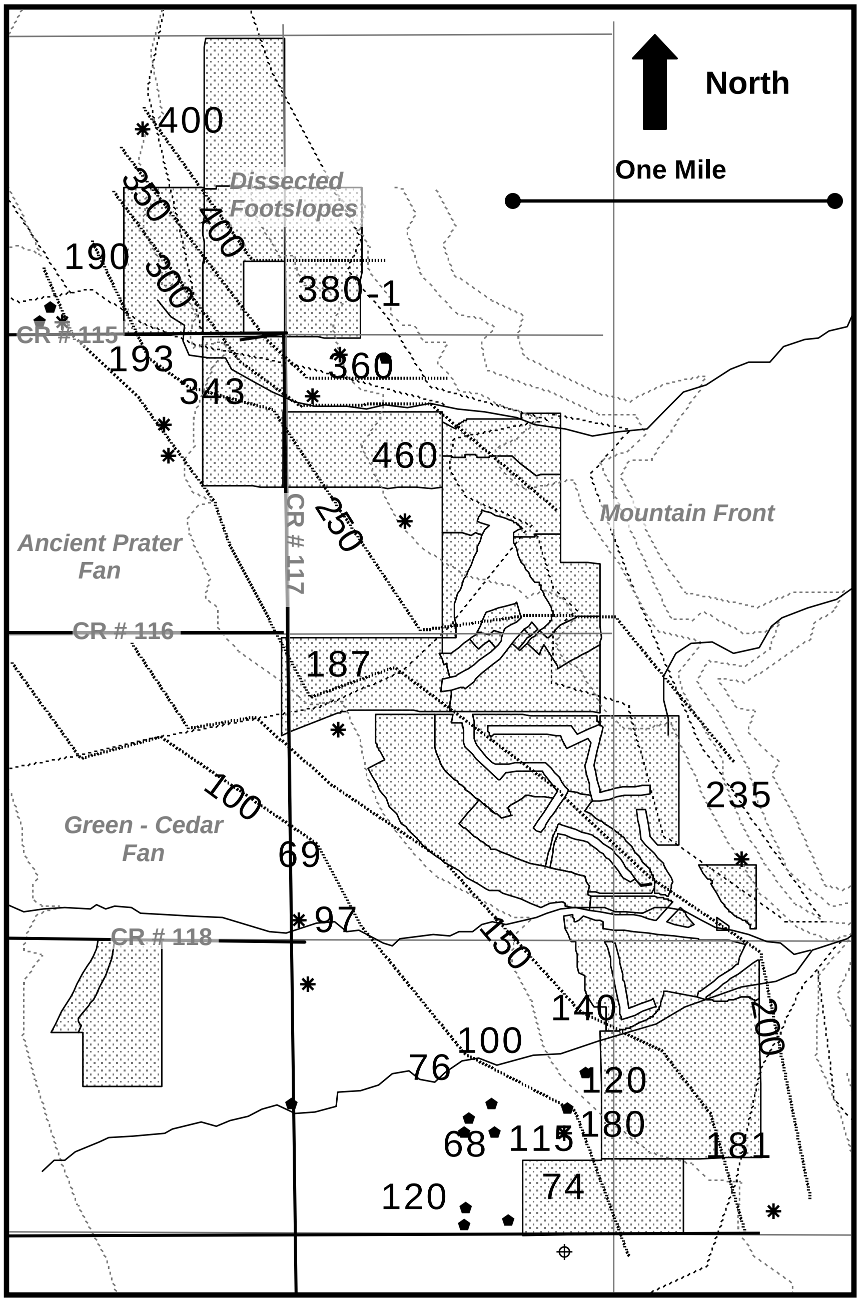

Figure 13. Depth to water. Contours of equal depth to static water level for wells screened in the Shallow Aquifer within 1200 feet of the Town. The lack of wells within the Town requires the extrapolation of depth data beneath the town. The irregular topography along the mountain front and the increase in elevation at the boundary between the Prater and Green-Cedar fans creates abrupt changes in depth to water.

