Floyd Hill Groundwater Planning

Submitted to:

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Submitted by:

F18-30
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Final Design Report

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1.0 Executive Summary

Starting last fall, the Floyd Hill Water Engineers were tasked with determining if a new development in the Floyd Hill area would have negative effects on the water supply for the existing homeowners. After a few weeks we learned that the developer pulled out of the deal, but we still continued the work as it would be beneficial to the community for future reference and potential future developments. We initially gathered all historical well data from the well permits which covered about 500 homes. From there we made a map of wells that we would actually test for current water level. After much debate and research we determined that 7 wells should be tested for static water level, along with 22 homes being tested for chemicals in the water. The current water level would show how the water supply has changed over the past 40 years. The chemical tests would show potential connectivity between wells based on similarities. This was crucial because the Floyd Hill area sits on a system of fractured bedrock which is essentially random pockets of water of various size and shape. This made the project very difficult because there isn't a defined aquifer with a known volume and reach.

Once all of the data was collected we put together a 3D model of the land along with the measured wells and their depths. This is one of the key deliverables for our project. As for the chemical testing of the water, we took that data and put it into a Stiff Diagram which can be seen in Figures 9-10 . These diagrams show different anions and cations in each water sample, which help to visualize any connections among the wells because the diagrams will look very similar. The tests will also show concentrations of nitrate which could be a possible indication of a septic leak upstream if the levels are higher than the allowable limits. This doesn't have any relevance to our project, but it's good information for the homeowner to have. We were unable to test for the age of the water due to budget and time constraints. We also used historical rain and snowfall data to help estimate a recharge rate for the area. This data along with the water quality test results were put into a program called AnAqSim which produced a model that encompasses the watershed area of Floyd Hill and shows us flow paths, and can predict future recharge and use rates with the data that we input. We also used the original development plan from 1999 for reference and found similar conclusions to what they published. From our well testing we suggested that some of the well levels have dropped over the past 40 years. This finding along with the fact that the initial Beaver Brook report recorded draw down in monitoring wells, we determined that a new development would decrease the water levels in the Floyd Hill area. However, we cannot say to

what extent because we don't know the volume of the aquifer, and the developer would have to propose a way to replace 95% of the water used from the development. We hope that our findings can help future projects in the Floyd Hill area.

2.0 Project Review

The beginning of the project consisted mainly of doing research and figuring out how we wanted to attack the problem. The client had asked us to look into water rights so we spent hours looking over documents that had relevance to the project. We contacted a lawyer who specializes in water rights cases and he told us that it was illegal to do anything with the rights because we were not licensed lawyers, so we quickly stopped doing that. Per the client's request we looked into the wetlands and if they were protected in anyway, which we learned that they were not. Our next big task was digging up all of the well permits of the area and putting their data into a spreadsheet. There were over 500 wells that we looked up and found data for. We were mainly after the static water level in the well when it was drilled because we knew that our end goal was to compare measured values to the originals. We were also able to determine the total depth of the well from the permits. Towards the end of the first semester we began to contact homeowners to see if they would allow us to conduct the well and water tests. This was one of our biggest challenges because it was extremely difficult to get them to respond in a timely matter, or even at all. We ended the semester with a plan of attack to begin our testing early in the spring semester so we could start building the models.

The first time we went up to Floyd Hill to test well depth, we quickly realized how unprepared we were for the challenge of testing them. Most of the well heads hadn't been touched in over 40 years so the bolts were completely rusted and seized. We sheared two bolts in half trying to take the head off, and we quickly realized we needed a better plan. Our plan was to have the home owners send us pictures of the well heads so that we knew ahead of time if we needed any specific tools, and if it was easily accessible or not. We had success with Linda's well and measured the static water level with a probe. We continued this process with 4 other wells. The last well that we tested proved problematic because the probe got stuck down in the well. Thanks to Geowater, we were able to find a solution. The measuring tape was cut and the probe was left down in the well because it was impossible to remove. However, there was no damage done and the homeowner was very understanding. Along with the water depth testing, we gathered water samples from 10 different households to analyze the chemistry. With the resulting data we put together Stiff diagrams to show connectivity between each well.

The final aspect of our project was to put all of the data we collected into various models which was one of the major deliverables. All 500 wells and their depths were put into a 3D model to show their geographic locations and elevations. See Figure 11 for the model. A hydrogeologic model was also created using use and recharge values to predict what would happen to the groundwater supply if the development were to be built. After building and running the model we concluded that a development would in fact deplete the water supply if no measures were taken to counteract the drawdown. We wrapped up the semester with a final meeting with our clients and presenting all of our findings.

3.0 Design Critique

The purpose of the design critique was to identify and evaluate the safety, health, and environmental risks associated with our project. The uncertainties were then analyzed to create a mitigation plan to minimize the impact of each risk. The tool selected for this process began with an Environmental Hazard Analysis from the Environmental Protection Agency (EPA). After taking the risk assessment from the EPA into consideration, a risk management matrix was used to organize and rate each risk. The matrix can be referenced in the Appendix A section 1.

3.1 Environmental Hazard Analysis

Risk assessments are utilized by the EPA to "characterize the nature and magnitude of health risks to humans (e.g., residents, workers, recreational visitors) and ecological receptors (e.g., birds, fish, wildlife) from chemical contaminants and other stressors, that may be present in the environment" [1]. While this analysis was a good start to identifying the risks associated with our project, there are other areas the need to be taken into consideration.

3.1 Risk Management Matrix

The risk management matrix was utilized as an organizational tool to help visualize which risks are the most prominent in our project. The tool considers the likelihood of occurrence of each risk against the severity of the possible outcome. Each risk was then rated using the risk management matrix in Appendix A section 1.

The main risks taken into consideration:

- Environmental and economic impacts of a new development
- Rough groundwater supply projection
- Health implications of potential septic tank seepage
- Health implications of water quality analysis results
- Potential damage to the well during testing

A more in depth analysis of the risks associated with our project is shown in Appendix A section 2.

3.3 Results

Unfortunately, many of the potential risks with the original project scope are not able to be taken into consideration. Impact of a new development depends mostly on the developer and the details associated with the plans which are not available to the team at this time. Adverse effects on the wetlands, potential flooding, traffic congestion, and projected water use depends entirely on how many units would be constructed as well as the overall footprint and demand of the proposed development. The team does not want to make any assumptions as to what could be proposed because of the wide variety in possibilities.

The team completed a rough estimate of the groundwater supply in the area as well as projected recharge rates. Without having the budget to test for the age of the water, drilling observation wells, or enough data to calculate exact recharge rates, the AnAqSim model is only able to provide a rough estimate of the impact with and without a development. Three of the five wells were tested for depth with the pump shut off, while the other two had to be tested with the pump still on. This creates a large uncertainty as the water levels obtained are most likely not the exact static level. Even for the three wells that had their pump shut off, it is possible that there was not adequate time for the water level to return to static before the level was measured. While the team made progress on gathering well depths, the uncertainties presented produce a medium level of risk initially. Recharge rates are also a rough estimate as the historical data from the exact area was not able to be obtained to predict future precipitation and recharge. However, the analysis of the data from the nearest gauge approximately 10 miles away was able to provide a rough estimate on the impact with and without a development and give a preliminary idea of the effects.

Water quality analysis and testing was also successfully completed by the team. The data acquired consists of 12 samples overall which includes two sets of samples taken before and after treatment systems as well as a retest of one sample that was an outlier. A baseline sample was also taken on the Colorado School of Mines campus to serve as a comparison for the data. Research on the levels safe for drinking water was completed and can be referenced in Attachment 3 based on the current standards. The majority of the regulations were from the EPA's National Primary Drinking Water Regulations which are enforceable [2]. The Secondary Drinking Water Standards account for a few of the other water quality standards, but are not mandatory [3]. Out of the contaminants listed, nitrate is the only one that poses an extreme risk at this time. Seven of the 12 samples have levels of nitrate over the enforceable level as shown on the following page in Table 1.

