CUWCD UNDERGROUND WATER ANALYSIS
Project ID: CEEn_CPST_017

by

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A Capstone Project Final Report

Submitted to

K.C. Shaw
Central Utah Water Conservancy District

Department of Civil and Construction Engineering
Brigham Young University

April 17, 2023

Executive Summary

PROJECT TITLE: CUWCD UNDERGROUND WATER ANALYSIS
PROJECT ID: CEEn_CPST_17
PROJECT SPONSOR: Central Utah Water Conservancy District
TEAM NAME: Liquid Steel

For the project, we were tasked with finding the characteristics of the aquifers at the Vineyard well site, as well as the water elevation levels within the aquifers under certain pumping scenarios from the recently built wells. The elevation levels would be projected through the use of a modeling system, which was MODFLOW in our case.

The initial phase of the project, which occurred during Fall 2022, involved the gathering of necessary data for the wells and putting this information into spreadsheets to begin the process of calculating the aquifer characteristics. During the semester of Winter 2023, we calculated the aquifer characteristics and established the model for the well pumps, both of which were completed around the beginning of April 2023.

Using data from the well completion reports at each well site, we analyzed and calculated the aquifer characteristics (thickness, hydraulic conductivity, hydraulic gradients, transmissivity, etc.). Then, we used MODFLOW to create a model to understand the flow of water. This underground water analysis shows the impact of pumping in the wells and the cone of depression from each site.

From the model we were able to extract data of the most extreme drawdowns and elevation levels, as well as maps of the modeled wells and their impact on water elevation levels within the aquifer over time. Several animations were created that depicted the changes in water levels as the pumps were turned on and off. The characteristics data and created maps from the model were the deliverables for the project.

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Introduction

For our project, we were tasked with modeling the groundwater elevation levels at the new wells that Central Utah Water Conservancy District (CUWCD) drilled to supplement current water production from the Orem water treatment plant. 8 wells have been built so far, with more under construction. CUWCD is concerned about the water elevation levels as the wells are brought online to provide for the growing water consumption. These wells draw from three confined aquifers going down to a depth of 1500 ft below the surface. Each aquifer has its own properties with monitoring wells to record piezometric heads in each respective aquifer.

The team met every Monday after class and Friday evening around 6pm. Periodically we met with our project sponsor to discuss challenges we faced with the data. We also met with our faculty mentor, Dr. Jones, every first Monday of the month and several other days to discuss our model.

The following was our projected deliverable dates:

March 30, 2023: Submit a detailed summary report with maps, figures and other graphics necessary to portray aquifer properties.

March 30, 2023: Submit groundwater model results of projected maximum pump rates.

April 10, 2023: Have the final presentation of the project ready to present.

The assumptions that were made to complete the project include calculating one average conductivity for the three aquifers. Another assumption was the 10% rainfall value to compute the recharge. Porosity was also assumed to be 0.2 to compute the underground water analysis model.

The expectations included computing the characteristics of the aquifers, which included hydraulic conductivity, transmissivity, hydraulic gradient, etc., in addition to a groundwater model, complete with maps of the projected elevation levels under certain pumping scenarios.

Schedule

We met every week, twice a week, with an average of 2-3 hours together. Our first task together was to analyze the aquifer characteristics from the reports, focusing especially on hydraulic conductivity. Hydraulic Conductivity was complicated to compute. There was a lot of data which had to be organized, so we spent a couple weeks working on it. We finished our calculations around early March.

Once we got the average hydraulic conductivity for the three aquifers, then we moved on to finish the other characteristics, all of which required the hydraulic conductivity in order to calculate them. These characteristics included the transmissivity and hydraulic gradient. We finished the calculations of all aquifer characteristics by mid-March, which was more time than we anticipated using.

After acquiring all the necessary characteristics, we plugged them into MODFLOW and began working on creating the model for the water elevations. In addition to the aquifer characteristics, we also spent time calculating the recharge rate of the aquifers through rainfall and lateral inflows from the nearby mountains. The model for the aquifer took about 3 weeks to finish, which put us right near the deadline for the project. Our first maps were produced near the end of March, while our final maps were created around the end of the first week of April.