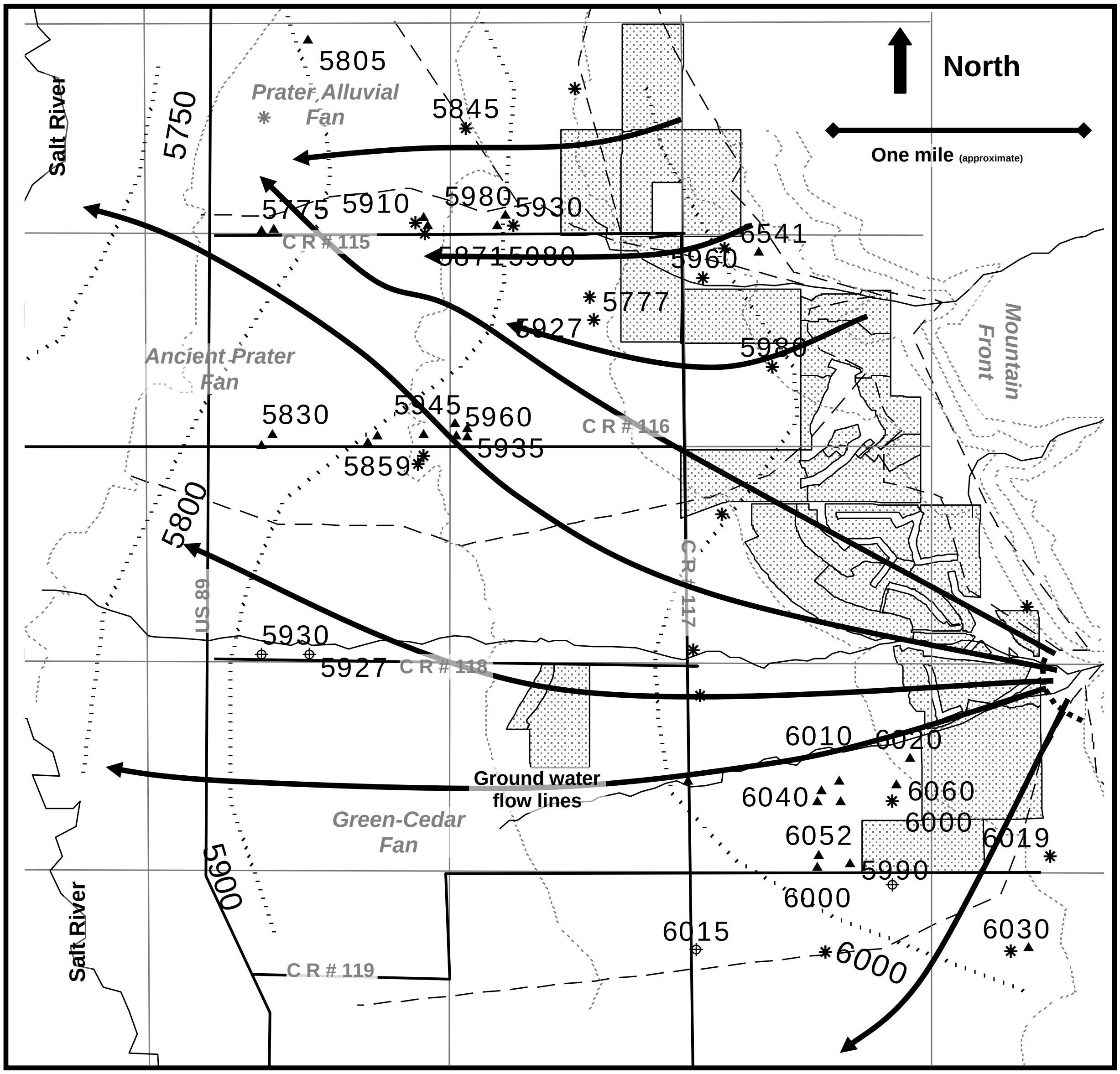

Figure 14. Potentiometric map of the shallow Aquifer. Approximation of the potentiometric surface (elevation to which water will rise in a well as shown by the equipotential lines or contours) and for the inferred elevation of the water table under the Salt River floodplain. The potentiometric surface tends to parallel the surface contours (light grey dotted) in the southern part of the map (south of CR# 118) under the Green-Cedar fan and to slope more steeply than the surface contours under the ancient Prater fan in the northern part of the map. The heavy lines are ground water flow lines drawn perpendicular to the contours.