Table 1: Water quality compared to recommended levels

Contaminant	Recommended Level (mg/L)	Water Samples Exceeding Recommended Level (mg/L)
Fluoride*	4.0	None
Chloride**	250.0	None
Nitrite*	1.0	476 Aspen (**1.53**) Linda 2: tap (**2.56**)
Bromide***	Trace amounts-0.05	477 Aspen (**0.14**) 476 Aspen (**0.17**) Linda 2: tap (**0.06**)
Nitrate*	10.0	Will (**17.73**) Linda (**94.10**) Linda 2: tap (**80.29**) Linda 2: raw (**69.31**) 1300 Ponderosa: tap (**29.64)** 1300 Ponderosa: raw (**33.43**) 476 Aspen (**15.69**)
Phosphate***	0.005-0.05	None
Sulfate**	250.0	None

*=Enforceable
**=Not mandatory
***=Natural Levels

High nitrate levels create a risk of infants below the age of six becoming very ill with symptoms of shortness of breath and blue-baby syndrome. The high levels of nitrate would most likely be coming from leaking septic tanks based on the area conditions. Steps to mitigate this extreme risk are to take new samples from the homes affected to confirm the high levels of nitrate and ensure there was no other reason such as laboratory error. Other than this, the water quality analysis should not pose a risk other than uncertainties by making assumptions to help show which wells are connected by comparing similar results.

The last major risk identified is possible damage to the well during depth testing. This risk is believed to be low as careful consideration of the wires and components of the well are taken during each test. The probe has been lowered slowly in the middle of the well to attempt to mitigate any risk of damaging the well and pump connections. However, during the last round of well testing, the risk greatly increased due to the fact that the testing probe got stuck in a well. The probe was stuck in the space between the inner tube and the outer casing of the well. Therefore, there was no contact with the water or the pump. After this occurrence, it was decided by the team that the risk of this happening again was too high and the team would work with the data previously collected.

The Environmental Hazard Analysis along with the Risk Management Matrix was used to identify and discuss the risks associated with our project. The current items that pose the biggest risk are the high levels of nitrate found as well as the uncertainties and assumptions related to depth testing, recharge rate, and the AnAqSim model. Efforts to mitigate the mentioned risks were implemented to produce the most accurate results possible.

4.0 Engineering Analysis

4.1 Hydrologic Model

A hydrogeologic model is required for the project to understand the water supply around the Floyd Hill area and how a development would change the supply. After meeting with a hydrogeologist consultant, Michael Gabora, we were given several options for possible models. The USGS MODFLOW and the DHI FEFLOW are two of the options presented to us. These models use the finite element method and analysis which is used to break the analysis in to smaller parts to make the analysis more accurate. Although the calculated output is more accurate, the models described need more data inputted and takes a longer time to execute different scenarios. Based on this information, we determined that these models would not be the best option for our project. The team instead decided to go with the AnAqSim software by Fitts Geosolutions. This software is a quick solution to other models and is easy to set up with limited waiting time while the scenario is solved for. The AnAqSim model created for the area shows a basic idea of what would occur to the water supply in the area through time.

To define the boundaries of the model, the team cited the Beaver Brook Residence Development (BBRD) hydrologic report shown in Figure 1 with the approximate watershed around the development is shown. The team created a model boundary in ArcGIS that was larger on the east side to make the development area not near the boundary condition for better results. After doing some more research, the team discovered the USGS geologic map shown in Figure 4 that showed the rock formations near Floyd Hill. Based on that image, the team selected the boundary shown in Figures 2 and 3 showing the model boundary on a topographic basemap and on the USGS geologic basemap, respectively. The proposed development is located on a thin layer of Piney Creek Alluvium and on top of that (or interbedded with the alluvium) is a layer of colluvium. Below all these levels, there are igneous and metamorphic rocks containing mostly granite, gneisses, and amphibolite. The figures used for the model set up also show the wells where static well water levels were measured by the team throughout the project.

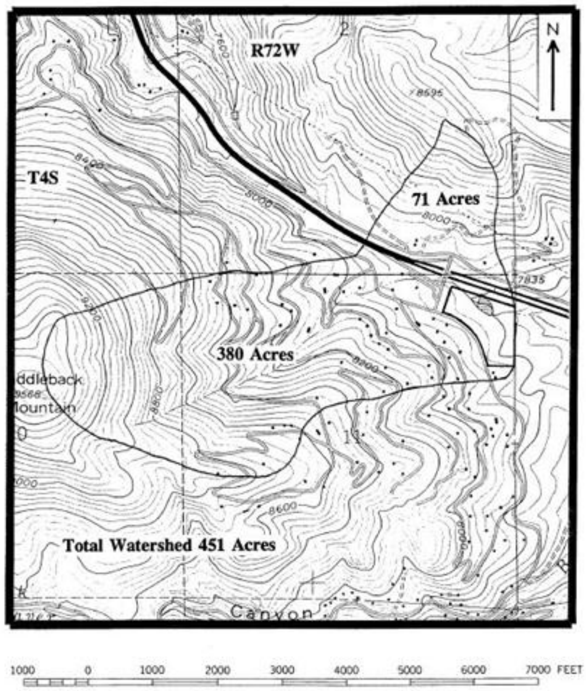


Figure 1: Watershed boundary from BBRD report [4]