One of the major challenges we faced during the course of the project was our group's unfamiliarity with groundwater and groundwater modeling. None of our group members had taken any classes associated with groundwater. For that matter, only a couple of members had taken any classes focusing on water resources. As a result, the calculations and modeling of the aquifers took more time than we initially expected, as we struggled to understand some of the underlying math for our calculations and models.

Assumptions & Limitations

Since our model could not define the wells as accessing three separate aquifers, we assumed an average hydraulic conductivity. We averaged the hydraulic conductivity found at each well casing. This assumption has a major limitation, being that it does not represent the changes in hydraulic conductivity that occur throughout the well site due to differences in geotechnical properties at each site. However, our calculations found similar hydraulic conductivities at each site, so we believe that this assumption was not far off from reality.

We assumed the recharge rate of 10% of rainfall. This was based off historical data for Utah County rainfalls and the typical percentage of rainfall that infiltrates aquifers. The rainfall rate could increase some years which would allow the aquifers to recharge faster. However, the recharge rate could also be lower which would impact the recharge rate and could be a problem for the wells that are constantly pumping.

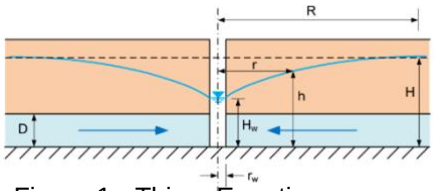
We also assumed the porosity value of 0.2. This assumption led to the limitation of how the soil impacted the hydraulic conductivity. The porosity of soil was not in drill reports which we checked for each well. This assumption was made based on research on similar aquifers in soil in Utah.

As a result of these assumptions, the main limitation is found in the consistency of our data. Since we averaged a lot of the ground conditions throughout the site, this eliminated any possible anomalies that a more thorough analysis of the area might have found. We were mostly concerned with our projections being close to the recorded changes in elevation that CUWCD gave us, so not having these situations come up in the model was not a concern.

Another limitation was the possible change in site conditions that could have occurred since the date of the rainfall and hydrology studies conducted on the area. Utah is currently experiencing drought conditions, which was not true when these studies were done. It is possible that aquifer conditions have changed enough since then that our assumptions are no longer representative of the area.

Design, Analysis & Results

The Theim equation was used to calculate the hydraulic conductivity for a confined aquifer. The drawdown in the well during pump tests, the max pump rate or q, the radius of influence, the radius of the well, and the thickness of the aquifer, were variables in the equation as shown below.



$$q = 2\pi kD\frac{H - H_w}{\ln(R/r_w)}$$

Figure 1 - Thiem Equation

The project affects the Northern Utah County aquifer, which is confined and composed of multiple aquifers. The wells pass through the intermediate, deep, and basement aquifers down to a depth of around 1500 feet. These aquifers do connect in some areas thanks to the drilling of the wells, and in the design we combined their total thickness and assumed them to be connected.

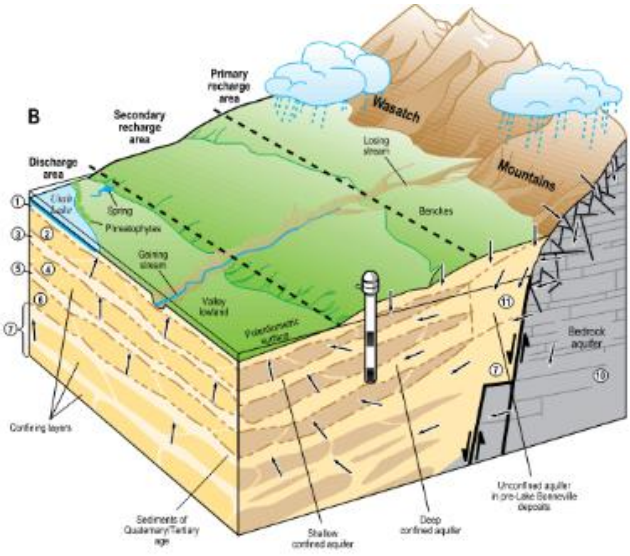


Figure 2 - North Utah County Aquifer Cross Section

The table below shows the results of hydraulic conductivity and transmissivity in each of the wells and the average that was used in the prepared model. This was calculated using the assumptions from the aquifer characteristics explained above.

