PHASE II – LARAMIE MONITOR WELL PROJECT REPORT

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North Well at Imperial Heights Park

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Chapter 1 – Introduction

The City Monitor Well Program (CMWP) is an on-going long-term effort by the City of Laramie to install monitor wells in the Casper Aquifer as recommended in the 2008 Casper Aquifer Protection Plan (CAPP). The Laramie Monitor Well Project is the City's initial efforts to develop the monitor well network. The City hired Hinckley Consulting and Wyoming Groundwater to assist in the development and execution of a monitor well installation program. The work was performed in two phases with documentation provided to the City at the end of each phase.

Phase I – Drilling Program Development

On October 15, 2014, the consultants submitted the Phase I Report that provides an overview of the objectives of the CMWP, the hydrogeology of the Casper Aquifer, and recommendations for monitor well siting, drilling, sampling, and testing. To make this Phase II report a stand alone document, the Phase I Report is provided as Appendix 1 of this report.

This project begins a program of consistent, focused groundwater monitoring to better define the occurrence and movement of potential contaminants in the Casper Aquifer in the area that contributes groundwater to the City of Laramie municipal water supply wells. Specific objectives of the Laramie Monitor Well Project are:

- Install monitor wells upgradient of the Turner Wellfield that provide water quality data representative of groundwater that flows towards the wellfield.
- Install a monitor well on City property downgradient from the East Grand Avenue county subdivisions to assess their potential impacts to aquifer water quality.
- Evaluate the hydraulic characteristics of the Sherman Hills Fault by construction and testing of wells on opposite sides of the fault.
- Install a production well that can be used to irrigate Imperial Heights Park.

Phase II – Monitor Well Installation and Testing

This Phase II report presents the results of monitor well installation and testing with a discussion of the hydrogeology of the Casper Aquifer. Figure 1-1 shows the location of monitor wells installed on City-owned property at the Triangle site and at Imperial Heights Park. One monitor well was installed at the Triangle site. Two monitor wells and one temporary borehole were installed at the Imperial Heights Park site. As of this writing, the monitor well permanent completions await final investigations and design decisions. Recommendations for final well completion are provided in Chapter 6 of this report.

The report is organized as follows:

- Chapter 2: Monitor Well Drilling and Field Data
- Chapter 3: Groundwater Quality
- Chapter 4: Aquifer Testing
- Chapter 5: Groundwater Flow in the Casper Aquifer

- Chapter 6: Monitoring Recommendations

General Hydrogeology

This report describes a detailed hydrogeologic study that included three monitor wells that achieve the objectives of the CMWP and this project. A substantial amount of hydrogeologic data was collected and analyzed in the course of this project. The results provide a significant advancement in understanding the Casper Aquifer permeability and groundwater flow characteristics which in turn will better guide further development of the CMWP. The following narrative provides the reader basic background information on the Casper Aquifer in the project area. (See the Phase I report for additional background, including the history of aquifer protection activities.)

The Casper Aquifer consists of the saturated portion of the Casper Formation. The Casper Formation is approximately 700 feet thick and consists of porous sandstone layers sandwiched between low-permeability limestone layers. The formation is exposed at Imperial Heights Park and on the foothills and west flank of the Laramie Range east of the City.

To facilitate stratigraphic discussion, previous investigators have divided the sandstone/limestone sequences of the Casper Formation into informal members, from top to bottom: epsilon, delta, gamma, beta, and alpha (Lundy, 1978). Except for the epsilon, each member is capped by a laterally continuous limestone layer. Table 1-1 summarizes the stratigraphy of the project area with special emphasis on the water-bearing layers of the Casper Formation. Lithologic descriptions are condensed from Ver Ploeg (2009) with modifications to reflect local City wells and data from this project. Individual sandstone and limestone beds within some of these members were evaluated under the present project.

Stratigraphic features such as bedding planes and structural features such as faults and folds commonly have fractures that enhance the original permeability of sandstone and limestone. Bedding planes are ubiquitous in the aquifer whereas faults and folds occur at specific locations as identified on geologic maps (e.g. Lundy, 1978; Ver Ploeg, 2009).

Figure 1-2 is a simplified schematic west-east cross-section through the project area, between the Quarry and Sherman Hills faults. The figure illustrates the basic subsurface stratigraphy, the westward dip of the formations, and the relative locations and depths of the wells associated with this project. The figure also shows the stratigraphic location of the East Grand Avenue city and county subdivisions, and the area beneath which the Casper Aquifer is confined by the overlying Satanka Formation.

The Triangle site is not located on a mapped geologic feature but is located south of the Quarry Fault and north of the Sherman Hills Fault zone. At Imperial Heights Park, however, the east-west trending Sherman Hills Fault zone runs through the center of the site. The location and orientation of the fault zone was refined by near-surface geophysical investigations performed by the University of Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG). As discussed in the Phase I report, the fault is a high angle reverse fault, up on the north and down on the south, and the geophysics indicated up to 60 feet of vertical displacement. The geophysical investigation suggests disrupted strata (i.e. a fault zone rather than a single plane) south of the main trace of the fault.

In the area of the Triangle and Imperial Heights Park sites, groundwater flow in the Casper Aquifer is to the northwest, towards discharge points associated with City Springs and the Turner Wellfield. The hydraulic role of the Sherman Hills Fault has been an issue with respect to the flow of groundwater with elevated nitrate concentrations from the East Grand Avenue subdivisions towards the City water supply wells at City Springs. The presence of elevated nitrate from the subdivisions and the hydraulic role of the Sherman Hills Fault are addressed rigorously in this project.

Acknowledgement

Dr. Brad Carr of WyCEHG donated considerable time, equipment, and effort during this project. The near-surface geophysical surveys at the front-end of the project guided us towards more reliable well locations. The downhole geophysical logs performed at the monitor wells and the temporary borehole provided high-quality data on aquifer characteristics that supplement and substantiate field data collected during drilling and testing. His efforts are much appreciated by the City and project consultants.

Chapter 2 – Monitor Well Drilling and Field Data

This chapter describes the methods used and hydrogeologic data collected during drilling and the basic interpretation of the data. This information provides a detailed geologic framework and context for subsequent chapters on groundwater-quality, aquifer testing, and groundwater flow in the Casper Aquifer.

Drilling Contractor and On-Site Professional Services

Via a public bid and selection process, G & J Drilling (dba Watson Well Service) contracted with the City to drill and test three monitor wells in the Casper Aquifer at the Triangle and Imperial Heights Park sites. During the project, a change order was executed to install an additional, temporary borehole at the Imperial Heights Park site.

On-site professional services were provided by Chris Moody of Wyoming Groundwater and Bern Hinckley of Hinckley Consulting. Mr. Moody and Mr. Hinckley are Wyoming licensed professional geologists and were contracted with the City to supervise well drilling/testing and to collect/interpret hydrogeologic data from drilling and testing activities.

Permits

Monitor wells and temporary boreholes are not required to be permitted by the State Engineer's Office (SEO). Regardless, it is our opinion that information obtained from the monitor wells should be part of the public record, so well permits were obtained for the monitor wells, with Statements of Completion to be submitted for the public record upon final well completion. Copies of approved well permit applications (U.W. 5) are in Appendix 3. The Statements of Completion (U.W. 6) for each well are not included because the monitor wells have not yet been constructed per final design. This Phase II report provides a recommended design for final construction of each monitor well.

A permit was obtained from the Wyoming Department of Environmental Quality that authorized the discharge of water associated with pump tests and well development (#WYG720363; attached in Appendix 3). Water sampling and reporting were performed per terms of the permit.

Drilling and Data Collection Methods

Air-rotary and air-percussion hammer methods were used to drill the monitor wells. These methods utilize the injection of a high pressure mixture of air and water (i.e. the drilling fluid) through the drill bit, which cools the bit and lifts cuttings out of the borehole. The source of injected water was City water from a local fire hydrant. When water-saturated rock is encountered, groundwater that is flowing out of the borehole sidewall will be lifted to the surface. In general, the amount of water air-lifted out of the borehole is directly related to the permeability of the aquifer.

The injection of water that is part of the air-water drilling fluid can be temporarily shut-off such that one can then observe and estimate the amount of groundwater that is being air-lifted out of the hole. Successive observations of air-lift water production as drilling proceeds allows the on-site geologist to determine the occurrence, depth, and relative contribution of water producing zones. Extended periods of air-lift allow the removal of residual drilling fluid and the subsequent collection of water samples that are representative of groundwater that has flowed into the borehole from the aquifer. After an extended period of air-lift followed by the termination of air injection, the drill pipe was tripped out of the hole and the gradual rise of water level in the well was measured using a sounder. These air-lift "recovery" tests were performed at each monitor well to provide preliminary estimates of aquifer productivity. At specific drilled depths in each well, the on-site geologist documented visual and/or measured (i.e. bucket timings) estimates of water production, collected water samples, and obtained recovery and near-stable water level data.

Cuttings are rock broken up and pulverized by the bit and air-lifted out of the borehole. Because the monitor wells are relatively shallow (i.e. maximum depth of 163 feet), there was negligible lag time between when the cuttings were generated at the bit and their arrival at the surface. Cuttings were examined as drilling proceeded, and collected in sample bags at 10-foot intervals.

Observations of drill rig behavior such as fast/slow drilling rate and intervals of smooth-quiet versus jumpy-chatter are important indicators of lithology changes (e.g. sandstone/limestone/shale), fractured rock, and potential zones of high permeability and water production.

During this project, a condition referred to as "lost circulation" occurred at two of the monitor wells. To advance a borehole effectively, the drilling fluid (air-water) must be able to circulate up the borehole to remove cuttings. When high permeability features are encountered, such as open fractures or cavities, the path of least resistance for the drilling fluid may be back into the formation rather than up the borehole. Air, water, and cuttings no longer come to the surface and, instead, are forced back into the high permeability feature. Without the ability to observe cuttings and water production, the only field indicator of down-hole conditions during lost circulation is drilling behavior. Lost circulation in the unsaturated zone is especially problematic because the zone captures all subsequent water production, whereas lost circulation in the saturated zone commonly indicates the potential for abundant water production.

In addition to observations of drilling and water-production characteristics, water levels were measured as drilling proceeded into the aquifer. For example, when water production from the borehole was first indicated by air-lift, the borehole was air-lifted to remove downhole water and drilling fluid, the drill pipe tripped out of the hole, and a water level sounder lowered into the hole to determine whether or not groundwater was flowing into and filling the bottom of the hole. If groundwater was present, water level measurements continued until a near-stable water level was achieved. These water level measurements (head) were used to investigate the hydraulic relationship between the water-bearing sandstones of the Casper Aquifer.

The water quality field parameters pH, conductivity, and temperature of air-lift samples were measured using an Oakton pH/CON 10 Series meter. The same conductivity meter was used throughout the project to ensure comparability of results. A comparison of conductivity values with depth in a well and between wells indicates potential water quality changes within and between wells that were verified later by water samples analyzed by a laboratory.

Observations of drill rig behavior, cuttings, air-lift water production, lost circulation, water levels, and water quality provide the field data used to interpret borehole conditions and hydrogeology. Additional technical data are provided by geophysical logs run in each monitor well and the temporary borehole following drilling. Geophysical logs created by WyCEHG consisted of caliper, natural gamma, resistivity, borehole fluid temperature, borehole conductivity, acoustic and optical images, and spinner (Appendix 5). The correlation of field observations with the geophysical logs provides a robust interpretation of hydrogeology and borehole conditions at each well.

Well Data Table and Diagrams

Well stratigraphy, water levels, water production zones, and water quality data from each well are summarized in Table 2-1 and shown graphically on Figures 2-1 to 2-4. In this chapter, the narratives of each well focus on the hydrostratigraphy, air-lift water production with depth, and unique observations of drilling behavior and geophysical logs. Subsequent chapters will present groundwater-quality and pumping test data and a discussion of groundwater flow in the Casper Aquifer in the project area.

Triangle Site

One monitor well (Triangle Well) was installed at the Triangle site (Figure 1-1) to provide water quality data upgradient of the Turner Wellfield and at a substantial distance downgradient of areas with known impacts to Casper Aquifer water quality. The Triangle Well will serve to identify the occurrence of groundwater contaminants prior to reaching the Turner Wellfield.

The Triangle Well is located on the south side of East Grand Avenue and the east side of the Wal-Mart parking lot, between the Quarry Fault to the north and the Sherman Hills Fault to the south. The well is not located on a mapped structural feature. As shown on Figure 2-1, the bottom of the Satanka Shale is at 29 feet and the well penetrates the epsilon member and most of the delta member of the Casper Formation.

The thickness of the epsilon sandstone at the Triangle Well is 62.5 feet which is similar to the 63 to 64 feet of epsilon sandstone documented at the LCCC campus wells 0.46 miles to the west (Wyoming Groundwater, 2006; Figure 1-1). The upper 26 feet of the epsilon sandstone is unsaturated at the Triangle Well. Air-lift water production from the saturated part of the epsilon member from 55 to 91 feet was approximately 40 to 50 gpm. A noticeable increase in water production occurred while drilling 85 to 90 feet and is probably due to fractures at 81 and 84 feet as indicated on the acoustic image and caliper logs. The spinner log indicates that the fracture at 84 feet is especially permeable.

At 92 feet, drilling was stopped and the water level in the epsilon sandstone was allowed to recover (i.e. rise) to a near-stable level. The depth to water was 60.2 feet relative to the top of casing. Drilling continued through the delta limestone-1 and delta sandstone-1 to 126 feet where air-lift was stopped and groundwater allowed to recover to a near-stable level. The depth to water at 126 feet with the borehole open to both the epsilon and delta was 55.5 feet. The head in the delta sandstone-1 is at least 4 feet higher than the head in the overlying epsilon sandstone. Drilling behavior, air-lift water production, and geophysical logs do not indicate permeable features in the delta limestone-1. At this location, the delta limestone-1 appears to provide hydraulic separation between the epsilon sandstone and delta sandstone-1.

Delta sandstone-1 occurs from 99 to 124 feet with noticeable increases in air-lift water production at 102 feet and from 116 to 124 feet. Immediately beneath the delta limestone-1 at 100 feet, there was a slight drill bit drop and prominent horizontal fractures are seen in the acoustic and optical image logs. The caliper log indicates an enlarged borehole diameter at 100 feet. Air-lift water production at 102 feet was approximately 80 gpm. A sudden and significant increase in air-lift water production occurred at 124 feet; again, where horizontal fractures are indicated by the acoustic and optical image, caliper, and spinner logs. Bedding plane fractures and increased air-lift water production occurs at the top and bottom of the delta sandstone-1, immediately underlying/overlying the adjacent delta limestones-1 and -2.

As drilling proceeded through the delta limestone-2, air-lift water production from the delta sandstone-1 flooded the drilling area and visual estimates of water production were not possible. After drilling through 13 feet of the delta sandstone-2 to the total well depth of 156.6 feet, air-lift water production was estimated to be 380 gpm or more. This production estimate is based on the capacity and efficiency of the trash pump used to keep the cuttings pit from overflowing while drilling.

Although unusual drilling behavior was not noted while drilling the last five feet of borehole, the acoustic and optical image logs indicate large horizontal fractures from 151 to 154 feet in the upper part of the delta sandstone-2. The caliper log indicates a substantial increase in borehole diameter in this interval. These fractures are probably highly productive; however, the relative contribution and/or production potential could not be assessed because of the volume of water being air-lifted out of the well from up-hole.

The spinner log indicates noticeable groundwater flow within the borehole at 84 and 124 feet which correlate with depths of noticeable increases in air-lift water production. At the end of drilling and air-lift activities, the near-stable water level was measured at 55.5 feet which is identical to the water level measured at a drilled depth of 124 feet, and suggests a similar head in the delta sandstone-1 and -2, and a noticeably higher head in the delta sandstones than in the overlying epsilon sandstone.

The Triangle Well provides important insights regarding the permeability characteristics of the Casper Aquifer:

- High permeability features and associated large water production can occur in areas that are not located on or adjacent to mapped geologic structures. High permeability can occur anywhere in the Casper Aquifer and, to coin a phrase, is where you find it.

- High permeability features at this location are horizontal fractures in sandstone that produce significant amounts of groundwater.
- Significant fracturing and observable groundwater production were not encountered in the limestone.
- As indicated by the head difference between the epsilon and delta sandstones, vertical fractures that cut through the delta limestone-1 are absent at this location.

The term "horizontal fracture" will be used often in this report and requires some clarification. The acoustic and optical image logs show distinct horizontal to sub-horizontal dark bands around the borehole indicative of open fractures. The fractures are not vertical or sub-vertical in orientation. At the scale of the borehole, these are horizontal features; however, on a large scale, these planar features probably dip gently to the west with the stratigraphy. This interpretation is guided by the observation that many of the productive fractures occur at sandstone/limestone contacts (e.g. 100 and 124 feet) such that the fractures are related to bedding planes (i.e. planes that separate individual layers, beds, or strata). Bedding plane fractures also occur within the sandstone units (e.g. 84 and 151 to 154 feet). As will be shown in the sections to follow, fracture characteristics seen at the Triangle Well were also observed at the North and South wells.

Imperial Heights Park Site

Two monitor wells and one temporary borehole were installed at Imperial Heights Park (Figure 1-1). The park is currently undeveloped and is located at the south edge of the Imperial Heights subdivision and at the northwest corner of the Sherman Hills subdivision. The Imperial Heights subdivision is within the City corporate limits and is served by City water and sewer. Sherman Hills is a rural (Albany County) residential subdivision with individual domestic water wells and wastewater disposal systems (i.e. septic tank and leachfield). As described in the Phase I report, the Sherman Hills Fault trends east-west through the approximate center of the park.

There were several objectives associated with well installation and testing at Imperial Heights Park. One objective was to install a monitor well (i.e. South Well) on City property downgradient from portions of the Sherman Hills subdivision to assess potential impacts to groundwater-quality from upgradient septic systems. A second objective was to evaluate the hydraulic characteristics of the Sherman Hills Fault using wells installed on the north and south sides of the fault (i.e. North and South wells, respectively). A third objective was to install a production well that can be used to irrigate the park (i.e. North Well)

<u>North Well</u>

At the North Well, the stratigraphic sequence from 13.5 to 87 feet consists of unsaturated epsilon sandstone, delta limestone-1, delta sandstone-1, delta limestone-2, and the upper 4 feet of delta sandstone-2 (Figure 2-2). The thicknesses of the delta sandstone/limestone units are similar to thicknesses observed at the Triangle Well (Figure 2-1). An interval of rapid drilling occurred from 47 to 49 feet in the central part of the delta sandstone-1 which correlates with an enlarged borehole per the caliper log.

From 82 to 84 feet, immediately beneath the delta limestone-2, the delta sandstone-2 drilled very fast (bit drop) and large sandstone rock fragments were observed in the cuttings. Lost circulation occurred temporarily at 84 feet and was regained to a limited degree while drilling from 84 to 124 feet. Very soft and fast drilling occurred from 108 to 110 feet. Air-lift water production at 117.5 feet was approximately 40 to 45 gpm; however, water production declined during air-lift, suggesting the loss of water into the formation. At 124 feet, lost circulation occurred again and could not be regained.

In the delta sandstone-2, the geophysical logs indicate horizontal fractures and a cavity (?) in the 82 to 90 feet interval, and horizontal fractures from 107 to 110 feet. The spinner log indicates a particularly productive fracture at 108 feet. Specific fracture zones are noted on the well diagram (Figure 2-2). It appeared likely that the zone primarily responsible for lost circulation was the fractures in the unsaturated zone immediately above the water-table.

Continuing to drill under lost circulation conditions would compromise drilling efforts, data collection, and well construction. Consequently, a spot-plug of neat cement was installed in the fractured interval of 82 to 90 feet. Pea gravel was installed in the bottom of the wellbore from 91 to 124 feet, chip bentonite from 90 to 91 feet, and 20 sacks of neat cement was tremmied on top of the bentonite. After 35 hours cure time, the top of the cement was tagged at 80.5 feet and the cement in the wellbore (i.e. 80.5 to 90 feet) and underlying pea gravel were drilled out. The large volume of cement (24 ft^3) needed to plug a 9.5-foot interval reflects the large permeability associated with the fractures in this interval. The cement plug can be seen in the optical image log on Figure 2-2. The cement plug held and lost circulation conditions did not occur again during drilling.

With circulation re-established, an air-lift test was conducted at 124 feet to estimate water production and to measure the water level in the delta sandstone-2. Air-lift water production was approximately 60 gpm and the near-stable water level was 90.5 feet relative to the top of casing. The water level indicates that the upper 8 feet of delta sandstone-2 is unsaturated.

Gamma limestone-1 occurs from 117.5 to 131 feet with an interval at 126 feet that appeared to make some water from a sandy interbed or possible fracture. Air-lift water production from 131 feet was approximately 92 gpm.

Gamma sandstone-1 occurs from 131 feet to the total depth of the well at 160 feet. At 135 feet, air-lift water production suddenly increased and cuttings included sandstone fragments. Acoustic and optical image logs indicate a prominent horizontal fracture at 137 feet, and the spinner log indicates a particularly productive fracture at 134 feet. At 160 feet, a visual estimate of air-lift water production was 250 to 300 gpm. The fractures in the gamma sandstone at 134 and 138 feet are the primary water production feature in the well. Like the Triangle Well, high permeability features in the North Well are horizontal fractures within sandstone units and at or near sandstone/limestone contacts.

Water level measurements from the delta sandstone-2 and from the combined delta sandstone-2 and gamma sandstone-1 indicate similar heads in these two sandstone units (Table 2-1). At this location, the gamma limestone-1 may not provide significant hydraulic separation between the delta and gamma sandstones.

Middle Borehole (Temporary)

Whereas the North and South wells are located on either side of the Sherman Hills Fault, the Middle Borehole is located within the fault zone. The Middle Borehole was added to the drilling program to obtain information on aquifer characteristics within the fault zone.

At the Middle Borehole, the stratigraphic sequence from 17 to 88 feet consists of unsaturated epsilon sandstone, delta limestone-1, and 19 feet of delta sandstone-1 (Figure 2-3). Drilling through this sequence was unremarkable; the sandstones drilled smooth and fast and the limestone hard and slow.

There was no observable air-lift water production at 99 feet from the lower 8 feet of the saturated delta sandstone-1, likely due to the small submergence of the airlift. However, after the termination of air-lift, groundwater flowed into the borehole as documented by a measured water level of 89.8 feet relative to top of casing.

Drilling through the saturated limestones and sandstones from 88 to 152 feet was unremarkable. The delta limestone-2 and gamma limestone-1 drilled hard and slow, and the delta sandstone-2 drilled smooth and fast. At a total depth of 152 feet, air-lift water production was only 10 to 15 gpm and the water remained cloudy and colored with sand and silt after 15 minutes of air-lift. Lost circulation did not occur during drilling. Drilling behavior and air-lift water production indicate that lithologic conditions in the fault zone are less conducive to large water production than at the adjacent well sites.

The caliper log of the Middle Borehole indicates significant borehole enlargement and instability over fairly wide intervals of the epsilon sandstone and delta sandstone-1. The observation of abundant sand in air-lift water is consistent with the borehole instability indicated by the caliper log. A comparison of the character of caliper logs from the Triangle, North, South, and Middle wells provides some insight into lithologic conditions and permeability in the fault zone. Borehole enlargements at the Triangle, North, and South wells occur over short intervals at thin discrete fractures. Permeability and water production in these wells is provided by these fractures. Locally at the Middle Borehole, however, the integrity of the bulk sandstone appears to be reduced (i.e. loose rather than well-cemented sandstone) and the character and/or lateral continuity of the horizontal fractures has been disrupted.

Water level measurements at drilled depths in the delta sandstone-1 and in the combined delta sandstone-1 and delta sandstone-2 indicate identical head in these two sandstone units (Table 2-1). At this location, the delta limestone-2 may not provide significant hydraulic separation between the delta sandstones.

South Well

At the South Well, the stratigraphic sequence from 15 to 90 feet consists of unsaturated epsilon sandstone, delta limestone-1, and 13 feet of delta sandstone-1 (Figure 2-4). The thicknesses of the delta sandstone/limestone units are similar to thicknesses observed at the Triangle and North wells (Figures 2-1 and 2-2). Drilling from 80 to 83 feet was fast and correlates with substantial borehole enlargement from 80.5 to 81.5 feet on the caliper log and a horizontal fracture on the optical image log.

Air-lift water production at 103 feet from the lower half of the delta sandstone-1 was 10 to 15 gpm. Lost circulation occurred at 108 feet and persisted to the total depth of 163 feet. Horizontal fractures in the unsaturated delta sandstone-1 were probably responsible for lost circulation. Small amounts of water and cuttings were occasionally air-lifted from the borehole using biodegradable foam.

Lithology and horizontal fractures shown on Figure 2-4 are based on drilling rate, rare cuttings, and the geophysical logs (i.e. natural gamma, caliper, and acoustic/optical image). Due to lost circulation, drilling field data were unavailable to estimate air-lift water production and identify zones of high permeability. However, the horizontal fractures shown on Figure 2-4 are potential zones of high permeability. Because of the lack of air-lift water production data and the need to remove residual foam, a short pump test was conducted at the South Well. The pump test provided a representative water sample and reliable aquifer production data as discussed in subsequent chapters.

Water level measurements at drilled depths in the delta sandstone-1 and in the combined delta sandstone-1 and delta sandstone-2 indicate identical head in these two sandstone units (Table 2-1). At this location, the delta limestone-2 may not provide significant hydraulic separation between the delta sandstones.

Summary of Geology at Imperial Heights Park

Most of Imperial Heights Park is covered by 13 to 17 feet of alluvial material consisting of loose sand and rock fragments. The delta limestone-1 is exposed in the drainage at the northeast corner of the part site. The Satanka Shale and upper part of the epsilon sandstone of the Casper Formation have been eroded away such that the alluvial material lies directly on top of the epsilon sandstone.

The Sherman Hills Fault trends east-west thorough the Imperial Heights Park. Additional detail was provided by the near-surface geophysical investigation performed during Phase I of this project (Appendix 1) and by stratigraphic data obtained from the monitor wells and temporary borehole. Using the top of the delta limestone-1 as a stratigraphic datum, there are 39 feet of vertical offset across the fault zone between the North and South wells (Table 2-1). The fault is up on the north side and down on the south side. The Middle Borehole is located within the fault zone as indicated by 9.4 feet of vertical offset between the Middle Borehole and the South Well. The remaining 30 feet of offset occurs between the Middle Borehole and the North Well. Rather than a single fault with 39 feet of vertical displacement, displacement occurs within a fault zone comprised of multiple faults (i.e. step-faults) that together produce a total offset of 39 feet.

The North and South wells demonstrate the occurrence of horizontal fractures in sandstone units and at or near limestone/sandstone contacts, and the fractures' role in water production. Drilling and geophysical data from the Middle Borehole suggests that horizontal fracture networks are disrupted within the Sherman Hills Fault zone.

Groundwater Elevations

On May 20, 2015, a survey-grade location and elevation survey (i.e. State Plane Wyoming East Zone NAD 83) was performed at project wells and related locations. Survey elevations and calculated groundwater elevations at project wells are listed in Table 2-2.

Chapter 3 - Groundwater Quality

This chapter describes the collection and analysis of groundwater-quality samples from the three wells and one borehole of this project.

Background, Methods, and Sample Data

The chemical composition of groundwater in the Casper Aquifer is a function of: 1) the chemistry of rainfall and snowmelt across the outcrop area; 2) dissolving natural materials from the soil and rock layers during infiltration to the aquifer (recharge); 3) chemical reactions with and within the aquifer; and 4) contributions from surface activities, i.e. the intentional infiltration of septic system effluent and the unintentional infiltration of the variety of chemicals associated with residential and commercial land use. The first three factors predate human occupancy and produce a "background" water quality upon which human activities and contributions are superimposed. Alterations of background water quality may be considered desirable, as in the case of chlorine added to control bacteria in water systems or fluoride added to promote dental health, or undesirable, as many potential additions have adverse health and/or aesthetic impacts.

With respect to modifications of background water quality, the primary water-quality parameter discussed in this project is nitrate. Nitrate is conservative[1], inexpensive to analyze, and there are known occurrences of elevated nitrate concentrations in up-gradient areas of the aquifer. This is by no means intended to suggest that nitrate is the only constituent of concern, nor that nitrate is a fully representative surrogate for any other potential contaminant (see Phase I Report, attached as Appendix 1).

Analyses are also provided for chloride, another constituent commonly used to investigate the impacts of human activity on groundwater quality, and various other standard water-quality parameters. In general, all parameters measured show the same patterns of distribution.

The nitrate concentrations presented here are either expressed as "nitrate as N" or "nitrate and nitrite as N" in the laboratory analyses. The term "nitrate" is used throughout the text. For the first six samples of this project (Triangle and North wells), separate analyses were provided for nitrate and nitrite (Appendix 2). As expected, nitrite concentrations are always below detection limits. Thus, the "nitrate" concentration is the same as the concentration of "nitrate + nitrite". Note also that all values are expressed as equivalent nitrogen (N). The actual weight concentration of nitrate in a sample will be 4.4 times the concentration "as N".

The nitrate concentrations reported from the monitor wells and temporary borehole vary from 1.1 to 8.3 mg/l[2], although somewhat higher levels are likely present in discrete layers, not discernable in the composite samples. The US EPA has established a Primary Drinking Water Maximum Contaminant Level (MCL) for nitrate of 10 mg/l. A Public Water Supply is barred from providing water in excess of MCLs to its users. (There are no enforceable standards for

[1]"Conservative" in this context indicates a lack of chemical reactivity within the aquifer.

[2]One milligram per liter (mg/l) is approximately the equivalent of one part per million (ppm).

private water supplies.) The East Laramie Waste Water Feasibility Study (WWC Engineering, 2013) states that natural background nitrate concentrations in groundwater are typically less than 2 mg/l. The feasibility study's evaluation of samples from domestic wells in the subdivisions east of Laramie described groundwater with nitrate concentrations between 2 and 5 mg/l as "impacted", between 5 and 10 mg/l as "significantly impacted", and greater than 10 mg/l as "unsafe".

Groundwater quality data were collected over the course of drilling each well to help guide drilling and well-design decisions, and during the pump testing of select wells to assess changes in water quality over the test period. Field data consisted of electrical conductivity (a generalized measure of total mineral content), pH, temperature, and, in one case, dissolved oxygen. Samples were submitted for laboratory analysis of individual chemical constituents.

Samples were collected over the course of drilling by lifting water from the well using compressed air. In this procedure, air is injected into the well below the water table via the drill pipe, producing a flow of air and groundwater from the well. (The same procedure is used to remove cuttings from the borehole during drilling[4].) Due to the non-reactive character of the constituents of interest, there is no concern that the air-lift sampling method significantly changes individual concentrations[5].

Laboratory analyses for all samples are by Energy Labs, an EPA-certified laboratory located in Casper, Wyoming. Individual lab data sheets are attached as Appendix 2. Although Energy Labs provides full quality assurance/quality control reporting with each analysis, given the importance of the laboratory analyses in guiding drilling and well completions, an additional assessment of project nitrate analyses was provided by repeat analyses for the four samples from the Triangle Well. Those values averaged a 7.8% difference from the original analyses. (The repeat analyses are those reported in Table 3-1.)

Samples collected over the course of drilling provide reconnaissance-level discrimination of the differences in chemistry between the individual aquifer sandstones. For example, a sample collected from the well when it has only penetrated the first water-bearing sandstone may be different than a sample collected from the well when it has penetrated two sandstone units. The former represents the first sandstone. The latter represents a combination of the first and second sandstones. The proportionate contribution from each unit is a function of the relative permeability of the two, i.e. a layer that produces water more readily may dominate the combined-sample chemistry.

Samples were collected over the course of pump testing simply by drawing a sample from the discharge stream. Only the pump test of the North Well was sampled repeatedly over the course

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[4]The conductivity of this water was 347 µS (µmhos/cm). Complete chemical analyses may be obtained from the City.

[5]The nitrate data from the North Well demonstrate little difference between "airlift" and "pumped" sampling, i.e. 1.3 and 1.1 mg/l.

of a pumping period. Pump test samples were of course produced from the entire depth of the well.

Tables 3-1 and 3-2 compile the groundwater quality data developed over the course of this project. Table 3-1 presents the more numerous nitrate and chloride data; Table 3-2 presents major cations and anions for a smaller set of samples. Figures 2-1 through 2-4 show the depth intervals for each sample in graphical form. The bracket associated with each sample on those figures shows the potentially contributing interval of the well at the time of sampling.

For each well, the first groundwater encountered was sampled. Subsequent sampling was targeted to identify water-quality differences between the individual water-bearing sandstones of the aquifer.

For each well, additional samples were collected as successive sandstone units were penetrated. Due to the westward dip of the Casper Aquifer, each sandstone and intervening limestone is present at the surface - and thus subject to surface-sourced contaminants - successively further east. For example, the top of the delta limestone-1 occurs at 71 feet in depth at the South Well, but rises to the surface approximately 1200 feet to the east. The Phase I report compiled the occurrence of domestic septic systems providing infiltration to each of the Casper members from the 2008 CAPP. There were 70 septic systems located above the subcrop of the delta member, compared to 25 septic systems above the epsilon member and 21 septic systems above the gamma member. Figure 1-2 shows the location of city and county subdivisions relative to the subcrop of these members.

As noted above, samples collected with the well open to more than one sandstone unit reflect a composite chemistry. For example, the 4.8 mg/l nitrate concentration of the sample from the epsilon sandstone and delta sandstone-1 in the Triangle Well is a combination of 3.5 mg/l water from the epsilon and water with a concentration likely in excess of 4.8 mg/l from delta sandstone-1. (For the combined concentration to be 4.8 when one of the two components is 3.5, the other component must be greater than 4.8.) The same logic indicates that for the three-layer concentration to drop to 4.2 mg/l in this well, the delta sandstone-2 must have a concentration somewhat lower than 4.2. That the dominant water production in this well appeared to be from the delta sandstone-1 suggests that the nitrate concentration in that layer may not be much more than the combined-sample 4.8 mg/l, but that the concentration in delta sandstone-2 may be substantially less than the combined-sample (4.2 mg/l) in order to reduce the combined value.

Triangle Site

Nitrate concentrations from the Triangle Well range from 3.2 to 4.8 mg/l. Like the head differences discussed in Chapter 2, the chemistry data also indicate distinct water-bearing units at this location. The highest nitrate concentration occurs in the delta sandstone-1, which in the full borehole is diluted by input from lower concentrations in the epsilon sandstone and delta sandstone-2[6]. (See Figure 2-1.) Chloride and conductivity values show the same relationship.

[6]Chapter 6 includes recommendations for final well completions to prevent cross-flow between subaquifers and to isolate individual aquifer units for subsequent sampling.

The occurrence of the highest nitrate and chloride values in the middle of these three sandstones argues against a source infiltration in the immediate area of the well. Were that the case, concentrations should be highest in the uppermost unit, and decrease downward. Instead, the higher-permeability strata encountered in the delta sandstone-1 appears to be carrying nitrates sourced from areas up-gradient[7]. This is consistent with both the absence of identified contaminant sources in the immediate area and the inhibitory effect of the overlying Satanka Shale on deep infiltration.

Combined with the head difference across the delta limestone-1, the water-quality profile of the Triangle Well directs source investigation to outcrops of the delta sandstone-1. In the area between the Quarry and Sherman Hills faults (see Figures 1-1 and 1-2), such outcrops occur only east of the Imperial Heights subdivision. This suggests the Imperial Heights subdivision is not the primary source of elevated nitrate. (Although this subdivision is served by the municipal sewer system rather than individual on-site septic systems, other small chemical inputs to groundwater likely occur through routine residential activities like fertilizer, herbicide, and insecticide application, accidental spills, improper waste disposal, etc.)

Imperial Heights Park Site

North Well

Nitrate concentrations at the North Well range from 1.1 to 1.6 mg/l. Although there may be some reflection of differences in recharge chemistry for the layers penetrated by the North Well, all three values are within the range of typical background concentrations for nitrate. Given the proximity and hydraulic connection (see Chapter 4) with strata across the Sherman Hills Fault, the somewhat higher concentration in the shallower strata of the North Well may be at least partially the result of higher nitrate concentrations moving from the delta sandstone-1 across the fault.

The relative concentrations of nitrates (and other parameters) for the three Imperial Heights Park sample points (North, Middle, and South) document significant difference across the Sherman Hills Fault at this location (see Tables 3-1 and 3-2). The 2-day, 400 gallon per minute (gpm) pump test at the North Well provided an opportunity to observe how groundwater withdrawal on the north side of the fault changes the distribution of elevated nitrate concentrations. As a result of this withdrawal, concentrations increased measurably on the north side of the fault.

Note that the first three samples from the North Well (Table 3-1) were collected before the pump test shifted the local distribution of groundwater quality. The dissolved oxygen concentration in groundwater from the Casper Aquifer at the North Well is 10.98 mg/l which indicates highly oxygenated water. Dissolved oxygen was measured in the field from pump test discharge prior to contact with atmospheric oxygen. Water quality data collected during the pump test are addressed further in Chapter 4.

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[7] "Up-gradient" in groundwater is the equivalent of "upstream" for surface streams; it describes the area from which water flows towards the point of interest.

Middle Borehole (Temporary)

Nitrate concentrations at the Middle Borehole range from 5.8 to 7.0 mg/l. Nitrate concentration is somewhat higher in the lower, delta sandstone-2 than in the delta sandstone-1. This suggests infiltration from the immediate surface is not the primary source, as expected for this undeveloped site. Most notable is the distinctly higher nitrate concentration at this location than at the North Well. The increased proximity to nitrate sources in the Sherman Hills and Pilot Peak subdivisions is the obvious explanation. (The Pilot Peak subdivision is immediately east of the Sherman Hills subdivision.)

South Well

Nitrate concentrations at the South Well range from 7.5 to 8.3 mg/l. The latter is the highest nitrate concentration measured on this project and approaches the public water supply drinking water MCL of 10 mg/l. The relatively high value, the small decrease in nitrates with depth, and the proximity to the adjacent subdivisions are all consistent with septic system discharge and residential land use being the primary sources. The delta sandstones specifically were identified in the Phase I report as the units receiving effluent from the largest number of septic systems.

Although a nitrate concentration of 8.3 mg/l remains below the EPA MCL of 10 mg/l, development of a drinking water supply by the City at this location is not recommended.

Chapter 4 - Aquifer Testing

This chapter describes the collection and analysis of groundwater production data from the three wells and one borehole of this project.

Background, Methods, and Drawdown Data

Aquifer testing consists of careful measurements of water levels in an aquifer to assess how the aquifer responds to an applied stress, such as pumping. This process provides direct measurement of short-term aquifer productivity and inter-well communication, and data which can be used to interpret aquifer characteristics in the vicinity of a well.