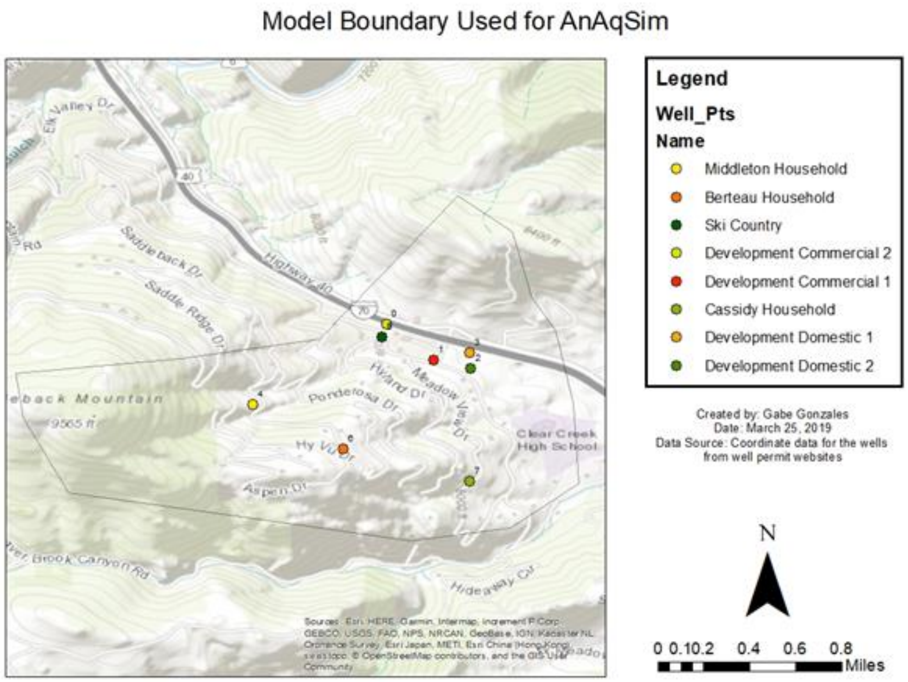


Figure 2: Model boundary and wells used for AnAqSim

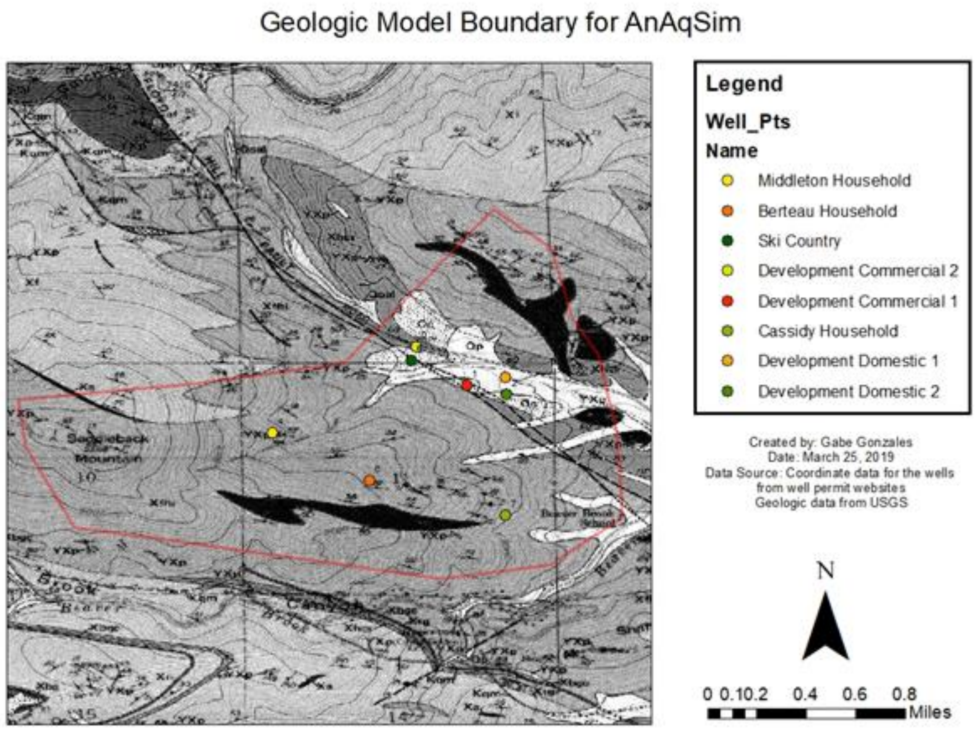


Figure 3: Model boundary on USGS geologic map

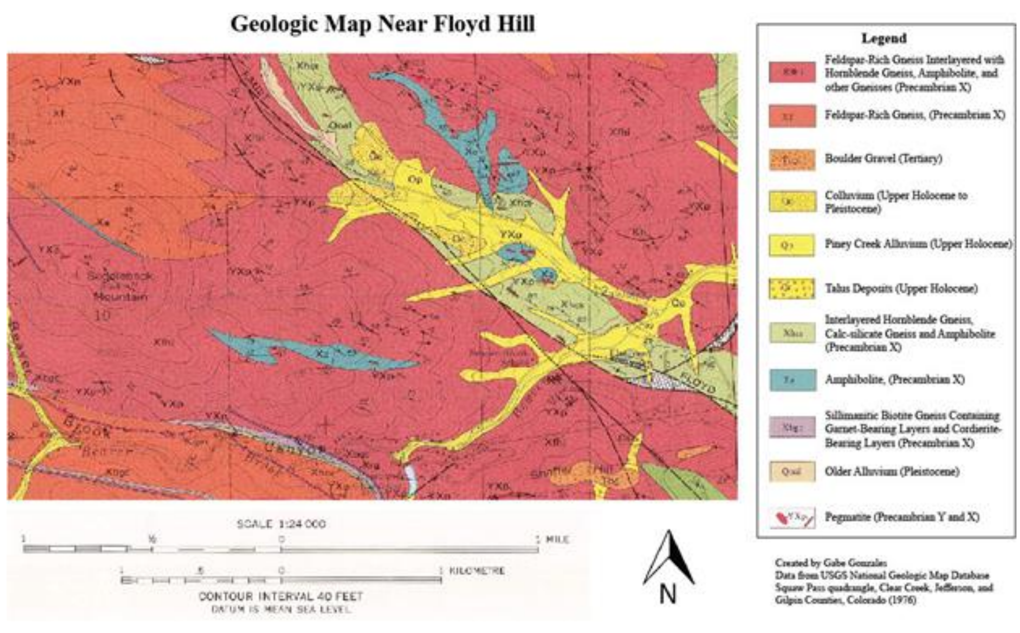


Figure 4: Geologic map of the Floyd Hill area [5]

The piezometric surface map shown in Figure 5 shows the flow path of runoff in the Floyd Hill area. The map shows that due to the topography of the area, the water that lands on the higher portions of Floyd Hill generally flow in a NE direction down the mountain surface. This information is important to understand the general patterns of surface water as it travels within the model boundary. The BBRD hydro report drilling tests also gave a good profile of the subsurface around the development area. The profile of the boundary is shown in Figure 6.

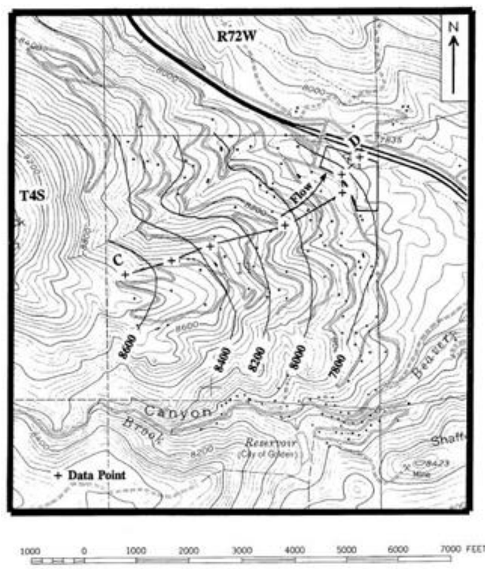


Figure 5: Piezometric surface map [4]

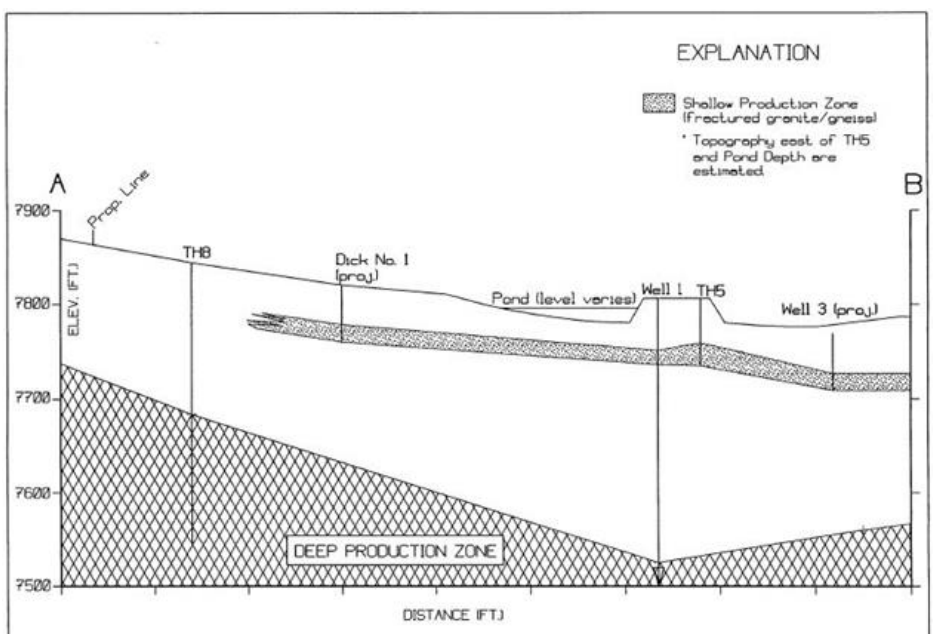


Figure 6: Subsurface profile from BBRD report [4]

The procedure for the hydrologic model was found by using the tutorials provided by the AnAqSim website. After loading the information into the AnAqSim model, the units were set with feet as the length unit and days as the time unit. This is the only point in the model where units were inputted, and the subsequent values for the parameters were in those units to show consistency with the results. Once the units were selected, the model boundary was created, and the necessary parameters were found. The well information gathered and researched, and the final values used in the model are shown in Table 2 and Table 3 below.

Table 2: Well data gathered and used for AnAqSim

Owner	Longitude	Lattitude	Elevation of Well Head (ft)	Well Depth (ft)	Water Level (ft)	Water Elevation (ft)	Static Water Level (ft)	Static Water Elevation (ft)
Will & Linda Cassidy	-105.408310	39.712326	7993	300	75	7918	110.24	7882.8
Paul & Linda Berteau	-105.416298	39.714386	8555	650	61	8494	60.86	8494.1
Ski Country	-105.412776	39.711561	7946	300	25	7921	23.29	7922.7
Cole & Debra Krems	-105.433775	39.735397	7631	195	90	7541	128.28	7502.7
Mike Middleton	-105.421995	39.717184	8445	590	50	8395	56.1	8388.9
Snow Mountain LLC (Domestic 2)	-105.408254	39.719459	7833	60	30	7803	NA	NA
Snow Mountain LLC (Commercial 1)	-105.41057	39.719969	7882	500	45	7837	NA	NA
Average Head						8038.246		

Table 3: AnAqSim inputs values

Boundary Conditions											
Domain Type	Top Elevation (ft)	Bottom Elevation (ft)	Average Head (ft)	Porosity	Storativity	Specific Yield	K1 Horizontal (ft/day)	K2 Horizontal (ft/day)	Angle K1 to x-axis	K3 Verticle Top Half (ft/day)	K3 Verticle Bottom Half (ft/day)
Unconfined	9590	7660	8038	0.1	0.001	0.1	13.57	13.57	0	0.1	0.1

