

# PROVO CITY SEWER AUDIT

CCE\_CPST\_016 | F.M. WILLIAMS & PRICE

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## **Capstone Project Sewer Audit Report**

SUBMITTED TO

LANE PIERCE

PROVO CITY

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

BRIGHAM YOUNG UNIVERSITY

APRIL 08, 2024

## Executive Summary

**PROJECT TITLE:** PROVO CITY SEWER AUDIT  
**PROJECT ID:** CCE\_CPST\_016  
**PROJECT SPONSOR:** Provo City  
**TEAM NAME:** F.M. Williams & Price

This project conducted an audit on a discrete segment of Provo City's sewer system, focusing on a specific area for the monitoring of flows entering the sewer treatment plant. Using data collection and analysis, the project compared measured sewer flows with expected sewer flows to determine overall sewer contributions to the pipe system and confirm appropriate sizing. This included checking for infiltration and other factors that may misrepresent flows which vary based on the time of day. The project involved GIS-based basin delineation, meter installation, monthly flow monitoring, and observation of monthly precipitation data. The team utilized tools such as GPS survey equipment, ArcGIS Pro, and Excel VBA for measurements and modeling throughout the process. The project timeline extended from October 15, 2023, to April 17, 2024, with specific tasks allocated to each phase (see Schedule). From Mannings and infiltration analyses, the project concluded that the sewer pipe operated within the expected parameters and that infiltration was negligible. From the findings of this BYU Capstone project for Provo City Public Works, it is recommended that future audits be performed (see Recommendations). Deliverables include this comprehensive report, Mannings VBA program, GIS-based maps, an infiltration analysis, and various data graphs.

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## Introduction

The Provo City Sewer Audit, performed by capstone team #16 (F.M. Williams & Price) in collaboration with Brigham Young University's Department of Civil and Construction Engineering, entailed a comprehensive evaluation of a discrete segment of Provo City's sewer system. The primary objective of assessing the sewer was to ensure proper sizing for a sewer treatment plant in the area. This project included the on-site installation of a Hach Flo-Dar sensor, data collection and analysis, and ArcGIS modeling exercises.

The project was given in response to the need for accurate sewer flow measurements and the identification of potential infiltration sources. Analysis methods included the comparison of flow data collected from the sewer to expected flows using Manning's equation, the comparison of collected sewer data with precipitation data from the Provo airport for analysis of potential infiltration, and the comparison of expected flows using ArcGIS basin delineation.

Beginning in the Fall semester of 2023, this project was scheduled to span from October 15, 2023, to April 17, 2024. The scope of the project was divided into stages of completion to meet respective deadlines (see Schedule). Starting with the initial meter installation, the project progressed through phases of data collection, analysis, modeling, and reporting. Monthly data acquisition ensured continuous monitoring, while additional tasks such as the infiltration analysis and ArcGIS analysis were conducted as needed throughout the project's duration.

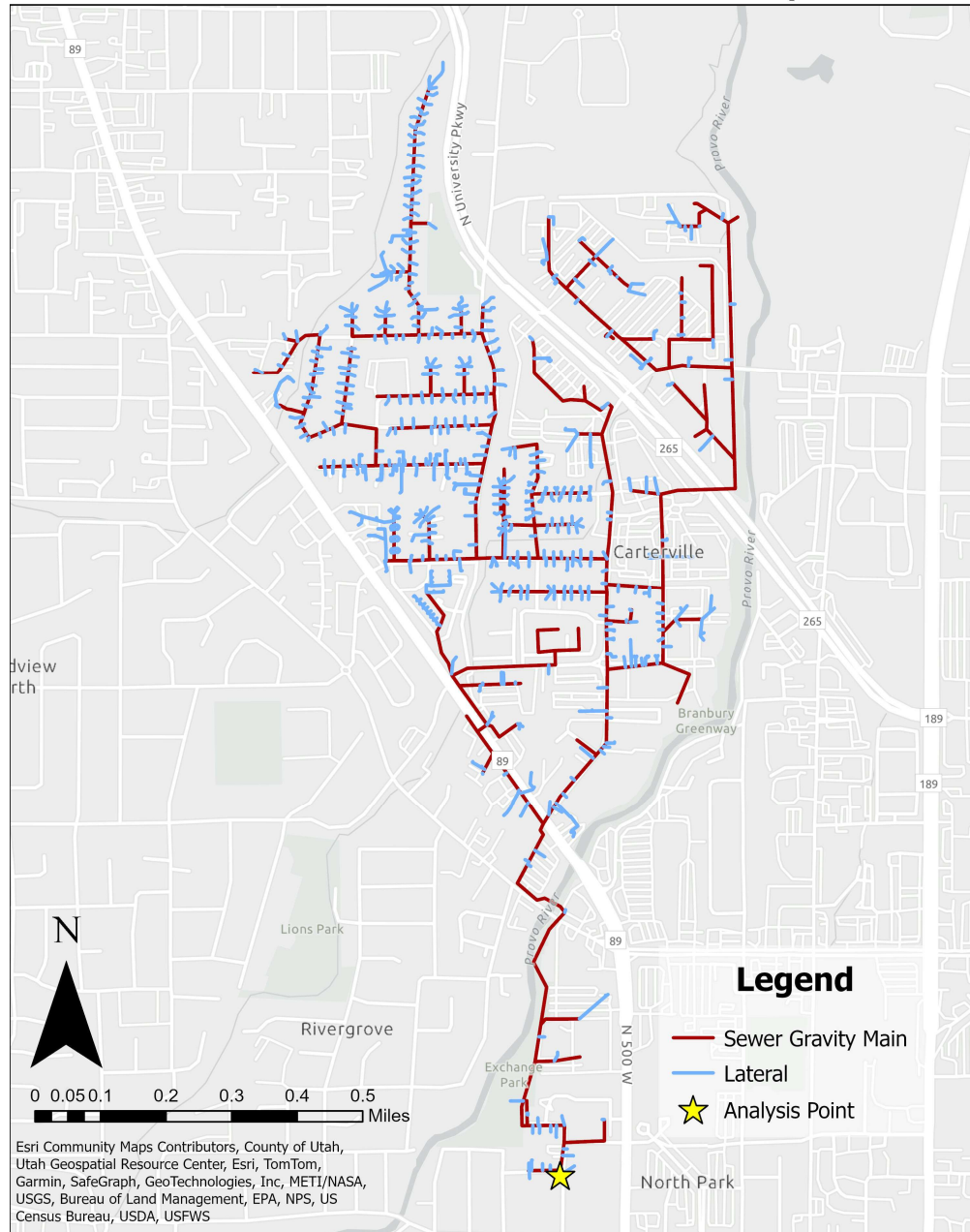
Central to the project's execution were several key assumptions. These included considerations regarding backwater occurrence, the roughness values for the Manning's equation calculations ( $n$ ), slopes used in design, household flow averages, and rainfall data sources. While these assumptions provided a foundational framework for analysis,

they also highlighted the project's limitations and areas of uncertainty (see Assumptions and Limitations).