Table 1 - Hydraulic Conductivity and Transmissivity in each Well

Drawdown	Well	k (ft/s)	k (ft/day)	T (ft^2/s)	T (ft^2/day)	i (HG)
51.47	Well 8	0.000349842	30.23	0.343	29621.9	0.0128675
121.97	Well 9	0.000147629	12.76	0.145	12500.1	0.0304925
148.33	Well 10	0.00012139	10.49	0.119	10278.7	0.0370825
81.71	Well 11	0.00022	19.04	0.216	18659.1	0.0204275
29.4	Well 12	0.00056	48.49	0.550	47524.6	0.00735
110	Well 13	0.00015	12.96	0.147	12702.0	0.0275
120	Well 14	0.00014	12.29	0.139	12045.4	0.03
260	Well 15	0.00003	2.71	0.031	2658.3	0.065
	AVG	0.000215523	18.62			0.02884

Well locations were provided by CUWCD as well as results of pump tests for each well. Monitoring wells also recorded historic piezometric head elevations for each of the three aquifers going back to 2012. With this information we were able to enter well coordinates into the hydraulic model to see the combined effect of pumping all wells simultaneously.

Figure 4

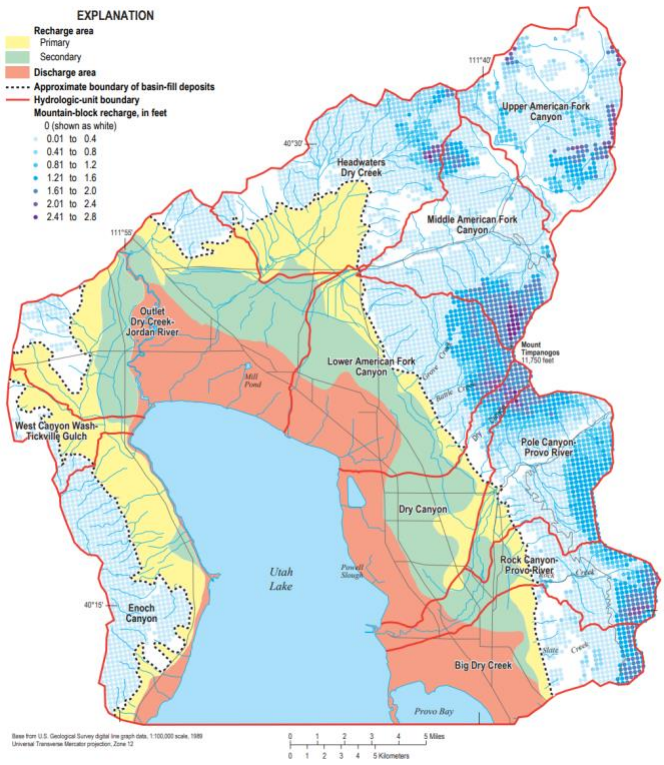


Figure 3

The recharge rate of the aquifers was found to be 10% of average rainfall, or about 1.8 inches per year. In addition to the rainfall, the aquifers also receive water from lateral inflows from the mountains. These lateral inflows were calculated using a 2008 report from USGS of the hydrology of Utah County. The inflows were found to be an additional 16,500 acre-ft/year, or around 55,800 m^3/day.

After achieving steady-state conditions on the well elevations, the largest drawdowns occurred at Wells 8-10 and Wells 11 and 12. These drawdowns were typically around 25 m, or about 82 feet. The elevation levels around the monitoring wells drew down about 20 m, or 66 feet.