The most basic measure of well productivity is "specific capacity", which is the ratio of production to drawdown[1]. For example, a specific capacity of 10 gpm/ft would be calculated if production of 100 gpm were accompanied by 10 feet of drawdown in a well. If one had to pull the water level down 50 feet to induce 100 gpm to flow from the aquifer into the well, the specific capacity would be 2 gpm/ft.

By way of perspective, the specific capacities of the City of Laramie municipal wells vary from 580 gpm/ft at the phenomenally productive Spur No. 1 Well (WWC, 1997a), to 62 and 66 gpm/ft at the Turner wells (WWC Engineering, 2006), and 40 to 125 gpm/ft at the Pope wells (WWC Engineering, 2006). By any standard, the City wells are considered exceptionally productive and numerous studies have demonstrated that the excellent production is the result of the wells penetrating fractures (Huntoon and Lundy, 1979; WWC, 1997a; Wyoming Groundwater 2004 and 2011), Casper Aquifer wells completed in unfractured aquifer commonly have much lower productivity (Huntoon and Lundy, 1979; WWC 1997b). The Huntoon #1 monitor well, for example, has a tested specific capacity of 0.63 gpm/ft (Lundy, 1978). Similarly, WWC (1995) suggested 1 gpm/ft as typical for domestic wells across the wider aquifer.

With respect to the aquifer, specific capacity is a function of permeability - how easily water moves through the aquifer material. A related term used here is "transmissivity", which is simply the permeability times the aquifer thickness. The more thickness one has of a given permeability, the more groundwater flow can occur. Hydrogeologists refer to "primary" permeability as a reflection of undisturbed aquifer material, i.e. water is moving through pores, around mineral grains, like it would through a sandbox. In consolidated sandstone, that permeability is low, and in solid limestone, basically zero. This primary permeability supports many of the small, domestic wells dispersed across the aquifer. Permeability is greatly increased where a bedrock aquifer is fractured, as occurs along faults and folds – identified as "vulnerable features" that enhance the potential for aquifer contamination (CAPP, 2008; and City ordinance). This type of "secondary" permeability is typically the target for development of large-capacity wells throughout Wyoming, including the Laramie municipal wells.

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[1]Because specific capacity is also a function of well diameter, well construction, and the time period over which it is measured, it provides only a general assessment of aquifer characteristics.

More sophisticated collection and analysis of test data examines the rate at which water levels change over a pumping period to derive estimates of aquifer hydraulic parameters like permeability and storativity. (The "storativity" or "storage coefficient" of an aquifer is the volume of water that can be extracted from a unit volume of the aquifer with a specified decline in hydraulic head.)

As discussed in the Phase I report, the North Well was targeted for a pump test to assess hydraulic communication across the Sherman Hills Fault and to investigate its potential as a long-term water-supply well for the future Imperial Heights Park. However, similar information was collected from the other three boreholes as opportunity presented itself.

Table 4-1 presents a summary of test results, expressed as the maximum drawdown observed as a result of the listed pumping rate and duration. The following sections examine test results site-by-site. Individual water-level measurements and related field notes are provided in Appendix 4.

Triangle Site

Aquifer performance at the Triangle site was investigated by visual estimation of the air-lift discharge rate (confirmed by pumping water from the discharge pit with a pump of known capacity) and measurement of the water level recovery following termination of a period of air-lift "pumping".

Figure 4-1 presents the recovery data at the Triangle Well following one hour of approximately 380 gpm discharge. The rate of water level rise suggests an aquifer transmissivity of approximately 90,000 gpd/ft[2]. This identifies a very productive aquifer at this location, only slightly less productive than that developed at the Turner wells themselves, and consistent with the qualitative observations during drilling. Were a 12-inch diameter well completed at this location, a 2-day specific capacity of approximately 55 gpm/ft is indicated by this transmissivity estimate.

Imperial Heights Park Site

<u>North Well Testing</u>

The North Well was used for the most complete pump test of this project. Following a series of step tests (see Table 4-1), the water level was allowed to recover and was then pumped at a constant rate of 400 gpm for 2 days. Water levels were measured manually with an electric sounder and recorded automatically with a transducer/datalogger installed in the well for backup. Companion water level measurements were taken in the same manner at the Middle and South wells throughout the test period. Discharge was measured with an in-line flow meter, calibrated on site through comparison with the stopwatch time to fill a 400-gallon water trough.

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[2]This interpretation is based on application of a standard "Jacob" analysis.

To preclude discharge water re-entering the aquifer and affecting local water levels, the discharge water was conveyed in a closed pipe to a point 1,100 feet north of the North Well before being discharged to the surface[3].

The 2-day specific capacity of the North Well is 21 gpm/ft, less than that of most of the City municipal wells, but clearly reflecting the presence of the water-transmitting fractures observed during drilling.

Figure 4-2 presents drawdown measurements at the North Well during the 2-day pump test. Projection of the data shown on Figure 4-2 to longer pumping times indicates that the North Well can sustain production on the order of the 400 gpm tested, and, very likely, considerably more. A groundwater supply capable of meeting local park needs is secure.

Table 4-1 includes the final drawdown for each of the four 30-minute step tests of the North Well. The 30-minute specific capacity at the North Well was 30% less at 432 gpm than at 49 gpm, suggesting some loss of well efficiency at higher production rates. Such losses are commonly attributed to the occurrence of turbulent flow in the near-well portions of a fractured-rock aquifer, which is consistent with the borehole observations discussed above. (These "losses" do not present any obstacle to the long-term productivity of this well.)

Observation Well Data. At both the Middle Borehole and South Well, measurable drawdown occurred within a few minutes following the start of pumping of the North Well, even at the lowest pumping rate of 49 gpm. Drawdown at these two observation wells was directly proportional to the various production rates of the four step tests, as expected in a well-connected aquifer.

Figures 4-3 and 4-4 present the drawdown measurements at the two observation wells over the 2-day, 400 gpm pumping of the North Well. Included on the figures are red lines calculated using the "Theis Equation". This equation and its derivatives are the most commonly used mathematical representations of aquifer behavior. Although the equation was derived for an "ideal" aquifer (e.g. entirely homogeneous, of infinite extent, the same in all directions, etc.), it has proven to be widely applicable in real-world situations. The Casper Aquifer across the study area of this report is clearly not such an ideal aquifer. For example, the permeability distribution is known to be extremely heterogeneous (see Chapter 2). However, the net effect of the varying productivity of different layers, as subject to the horizontal fracturing observed in the well bore and the vertical fracturing associated with the nearby Sherman Hills Fault, is surprisingly conformable to this simple model.

Modeling the aquifer between the North and South Wells as an ideal ("Theis") aquifer, the known presence of the Sherman Hills Fault notwithstanding, produces a reasonable match to the observed drawdown with an aquifer transmissivity (T) of approximately 60,000 gpd/ft, and a storage coefficient (S) of approximately 0.02 (Figures 4-3 and 4-4).

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[3]Step-test production was discharged to the drainage adjacent to the North wellsite.

Considering the 39-foot offset across the Sherman Hills Fault and the substantial, small-scale variations in aquifer character detailed in Chapter 2, the aquifer is certainly far more complicated than a simple "sandbox" in which all parts readily communicate and aquifer properties are the same in all directions and at all locations. Nonetheless, that the aquifer performance in the area of the three Imperial Heights Park wells can be modeled to a first approximation in this straightforward manner indicates many of the local variations "average out" over the larger area. Even the structurally well-defined Sherman Hills Fault does not appear to exert a significant impact on aquifer hydraulics.

Pumped Well Data. Figure 4-2 presents the drawdown data from the North Well. Included on Figure 4-2 are guidelines marking linear segments of the drawdown plot per a standard "Jacob" analysis (drawdown plotted with the logarithm of the pumping time). In an ideal aquifer, the slope of such a line is proportional to the transmissivity of the aquifer. In this case, the measured drawdown over time indicated a transmissivity of 50,000 gpd/ft initially, when groundwater was being produced from the near-well portions of the aquifer, then a rate of drawdown indicating a lower transmissivity (approximately 25,000 gpd/ft) as a wider area of the aquifer began contributing water.

Comparison with the drawdown observed in the Middle and South wells (discussed above) suggests this decrease is a function of aquifer conditions to the north rather than to the south, e.g. perhaps the termination of some of the more productive horizontal fractures in that direction.

The water-quality analysis for three samples collected over the course of testing the North Well are presented on Table 3-1. Conductivity was measured in the field to provide a more frequent assessment of potential changes in groundwater chemistry over the course of the test. Those data are presented on Figure 4-5.

Water quality changed somewhat over the course of the 2-day pumping period, with increases in conductivity, nitrate, and chloride values. The conductivity values indicate comparable increases in other individual constituents as well, but these were not specifically assessed. The conductivity values present an initial increase of approximately 6% over the first day of pumping, followed by relative stability over the second day.

The measured concentrations of these components at the North, Middle, and South wells (see Tables 3-1 and 3-2) define a gradient across Imperial Heights Park, i.e. increasing concentrations from north to south. The change in concentrations demonstrates that drawdown associated with the North well test was sufficient to warp groundwater flow sufficiently to shift mineral concentrations slightly northward over the course of pumping. Because this drawdown was localized and temporary, however, pre-test gradients and flow patterns would soon have become reestablished following testing.

<u>Middle Borehole Observations</u>

This borehole was completed primarily to identify structural relationships within the Sherman Hills Fault zone and to provide intermediate water level measurements (between the North and South wells) during the pumping of the North Well. Water production during drilling was distinctly less than at any of the other three locations of this project, so a brief "slug test" was performed to assess local aquifer productivity. In this case, approximately 300 gallons of water were added to the well over a 3-minute period and the subsequent decline in water level was monitored with an electric sounder[5].

Ideally, an aquifer will accept water under injection at the same rate it gives up water under pumping. For example, if a well will produce 100 gpm with 10 feet of drawdown, it will accept 100 gpm with 10 feet of imposed head. At the first measurement after discharging water into the Middle Borehole, the water level was 25 feet above the static water level. Based on the diameter of the borehole and the time elapsed to the next measurement, the hole was accepting water at a rate of 49 gpm, for a short-term suggested specific capacity of 2 gpm/ft.

Given the observed responses to the pump testing of the North and South wells, we are skeptical that the lower permeability observed at the Middle Borehole is representative of a large portion of the Sherman Hills Fault zone. Were this suggested specific capacity (greater than that of undisturbed Casper Aquifer wells elsewhere but distinctly less than found in the North and South wells) more than a local condition, the inter-well responses to pumping would likely have indicated much lower transmissivity values.

South Well Testing

Because lost circulation allowed some quantity of the water used during drilling to invade the formation at this site, a pumping period to remove this possible compromise of native groundwater quality was conducted. The well was pumped for 162 minutes at a rate of 94 gpm (15,000 gallons; 68 well volumes). Discharge rate was measured with an in-line flow meter; water level was measured with an electric sounder at both the South, Middle, and North wells.

The 2.5-hr. specific capacity of the South Well is 28 gpm/ft, less than that of most of the City municipal wells, but clearly reflecting the presence of the water-transmitting fractures observed during drilling.

Figure 4-6 presents the drawdown data from the South Well over the pumping period. The rate of water level decline over the first 10 minutes of the test indicate an aquifer transmissivity of approximately 70,000 gpd/ft in the immediate vicinity of the well. Beyond 10 minutes, however, it appears the spreading drawdown encountered less permeable portions of the aquifer, producing an effective transmissivity at the well of approximately 14,000 gpd/ft. In any case, the aquifer at this location is clearly quite productive, consistent with the observations during drilling.

Figure 4-7 presents the drawdown data from the Middle Borehole over the South Well pumping period. Analysis of these data as an ideal ("Theis") aquifer provides the red line on the graph. The modeled line provides a good match to the observed data with a transmissivity of 40,000 gpd/ft and a storage coefficient of 0.0006. This transmissivity is reasonably consistent with the results of the North Well testing. The storage coefficient is substantially lower, perhaps

[5]This test was performed following groundwater sampling; the analyses of Tables 3-1 and 3-2 are of native groundwater.

indicating the more rapid response to pumping commonly seen in short-term tests between wells sharing a permeability zone without ready access to the water table.

Only a few water level measurements were made at the North Well during this short pump test. Drawdown at the North Well can be closely approximated with the Theis Equation with transmissivity = 40,000 gpd/ft and a storage coefficient of 0.011, similar to the results obtained for both of these parameters from the North well test.

Chapter 5 - Groundwater Flow in the Casper Aquifer

This chapter combines the information from the previous chapters to provide the following conclusions about how groundwater and its chemical constituents move within the project area.

1. Residential activity at the Sherman Hills subdivision has impacted groundwater quality at Imperial Heights Park.

The South Well nitrate concentration of 8.3 mg/l and the Middle Borehole nitrate concentration of 7.0 mg/l clearly show that adjacent upgradient residential subdivisions have impacted groundwater quality beneath Imperial Heights Park. Data from these wells are consistent with the results of extensive sampling completed in 2009/10 in the rural subdivisions along East Grand Avenue, which found elevated nitrate concentrations in the domestic wells of the Sherman Hills subdivision area. (Those data are presented in the East Laramie Waste Water Feasibility Study (WWC Engineering, 2013).)

2. The Sherman Hills Fault zone is not a barrier to groundwater flow.

There is a hydraulic gradient between the South and Middle wells and between the Middle and North wells, spanning the Sherman Hills Fault zone. Hydraulic connection across the fault zone was demonstrated by the pump testing of the North Well which showed head responses at cross-fault wells and by the increase in nitrate concentration over the course of that pump test. Although these data are insufficient to identify the precise flow pathways and chemical flux, the presence of hydraulic gradient and connection produces groundwater flow across the fault.

This conclusion is consistent with the representation of Casper Formation faults in general as important zones of high permeability since the earliest hydrogeologic work in the area. Thesis work by Lundy (1978) and Thompson (1979) and professional-journal articles echo this understanding, e.g. "Large transmissivities occur in fracture zones associated with faults and folds in the area … Transmissivities in fracture zones are 100 times greater than those in unfractured parts of the aquifer." (Huntoon and Lundy, 1979), and faults and folds are specifically identified as "vulnerable features" in the 2008 CAPP due to the associated enhancement of permeability. The Sherman Hills Fault specifically was modeled as a zone of "large hydraulic conductivity" by Thompson (1979), whose results showed the drawdown from pumping extending across the fault. What is new with the present study is the opportunity to directly observe cross-fault characteristics in a specific area of interest with a focused drilling and testing program.

Although permeability at all three of the near-fault sites is substantially higher than that of unfractured Casper Formation elsewhere, the experience of the Middle Borehole suggests the permeability may have been locally decreased within some areas of the fault zone. This may be explained by the highly-permeable bedding plane fractures that produce abundant groundwater at the North and South wells being disrupted and less coherent in the Middle Borehole. Increased permeability is produced by the rubblization accompanying faulting, as further evidenced by the abundance of loose sand produced at the Middle Borehole, but the continuity of the important horizontal fractures is reduced in the process. This permeability variation may also be responsible for the hydraulic gradient being approximately twice as steep between the Middle and North wells, where the displacement is greatest, as it is between the Middle and South wells.

3. City Springs and the Turner Wellfield receive a portion of their groundwater discharge from the southeast, including the area beneath the East Grand Avenue subdivisions.

Figure 5-1 plots measured nitrate concentrations and groundwater elevations for the project area. For the four monitoring points established with this project, the highest concentration is plotted. Discrimination of water quality between individual aquifer units is not available for the LCCC well, the well opposite Imperial Heights across East Grand Avenue, or the Turner wells; the value plotted is a composite from the aquifer interval open to the completed well.

Basically, the North Well pump test was a carefully conducted miniature version of the natural discharge and routine pumping of the Casper Aquifer. Under the natural conditions that have prevailed for thousands of years, approximately 1200 gpm have discharged from City Springs, day in and day out. Since the early 1980s that discharge has been augmented seasonally by the pumping of the Turner Wellfield, increasing the rate to 2800 gpm during the summer months. This sustained discharge is located 2700 feet north of the Sherman Hills Fault, drawing groundwater from a large area of the surrounding aquifer. The North Well discharged groundwater at 400 gpm for 2 days. It is located approximately 200 feet north of Sherman Hills Fault. Just as the North Well was observed to induce cross-fault flow, as evidenced by both water-level and water-quality observations, it is reasonable to conclude that the vastly greater quantities of groundwater discharged from the aquifer at City Springs/Turner Wellfield have the same effect. And, as with the North Well experiment, the functioning of the larger, permanent groundwater flow system is demonstrated by both the distribution of water levels and of groundwater-quality (Figure 5-1).

The City Springs/Turner Wellfield represents a regional natural discharge point for the Casper Aquifer, enhanced by the pumping of the municipal wells. The area that contributes groundwater to this discharge includes the relatively undeveloped areas to the north, northeast, and east, and the developed areas to the southeast. The latter includes domestic septic systems in the rural subdivisions and the activities associated with residential development in these subdivisions and Imperial Heights. Groundwater in the Casper Aquifer across the southeast recharge area flows generally westward, and is deflected northward by the drawdown associated with City Springs/Turner Wellfield. The elevated nitrate concentration at the Triangle Well is a manifestation of this relationship between contaminant source and groundwater flow direction. Water quality from City Springs/Turner Wellfield reflects the relative contributions of groundwater converging on the springs area from all directions, and from deeper in the aquifer. Thus, groundwater with elevated nitrates (and whatever accompanying constituents are present) is substantially diluted by groundwater arriving from the relatively unimpacted recharge areas and from greater depths (i.e. beta and alpha members) within the aquifer.

WWC Engineering (2013) compiled over 40 years of data from the City Springs/Turner Wellfield, finding an average nitrate concentration of 1.63 mg/l. While they concluded, “The concentrations at the Turner and Soldier wellfields exhibit trends of slight increases over time”, they further noted that this trend would leave the levels well below action thresholds for a very long time.

4. The detailed distribution of groundwater quality within the Casper Aquifer is a complex function of the distribution, concentration, and volume of sources, and of groundwater movement through the aquifer in response to regional and local groundwater gradients and the three-dimensional distribution of aquifer permeability. Chemical concentrations may be substantially different at different depths and may vary significantly over short distances horizontally.

Within the general flow pattern described in conclusion #3, the experience of these monitor wells[1] demonstrates considerable local variation. Of particular importance is the presence of high-permeability, bedding plane fractures that occur in the sandstone units and at the limestone/sandstone interfaces within the Casper Aquifer. These features clearly play a major role in the localized productivity of the aquifer. Thus, the fractures are also important in the flow and distribution of the chemical constituents within the groundwater.

For example, the zone of lost circulation and associated fractures encountered in the North Well during drilling were immediately above the water table. Had that zone been below the water table, it would likely have been a major source of water-producing permeability. Given the westward dip of the Casper Aquifer beneath the project area, that zone becomes progressively deeper to the west and becomes saturated and available to transmit groundwater a short distance west of the North Well. Similarly, the entire thickness of the epsilon sandstone is unsaturated at the Imperial Heights Park monitor wells. Proceeding westward, however, the epsilon sandstone becomes progressively saturated on both sides of the fault and thus available for groundwater transport. Local variations in the distribution of permeability within the Casper Aquifer, discussed here and in Chapter 2, likely exert significant control on the details of groundwater flow.

5. In combination with previously constructed monitor wells for other projects, the three new wells are well located to assess aquifer water-quality in the recharge area for the Turner Wellfield.

A) The South Well is representative of the north edge of the groundwater moving west and northwest from beneath the East Grand Avenue subdivisions; and

B) The Triangle Well is representative of groundwater moving within high-permeability fracture systems towards the Turner Wellfield; and

C) In addition to having proven its value as a high-production water supply well, the North Well appears to currently represent a reasonable "background" well for the aquifer and may also serve to monitor any groundwater-quality changes as a result of future residential/commercial developments to the east.

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[1]Sampling of domestic wells within the East Grand subdivisions also found wide variations in nitrate concentrations.

Chapter 6 - Monitoring Recommendations

This chapter describes the recommended completion of each of the three permanent monitoring wells, and the abandonment of the temporary borehole. It suggests a sampling plan going forward, and offers a number of recommendations for next steps in the City Monitor Well Program.

Monitor Well Completion

The next step in the completion of long-term monitor wells is to case and seal the existing boreholes. Figures 6-1 through 6-4 present our recommendations for final well completions. These designs are based on four objectives:

1) Permanent monitor wells should not provide conduits for surface or near-surface contaminants to migrate into the aquifer along their casings. Although the surface casings currently cemented in place likely provide adequate protection in this regard, complete sealing against the borehole down to the target interval is recommended.

2) Permanent monitor wells should not provide opportunities for groundwater migration between water-bearing zones of different water quality. Thus, completions are designed to isolate a single zone within each well, and to seal the well through all other intervals.

3) Permanent monitor wells should allow periodic sampling of the discrete water-bearing zones of most importance to the transport of contaminants through the larger aquifer. Thus, completions are targeted at the most productive zones and the zones demonstrated to carry the highest contaminant concentrations.

4) Permanent monitor wells should be designed to accommodate seasonal and long-term fluctuations in water levels without going dry. Historical monitoring of water levels in the Casper Aquifer suggests levels are currently relatively high. Thus, monitoring well open intervals should extend sufficiently below the current water level to allow for future water-level declines.

5) Permanent monitor wells should retain maximum opportunity for further investigation in the future. Thus, the recommended completions through the target zones are "open hole" to retain direct access to the formation for geophysical tools, downhole video, etc.

Monitor Well Sampling

An initial sampling of each well should follow final well completion. Subsequent sampling should be conducted twice a year. Sampling should include, at a minimum, field measurements and submission of samples for laboratory analysis, as follows:

- water level (prior to sampling, referenced to permanent well casing)
- nitrate
- chloride

- dissolved oxygen (measured on-site)
- conductivity (measured on-site)
- fecal coliform
- Optional: human-specific chemical constituents (e.g. see Phase I report).

Volatile organic compounds should be sampled and analyzed during the first round of sampling and continued only in the event of detections and perhaps once every 2-3 years.

Primary monitoring and sample collection equipment should include:

- water level sounder
- pH, conductivity, temperature meter
- dissolved oxygen meter
- dedicated sampling equipment in each well (e.g. 3-inch submersible pumps or salvage submersible pumps from Soldier monitor wells) or a non-dedicated (e.g. "Redi-flow") pumping system installed for specific sampling events
- dedicated automatic water level monitoring equipment (e.g. dataloggers pulled from selected Spur monitor wells and reinstalled in Triangle/North/South wells or purchased new)
- use of proper sample containers and preservatives as provided by the analytical laboratory
- use of an EPA-approved analytical laboratory that provides adequate quality assurance/quality control (QA/QC) procedures and documentation

It is recommended that the City obtain professional services from a qualified consultant to work with the City to develop a detailed sampling procedure, and to perform sample collection for at least the first year of sampling. The City has a preliminary document of sampling procedures and protocols developed by a previous Water Outreach Coordinator to work from. During the first year, the consultant can train City staff on sampling procedure and QA/QC. After the first year of sampling, the City can decide whether to perform sampling in-house or continue with contract sampling.

Additional Considerations

This project represents the first step in the development of the City Monitor Well Program. The following are project-related considerations for the continuation of the program.

- We believe the conclusions of this report are well supported by the data developed to date. While there are a host of additional questions of potential scientific interest, e.g. more details of groundwater flow and water-quality distribution within this general framework, decisions on additional monitor wells should be guided by identification of issues of genuine significance and relevant uncertainty with respect to City interests.

- Install a monitor well located directly east or northeast of City Springs in the State-of-Wyoming owned Section. Future development in or up-gradient from this area is unlikely. Thus, such a well should provide useful long-term “background” water-quality information.

- Extend the City Monitor Well Program to address recharge for the other three municipal wellfields – Soldier, Pope, and Spur – including coordination with the ongoing I-80 study.
- Develop a comprehensive City Monitor Well Program planning document that describes program objectives, status, and priorities for future work.
- Gather water-level measurements from the Triangle and South wells during any future pump testing at the Turner Wellfield.
- Secure the continued use of the Huntoon #1 and Huntoon #2 monitor wells for water level monitoring.

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Wyoming Groundwater, 2011, Downhole Camera Inspection of the Turner No. 1 Well, Consultant technical memorandum to the City of Laramie.

Table 1-1 - Summary of Project Area Stratigraphy. Laramie Monitor Well Project.		
Unit	Approximate Thickness (ft)	Description
Alluvium	0 - 20	Unconsolidated and poorly consolidated clay, silt, sand, and gravel. (Qa, Qac, Qs, Qf, Qt units of Ver Ploeg, 2009)
Satanka Shale	295 - 310	Red siltstone and soft sandstone, thin limestone beds, and local gypsum beds, especially near the top. Buff to orange to red, fine-grained sandstone with ripple marks common near base.
Casper Fm. – epsilon member	62 - 64	Pink to tan, medium- to fine-grained sandstone that grades into the overlying Satanka Shale. Sandstone is moderately cemented. In the Laramie area, there is no limestone capping the epsilon sandstone.
Casper Fm. – delta member	87 - 90	Top is a white-gray to pink, massive limestone (delta limestone-1: 6 to 8 ft. thick). Underlying strata are: reddish-brown to buff, thinly laminated sandstone (delta sandstone-1: 25 to 28 ft. thick); a pink to light-gray, massive, limestone (delta limestone-2: 15 to 20 ft. thick); a light-tan to red, calcareous, cross-laminated sandstone (delta sandstone-2: 35 to 36 ft. thick).
Casper Fm. – gamma member	73 - 86	Top is 13 ft. thick sandy grayish limestone (gamma linestone-1). Underlying strata are 50 to 60 feet thick pink to red, fine- to medium-grained, friable, calcareous sandstone with interbedded limestone units. One well on this project penetrated 29 feet of gamma sandstone-1 but did not fully penetrate the gamma sandstones and intervening limestones.
Casper Fm. – beta member	141 - 158	Top is 8 to 12 feet thick dense, highly fractured limestone. Underlying strata are red to buff, thick, moderately sorted sandstone layers with an interbedded dense, ridge-forming limestone, 18 to 26 feet thick. Project wells did not penetrate the beta member.
Casper Fm. – alpha member	266 - 375	Top is 29 to 40 feet thick limestone. Remainder of formation includes fine-grained sandstone unit, 75 to 80 feet thick, an 8 to 12 feet thick sandy limestone, a fine-grained sandstone, 65 to 80 feet thick, and a basal sandstone unit, 80 to 150 feet thick, that is slightly arkosic as it grades into the underlying Fountain Formation. Project wells did not penetrate the alpha member.

Table 2-1: Summary of Monitor Well and Temporary Borehole Field Data. Laramie Monitor Well Project.

Monitor Well	Ground Elevation ft. amsl	Total Depth, ft.	Surface Casing, ft.	Open Hole, ft. and Diameter, in.	Formation and Members Penetrated, ft.	Depth to Water*, ft.	Depth to Water, ft. (5/20/15) and WLE, ft. amsl	Water Conductivity µS	Geophysical Log, ft.	Top of Delta Limestone-1 Elevation, ft. amsl	Observations During Drilling
Triangle (Triangle Site)	7357.02	156.6	0 to 35	35 to 156.6 8 3/4	Satanka Shale: 5.4 to 29 Casper epsilon: 29 to 91.5 Casper delta: 91.5 to 156.6	60.2 ε 55.5 ε + δ	54.53 7304.61	398 to 428	HF: 81 and 84 HF: 100 HF: 124 HFZ: 151 to 154	7265.5	Air-lift production increases at 85 feet. Bit drop and fast drilling at 100 feet. Huge increase in air-lift production at 124 feet. Air-lift production at 155 feet estimated 380+ gpm. No lost circulation.
North (IHP Site)	7408.82	160	0 to 21	21 to 160 10	Casper epsilon: 13.5 to 27 Casper delta: 27 to 117.5 Casper gamma: 117.5 to 160	90.4 δ2 89.8 δ2 + γ1	88.83 7321.91	339 to 347	HFZ: 82 to 90 HFZ: 107 to 110 HF: 126 HF: 134 HF: 138	7381.8	Lost circulation at 124 feet due to fractures at 82 to 90 feet. Large increase in air-lift water production (250 to 300 gpm) at 135 to 137 feet.
South (IHP Site)	7413.86	163	0 to 20.8	20.8 to 163 8 3/4	Casper epsilon: 15 to 71 Casper delta: 71 to 158 Casper gamma: 158 to 163	92.3 δ1 92.3 δ1 + δ2	91.84 7324.06	482 to 537	HF: 81 to 82 HF: 96 HF: 102 HF: 104.5 HFZ: 122 to 123.5 HF: 157	7342.9	Lost circulation at 108 feet.
Temporary Borehole Middle (IHP Site)	7411.28	152	0 to 18.7 (temporary)	18.7 to 152 6	Casper epsilon: 17 to 59 Casper delta: 59 to 146.5 Casper gamma: 146.5 to 152	89.8 δ1 89.8 δ1 + δ2	89.60 7323.31	450 to 486	RFZ: 87 to 95 HF: 140	7352.3	Sandstones drill soft and fast. Limestones drill hard and slow. Air-lift water production at 152 feet is approximately 10 to 15 gpm. No lost circulation.

Notes: All depths in feet relative ground unless otherwise noted
*Depth to water measurements obtained during drilling and relative to top of casing at the time of measurement
HF = Horizontal Fracture as indicated by acoustic and optical image logs and caliper log
HFZ: Horizontal Fracture Zone (i.e. probable multiple fractures) as indicated by acoustic and optical image logs and caliper log
RFZ: Rubble and/or Fracture Zone

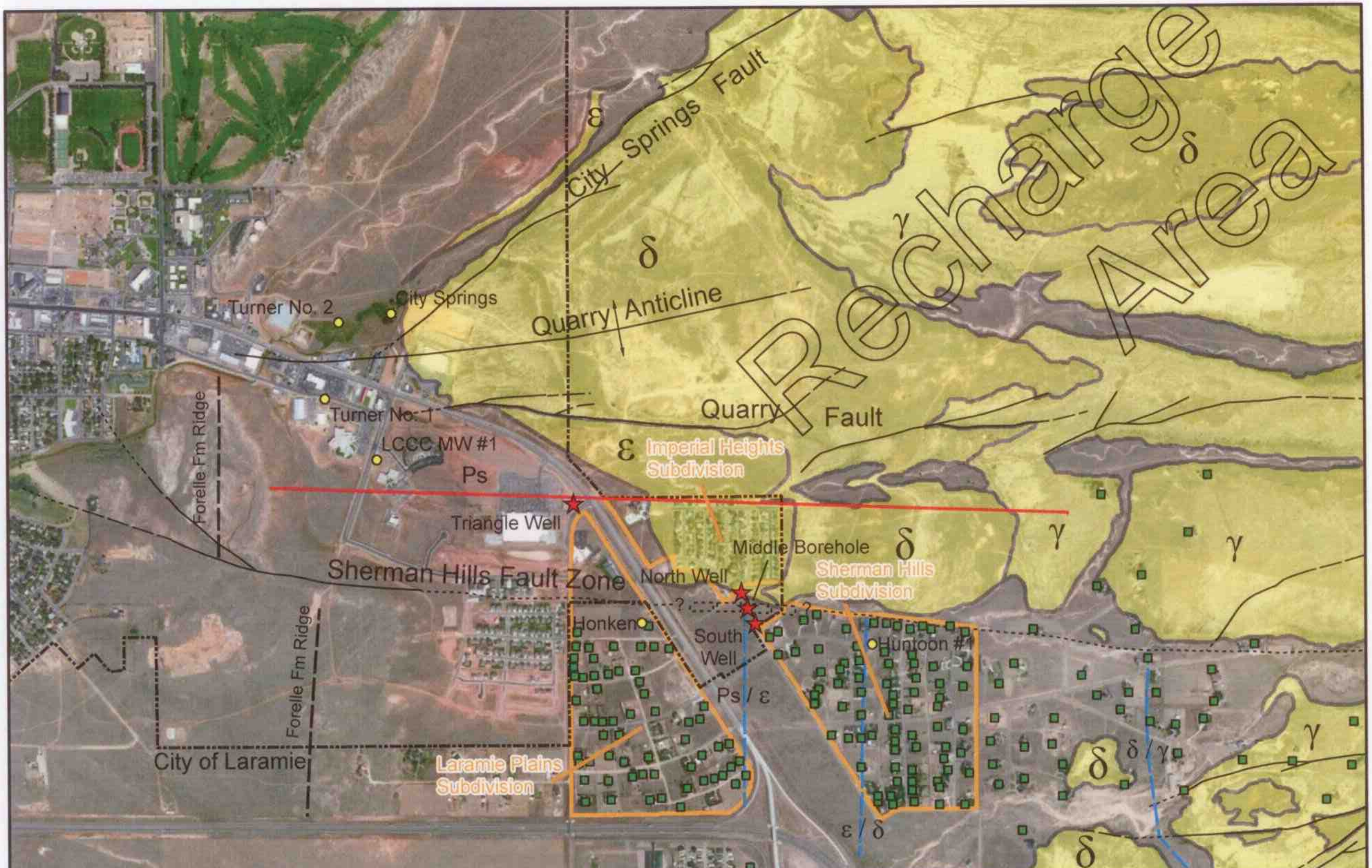
Table 2-2: Groundwater Elevations at Project Wells/Borehole. Laramie Monitor Well Project.				
Well/Borehole	Ground Elevation, ft.	Top of Casing Elevation, ft.	5/20/2015 Depth to Water*, ft.	Groundwater Elevation, ft. amsl
Triangle Well	7357.02	7359.13	54.53	7304.60
North Well	7408.82	7410.74	88.83	7321.91
South Well	7413.86	7415.90	91.84	7324.06
Middle Borehole	7411.28	7412.91	89.60	7323.31
Note: *Depth to water measurements are relative to top of casing				

Table 3-1 - Nitrate and Chloride Data. Laramie Monitor Well Project					
Sample ID	Sampled Interval (ft)	NO3 (mg/l as N)	Cl (mg/l)	Sample Date	Notes
Triangle Well					
T-70	55-70	3.2	12	3/31/15	airlift sample; Cond = 398 µS
T-92	55-92	3.5	11	3/31/15	airlift sample; Cond = 402 µS
T-126	55-126	4.8	15	3/31/15	airlift sample; Cond = 428 µS
T-155	55-155	4.2	12	3/31/15	airlift sample; Cond = 410 µS
Imperial Heights Park - North Well					
NW-104	90-104	1.6	3	4/6/15	airlift sample; Cond = 342 µS
NW-117	90-117	1.3	2	4/6/15	airlift sample; Cond = 339 µS
NW-160	90-160	1.1	NA	4/8/15	airlift sample; Cond = 347 µS
NW-ET160	90-160	1.3	2	4/23/15	pumped sample at 160 min, 400 gpm; Cond = 350 µS
NW-ET1390	90-160	2.2	6	4/24/15	pumped sample at 1390 min, 400 gpm; Cond = 370 µS
NW-END	90-160	2.3	7	4/25/15	pumped sample at 2900 min, 400 gpm; Cond = 374 µS
Imperial Heights Park - Middle Borehole					
MTH-99	88-99	5.8	NA	4/14/15	airlift sample; Cond = 415 µS
MTH-152	88-152	7.0	31	4/14/15	airlift sample; Cond = 484 µS
Imperial Heights Park - South Well					
SW-103	92-103	8.3	42	4/13/15	airlift sample; Cond = 537 µS
SW-PT	92-163	7.5	37	4/15/15	pumped sample at 125 min, 94 gpm; Cond = 519 µS
Note: NA – Not Analyzed					

Table 3-2 - Additional Water-Quality Data (mg/l). Laramie Monitor Well Project.

	North Well		Middle Borehole	South Well	
Sample ID	NW-104	NW-END	MTH-152	SW-103	SW-PT
Date	4/6/15	4/15/15	4/13/15	4/13/15	4/13/15
Sampled Interval (ft)	90-104	90-160	88-152	92-103	92-163
CO3	<5	<5	<5	<5	<5
HCO3	238	253	224	218	242
Calcium	63	61	70	75	74
Chloride	3	7	31	42	37
Magnesium	18	16	19	22	20
Nitrogen (Nitrate+Nitrite as N)	1.6	2.3	7.0	8.3	7.5
Potassium	2	<1	2	2	1
Sodium	3	4	17	24	20
Sulfate	10	11	25	29	25
Field Conductivity	342 µS	374 µS	484 µS	537 µS	519 µS
TDS (sum)	339	354	395	420	427

Table 4-1 - Laramie Monitoring Wells Testing Summary. Laramie Monitor Well Project.				
Triangle Well - Airlift Recovery Test, March 31, 2015				
Specific capacity of 62 gpm/ft estimated for 3-hr. pumping of a 12-in well based on transmissivity interpreted from recovery response.				
North Well - Step Tests, April 22; Constant-Discharge Test, April 23, 2015				
Discharge (gpm)	Duration (min)	Final Drawdown (ft)		
		North Well	Middle Borehole	South Well
49	30	1.06	0.05	0.02
100	30	2.38	0.09	0.04
197	30	5.66	0.13	0.08
432	30 (168)	13.61 (15.84)	0.51(1.09)	0.17 (0.45)
400	2,901	18.98	5.87	1.95
The 3-hr. specific capacity of the North Well at 432 gpm was 27 gpm/ft.				
South Well - Constant Discharge Test, April 15, 2015				
94	162	0.07	1.09	3.34
The 3-hr. specific capacity of the South Well at 94 gpm was 28 gpm/ft.				
Middle Borehole - Slug Test, April 28, 2015				
A brief injection test suggests a specific capacity of < 2 gpm/ft.				