Expectations for project deliverables included a comprehensive report of work performed, GIS-based maps, infiltration analysis, and data comparison graphs for the sake of the sewer audit. Additionally, the team aimed to provide the city of Provo with software they created to facilitate future sewer audits utilizing VBA code within Microsoft Excel.

In adherence to performance standards, the team is committed to delivering work of the highest quality by implementing best practices and collective expertise. However, it is important to note that project results are not intended as stamped deliverables and must undergo review and approval by licensed professionals before formal acceptance.

## Sewershed from Point of Analysis



**Figure 1** Site map for sewer audit.

Figure 1 shows the basin laterals contributing to the analysis point of the sewer audit. Each lateral is a household or commercial property connecting to the sewer main. This is used as a site map for the GIS Analysis.

## Schedule

Project Timeline: October 15, 2023, to April 17, 2024

October 23, 2023: Project Initiation

- Project Kick-off Meeting

November 1 - November 15, 2023: Initial Fieldwork

- Installation of Flo-Dar with assistance from Provo City Public Works.
- Commence Measured vs Expected Flow Analysis using Survey and GPS Equipment
- Use Philadelphia Rods for Pipe Inverts and Depth of Flow Measurements
- Comparison of Meter Readings with Manning Calculation
- Review and Familiarization with GIS Data

November 16 - December 15, 2023: Data Collection and Analysis

- Initiating Monthly Flow Monitoring Schedule
- Begin Infiltration Source and Locations

December 16 - January 15, 2024: Inflow & Infiltration Analysis

- Initiate Rain, Snow, and Snowmelt Data Collection

January 16 - February 15, 2024: Modeling and Reporting

- VBA Code in Excel for Manning's Analysis
- Compile Monthly Flow Monitoring Data for Reporting
- Continue Source Identification of Inflow & Infiltration

February 16 - March 15, 2024: Data Analysis and Recommendations

- Utilize Software Tools for Meter Flow Data Analysis
- Begin Comprehensive Report Writing, including Methodologies and Analyses

March 16 - April 1, 2024: Final Deliverables and Closing Tasks

- Finalize Basin Delineation Map using GIS Data

- Provide Initial Project Recommendations
- Complete Infiltration Source and Locations Documentation
- Develop Final Report with Recommendations, Economic, and Environmental Considerations
- Prepare and submit Project Poster

April 15, 2024: Final Presentation and Project Closure

- Create Project Presentation
- Deliver Final Presentation of Project Summary to Sponsor
- Submit Comprehensive Report
- Obtain Client's Approval of Final Report and Recommendations
- Project Closure

## Assumptions & Limitations

Assumptions made for this project:

- Backwater is considered a common occurrence in sanitary systems, suggesting solids within the pipe are not flowing freely from gravity. The solids, blockages, and discarded items slow flows compared to “clean” water. The depth of water is impacted resulting in a reduction in the expected maximum capacity when based solely on gravity-fed flow. For the pipe size of 24 inches to fit the manning’s data, a backwater of 1” was used.
- A Manning’s n value was assumed at 0.013 to be consistent with calculations and results from Provo City. A higher Manning’s n value is more conservative.
- Slopes in design from bid drawings used slopes of 0.0067 ft/ft, while the survey points collected for the project indicated a slope of 0.0098 ft/ft. For this report, a slope of 0.0067 was used.
- The assumed value for the GIS average household is given by Utah Administrative Code R317-3-2. This value is 100 gallons per capita per day.
- Rain gauges in a nearby perimeter of the testing location were not part of the scope of this project. Thus, all rainfall data was taken from readings from the Provo Municipal Airport, it is assumed that the rainfall will be similar to the testing location.
- Flow during early hours (about 3 AM to 6 AM) is infiltration.

- The weather is unpredictable, so many of the infiltration and inflow calculations were based on storm events.
- The pipe includes commercial evening flows thus flows will not reach zero at night.
- There was a large reduction of flow during BYU's winter break period as a result of tenants returning home for winter break. This reduction occurred during rain events in December limiting calculations for inflow and infiltration.

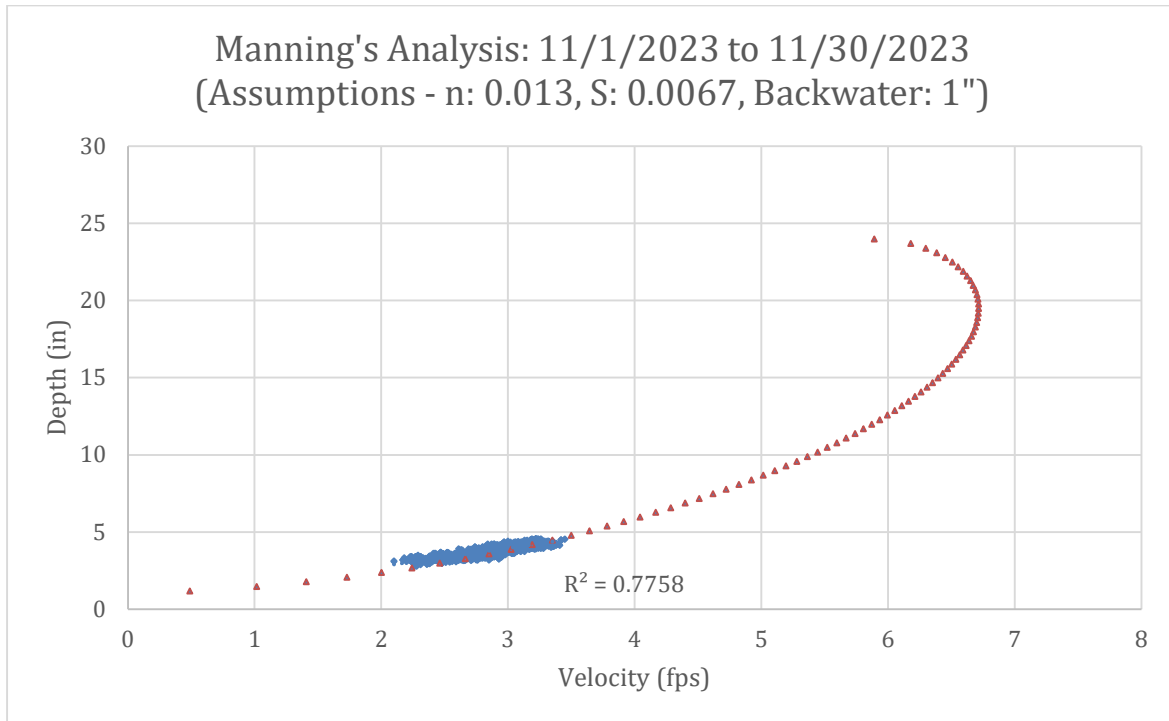
## Design, Analysis & Results

### **Manning's Summary**

Manning's analysis shows that the Flo-Dar sensor provides data that can be used for infiltration calculations. For this analysis, an Excel VBA program was created that takes the following inputs: CSV data from the sensor, Manning's roughness coefficient, pipe slope, pipe size, and backwater depth. The program then creates the figures and tables used in Figures 1 through 5 and Tables 1 through 5. The program can be used for future projects using the Flo-Dar sensor. A portion of the code used in the program is included in Appendix B of this report. The program will also be given to Provo City Public Works as part of this report.