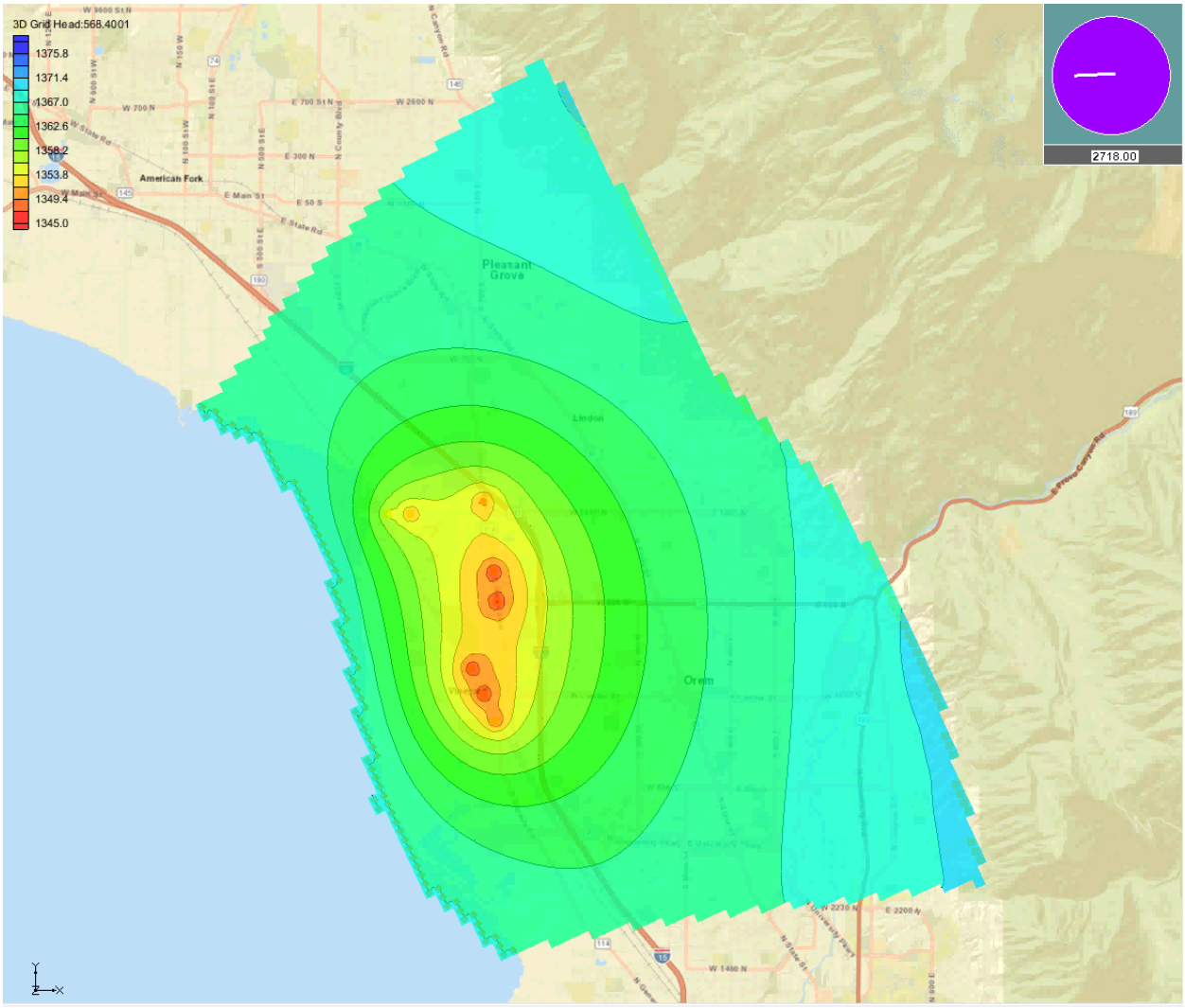
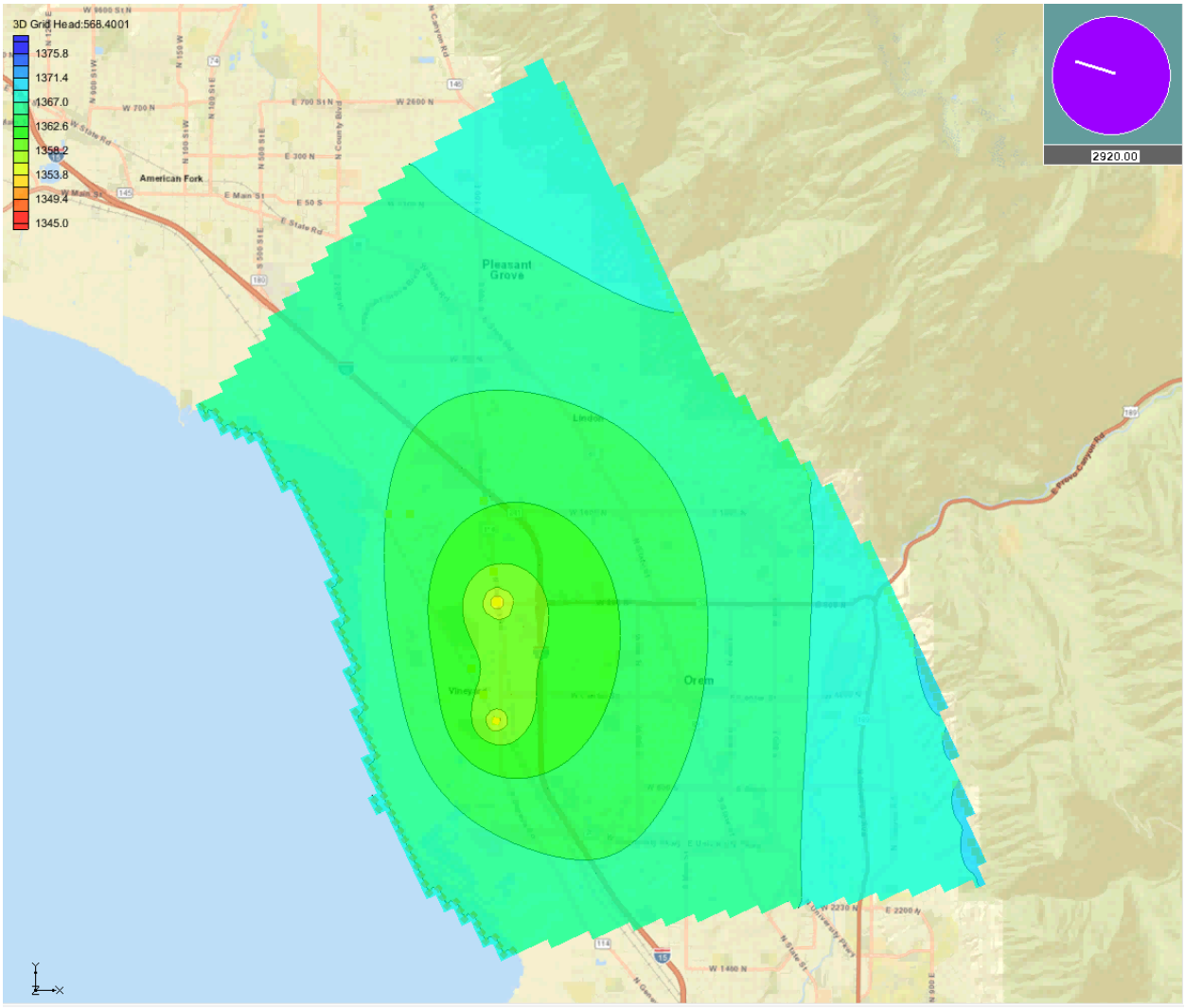