- Septic Systems (2008 CAPP)
- Buried Contact (Inferred Location)
- Line of Section Figure 1-2
- Casper Formation Outcrop (with exposed contacts)
- Fault or Fold (dashed where buried)
- Fault Zone
- Exposed Contact

Ps - Satanka Shale
Casper Formation Members:
ε - Epsilon
δ - Delta
γ - Gamma

(Geology modified after VerPloeg, 2009)

0 1,000 2,000 Feet

Figure 1-1 - Location Map
Laramie Monitor Well Project

Figure 1-2 Casper Aquifer Schematic Cross-Section

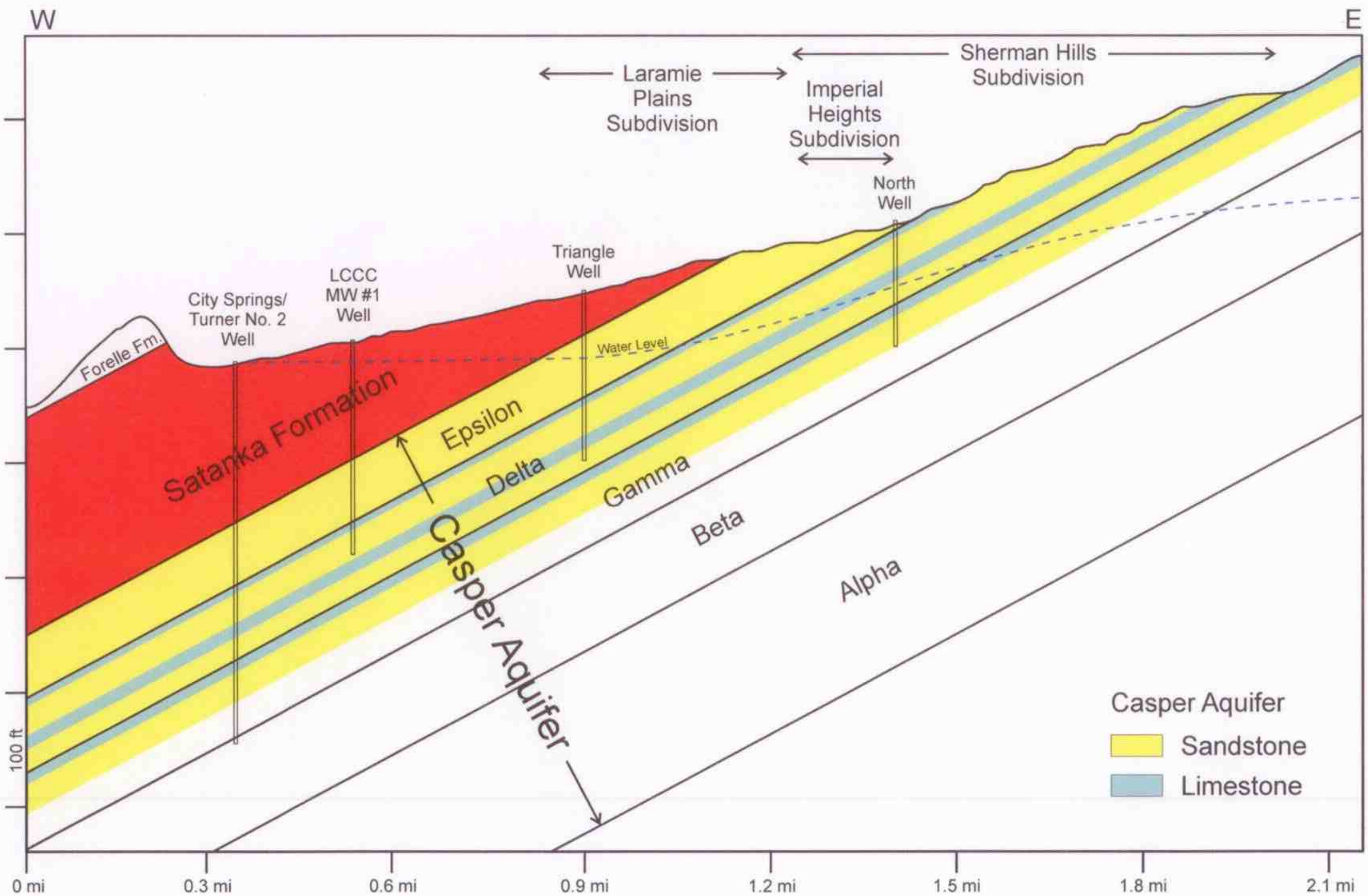
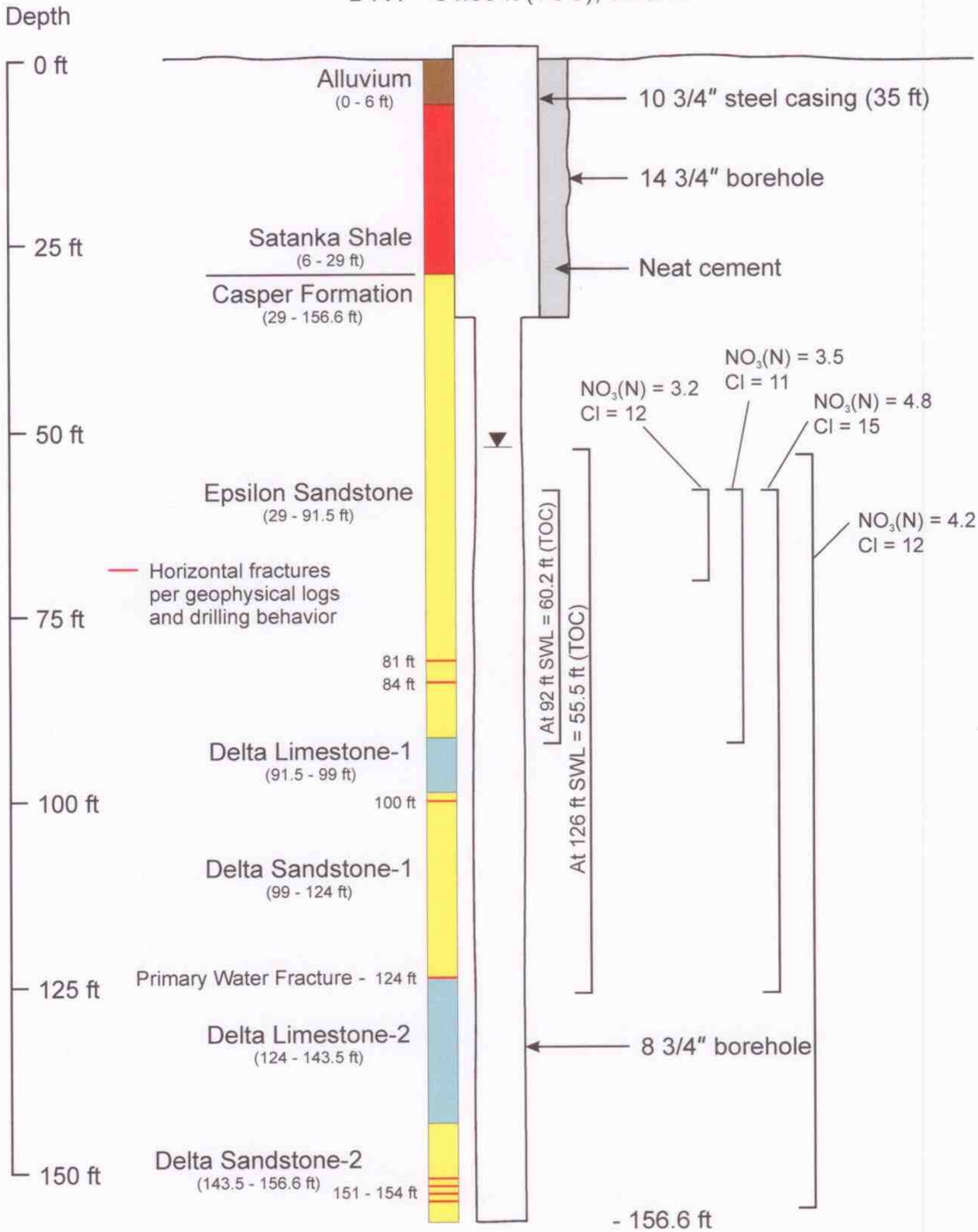
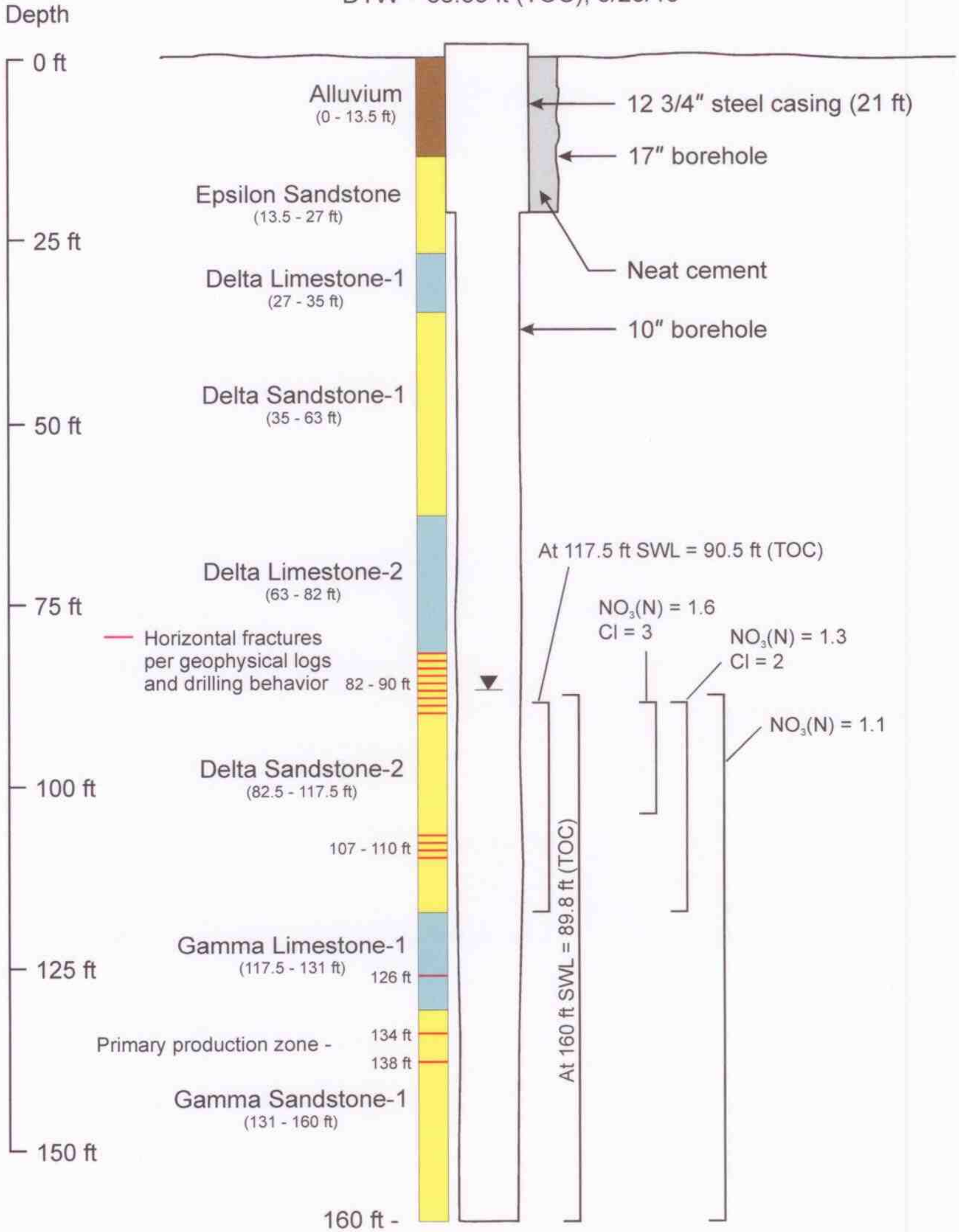


Figure 2-1 - Triangle Monitor Well
U.W. 203337; Ground Elevation: 7357 ft AMSL
DTW = 54.53 ft (TOC); 5/20/15



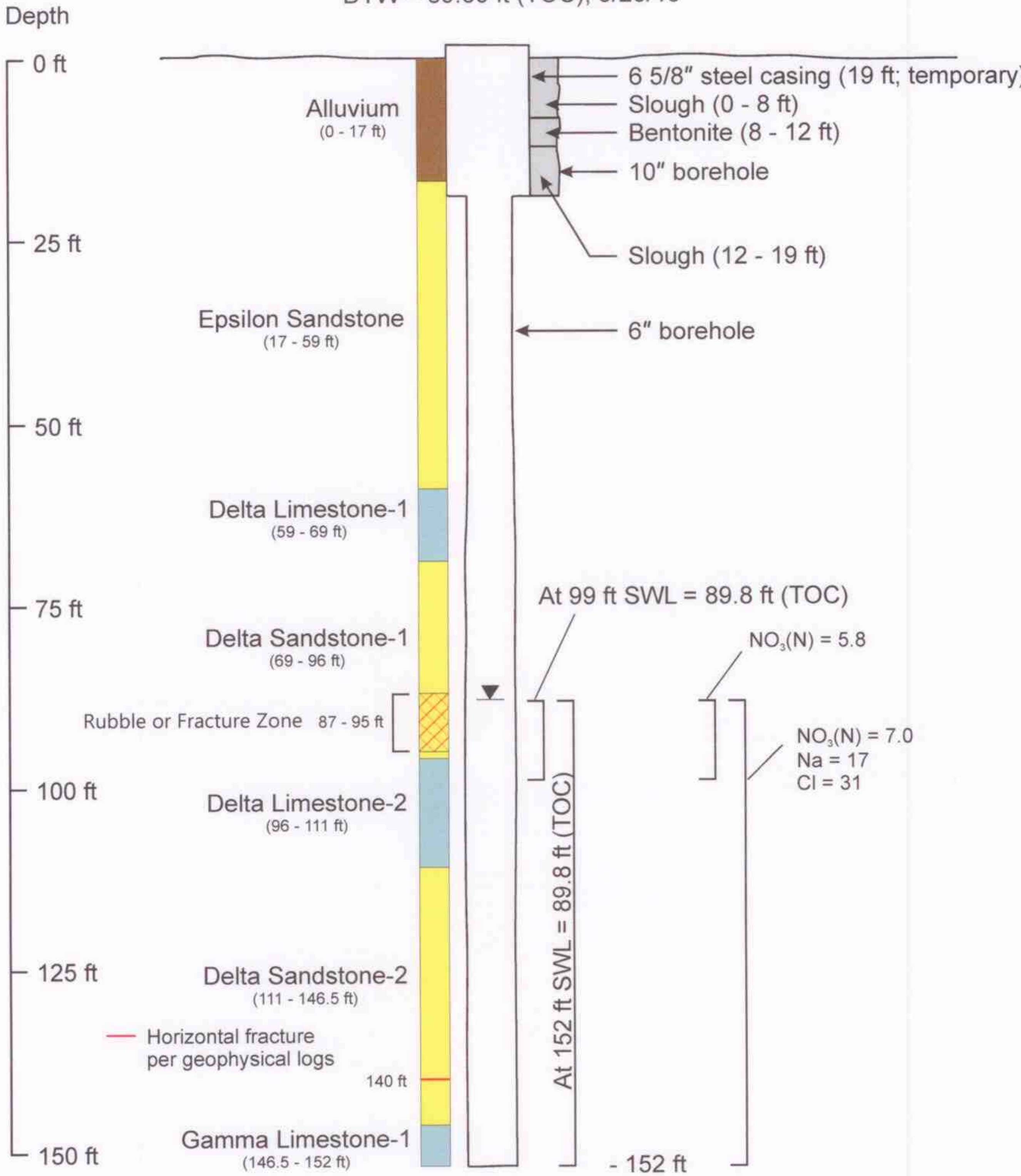
Note: TOC elevation = 7359.13 ft
All depths relative to ground unless otherwise noted

Figure 2-2 - Imperial Heights Park North Production Well
U.W. 203338; Ground Elevation: 7409 ft AMSL
DTW = 88.83 ft (TOC); 5/20/15



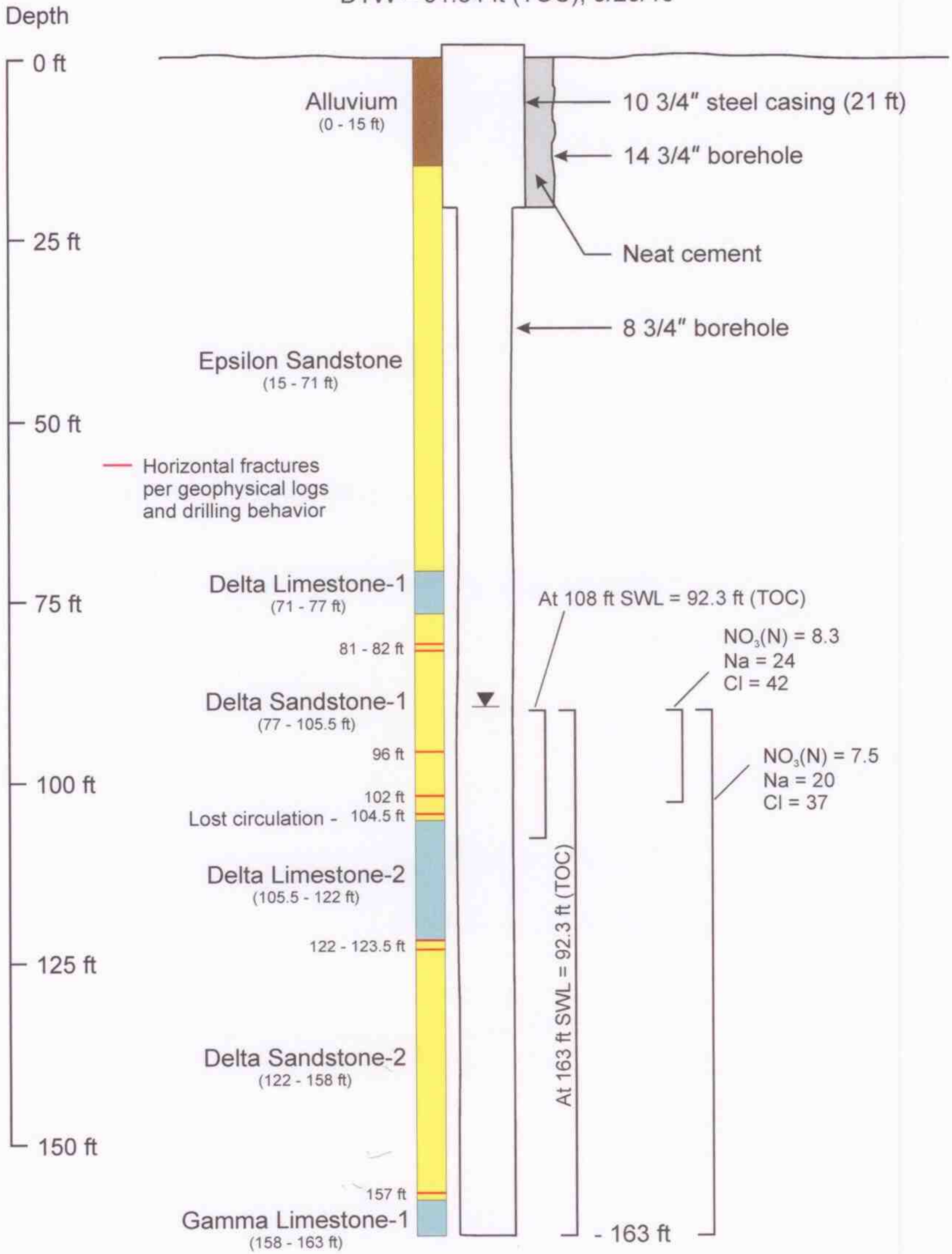
Note: TOC elevation = 7410.74 ft
All depths relative to ground unless otherwise noted

Figure 2-3 - Imperial Heights Park Middle Borehole (Temporary)
Ground Elevation: 7411 ft AMSL
DTW = 89.60 ft (TOC); 5/20/15



Note: TOC elevation = 7412.91 ft
All depths relative to ground unless otherwise noted

Figure 2-4 - Imperial Heights Park South Monitor Well
U.W. 203339; Ground Elevation: 7414 ft AMSL
DTW = 91.84 ft (TOC); 5/20/15



Note: TOC elevation = 7415.90 ft
All depths relative to ground unless otherwise noted

Figure 4-1 Triangle Well Recovery (380 gpm)

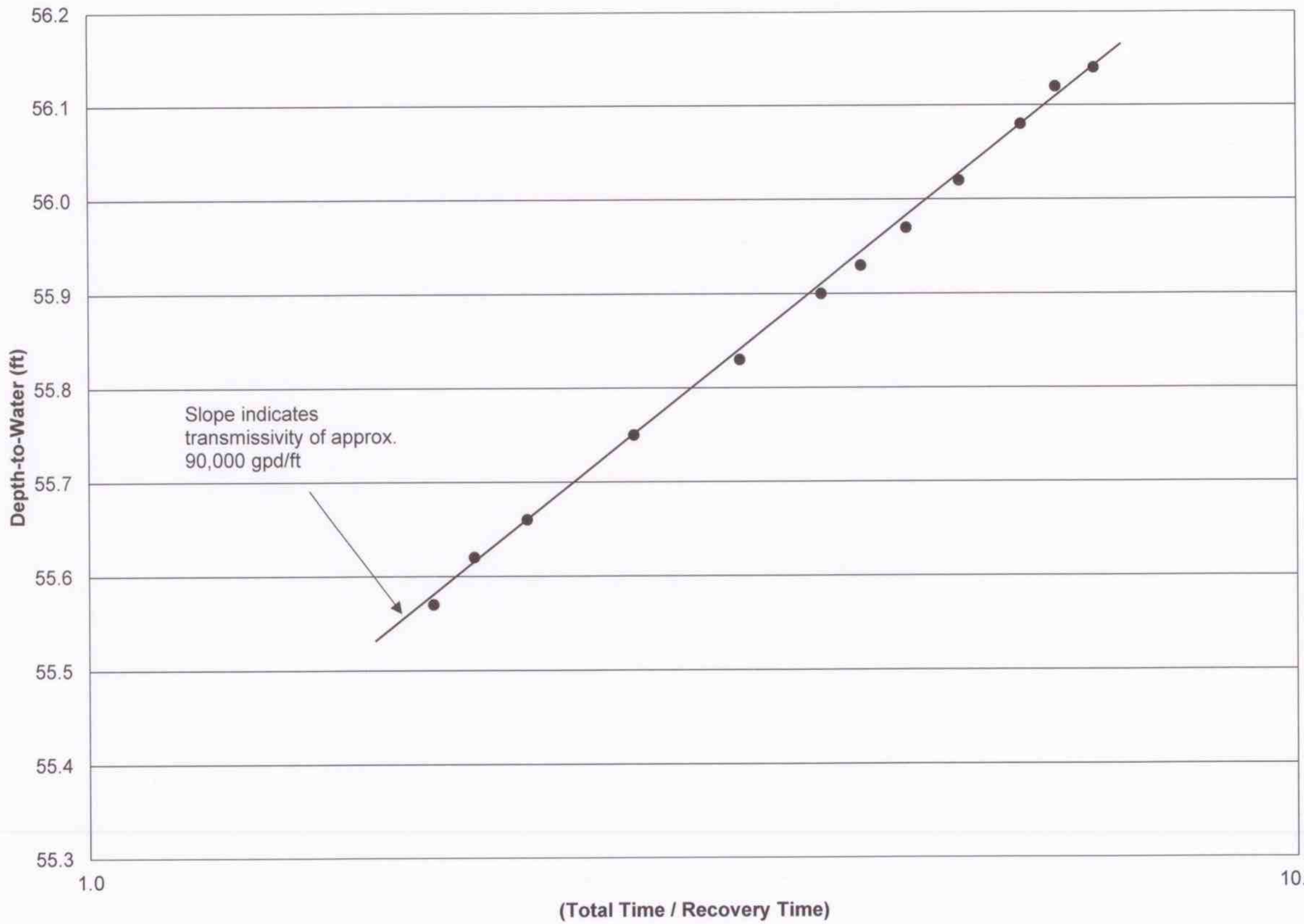


Figure 4-2 North Well Constant Discharge (400 gpm)

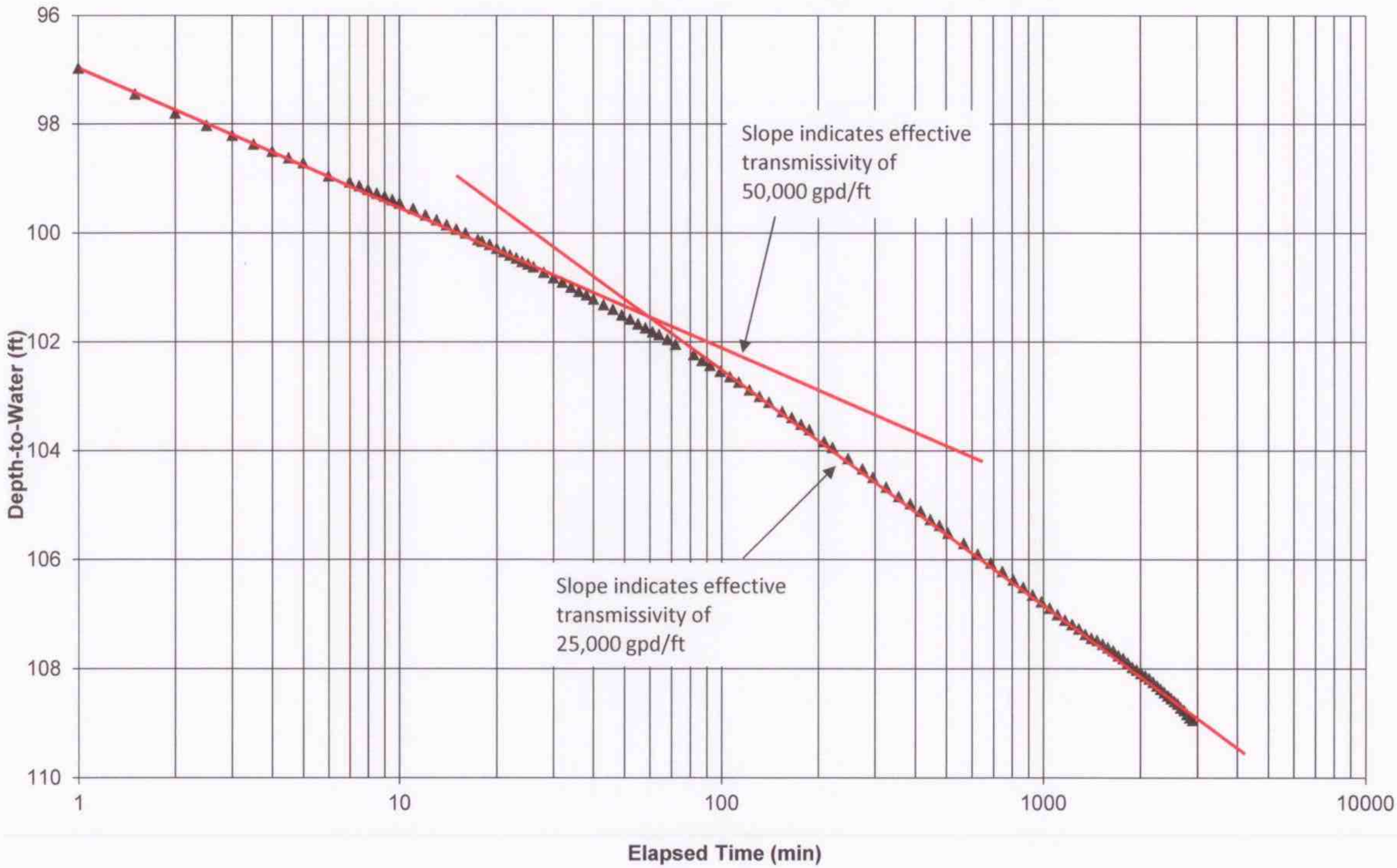


Figure 4-3 Middle Borehole as Observation Well (North Well at 400 gpm)

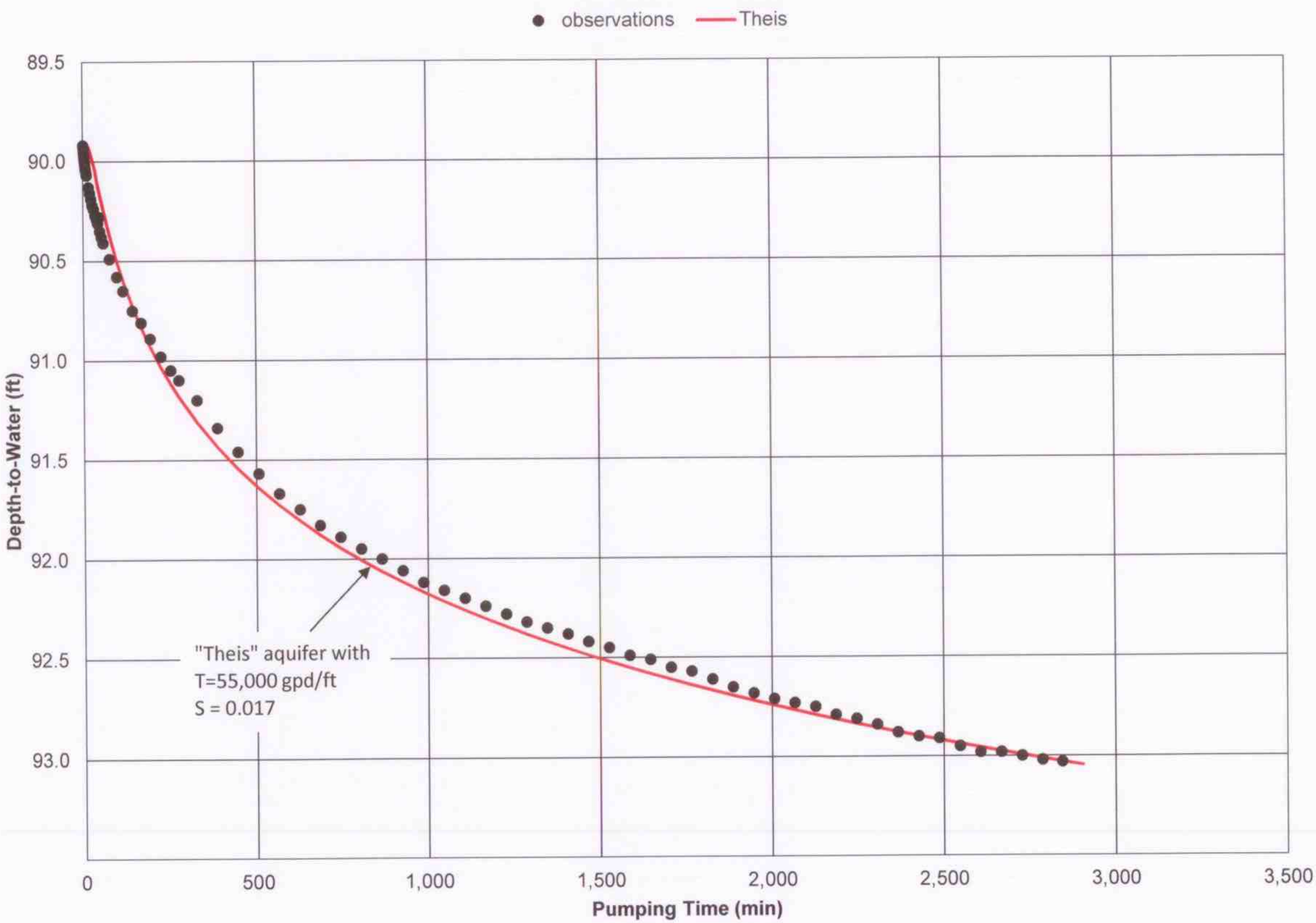


Figure 4-4 South Well as Observation Well (North Well at 400 gpm)

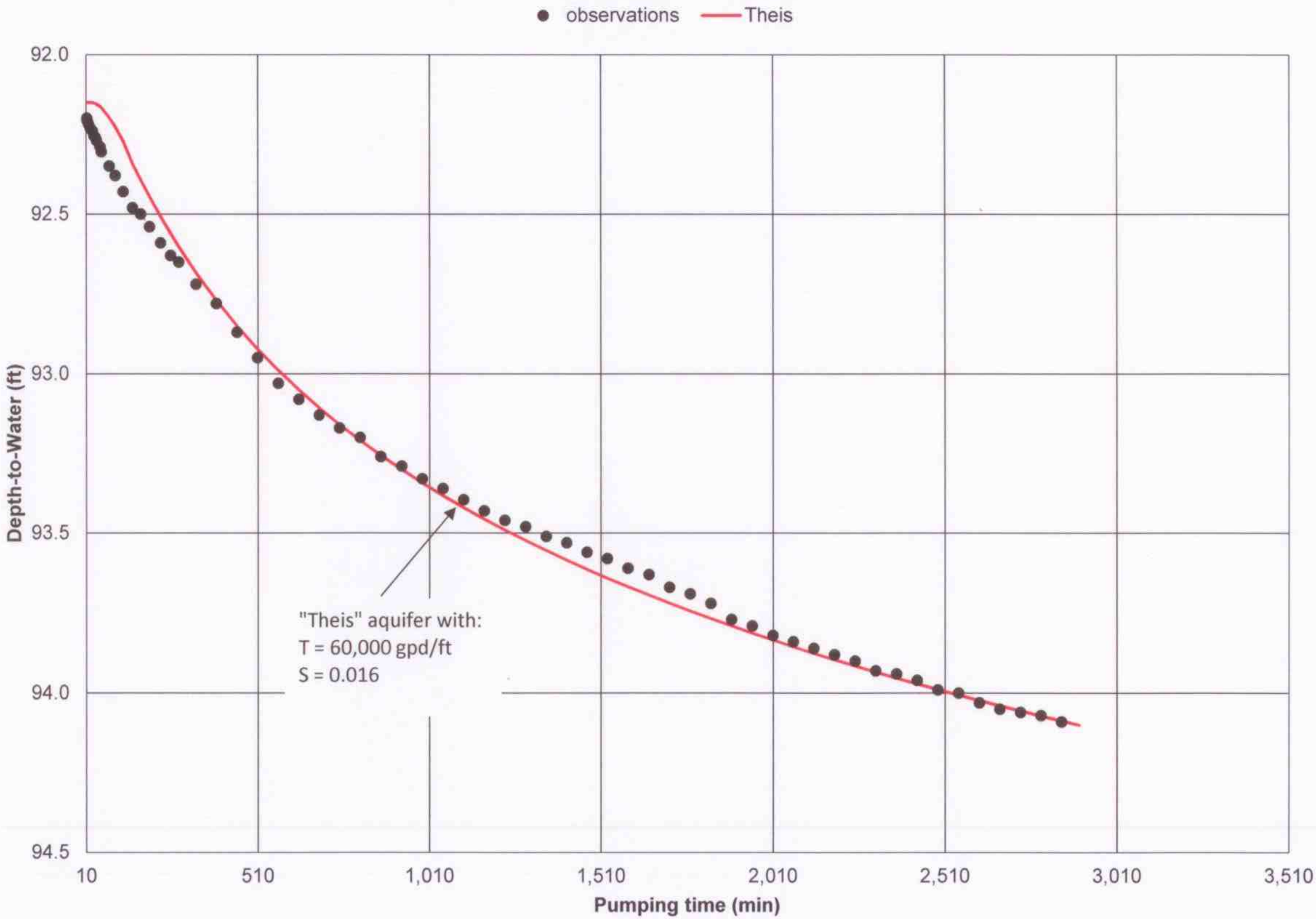


Figure 4-5 North Well Constant Discharge (400 gpm)
Conductivity

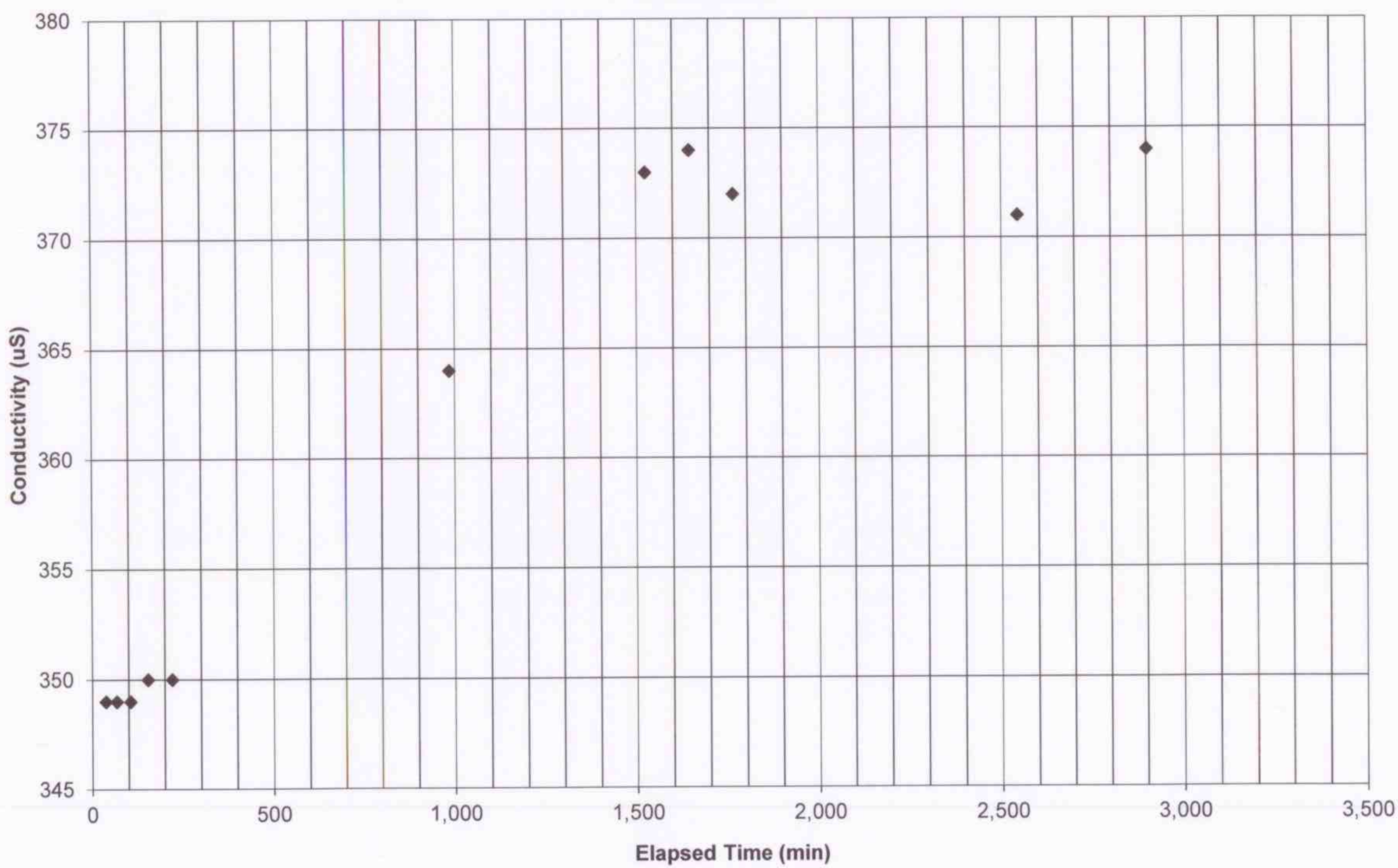


Figure 4-6 South Well Constant Discharge (94 gpm)