Plotting the measured sensor data to Manning's curve ensures that the Flo-Dar data fits calculated trends typical of theoretical pipe flows. The Flo-Dar sensor took readings of velocity and depth every 15 minutes and flows were calculated within the Flo-Dar software. The average per day of these values is shown in Tables 1 through 5 along with flows in gallons per minute and millions of gallons per day. Flows are representative of typical flows—the  $R^2$  values in Figures 1 through 5 show little variance between data points. Thus, the Flo-Dar data throughout this audit is representative of the actual flow in the pipe segment.

### Manning's Analysis

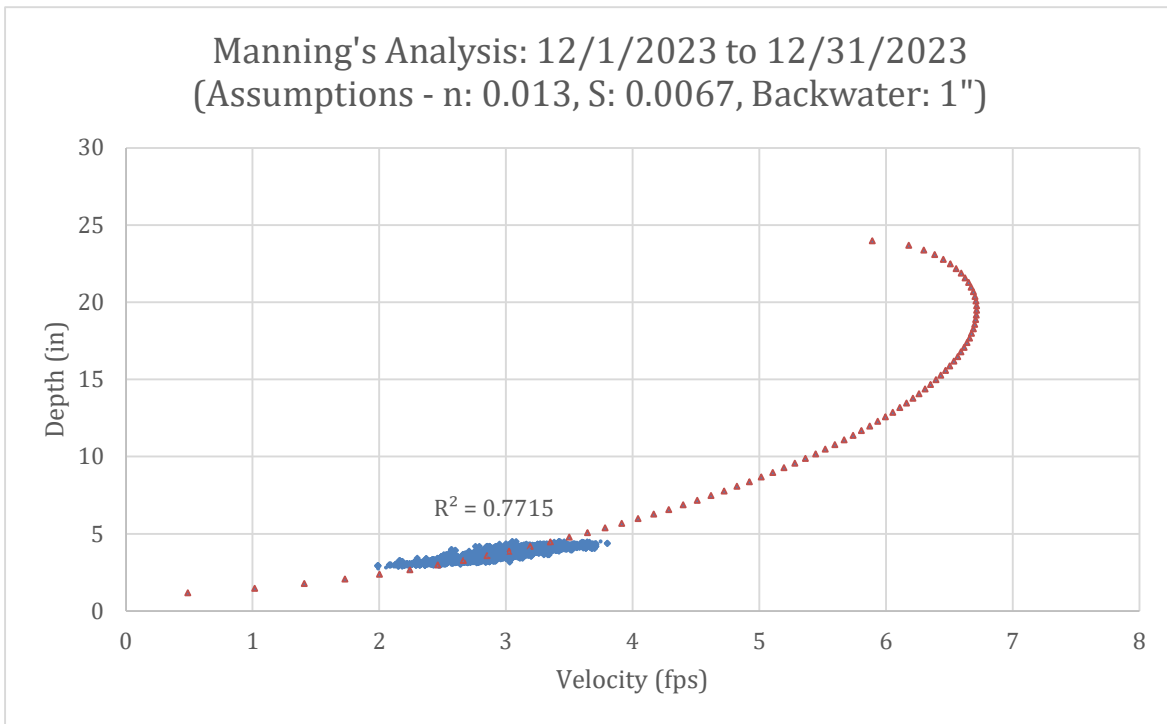


**Figure 2. November Flo-Dar data points fitted to Manning's curve**

Measured flows from the Hach Flo-Dar Sensor gave results within the recommended slope range for pipe size when compared to an expected curve from Manning's equation. One inch of backwater is assumed. Backwater is a common occurrence in sanitary systems indicative of blockages that impede gravitational flow and reduce the expected maximum capacity of the pipe. As shown in Figure 2, the November  $R^2$  value was 0.7758 showing a strong correlation between the measured data and the expected Manning's curve. The averages of these points are tabulated in Table 1. These results are consistent in each month of the sewer audit indicating that the Flo-Dar sensor was operating correctly.

*Table 1. November Average Daily Flows*

Date	Level (in)	Velocity (fps)	Flow (gpm)	Flow (mgd)
11/1/2023	4.16	3.07	491.26	0.71
11/2/2023	4.04	3.03	470.54	0.68
11/3/2023	3.97	3.02	456.88	0.66
11/4/2023	3.86	2.96	432.17	0.62
11/5/2023	3.79	2.91	413.58	0.6
11/6/2023	3.96	3.01	453.08	0.65
11/7/2023	3.93	2.99	445.12	0.64
11/8/2023	4	2.98	455.97	0.66
11/9/2023	3.94	2.92	433.73	0.62
11/10/2023	3.92	2.92	431.16	0.62
11/11/2023	3.87	2.95	428.79	0.62
11/12/2023	3.77	2.88	404.24	0.58
11/13/2023	3.8	2.88	409.09	0.59
11/14/2023	3.81	2.91	413.86	0.6
11/15/2023	3.78	2.86	404.3	0.58
11/16/2023	3.96	3.1	465.81	0.67
11/17/2023	3.91	3.13	461.33	0.66
11/18/2023	3.83	3.09	441.55	0.64
11/19/2023	3.94	3.04	455.15	0.66
11/20/2023	4.07	3.02	470.19	0.68
11/21/2023	4.03	3	461.41	0.66
11/22/2023	3.91	2.96	437.3	0.63
11/23/2023	3.6	2.68	350.37	0.5
11/24/2023	3.74	2.67	370.24	0.53
11/25/2023	3.98	2.86	435.17	0.63
11/26/2023	3.92	2.81	416.53	0.6
11/27/2023	4.1	2.95	467.74	0.67
11/28/2023	4.05	2.95	460.27	0.66
11/29/2023	3.92	2.89	430.67	0.62
11/30/2023	3.8	2.83	407.36	0.59