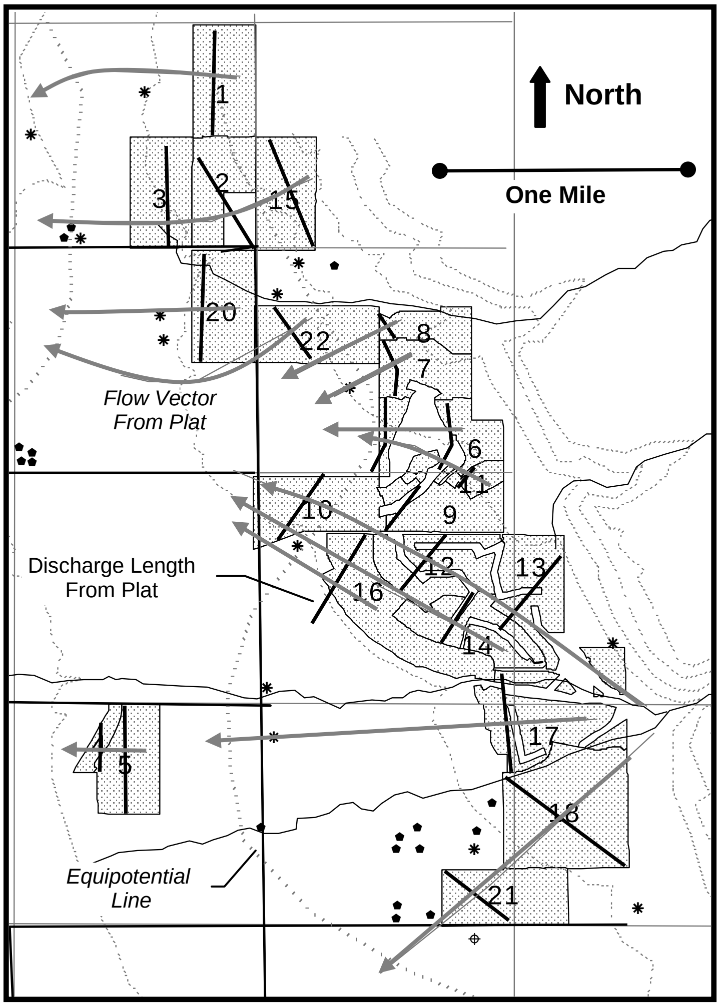

Figure 15. Discharge length for plats. The discharge length (heavy black line) is distance across which the aquifer underlying each plat discharges the contaminated ground water down gradient. The ground water vector is the direction in which the contaminated ground water flows upon crossing the plat boundary. It shows the down gradient plats affected by the increase in ambient nitrates and viral densities from the neighboring up gradient plats and thus the linkages between plats.