The top and the bottom elevation for the modeled area was determined using Google Earth to determine the value in feet. The water level information listed was gathered from the well permits for each residence that describe the water level when the well was drilled. Having conducted the testing on the wells we were able to gain access to, we had an idea of some static water levels in the area. The team gathered the static water levels by asking the homeowners to turn of their pumps about two hours before the team arrived to measure the water level. That way the water level would not fluctuate from pumping and the level would be constant, showing the hydrologic profile of the area. There is some uncertainty around the static water level because for a better measurement, the pumps should be turned off for longer. Because the homes we tested were residential, this was not realistic and the team decided that two hours would be sufficient. Those values were then averaged to get an idea of what the average head over the area would look like. This is an assumption that can lead to some inaccuracies because the profile over the model area has varying elevations. The porosity value was calculated from an average value based on the type of rock that the aquifer would be composed of. The igneous and metamorphic rocks are in a fractured system, so the porosity was estimated to be 10% [6]. Because the model created is steady-state and not transient, the storativity and specific yield values do not matter and are not used in the calculations. For the hydraulic conductivity, the system was assumed to be anisotropic and the hydraulic conductivity (k_1 and k_2 values) was determined using the web soil survey. The boundary was inputted into the site and the data returned was turned into a weighted average [7]. The k_3 values are also not relevant or used in this type of value. Once the model geologic parameters were inputted into the model, the model boundary was defined. The boundary was parameterized based upon the head. The head was inputted as the average of the heads of the known wells that were tested. The wells were then characterized based on the discharges that would be pumped out of each well. For the wells that were tested by the team, we assumed the usage rate was 70 gallons per day per person [8]. It was also determined that the size of a household in the area of interest is about 3 people [9], resulting in a usage rate for the domestic rates equal to 210 gallons per day. The two wells on the development that are going to be used to provide water for a potential development were then pumped according to the rate shown in the BBRD report [4]. For the well labeled Commercial 1, the pumping rate is 15 gallons per minute and Domestic 2 would be 45 gallons per minute. The values used are shown in Table 4 below. There was also the need to input a value for the recharge of the area. Based on calculations completed by W. W. Wheeler and Associates, Inc. it is estimated that on an average year there will be a recharge of 0.34 acre-feet per year per acre [4]. Although this value was calculated based on historical information, this value can be less accurate today since it is 20 years after the report was created. The calculations and value used for the top flux of the model is shown in Table 5 below based on that information.

Table 4: Well pumping rates used in model

Well Label	Radius (ft)	Usage Rate (gal/day)	Usage Rate (cf/day)
Middleton	0.5	-210	-28.07
Berteau	0.5	-210	-28.07
Ski Country	0.5	-210	-28.07
Cassidy	0.5	-210	-28.07
Development Commercial 1	0.5	-21600	-2887.70
Development Domestic 2	0.5	-64800	-8663.10

Table 5: Recharge values used in model

Area of Model (Acres)	Recharge for Model (AF/Yr)	Top Flux (ft/year)	Top Flux (ft/day)
1715.14	583.15	0.34	0.000931507

The parameters required to solve the model were all input into AnAqSim and the model was run according to the pumping rates in the table. The negative sign is used in AnAqSim to show that the water is leaving the system because it is pumped out. The solution settings were the standard settings as suggested in the tutorial. After the AnAqSim model was solved according to the pumping of the 6 wells, an interesting plot was created. A plot showing the contour of the well drawdown was created and is shown in Figure 7. To get a better idea of the development area and the effects there, a closer image is created in Figure 8.

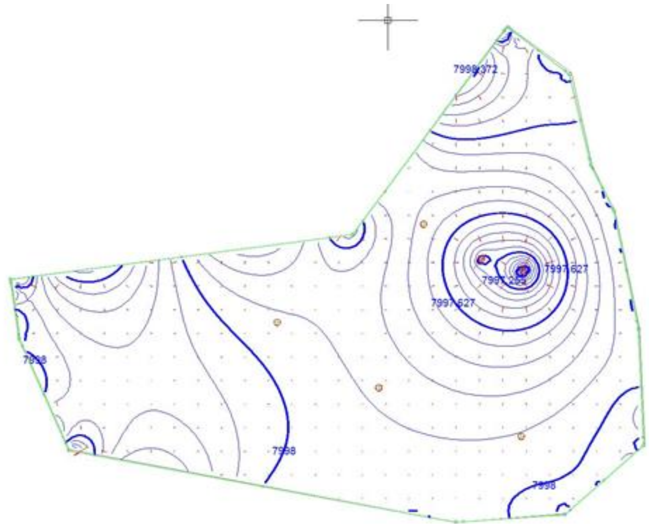


Figure 7: Results from pumping model

Figure 8: Results from pumping model (close-up)

Both Figure 7 and 8 show that the contours of the water after the pumping of the 4 known wells and the two development wells. The contours of the map as similar to a topographic map that show the results of the system after the wells were pumped according to the rates discussed above. Figure 7 shows the contours are larger due to the larger drawdown near the wells that are pumped. Due to the amount of assumptions and the simplistic representation of the fractured rock system, the team does not want to specifically quantify the amount of drawdown that would occur.

In reality, there are hundreds of wells in the area that contribute to the pumping of the fractured rock aquifers. The limitations with the amount of wells that were tested for current data made it so only 4 current water levels were used in the AnAqSim model. Although the created model is simplistic, it shows a general idea of what would likely occur when the development is pumped to fit the water needs of the residents. The patterns from the AnAqSim model are supported by the pumping tests conducted on the two wells that are connected to the shallow aquifer [4]. The effect of pumping the wells for the development needs, will likely decrease the water level in the shallow aquifer and may lead to supply shortage issues if it is not replaced. The BBRD hydrologic report states that the effluent from the water treatment plant would be discharged in the wetlands area to act as an artificial recharge. The water discharged must be up to the acceptable standards for the area ensuring the safety of the users after the water is pumped. During the well pumping tests for the BBRD, there was some rainfall that increased the level of water in the well. This suggests that the wetlands area on the property are connected directly to the shallow aquifer [4]. According to the figures in the report based on the proposed development, this strategy would replace about 95% of the average annual demand [4]. As long as this method replaces the water that is being pumped from the shallow aquifer, there should be no threat for the development. Although this method will likely not affect the nearby community, there may be concerns for other water supply needs that are downstream of the Floyd Hill area. If the recharge is not sufficient and the shallow aquifer has a severe decrease in water level, then there may be a threat for the supply of the surrounding communities because the development would need to pump from the wells that are in the deeper aquifer. There are rules and regulations that can be set up that will ensure the protection of the water rights in the surrounding homes.

4.3 Precipitation Analysis

Per client request, precipitation data was gathered and analyzed. Unfortunately, there are no weather gages in the immediate vicinity of the area. Given this, the team decided to use data from a SNOTEL gage approximately ten miles away from the study site, shown below in Figure 9. This gage is part of the Snow Telemetry project, a part of the Snow Survey and Water Supply Forecasting (SSWSF) Program for the National Water and Climate Center [10]. The gage itself is located at approximately 10,600 feet.