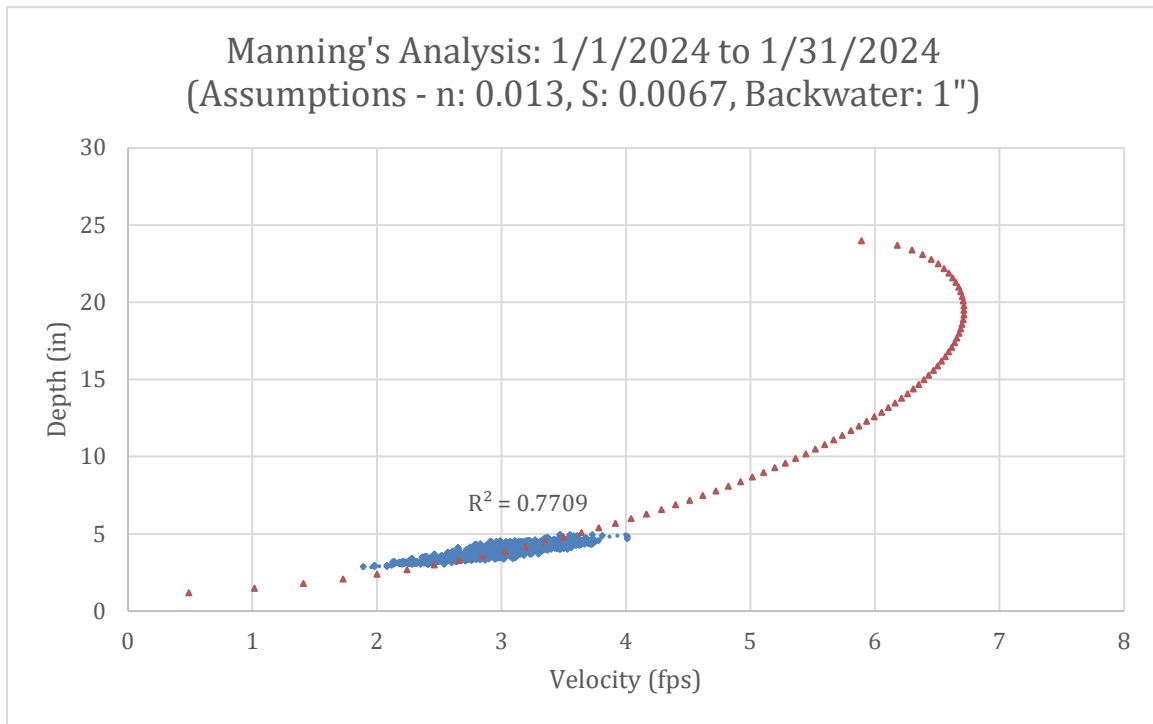


**Figure 3. December Flo-Dar data points fitted to Manning's curve**

As shown in Figure 3, the December  $R^2$  value was 0.7715 showing a strong correlation between the measured data and the expected Manning's curve. The averages of these points are tabulated in Table 2.

*Table 2. December Average Daily Flows*

Date	Level (in)	Velocity (fps)	Flow (gpm)	Flow (mgd)
12/1/2023	3.8	2.86	405.89	0.58
12/2/2023	3.79	2.99	427.03	0.61
12/3/2023	3.79	2.95	418.11	0.6
12/4/2023	4.05	3.2	496.89	0.72
12/5/2023	4.05	3.3	512.45	0.74
12/6/2023	3.97	3.25	491.22	0.71
12/7/2023	3.98	3.14	474.52	0.68
12/8/2023	3.96	3.13	471.87	0.68
12/9/2023	3.88	3.09	450.52	0.65
12/10/2023	3.82	3.13	447.67	0.64
12/11/2023	3.92	3.14	465.63	0.67
12/12/2023	3.96	3.11	465.74	0.67
12/13/2023	3.96	3.13	471.6	0.68
12/14/2023	3.88	3.17	463.51	0.67
12/15/2023	3.88	3.14	460.35	0.66
12/16/2023	3.86	3.01	438.07	0.63
12/17/2023	3.76	3.07	428.63	0.62
12/18/2023	3.84	3.07	442.06	0.64
12/19/2023	3.89	3.12	456.07	0.66
12/20/2023	3.8	3.03	430.33	0.62
12/21/2023	3.73	3.05	420.52	0.61
12/22/2023	3.67	2.96	397.76	0.57
12/23/2023	3.54	2.79	357.31	0.51
12/24/2023	3.49	2.76	344.01	0.5
12/25/2023	3.37	2.62	312.24	0.45
12/26/2023	3.62	2.77	368.28	0.53
12/27/2023	3.61	2.85	375.76	0.54
12/28/2023	3.58	2.85	371.89	0.54
12/29/2023	3.57	2.88	373.11	0.54
12/30/2023	3.55	2.86	367.84	0.53
12/31/2023	3.47	2.69	339.79	0.49

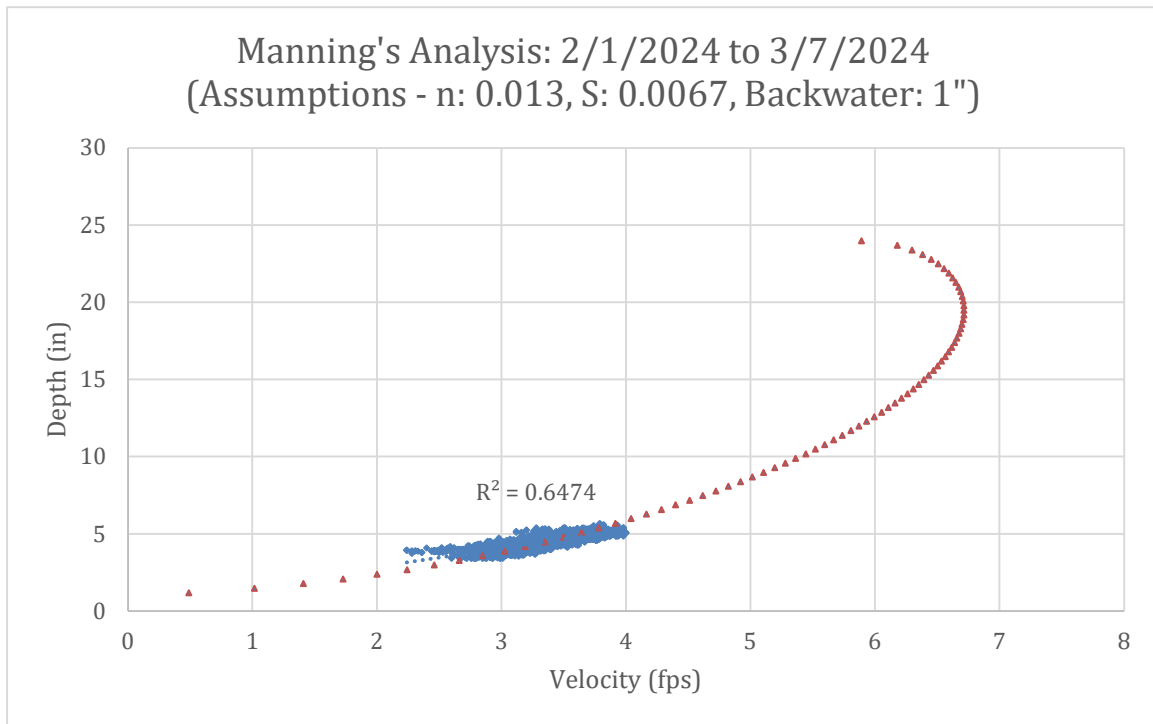


**Figure 4. January Flo-Dar data points fitted to Manning's curve**

As shown in Figure 4, the January  $R^2$  value was 0.7709 showing a strong correlation between the measured data and the expected Manning's curve. The averages of these points are tabulated in Table 3.