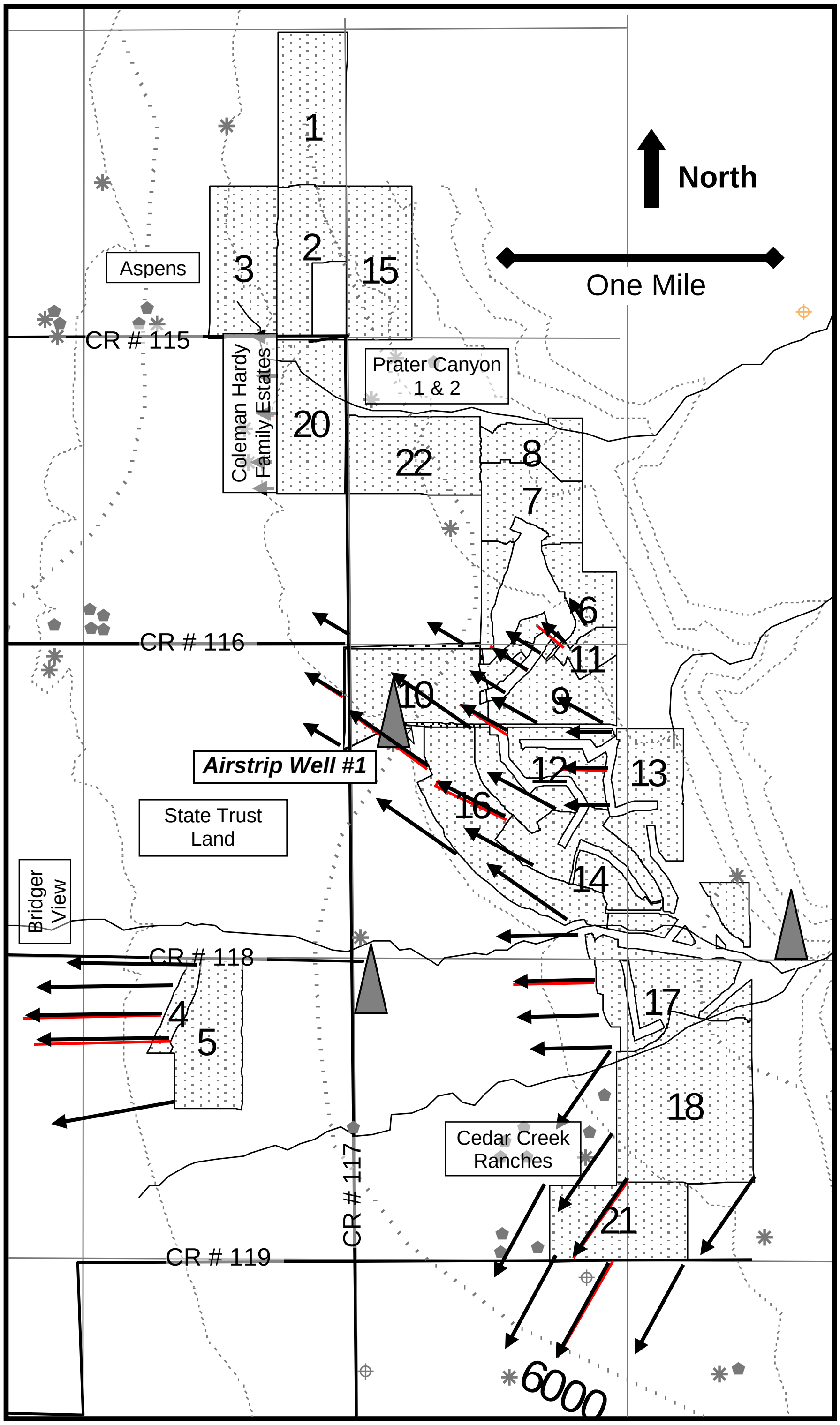

Figure 16. Potential water quality problems. Plat 10 will exceed EPA nitrate limits at 65 percent build out. The bold arrows represent viral travel routes and distances within the Shallow Aquifer. Water quality problems could develop in domestic wells southwest of Plats 18 and 21, west of Plats 4, 5 and 17 and the Airstrip Well #1 in Town if drawdown is high.

Appendix A
WELL RECORDS

Table A1. Records of wells in the vicinity of the Town of Star Valley Ranch.