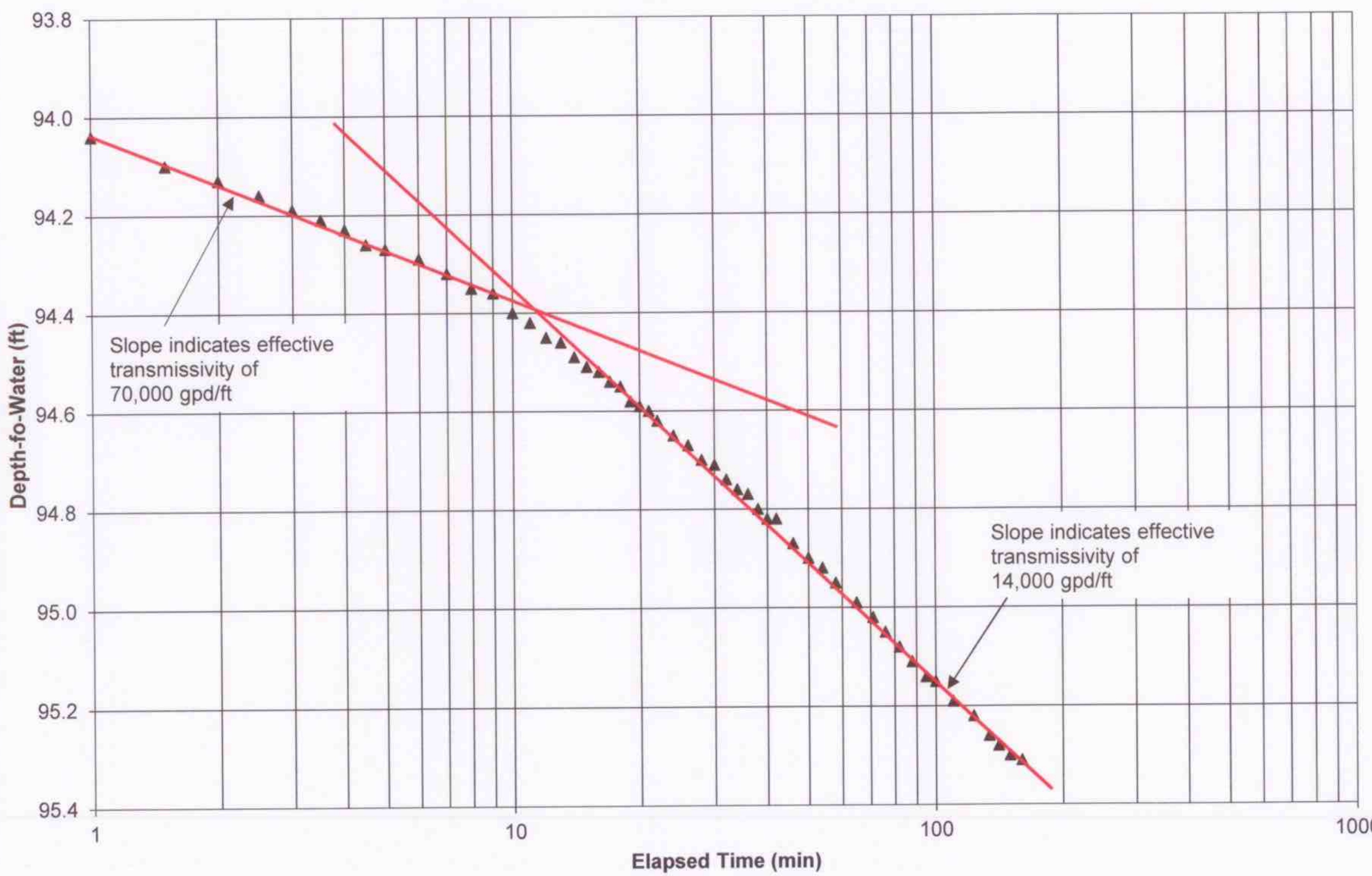
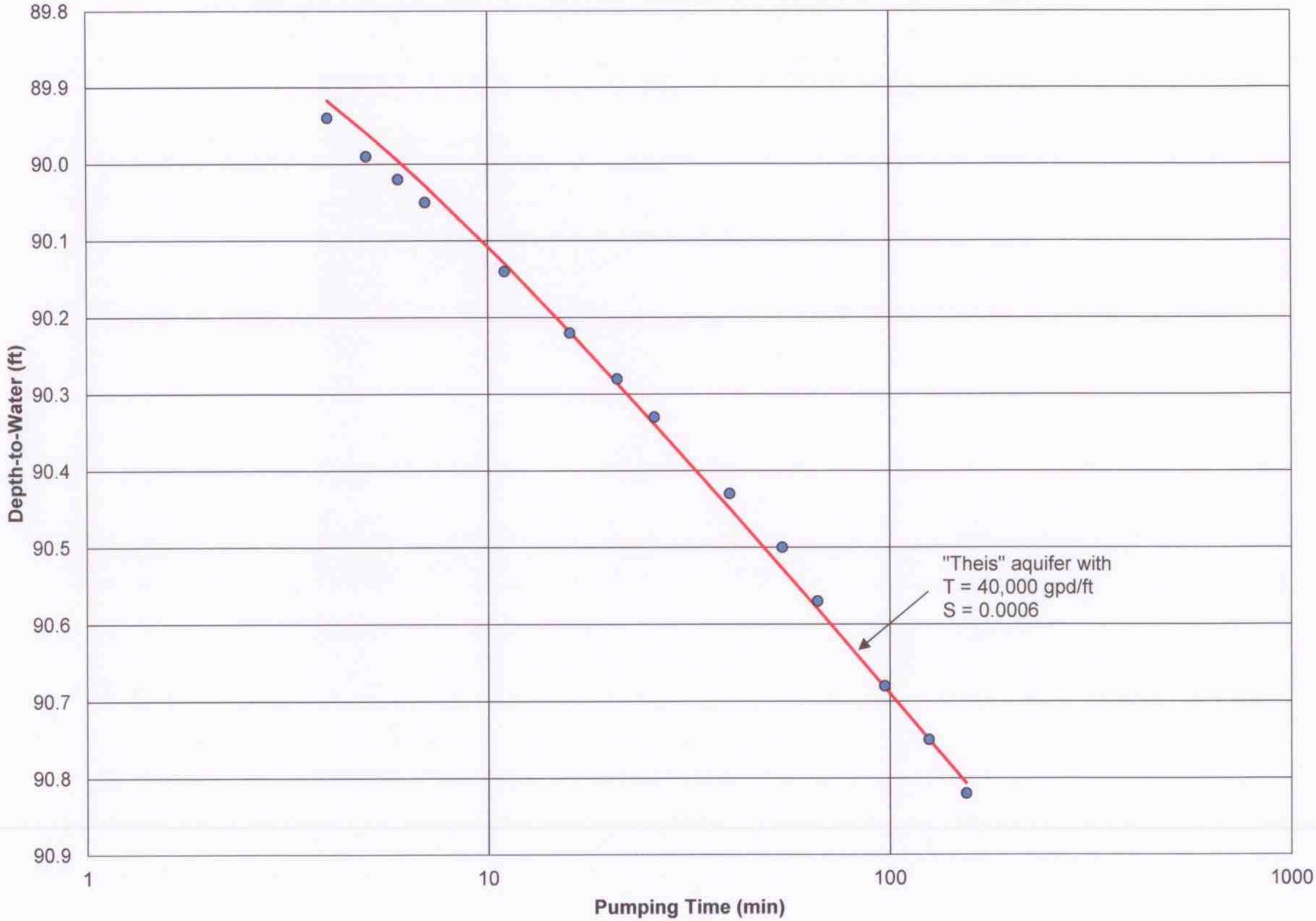


Figure 4-7 Middle Borehole as Observation Well (South Well at 94 gpm)



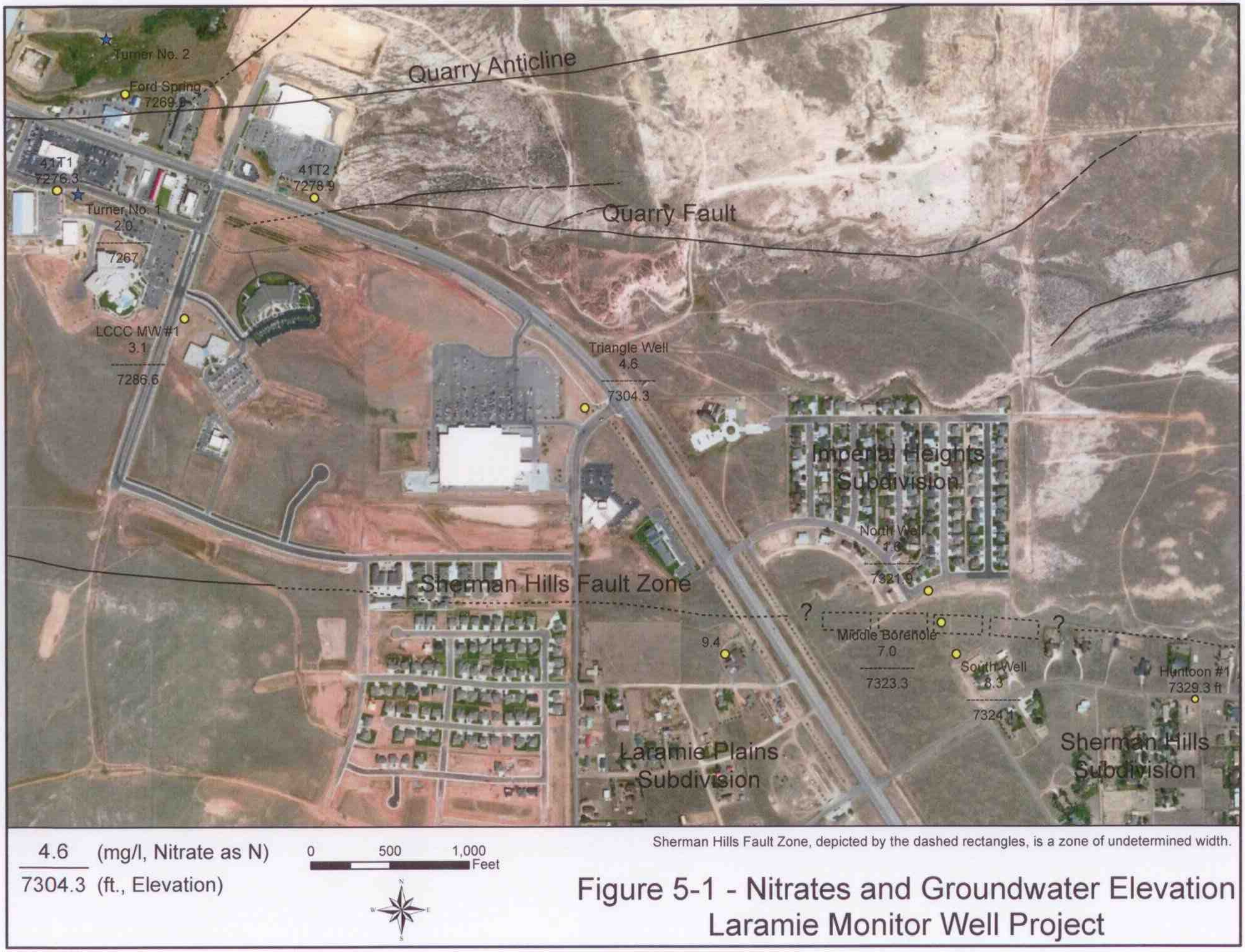


Figure 5-1 - Nitrates and Groundwater Elevation
Laramie Monitor Well Project

Figure 6-1 - Triangle Monitor Well
Recommended Final Well Completion

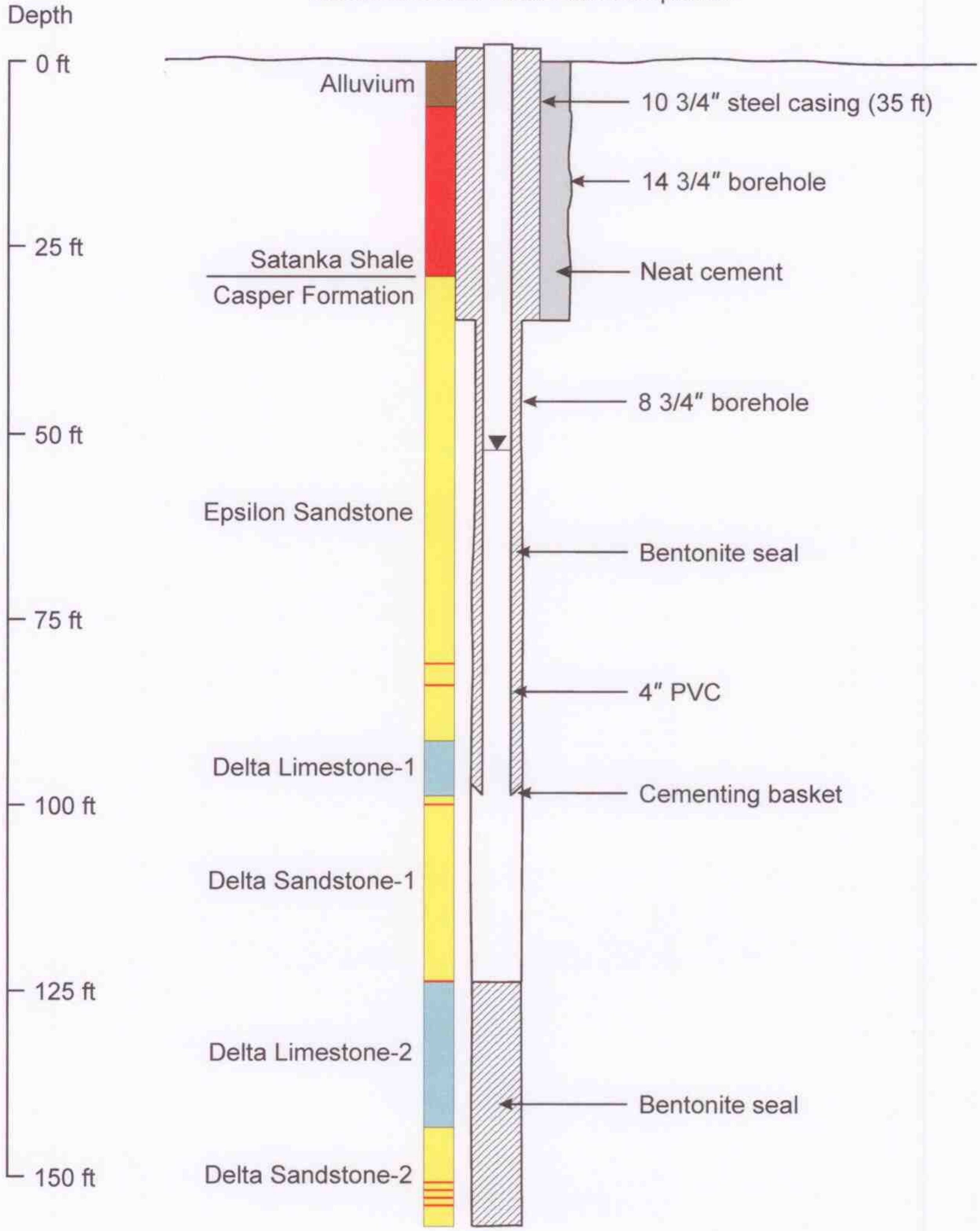


Figure 6-2 - Imperial Heights Park North Production Well
Recommended Final Well Completion

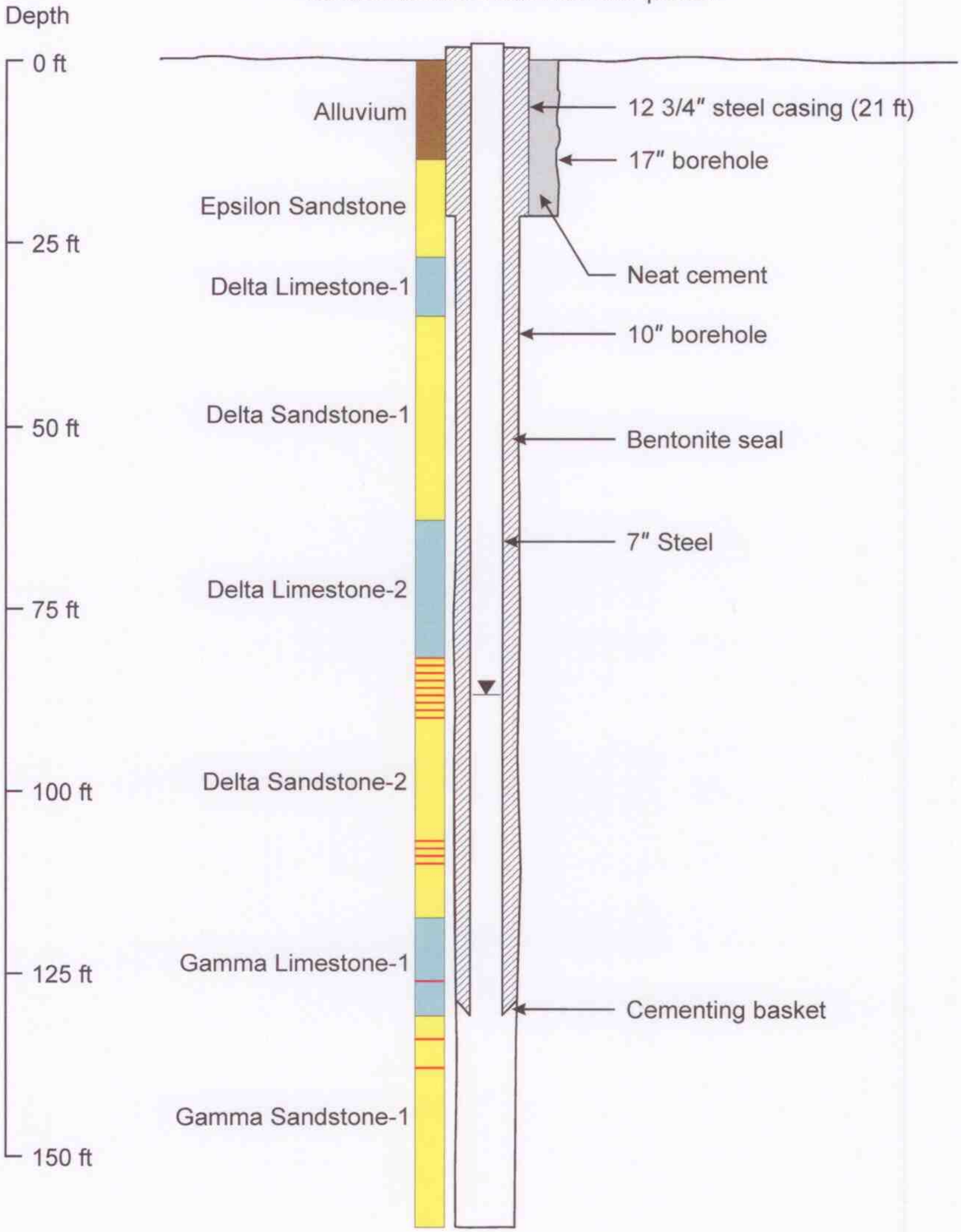


Figure 6-3 - Imperial Heights Park Middle Borehole (Temporary)
Recommended Borehole Abandonment

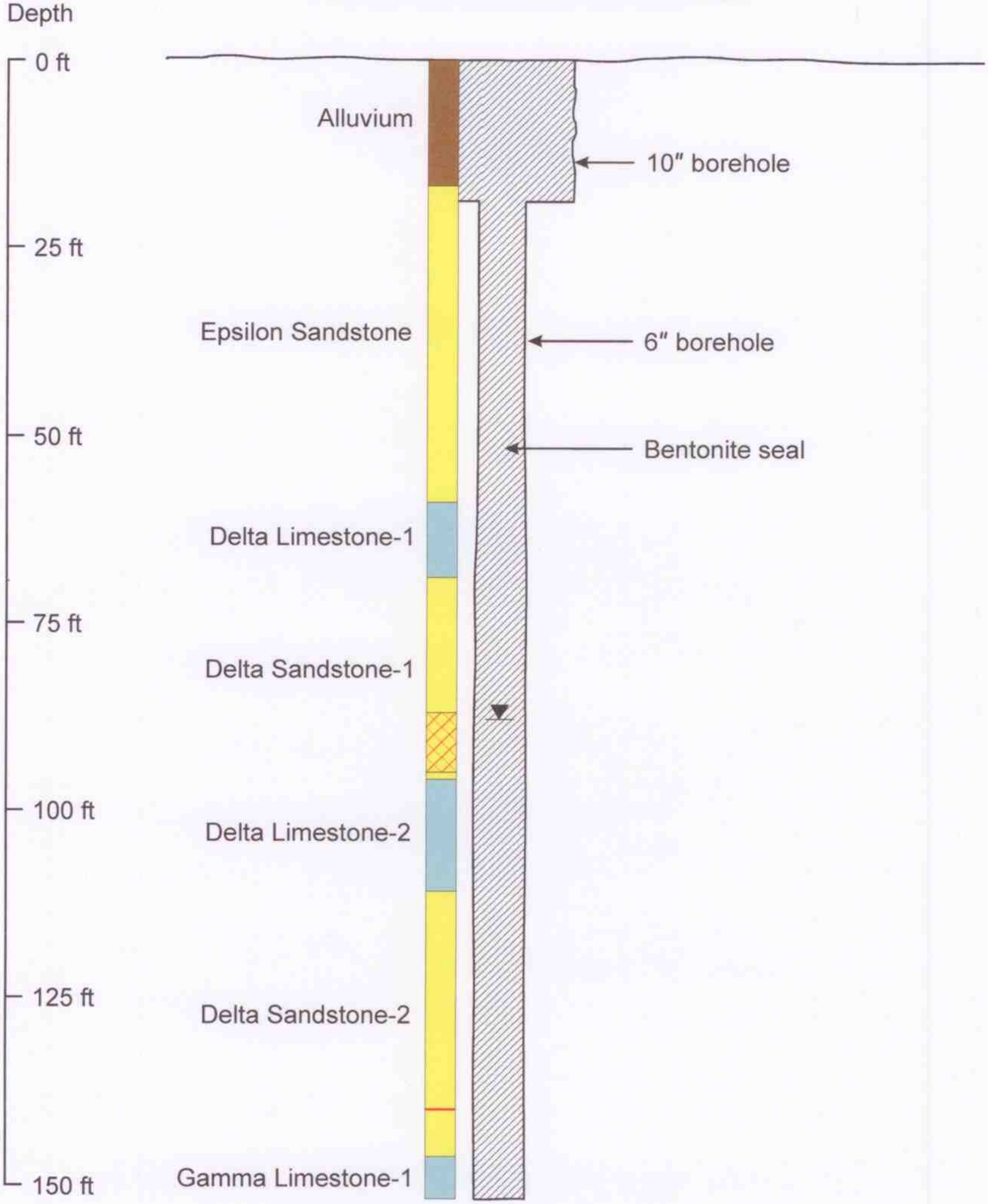
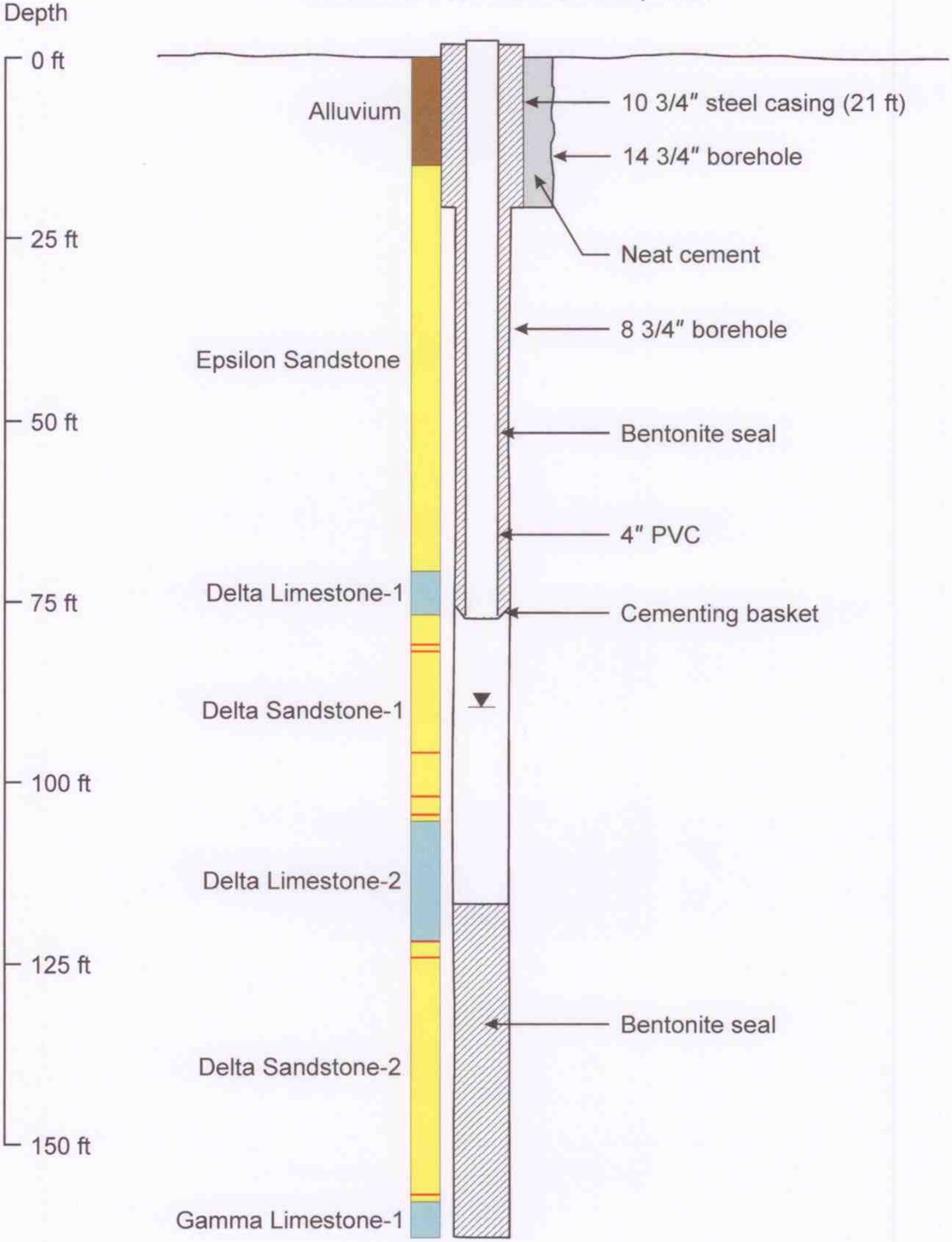


Figure 6-4 - Imperial Heights Park South Monitor Well
Recommended Final Well Completion



Appendix 1 - Phase I Report
Laramie Monitor Well Project

HINCKLEY
CONSULTING

WYOMING GROUNDWATER, LLC

LARAMIE MONITOR WELL PROJECT
PHASE I REPORT

TO: Darren Parkin, Water Resource Specialist
City of Laramie

DATE: October 15, 2014

FROM: Bern Hinckley - Hinckley Consulting   Chris Moody - Wyoming Groundwater

---

I. Introduction / Background

This report provides a systematic program for the initial construction of groundwater monitoring wells in the portion of the Casper Aquifer potentially contributing to the Laramie municipal Turner No. 1 and Turner No. 2 wells (see Fig. 1).

We first provide a cursory review of the history of concern with the aquifer and the associated reports, beginning in approximately 1993. This is followed by articulation of the objectives of this study and explanation of the hydrogeologic setting for the Turner Wells, with particular reference to those elements relevant to a program for long-term monitoring of water levels and groundwater quality. Individual monitoring well locations, first existing, then potential, are then examined with respect to project objectives and specific recommendations are presented to maximize the utility of well construction at each of three sites.

Approximately 50% of the municipal water supply for the City of Laramie currently comes from a series of wellfields developed in the Casper Aquifer. This aquifer is recharged over the hillside immediately east of the city. The municipal wells are located at the toe of that recharge area and are thus subject to whatever contamination may enter the aquifer across its exposed outcrop. The hydraulics of this aquifer have been studied for many years. Key references are included in the bibliography at the end of this memorandum.

The Casper aquifer is the source of City Springs, historically a critical source of water for steam locomotives and one reason Laramie was founded here in the first place. These and similar springs at Pope and Soldier were the initial water supply for the City. A surface-water treatment plant on the Laramie River was added in 1946. In 1982, in order to better manage the groundwater resource, the city began a program of well construction with completion of the Turner No.1 and Turner No.2 wells. Together these comprise the present Turner Wellfield, which is the focus of the present investigation.

Given the historical interest in the hydraulics of the aquifer (i.e. how water moves into, through, and out of the aquifer), there have been many measurements of groundwater levels. The most systematic of these in the project area is from the Huntoon #1 monitor well, for which measurements started in 1979 and continue to date (see Fig. 2).

Concern with the quality of groundwater in the Casper Aquifer is a more recent development. The first wellhead protection plan was produced by Western Water Consultants (WWC) in 1993. Following general EPA guidelines, that report focused on groundwater travel times to specific city wells. The report focused strongly on the role of faults as avenues of enhanced permeability guiding groundwater to the natural discharge areas subsequently targeted by municipal wells.

In the late 1990s, the focus of groundwater quality concern shifted from a wellhead focus to a more comprehensive view of the aquifer - recharge areas, groundwater flows, and identified and potential sources of contamination. A broad-based group of citizens and local hydrogeologists began creation of a Casper Aquifer Protection Plan (CAPP), the first version of which was finalized in 2002.

The 2002 plan included theoretical calculations suggesting groundwater nitrate levels[1] were likely to be substantially exceeding the EPA Primary Drinking Water standard ("maximum contaminant level" (MCL)) of 10 mg/l in the oldest of the subdivisions along East Grand Ave. (i.e. Laramie Plains) that still have individual septic systems. However, there were no comprehensive measurements of groundwater quality from the aquifer available to directly address contamination concerns. (Although there are a great many potential groundwater contaminants associated with septic systems, nitrates is the most common indicator due its ease of measurement and high concentration in septic system effluent relative to natural background levels.)

This continued to be the case through the 2008 update of the City of Laramie CAPP, for which the Contaminant Management Plan noted:

> "To date, there has not been a systematic, aquifer-wide, long-term groundwater monitoring program to assess water quality in the Casper Aquifer." (p. 91)

and concluded:

> "It is recommended that the City and County develop a program to routinely collect groundwater samples and water levels throughout the CAPA to establish baseline water quality data and to evaluate changes in groundwater quality over time. The baseline data collected from this program should be used to set standards for quantifying contamination in the Casper Aquifer. A systematic monitoring program has a secondary benefit of increasing understanding of the Casper Aquifer. The City of Laramie should

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[1]By convention, nitrate concentrations are typically reported as equivalent nitrogen, properly termed "Nitrate as N". That is the basis for the EPA standard of 10 mg/l. The difference is a factor of 4.45, i.e. actual nitrate = "Nitrate as N" X 4.45. "Nitrate" references throughout this report are all "Nitrate as N" values to allow ready comparison with EPA standards and other reports.

> continue to evaluate water-quality at the City wells in the current manner of comparing current results to historical concentrations and initiating additional sampling when results show increased concentrations.
>
> "A good monitoring program can provide an 'early warning' to the arrival of contaminated groundwater at a municipal supply well. The monitoring wells should be located throughout Zones 2 and 3 such that detection would provide enough lead time to either mitigate the in-coming contamination before it can reach a municipal well or to arrange for an alternate drinking water supply or treatment." p. 91)

The 2008 CAPP identified specific locations for monitor well construction, and recommended that "establishing a routine groundwater monitoring program be one of the City of Laramie's highest priorities for implementation." (Fig. F-1 and p. 60).

In 2009, with limited re-sampling in 2010, the City collected samples from 115 domestic wells across the Casper Aquifer recharge area. These data were analyzed by WWC Engineering (2013), who concluded that in the Laramie Plains and Sherman Hills Subdivision areas (their "Clusters" A and B) 100% and 45% respectively of the wells had been "impacted" by nitrate contamination[2], with 52% and 27% of those wells "significantly impacted" or "unsafe" (p. 8). They characterized the "risk to county residents" as "significant", but the "risk to city wells" as "low" (Laramie City Council presentation slides, July 13, 2010). A "statistically significant" trend of "slightly" increasing nitrate concentrations was cited for the Turner wells, but even very long-term projection of that trend fell well short of the EPA MCL.

In 2009, the City and County jointly began an investigation of possible mitigation measures for the aquifer contamination that could result from a hazardous materials spill on Interstate 80 where it traverses the recharge area in Telephone Canyon. The first report from the program (Trihydro, 2011) surveyed the vulnerability of the aquifer to this mode of contamination and outlined a series of potential monitoring, containment, and mitigation alternatives. As of this writing, additional feasibility studies and evaluation of possible I-80 monitor wells are on-going under that investigation.

As of January 2012, the City accounted their "investment in aquifer protection over the past two biennium" at $1,316,150 (1/25/12 letter to Gov. Mead from City Manager). The monitor well project is a continuation of that investment.

II. Project Area / Project Objectives

Because the density of potential and known sources of contamination is higher in the area east of the Turner Wells than potentially up-gradient of the other municipal wellfields, and because its

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[2]The "impacted" designation was applied to all samples with nitrate concentrations over the natural background level of "less than 2 mg/L".

proximity to the city provides continuing development pressure, the Turner area was selected for this initial development of a focused monitor well program.

The project area for this report is the City of Laramie Turner Wellfield, consisting of the Turner No.1 and Turner No.2 municipal wells, and the portion of the Casper Aquifer potentially contributing groundwater to those wells. The 1993 WWC report suggested the "zone of contribution" for the Turner Wells is entirely north of the Sherman Hills Fault, i.e. something of a groundwater collection network via the Quarry, City Springs, and Jackrabbit fault zones. Review comments on the 1993 report by long-time U.Wyo geology professor Peter Huntoon disagreed, opining that the "major contributing zone for City Springs" extends up to 2 miles south of that fault. (The role of the Sherman Hills Fault in groundwater movement related to the East Grand Avenue subdivisions continues to be a major point of discussion.)

The previous identification of "potential and known sources of contamination" in the 2008 CAPP clustered along East Grand contrasts markedly with the mostly undeveloped area north of the Quarry Fault (see Fig. 1). Future development pressure based on land ownership and simple developability (topography, access, utilities, etc.) is also greatest in and around the area of existing development. Thus, attention is focused on the southern portion of the potential recharge area for the Turner Wells. This encompasses the area from the Turner wells east to the point where no further development is present on the aquifer and south from the Turner wells to the vicinity of the East Grand Ave. / Interstate-80 interchange.

As discussed further below, contamination above background levels is widespread in the developed portion of the project area, but groundwater quality is in nearly all cases well within EPA standards for public water supplies[3]. This project is not predicated on acceptance of "legal" as the threshold of concern, but rather on an objective of the Laramie municipal water supply remaining as free of contaminants as practically possible. Thus, the presence of contaminants at concentrations below regulatory levels, but above natural background, and of contaminants for which no specific health thresholds have been established are of interest.

The objective of this project is to start a program of consistent, focused groundwater monitoring to better understand the occurrence and movement of potential contaminants in the Casper aquifer tributary to the City of Laramie municipal water supply wells.

III. Hydrogeologic Setting

The project area aquifer consists of the saturated sandstones and limestones of the Casper Formation, which receives recharge across its outcrop area east of the city (see Fig. 1). Absent disruption by faulting and folding, which are understood to provide locally enhanced permeability, the Casper consists of a series of sandstone subaquifers (members designated epsilon, delta, gamma, beta, alpha, from top to bottom) sandwiched between low-permeability limestone layers (see Fig. 3). Faults and folds with substantial surface expression are included

[3]EPA regulations do not apply to domestic wells.

on Figure 1, the geologic mapping for which was performed by the Wyoming Geological Survey (VerPloeg, 2009).

Stratigraphy: Table 1 summarizes the stratigraphy of the project area. Lithologic descriptions are condensed from VerPloeg (2009) with modifications to reflect local conditions and thicknesses as reported in local wells and observed in downhole video (e.g. Turner No. 1, Turner No. 2, 41T2). The overall thickness of the Casper Fm. is approximately 700 ft. With the exception of the uppermost member (epsilon), each member is capped with a continuous limestone bed.

Table 1 - Summary of Turner Wells Area Stratigraphy

Unit	Approximate Thickness (ft)	Description
Quaternary deposits	0 - 20	Unconsolidated and poorly consolidated clay, silt, sand, and gravel. (Qa, Qac, Qs, Qf, Qt units of VerPloeg, 2009.)
Chugwater Formation	650 - 800	Red shale and siltstone with interbedded red to salmon to buff, fine-grained sandstone.
Forelle Limestone	10 - 30	Gray to purple, thin bedded limestone locally interbedded with red siltstone and thin gypsum laminations.
Satanka Shale	295 - 310	Red siltstone and soft sandstone, thin limestone beds, and local gypsum beds, especially near the top. Buff to orange to red, fine-grained sandstone with ripple marks common near base.
Casper Fm. - epsilon	62 - 64	Red to pink , medium- to fine-grained sandstone. Grades into the overlying Satanka Shale. Porous sandstone that is poorly to moderately cemented.
Casper Fm. - delta	106	Top is a 10-13-foot-thick , white-gray to pink , massive, fractured limestone. Underlying strata are: reddish-brown to buff, thinly laminated, 19 - 24 ft. thick sandstone; 15-19-ft pink to light-gray , massive, fractured limestone; and 50-ft. light-tan to red, calcareous, cross-laminated, porous sandstone.
Casper Fm. - gamma	73 - 86	Top is 7 ft thick sandy grayish limestone. Underlying strata are 50 to 60 feet thick pink to red, fine- to medium-grained, friable, calcareous sandstone with interbedded limestone units (not extensive).
Casper Fm. - beta	141 - 158	Top is 8 to 12 feet thick finely crystalline, purple to pink , dense, highly fractured limestone. Underlying strata are red to buff, moderately resistive, extremely calcareous, thick , moderately sorted sandstone layer with an interbedded dense, ridge-forming limestone, 18 to 26 feet thick .

Casper Fm. - alpha	266 - 375	Top is 29- to 40- foot thick limestone. Remainder of formation includes light-brown to reddish-brown, poorly sorted, fine-grained sandstone unit, 75 to 80 feet thick, an 8 to 12 feet thick, pink to purple, sandy limestone, a pink to brown, calcareous, cross-laminated, medium sorted, fine-grained sandstone, 65 to 80 feet thick, and a basal sandstone unit, 80 to 150 feet thick, that is slightly arkosic as it grades into the Fountain Formation.
Fountain Formation	0 - 30	Coarse-grained pink to red to purple sandstone and arkose, with some conglomerates, siltstones and shales.
Precambrian		Sherman Granite

The Satanka is generally recognized as a “confining” bed due to the low permeability of its shale and siltstone units. The Satanka outcrop is used, in various forms, to mark the western edge of the Casper aquifer recharge area. The 1993 wellhead protection study (WWC) recognized that the overlying Satanka Shale “is a good confining layer”, but included “except where the confining integrity is lost due to fractures”. Noting the occurrence of Casper-sourced springs issuing from the Satanka, the authors extended the suggested wellhead protection plan up to 0.5 miles west of the Satanka - Casper contact, “where a local reversal in the vertical gradient in the area of the Turner and Pope Well Fields may induce leakage from the Satanka” (p. 45).