*Table 3. January Average Daily Flows*

Date	Level (in)	Velocity (fps)	Flow (gpm)	Flow (mgd)
1/1/2024	3.55	2.67	341.92	0.49
1/2/2024	3.7	2.76	377.87	0.54
1/3/2024	3.71	2.78	382.96	0.55
1/4/2024	3.78	2.9	408.64	0.59
1/5/2024	3.78	2.89	406.74	0.59
1/6/2024	3.78	2.86	405.41	0.58
1/7/2024	3.78	2.86	403.65	0.58
1/8/2024	3.97	2.87	434.41	0.63
1/9/2024	3.91	2.83	418.43	0.6
1/10/2024	3.85	2.84	409.65	0.59
1/11/2024	3.83	2.81	404.51	0.58
1/12/2024	3.84	2.94	425.98	0.61
1/13/2024	3.83	3.02	438.24	0.63
1/14/2024	4.03	3.12	481.48	0.69
1/15/2024	4.33	3.32	567.54	0.82
1/16/2024	4.27	3.2	537.32	0.77
1/17/2024	4.3	3.23	546.66	0.79
1/18/2024	4.33	3.22	545.67	0.79
1/19/2024	4.27	3.25	543.15	0.78
1/20/2024	4.23	3.25	536.47	0.77
1/21/2024	4.06	3.28	510.89	0.74
1/22/2024	4.23	3.32	549.24	0.79
1/23/2024	4.16	3.29	528.57	0.76
1/24/2024	4.14	3.2	511.57	0.74
1/25/2024	4.13	3.26	521.84	0.75
1/26/2024	4.17	3.3	533.64	0.77
1/27/2024	4.12	3.29	524.84	0.76
1/28/2024	3.98	3.22	487.67	0.7
1/29/2024	4.11	3.25	516.07	0.74
1/30/2024	4.07	3.13	486.73	0.7
1/31/2024	3.81	3.04	445.38	0.64

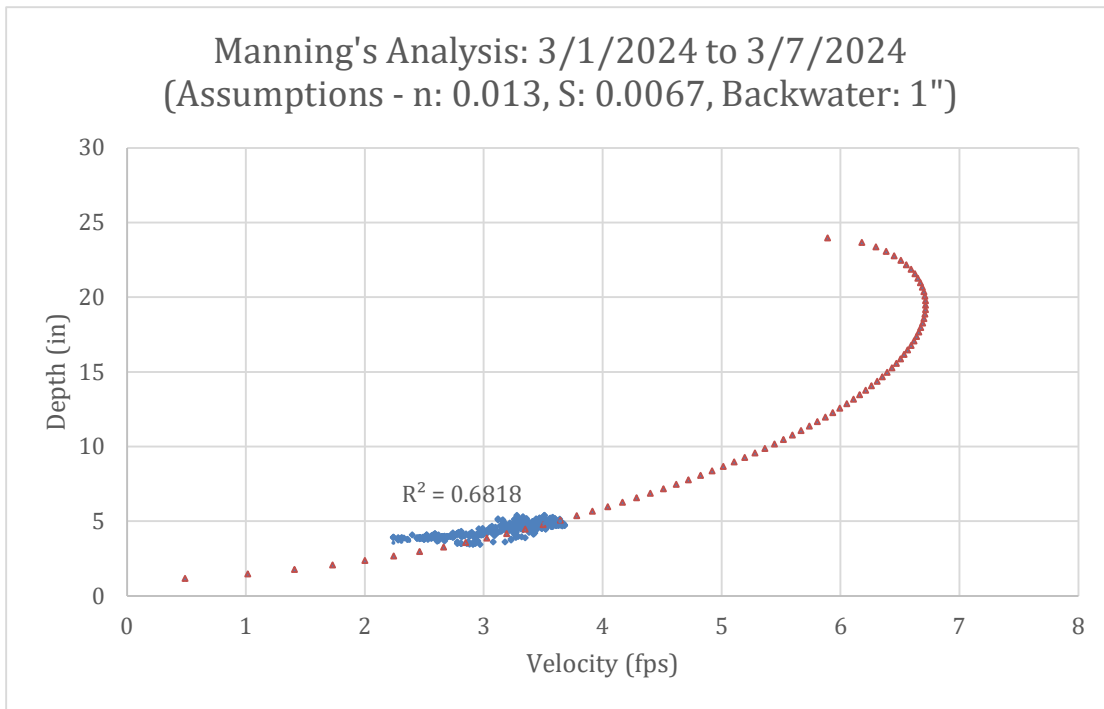


**Figure 5. February Flo-Dar data points fitted to Manning's curve**

As shown in Figure 5, the February R<sup>2</sup> value was 0.6474 showing a strong correlation between the measured data and the expected Manning's curve. The averages of these points are tabulated in Table 4.

*Table 4. February Average Daily Flows*

Date	Level (in)	Velocity (fps)	Flow (gpm)	Flow (mgd)
2/1/2024	4.06	3.23	503.68	0.73
2/2/2024	4.29	3.28	553.64	0.8
2/3/2024	4.68	3.42	652.85	0.94
2/4/2024	4.6	3.46	643.03	0.93
2/5/2024	4.7	3.47	667.04	0.96
2/6/2024	4.61	3.48	649.18	0.93
2/7/2024	4.88	3.53	720.85	1.04
2/8/2024	5.04	3.57	754.23	1.09
2/9/2024	5	3.63	758.68	1.09
2/10/2024	4.85	3.62	724.37	1.04
2/11/2024	4.64	3.52	663.5	0.96
2/12/2024	4.69	3.55	680.04	0.98
2/13/2024	4.54	3.46	631.89	0.91
2/14/2024	4.44	3.45	606.29	0.87
2/15/2024	4.46	3.45	613.34	0.88
2/16/2024	4.43	3.36	591.69	0.85
2/17/2024	4.31	3.34	566.34	0.82
2/18/2024	4.13	3.2	507.88	0.73
2/19/2024	4.3	3.26	550.93	0.79
2/20/2024	4.25	3.21	530.38	0.76
2/21/2024	4.31	3.22	543.1	0.78
2/22/2024	4.3	3.28	551.93	0.79
2/23/2024	4.28	3.29	550.2	0.79
2/24/2024	4.21	3.27	534.87	0.77
2/25/2024	4.13	3.18	507.66	0.73
2/26/2024	4.22	3.19	523.11	0.75
2/27/2024	4.23	3.18	522.32	0.75
2/28/2024	4.18	3.13	507.15	0.73
2/29/2024	4.14	3.14	500.41	0.72



**Figure 6. March Flo-Dar data points fitted to Manning's curve**

As shown in Figure 6, the March  $R^2$  value was 0.6818 showing a strong correlation between the measured data and the expected Manning's curve. The averages of these points are tabulated in Table 5.

**Table 5. March Average Daily Flows**

Date	Level (in)	Velocity (fps)	Flow (gpm)	Flow (mgd)
3/1/2024	4.36	3.29	569.64	0.82
3/2/2024	4.55	3.21	591.66	0.85
3/3/2024	4.51	3.22	586.39	0.84
3/4/2024	4.8	3.23	645.69	0.93
3/5/2024	4.68	3.19	610.42	0.88
3/6/2024	4.58	3.23	600.14	0.86
3/7/2024	4.35	2.96	524.42	0.76

### Infiltration Summary

The infiltration and inflow analysis were intended to estimate the amount of groundwater or precipitation entering the system through cracks or manhole openings. These calculations assumed that there is little to no flow in the pipe during nighttime hours and that the remaining water is infiltration. These specific calculations can be found in Appendix B. The calculations found higher levels of infiltration and inflow into the sewer system than expected. With further inspection, it was found that commercial facilities, such as the Utah Valley Hospital, significantly contributed to nighttime flows that appeared as infiltration. Taking this into consideration, infiltration percentages are most likely negligible.