Permit #	Status	Township (suffix N)	Range (suffix W)	Sect.	Qtrqtr	Facility Name	Uses	Yld Act	Well Depth	Static Depth	Mwbz Top	Mwbz Bottom	Well Log	Chemical Analysis
P30438W	GST	34	118	5	SWSE	RALON #1 WELL #1	DOM	16	287	181	220	287	Yes	No
P96310W	GST	34	118	6	SWNE	CIRCLE Y WELL #1	DOM	10	200	130	180	200	Yes	No
P92429W	UNA	34	118	6	SESE	JEWELL #1	DOM						No	
P89876W	GST	34	118	6	SWSE	DONOVAN WELL #1	DOM	25	157	120	133	158	Yes	No
P89402W	UNA	34	118	6	NWNW	STAR VALLEY RANCH RV PARK #1	MIS	300	400	97	260	400	Yes	No
P89331W	GST	34	118	6	SESE	JACKSON #1	DOM	25	170	130	150	170	Yes	No
P67838W	CAN	34	118	6	NWSE	COZAD #1	DOM						No	
P64444W	GST	34	118	6	SWSE	HANICH #1	DOM, STO	25	141	76	120	141	Yes	No
P48394W	CAN	34	118	6	NESE	DUGDALE # 1	DOM						No	
P47934W	GST	34	118	6	SENE	CHECKETTS #1	DOM	10	167	140	130	167	Yes	No
P39153W	GST	34	118	6	NWSW	TAG #1	DOM, STO	25	140	90	132	140	No	No
P173921W	GSI	34	118	6	SESW	TOMS 001	DOM						No	
P169291W	GSI	34	118	6	SWSE	BENZ #1	DOM						No	
P167456W	GSI	34	118	6	NESE	MUNGER #1	DOM						No	
P157310W	CAN	34	118	6	SWSE	BEWKES #2	DOM						No	
P156290W	GSI	34	118	6	SWSE	SONDGEROTH #1	DOM						No	
P154577W	GST	34	118	6	NWSE	TALOREK #1	DOM	25	180	100	160	180	Yes	No
P148790W	GST	34	118	6	NESE	HAILEY SPRING # 3	DOM	25	215	180	180	215	Yes	Yes
P146675W	GST	34	118	6	NESE	DICKSON # 1	DOM	20	180	120	120	180	Yes	No
P128700W	CAN	34	118	6	SWNE	BECK #1	DOM						No	
P126721W	GST	34	118	6	NWSE	BUSCH #1	DOM	25	170	115	115	170	Yes	No
P125323W	GST	34	118	6	NWSE	ADEE #1	DOM	17	160	120	120	140	Yes	No
P106315W	GST	34	118	6	SWSE	J.E. HUHTALA WELL #1	DOM	10	140	68	120	140	Yes	No
P83400W	ADJ	34	118	7	NWSW	ENL TITENSOR #2	IRR	250	105	22	55	105	Yes	No
P79356W		34	118	7	NWSW	ROOT #1	DOM	20	55	20	20	55	Yes	No
P76748W	ADJ	34	118	7	NWSW	TITENSOR #2	IRR	450	105	22	55	105	Yes	No
P70155W	GST	34	118	7	SWNW	HEBDON #2	DOM	10	50	30	Unknown	Unknown	Yes	No
P68110W	GST	34	118	7	NWSW	ROOT #1	DOM	8	52	23	36	52	Yes	No
P61114W	GST	34	118	7	NENE	SIMPSON #1	DOM, STO	10	94.5	74	65	94	Yes	No
P61107W	GST	34	118	7	SESE	HEINER #2	DOM	10	107	50	68	107	Yes	No
P56157W	GST	34	118	7	NWSW	TITENSOR #1	DOM	18	70	45	65	73	Yes	No
P52144W	GST	34	118	7	SWSW	PENDLETON #4	DOM, STO	20	67	25	50	66	No	No
P50169W	GST	34	118	7	SWSW	WARD #1	DOM	10	125	100	100	120	Yes	No
P3407P	GST	34	118	7	SWSW	PENDLETON #2	DOM, STO	10	60	25	Unknown	Unknown	No	No
P2649W	ADJ	34	118	7	SENE	PENDLETON #1	STO,IRR	1200	224	75	104	224	Yes	No
P96952W	GST	34	118	8	NESW	MORLEY WELL #1	DOM	10	180	140	155	180	Yes	No
P96907W	CAN	34	118	8	SWSE	KEITH #1	DOM, STO						No	
P96625W	GST	34	118	8	SWSE	CHERIE'S WELL #1	DOM	10	240	170	210	240	Yes	No
P58174W		34	118	8	NESE	MCADAM #1	STO, MIS,DOM	25	338	150	280	330	Yes	No
P57990W	GST	34	118	8	SENW	JORDAN #4	DOM	15	255	180	220	255	Yes	No
P53454W	GST	34	118	8	NESE	PHIL DOUGLAS #1	DOM	25	280	45	Unknown	Unknown	No	No
P46038W	GST	34	118	8	SESE	J F WAGNER #1	DOM	22	280	240	240	280	Yes	No
P39549W	ADJ	34	118	8	SESE	ENL LOST CREEK RANCHETTES SUB WELL #1	MON	0	344	219	219	344	Yes	No
P36811W	CAN	34	118	8	NESE	PHIL DOUGLASS #1	DOM	7	280	250	250	280	Yes	No
P22468W	ADJ	34	118	8	SESE	LOST CREEK RANCHETTES SUB WELL #1	MIS	45	344	219	219	344	Yes	No
P152215W	GST	34	118	8	NWSE	OK-1	DOM	25	260	180	240	260	Yes	No
P146971W	CAN	34	118	8	SESE	LCRWC	MIS						No	