Figure 5

This quickly rebounds to a max drawdown of about 18 m, or 60 ft. The monitoring wells hover around 14 m of drawdown, or 46 ft.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1371.4
1367.0
1362.6
1358.2
1353.8
1349.4
1345.0
2920.00
Pleasant Grove
Orem
American Fork

Figure 6

Related Issues

Utah is one of the driest states in the U.S., so water management is an extremely important aspect to monitor in order to maintain the welfare and health of the affected communities. CUWCD must make sure that water deliveries are being made and are sufficient according to water rights, which is difficult enough if only the drought conditions were considered. However, Utah has also seen significant population growth, especially in and surrounding Utah County. As a result, CUWCD has turned to the use of aquifer water to supplement their current supply. The water levels within the aquifer could dip below recoverable levels, so knowing how much the constant pumping of the wells affects the aquifer levels is key to prevent issues related to overpumping.

As mentioned before, the significant population growth of Utah County and the state of Utah as a whole makes it difficult to project the water demand going forward. A higher than anticipated growth could lead to higher water demand than expected. If this were to occur, CUWCD would likely need to rely on production from the wells even more. If there is not enough water to supply the growing demand, it could have major impacts on economic growth for the region.

Some of the wells that we modeled in our project have issues with high levels of certain elements, specifically manganese and iron. While not necessarily dangerous to the public, the change in color, odor or taste that these elements cause would give the public pause in using the water. As a result, many of the wells first pump their water into a polishing plant before it makes its way to the public system. Since the additional operation and maintenance of a water polishing plant is more added cost, it would make sense to know how much the wells that do not experience the water quality issues can be utilized in order to bypass the other wells.