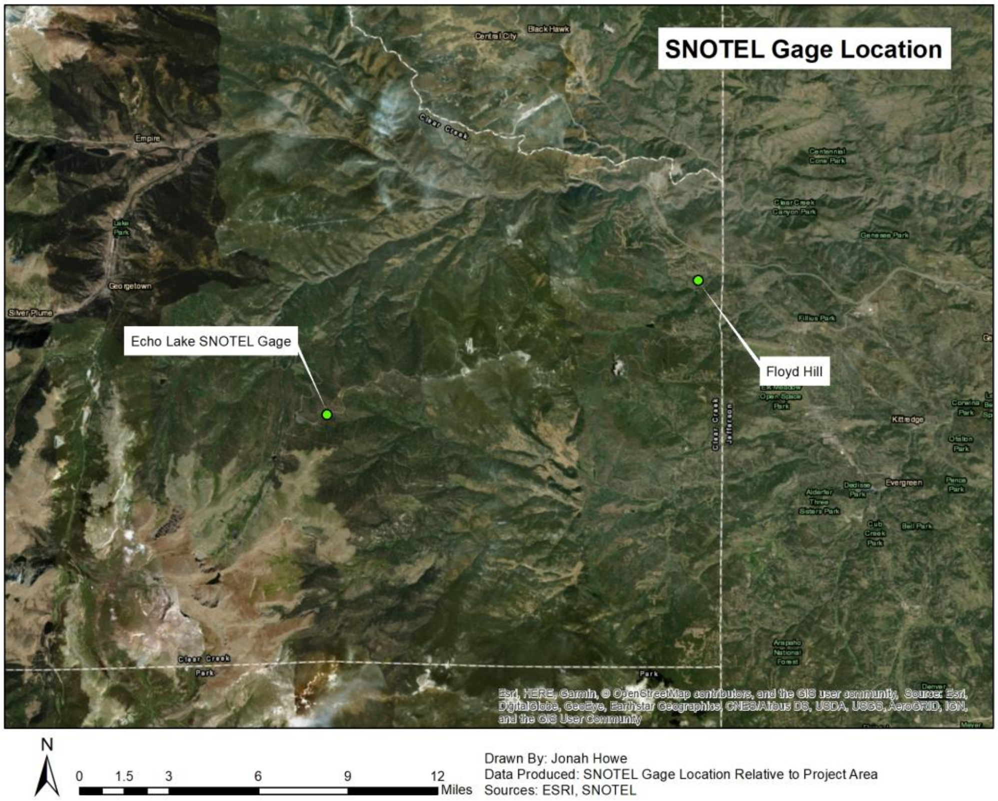


Figure 9: Location of the SNOTEL gage relative to the study site

Given the difference in location and altitude between the study area and the SNOTEL gage, the accuracy of the following results are qualified, however in interest of providing some baseline data regarding precipitation and temperature for the project site the results are included. Figures 10 and 11 on the following page show precipitation and temperature data, respectively. The data follows expected seasonal trends, with precipitation steadily increasing from October to August, where it peaks at 24.9 inches of precipitation due to large, late-summer storms that are typical of the region. Temperature follows an expected trend as well, hitting a low point in December-February and its highest point in July. Again, due to the location of the gage relative to the site, this data should not be used to analyze precipitation and temperature for Floyd Hill specifically, but do give general trends that can be understood to be similar near the project site.

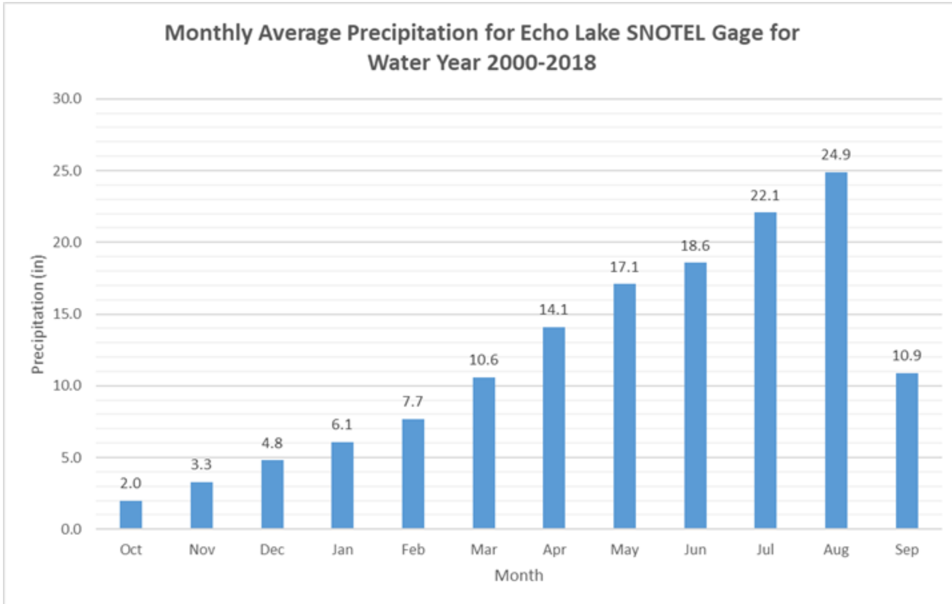


Figure 10: Monthly average precipitation for the SNOTEL gage for water year 2000-2018

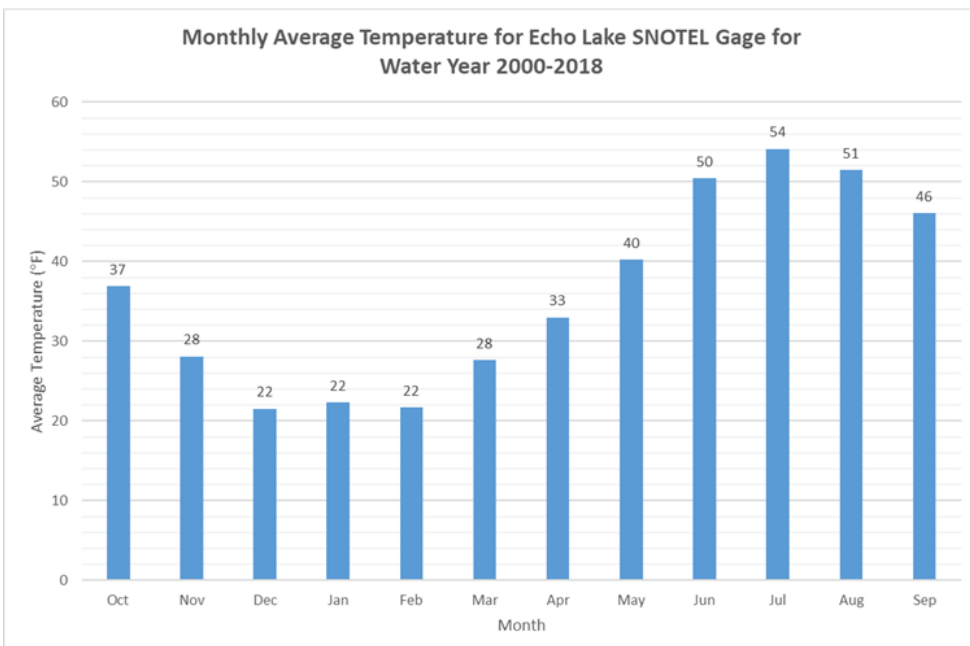


Figure 11: Monthly average temperature for the SNOTEL gage for water year 2000-2018

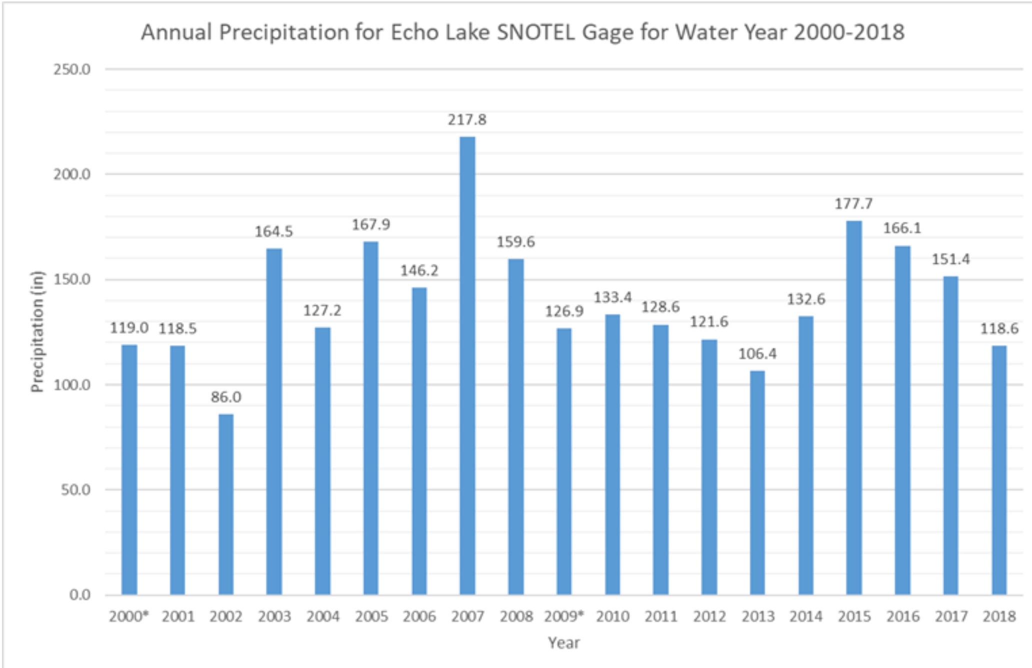


Figure 12: Annual precipitation for the SNOTEL gage for water year 2000-2018

Additionally, the annual precipitation for the SNOTEL gage is shown above for water years 2000-2018 in Figure 12 above. Note, the years 2000 and 2009, shown with asterisks, have missing data and therefore do not reflect the actual total annual precipitation for that year.