The role of the Satanka is discussed in the various versions of the CAPP. The 2002 CAPP concluded that a thickness of 75 ft. of Satanka overlying the Casper was sufficient to preclude surface-based contaminants from entering the aquifer, and established land use protections accordingly. For ease of application and in recognition of uncertainties in where the desired 75 ft. is present, the 2008 CAPP revised the aquifer-protection boundary westward to conform with established survey lines. The 2011 Albany County version of the CAPP[4] did not make this adjustment, leaving two different western boundaries for the formal aquifer protection area. For the present project, the relevant difference is primarily the western 2/3 of the Laramie Plains subdivision. We have adopted the City CAPP boundary and included the entirety of this subdivision in the area of potential contaminant sources due to uncertainty in the integrity of the Satanka Shale as a sealing unit.

The character of the individual members of the Casper is important to our project to the extent they control the flow of groundwater and potential contaminants. While it is commonly understood that the limestone strata separating these members are relatively impermeable where they are unfractured, there are many zones of fracturing in the Casper, e.g. commonly associated with faults and folds. Such zones have been identified as “vulnerable features” since the first wellhead protection plans and CAPPs were developed due to their expected role as conduits for groundwater flow into and through the Casper aquifer. While previous investigators have widely

[4]Prior to 2008, there was a single City and County CAPP developed jointly. In 2008, differences of opinion led to creation of separate CAPPs. Unless otherwise specified, the “CAPP” referred to in this report is that approved by the City in 2008.

acknowledged the likely locally confining nature of the limestone strata, their interpretations of water table (or head) surfaces have not suggested anything but a single integrated water table. Detailed video logs of the Turner No. 1 and No. 2 wells documented significant horizontal fractures within the sandstone strata of both the epsilon and delta members, e.g. “large open horizontal fracture” (epsilon, Turner No. 1), “very large horizontal openings and bedding plane fractures in sandstone (delta, Turner No. 2); (Wyoming Groundwater, 2004 and 2011). Thus, the concept of fracture-enhanced permeability in the Casper should be extended beyond the conventional focus on fault / fold / fracture systems to include more horizontal features.

Subject to further investigation (see below) our working hypothesis is that fracturing is sufficient to largely homogenize water levels beyond the local level.

The epsilon member of the Casper is commonly identified by as having the greatest intrinsic (i.e. absent fracturing) permeability of the five members of the Casper (e.g. Thompson, 1979; WWC, 1995) and the upper Casper (epsilon and delta members) is “the primary water producing zone” (WWC, 1995; p. 6-1). The epsilon has been the most developed member for groundwater, both because it is generally productive (where saturated) and simply because it is the first unit encountered in most areas. Careful testing of the 41T2 well suggested that production declined once productive fractures in the delta member were dewatered at that location (WWC, 1996).

Subject to further investigation, our working hypothesis is that the epsilon and delta members form the most productive portion of the Casper aquifer, with the gamma, beta, and alpha members being generally less productive. However, isolated testing of the alpha member at the 41T2 well along the Quarry Fault found a specific capacity[5] of 6.8 gpm/ft (WWC, 1996), a value as high as the better epsilon and delta member wells in the east Grand Ave. subdivisions.

The Turner No. 1 well is completed in the epsilon and delta members; the Turner No. 2 well is completed in the epsilon, delta, gamma, and beta members (WWC, 1996). However, pump testing of the alpha member at 41T2 well (WWC, 1996) demonstrated that both Turner wells are in hydraulic connection with the entire Casper Fm., presumably as a result of the hydraulic homogenization in this area of intersecting faults, fractures, and the Quarry Anticline.

Structure: Figure 1 presents the most detailed published geology of the project area (VerPloeg, 2009), modified as follows for the present report:

- The contact between the epsilon and delta members of the Casper Fm. has been refined in the vicinity of the Sherman Hills Fault based on direct field inspection. Specifically, the limestone bed at the top of the delta member can be observed in the drainage along the south side of the Imperial Heights subdivision.

[5]Specific capacity is the production rate divided by the drawdown, e.g. a well than produces 20 gpm with only 2 ft of drawdown has a specific capacity of 20 gpm/ft, and is much more productive than a well with a specific capacity of 2 gpm/ft.

- The contact between the Satanka Shale and the epsilon member north of the fault has been taken from Lundy (1978) to project through the area for which VerPloeg (2009) mapped only the surficial deposits (rather than interpreting the underlying bedrock).

- South of the Sherman Hills Fault, the Satanka/epsilon, epsilon/delta, and delta/gamma contacts have been projected beneath the cover of unconsolidated material (alluvial fan, terrace, and eolian deposits) based on well logs and the westward dip of the strata.

The magnitude of the westward dip of the Casper and overlying formations is calculated from pairs of wells in which a specific stratum is identifiable from the available logs. For example, the Huntoon #1 (P35758) well hit the limestone at the top of the delta member at 40 ft. The Honken (P99001) well hit the top of the epsilon member at 102 ft., addition of the epsilon thickness of 63 ft. puts the top of the delta at 165 ft. (The Honken well stopped at 150 ft., in the epsilon.) These two wells are 3,000 ft. apart, perpendicular to strike, and 80 ft. different in surface elevation. Thus, the indicated formation dip is 3.9º. Similar geometry from other well pairs indicates similar dips, i.e. around 4º. This compares with dips of 3º and 4º mapped by VerPloeg on outcrops of the Forelle Limestone on both sides of the fault and with 3º on the Casper just east of Imperial Heights.

The effect of displacement of these westward-dipping strata along the Sherman Hills Fault is readily apparent in the "jog" in the Forelle Limestone ridge running south from the Turner Wells. This ridge is approximately 1600 ft. further west on the north side of the fault than on the south side. At the dip calculated above, an equivalent vertical displacement of approximately 100 ft. is indicated. Lundy estimated a displacement of 65 ft. at a point with Casper Fm. exposure on both sides of the fault one mile east of the Imperial Heights Park, consistent with displacement decreasing eastward and subsequent attenuation of the mapped fault in that direction.

Due to the cover of unconsolidated material, the exact character and location of the Sherman Hills Fault is uncertain. (It is consistently mapped as "covered" through most of our project area.) Recent geophysical investigations by the University of Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG) on the University property along East Grand Avenue and on the City's Imperial Heights Park found the main fault trace beneath the northern portion of the park, with an indicated displacement of approximately 60 ft. and a steep northward dip (approx. 77º). The fault is a high angle reverse fault, up on the north and down on the south. North of the fault, a coherent bedrock block is indicated by the geophysics, which is consistent with the observable outcrop. South of the fault, the geophysical characteristics suggest a zone of disrupted strata, e.g. subsidiary faults or associated fracturing.

Figure 6 presents a schematic cross-section from the Turner Wells to the middle of the Sherman Hills subdivision. Particularly north of the Sherman Hills Fault, the geometry is not well constrained by wells or outcrop data. The intersection of various folds and faults may create complex permeability distributions and groundwater flow patterns.

Groundwater Flow: Once recharge from the surface reaches the water table, it will flow horizontally along with the groundwater to which it is added, in response to groundwater gradients. Groundwater, like surface water, runs “downhill”, although the groundwater “hill” is defined by the water table (or potentiometric head surface). Figure 4 provides an approximate contour map of groundwater head for the project area based on measured depths-to-water in various wells. Although limited to carefully-measured values, mostly from November, 2005 (WWC Engineering, 2006) some other sources and dates are included. (Consideration of Figure 2 demonstrates the potential scale of the approximation created by combining water levels from different times. A synoptic set of measurements of all available data points should be provided at some point.)

The contouring of Figure 4 was done without regard for the potential influence of zones of higher or lower permeability created by confining layers, fractures, fault offsets, etc. The focus on November data is intended to minimize the impact of domestic and municipal well pumping. At this basic level, the groundwater flow directions indicate a potential natural contribution to the area of the Turner wells from the area of the east-Grand subdivisions. In addition, when the Turner wells are being aggressively pumped, a “cone of depression” will extend outward from each well, creating much steeper local groundwater gradients and drawing groundwater toward the well discharge. The operating drawdown at the Turner No. 1 well is approximately 30 ft.; the pumping drawdown at the Turner No. 2 well is approximately 20 ft. (WWC Engineering, 2006).

A cursory review of reported static water levels from the domestic wells in the Sherman Hills and Laramie Plains areas was made to obtain additional data on groundwater gradients in those specific areas. These are plentiful, but generally low-quality data, subject to measurement errors by untrained personnel, variations due to seasonal and long-term fluctuations, and errors due to incomplete well recovery from construction and testing operations. However, in both areas the reported static water levels suggest somewhat more northwesterly flow components than the contouring of Figure 4.

North of the Sherman Hills Fault, water level data are insufficient to discern gradients in detail. More importantly, in the presence of preferential permeability pathways, groundwater may not flow perpendicular to the gradient contours. Comparable to a ditch cutting across a hillside and thus re-directing “downhill” flow, groundwater will take the path of least resistance which may mean flowing into and along, rather than across, a fractured fault system.

There is wide agreement that the convergence of several fault systems (City Springs, Quarry) and a sharp fold (Quarry Anticline) on the City Springs is the source of the spring’s abundant flow and of the highly productive nature of the Turner wells (e.g. Lundy, 1979, WWC 1993). The role of the Sherman Hills Fault is less clear. As noted above, there have been divergent interpretations of whether groundwater flow from the area south of the fault simply proceeds westward to eventually discharge up through the overlying Satanka, Forelle, and Chugwater formations (e.g. at Huck Finn Pond), or moves northwestward out of the fault zone to discharge at City Springs / Turner Wells.

Cursory review of specific capacity information supplied by drillers on well Statements of Completion indicates the productivity of Casper Fm. wells within the subdivisions vary substantially, but are mostly less than the Turner wells. This is reasonable in that the location of a domestic well is constrained to the owner's lot, whereas the City wells were deliberately located for maximum production. Whereas the Turner No. 1 and No. 2 wells have high specific capacities (90 and 35 gpm/ft., respectively (WWC, 1995), a sampling of wells in the Sherman Hills and Laramie Plains subdivisions reported specific capacities from 0.3 to 5.0 (still a 17-fold range). Exceptions include a well just south of the Sherman Hills Fault, for which a specific capacity of 36 gpm/ft was carefully measured (Weston Engineering, 1995). (This may indicate a zone of fracturing extending southward from the main fault, as discussed above.)

The nature of faulting beneath the subdivisions is unknown, although the density of faults mapped in the surrounding areas of Casper outcrop suggests the Casper is not a monolithic block beneath the mapped Quaternary deposits. Similarly, as noted above, although the Sherman Hills Fault is conceptualized as a discrete linear feature, comparison with the mapped Quarry, City Springs, and Red Hill Faults (and the Sherman Hills Fault where it has been mapped at the surface) indicates splinters and bifurcations and offshoots are likely (see Fig. 1).

Groundwater Contamination

The known and potential contaminant sources of interest to this project are at the surface (or, in the case of septic system leach fields, in the shallow subsurface). Septic systems and specific potential sources of contamination were identified in the project area on Figure 4-2c of the 2008 CAPP and are included on our Figure 1[6]. The routine activities in the Imperial Heights subdivision likely involve opportunities for the introduction of contaminants into the subsurface, e.g. over-application of fertilizers, pesticides, herbicides; inappropriate waste disposal. Finally, the "urban runoff" from Imperial Heights and East Grand Ave. development that enters the drainage north of Imperial Heights and along the Quarry Fault is an obvious source of groundwater recharge to the exposed epsilon member (see Fig. 1).

The "potential sources of contamination" identified in the CAPP were based on certain types of activities known to generate hazardous wastes. There was no evaluation of the actual waste-disposal practices of these operations, nor was any investigation made of whether local groundwater had been in any way impacted. These sources and others like them are simply "potential" in that they are located in areas which, if wastes were released onto or into the ground, could contaminate the Casper aquifer.

The "existing" sources of contamination identified in the CAPP were the septic systems associated with residences in and adjacent to the Casper aquifer recharge area. As noted above, no direct measurements of impact were made, but aquifer "loading" in terms of nitrates entering the groundwater system was estimated using standard rates and concentrations promulgated by

[6]This coverage is a combination of GIS files received from Albany County 8/2014 and the printed figure in the 2008 CAPP.

the Wyoming DEQ (e.g. Chapter 23) (2008 CAPP, App. K). At the assigned factors of 300 gallons of septic system discharge to groundwater per household per day, with a nitrate concentration of 40 mg/l, the 2001 Environmental Advisory Committee estimated a nitrate loading rate of 16.1 kilograms/yr per household[7]. (These calculations were adopted in the 2008 CAPP as App. K.) Long-time University of Wyoming hydrogeology professor and Sherman Hills subdivision resident Peter Huntoon observed, "I have been anticipating [nitrate] hits in Sherman Hills for years" (pers. comm. 2/7/2010).

Nitrates are perhaps the most commonly assessed indicator of groundwater contamination. This is because natural background concentrations are consistently low (0 - 2 mg/l) (e.g. WWC Engineering, 2013), they are a common result of human activity (feedlots, crop fertilization, septic systems), they dissolve into and travel with ambient groundwater, are generally "conservative"[8], and they are inexpensive to analyze. However, and particularly when associated with the broad range of activities and waste disposal associated with rural residential properties, of course, nitrate is but one of many potential contaminants.

For example, Godfrey et al (2007) found various pharmaceuticals in an aquifer beneath septic systems in Missoula, Montana; Seiler et al. (1999) found pharmaceuticals and caffeine in wells in a septic-system served subdivision in Reno, Nevada; Miller et al (2006) found 22 different PPCPs (pharmaceuticals and personal care products) in domestic wells drawing from an aquifer with septic systems in Helena, Montana, concluding, "Low levels of various PPCPs in ground water provide clear evidence that domestic wastewater is a source of contamination." Although it is our understanding that private parties in the subdivisions area have been sampling wells for chlorides, we are aware of no publically-available groundwater analyses beyond nitrates and bacteria that have been made to assess potential contamination of the Casper aquifer in the project area.

Our cursory review of the literature on this topic suggests the conclusion of Seiler et al (1999) has not changed substantially over the subsequent decade's investigations: "The usefulness of caffeine as an indicator of recharge from septic systems is limited because it apparently is not conservative. The usefulness of human pharmaceuticals as indicators also is limited because the presence of pharmaceuticals is unpredictable." (By "not conservative", the authors mean that caffeine, although obviously common in domestic wastewater, is metabolized by bacteria in the septic system and leach field, so only proceeds into the groundwater system in much-reduced concentration.)

The primary value of PPCP testing for this project is the unambiguous association with human activity. Whereas nitrate concentrations as high as 2 mg/l can arguably be assigned to natural

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[7]300 gal/d * 3.79 l/gal * 40 mg/l * 365.25 d/yr = 16.6 million mg/yr

[8]In this context, "conservative" is used to describe chemical constituents that do not react within the aquifer.

sources (some suggest even higher), the natural threshold for PPCPs is zero. Thus, limited analysis of samples from monitor wells most likely to see septic-system impact is suggested.

Nitrate and chlorides remain the most consistently used indicators of septic system input to groundwater. Chlorides are the more conservative of the two, in that there are few natural processes that remove chloride from groundwater, i.e. the concentration is a reasonably straightforward function of input and dilution. Under certain aquifer conditions, nitrates in groundwater are "denitrified" and the nitrogen released as a gas. These conditions only occur when oxygen has been depleted from the system, however, which is unlikely to occur up-gradient from the Turner Wells. Hinkle et al (2009) describe water with 3 - 8 mg/l dissolved oxygen as "well oxygenated" and not subject to denitrification processes. Phelps (2004) found dissolved oxygen concentrations of 1 - 3 mg/l too high to allow denitrification. For comparison, dissolved oxygen concentrations routinely measured in the LCCC monitor well are approximately 10 mg/l. Denitrification is unlikely to play a significant role in the fate of nitrate contamination up-gradient of the Turner Wells.

Nitrogen isotope analysis has been suggested as a way to differentiate the potential sources of higher-than-background nitrate concentrations in groundwater. In situations where there is ambiguity among various potential sources - agricultural operations applying nitrogen fertilizers, animal feedlots, land application of municipal wastewater treatment solids, domestic septic systems, etc. – this may have value, but the sources of nitrates in the Turner Wells recharge area are obvious and limited. Isotopic analysis is not recommended for the initial sampling under this program.

At this point, the primary source of attenuation of contaminants reaching the groundwater in the Casper aquifer appears to be simple dilution.

The 2004 - 2013 average annual production from the Turner Wells was approximately 250 million gallons. Addition of the nitrate loading calculated above, i.e. without other dilution or attenuation, would produce a concentration of 0.02 mg/l per contributing household. As compiled below, there could be as many as 177 septic systems in the Turner Wells contributing area, for a combined nitrate concentration impact of 3 - 4 mg/l. Thus, it is virtually impossible for the routine operation of the current septic systems in the Turner Wells recharge area to increase nitrate concentrations at the wellfield to values approaching the EPA Maximum Contaminant Level. This calculation is consistent with the conclusion of the WWC Engineering report (2013, p. i) that, "Private septic systems east of Laramie do not pose a significant risk of nitrate contamination to the City of Laramie public drinking water supply wells at this time."

The locations of the epsilon and delta subcrops on Figure 1 are based on projection of formation dips discussed above into the area beneath the mantle of Quaternary-age deposits in the Laramie Plains / Sherman Hills subdivisions area. Static water levels are deeper than the alluvial mantle is thick, so septic system effluent is expected to migrate vertically downward until encountering flow-controlling strata in the bedrock formations and/or the water table.

Comparison of the CAPP-mapped locations of domestic septic systems (CAPP Fig. 4-2c) to the projected subcrops in the area provides the following estimation of the receiving strata for septic system effluent[9]:

Satanka Shale	61 systems	e.g. Laramie Plains Subdivision
Casper - epsilon	25 systems	e.g. western Sherman Hills
Casper - delta	70 systems	e.g. eastern Sherman Hills
Casper - gamma	21 systems	e.g. Pilot Peak Estates?

The 12 "potential contaminant sources" identified in the 2008 CAPP (Fig. 4-2c) are along and east of East Grand Avenue, placing them all on or above the Satanka Shale.

Recharge from surface sources will continue approximately downward until either the water table or a relatively low-permeability stratum is encountered. Where the limestone beds separating the various members of the Casper Fm. are intact, they may serve to divert recharge westward, i.e. infiltrating water may travel down dip along the top of the bed. Where those potentially confining limestone beds are broken by fracturing and faulting, however, the opportunity for continued downward migration is provided and deeper members of the Casper may be impacted. Similarly, in areas beneath the water table groundwater locally "trapped" beneath a confining limestone may move upward once a break in that layer is encountered.

Similar pathways through confining beds are provided by unsealed wellbores. The Statements of Completion filed with domestic wells in the project area were reviewed to investigate this situation. For many wells, insufficient information was reported to assess the well seal. For the others, a minority of wells had casings sealed to the water table, many were only sealed for the first 10 - 20 ft., and some are interpreted as having no significant seal at all (i.e. having an open or gravel-filled annulus around the well casing). This included Casper wells that penetrated portions of the Satanka Shale, providing the unsealed annulus as a potential pathway for migration of water from surface sources down into the Casper even in the areas west of Casper outcrop or subcrop.

Two wells reported from just south of the intersection of the Sherman Hills Fault and East Grand Avenue provide an example. An older well (P12798) was reportedly sealed to 50 ft., leaving another 60 ft. of Satanka open to the annulus, as well as the 20 ft. of underlying Casper assumed to be the main source of water. 30 years later, a new well (P99001) was constructed on the same lot, but was properly sealed to the top of the Casper Fm. In the latter well, a nitrate concentration of 9.4 mg/l was measured (Weston, 1995). The authors suggested contamination from the many septic systems to the east of this location may have been to blame for the high nitrates, but an alternate contaminant pathway may have been provided by the older well on the site allowing communication between local surface sources and the underlying Casper.

[9]The area for this count is east of Vista Drive and north of a line projecting eastward from the I-80 / Grand Avenue interchange.

Consideration of subsurface fracturing and faults and the known commonly poor sealing of domestic wells in the area, indicates that septic systems and surface contaminant sources within the area of the Laramie Plains subdivision are potential contributors to the Casper aquifer despite occurring in the Satanka Shale.

Once contaminants enter the groundwater flow system, dilution occurs through dispersion. This occurs mechanically, as a "mixing" process under groundwater hydraulic gradients, and chemically, as contaminants move in response to concentration gradients. Given that the contaminants of interest enter the groundwater from above, it is reasonable to assume concentrations will be highest (to the extent they vary) in the uppermost saturated portion of the aquifer. Conveniently, vertical groundwater flow is likely naturally upward through most of the area of interest (the westernmost outcrop area) due to the higher elevation of the recharge areas of the lower members of the Casper and the migration of groundwater to the natural discharge points (springs) at the top of the formation.

This suggests that groundwater quality sampling focus on the uppermost portions of the aquifer. As per Figure 2, water levels may vary as much as 25 ft., which should be taken into account to ensure monitor wells are completed with sufficient depth to ensure continuous access to saturated material.

The 2008 CAPP recommended, "that the contaminants listed in the National Primary Drinking Water Standards and National Secondary Drinking Water Standards be monitored for all wells on a yearly basis. The quarterly sampling should include all inorganic compounds and microorganisms on the National Primary and Secondary Drinking Water Standards, petroleum hydrocarbons, conductivity, and temperature. The petroleum hydrocarbons will be used as a surrogate for organic compounds. If a petroleum hydrocarbon is detected, the City should initiate additional organic parameter testing at the impacted well."

We concur with the recommendation that the inorganics on the standards list be included in the initial sampling of the wells to be completed under this project, but believe that analysis for all listed organics may be excessive given the extremely low likelihood of occurrence (e.g. industrial solvents). The recommended broad-spectrum hydrocarbon parameter (e.g. TPH - total petroleum hydrocarbons) is sufficient for initial sampling, with follow-up analyses as indicated.

In addition to analysis for recognized contaminants, we recommend analysis for major cations and anions and Total Dissolved Solids as a basic geochemical signature, and of dissolved oxygen and Total Organic Carbon (TOC) as inexpensive parameters to address denitrification potential.

IV. Monitor Well Evaluation

This section lists the existing monitor wells available to the City potentially in the Turner wells' recharge area and evaluates opportunities for construction of additional wells on property currently under City ownership. For each of the latter wells, specific objectives and recommendations for a construction/testing approach are presented. The final section provides general recommendations for Phase II refinement of well designs and preparation of contract specifications.

A. Existing Wells

Figure 1 includes the existing groundwater monitor wells to which the City has routine access. Table 2 provides summary information. Water levels are consistently measured in the Turner production wells, LCCC MW#1, and Huntoon #1 and #2. Water quality is monitored for EPA Public Water Supply compliance at the Turner wells and for WDEQ compliance at the LCCC well, although in both cases the specific analytes may or may not fully address aquifer contamination concerns. Other wells on the table are available for monitoring, but have not been routinely sampled.

Table 2 - Permanent Casper-Formation Monitor Wells (including production wells)

well	depth (ft)	SWL (ft)	open interval		sources
			ft	strata	
Turner No.1	240	6	98 - 240	epsilon, delta	WWC, 1993; WWC, 1996
Turner No.2	351	flowing	100 - 351	epsilon - gamma	WWC, 1993; WWC, 1996
Huntoon #1	182	105 - 130	142 - 180	gamma	Lundy, 1979
41T2	554	30	90 -	delta - alpha	WWC, 1996
LCCC MW#1	210	15	140 - 210	epsilon, delta	Wyoming Groundwater, 2006
41T3	240	68	30 - 240	Satanka, epsilon	WWC Eng., 2006; Wyoming Groundwater, 2014
SHFCA-1	360	20	308 - 360	epsilon, delta	WWC, 1997
LAPCA - 1	475	+44	403 - 475	epsilon, delta	WWC, 1997
LaPrele No. 1	880	+46	400 - 880	epsilon - beta	WWC, 1997

Figure 4 included points for which water levels have been carefully measured in association with past studies. The 2009/2010 nitrate sampling involved 115 wells in the recharge area for the various city wellfields. (Exact locations for those wells is confidential.) Finally, there are some 233 water wells of record for the project area. With the exception of the wells on Figure 1, all of these potential groundwater monitoring points are in private ownership and may or may not be available for future use at the discretion of the owners.

The following paragraphs discuss specific existing wells relevant to the citing of additional monitor wells for this project. All of the wells on Figure 1 remain of interest and should be considered in future monitoring programs.

41T2. This well was drilled in 1941, but was never used due to anticipated interference with flows from City Springs. The well is cased and sealed to a depth of 90 ft. and completed open-hole through the small remaining thickness of the delta member and the underlying gamma, beta, and most of the alpha members of the Casper. The reported static water level of 30 ft. indicates approximately 70% saturation of the delta and of all lower members. (The sealing of the casing to 90 ft. precludes sampling directly at the water table.)

The well has a reported specific capacity of 52 gpm/ft (WWC, 1995). This is relatively high, particularly for the lower members of the Casper Fm. to which it is open, likely reflecting the enhanced permeability of its location along the fracture system associated with the Quarry Fault.

A five-day pump test of the Turner No. 1 well (1600 ft away) at 2100 gpm, produced 9.4 ft. of drawdown in the 41T2 well, over 1/3 of the drawdown of the test well itself (WWC, 1993). High permeability and ready communication along the Quarry Fault was demonstrated. Most interesting is that when the alpha member of the Casper Fm. was isolated for pumping in the 41T2 well (WWC, 1996), drawdown was observed at the Turner wells, but not in the upper members of the Casper Fm. at the 41T2 well itself.

Video logging of 41T2 in 1994 observed “abundant borehole fractures from 55 - 64 feet with a large vertical facture intersecting the wellbore from 56 - 63 ft.”, i.e in the delta member. But the video also observed “large fractures” in the “sandstone intervals” of the alpha member at 411-419 feet and 488 - 504 feet (WWC, 1996; p. 4).

With respect to groundwater flow, the location of the 41T2 well in or just north of the Quarry Fault system should provide opportunity for sampling the head in the aquifer along the fault. With respect to groundwater quality, the well is exposed to recharge from a broad area of undeveloped land to the east and northeast, but also to recharge directly to the epsilon member along a drainage that receives surface runoff from the Imperial Heights subdivision, East Grand Avenue, and the Staples parking lot. Although unlikely to experience input from the area of septic systems to the southeast, this well may be a candidate for analysis of “urban runoff” components of potential contamination.

This location is similar to the “Turner MW-1" monitor well suggested in the 2008 CAPP, which was placed 0.5 miles farther east along the fault zone and thought to be within an approximately 1-year travel time of the Turner wells to “provide an early warning if contamination occurred”. This location ideally fits the recommendation from the 2013 WWC Engineering study (p. 10), “For monitoring related to the Turner Wellfield, at least one well should be sited along or immediately south of the Quarry Fault and between 1/4 and ½ mile east of the Turner wells. ... Given the density of existing development near the City, this monitoring location would be the highest priority.”

LCCC. There are four Casper Fm. wells on the Albany County campus of Laramie County Community College (LCCC). These were drilled in 2005 as part of a geothermal heating system for the facility (Wyoming Groundwater, 2006). The wells vary between 210 and 263 ft. in depth; all are completed open-hole through the epsilon member and into the delta member of the formation. Groundwater is withdrawn from one of two withdrawal wells, run though a heat exchanger, and injected into an injection well approximately 250 ft. away. Because the system is closed (all water returned to aquifer) no significant impacts on aquifer hydraulic relationships beyond the immediate area are likely, nor is the extraction of low-temperature heat anticipated to significantly impact groundwater chemistry.

The fourth well, LCCC MW#1, is used to monitor groundwater quality under the terms of the Wyoming DEQ permit for the system. Initial contacts with LCCC indicate this well could be made available for permanent monitoring as part of the City of Laramie monitor well network.

With respect to groundwater flow, this well is in a location that would monitor water levels along potential flow lines converging on the Turner Wells from the southeast, i.e. south of the Quarry Fault system and in the direction of the sources of potential contamination associated with development along East Grand Avenue Similarly, the well taps the upper members of the Casper Fm., the members most vulnerable to contamination from surface sources and the members through which the bulk of Casper Fm. water is thought to travel.

B. Additional Monitor Wells

In order to move forward with the Casper aquifer monitoring program with minimum delay, the utility of new monitor wells constructed on city-owned property is evaluated below. This will eliminate the time and expense associated with negotiation of purchase or access agreements and will ensure long-term continuity of water level and water-quality data.

Figure 7 presents September 2014 ownership status for the area of interest. City-owned property consists of: 1) Gateway Park; 2) the area immediately north across Grand Avenue; 3) an area informally termed the "triangle" at the intersection of Vista Drive and Grand Avenue; 4) the Imperial Heights Park just northeast of the Sherman Hills subdivision; and 5) a number of lots slated for development in the Turner Tract. The last of these is not available for permanent occupancy by city facilities. The others are likely to remain in city ownership indefinitely and are discussed here. Figure 7 includes recommended locations for three new monitor wells.

Fine-tuning of locations in consideration of drill rig access, utility lines, test discharge geometry, etc. will be accomplished along with construction specifications in Phase II of this project.

1. Imperial Heights Park

This location is of interest for two reasons: 1) it is the southeastern-most location within the City of Laramie boundary that is projected to remain undeveloped (due to being dedicated as a public park); and 2) it potentially spans the important Sherman Hills Fault.

The 2013 WWC Engineering study repeated the suggestion of their 1993 work that, "groundwater flow patterns near the Sherman Hills Fault restrict northward movement of groundwater from areas of highest septic system density and instead carry the groundwater generally west ...". This interpretation is of obvious interest to the City and to the residents of those "areas". A focused data collection effort is appropriate.

The nearest existing monitoring opportunity (beyond periodically available measurements from private wells) is the Huntoon #1 well, 1500 ft. to the east, on the south side of the fault. This land is not on public property, nor is there opportunity for a public-property companion well on the north side of the fault at this location.

Placement of monitor wells on both sides of the fault provides opportunity for testing the important issue of the hydraulic connection between the two sides.

North Well. A north-side well would encounter the top of the delta member immediately beneath shallow unconsolidated deposits. There is no existing well that is representative of this location. Based on the mapped geology, the delta member of the Casper would be fully penetrated within approximately 100 ft, and the gamma member at approximately 180 ft. Assuming hydraulic equilibrium across the fault, the water level would be approximately the same as in the south side well, i.e. around 90 ft. For this well, that would place first saturation near the top of the gamma member.

By imposing significant drawdown on the north side of the Sherman Hills Fault, this well would represent an extreme form of the Turner Wells, i.e. a sort of bringing of the wellfield up to the fault. The only historical precedent for such a test is that reported by Banner (1978). In that test, the 41T1 well was pumped at a rate of 1250 gpm for 51 days. The Huntoon #1 well was monitored for drawdown. The authors concluded that "the observation well was affected" (approximately 1 ft. is suggested by the provided data), but found the impacts to have been obscured by the larger drawdown cycles created by nearby domestic wells. They also observed, "this could be due to boundary effects from the Sherman Hills fault" (p. 20).

At the northward dip discussed above, the fault plane would be encountered 40 ft. further north for each 100 ft. in depth. Thus, to achieve the objective of completing this well entirely on the north side of the main fault, a location as far north on the park property as possible is recommended. There appears to be sufficient room for well construction on the north side of the small drainage bounding the Imperial Heights subdivision, and this is projected to be sufficiently far north to avoid intersection of the plane of the fault.

As the Sherman Hills Fault is projected to juxtapose saturated delta member (south side) against saturated gamma member (north side), the expected lower permeability of the gamma may inhibit cross-fault migration of groundwater. If the fault itself provides the expected high-permeability pathway, groundwater flow may be diverted westward down the fault until the saturated delta and epsilon members become available on the north side to accept groundwater moving northwestward out of the fault zone. This would occur west of Grand Avenue.

The objectives for the north-side well would be: 1) long-term water-level measurement; 2) pumping at sufficient rate and duration to generate a response in the companion well across the fault; 3) long-term assessment of groundwater quality in a portion of the aquifer which may be isolated from significant sources of contamination; and 4) evaluation of the permeability of the gamma member of the Casper in isolation.

Construction / Sampling Recommendations:

- This well should be drilled first (of the north-south pair at this site) to clarify local stratigraphy. Unlike the south well, the north well will start at a point certain, i.e. the top limestone of the delta member, and thus provide a detailed log of Casper Fm. layering in the immediate area.

- Borehole and casing size should accommodate a 6-inch pump to allow discharge of 200+ gpm during testing to adequately stress the aquifer and cross-fault permeability characteristics. This will require a minimum finished diameter of 8 inches, e.g. 9-7/8 inch borehole drilling.

- 12-inch surface casing should be installed and cemented in place to a depth of 20 ft. (more if conditions warrant) to preclude concern with contamination from the immediate surroundings

- The well should be drilled with air / foam circulation if possible to facilitate examination of water levels and water quality as drilling proceeds. The surface casing recommendation is oversized somewhat to accommodate the possibility of needing to telescope multiple casings to control caving conditions without having to resort to mud drilling.

- A tentative depth of approximately 200 ft. is recommended to verify local stratigraphy and to allow evaluation of potential water level and water quality differences between the delta, gamma, and beta members. Additional depth may be required to achieve a production goal of 200+ gpm.

- "First water" should be discretely sampled, and an equilibrated water level measured before drilling continues. Similarly, composite water quality and level should be sampled beneath each potentially confining bed penetrated.

- Provision should be made for geophysical investigations (e.g. by WyCEHG) prior to well completion, e.g. video and "spinner" logging to assess borehole conditions.

- Testing would follow construction of the "south" well of this pair, and should allow for a potential 2-phase approach (delay in between) depending on the response monitored in the "south" well.

- Test water disposal will be an issue for this site, in that rapid infiltration through the surficial deposits and underlying epsilon member could provide recharge within the period of testing. Transmission of test discharge westward far enough to overlie a significant thickness of Satanka Shale is strongly recommended. (There are four culverts under East Grand Avenue where it intersects drainages from the Imperial Heights Park.)

- Final well completion should be based on the results of drilling, water-quality analysis, geophysical logging, and pump testing. It may be desirable to seal the lower portion of the hole to establish long-term monitoring focused on the uppermost water-bearing strata. It may be desirable to complete the well open to the water table to provide sampling of the top of the groundwater column, with adequate provision for seasonal and long-term variations in depth-to-water.

South Well. A south-side well should be exposed to groundwater recharge from the northern portion of the Sherman Hills subdivision and, when paired with the existing Huntoon #1 well, a valid assessment of the east-west component of the groundwater gradient along the south side of the fault. A well at this location is anticipated to penetrate 10 - 20 ft. of unconsolidated material before hitting either the bottom-most strata of the Satanka Shale or the top of the epsilon member of the Casper. Full penetration of the epsilon member should occur within 80 ft. of the surface, and of the delta member within 180 ft. A static water level of 90 ft is indicated by the experience of domestic wells in the area, i.e. groundwater would be first encountered near the top of the delta member.

This location is comparable to the “Turner MW-5" monitor well suggested in the 2008 CAPP, which was placed in the northwest corner of the Imperial Heights neighborhood and thought to be within an approximately 1-year travel time of the Turner wells to “provide an early warning if contamination occurred”.

The objectives for the south-side well would be: 1) long-term water-level measurement; 2) monitoring response to pumping of the companion well across the fault; 3) long-term assessment of groundwater quality at the periphery of a cluster of potential contaminant sources; 4) assessment of the locally confining character of the top-of-delta limestone with potential implications for contaminant transport.

Construction / Sampling Recommendations:

- Borehole and casing size need only accommodate a sampling pump. To maintain flexibility in drilling, a conventional “domestic” well is recommended, i.e. 5-inch casing.

- 10-inch surface casing should be installed and cemented in place to a depth of 20 ft. (more if conditions warrant) to preclude concern with contamination from the immediate surroundings

- The well should be drilled with air / foam circulation if possible to facilitate examination of water levels and water quality as drilling proceeds. The surface casing recommendation is oversized somewhat to accommodate the possibility of needing to telescope multiple casings to control caving conditions without having to resort to mud drilling. The relatively open cementation of the epsilon member is locally observed in problematic sand production in the construction of some wells.

- A tentative depth of approximately 280 ft. is recommended to allow evaluation of potential water level and water quality differences between the epsilon, delta, gamma, and beta members.

- “First water” should be discretely sampled, and an equilibrated water level measured before drilling continues. Particular attention should be paid to the bottom strata of the epsilon member, as local recharge may be accumulated on top of the uppermost delta-member limestone. Similarly, composite water quality and level should be sampled beneath each potentially confining bed penetrated.

- Provision should be made for geophysical investigations (e.g. by WyCEHG) prior to well completion, e.g. video and “spinner” logging to assess borehole conditions. “Spinner” logging during pumping of the “north” well should be considered to assist identification of the most active groundwater flow strata.

- Provision should be made for possible partial completion to provide monitoring response to test pumping of the “north” well before and after sealing lower members open to the well.

- Final well completion should be based on the results of drilling, water-quality analysis, geophysical logging, and pump testing. It may be desirable to seal the lower portion of the hole to establish long-term monitoring focused on the uppermost water-bearing strata. It may be desirable to complete the well open to the water table to provide sampling of the top of the groundwater column, with adequate provision for seasonal and long-term variations in depth-to-water. Such a limited completion may also serve to reduce purging needs for future sampling and to avoid deeper strata dominating the sampled groundwater quality.

2. Gateway Park

This location is of interest primarily because of its proximity to the Turner wells. Groundwater moving into the production-well area from the east, e.g. along the Quarry Fault, could be monitored for water-quality parameters to detect changes before impacting the city wells.

A well at this location would be expected to experience approximately the same conditions (geology, water level) as the LCCC wells discussed above. Midway between the 41T2 well and the LCCC MW#1, however, a Gateway Park location is more ambiguous than either one in that it could receive groundwater both from the east, associated with flow controlled by the Quarry Fault system, and from the southeast, associated with inflow controlled by the Sherman Hills Fault and potentially exposed to contamination from south of that fault.

In the absence of the 41T2 and LCCC alternatives, the objectives for a well at this location would be: 1) long-term water-level measurement, and 2) long-term assessment of groundwater quality in an area likely contributory to the Turner Wells. This could best be accomplished by locating a well in the far southeast corner of the property, in order to provide separation from the Quarry Fault and sufficient distance from the Turner Wells to provide something of an “early warning system”. The most useful completion would be in the uppermost Casper Fm, i.e. the epsilon member at this location, as the zone most likely to carry surface-sourced contaminants.