### Infiltration Analysis

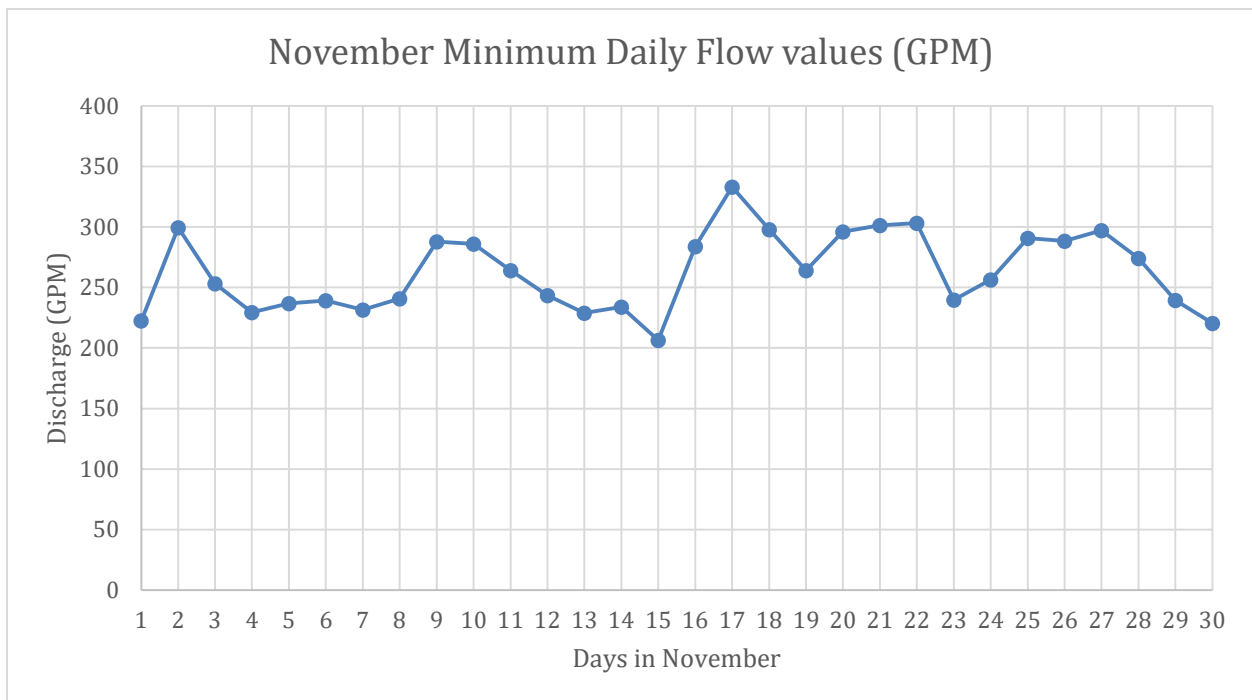
*Table 6. Infiltration Summary Table*

	1	2	3	4	5	6	7	8	9
Month	Minimum	Max	Average flow	Average Min flow	GW infiltration	Prec. Direct Inflow	Prec. Delayed Inflow	Provo River Infiltration	Irrigation Infiltration
November	206	627	435	263	47%	24%	14%	17%	-
December	191	662	424	259	45%	-	-	-	-
January	179	804	473	294	38%	15%	12%	-	-
February	314	956	596	403	53%	18%	17%	19%	-

Table 6 displays infiltration percentages and minimum, maximum, and average flows in the pipe. The calculations for the first three columns were computed using the associated min, max, and average functions in Microsoft Excel. The fourth through eighth columns have detailed calculations described in Appendix B. It is important to note that the infiltration values were unusually high. After further investigation, it was found that commercial facilities, such as the Utah Valley Hospital, significantly contributed to nighttime flows that initially appeared as infiltration values.

**Table 6 Columns 4 & 5 Calculations from November to February**

Figures 7 - 10 display November, December, and January daily minimum pipe flows. Average Minimum pipe values were calculated using an Excel pivot table. Minimum flow values typically occurred between the hours of 3 am and 6 am. The monthly minimum was then used to calculate the monthly groundwater infiltration percentage by dividing the minimum flow by the average daily flow (see Appendix B).

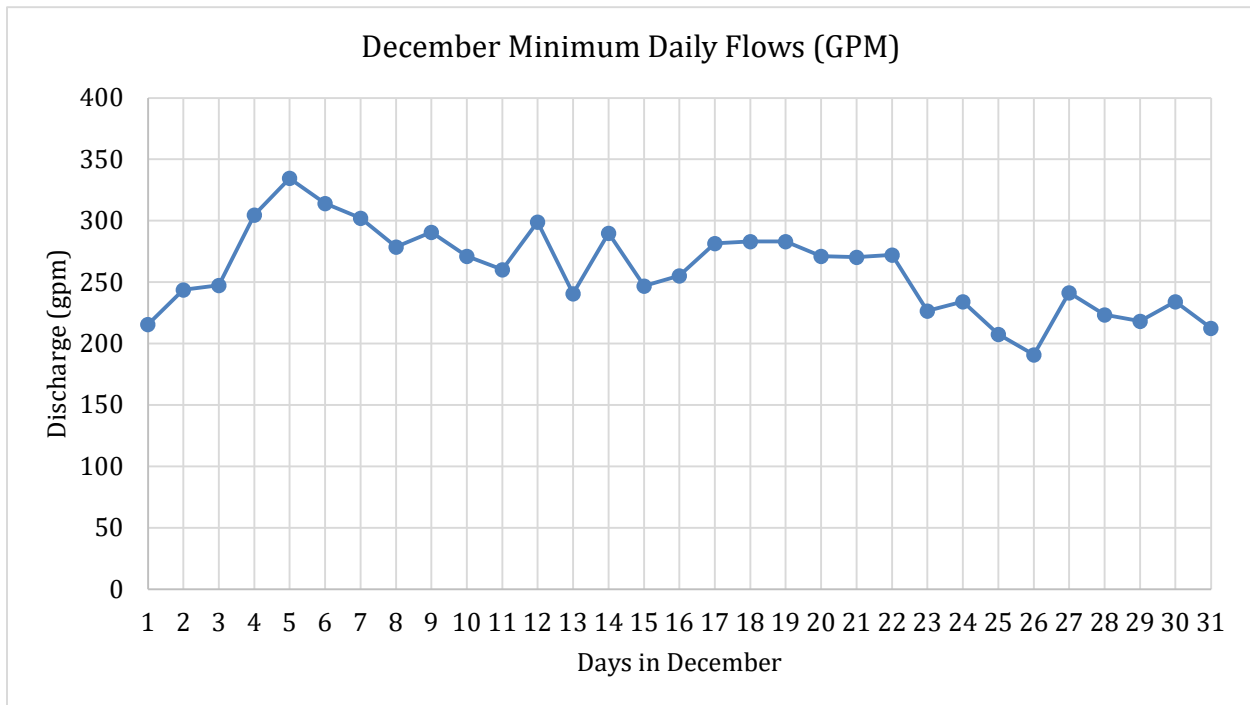


**Figure 7. November Daily Minimum Flows**

Figure 7 displays November’s daily minimum pipe flows. Flows are given in Table 7.