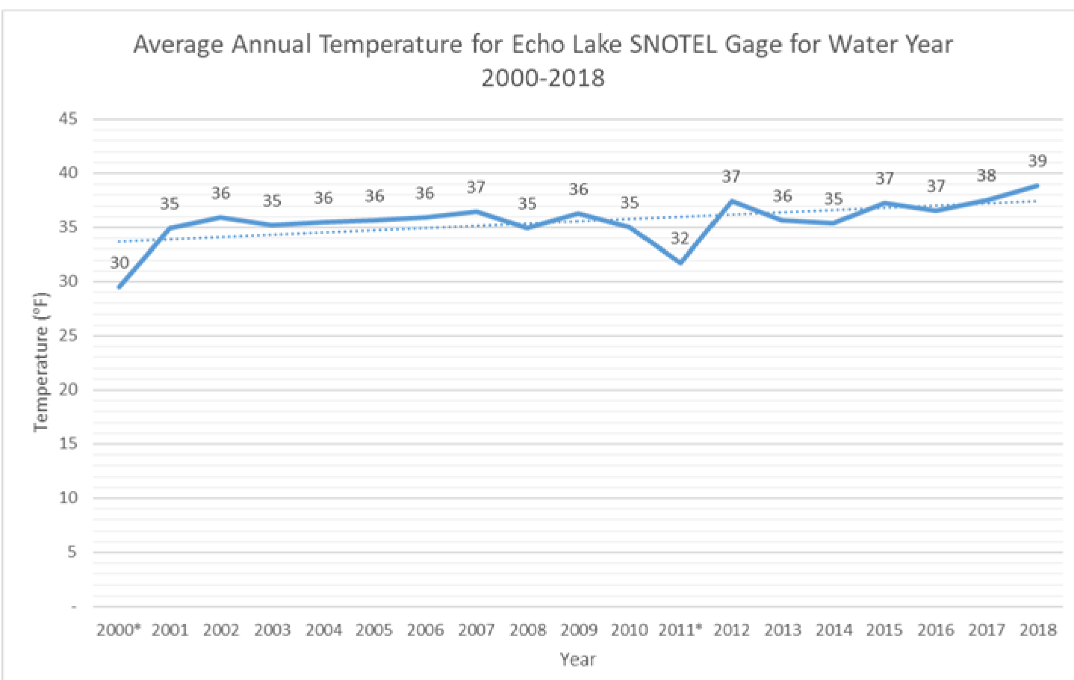


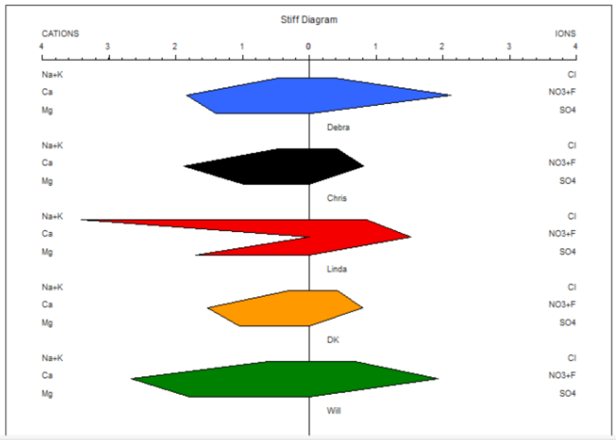
Figure 13: Annual average temperature for the SNOTEL gage for water year 2000-2018

Lastly, Figure 13 on the previous page shows the change in average annual temperature for the Echo Lake SNOTEL gage for water years 2000-2018. The chart shows an overall increase in average yearly temperature over the past two decades as evidenced by the positive slope on the trendline. The impact this will have on water supply is unknown, however as temperatures increase due to climate change, weather patterns will change greatly and a larger portion of the precipitation that does fall will fall as rain rather than snow, which will impact seasonal drainage patterns.

4.3 Chemical Analysis

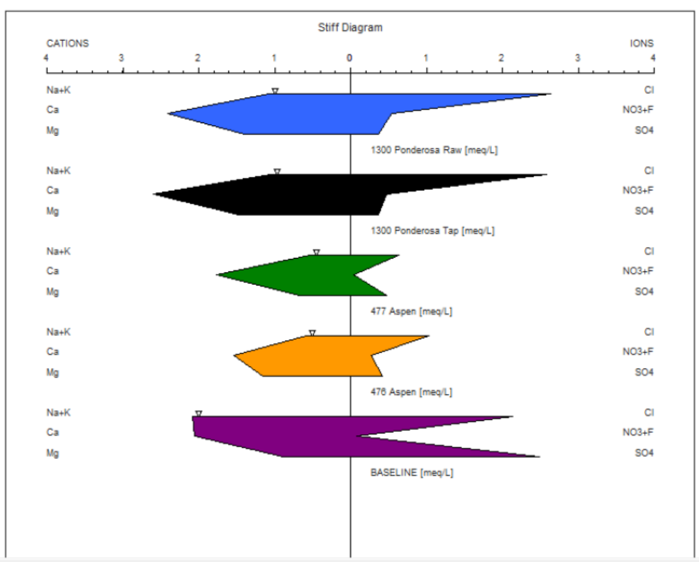
Through Zetaware's Zetastiff software, ten Stiff diagrams were created to display the important cations and anions in the well water. Stiff diagrams are common tool used for groundwater interpretation to visually show the distribution of elements found in Ion Chromatography (IC) and Inductively Coupled Plasma (ICP) spectrometry testing. Zetastiff uses the milligrams per liter taken in the field from the tap that was sent to the lab, and converts each element to milliequivalents per liter. This allows the composition of the water to properly be compared with water quality involving electrochemistry. As seen, the majority of the wells contain more cations than anions. The similarities and differences in diagrams (or constituent values) can allow the difference in source water to be speculated.

From Figure 14 and Figure 15 on the following page, the data can be interpreted as the stiff diagrams with similar shape come from the same source. This cannot be for certain due the fractured bedrock of the area. Through analysis, Figure 14 shows the DK and Chis are potentially linked to the same aquifer, as well as 476 and 477 Aspen in Figure 15. The purple stiff diagram shows the cation and anion results from the laboratory tap for comparison of treated drinking water to the well water accessed in Floyd Hill.



	Sample	Color	Na	K	Cl	Ca	NO3	F	Mg	SO4
1	Debra		8.8	3.1	13.4	36.7	3.2	19.7	17.1	1.5
2	Chris		8.0	4.5	15.1	37.7	4.0	7.2	11.9	0.2
3	Linda		2.1	130.2	30.3	0.1	94.1	0.0	20.6	0.1
4	DK		5.9	1.6	15.1	30.6	7.2	6.5	12.8	0.0
5	Will		12	3.1	24.3	53.4	17.7	15.7	21.9	0.0

Figure 14: Results from the first round of IC and ICP tests



	Sample	Color	Na	K	Cl	Ca	NO3	F	Mg	SO4
1	1300 Ponderosa Raw [meq/L]		22.9	3.2	93.5	48.4	33.4	0	17.1	17.9
2	1300 Ponderosa Tap [meq/L]		22.2	3.3	91.9	52.0	29.6	0	17.9	17.5
3	477 Aspen [meq/L]		10.2	3.5	22.5	35.5	0.17	0.35	8.3	22.6
4	476 Aspen [meq/L]		11.7	2.9	36.8	30.8	15.7	0.17	14.1	20.4
5	BASELINE [meq/L]		45.9	3.5	75.9	41.3	2.11	0.5	10.7	119.6

Figure 15: Results from the second round of IC and ICP tests

Stable isotope testing was completed on the first five initial wells that were tested. The results can be seen in Table 6. The oxygen and hydrogen stable isotopes were analyzed in the water and the results are reported in per mil relative to the V-SMOW International water isotope standard. The composition of these isotopes are associated with the movement of water in the hydrological processes and can lead to conclusions of the source of the groundwater recharge. The results from the water tests are consistent with meteoric water from this region, which suggests that the groundwater is recharged through precipitation.