P114473W	GST	34	118	8	SENW	FACTOR #1	DOM	10	192	130	160	190	Yes	No
P101533W	GST	34	118	8	NESW	LEAVITT #1	DOM	15	195	180	170	195	Yes	No
39/6/547W	UNA	34	118	8	NESW	VATALARO #1	DOM, STO						No	
P147759W	GST	35	118	30	NESW	SYLAR #1	DOM	25	540	460	500	540	Yes	No
P99744W	GST	35	118	30	NWNW	THE CANDRA DAY WELL #1	DOM	10	480	360	460	480	Yes	No
P99352W	CAN	35	118	30	SWSW	PRATER VIEW #1 TEST WELL	MON						No	
P94232W	GST	35	118	30	NWNW	ANDERSON #1	DOM, STO	25	480	380	380	Unknown	Yes	No
P93354W	CAN	35	118	30	NWNW	CHECKETTS #1	DOM						No	
P74009W	ABA	35	118	30	NENW	A CARLOS #1	DOM	0	136	-1	Unknown	Unknown	Yes	No
P6272W	CAN	35	118	30	NENW	HUMPHERYS #2	IRR,DOM						No	
P169303W	GSI	35	118	30	SWNW	HOWARD #1	DOM						No	
P90328W	UNA	35	118	31	SWNW	NORTH AIRSTRIP WELL	MIS	400	545	187	345	375	Yes	No
P137210W	UNA	35	118	31	SWSW	SVR RV PARK WELL # 2	MIS	325	360	69	300	360	Yes	No
P120239W	GSM	35	118	32	SESW	CEDAR #1	MIS	260	415	235	Unknown	Unknown	Yes	Yes
P92561W	GST	35	119	23	SESE	GRISSOM WELL #1	DOM	12	200	139	186	200	Yes	No
P71439W	GST	35	119	23	SESE	A & L ALLRED #1	DOM	10	190	164	168	190	Yes	No
P44054W	GST	35	119	23	SESW	RAINEY #1	DOM	18	148	115	130	148	Yes	No
P33872W	GST	35	119	23	SESE	HUMPHERYS #1	DOM, STO	25	170	150	150	170	No	No
P150308W	GSE	35	119	23	SWSW	WOLF DEN DRIVE INN # 1	STO, MIS	100	140	80	110	120	Yes	No
P140283W	GST	35	119	23	SESE	JASON # 1	DOM	15	200	100	195	200	Yes	No
P131807W	GST	35	119	23	NWNE	PETERSON # 1	DOM	15	180	155	155	180	Yes	No
P101183W	UNA	35	119	23	SWNW	MARTIN #1	MIS	150	312	65	Unknown	Unknown	Yes	No
P170152W	GSI	35	119	24	SESW	THE ASPENS #3	DOM						No	
P169472W	GSI	35	119	24	NENW	TAYLOR #1	DOM						No	
P159232W	GST	35	119	24	SESW	THE ASPENS #2	DOM	25	180	140	160	180	Yes	No
P149014W	GST	35	119	24	SESW	ROBERTS # 1	DOM	15	160	140	159	160	Yes	No
P145687W	GST	35	119	24	NWNE	GP #1	DOM, STO	5	664	400	663	664	Yes	No
P126915W	GST	35	119	24	SESW	E.D.R. WELL #1	DOM	18	300	190	280	300	Yes	No
P108223W	GST	35	119	24	SWNW	CRANF #1	DOM	22	300	125	253	300	Yes	No
39/6/61W	UNA	35	119	24	SESW	THE ASPENS #18	DOM						No	
39/5/61W	UNA	35	119	24	SESW	THE ASPENS #16	DOM						No	
P62071W	GST	35	119	25	SWSW	LD ROBERTS #2	DOM	10	112	80	85	112	Yes	No
P151810W	GST	35	119	25	SWNE	HARDY # 1	DOM	25	240	193	202	240	Yes	No
P151013W	GST	35	119	25	SWSW	FANCY #1	DOM	25	120	85	100	120	Yes	No
P150174W	GSM	35	119	25	SWSW	RAMBLIN HILLS # 1	MIS	33	118	90	97	118	Yes	No
P145094W	GST	35	119	25	SWSW	RAUTERKUS NO. 1	DOM	18	110	60	95	100	Yes	No
P140308W	GST	35	119	25	SENE	HUMPHREY # 1	DOM	25	420	343	360	420	Yes	No
P75214W	GST	35	119	26	SESW	JENKINS #1	DOM	8	150	120	120	150	Yes	No
P38826W	GST	35	119	26	SWSW	WARREN #1	STO	7	114	6	Unknown	Unknown	No	No
P32178W		35	119	26	SESE	ENL D. HOKANSON #1	IRR	500	175	78	78	175	Yes	No
P27470W		35	119	26	SESE	D HOKANSON #1	STO,IRR,DOM	25	175	78	78	175	Yes	No
P167420W	GSI	35	119	26	SWSE	CONGER #1	DOM, STO						No	
P150204W	GST	35	119	26	SWSE	DEVENY # 1	DOM	25	170	101	140	170	Yes	No
P89471W	CAN	35	119	35	NENE	FREEDOM #2 TEST WELL	MON	0	360	66.94	90	270	Yes	Yes
P45070W	GST	35	119	35	SWSW	JACKSON #3	DOM	15	65	20	35	60	Yes	No
P33873W	GST	35	119	35	SESW	JACKSON #1	DOM	15	48	23	23	48	Yes	No
P161381W	GSI	35	119	35	SENW	V.A. KRAMER WELL #1	DOM						No	
P101707W	UNA	35	119	35	NENE	FREEDOM #2	MUN, MIS	400	360	67	90	270	Yes	Yes