*Table 7. November Minimum Daily Flows*

Year, Month, Day	Min of Flow (gpm)
<b>2023</b>	<b>206.46</b>
<b>11</b>	<b>206.46</b>
<b>1</b>	222.57
<b>2</b>	299.39
<b>3</b>	253.26
<b>4</b>	229.41
<b>5</b>	236.79
<b>6</b>	239.35
<b>7</b>	231.63
<b>8</b>	240.81
<b>9</b>	287.92
<b>10</b>	285.94
<b>11</b>	264.21
<b>12</b>	243.37
<b>13</b>	228.83
<b>14</b>	233.98
<b>15</b>	206.46
<b>16</b>	283.97
<b>17</b>	333.19
<b>18</b>	297.94
<b>19</b>	264.13
<b>20</b>	296.17
<b>21</b>	301.41
<b>22</b>	303.12
<b>23</b>	239.72
<b>24</b>	256.31
<b>25</b>	290.89
<b>26</b>	288.47
<b>27</b>	297.03
<b>28</b>	274.2
<b>29</b>	239.61
<b>30</b>	220.53
<b>Monthly Minimum</b>	<b>206.46</b>

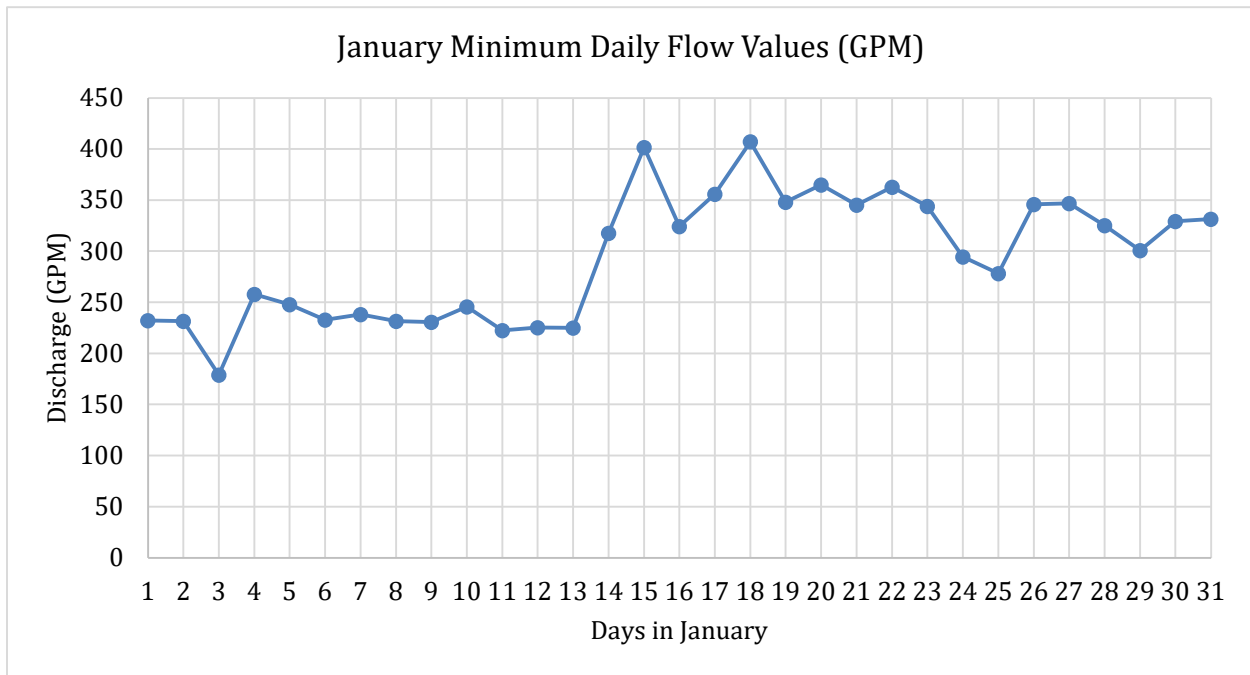


**Figure 8. December Daily Minimum Flows**

Figure 8 displays December’s daily minimum pipe flows. Flows are given in Table 8.

*Table 8. December Daily Minimum Flows*

Year, Month, Day	Min of Flow (gpm)
<b>2023</b>	<b>190.88</b>
<b>12</b>	<b>190.88</b>
<b>1</b>	215.58
<b>2</b>	243.78
<b>3</b>	247.28
<b>4</b>	304.63
<b>5</b>	334.53
<b>6</b>	314.19
<b>7</b>	302.01
<b>8</b>	278.53
<b>9</b>	290.62
<b>10</b>	271.05
<b>11</b>	260.11
<b>12</b>	299.03
<b>13</b>	240.63
<b>14</b>	289.73
<b>15</b>	246.8
<b>16</b>	255.26
<b>17</b>	281.47
<b>18</b>	283.15
<b>19</b>	283.03
<b>20</b>	270.96
<b>21</b>	270.29
<b>22</b>	272.16
<b>23</b>	226.66
<b>24</b>	234.09
<b>25</b>	207.46
<b>26</b>	190.88
<b>27</b>	241.48
<b>28</b>	223.47
<b>29</b>	218.13
<b>30</b>	234
<b>31</b>	212.49
<b>Monthly Minimum</b>	<b>190.88</b>