Lessons Learned

These are some of the challenges we faced and how we overcame each one:

- While we were excited to embark on the project, none of our team members had experience with groundwater modeling software. As the project went on, our lack of experience with the software and equations made it more time consuming to process the data. If we had spent more time getting familiar with the model, we likely would have been able to run more theoretical scenarios.
- Some of our team meetings were unproductive because we lacked a plan of attack before the meeting started. During our meetings when we knew what our objective was, we got significantly more work done on our calculations.
- At one point in our research into the aquifers, we realized that our initial choice for modeling software was not going to be adequate to model the complicated system of aquifers. As a result, we ended up wasting a lot of time trying to make the initial choice work. Always make sure that you have the proper tools to analyze work before diving headlong into it.
- We did not visit the site of the wells we were analyzing until very late in the project. Oftentimes it is much easier to understand the scope of a project when a person has a physical connection with the site. Our project supervisor also gave more detailed background into certain decisions for the wells due to environmental factors that were out of their control. While it was good to finally see the site in person, we wish we would have made a more concerted effort to schedule a visit earlier in the semester. We initially didn't view it as an important step, since we were already spending so much time on our aquifer characteristic calculations.
- We never had a sit-down meeting with our project supervisor to go over any confusing data for the wells. For the most part, any challenges or questions we had were resolved with our faculty mentor or over zoom with our supervisor. A physical meeting would have been more productive in indicating our misunderstandings to our supervisor so that he could have pointed us in the right direction quicker than we could figure it out ourselves. We should have felt more comfortable in relying on the background project knowledge of our supervisor.

Conclusions

By running certain scenarios for the pump schedules at each well, we were able to determine the projected drawdowns for each well and how they affected the water elevation levels. In the most extreme scenario, all currently built pumps were running non-stop until reaching steady-state conditions. While the drawdowns were extreme in some areas, the rebound rate for the aquifers was quick, allowing the system to recover from significant pulls without permanently affecting the water elevations. The typical scenario involves all the pumps only running during the peak summer months of May through September, so the drawdowns aren't as severe and the projected elevation levels after reaching steady-state conditions were similar to the recorded changes in elevation levels that CUWCD has found at their monitoring wells in the past few years.

Since the normal operations of the wells should be well below our model's extreme use case, we are confident in saying that the rebound rate of the aquifer is quick enough under normal rainfall conditions that we are not too concerned about the impact of the wells on the water elevation levels. The high rebound rate is the result of high lateral inflows from the mountains, which is usually more stable than the amount of rainfall that occurs in the valley each year. We believe this high rebound rate is sustainable under historic precipitation conditions for Utah Valley.

Recommendations

As mentioned in the conclusion, the scenarios in which the pumps were run non-stop for an entire year and when the pumps were running on their normal seasonal schedule produced drawdowns and elevation levels that became steady-state after about 4 years. Since the recharge rate from the rainfall infiltration and lateral inflows is high enough to come to this steady-state condition after such a short amount of time, our group is not concerned with the water levels within the aquifer being drawn down to a critical level. However, this is assuming historical precipitation levels for every year of the model.

Since several more wells are currently planned and under construction, we recommend building upon this model once future pump rates and drawdowns have been established at each new well. Particularly, monitoring the recorded elevation levels and comparing those values to this newly built model would help affirm the validity of these projections. A new model with all of the planned wells in place would give a clearer picture as to the future status of aquifers. In addition, we would recommend commissioning a new hydrology study for Utah County, as any change in the lateral inflows from the mountains would have a significant impact on the aquifer levels.