However, the location potentially in a relatively undisturbed block of the aquifer may provide opportunity during drilling to investigate head and water-quality differences between members.

3. “Triangle”

This location is of interest as intermediate between the potential sources of contamination in the east Grand subdivisions and the Turner wells. It should encounter groundwater flow components from the undeveloped areas to the east, between the Sherman Hills and Quarry faults, and, depending on the hydraulic effects of the Sherman Hills Fault, from the long-developed area to the southeast. It should also provide valuable data on local groundwater gradients for comparison to those estimated for the more well-rich area south of the Sherman Hills Fault.

Geologic structure in this area is obscure. The only nearby well of record is that for the Premier Bone & Joint Clinic, for which the following log was submitted:

0 - 25 ft.	sand & limestond; cementing pieces
25 - 30 ft.	red shale
30 - 36 ft.	sandstone
36 - 140 ft.	lost circulation - waterbearing perforated

The groundwater level reported for the well was 64 ft., so there was no description provided for the water-bearing portion of this hole. The occurrence of lost circulation is generally indicative of productive aquifer material, although the loss may have occurred in the unsaturated portion of the hole.

Based on the location of the well with respect to our Figure 6 schematic, it would first encounter a small thickness (<20 ft.) of Satanka Shale, then a full section of the Casper Formation. A static water level comparable to the Premier Bone & Joint well would provide saturation of the lowest portion of the epsilon member and of all lower members.

The reported specific capacity for the well was a modest 40 gpm/30 ft. (i.e. 1.3 gpm/ft), which is consistent with the projected strata and a location relatively undisturbed by fracturing associated with area faults and folds. If so, this location may provide opportunity to assess the confining nature of the member-separating limestone strata through careful observations of water levels during drilling.

Construction / Sampling Recommendations:

- Given the restricted character of this site, careful utility locates should be a part of final well siting to preclude conflicts during construction and long-term monitoring.

- Borehole and casing size need only accommodate a sampling pump. To maintain flexibility in drilling, a conventional “domestic” well is recommended, i.e. 5-inch casing.

- 10-inch surface casing should be installed and cemented in place to a depth of 20 ft. or completely through the Satanka Shale, whichever is greater, to preclude entry of Satanka water during subsequent drilling and to preclude concern with contamination from the immediate surroundings.

- The well should be drilled with air / foam circulation if possible to facilitate examination of water levels and water quality as drilling proceeds. The surface casing recommendation is oversized somewhat to accommodate the possibility of needing to telescope multiple casings to control caving conditions without having to resort to mud drilling.

- A tentative depth of approximately 200 ft. is recommended to provide observation of local stratigraphy and evaluation of potential water level and water quality differences between the epsilon, delta, and gamma members.

- "First water" should be discretely sampled, and an equilibrated water level measured before drilling continues. Particular attention should be paid to the bottom strata of the epsilon member, as local recharge may be accumulated on top of the uppermost delta-member limestone. Similarly, composite water quality and level should be sampled beneath each potentially confining bed penetrated.

- Provision should be made for geophysical investigations (e.g. by WyCEHG) prior to well completion, e.g. video and "spinner" logging to assess borehole conditions. "Spinner" logging during pumping of the "north" well or the municipal Turner wells should be considered to assist identification of the most active groundwater flow strata.

- Provision should be made for possible partial completion to provide monitoring response to test pumping of the "north" well before and after sealing lower members open to the well.

- Final well completion should be based on the results of drilling, water-quality analysis, geophysical logging, and pump testing. It may be desirable to seal the lower portion of the hole to establish long-term monitoring focused on the uppermost water-bearing strata. It may be desirable to complete the well open to the water table to provide sampling of the top of the groundwater column, with adequate provision for seasonal and long-term variations in depth-to-water. Such a limited completion may also serve to reduce purging needs for future sampling and to avoid deeper strata dominating the sampled groundwater quality.

4. "Background"

Although not part of the immediate monitor well construction program, a well specifically sited to provide "background" water quality should be considered. Despite the clear association of the frequency of elevated nitrate values with areas of higher septic system density, there remains controversy about Casper aquifer contaminant levels (e.g. nitrates) in the absence of any significant development. With respect to the Turner wells, locations along major fracture systems converging from the east and northeast are suggested. The entirety of Section 36, directly east of the Turner wells, is State of Wyoming property, perhaps facilitating permanent access. That Section includes the Quarry Anticline and the City Springs Fault (see Fig. 1), neither of which has significant up-gradient development to source contaminant input to recharge.

The objectives for such a well would be: 1) long-term water-level measurement; and 2) long-term assessment of "background" water quality.

C. General Construction and Testing Recommendations

Our recommendation for Phase II of this project is to proceed with construction of two monitor wells at the Imperial Heights Park site, and one monitor well at the "Triangle" site. In addition to the well-specific criteria presented above, we recommend Phase II include:

1. Provision for a combined "lump sum" and "time and materials" well construction and testing contract. This will require flexibility on the part of the contractor, but will allow an adaptive response to maximize the information obtained from the well-construction program. To be refined in Phase II, our initial view is the following contract items are appropriately offered on a "lump sum" basis:

- overall mobilization / demobilization
- mobilization between sites
- furnish and install test pumping equipment
- furnish and install pump discharge piping

and the following items are appropriately priced on a unit basis:

- hourly rate for borehole drilling
- hourly rate for well construction and misc. work
- hourly rate for air-lifting / well development
- hourly rate for standby time, e.g. waiting on water-level equilibration

2. Provision for construction pauses to accommodate laboratory analyses (local lab can provide 1-day turnaround for nitrates) and geophysical logging (e.g. WyCEHG) to inform final well completion design.

3. Provision for full-time monitoring of well construction by a professional geologist thoroughly familiar with project objectives and concerns.

4. Provision for field testing of nitrates to assist ongoing decisions on construction and sampling.

5. The Phase II construction and testing program should include detailed documentation and sufficient written analysis of "lessons learned" regarding such issues as fault and stratigraphic control of groundwater flow and of contaminant distribution to guide future monitor well siting and construction. The Phase II program should also include recommendations for the appropriate degree of long-term monitoring/sampling of all available wells. For example,

periodic synoptic measurement of water levels should be undertaken to better define flow gradients and directions.

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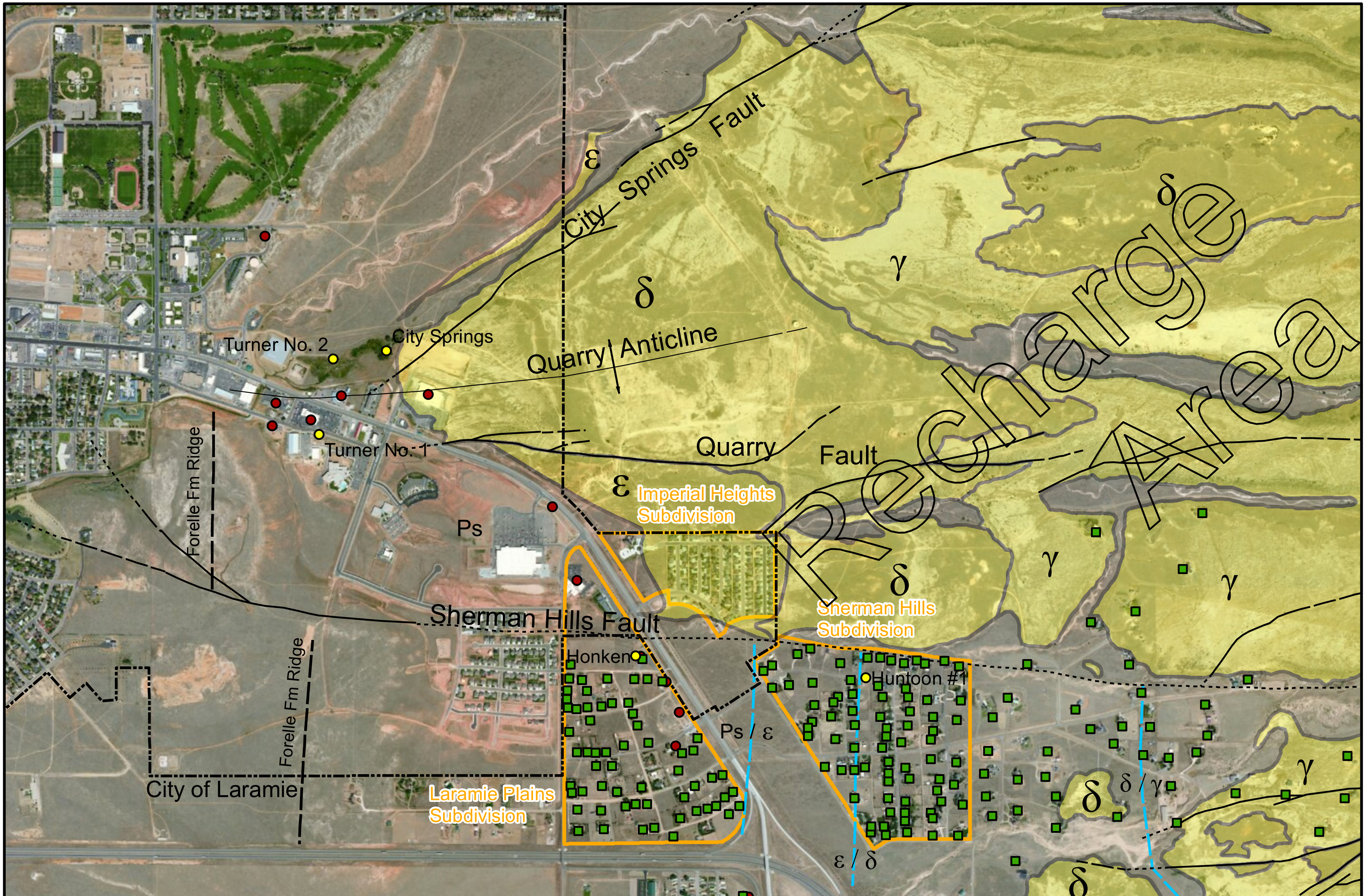


Septic Systems (2008 CAPP)
Potential Contamination Sources (2008 CAPP)
Buried Contact

Ps - Satanka Shale
Casper Formation Members:
ε - Epsilon
δ - Delta
γ - Gamma

(Geology modified after VerPloeg, 2009)

0 1,000 2,000 Feet

Figure 1 - Location Map
City of Laramie
Casper Aquifer Monitoring Program

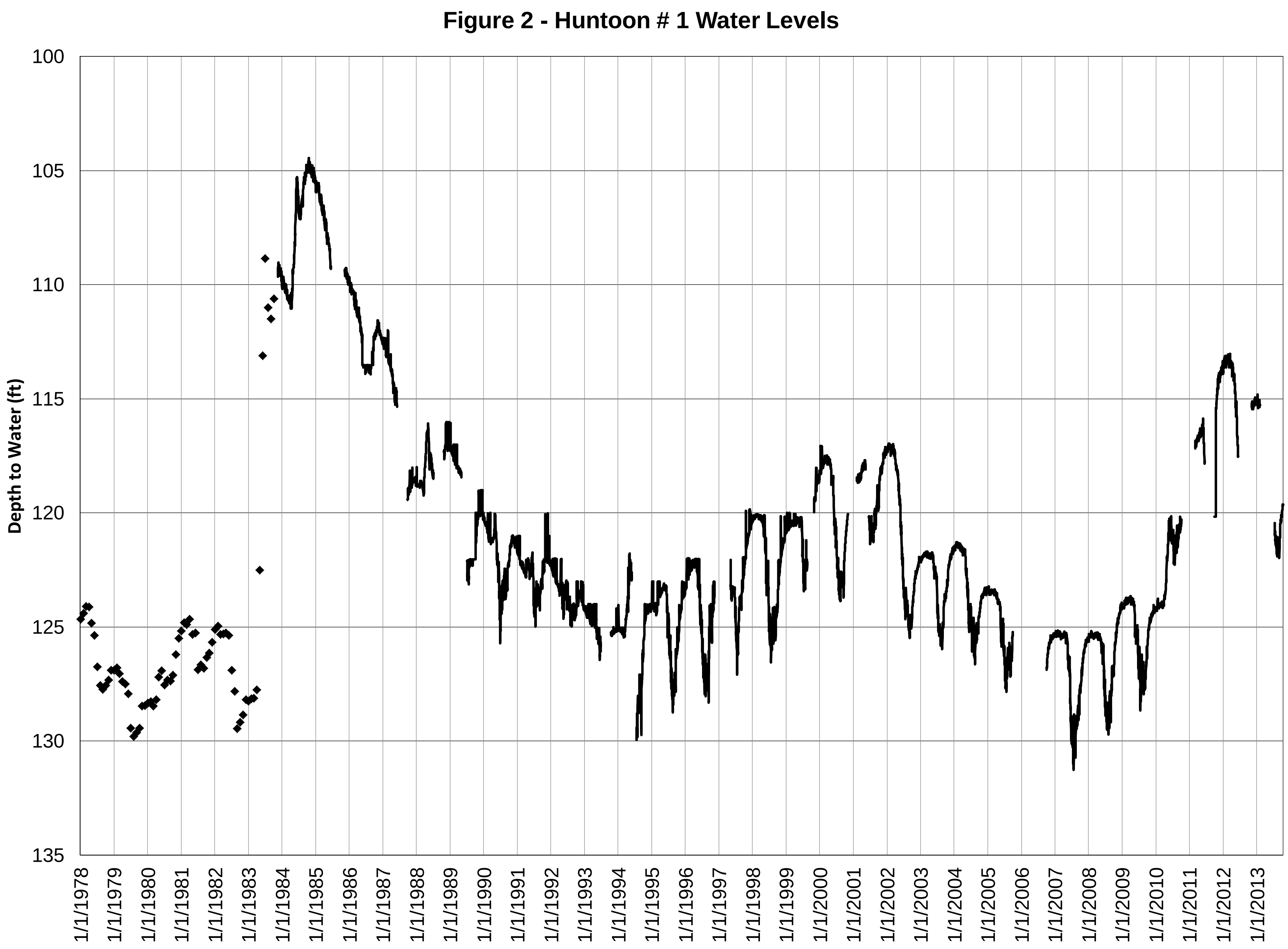


Figure 2 - Huntoon # 1 Water Levels
Depth to Water (ft)
100
105
110
115
120
125
130
135
1/1/1978
1/1/1979
1/1/1980
1/1/1981
1/1/1982
1/1/1983
1/1/1984
1/1/1985
1/1/1986
1/1/1987
1/1/1988
1/1/1989
1/1/1990
1/1/1991
1/1/1992
1/1/1993
1/1/1994
1/1/1995
1/1/1996
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013

Schematic relationship between Lundy's (1978) informal members of the Casper Formation and the Casper limestones (1-10) as defined by Benniran (1970) in the vicinity of Laramie, Wyoming. Map area falls within diagram, but not all units crop out in the map area.

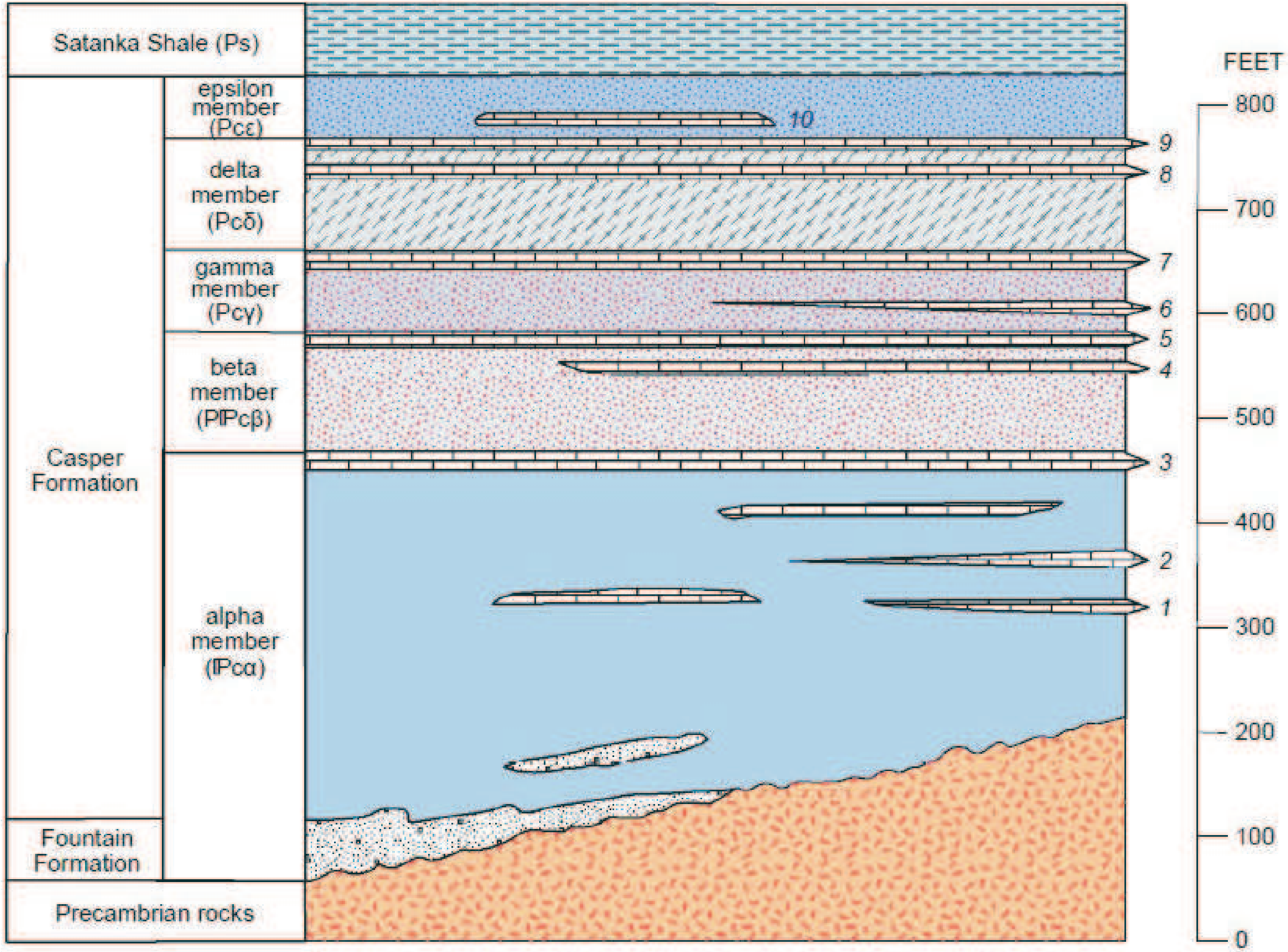


Figure 3 - Casper Formation Stratigraphy

Source: VerPloeg, 2009

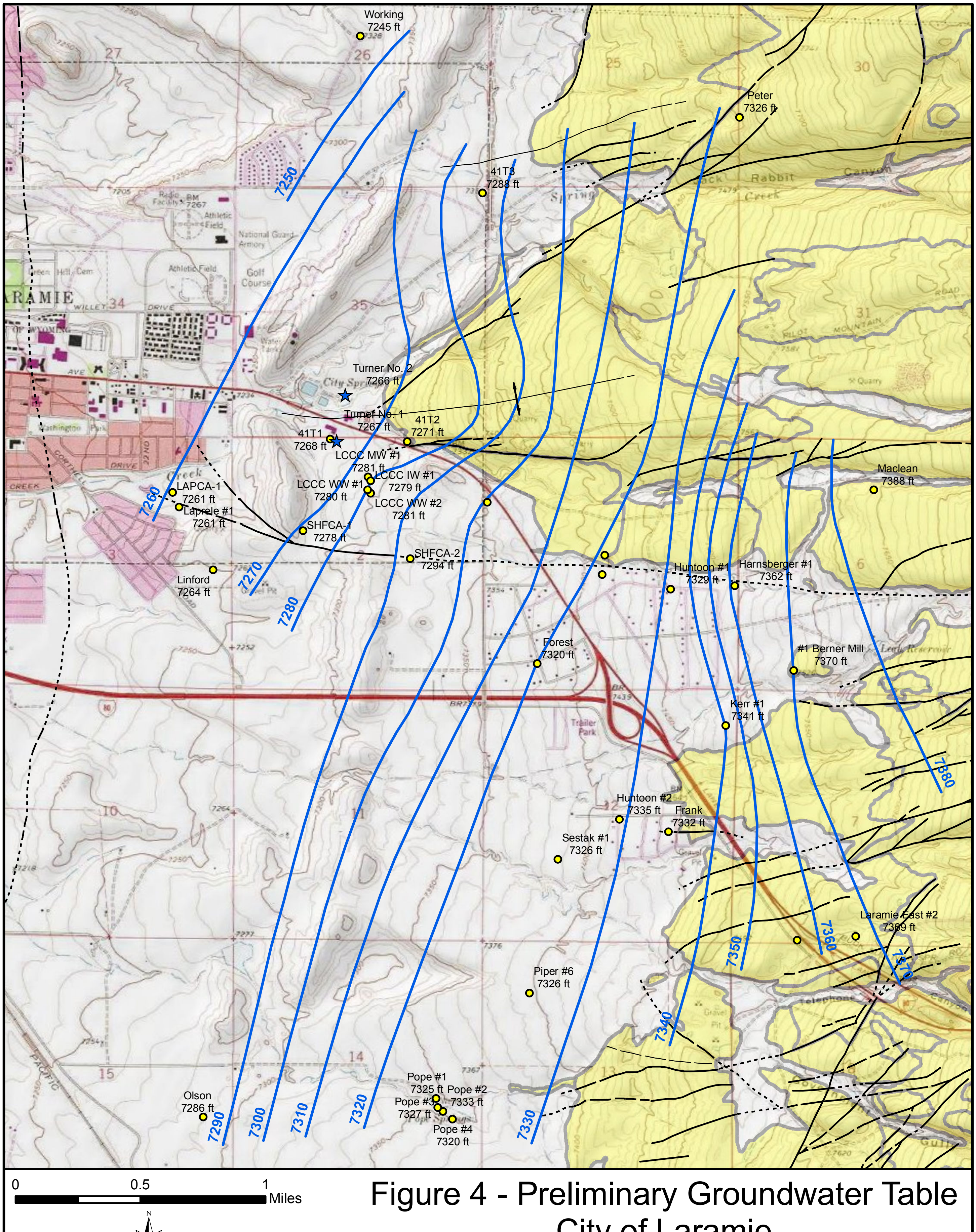
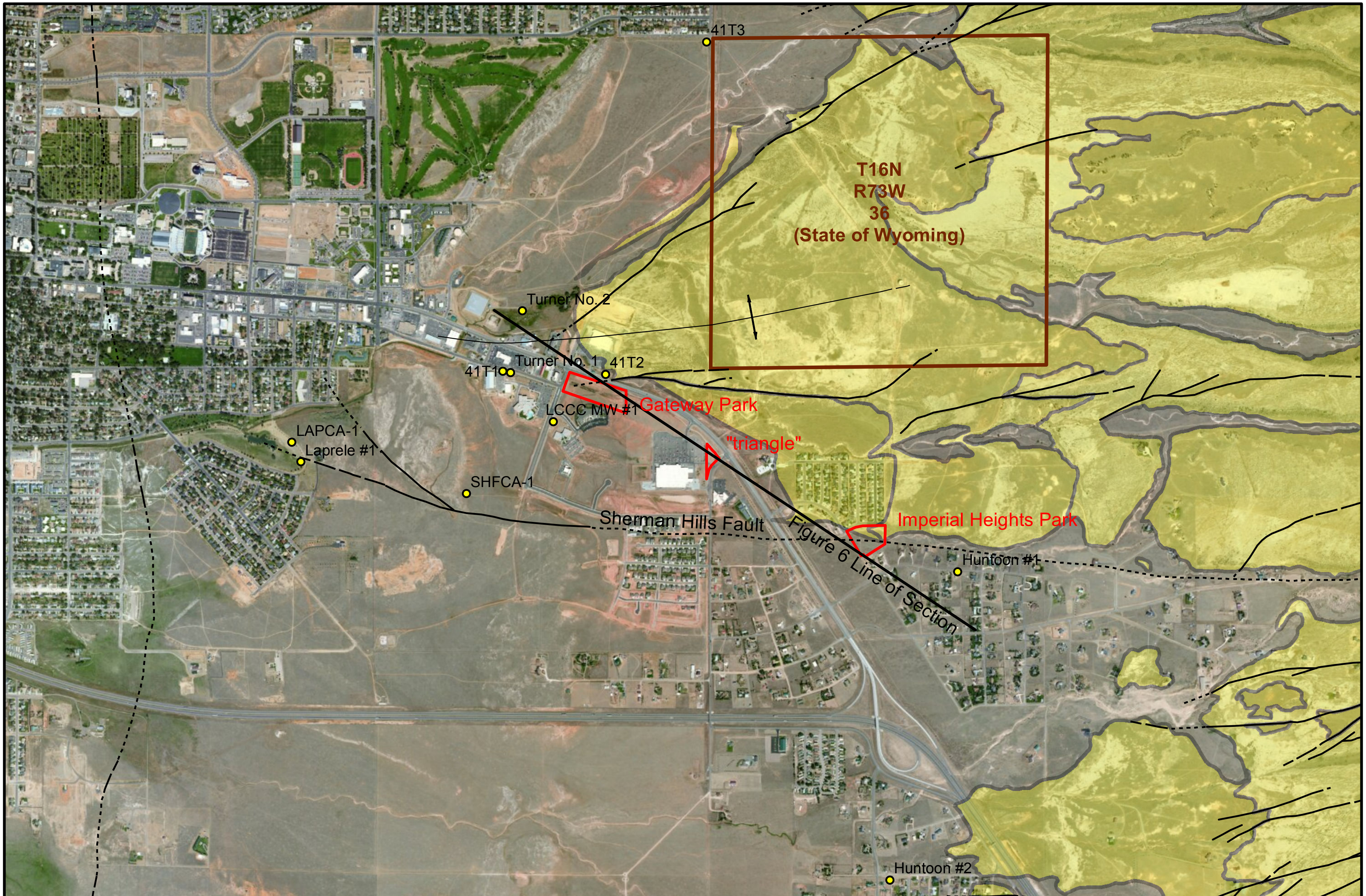


Figure 4 - Preliminary Groundwater Table
City of Laramie
Casper Aquifer Monitoring Program



Permanent Monitoring Points

0 1,000 2,000 Feet

Figure 5 - Existing Monitoring Sites
City of Laramie
Casper Aquifer Monitoring Program

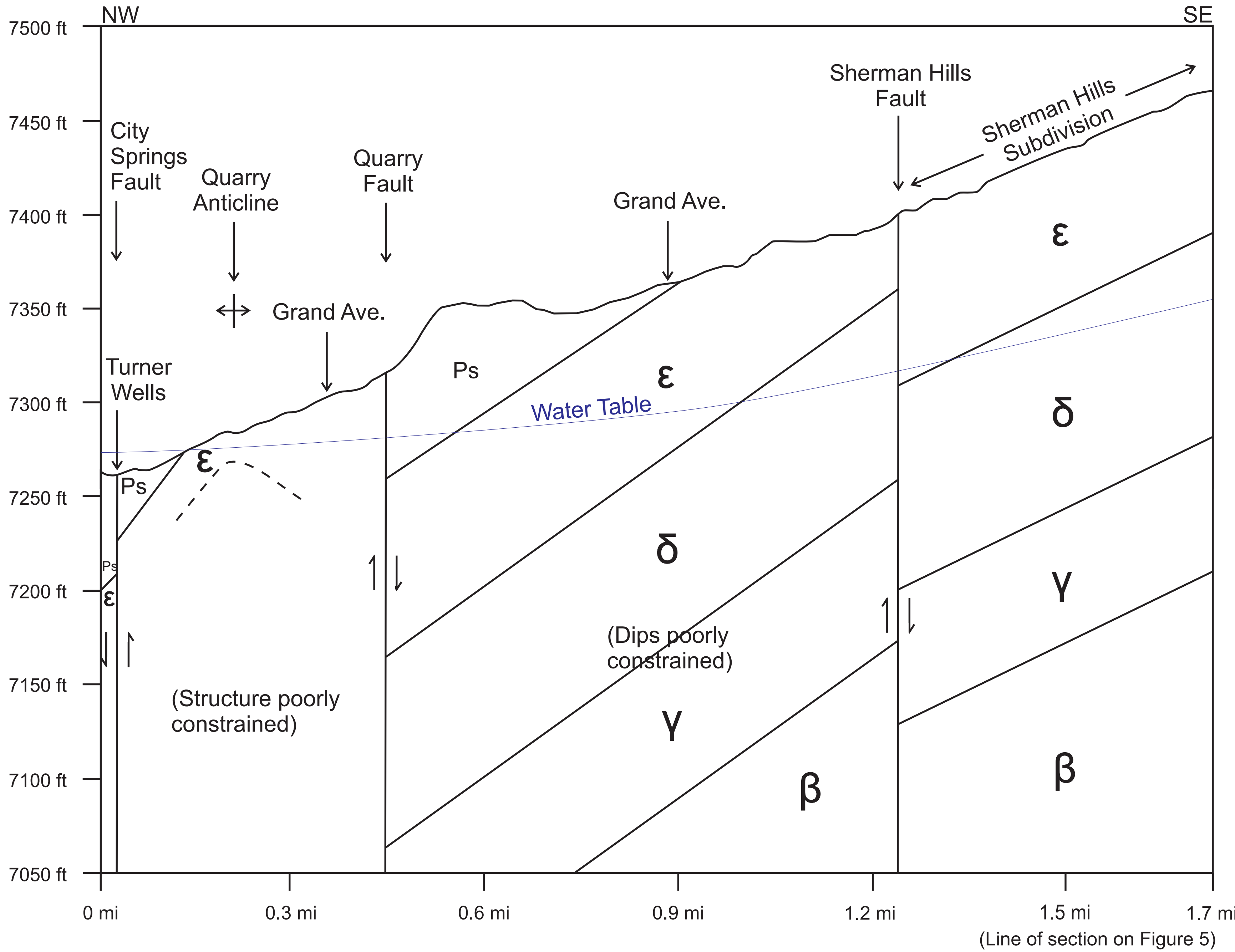


Figure 6 - Schematic Geologic Cross-Section

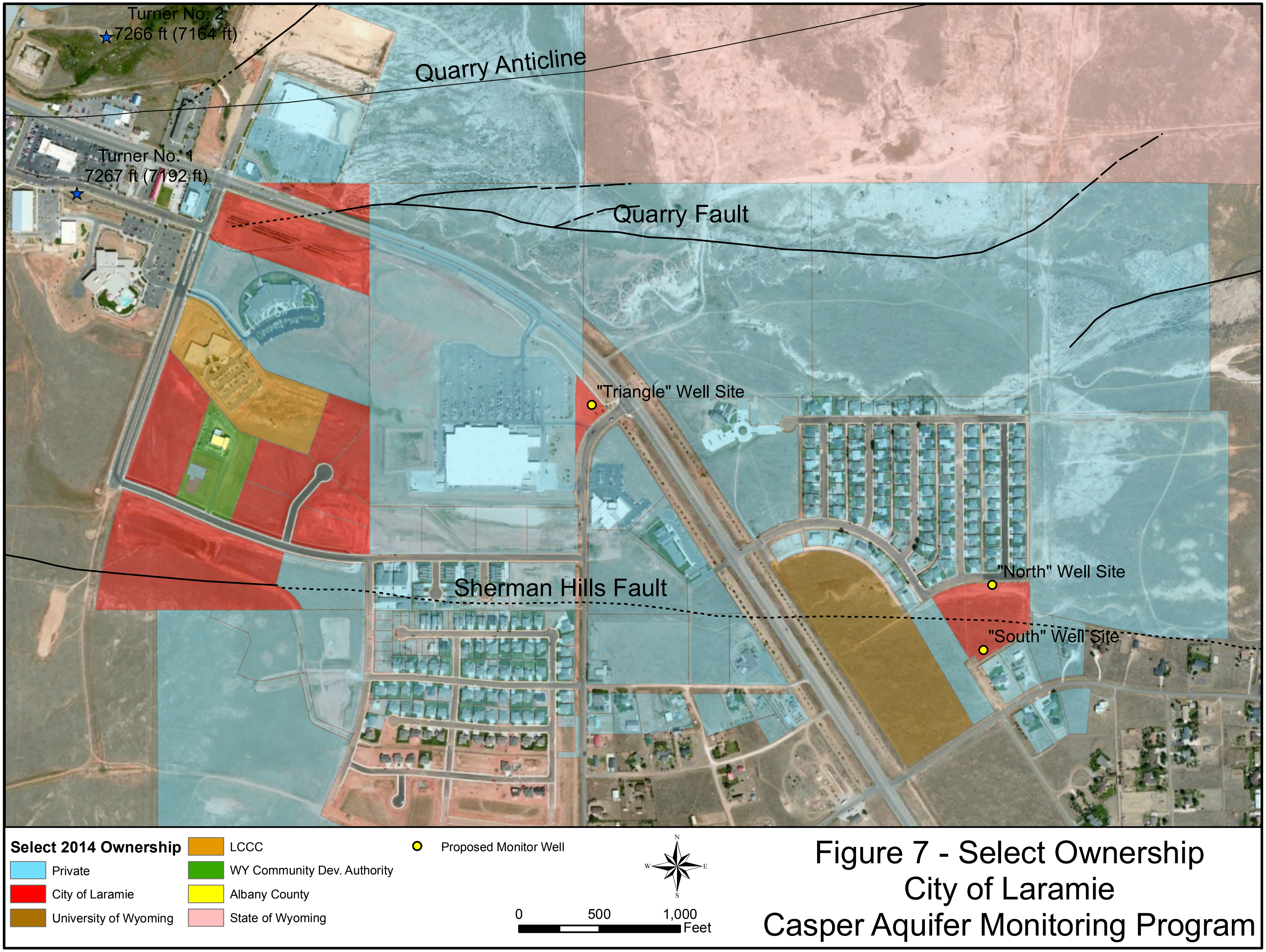


Figure 7 - Select Ownership
City of Laramie
Casper Aquifer Monitoring Program

Appendix 2 - Water Quality Lab Reports
Laramie Monitor Well Project

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Revised Date:**	04/17/15
Project:	Laramie Monitor Well	**Report Date:**	04/07/15
Lab ID:	C15040052-001	**Collection Date:**	03/31/15 11:10
Client Sample ID:	Triangle-70	**DateReceived:**	04/02/15
		Matrix:	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	12	mg/L		1		E300.0	04/03/15 15:19 / wc
Nitrogen, Nitrate+Nitrite as N	3.2	mg/L	D	0.2		E353.2	04/15/15 15:40 / lr
Nitrogen, Nitrite as N	ND	mg/L		0.1		A4500-NO2 B	04/02/15 10:27 / lr

Report Definitions:

RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Revised Date:**	04/17/15
Project:	Laramie Monitor Well	**Report Date:**	04/07/15
Lab ID:	C15040052-002	**Collection Date:**	03/31/15 12:15
Client Sample ID:	Triangle-92	**DateReceived:**	04/02/15
		Matrix:	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	11	mg/L		1		E300.0	04/03/15 15:37 / wc
Nitrogen, Nitrate+Nitrite as N	3.5	mg/L	D	0.2		E353.2	04/15/15 15:42 / lr
Nitrogen, Nitrite as N	ND	mg/L		0.1		A4500-NO2 B	04/02/15 10:28 / lr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client: WY Groundwater LLC
Project: Laramie Monitor Well
Lab ID: C15040052-003
Client Sample ID: Triangle-126

Revised Date: 04/17/15
Report Date: 04/07/15
Collection Date: 03/31/15 13:50
DateReceived: 04/02/15
Matrix: Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	15	mg/L		1		E300.0	04/03/15 15:55 / wc
Nitrogen, Nitrate+Nitrite as N	4.8	mg/L	D	0.2		E353.2	04/15/15 15:45 / lr
Nitrogen, Nitrite as N	ND	mg/L		0.1		A4500-NO2 B	04/02/15 10:28 / lr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Revised Date:**	04/17/15
Project:	Laramie Monitor Well	**Report Date:**	04/07/15
Lab ID:	C15040052-004	**Collection Date:**	03/31/15 15:45
Client Sample ID:	Triangle-155	**DateReceived:**	04/02/15
		Matrix:	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	12	mg/L		1		E300.0	04/03/15 16:14 / wc
Nitrogen, Nitrate+Nitrite as N	4.2	mg/L	D	0.2		E353.2	04/15/15 15:47 / lr
Nitrogen, Nitrite as N	ND	mg/L		0.1		A4500-NO2 B	04/02/15 10:28 / lr

Report Definitions:

RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client: WY Groundwater LLC
Project: Laramie Monitor Well
Lab ID: C15040229-001
Client Sample ID: NW-104

Report Date: 04/15/15
Collection Date: 04/06/15 12:05
DateReceived: 04/08/15
Matrix: Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	3	mg/L		1		E300.0	04/08/15 21:45 / wc
Nitrogen, Nitrate+Nitrite as N	1.6	mg/L		0.1		E353.2	04/09/15 16:03 / lr
Nitrogen, Nitrite as N	ND	mg/L		0.1		A4500-NO2 B	04/08/15 11:03 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	04/23/15
Project:	Laramie Monitor Well	**Collection Date:**	04/06/15 12:05
Lab ID:	C15040558-001	**DateReceived:**	04/17/15
Client Sample ID:	NW-104	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Carbonate as CO3	ND	mg/L	H	5		A2320 B	04/20/15 15:38 / wc
Bicarbonate as HCO3	238	mg/L	H	5		A2320 B	04/20/15 15:38 / wc
Calcium	63	mg/L		1		E200.7	04/21/15 15:17 / sf
Chloride	3	mg/L		1		E300.0	04/21/15 12:29 / wc
Magnesium	18	mg/L		1		E200.7	04/21/15 15:17 / sf
Potassium	2	mg/L		1		E200.7	04/22/15 14:41 / sf
Sodium	3	mg/L		1		E200.7	04/21/15 15:17 / sf
Sulfate	10	mg/L		1		E300.0	04/21/15 12:29 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
H - Analysis performed past recommended holding time.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client: WY Groundwater LLC
Project: Laramie Monitor Well
Lab ID: C15040229-002
Client Sample ID: NW-117

Report Date: 04/15/15
Collection Date: 04/06/15 12:45
DateReceived: 04/08/15
Matrix: Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	2	mg/L		1		E300.0	04/08/15 22:04 / wc
Nitrogen, Nitrate+Nitrite as N	1.3	mg/L		0.1		E353.2	04/09/15 16:10 / lr
Nitrogen, Nitrite as N	ND	mg/L		0.1		A4500-NO2 B	04/08/15 11:04 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client: WY Groundwater LLC
Project: Laramie Monitor Well
Lab ID: C15040558-005
Client Sample ID: NW-160