Table 6: Stable Isotope Results

Well	**dD**	**d18 O**	**D - Excess**
Will and Lisa Cassidy	-113.9	-15.1	6.96
David Kempa	-112.9	-15.07	7.71
Paul and Linda Berteau	-107.8	-14.58	8.78
Chris Pearson	-114	-15.35	8.78
Cole and Debra Krems	-106.7	-14.23	7.16

4.4 3D Model

A 3D map of all the wells in the Floyd Hill, Beaver Brook, and Saddleback Mountain was constructed using ArcGIS and is shown in Figure 16. The data to create this map was taken from each individual well permit that was found on the State of Colorado website. This map consists of roughly five-hundred wells. In the map, the well heads are shown at the ground elevation and are extruded down to the depth of the well drilled. The blue layer was constructed by connecting the static water level of each well. This layer is the interpolated water table beneath Floyd Hill, however since it is fractured bedrock, this is not an accurate representation of the aquifers. Likewise, the blue layer just represents the water level and does not indicate the depth of the water table since it is unknown.

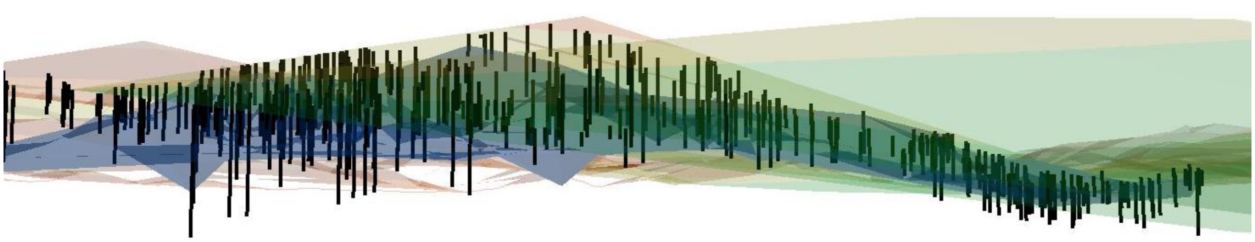


Figure 16: 3D map of the wells in the Floyd Hill area

5.0 Project Management

Over the course of the project, the team's expected managerial approach changed greatly due to many factors, including schedule changes, communication issues with homeowners, and unforeseen mishaps. The following sections outline the way in which the work breakdown structure (WBS), schedule, and project budget changed over the course of the year.

5.1 Work Breakdown Structure

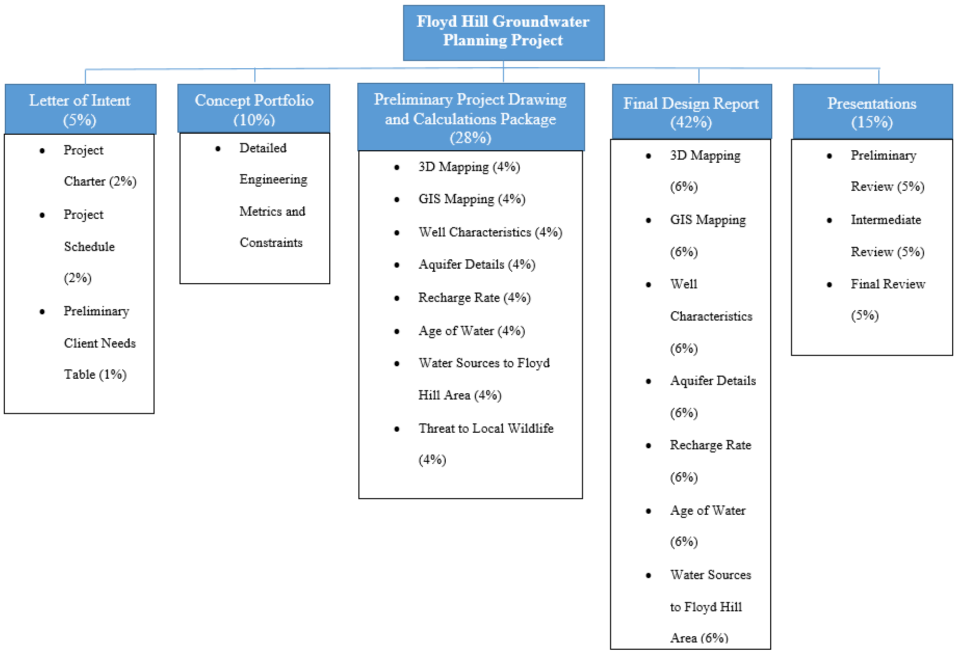


Figure 17: Initial WBS created at the beginning of the project.

Figure 17 above shows the Initial WBS that was created by the team to estimate the amount of time and effort that would be expended on each large section of the project, including the Letter of Intent, Concept Portfolio, the Preliminary Project Drawing and Calculations Package, the Final Design Report, and each of the three presentations throughout the year to the clients. This WBS was completed early on in the project, well before any well testing or water sampling began and before the team knew what to expect from each aspect of the project. This is reflected in the fairly simplistic breakdown of the percentage of work that would go to each task — all of the sub-tasks in each section were weighted equally. As the project progressed and especially now as the team looks back at the project, this WBS does not accurately reflect the amount of work that went into each task, nor does it accurately show the tasks and deliverables that the team actually completed. Figure 18 below shows the updated WBS that was completed at the conclusion of the project. This updated WBS reflects the work that went into each task and deliverable much more accurately. All of the overall work percentages that went into each section of the project, however many of the subtasks changed and their respective percentages reflect the effort expended on them more accurately than in the initial WBS. Most of the changes were a result of underestimation of time dedicated to a certain task or not realizing that certain tasks would even be incorporated into the project. Examples of these tasks include well depth measurement, water sampling (including repeat samples), the AnAqSim hydrogeologic model, and data processing for both the water sampling and well depth measurements.

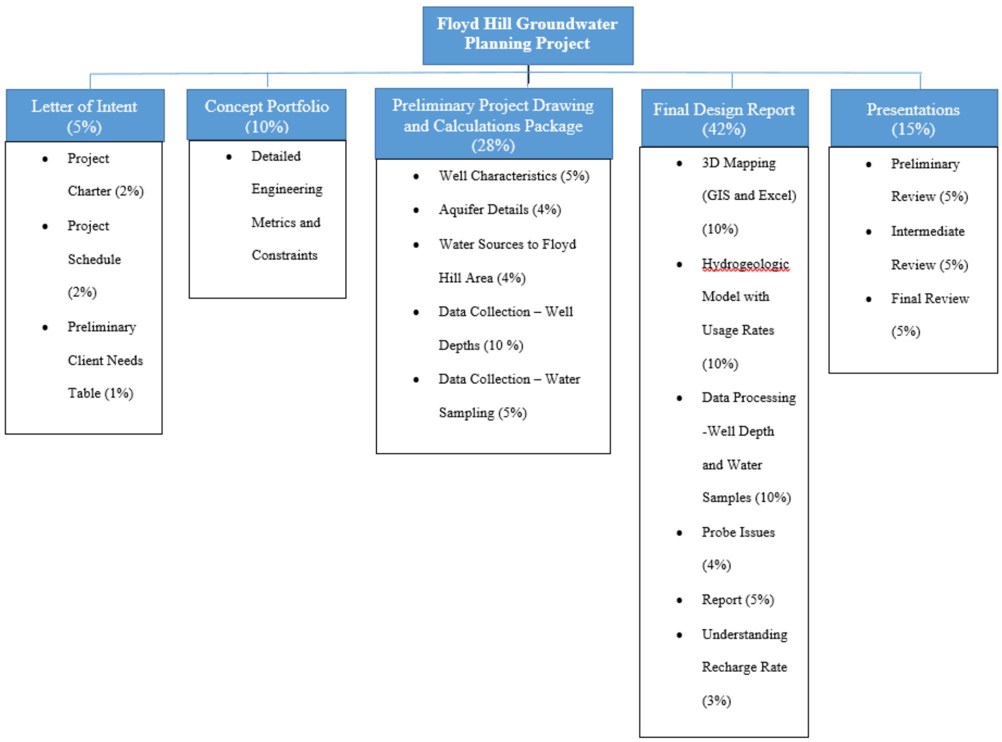


Figure 18: Updated WBS created at the conclusion of the project.