Appendix A

BYU ENGINEERING
Civil & Construction Engineering

CAPSTONE

Andrew Thornton

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EDUCATION

B.S. Civil Engineering, Brigham Young University — **Apr 2023**, Provo, Utah

- 3.74 GPA
- Minor in Mathematics
- Received BYU full tuition scholarship, half tuition scholarship, and on Dean's List

RELEVANT EXPERIENCE

Structural Engineer Intern, Horrocks Engineers — **May 2022 - Present**, Pleasant Grove, Utah

- Designed structural bridge components adhering to ACI code and UDOT standards including; parapet, bridge deck, and expansion joint design, for a bridge on I-15
- Collaborated with CAD technicians to prepare plan sheets for box culvert crossings and structural signs as the design engineer for 2 UDOT projects
- Performed quality control for calculations of concrete quantities and geometries

Science and Engineering Reference Assistant, BYU Library — **Aug 2020 - Apr 2022**, Provo, Utah

- Utilized Compendex and Scopus databases to provide cutting edge information to students researching science and engineering
- Designed 3 posters and infographics with ArcGIS and Adobe Photoshop software to help patrons navigate the library with ease

Concrete Canoe Team Member, RMC — **Sep 2020 - Apr 2021**, Provo, Utah

- Controlled the weights of each material needed to construct the canoe for the competition based on their respective specific gravity and volume.
- Adhered to competition criteria and industry standards for material testing to fabricate the lightest possible concrete while still maintaining its structural integrity

Volunteer Representative for The Church of Jesus Christ of Latter-day Saints — **Jun 2018 - Apr 2020**, Bogotá Colombia

- Directed 24 volunteers providing training and leading meetings to increase productivity and performance
- Worked 70+ hours each week
- Developed proficiency in speaking, writing, and communicating in Spanish

ADDITIONAL SKILLS & COURSES

- Reinforced Concrete
- Asphalt, Concrete, and Masonry
- Metals, Woods, and Composites
- Foundation Engineering
- Dynamics
- Mechanics of Materials
- Asphalt Mix Design
- Hydraulics and Fluid Flow
- Soil Mechanics
- Geology for Engineers
- 3D Printing
- C++
- ArcGIS Software
- Adobe Photoshop

William Thomas

208-240-8489 | thomwillmets@gmail.com | www.linkedin.com/in/william-thomas-452207205

Education

BS, Civil Engineering
Brigham Young University | April 2023

- 3.14 GPA
- Perfect 36 on ACT
- Passed FE Exam

Work Experience

Asset Management Intern | April 2022 – Present
Central Utah Water Conservancy District | 1426 E. 750 N. Suite 400, Orem, UT

- Held position of lead intern trusted to manage schedule and tasks for 5 interns, including scheduling of field visits
- Reviewed 10+ sets of record drawings and 40+ RFIs, submittals, and memos for clarification and errors
- Built out 2 facilities of 50 or more assets within an asset registry
- Updated and reviewed the status and health of over 500 assets
- Researched and presented about 5 different SOP software systems to replace existing system

Computer Support Technician | August 2020 – April 2022
Brigham Young University Print & Mail | 701 E University Parkway, Provo, UT 84602

- Held position of student supervisor tasked with creating schedules for fellow technicians and training new technicians on computer support practices
- Deployed and maintained over 70 printers across campus for use by students
- Set up printers to work remotely over the network with server
- Maintained health of a network of over 100 computers and specialized printers in my department

Volunteer Experience

Full-time Representative | September 2017 – September 2019
The Church of Jesus Christ of Latter-Day Saints

- Harbored relationships with locals through 10-12 hours of communication per day in Spanish
- Helped organize community activities and service opportunities
- Trained and supervised 12 representatives: improved morale, communication skills and teaching ability

Skills

- Adobe Acrobat
- AutoCAD, Revit, ArcGIS
- Spanish Proficiency
- Python and C++

Devyn Txwvzeej Sayao Vang

563 S 575 W Unit 10, Springville, UT 84663
Cell: (559) 408-8196
E-mail: devyn.vang11@gmail.com
LinkedIn profile: www.linkedin.com/in/devyn-vang-structural-civil

Summary:

- Self-driven and task oriented with a strong work-ethic
- Enthusiastic and innovative with strong interpersonal skills
- Well regarded for strategic leadership and creating team dynamics
- High learning capacity
- Ability to learn quickly and demonstrate leadership competency
- Technically competent: Revit, AutoCAD, Civil 3D, Chief Architect, RISA, Forte, Enercalc

Education:

- **BS, Civil Engineering**
- Brigham Young University
  - December 2023
  - 3.00 GPA

Employment Experiences:

Blue Raven Solar (Orem, UT) (September 2022-Current)

- Analyzing structural framing of homes as a Structural Specialist in order to verify if roof is capable of bearing solar panels.
- Reviewing and creating permit packets to include all electrical and structural connections during design and permitting process.