Appendix B
CHAPTER 23, APPENDICES A and B

Appendix A

Cumulative Nitrate Loading Analysis

In order to calculate the nitrate concentration from multiple septic systems at the downgradient property boundary of the proposed subdivision the following nitrogen mass balance equation (Wehrmann Model) is used. If C_o exceeds 10 mg/L NO_3^- as N, WDEQ recommend to the County Commission that the subdivision not be approved unless modified to achieve the standards within this chapter.

$$C_o = V_bC_b + V_iC_i + V_sC_s - V_pC_p / (V_b + V_i + V_s - V_p)$$

Where:

C_o = diluted concentration of NO_3^- as N leaving the subdivision
V_b = volume of ground water entering the subdivision from upgradient area
C_b = ambient concentration of NO_3^- as N contained in the ground water entering the subdivision
V_i = volume of precipitation infiltrating beneath the subdivision
C_i = concentration of NO_3^- as N contained in the infiltrating precipitation
V_s = volume of septic effluent introduced beneath the subdivision
C_s = concentration of NO_3^- as N contained in the septic effluent (assume 40 mg/L for conventional septic systems, and manufacturer specifications (mg/L) for enhanced treatment systems)
V_p = volume of ground water pumped by wells beneath the subdivision (use only if same aquifer as V_s)
C_p = concentration of nitrate-nitrogen contained in the pumped ground water

Source: Wehrmann, H.A. 1984. Managing Ground Water Nitrate Quality by Mass Balance Modeling in the Rockton-Roscoe Area, Illinois. In *Proceedings of the NWWA Eastern Regional Conference on Ground Water Management*, National Water Well Association, Dublin, Ohio, pp. 558-587.

Appendix B

Minimum Isolation Distance Analysis

VERTICAL TRAVEL TIME CALCULATION:

The following equation is used to determine the vertical travel time (t_1) from the leach field to the water table:

Given: $t_1 = d * \theta \div 0.5(\alpha)$

Where:

t_1 = vertical travel time (years)
α is total recharge (effluent + precipitation in cm/yr)
θ is volumetric soil moisture in a sandy clay (mL/cm^3)
d is the depth to groundwater (cm)
0.5 is the infiltration factor (assumes 50% of precipitation will infiltrate the soil)

(Note: α, **θ**, and **d** will change from site to site.)

Example calculation of α:

Assuming that 100 gallons per day of wastewater will be generated per bedroom, a typical 3 bedroom house is expected to discharge an average of 300 gallons per day.

Total yearly effluent discharge = 300 gallons/day * 365 days/year * 1 ft^3/7.48 gallons
= 14,639 ft^3

Next, calculate the required soil absorption surface area (square feet) by referencing Figure 7 of Chapter 11, Part D, Section 38 (a) of Water Quality Rules and Regulations. The sizing of a leach field is dependant upon the soil percolation rate and the average daily effluent discharge. For this example use the median soil percolation rate of 15 minutes per inch. Also, use the previously calculated 300 gallons per day effluent discharge per house.

Required soil absorption infiltrative area = 300 gallons/day * 1ft^2 day/0.52 gallons = 577 ft^2

Next, calculate the pro-rated inches per year of effluent recharge to the aquifer:

14,639 ft^3 * (577 ft^2)-1 = 25.4 ft * 12 inches/ft = 304 inches/year

To obtain TOTAL average annual recharge to the aquifer (effluent + precipitation) add the average annual precipitation for the area (15 inches/year) to the pro-rated effluent recharge, which equates to 319 inches/year or 810 cm/year (α). Note the average annual precipitation for an area can be obtained from Chapter 17, Wyoming Water Quality Rules and Regulations (Figure 2) or from the USDA. National Resources Conservation Service.

Volumetric Soil Moisture Content at Field Capacity

Soil Type	**Volumetric Soil Moisture Content @ Field Capacity, θ, mL/cm^3**
Cobble sand	0.045
Sand	0.062
Sandy loam	0.190
Loam	0.232
Silty loam	0.284
Sandy clay loam	0.244
Clay loam	0.310
Silty clay loam	0.342
Sandy clay	0.321 (default)
Silty clay	0.371
Clay	0.378

* Source: WDEQ Water Quality Rules and Regulations, Chapter 17

Appendix C
WDEQ Spreadsheets
for Chapter 23 Calculations

Appendix A, Chapter 23, Cumulative Nitrate Loading Analysis

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WYDEQ Spreadsheet

(Vi) gpd	Length (ft)	Width (ft)	Infiltration (ft/day)				L & W (ft)	Gross Acres
6,256	1,616.7	1,616.7	3.20E-04				1,616.7	60.0
(Vs) gpd	**# Bedrooms**	**gpd/lot**	**# Lots**					
5,600	2.0	200.0	28.0					
(Vb) gpd	**K (ft/day)**	**i (ft/ft)**	**A (ft^2)**		**L (ft)**	**b (ft)**		
5,135	7.0	0.00700	14,010		467.0	30.0		
(Vp) gpd	**gpd/Lot**	**# Lots**	**Lawn Irr. (acres)**	**Same Aquifer? Y=1; N=0**				
0	0	28.0	25.00	0.0				

NOTE: Enter data into RED boxes ONLY!