5.2 Project Schedule

Table 7: Project Schedule

Event	***Date***	***Expected Attendees***	***Task Completed (Y/N)***
Initial Site Visit	9/25/18	All	Yes
Preliminary Design Review	11/19/18	All	Yes

Project Calculation Package	02/12/19	All	Yes
Intermediate Design Review	02/26/19	All	Yes
Final Design Review	04/16/19	All	Yes
Final Design Report	04/18/19	All	Yes
Trade Fair	04/25/19	All	No

Table 7 above shows the project schedule with completion dates for all major project milestones. All major project deadlines were met, however at the time of this report's completion the Trade Fair had yet to take place so it could not be counted as completed. As far as scheduling issues within the team, the most glaring one was related to well testing. The team got a late start on well testing as a result of communication issues with homeowners, issues with acquiring the necessary equipment, and due to an underestimation of the quantity of work and time that would be associated with testing wells. The problems posed by this late start were compounded further once testing began by continued issues with homeowner contact, stuck and broken wellheads, inclement weather, and finally a probe that was stuck in a well that ended testing completely. These continued scheduling errors were detrimental to the team because far fewer data points were able to be collected than initially promised. However, these mishaps proved to be one of the biggest learning experiences for the team.

5.3 Project Budget

Overall, the team was very effective with the given budget of $500 thanks in part to pragmatic allocation of the funds and also thanks to receiving much of what was needed to complete the project pro bono or for free. Table 8 on the following page shows the initial breakdown of costs the team expected to incur over the course of the project back in December, before any testing or earnest work on final project deliverables had begun. This cost breakdown included only the sample vials and accessories and the expected cost of testing through the INSTAAR laboratory in Boulder to perform the age of water tests. However, as was discovered later on, the age of water could not be determined given that a single test ran $400, or 80% of the project budget. Given this change, along with others that occurred including no longer requiring $25 for each sample, the final project budget breakdown can be found in Table 9 on the following page.

Table 8: Initial Budget Breakdown *(December 2018)*

Item	Quantity	Unit Cost ($)	Total Cost ($)
Instaar Lab Samples	12	$25.00	$300.00
UltraCruz Parafilm	1	$17.99	$17.99
Amber Boston Round	1 Set of 50	$24.75	$24.75

Glass Bottle			
Total Cost			$342.74
Expected Remaining Funds			$157.26

Table 9: Final Budget Breakdown *(April 2019)*

Item	Quantity	Unit Cost ($)	Total Cost ($)
INSTAAR Lab Samples	5	$25.00	$125.00
Lab Samples (Mines CEE Dept.)	8	$12.00	$96.00
UltraCruz Parafilm	1	$17.99	$17.99
Amber Boston Round Glass Bottle	1 Set of 50	$24.75	$24.75
Total Cost			$263.74
Remaining Funds			$236.26

As shown above, our final budget expenditures were much lower than expected. The lab samples being tested at Mines greatly reduced their cost, while the initial sunk cost of the parafilm and sample bottles remained the same. Additionally, the team still obtained five samples from the INSTAAR lab which helped determine the potential source of the water being tested. However, our budget could have run much higher as mentioned previously. Thanks to the generosity of many who were mentioned in the acknowledgements section of this report, the team received pro bono consultation with an environmental attorney (who has graciously decided to continue supporting our clients efforts), free consultation with a hydrogeologist who not only offered up his expertise but also allowed the team to use his software free of charge, and free consultation with a hydrology expert who helped with 3D mapping efforts. Lastly, when the team ran into the problem of having the well depth meter stuck in a homeowner's well, a well contractor was able to remove the depth meter, and fix it after it was broken in the process, entirely for free. This could have cost the team hundreds of dollars and broken the budget, but thankfully this was averted.

6.0 Conclusion/ Lessons Learned

Throughout this project many lessons were learned. Prior to beginning the field work, the deliverables were discussed with the clients, yet it took multiple weeks to fully understand and gain clarity as to how to meet client needs. As the clients expressed their desires for this project, our team agreed to accomplish all of what was asked not knowing the challenges ahead. Since then a variety of lessons have been learned. Beginning with field work, considering weather, field work should have started earlier, but homeowners and access to field equipment was not yet available. We learned that there are many obstacles when working in the field, such as communicating with homeowners and equipment malfunctions. Next challenge we faced included the modeling we planned to do concerning the project development and Floyd Hill. In retrospect, it would have been ideal to consult with professionals, Michael Gabora, earlier than halfway through the project. This would have helped guide where to take the project and clarify data collection. Overall if this project were to be done a second time, we would advise to assess at the beginning the realistic ability to model, consult more professionals, advise the clients of our limitations as students, and encourage clients to join in meeting with professionals to assure understanding for all.

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Appendix A:

Section 1.

RISK RATING KEY	LOW	MEDIUM	HIGH	EXTREME
	0 – ACCEPTABLE	1 – ALARP (as low as reasonably practicable)	2 – GENERALLY UNACCEPTABLE	3 – INTOLERABLE
	OK TO PROCEED	TAKE MITIGATION EFFORTS	SEEK SUPPORT	PLACE EVENT ON HOLD

	SEVERITY			
	ACCEPTABLE LITTLE TO NO EFFECT ON EVENT	TOLERABLE EFFECTS ARE FELT, BUT NOT CRITICAL TO OUTCOME	UNDESIRABLE SERIOUS IMPACT TO THE COURSE OF ACTION AND OUTCOME	INTOLERABLE COULD RESULT IN DISASTER
LIKELIHOOD				
IMPROBABLE RISK IS UNLIKELY TO OCCUR	LOW – 1 –	MEDIUM – 4 –	MEDIUM – 6 –	HIGH – 10 –
POSSIBLE RISK WILL LIKELY OCCUR	LOW – 2 –	MEDIUM – 5 –	HIGH – 8 –	EXTREME – 11 –
PROBABLE RISK WILL OCCUR	MEDIUM – 3 –	HIGH – 7 –	HIGH – 9 –	EXTREME – 12 –

Appendix A:

Section 2.

NAME	Flyod Hill Water Engineers								
REF/ID	PRE-MITIGATION				MITIGATIONS / WARNINGS / REMEDIES	POST-MITIGATION			
	RISK	RISK SEVERITY	RISK LIKELIHOOD	RISK LEVEL		RISK SEVERITY	RISK LIKELIHOOD	RISK LEVEL	ACCEPT TO PRO
Impacts of New Development									
Scenario 1 (+)	Impact on Current Community	ACCEPTABLE	POSSIBLE	**LOW**	None Needed	ACCEPTABLE	POSSIBLE	**LOW**	YES
Scenario 2 (-)	Impact on Current Community	UNDESIRABLE	PROBABLE	**HIGH**	Check well adjudication, water needed by development, current water levels (vague since there isn't a developer at this time)	TOLERABLE	POSSIBLE	**MEDIUM**	YES
Groundwater Supply Projection									
3	Well Depths	UNDESIRABLE	PROBABLE	**HIGH**	Difficulty getting residents to shut pumps off for desired amount of time to obtain static water level could result in inaccurate results. Insist that pumps need to be shut off before testing.	TOLERABLE	POSSIBLE	**MEDIUM**	YES
4	Recharge Rate	UNDESIRABLE	POSSIBLE	**HIGH**	Obtaining precipitation data and static water levels will majorly impact the recharge rates calculated (and the model). Careful analysis of conditions to help model predictions.	TOLERABLE	POSSIBLE	**MEDIUM**	YES
Health Implications									
5	Septic Seepage	INTOLERABLE	POSSIBLE	**EXTREME**	Test wells with outlying data again to confirm levels. Continue research on safe levels or indications of septc seepage	UNDESIRABLE	POSSIBLE	**HIGH**	YES
6	Water quality analysis	TOLERABLE	IMPROBABLE	**MEDIUM**	Continue to test an even spread of homes to understand flow of water and water quality in the area.	TOLERABLE	IMPROBABLE	**MEDIUM**	YES
Well Testing									
7	Damage to Well	UNDESIRABLE	IMPROBABLE	**MEDIUM**	Being careful when opening the well and dropping probe into the well. Careful consideration of wires or other important components of the well.	ACCEPTABLE	IMPROBABLE	**LOW**	YES