FOCUS Engineering and Surveying (Midvale, UT) (March 2022-Current)

- Engineering and designing structural plans for commercial buildings as well as custom homes
- Engineering and creating, in full, the structural plans (gravity and lateral design) for a project
- Creating solar letters and truss designs and calculations in order to verify if roofs are adequate for extra loads

Hillwood Homes (Park City, UT) (Aug 2021-Feb 2022)

- Drafter for homes using Chief Architect (Structural, electrical, architectural designing, Permit sets and HOA packets)
- Home designing for homes being built in Park City Utah

Solcius (Orem, UT) (July 2021-Jan 2022)

- Utilizing AutoCAD as a permit designer to draw roof plans and add panels to roof with proper jurisdictions
- Implementing an Engineer's coded excel sheet as a structural analyzer to determine the structural load capacity of roofs

Sheeran Consulting Services (Salt Lake City, UT) (July 2019-July 2021)

- Designed and worked on detailing, revising, and co-designing projects within the State of Utah using Revit and AutoCAD (Homes, Garages, Large cargo Storage Units, etc…)
- co-drafting and drawing a large cargo storage unit that will be built in Salt Lake City
- demoing and removing walls in an old building to create more space for a new purpose (a multi-usage office)
- drafted and expanded Zagg buildings throughout Utah
- building the foundation work for a larger project with multiple companies participating

Daira Sofia Velasco Vega

Current Address:
248 N 1325 W
Springville, Utah

Phone number: 801 800 0870
Email: velascovegadaira@gmail.com

Education

B.S. Civil Engineering, Brigham Young University, Provo, UT — Sep 2020 – May 2024
- Enrolled 18 Credits — GPA: 3.3
- **American High School Diploma** American International School of Bolivia — Aug 2016 - May 2020
- Diploma of graduation — Overall GPA: 3.88/4.0

International Diploma American International School of Bolivia — Aug 2018 – May 2020
- Bilingual Diploma Awarded — Overall GPA: 31/42

Bolivian Diploma American International School of Bolivia — Feb 2013 – Nov 2019
- Bachelor Diploma in humanities — Overall GPA: 3.88/4.0
- Middle Administration Technician Title — Overall GPA: 3.88/4.0

Work Experience

Research Assistant, BYU Civil Engineering — May 2022 -Present
- Research on structural analysis software

Research Assistant, BYU Civil Engineering — April 2022-Present
- Collaborate to innovate in house design for the solar decathlon competition

Teaching Assistant, BYU Civil and Construction Engineering — June 2022-Present
- Assist on the sustainability course

Research Mentorship Program, BYU Civil Engineering — Aug 2021- April 2022
- Researched on low head dams

Teaching Assistant, Honors Program BYU 120 Course — Aug 2021-Dec2021
- Reinforce the material taught

Dining services, Chick-fil-A BYU Cougareat — Feb 2021- May 2021
- Front desk position

Administrative Assistant, Paper Lab S.R.L Cochabamba Bolivia — Feb 2018- Feb 2020
- Developed research on the market to launch food packaging

Volunteer Work

New Student Orientation Leader, BYU — Aug 2021
- Guide and interact with new students

Research Mentorship Program, BYU Civil Engineering — Jan 2021- June 2021
- Collaborate with graduate students 3D Modeling

Service The Church of Jesus Christ of Latter-day Saints, — May – December 2020
- Conducted English Classes Stake University, Bolivia

Hackathon Technological Community GP4 TECH — Feb 2019
- Developed research in technology to satisfy people's disability

"Sonrisa" Movement Viedma Hospital (3 hrs/week) — July 2018– July 2020
- Foment love and happiness in children section

Awards

- Approval to proceed in the Solar Decathlon Competition, build section
- Awarded as student of the year in the Annual Banquet at BYU
- Recognition of Outstanding Academic Achievement, President's Education Awards Program
- National Honor Society. Membership is based on Scholarship, Leadership, Service and Character.
- Physics and Mathematics Subject Contest, Ministry of Education Science and Technology.

Skills and Interests

- Music and Dance: Play the violin and piano, dance Ballet
- National Swimmer Competitor
- Model United Nation