Note: Vp > 0 only if pumping from same aquifer zone as Vs receptor aquifer zone; otherwise Vp = 0

Lawn irrigation assumes net 18 gallons/ft^2/year for bluegrass (Source: NRCS, Laramie County)

WEHRMANN NITRATE MODEL

Co (mg/L)	(Vi) Vol of Infiltration (gpd)	(Ci) Infiltration (mg/L)	(Vs) Vol of Leach Fields (gpd)	(Cs) Leach Nitrate (mg/L)	(Vb) Vol of Ambient Subdivision (gpd)	(Cb) Ambient Nitrate (mg/L)	(Vp) Wells pumped (gpd)	(Cp) Well Nitrates (mg/L)
13.4	6,256	0.05	5,600	40.0	5,135	0.5	0	2.0
	13.4							

Co = ViCi + VsCs + VbCb - VpCp / (Vi + Vs + Vb - Vp)

Helpful Conversions:

liters	ft^3	gallons
722,746.0	25,561.9	191,202.6

ft^3	liters	gallons
1.0	28.3	7.5

gallons	liters	ft^3
1,930.0	7,295.4	258.0

T(gal/day/ft)	ft^2/day
897.0	119.9

T(ft^2/day)	gal/day/ft
119.9	896.9

K(gal/day/ft^2)	ft/day
40.00	5.360

K(ft/day)	gal/day/ft^2
5.00	37.313

T(ft^2/day)	K(ft/day)	b(ft)
150	5	30

Appendix B, Chapter 23, Minimum Isolation Distance Analysis

Calculating the vertical travel time (VT) in the vadose zone (bacteria & virus die-off analysis)

(Modified from Wyoming Department of Environmental Quality, Chapter 17)

VT = d[TH]/0.5(AP)(1 mL/cm^3) Note: (0.5 * AP) assumes 50% infiltrates and 50% lost to evaporation/evapotranspiration

Instructions: Enter data in blue boxes (ONLY)

			(100 gpd/bedroom x 3 bedrooms)
ENTER AP (precipitation + pro-rated leach field infiltration)	**319**	inches/year	300 gpd = 304"/year
ENTER TH (volumetric soil moisture obtained from Table 1)	**0.321**	mL/cm^3	
ENTER d (depth to seasonal high groundwater beneath leach field)	**100**	feet	Must be 4 feet minimum

(Metric conversions - do not alter)		
AP	810	cm/yr
d	3038	cm

Note: **AP** changes throughout the State, **d** and **TH** change from site to site.
One must multiply denominator by 1 mL/cm^3 to cancel TH units

VT (vertical travel time in vadose zone) =	**2.407**	**years**
VT (vertical travel time in vadose zone) =	**879**	**days**

Calculating the horizontal travel time distance (HD) in the groundwater

(Fetter, C.W. 1994. Applied Hydrogeology, 3rd ed, Prentice Hall, New Jersey, 691 pp.)

HD =((730-(VT*365)))(Ki/n)

ENTER K (horizontal hydraulic conductivity)	**5**	feet/day
ENTER i (gradient)	**0.0076**	feet/feet
ENTER n (effective porosity)	**0.2**	
VT (vertical travel time)	879	days *(calculated from VT)*
HD (2 year horizontal travel time distance)	-28	feet
HD (2 year horizontal travel time distance)	**0**	**feet *(compensates for VT > 2 years)***

(If HD is less than 100 feet, use 100 feet)

Table 1 (Volumetric Soil Moisture Content at Field Capacity (TH) *)

Soil Type	***mL/cm^3***
Cobble sand	0.045
Sand	0.062
Sandy loam	0.19
Loam	0.232
Silty loam	0.284
Sandy clay loam	0.244
Clay loam	0.31
Silty clay loam	0.342
Sandy clay	0.321
Silty clay	0.371
Clay	0.378

** Wyoming Department of Environmental Quality, Chapter 17*

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