Report Date: 04/23/15
Collection Date: 04/08/15 13:05
DateReceived: 04/17/15
Matrix: Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Nitrogen, Nitrate+Nitrite as N	1.1	mg/L		0.1		E353.2	04/20/15 14:03 / lr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	05/07/15
Project:	Laramie Monitor Well	**Collection Date:**	04/23/15 15:15
Lab ID:	C15040814-001	**DateReceived:**	04/28/15
Client Sample ID:	NW-ET160	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	2	mg/L		1		E300.0	04/30/15 15:45 / wc
Nitrogen, Nitrate+Nitrite as N	1.3	mg/L		0.1		E353.2	04/29/15 15:18 / lr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	05/07/15
Project:	Laramie Monitor Well	**Collection Date:**	04/24/15 11:45
Lab ID:	C15040814-002	**DateReceived:**	04/28/15
Client Sample ID:	NW-ET1390	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Chloride	6	mg/L		1		E300.0	04/30/15 16:37 / wc
Nitrogen, Nitrate+Nitrite as N	2.2	mg/L		0.1		E353.2	04/29/15 15:21 / lr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	05/07/15
Project:	Laramie Monitor Well	**Collection Date:**	04/25/15 12:45
Lab ID:	C15040814-003	**DateReceived:**	04/28/15
Client Sample ID:	NW-END	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Carbonate as CO3	ND	mg/L		5		A2320 B	04/30/15 18:49 / wc
Bicarbonate as HCO3	253	mg/L		5		A2320 B	04/30/15 18:49 / wc
Calcium	61	mg/L		1		E200.7	04/30/15 17:53 / sf
Chloride	7	mg/L		1		E300.0	04/30/15 16:54 / wc
Magnesium	16	mg/L		1		E200.7	04/30/15 17:53 / sf
Nitrogen, Nitrate+Nitrite as N	2.3	mg/L		0.1		E353.2	04/29/15 15:23 / lr
Potassium	ND	mg/L		1		E200.7	04/30/15 17:53 / sf
Sodium	4	mg/L		1		E200.7	04/30/15 17:53 / sf
Sulfate	11	mg/L		1		E300.0	04/30/15 16:54 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	05/07/15
Project:	Laramie Monitor Well	**Collection Date:**	04/25/15 12:38
Lab ID:	C15040814-004	**DateReceived:**	04/28/15
Client Sample ID:	Test Outfall	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Solids, Total Dissolved TDS @ 180 C	227	mg/L		10		A2540 C	04/29/15 10:42 / lmc
Solids, Total Suspended TSS @ 105 C	ND	mg/L		10		A2540 D	04/29/15 09:53 / lmc
VOLATILE ORGANIC COMPOUNDS							
Tetrachloroethene	ND	ug/L		1.0		SW8260B	05/01/15 14:29 / jlr
Trichloroethene	ND	ug/L		1.0		SW8260B	05/01/15 14:29 / jlr
Surr: 1,2-Dichlorobenzene-d4	107	%REC		80-120		SW8260B	05/01/15 14:29 / jlr
Surr: Dibromofluoromethane	110	%REC		53-143		SW8260B	05/01/15 14:29 / jlr
Surr: p-Bromofluorobenzene	95.0	%REC		80-130		SW8260B	05/01/15 14:29 / jlr
Surr: Toluene-d8	100	%REC		80-120		SW8260B	05/01/15 14:29 / jlr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client: WY Groundwater LLC
Project: Laramie Monitor Well
Lab ID: C15040558-006
Client Sample ID: MTH-99

Report Date: 04/23/15
Collection Date: 04/14/15 13:31
DateReceived: 04/17/15
Matrix: Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Nitrogen, Nitrate+Nitrite as N	5.8	mg/L	D	0.2		E353.2	04/20/15 14:06 / lr

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	04/23/15
Project:	Laramie Monitor Well	**Collection Date:**	04/13/15 15:00
Lab ID:	C15040558-003	**DateReceived:**	04/17/15
Client Sample ID:	MTH-152	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Carbonate as CO3	ND	mg/L		5		A2320 B	04/20/15 16:10 / wc
Bicarbonate as HCO3	224	mg/L		5		A2320 B	04/20/15 16:10 / wc
Calcium	70	mg/L		1		E200.7	04/21/15 15:25 / sf
Chloride	31	mg/L		1		E300.0	04/21/15 13:06 / wc
Magnesium	19	mg/L		1		E200.7	04/21/15 15:25 / sf
Nitrogen, Nitrate+Nitrite as N	7.0	mg/L	D	0.5		E353.2	04/20/15 13:58 / lr
Potassium	2	mg/L		1		E200.7	04/22/15 14:49 / sf
Sodium	17	mg/L		1		E200.7	04/21/15 15:25 / sf
Sulfate	25	mg/L		1		E300.0	04/21/15 13:06 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client:	WY Groundwater LLC	**Report Date:**	04/23/15
Project:	Laramie Monitor Well	**Collection Date:**	04/13/15 12:17
Lab ID:	C15040558-002	**DateReceived:**	04/17/15
Client Sample ID:	SW-103	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Carbonate as CO3	ND	mg/L		5		A2320 B	04/20/15 15:54 / wc
Bicarbonate as HCO3	218	mg/L		5		A2320 B	04/20/15 15:54 / wc
Calcium	75	mg/L		1		E200.7	04/21/15 15:21 / sf
Chloride	42	mg/L		1		E300.0	04/21/15 12:48 / wc
Magnesium	22	mg/L		1		E200.7	04/21/15 15:21 / sf
Nitrogen, Nitrate+Nitrite as N	8.3	mg/L	D	0.5		E353.2	04/20/15 13:56 / lr
Potassium	2	mg/L		1		E200.7	04/22/15 14:45 / sf
Sodium	24	mg/L		1		E200.7	04/21/15 15:21 / sf
Sulfate	29	mg/L		1		E300.0	04/21/15 12:48 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

Prepared by Casper, WY Branch

Client: WY Groundwater LLC
Project: Laramie Monitor Well
Lab ID: C15040558-004
Client Sample ID: SW-PT

Report Date: 04/23/15
Collection Date: 04/13/15 11:50
DateReceived: 04/17/15
Matrix: Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
MAJOR IONS							
Carbonate as CO3	ND	mg/L		5		A2320 B	04/20/15 16:18 / wc
Bicarbonate as HCO3	242	mg/L		5		A2320 B	04/20/15 16:18 / wc
Calcium	74	mg/L		1		E200.7	04/21/15 15:29 / sf
Chloride	37	mg/L		1		E300.0	04/21/15 13:24 / wc
Magnesium	20	mg/L		1		E200.7	04/21/15 15:29 / sf
Nitrogen, Nitrate+Nitrite as N	7.5	mg/L	D	0.5		E353.2	04/20/15 14:01 / lr
Potassium	1	mg/L		1		E200.7	04/22/15 15:05 / sf
Sodium	20	mg/L		1		E200.7	04/21/15 15:29 / sf
Sulfate	25	mg/L		1		E300.0	04/21/15 13:24 / wc

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

Appendix 3 - SEO Permit and DEQ WYPDES Groundwater Discharge Permit Information Laramie Monitor Well Project

Vista & Grand ("Triangle") Monitor Well - SEO Permit
Imperial Heights Park North Monitor Well - SEO Permit
Imperial Heights Park South Monitor Well - SEO Permit
Imperial Heights Park North Monitor Well WYPDES Permit, Termination Notice, and Discharge Monitoring Reports (DMRs)

01/15/15 12:22 PM

FORM UW5-21346
Rev. 6/07
FILING FEE SCHEDULE ON REVERSE SIDE

STATE OF WYOMING

OFFICE OF THE STATE ENGINEER
HERSCHLER BLDG., 4-E CHEYENNE, WYOMING 82002
(307) 777-6163

APPLICATION FOR PERMIT TO APPROPRIATE GROUND WATER

APPLICATION FOR WELLS AND SPRINGS

Note: Only springs flowing 25 gallons per minute or less, where the proposed use is domestic and /or stock watering, will be considered as ground water appropriations.

FOR OFFICE USE ONLY

Temporary Filing No. U.W. 43-4-535W

PERMIT NO. U.W. 203337
WATER DIVISION NO. 1 DISTRICT 4A
U.W. DISTRICT Laramie Ground Water District

NOTE: Do not fold this form. Use typewriter or print neatly with black ink.
ALL ITEMS MUST BE COMPLETED BEFORE APPLICATION IS ACCEPTABLE

NAME AND NUMBER OF WELL or SPRING VISTA & GRAND MONITOR WELL

1. Name of applicant(s) CITY OF LARAMIE Phone: ______
2. Address of applicant(s) P.O. BOX C LARAMIE Wyoming 82073
   (MAILING ADDRESS) (CITY) (STATE) (ZIP)
3. Name & address of agent to receive correspondence and notices HINCKLEY CONSULTING
   P.O. BOX 452 LARAMIE Wyoming 82073 Phone: 307-745-0066
   (MAILING ADDRESS) (CITY) (STATE) (ZIP)
4. Use to which the water will be applied:

☐	Domestic:	Use of water in 3 single family dwellings or less, noncommercial watering of lawns and gardens totaling one acre or less. Number of houses served?____.
☐	Stock Watering:	Normal livestock use at four tanks or less within one mile of well or spring. Stockwatering pipelines and commercial feedlots are a miscellaneous use. Number of stock tanks?____.
☐	Irrigation:	Watering of any lands for agricultural purposes not covered by the definition of domestic use (large-scale lawn watering of golf courses, cemeteries, recreation areas, etc., is miscellaneous use).
☐	Municipal:	Use of water in incorporated Towns and Cities. Note 1: use of water in unincorporated towns, subdivisions, improvement districts, mobile home parks, etc. is classified as miscellaneous use. Note 2: a permit may be required by the Wyoming Department of Environmental Quality (WDEQ) if the well will be classified as a public water supply under the WDEQ's rules and regulations.
☐	Industrial:	Long term use of water for the manufacture of a product or production of oil/gas or other minerals (oil field water flood operations, power plant water supply, etc.). (Describe in REMARKS)
☐	Miscellaneous:	Any use of water not defined under previous definitions such as stock water pipelines, subdivisions, mine dewatering, mineral/oil exploration drilling, potable supplies in office, etc. (Describe in Remarks). Note: a permit may be required by the WDEQ if the well will be classified as a public water supply under the WDEQ's rules and regulations.
☐	Coalbed Methane	Water produced in the production of coal bed methane gas. Note: wells used in the production of coal bed methane gas will require a permit from the Wyoming Oil and Gas Conservation Commission.
X	Monitor, Observation	Note: a WDEQ permit may be required ☐ Test Well: (Describe in REMARKS)

5. Location of the well or spring: (NOTE: Quarter-quarter (40 acre subdivision) MUST be shown. EXAMPLE: SE 1/4 NW 1/4 of Sec. 12, Township 14 North, Range 68 West.) O.S. MN 1/16/15
   Albany County, SW 1/4 NW 1/4 of Sec. 01, T. 015N, R. 073W, of the 6th P.M. (W.R.M.), Wyoming. If located in a platted subdivision, also provide Lot/Tract ___ Block ___ of the ______ Subdivision (or Add'n) of Albany. Resurvey Location: Tract ______, (or Lot) ______.
6. Estimated depth of the well or spring is 200 feet. Estimated production interval is 60 ft. to 200 ft.
7. (a) MAXIMUM instantaneous flow of water to be developed and beneficially used: 0 gallons per minute. NOTE: if for domestic and / or stock use, this application will be processed for a maximum of 25 gallons per minute. For a spring, after approval of this application, some type of artificial diversion or improvement must be constructed to qualify for a water right.

   (b) MAXIMUM volumetric quantity of water to be developed and beneficially used per calendar year: 0 gallons. Circle appropriate units: (Gallons) (Acre Feet) A four person family utilizes approximately one (1) acre-foot of water per year or 325,000 gallons.
8. Mark the point(s) or area(s) of use in the tabulation box below. Note: Upper row refers to the quarter of the section. Next row refers to the quarter of the quarter section.

TABULATION BOX

TWP	RNG	SEC	NE¼				NW¼				SW¼				SE¼				TOTAL
			NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	
O.S. ~~Unknown~~																			
015N	073W	01							X A										
																		Total:	X

SEE REVERSE SIDE

Permit No. U.W. 203337 Book No. 1461 Page No. 37

9. If for irrigation use:
   a. Describe MAXIMUM acreage to be irrigated in each 40 acre subdivision in the tabulation box above.
   b. ☐ Land will be irrigated from this well only.
   c. ☐ Land is irrigated from existing water right(s) with water from this well to be additional supply. Describe existing water right(s) under REMARKS.

10. If for irrigation use, describe method of irrigation, i.e. center pivot sprinkler, flood, etc.: ____________

11. The well or spring is to be constructed on lands owned by CITY OF LARAMIE
   (The granting of a permit does not constitute the granting of a right-of-way. If any easement or right-of-way is necessary in connection with this application, it should be understood that the responsibility is the applicant's. A copy of the agreement should accompany this application, if the land is privately owned and the owner is not the co-applicant.)

12. The water is to be used on lands owned by N/A
   (If the landowner is not the applicant, a copy of the agreement relating to the usage of the appropriated water on the land should be submitted to this office. If the landowner is included as co-applicant on the application, this procedure need not be followed.) NOTE: Water rights attach to the area(s) and/or point(s) of use.

REMARKS: This well is intended for monitoring water levels and water quality in the Casper Aquifer, the groundwater source for the City of Laramie municipal water supply.

Under penalties of perjury, I declare that I have examined this application and to the best of my knowledge and belief it is true, correct and complete.

For HINCKLEY CONSULTING — January 15, 20 15
Signature of Applicant or Authorized Agent — Date

THE LEGALLY REQUIRED FILING FEE MUST ACCOMPANY THIS APPLICATION

DOMESTIC AND/OR STOCK WATERING USES (Domestic use is defined as use of water in 3 single family dwellings or less, noncommercial watering of lawns and gardens totalling one acre or less.)	$50.00
COAL BED METHANE USE	$50.00
IRRIGATION, MUNICIPAL, INDUSTRIAL, MISCELLANEOUS USES	$75.00
MONITOR(For water level measurements or chemical quality sampling) or TEST WELL USES	No Fee

IF WELL WILL SERVE MULTIPLE USES, SUBMIT ONLY ONE (THE HIGHER) FILING FEE.

THIS SECTION IS NOT TO BE FILLED IN BY APPLICANT

THE STATE OF WYOMING)
) ss.
STATE ENGINEER'S OFFICE)

This instrument was received and filed for record on the 15 day of January, A.D. 20 15, at 12:22 o'clock P M.

Permit No. U.W. 203337

[signature]
for State Engineer

THIS IS TO CERTIFY that I have examined the foregoing application and do hereby grant the same subject to the following limitations and conditions:

This application is approved subject to the condition that the proposed use shall not interfere with any existing rights to ground water from the same source of supply and is subject to regulation and correlation with surface water rights, if the ground and surface waters are interconnected. The use of water hereunder is subject to the further provisions of Chapter 169, Session Laws of Wyoming, 1957, and any subsequent amendments thereto.
Granting of a permit does not guarantee the right to have the water level or artesian pressure in the well maintained at any specific level. The well should be constructed to a depth adequate to allow for the maximum development and beneficial use of ground water in the source of supply.
If the well is a flowing artesian well, it shall be so constructed and equipped that the flow may be shut off when not in use without loss of water into sub-surface formations or at the land surface.
Coal Bed Methane wells have Additional Conditions and Limitations on attachment sheet.

Approval of this application may be considered as authorization to proceed with construction of the proposed well or spring. A Statement of Completion will be filed within thirty (30) days of completion of construction, including pump installation.

Completion of construction ~~and completion of the beneficial use of water~~ for the purposes specified in Item 4 of this application will be made by December 31, 2016.

~~The amount of appropriation shall be limited to the quantity to which permittee is entitled as determined at time of proof of application of water to beneficial use.~~

Witness my hand this 29th day of January, A.D. 20 15.

[signature]
Patrick T. Tyrrell, State Engineer

SCANNED FEB 18 2015

01/15/15 12:21 PM

FORM UW5-21347
Rev. 6/07
FILING FEE SCHEDULE ON REVERSE SIDE

STATE OF WYOMING

OFFICE OF THE STATE ENGINEER
HERSCHLER BLDG., 4-E CHEYENNE, WYOMING 82002
(307) 777-6163

APPLICATION FOR PERMIT TO APPROPRIATE GROUND WATER

APPLICATION FOR WELLS AND SPRINGS
Note: Only springs flowing 25 gallons per minute or less, where the proposed use is domestic and /or stock watering, will be considered as ground water appropriations.

FOR OFFICE USE ONLY

Temporary Filing No. U.W. 43-5-535W

PERMIT NO. U.W. 203338
WATER DIVISION NO. 1 DISTRICT 4A
U.W. DISTRICT Laramie Ground Water District

NOTE: Do not fold this form. Use typewriter or print neatly with black ink.
ALL ITEMS MUST BE COMPLETED BEFORE APPLICATION IS ACCEPTABLE

NAME AND NUMBER OF WELL or SPRING: IMPERIAL HEIGHTS PARK NORTH MONITOR WELL

1. Name of applicant(s): CITY OF LARAMIE Phone: ______

2. Address of applicant(s): P.O. BOX C (MAILING ADDRESS) LARAMIE (CITY) Wyoming (STATE) 82073 (ZIP)

3. Name & address of agent to receive correspondence and notices: HINCKLEY CONSULTING
P.O. BOX 452 (MAILING ADDRESS) LARAMIE (CITY) Wyoming 82073 (STATE) (ZIP) Phone: 307-745-0066

4. Use to which the water will be applied:

☐ Domestic: Use of water in 3 single family dwellings or less, noncommercial watering of lawns and gardens totaling one acre or less. Number of houses served? ____.

☐ Stock Watering: Normal livestock use at four tanks or less within one mile of well or spring. Stockwatering pipelines and commercial feedlots are a miscellaneous use. Number of stock tanks? ____.

☐ Irrigation: Watering of any lands for agricultural purposes not covered by the definition of domestic use (large-scale lawn watering of golf courses, cemeteries, recreation areas, etc., is miscellaneous use).

☐ Municipal: Use of water in incorporated Towns and Cities. Note 1: use of water in unincorporated towns, subdivisions, improvement districts, mobile home parks, etc. is classified as miscellaneous use. Note 2: a permit may be required by the Wyoming Department of Environmental Quality (WDEQ) if the well will be classified as a public water supply under the WDEQ's rules and regulations.

☐ Industrial: Long term use of water for the manufacture of a product or production of oil/gas or other minerals (oil field water flood operations, power plant water supply, etc.). (Describe in REMARKS)

☐ Miscellaneous: Any use of water not defined under previous definitions such as stock water pipelines, subdivisions, mine dewatering, mineral/oil exploration drilling, potable supplies in office, etc. (Describe in Remarks). Note: a permit may be required by the WDEQ if the well will be classified as a public water supply under the WDEQ's rules and regulations.

☐ Coalbed Methane: Water produced in the production of coal bed methane gas. Note: wells used in the production of coal bed methane gas will require a permit from the Wyoming Oil and Gas Conservation Commission.

X Monitor, Observation: Note: a WDEQ permit may be required ~~X~~ out Test Well: (Describe in REMARKS)
MM 1/16/15 well is for a one time 4 day pump test, afterwards a monitor well

5. Location of the well or spring: (NOTE: Quarter-quarter (40 acre subdivision) MUST be shown. EXAMPLE: SE 1/4 NW 1/4 of Sec. 12, Township 14 North, Range 68 West.) O.S. MM 1/16/15
Albany County, SE 1/4 NW 1/4 of Sec. 01, T. 015N, R. 073W of the 6th P.M. (W.R.M.), Wyoming. If located in a platted subdivision, also provide Lot/Tract ___ Block ___ of the ______ Subdivision (or Add'n) of Albany. Resurvey Location: Tract ______, (or Lot) ______.

6. Estimated depth of the well or spring is 200 feet. Estimated production interval is 90 ft. to 200 ft.

7. (a) MAXIMUM instantaneous flow of water to be developed and beneficially used: 0 gallons per minute.
NOTE: if for domestic and / or stock use, this application will be processed for a maximum of 25 gallons per minute. For a spring, after approval of this application, some type of artificial diversion or improvement must be constructed to qualify for a water right.

(b) MAXIMUM volumetric quantity of water to be developed and beneficially used per calendar year: 0 acre-feet.
Circle appropriate units: (Gallons) (Acre Feet) A four person family utilizes approximately one (1) acre-foot of water per year or 325,000 gallons.

8. Mark the point(s) or area(s) of use in the tabulation box below. Note: Upper row refers to the quarter of the section. Next row refers to the quarter of the quarter section.

TABULATION BOX

TWP	RNG	SEC	NE¼				NW¼				SW¼				SE¼				TOTAL
			NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	
O.S. ~~Unknown~~																			
015N	073W	01								X A									
																		Total:	X

SEE REVERSE SIDE

Permit No. U.W. 203338 Book No. 1461 Page No. 38

9. If for irrigation use:
   a. Describe MAXIMUM acreage to be irrigated in each 40 acre subdivision in the tabulation box above.
   b. ☐ Land will be irrigated from this well only.
   c. ☐ Land is irrigated from existing water right(s) with water from this well to be additional supply. Describe existing water right(s) under REMARKS.

10. If for irrigation use, describe method of irrigation, i.e. center pivot sprinkler, flood, etc.: ______

11. The well or spring is to be constructed on lands owned by CITY OF LARAMIE
(The granting of a permit does not constitute the granting of a right-of-way. If any easement or right-of-way is necessary in connection with this application, it should be understood that the responsibility is the applicant's. A copy of the agreement should accompany this application, if the land is privately owned and the owner is not the co-applicant.)

12. The water is to be used on lands owned by N/A
(If the landowner is not the applicant, a copy of the agreement relating to the usage of the appropriated water on the land should be submitted to this office. If the landowner is included as co-applicant on the application, this procedure need not be followed.) NOTE: Water rights attach to the area(s) and/or point(s) of use.

REMARKS: No type of supply (DOM, STO, etc.) is being sought for this well. The application for a test well permit is simply to run a 4-day pump test to better understand aquifer characteristics. This well is intended for monitoring water levels and water quality in the Casper Aquifer, the groundwater source for the City of Laramie municipal water supply

Under penalties of perjury, I declare that I have examined this application and to the best of my knowledge and belief ~~it~~ is true, correct and complete.

For HINCKLEY CONSULTING — Signature of Applicant or Authorized Agent

January 15, 20 15 — Date

THE LEGALLY REQUIRED FILING FEE MUST ACCOMPANY THIS APPLICATION

DOMESTIC AND/OR STOCK WATERING USES (Domestic use is defined as use of water in 3 single family dwellings or less, noncommercial watering of lawns and gardens totalling one acre or less.)	$50.00
COAL BED METHANE USE	$50.00
IRRIGATION, MUNICIPAL, INDUSTRIAL, MISCELLANEOUS USES	$75.00
MONITOR(For water level measurements or chemical quality sampling) or TEST WELL USES	No Fee

IF WELL WILL SERVE MULTIPLE USES, SUBMIT ONLY ONE (THE HIGHER) FILING FEE.

THIS SECTION IS NOT TO BE FILLED IN BY APPLICANT

THE STATE OF WYOMING)
) ss.
STATE ENGINEER'S OFFICE)

This instrument was received and filed for record on the 15 day of January, A.D. 20 15, at 12:21 o'clock P M.

Permit No. U.W. 203338

for State Engineer

THIS IS TO CERTIFY that I have examined the foregoing application and do hereby grant the same subject to the following limitations and conditions:

This application is approved subject to the condition that the proposed use shall not interfere with any existing rights to ground water from the same source of supply and is subject to regulation and correlation with surface water rights, if the ground and surface waters are interconnected. The use of water hereunder is subject to the further provisions of Chapter 169, Session Laws of Wyoming, 1957, and any subsequent amendments thereto.
Granting of a permit does not guarantee the right to have the water level or artesian pressure in the well maintained at any specific level. The well should be constructed to a depth adequate to allow for the maximum development and beneficial use of ground water in the source of supply.
If the well is a flowing artesian well, it shall be so constructed and equipped that the flow may be shut off when not in use without loss of water into sub-surface formations or at the land surface.
Coal Bed Methane wells have Additional Conditions and Limitations on attachment sheet.

Approval of this application may be considered as authorization to proceed with construction of the proposed well or spring. A Statement of Completion will be filed within thirty (30) days of completion of construction, including pump installation.

Completion of construction ~~and completion of the beneficial use of water~~ for the purposes specified in Item 4 of this application will be made by December 31, 2016.

~~The amount of appropriation shall be limited to the quantity to which permittee is entitled as determined at time of proof of application of water to beneficial use.~~

Witness my hand this 29th day of January, A.D. 20 15.

Patrick T. Tyrrell, State Engineer

SCANNED FEB 18 2015

01/15/15 12:21 PM

FORM UW5-21349
Rev. 6/07
FILING FEE SCHEDULE
ON REVERSE SIDE

STATE OF WYOMING

OFFICE OF THE STATE ENGINEER
HERSCHLER BLDG., 4-E CHEYENNE, WYOMING 82002
(307) 777-6163

APPLICATION FOR PERMIT TO APPROPRIATE GROUND WATER

APPLICATION FOR WELLS AND SPRINGS
Note: Only springs flowing 25 gallons per minute or less, where the proposed use is domestic and /or stock watering, will be considered as ground water appropriations.

FOR OFFICE USE ONLY

Temporary Filing No. U.W. 43-7-535W

PERMIT NO. U.W. 203339
WATER DIVISION NO. 1 DISTRICT 4A
U.W. DISTRICT Laramie Ground Water District

NOTE: Do not fold this form. Use typewriter or print neatly with black ink.
ALL ITEMS MUST BE COMPLETED BEFORE APPLICATION IS ACCEPTABLE

NAME AND NUMBER OF WELL or SPRING IMPERIAL HEIGHTS PARK SOUTH MONITOR WELL

1. Name of applicant(s) CITY OF LARAMIE Phone:
2. Address of applicant(s) P.O. BOX C LARAMIE Wyoming 82073
(MAILING ADDRESS) (CITY) (STATE) (ZIP)
3. Name & address of agent to receive correspondence and notices HINCKLEY CONSULTING
P.O. BOX 452 LARAMIE Wyoming 82073 Phone: 307-745-0066
(MAILING ADDRESS) (CITY) (STATE) (ZIP)
4. Use to which the water will be applied:

☐	Domestic:	Use of water in 3 single family dwellings or less, noncommercial watering of lawns and gardens totaling one acre or less. Number of houses served?____.
☐	Stock Watering:	Normal livestock use at four tanks or less within one mile of well or spring. Stockwatering pipelines and commercial feedlots are a miscellaneous use. Number of stock tanks?____.
☐	Irrigation:	Watering of any lands for agricultural purposes not covered by the definition of domestic use (large-scale lawn watering of golf courses, cemeteries, recreation areas, etc., is miscellaneous use).
☐	Municipal:	Use of water in incorporated Towns and Cities. Note 1: use of water in unincorporated towns, sub-divisions, improvement districts, mobile home parks, etc. is classified as miscellaneous use. Note 2: a permit may be required by the Wyoming Department of Environmental Quality (WDEQ) if the well will be classified as a public water supply under the WDEQ's rules and regulations.
☐	Industrial:	Long term use of water for the manufacture of a product or production of oil/gas or other minerals (oil field water flood operations, power plant water supply, etc.). (Describe in REMARKS)
☐	Miscellaneous:	Any use of water not defined under previous definitions such as stock water pipelines, subdivisions, mine dewatering, mineral/oil exploration drilling, potable supplies in office, etc. (Describe in Remarks). Note: a permit may be required by the WDEQ if the well will be classified as a public water supply under the WDEQ's rules and regulations.
☐	Coalbed Methane	Water produced in the production of coal bed methane gas. Note: wells used in the production of coal bed methane gas will require a permit from the Wyoming Oil and Gas Conservation Commission.
X	Monitor, Observation	Note: a WDEQ permit may be required ☐ Test Well: (Describe in REMARKS)

5. Location of the well or spring: (NOTE: Quarter-quarter (40 acre subdivision) MUST be shown. EXAMPLE: SE 1/4 NW 1/4 of Sec. 12, Township 14 North, Range 68 West.) O.S. MM 1/16/15
Albany County, NE 1/4 SW 1/4 of Sec. 01, T. 015N, R. 073W of the 6th P.M. (W.R.M.), Wyoming. If located in a platted subdivision, also provide Lot/Tract ___ Block ___ of the ___ Subdivision (or Add'n) of Albany. Resurvey Location: Tract ___, (or Lot) ___.
6. Estimated depth of the well or spring is 280 feet. Estimated production interval is 90 ft. to 280 ft.
7. (a) MAXIMUM instantaneous flow of water to be developed and beneficially used: 0 gallons per minute.
NOTE: if for domestic and / or stock use, this application will be processed for a maximum of 25 gallons per minute. For a spring, after approval of this application, some type of artificial diversion or improvement must be constructed to qualify for a water right.

(b) MAXIMUM volumetric quantity of water to be developed and beneficially used per calendar year: 0 acre-feet.
Circle appropriate units: (Gallons) (Acre Feet) A four person family utilizes approximately one (1) acre-foot of water per year or 325,000 gallons.
8. Mark the point(s) or area(s) of use in the tabulation box below. Note: Upper row refers to the quarter of the section. Next row refers to the quarter of the quarter section.

TABULATION BOX

TWP	RNG	SEC	NE¼				NW¼				SW¼				SE¼				TOTAL
			NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	
O.S. ~~Unknown~~																			
015N	073W	01									X A								
																		Total:	X

SEE REVERSE SIDE

Permit No. U.W. 203339 Book No. 1461 Page No. 39

9. If for irrigation use:
   a. Describe MAXIMUM acreage to be irrigated in each 40 acre subdivision in the tabulation box above.
   b. ☐ Land will be irrigated from this well only.
   c. ☐ Land is irrigated from existing water right(s) with water from this well to be additional supply. Describe existing water right(s) under REMARKS.

10. If for irrigation use, describe method of irrigation, i.e. center pivot sprinkler, flood, etc.: ______

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(The granting of a permit does not constitute the granting of a right-of-way. If any easement or right-of-way is necessary in connection with this application, it should be understood that the responsibility is the applicant's. A copy of the agreement should accompany this application, if the land is privately owned and the owner is not the co-applicant.)

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(If the landowner is not the applicant, a copy of the agreement relating to the usage of the appropriated water on the land should be submitted to this office. If the landowner is included as co-applicant on the application, this procedure need not be followed.) NOTE: Water rights attach to the area(s) and/or point(s) of use.

REMARKS: This well is intended for monitoring water levels and water quality in the Casper Aquifer, the groundwater source for the City of Laramie municipal water supply.

Under penalties of perjury, I declare that I have examined this application and to the best of my knowledge and belief it is true, correct and complete.

For HINCKLEY CONSULTING — Signature of Applicant or Authorized Agent

January 15, 20 10 — Date

THE LEGALLY REQUIRED FILING FEE MUST ACCOMPANY THIS APPLICATION

DOMESTIC AND/OR STOCK WATERING USES (Domestic use is defined as use of water in 3 single family dwellings or less, noncommercial watering of lawns and gardens totalling one acre or less.)	$50.00
COAL BED METHANE USE	$50.00
IRRIGATION, MUNICIPAL, INDUSTRIAL, MISCELLANEOUS USES	$75.00
MONITOR(For water level measurements or chemical quality sampling) or TEST WELL USES	No Fee

IF WELL WILL SERVE MULTIPLE USES, SUBMIT ONLY ONE (THE HIGHER) FILING FEE.

THIS SECTION IS NOT TO BE FILLED IN BY APPLICANT

THE STATE OF WYOMING)
) ss.
STATE ENGINEER'S OFFICE)

This instrument was received and filed for record on the 15 day of January, A.D. 20 15, at 12:21 o'clock P M.

Permit No. U.W. 203339

for State Engineer

THIS IS TO CERTIFY that I have examined the foregoing application and do hereby grant the same subject to the following limitations and conditions:

This application is approved subject to the condition that the proposed use shall not interfere with any existing rights to ground water from the same source of supply and is subject to regulation and correlation with surface water rights, if the ground and surface waters are interconnected. The use of water hereunder is subject to the further provisions of Chapter 169, Session Laws of Wyoming, 1957, and any subsequent amendments thereto.
Granting of a permit does not guarantee the right to have the water level or artesian pressure in the well maintained at any specific level. The well should be constructed to a depth adequate to allow for the maximum development and beneficial use of ground water in the source of supply.
If the well is a flowing artesian well, it shall be so constructed and equipped that the flow may be shut off when not in use without loss of water into sub-surface formations or at the land surface.
Coal Bed Methane wells have Additional Conditions and Limitations on attachment sheet.

Approval of this application may be considered as authorization to proceed with construction of the proposed well or spring. A Statement of Completion will be filed within thirty (30) days of completion of construction, including pump installation.

Completion of construction ~~and completion of the beneficial use of water~~ for the purposes specified in Item 4 of this application will be made by December 31, 2016.

~~The amount of appropriation shall be limited to the quantity to which permittee is entitled as determined at time of proof of application of water to beneficial use.~~

Witness my hand this 29TH day of January, A.D. 20 15.

Patrick T. Tyrrell, State Engineer

SCANNED FEB 18 2015

Authorization to Discharge Wastewater Associated with Ground Water Well Pump Testing and Development
Well Pump Tests of Domestic Use Water Supplies
Under the Wyoming Pollutant Discharge Elimination System

Authorization # WYG720363

In compliance with the provisions of the Federal Water Pollution Control Act and the Wyoming Environmental Quality Act,

City of Laramie, Attn: Hinckley Construction, P.O. Box 452, Laramie, WY 82073

is authorized to discharge wastewater associated with Ground Water Well Pump Testing and Development activities from:

Laramie Monitoring Well Project – City of Laramie, WY

Outfall 001: SENW Section 1, Township 15N, Range 73W, Latitude: 41.29943, Longitude: -105.52915, Albany County

to surface waters of the State of Wyoming in accordance with the requirements of the enclosed General Permit for Temporary Discharge Associated with Ground Water Well Pump Testing and Development:

Unnamed ephemeral tributary (class 3B) to Spring Creek (class 2AB), North Platte River basin.

The wastewater discharged from this location associated with **WELL PUMP TESTS OF DOMESTIC WATER SUPPLIES** shall be limited and monitored by the permittee as specified below:

Effluent Limitations

Parameter	Authorization Maximum	Monthly Average	Weekly Average	Daily Maximum
Duration of Discharge (each well or outfall)	31 days	N/A	N/A	N/A
pH, su (standard units)	N/A	N/A	N/A	6.5-9.0
Total Suspended Solids, mg/L	N/A	30	45	90
Total Dissolved Solids (TDS), mg/L	N/A	N/A	N/A	5,000

Monitoring Requirements

Parameter	Measurement Frequency	Sample Type
Flow, gpm	Daily	Instantaneous or Continuous
pH su (standard units)	Daily	Grab
TSS, mg/L	Weekly	Grab
TDS, mg/L	Weekly	Grab

If the duration of the discharge is shorter than the required sample frequency, a minimum of one sample shall be taken for all parameters.

All waters shall be discharged in a manner to prevent erosion, scouring, or damage to stream banks, stream beds, ditches, or other waters of the state at the point of discharge. In addition, there shall be no deposition of substances in quantities which could result in significant aesthetic degradation, or degradation of habitat for aquatic life, plant life, or wildlife; or which could adversely affect public water supplies or those intended for agricultural or industrial use.

REPORTING REQUIREMENTS FOR THIS AUTHORIZATION

Reporting is required monthly, using Discharge Monitoring Reports (DMRs) to be submitted by the 28th day of the month following the completed reporting period, to WYPDES Permits Section, DEQ/WQD, Herschler Building - 4 W, 122 West 25th Street, Cheyenne, WY 82002. For eDMR please follow the instructions at the following website: http://deq.state.wy.us/wqd/DMR/edmr.asp. For the paper DMR's please follow the instructions at the following website: http://deq.state.wy.us/wqd/DMR/paperdmr.asp. If no discharge occurred during the reporting period, "no discharge" shall be reported. **The first report is due by March 28, 2015 for any discharges occurring in February, 2015.**

For termination of this authorization, the enclosed Termination Notice (also available at http://deq.state.wy.us/wqd/WYPDES_Permitting/downloads/TD_NOT_2_07.doc) must be completed and submitted at the completion of the discharge. Authorizations cannot be terminated until all completed DMR's have been submitted to the WQD for review. Once the permittee has received a letter confirming receipt of the termination notice, the permittee does not have to submit any further DMR's.

All WYPDES general permit authorizations are subject to a $100 annual permit fee for as long as the authorization is active or until the general permit expires. Appropriate fees are expected to be submitted with the NOI. See the Wyoming Environmental Quality Act §35-11-312 for further information.

This facility has been assigned permit authorization number **WYG720363.**

Coverage under this General Permit for Temporary Discharge Ground Water Well Pump Testing and Development shall begin upon date of issuance below, and discharges are authorized to continue no longer than **12 months from the date of issuance below.**

If you have any questions concerning the conditions of this general permit, contact Marcia Porter at 307-777-6081, or email marcia.porter@wyo.gov.

Leah Coleman, Permitting Supervisor
Department of Environmental Quality
Water Quality Division

2/24/15
Date of Issuance

General Permit for Temporary Discharge

TERMINATION NOTICE

RECEIVED
MAY 21 2015
WATER QUALITY DIVISION
WYOMING

INSTRUCTIONS: Submit this form with *water quality monitoring results* upon completion of discharge activity.

1. Name, address, and telephone number of the company, individual, or organization which received authorization for a temporary discharge under the attached general permit.

   Name: Hinckley Consulting

   Address: P.O. Box 452, Laramie, WY 82073

   Telephone: 307-745-0066

2. Identification number assigned to this temporary discharge: WYG 720363

3. Project Name: Laramie Monitoring Well Project - City of Laramie, WY

4. Certification:

   I certify under penalty of law that the temporary discharge identified above has been completed and that the discharge locations have been returned to approximate pretest conditions. I understand that by submitting this notice I am terminating coverage under Wyoming's general NPDES permit for temporary discharges. I also understand that if, at a later date, it is determined that the site was inadequately reclaimed and pollutant discharge results, I may be liable for discharging pollutants without a permit.

Bern Hinckley	Principal	
Printed Name of Person Signing	Title	
[signature]	5/29/15	307-745-0066
Signature	Date	Telephone

Section 35-11-901 of Wyoming Statutes provides that:

> "Any person who knowingly makes any false statement, representation, or certification in any application ... shall, upon conviction, be fined not more than $10,000 per day for each violation or imprisoned for not more than one (1) year or both."

Upon completion, remove this notice from the permit and mail to:

WYPDES Permits Section
DEQ/WQD
Herschler Building - 4 W
122 West 25th Street
Cheyenne, WY 82002

BE SURE TO INCLUDE WATER QUALITY MONITORING RESULTS WITH THIS FORM!

Discharge Monitoring Report (DMR)

Hinckley Consulting
Laramie Monitoring Well Project - City of Laramie, WY

Bern Hinckley, for City of Laramie
PO Box 452
Laramie, Wyoming 82073

Submission Period: 1 mo(s) | 2/1/2015 - 2/28/2015

WYG720363-001

No Discharge For Period ☒ Outfall Not Constructed ☐

BegDate	EndDate	Comment	SmpTy	SmpFreq	#Exc's	Parameter (Loc)	SBCode	Limit	Units	Discharge Note	Value
02/01/2015	02/28/2015		GRAB	XX/XX		Duration of discharge (Effluent Gross)					
							MO TOTAL	<= 31	d		
			INSTAN	01/01		Flow (Effluent Gross)					
							DAILY MX	Report	gal/min		
							MO AVG	Report	gal/min		
			GRAB	01/01		pH (Effluent Gross)					
							INST MAX	<= 9	SU		
							INST MIN	>= 6.5	SU		
			GRAB	01/07		Solids, total dissolved (Effluent Gross)					
							DAILY MX	<= 5000	mg/L		
			GRAB	01/07		Solids, total suspended (Effluent Gross)					
							DAILY MX	<= 90	mg/L		
							MO AVG	<= 30	mg/L		
							WKLY AVG	<= 45	mg/L		

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER		SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT	TELEPHONE
Bern Hinckley	I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.	[signature]	307-745-0066
			DATE
			5/12/15

Hinckley Consulting
Laramie Monitoring Well Project - City of
Laramie, WY

Discharge Monitoring Report (DMR)

Bem Hinckley, for City of Laramie
PO Box 452
Laramie, Wyoming 82073

Submission Period: 1 mo(s) | 3/1/2015 - 3/31/2015

WYG720363 - 001

No Discharge For Period ☒ **Outfall Not Constructed** ☐

BegDate	EndDate	Comment	SmpTy	SmpFreq	#Exc's	Parameter (Loc)	SBCode	Limit	Units	Discharge Note	Value
03/01/2015	03/31/2015		GRAB	XX/XX		*Duration of discharge (Effluent Gross)*					
							MO TOTAL	<= 31	d		
			INSTAN	01/01		*Flow (Effluent Gross)*					
							DAILY MX	Report	gal/min		
							MO AVG	Report	gal/min		
			GRAB	01/01		*pH (Effluent Gross)*					
							INST MAX	<= 9	SU		
							INST MIN	>= 6.5	SU		
			GRAB	01/07		*Solids, total dissolved (Effluent Gross)*					
							DAILY MX	<= 5000	mg/L		
			GRAB	01/07		*Solids, total suspended (Effluent Gross)*					
							DAILY MX	<= 90	mg/L		
							MO AVG	<= 30	mg/L		
							WKLY AVG	<= 45	mg/L		

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER		SIGNATURE OF PRINCIPAL EXECUTIVE OFFICE OR AUTHORIZED AGENT	TELEPHONE
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			DATE
			5/29/15

Discharge Monitoring Report (DMR)

Hinckley Consulting
Laramie Monitoring Well Project - City of
Laramie, WY

Submission Period: 1 mo(s) | 4/1/2015 - 4/30/2015

Bern Hinckley, for City of Laramie
PO Box 452
Laramie, Wyoming 82073

WYG720363 - 001

No Discharge For Period ☐ **Outfall Not Constructed** ☐

BegDate	EndDate	Comment	SmpTy	SmpFreq	#Exc's	Parameter (Loc)	SBCode	Limit	Units	Discharge Note	Value
04/01/2015	04/30/2015		GRAB	XX/XX		0	*Duration of discharge (Effluent Gross)*					
							MO TOTAL	<= 31	d		3
			INSTAN	01/01	3/3	0	*Flow (Effluent Gross)*				
							DAILY MX	Report	gal/min		400
							MO AVG	Report	gal/min		400
			GRAB	01/01	11/3	0	*pH (Effluent Gross)*				
							INST MAX	<= 9	SU		7.88
							INST MIN	>= 6.5	SU		7.69
			GRAB	01/07	1/3	0	*Solids, total dissolved (Effluent Gross)*				
							DAILY MX	<= 5000	mg/L		227
			GRAB	01/07	1/3	0	*Solids, total suspended (Effluent Gross)*				
							DAILY MX	<= 90	mg/L	Non-Detect	
							MO AVG	<= 30	mg/L	"	
							WKLY AVG	<= 45	mg/L	"	

TSS reporting limit = 10 mg/L

Tetrachloroethene was non-detect (reporting limit = 1 ug/L)
Trichloroethene was non-detect (reporting limit = 1 ug/L)

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER		SIGNATURE OF PRINCIPAL EXECUTIVE OFFICE OR AUTHORIZED AGENT	TELEPHONE
Bern Hinckley	I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.	[signature]	307-745-0066
			DATE
			5/2/15

Discharge Monitoring Report (DMR)

Hinckley Consulting
Laramie Monitoring Well Project - City of Laramie, WY

Bern Hinckley, for City of Laramie
PO Box 452
Laramie, Wyoming 82073

Submission Period: 1 mo(s) | 5/1/2015 - 5/31/2015

WYG720363 - 001

No Discharge For Period ☒ **Outfall Not Constructed** ☐

BegDate	EndDate	Comment	SmpTy	SmpFreq	#Exc's	Parameter (Loc)	SBCode	Limit	Units	Discharge Note	Value
05/01/2015	05/31/2015										
			GRAB	XX/XX		*Duration of discharge (Effluent Gross)*					
							MO TOTAL	<= 31	d		
			INSTAN	01/01		*Flow (Effluent Gross)*					
							DAILY MX	Report	gal/min		
							MO AVG	Report	gal/min		
			GRAB	01/01		*pH (Effluent Gross)*					
							INST MAX	<= 9	SU		
							INST MIN	>= 6.5	SU		
			GRAB	01/07		*Solids, total dissolved (Effluent Gross)*					
							DAILY MX	<= 5000	mg/L		
			GRAB	01/07		*Solids, total suspended (Effluent Gross)*					
							DAILY MX	<= 90	mg/L		
							MO AVG	<= 30	mg/L		
							WKLY AVG	<= 45	mg/L		

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER		SIGNATURE OF PRINCIPAL EXECUTVE OFFICE OR AUTHORIZED AGENT	TELEPHONE
Bern Hinckley	I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.	[signature]	307-745-0066
			DATE
			5/29/15

Appendix 4 - Aquifer Test Data
Laramie Monitor Well Project

Triangle Well Recovery from Airlift, March 31, 2015
North Well Constant Discharge Test, April 23-25, 2015
Middle Borehole as Observation Well for North Well, April 23-25, 2015
South Well as Observation Well for North Well (400 gpm), April 23-25, 2015
South Well Constant Discharge Test, April 15, 2015
Middle Borehole as Observation Well for South Well, April 15, 2015
North Well as Observation Well for South Well, April 15, 2015

Laramie Monitor Well Project
Triangle Well - recovery from airlift - March 31, 2015

Pumping Well: Triangle Well
Field Personnel: Chris Moody, Wyoming Groundwater
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 3/31/15 @ 1454 (beginning of airlift period)
Test Date/End: 3/31/15 @ 1657
Measuring Point: Top of casing; 2.11 feet above ground
Pre-Test DTW: 55.38
Water Level Measuring Equipment: Heron water level sounder
Pump Rate: 380 gpm (estimate based on pumping rate from discharge pit)

Analysis Parameters:

estimated discharge rate	380	gpm
estimated discharge time	64	min, this cycle
SWL	55.38	ft

time	elaps t (min)	d/w (ft)	
15:48	0.00		stop airlift
15:59	11.00	56.14	
16:00	12.00	56.12	
16:01	13.00	56.08	
16:03	15.00	56.02	
16:05	17.00	55.97	
16:07	19.00	55.93	
16:09	21.00	55.9	
16:14	26.00	55.83	
16:23	35.00	55.75	
16:37	49.00	55.66	
16:47	59.00	55.62	
16:57	69.00	55.57	

same as t/t'

t/t'	d/w (ft)
6.818	56.14
6.333	56.12
5.923	56.08
5.267	56.02
4.765	55.97
4.368	55.93
4.048	55.9
3.462	55.83
2.829	55.75
2.306	55.66
2.085	55.62
1.928	55.57

Laramie Monitor Well Project
North Well - constant-discharge test - April 23 - 25, 2015

Pumping Well: North Well
Field Personnel: Chris Moody, Wyoming Groundwater; Bern Hinckley, Hinckley Consulting
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 4/23/15 @ 1235
Test Date/End: 4/25/15 @ 2911
Measuring Point: Top of Poly Tube; 0.64 feet above top of casing; 2.56 feet above ground
Pre-Test DTW: 89.96 feet
Water Level Measuring Equipment: Heron water level sounder
Water Quality Field Parameters: pH, Conductivity, Temperature using Oakton CON 10 meter
Pump Rate: 400 gpm per 3" in-line flowmeter (City) and cattle trough calibration

Date	Time	Elapsed Time, min.	Depth to Water, ft.	Drawdown feet	Notes
4/23/2015	1235	0.00	89.96	0.00	START - 400 gpm (valve adjusted from previous measurement)
		0.50	96.09	6.13	Note: no flow valve adjustments for entire test
		1.00	96.97	7.01	
		1.50	97.45	7.49	
		2.00	97.80	7.84	
		2.50	98.03	8.07	16.9 sec/100 flowmeter
		3.00	98.21	8.25	
		3.50	98.37	8.41	
		4.00	98.50	8.54	
		4.50	98.62	8.66	
		5.00	98.71	8.75	
		6.00	98.95	8.99	
		7.00	99.06	9.10	
		7.50	99.13	9.17	
		8.00	99.20	9.24	
		8.50	99.27	9.31	
		9.00	99.32	9.36	
		9.50	99.39	9.43	
		10.00	99.45	9.49	Storm squall moving in
		11.00	99.55	9.59	
		12.00	99.67	9.71	
		13.00	99.76	9.80	
		14.00	99.85	9.89	
		15.00	99.93	9.97	
		16.00	100.00	10.04	17.1 sec/100 flowmeter
		17.50	100.12	10.16	
		18.00	100.15	10.19	
		19.00	100.21	10.25	
		20.00	100.28	10.32	
		21.00	100.34	10.38	
		22.00	100.40	10.44	
		23.00	100.46	10.50	
		24.00	100.52	10.56	
		25.00	100.57	10.61	
		26.00	100.62	10.66	17.2 sec/100 flowmeter; 3578600 gals on totalizer
		28.00	100.72	10.76	
		30.00	100.82	10.86	
		32.00	100.90	10.94	17.2 sec/100 flowmeter
		34.00	100.99	11.03	
		36.00	101.07	11.11	
		38.00	101.13	11.17	pH = 7.69 Cond = 349 μS T = 8.6 °C
		40.00	101.21	11.25	water is clear with trace pink qtz sand
		43.00	101.31	11.35	

46.00	101.40	11.44	17.2 sec/100 flowmeter
49.00	101.50	11.54	
52.00	101.58	11.62	
55.00	101.67	11.71	
58.00	101.74	11.78	
61.00	101.81	11.85	
64.00	101.86	11.90	
68.00	101.95	11.99	pH = 7.70 Cond = 349 µS T = 8.6 ºC
72.00	102.04	12.08	17.2 sec/100 flowmeter
82.00	102.23	12.27	
87.00	102.34	12.38	
92.00	102.43	12.47	
99.00	102.54	12.58	17.1 sec/100 flowmeter
106.00	102.64	12.68	pH = 7.73 Cond = 349 µS T = 8.6 ºC
113.00	102.74	12.78	
122.00	102.88	12.92	
131.00	103.00	13.04	
140.00	103.11	13.15	
154.00	103.28	13.32	pH = 7.88 Cond = 350 µS T = 8.4 ºC
165.00	103.39	13.43	Sample: NW - ET 160 at 1515
176.00	103.51	13.55	17.1 sec/100 flowmeter
187.00	103.61	13.65	
208.00	103.83	13.87	
221.00	103.94	13.98	pH = 7.76 Cond = 350 T = 8.4
247.00	104.14	14.18	
274.00	104.33	14.37	
295.00	104.49	14.53	
325.00	104.67	14.71	
355.00	104.84	14.88	
385.00	104.97	15.01	
415.00	105.11	15.15	
445.00	105.26	15.30	
475.00	105.37	15.41	
505.00	105.51	15.55	
565.00	105.70	15.74	
625.00	105.90	15.94	
685.00	106.06	16.10	
745.00	106.22	16.26	
805.00	106.37	16.41	
865.00	106.51	16.55	
925.00	106.65	16.69	
985.00	106.77	16.81	pH = 7.77 Cond = 364 µS T = 8.0 ºC
1045.00	106.89	16.93	17.2 sec/100 gal
1105.00	107.01	17.05	Sample: NW-ET1390 pH = 7.81 Cond = 370 T = 8.6
1165.00	107.11	17.15	
1225.00	107.19	17.23	
1285.00	107.27	17.31	
1345.00	107.37	17.41	
1406.00	107.44	17.48	
1465.00	107.48	17.52	
1525.00	107.55	17.59	pH = 7.80 Cond = 373 µS T = 8.7 ºC
1585.00	107.61	17.65	17.1 sec/100 gal; 96 psi
1645.00	107.67	17.71	pH = 7.81 Cond = 374 µS T = 8.5 ºC
1705.00	107.76	17.80	
1765.00	107.81	17.85	pH = 7.87 Cond = 372 µS T = 8.4 ºC
1825.00	107.89	17.93	
1885.00	107.97	18.01	
1945.00	108.02	18.06	
2005.00	108.08	18.12	
2065.00	108.13	18.17	

2125.00	108.18	18.22	
2185.00	108.24	18.28	
2245.00	108.31	18.35	
2305.00	108.37	18.41	
2365.00	108.43	18.47	
2425.00	108.49	18.53	
2485.00	108.54	18.58	
2545.00	108.59	18.63	pH = 7.79 Cond = 371 µS T = 8.3 ºC
2605.00	108.64	18.68	
2665.00	108.71	18.75	
2725.00	108.76	18.80	pH = 7.72 Cond = 374 µS T = 8.8 ºC
2785.00	108.83	18.87	Sample: NW-END at 1245; pH = 7.75 Cond = 374 uS T = 8.6
2845.00	108.89	18.93	O2 = 10.98 mg/L 93% sat, T = 7.9
2901.00	108.94	18.98	17.2 sec/100 gal; totalizer = 4580100 gals; water is x-tal
2911.00	Pump Off		clear; no sand, no sediment

Laramie Monitor Well Project
Middle Borehole as observation well for North Well (400 gpm) - April 23-25, 2015

Pumping Well: North Well
Observation Well Distance: 212 ft.
Field Personnel: Chris Moody, Wyoming Groundwater; Bern Hinckley, Hinckley Consulting
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 4/23/15 @ 1235
Test Date/End: 4/25/15 @ 1300
Measuring Point: Top of casing; 1.63 feet above ground
Pre-Test DTW: 89.91
Water Level Measuring Equipment: water level sounder
Pump Rate: 400 gpm (North Well)

date	time	t (min)	d/w
4/23/2015	12:35:06	0	89.91
	12:35:56	0.83	89.92
	12:36:43	1.62	89.93
	12:37:09	2.05	89.94
	12:37:42	2.60	89.95
	12:38:16	3.17	89.96
	12:38:48	3.70	89.97
	12:39:17	4.18	89.98
	12:39:45	4.65	89.99
	12:40:23	5.28	90
	12:40:56	5.83	90.01
	12:41:26	6.33	90.02
	12:42:19	7.22	90.03
	12:43:05	7.98	90.04
	12:43:49	8.72	90.05
	12:44:40	9.57	90.06
	12:45:25	10.32	90.07
	12:51:04	15.97	90.13
	12:54:30	19.40	90.16
	12:58:15	23.15	90.19
	13:01:58	26.87	90.22
	13:05:40	30.57	90.24
	13:09:46	34.67	90.27
	13:13:50	38.73	90.29
	13:17:37	42.52	90.31
	13:21:00	45.90	90.28
	13:23:10	48.07	90.35
	13:27:45	52.65	90.38
	13:32:50	57.73	90.41
	13:51:00	75.90	90.49
	14:12:00	96.90	90.58
	14:30:00	114.90	90.65
	14:57:00	141.90	90.75
	15:22:00	166.90	90.81
	15:48:00	192.90	90.89
	16:19:00	223.90	90.98
	16:47:00	251.90	91.05
	17:11:00	275.90	91.1
	18:03:00	327.90	91.2
	19:02:00	386.90	91.34

	20:02:00	446.90	91.46
	21:02:00	506.90	91.57
	22:02:00	566.90	91.67
	23:02:00	626.90	91.75
4/24/2015	0:02:00	686.90	91.83
	1:02:00	746.90	91.89
	2:02:00	806.90	91.95
	3:02:00	866.90	92
	4:02:00	926.90	92.06
	5:02:00	986.90	92.12
	6:02:00	1046.90	92.16
	7:02:00	1106.90	92.2
	8:02:00	1166.90	92.24
	9:02:00	1226.90	92.28
	10:02:00	1286.90	92.32
	11:02:00	1346.90	92.35
	12:02:00	1406.90	92.38
	13:02:00	1466.90	92.42
	14:02:00	1526.90	92.45
	15:02:00	1586.90	92.49
	16:02:00	1646.90	92.51
	17:02:00	1706.90	92.55
	18:02:00	1766.90	92.57
	19:02:00	1826.90	92.61
	20:02:00	1886.90	92.65
	21:02:00	1946.90	92.68
	22:02:00	2006.90	92.71
	23:02:00	2066.90	92.73
4/25/2015	0:02:00	2126.90	92.75
	1:02:00	2186.90	92.79
	2:02:00	2246.90	92.81
	3:02:00	2306.90	92.84
	4:02:00	2366.90	92.88
	5:02:00	2426.90	92.9
	6:02:00	2486.90	92.91
	7:02:00	2546.90	92.95
	8:02:00	2606.90	92.98
	9:02:00	2666.90	92.98
	10:02:00	2726.90	93
	11:02:00	2786.90	93.02
	12:00:00	2844.90	93.03
	13:00:00	2904.90	93.045

Laramie Monitor Well Project
South Well as observation well for North Well (400 gpm) - April 23-25, 2015

Pumping Well: North Well
Observation Well Distance: 430 ft.
Field Personnel: Chris Moody, Wyoming Groundwater; Bern Hinckley, Hinckley Consulting
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 4/23/15 @ 1235
Test Date/End: 4/25/15 @ 1300
Measuring Point: Top of casing; 2.04 feet above ground
Pre-Test DTW: 92.15
Water Level Measuring Equipment: Heron water level sounder
Pump Rate: 400 gpm (North Well)

date	time	t (min)	d/w
4/23/2015	12:35:06	0.00	92.15
	12:47:00	11.90	92.2
	12:48:00	12.90	92.205
	12:49:20	14.23	92.21
	12:52:40	17.57	92.22
	12:57	21.90	92.23
	13:00	24.90	92.235
	13:04	28.90	92.24
	13:08	32.90	92.255
	13:12	36.90	92.26
	13:16	40.90	92.27
	13:26	50.90	92.29
	13:30	54.90	92.305
	13:53	77.90	92.35
	14:10	94.90	92.38
	14:33	117.90	92.43
	15:00	144.90	92.48
	15:24	168.90	92.5
	15:50	194.90	92.54
	16:22	226.90	92.59
	16:51	255.90	92.63
	17:15	279.90	92.65
	18:05	329.90	92.72
	19:04	388.90	92.78
	20:04	448.90	92.87
	21:04	508.90	92.95
	22:04	568.90	93.03
	23:04	628.90	93.08
4/24/2015	0:04	688.90	93.13
	1:04	748.90	93.17
	2:04	808.90	93.2
	3:04	868.90	93.26
	4:04	928.90	93.29
	5:04	988.90	93.33
	6:04	1048.90	93.36
	7:04	1108.90	93.395
	8:04	1168.90	93.43
	9:04	1228.90	93.46
	10:04	1288.90	93.48
	11:04	1348.90	93.51

	12:04	1408.90	93.53
	13:04	1468.90	93.56
	14:04	1528.90	93.58
	15:04	1588.90	93.61
	16:04	1648.90	93.63
	17:04	1708.90	93.67
	18:04	1768.90	93.69
	19:04	1828.90	93.72
	20:04	1888.90	93.77
	21:04	1948.90	93.79
	22:04	2008.90	93.82
	23:04	2068.90	93.84
4/25/2015	0:04	2128.90	93.86
	1:04	2188.90	93.88
	2:04	2248.90	93.9
	3:04	2308.90	93.93
	4:04	2368.90	93.94
	5:04	2428.90	93.96
	6:04	2488.90	93.99
	7:04	2548.90	94
	8:04	2608.90	94.03
	9:04	2668.90	94.05
	10:04	2728.90	94.06
	11:04	2788.90	94.07
	12:04	2848.90	94.09
	12:56	2900.90	94.1

Laramie Monitor Well Project
South Well - constant-discharge test - April 15, 2015

Pumping Well: South Well
Field Personnel: Chris Moody, Wyoming Groundwater; Bern Hinckley, Hinckley Consulting
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 4/15/15 @ 0945
Test Date/End: 4/15/15 @ 1227
Measuring Point: Top of Steel Casing; 2.04 feet above ground surface
Pre-Test DTW: 91.97 feet
Water Level Measuring Equipment: WLI water level sounder
Water Quality Field Parameters: pH, Conductivity, Temperature using Oakton CON 10 meter
Pump Rate: 94 gpm (stopwatch and 5-gal bucket)

Date	Time	Elapsed Time, min.	Depth to Water, ft.	Drawdown feet	Notes
4/15/2015	0921	0	91.97		Cond water truck (city water) = 340 uS
	0945	0	91.97	0.00	START
		0.5	93.89	1.92	Valve wide open; no adjustments
		1.0	94.04	2.07	Cond = 530 uS
		1.5	94.10	2.13	
		2.0	94.13	2.16	3.07 sec / 5 gal 98 gpm
		2.5	94.16	2.19	
		3.0	94.19	2.22	
		3.5	94.21	2.24	
		4.0	94.23	2.26	
		4.5	94.26	2.29	
		5.0	94.27	2.30	
		6.0	94.29	2.32	
		7.0	94.32	2.35	
		8.0	94.35	2.38	3.21 sec / 5 gal 93 gpm
		9.0	94.36	2.39	Cond = 557
		10.0	94.40	2.43	discharge out of pit to ground
		11.0	94.42	2.45	
		12.0	94.45	2.48	
		13.0	94.46	2.49	Cond = 556, Temp = 8.4 C
		14.0	94.49	2.52	3.35 sec / 5 gal 90 gpm
		15.0	94.51	2.54	
		16.0	94.52	2.55	
		17.0	94.54	2.57	
		18.0	94.55	2.58	
		19.0	94.58	2.61	Cond = 552, Temp = 8.5 C
		20.0	94.59	2.62	
		21.0	94.60	2.63	
		22.0	94.62	2.65	
		24.0	94.65	2.68	
		26.0	94.67	2.70	
		28.0	94.70	2.73	
		30.0	94.71	2.74	
		32.0	94.74	2.77	
		34.0	94.76	2.79	3.14 sec / 5 gal 96 gpm, Cond = 546, Temp = 8.5 C
		36.0	94.77	2.80	
		38.0	94.80	2.83	
		40.0	94.82	2.85	moved discharge from prairie to north drainage
		42.0	94.82	2.85	
		46.0	94.87	2.90	3.23 sec / 5gal 93 gpm
		50.0	94.90	2.93	Cond = 544, Temp = 8.5
		54.0	94.92	2.95	
		58.0	94.95	2.98	Cond = 538, Temp = 8.6 C, pH = 7.68

	65.0	94.99	3.02	
	71.0	95.02	3.05	
	76.0	95.05	3.08	3.20 sec / 5 gal 94 gpm
	82.0	95.08	3.11	Cond = 532, Temp = 8.4 C
	88.0	95.11	3.14	
	95.0	95.14	3.17	
	100.0	95.15	3.18	
	110.0	95.19	3.22	
	123.0	95.22	3.25	Cond = 519, Temp = 8.5 C, Collect water sample at 1150
	134.0	95.26	3.29	
	141.0	95.28	3.31	Cond = 518, Temp = 8.4 C, pH = 7.69
	150.0	95.30	3.33	
	160.0	95.31	3.34	Cond = 515, Temp = 8.3 C, pH = 7.68
1227	162.0			OFF (pull pump)

Laramie Monitor Well Project
Middle Borehole as observation well for South Well (94 gpm) - April 15, 2015

Pumping Well: South Well
Observation Point Distance: 218 ft.
Field Personnel: Chris Moody, Wyoming Groundwater; Bern Hinckley, Hinckley Consulting
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 4/15/15 @ 0945
Test Date/End: 4/15/15 @ 1227
Measuring Point: Top of Steel Casing; 1.63 feet above ground surface
Pre-Test DTW: 89.73 feet
Water Level Measuring Equipment: WLI water level sounder
Pump Rate: South Well (94 gpm)

Date	Time	Elapsed Time, min.	Depth to Water, ft.	Notes
4/15/2015	9:33		89.73	
	9:45	0		START
	9:49	4	89.94	
	9:50	5	89.99	
	9:51	6	90.02	
	9:52	7	90.05	
	9:56	11	90.14	
	10:01	16	90.22	
	10:06	21	90.28	
	10:11	26	90.33	
	10:25	40	90.43	
	10:39	54	90.5	
	10:51	66	90.57	
	11:22	97	90.68	
	11:50	125	90.75	
	12:20	155	90.82	

Laramie Monitor Well Project
North Well as observation well for South Well (94 gpm) - April 15, 2015

Pumping Well: South Well
Observation Well Distance: 430 ft.
Field Personnel: Chris Moody, Wyoming Groundwater; Bern Hinckley, Hinckley Consulting
Pump Test Operator: Jason Watson, Watson Well Service
Test Date/Start: 4/15/15 @ 0945
Test Date/End: 4/15/15 @ 1227
Measuring Point: Top of Steel Casing; 1.92 feet above ground surface
Pre-Test DTW: 89.14 feet
Water Level Measuring Equipment: WLI water level sounder
Pump Rate: South Well (94 gpm)

Date	Time	Elapsed Time, min.	Depth to Water, ft.	Notes
4/15/2015	9:45	0		
	10:09	24	89.14	START
	10:41	56	89.15	
	11:20	95	89.18	
	11:54	129	89.21	
	12:22	157	89.21	

Theis Equation

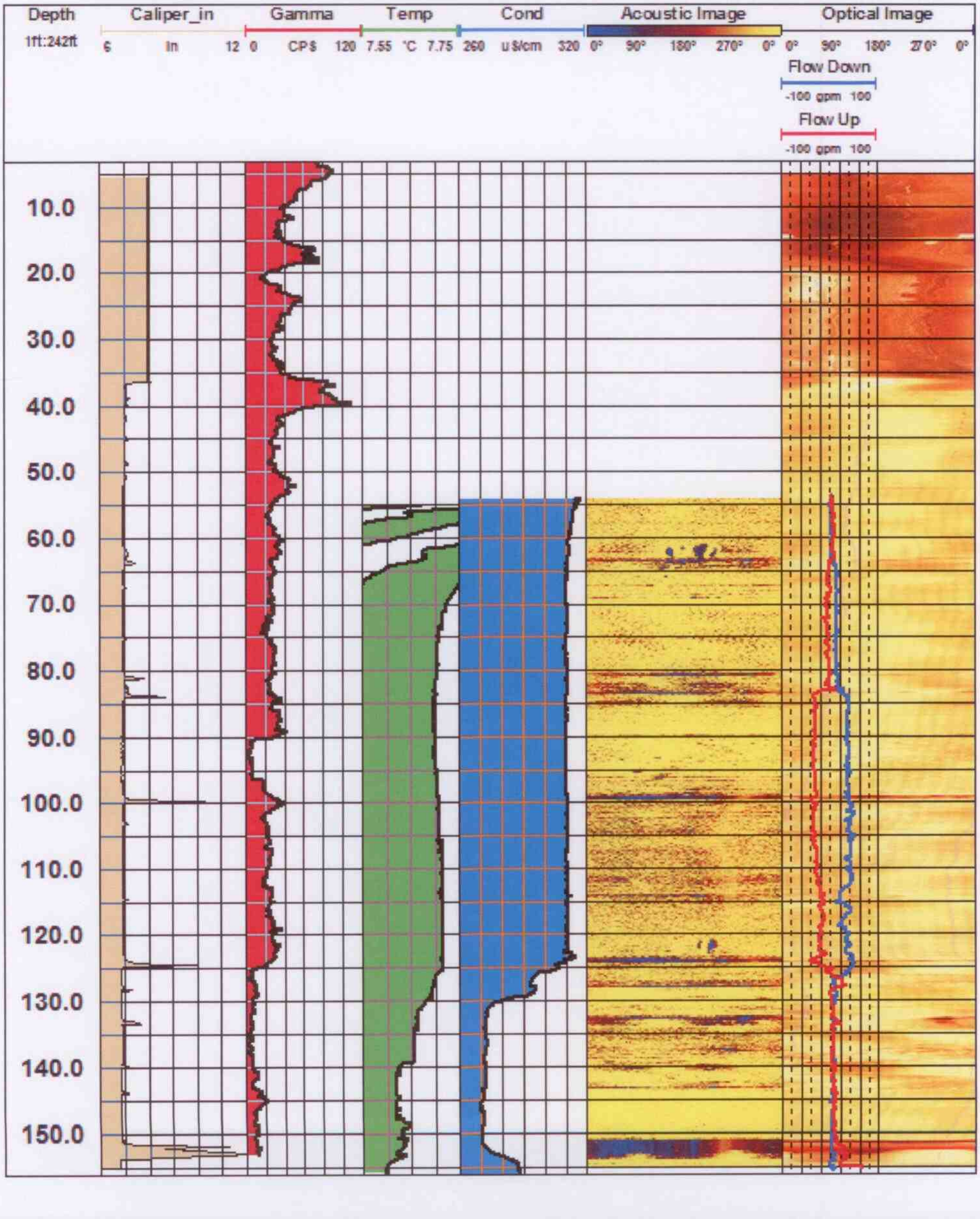
Q	94	gpm
r	400	ft
T	40000	gpd/ft
S	0.010768	

t (min)	s (ft)
24	89.14
56	89.15
95	89.18
129	89.21
157	89.23

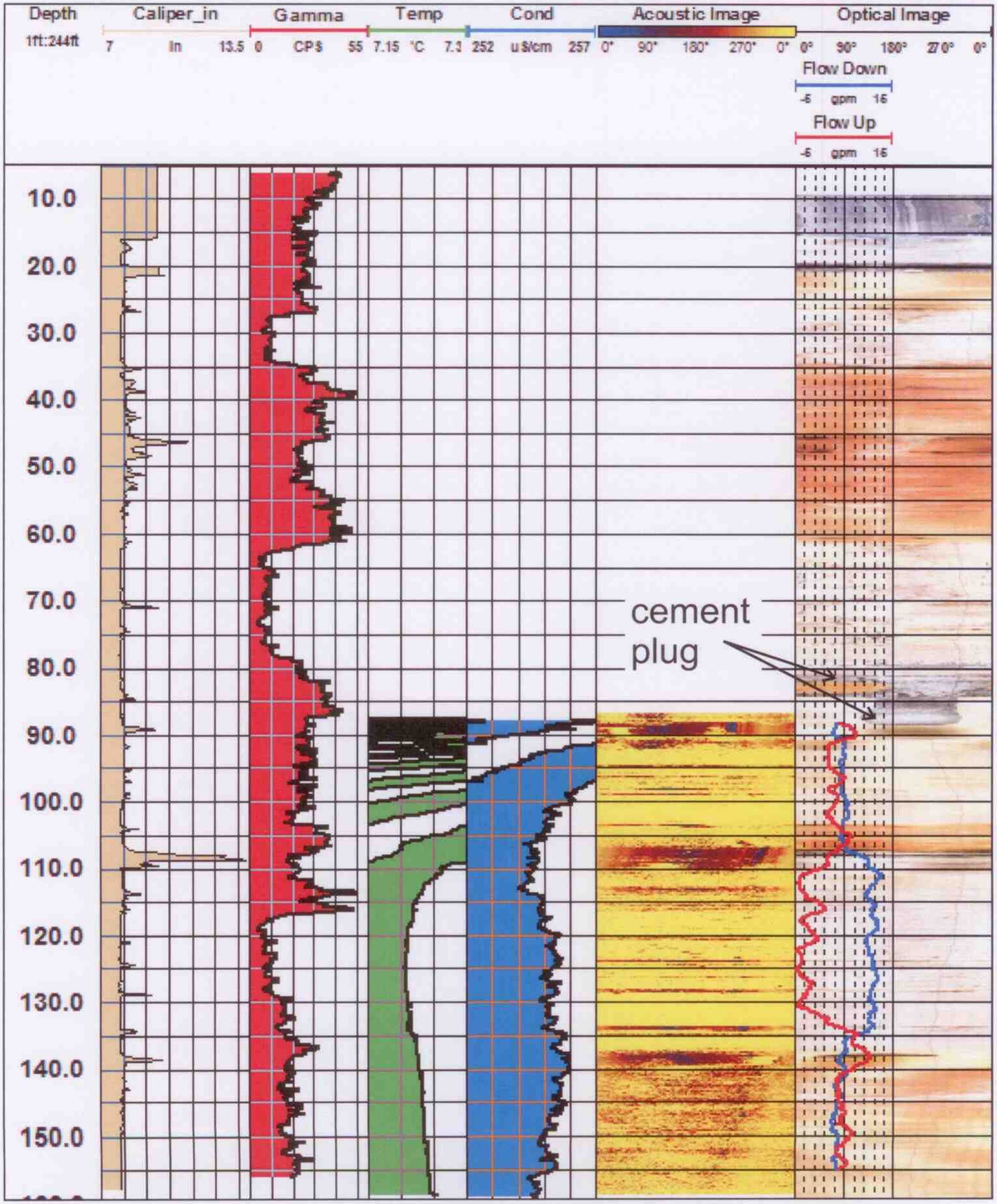
Appendix 5 - Wyoming Center for Environmental Hydrology and Geophysics Logs Laramie Monitor Well Project

Triangle Well
North Well
Middle Borehole
South Well

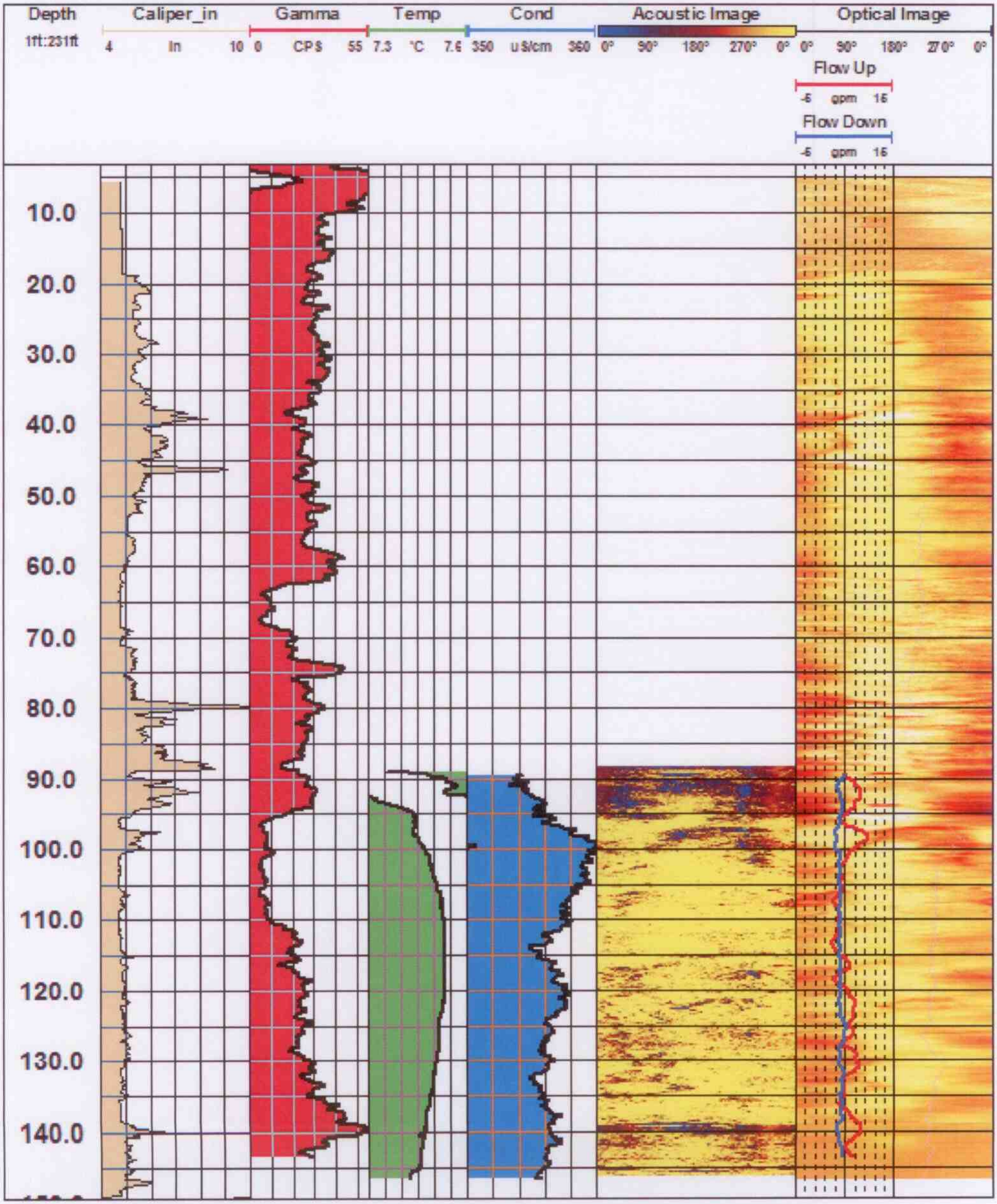
Laramie Monitor Well Project
Triangle Well Geophysical Logs



Laramie Monitor Well Project
North Well Geophysical Logs



Laramie Monitor Well Project
Middle Borehole Geophysical Logs



Laramie Monitor Well Project
South Well Geophysical Logs