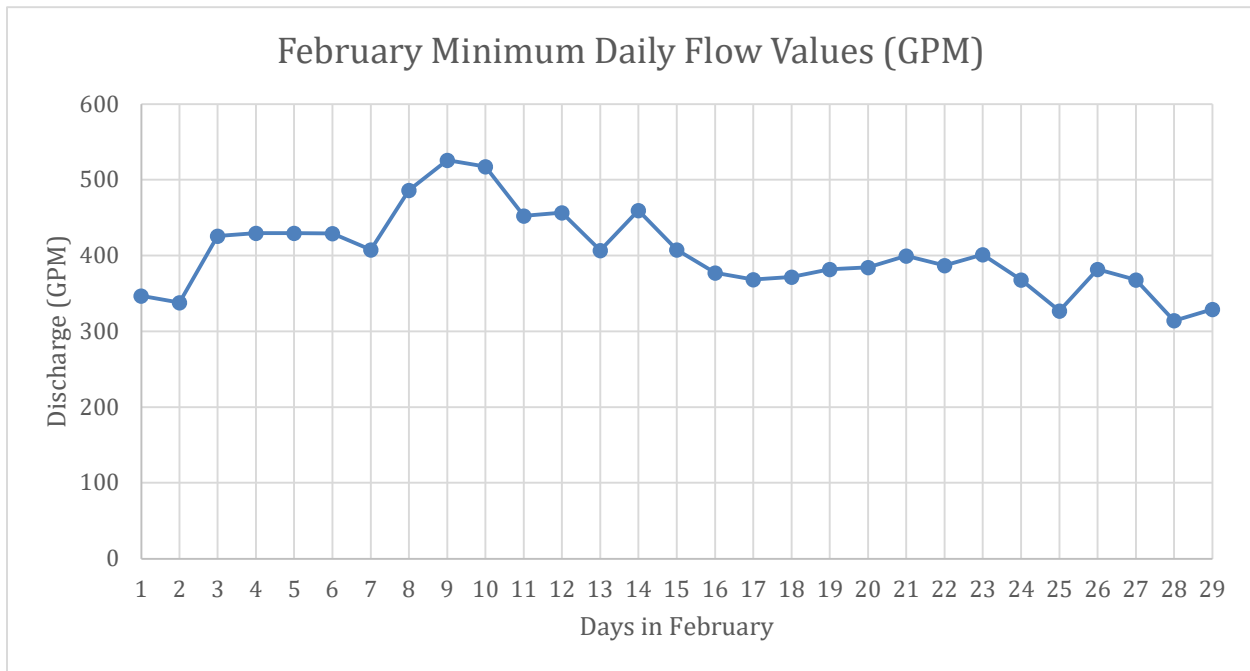


*Figure 9. January Daily Minimum Flows*

Figure 9 displays January's daily minimum pipe flows. Flows are given in Table 9.

*Table 9. January Daily Minimum Flows*

Year, Month, Day	Min of Flow (gpm)
<b>2024</b>	<b>179.01</b>
<b>1</b>	<b>179.01</b>
1	232.12
2	231.48
3	179.01
4	257.83
5	247.93
6	232.91
7	238.05
8	231.54
9	230.45
10	245.5
11	222.6
12	225.21
13	225.08
14	317.5
15	401.48
16	324.09
17	355.84
18	407.13
19	348.07
20	365.01
21	345.1
22	362.74
23	343.81
24	294.56
25	278.25
26	345.93
27	346.65
28	325.08
29	300.86
30	329.36
31	331.37
<b>Monthly Minimum</b>	<b>179.01</b>



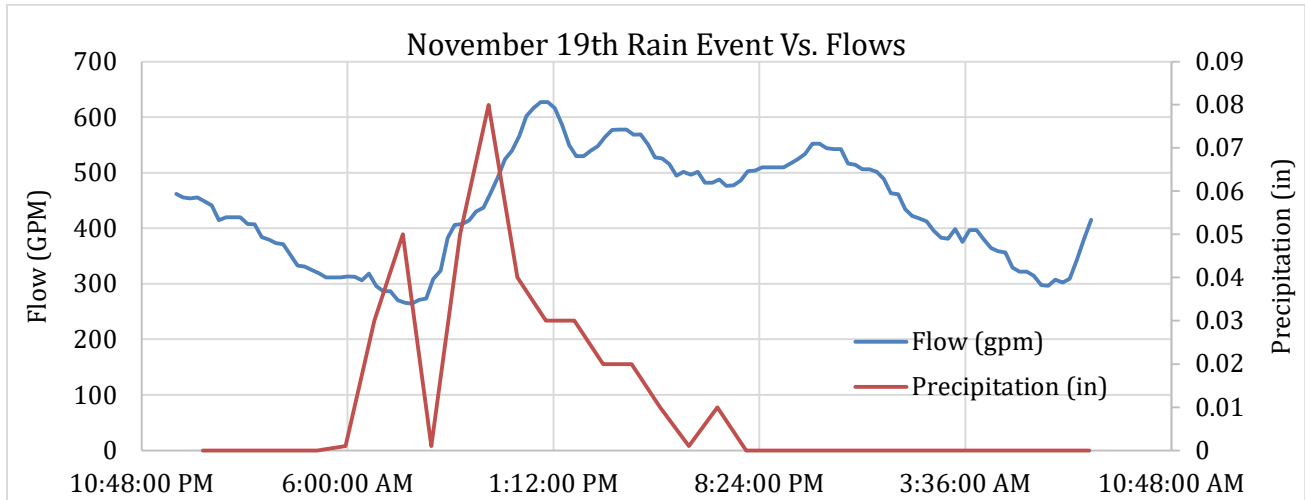
**Figure 10. February Daily Minimum Flows**

Figure 10 displays February's daily minimum pipe flows. Flows are given in Table 10.

*Table 10. February Daily Minimum Flows*

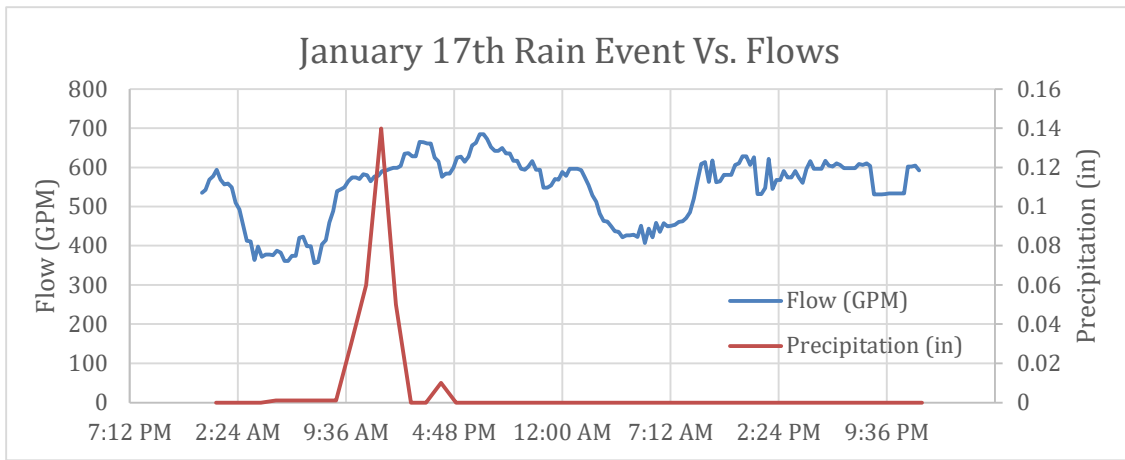
Year, Month, Day	Min of Flow (GPM)
<b>2024</b>	<b>314.19</b>
<b>2</b>	<b>314.19</b>
<b>1</b>	347.03
<b>2</b>	338.09
<b>3</b>	425.93
<b>4</b>	429.8
<b>5</b>	429.79
<b>6</b>	429.32
<b>7</b>	407.74
<b>8</b>	486.08
<b>9</b>	526.16
<b>10</b>	517.43
<b>11</b>	452.39
<b>12</b>	456.56
<b>13</b>	406.67
<b>14</b>	459.48
<b>15</b>	407.79
<b>16</b>	377.41
<b>17</b>	368.21
<b>18</b>	371.79
<b>19</b>	381.74
<b>20</b>	384.6
<b>21</b>	399.48
<b>22</b>	387.07
<b>23</b>	401.17
<b>24</b>	367.79
<b>25</b>	326.88
<b>26</b>	382.02
<b>27</b>	368.04
<b>28</b>	314.19
<b>29</b>	328.94
<b>Monthly Minimum</b>	<b>314.19</b>

**Table 6 Columns 6 & 7 Calculations**



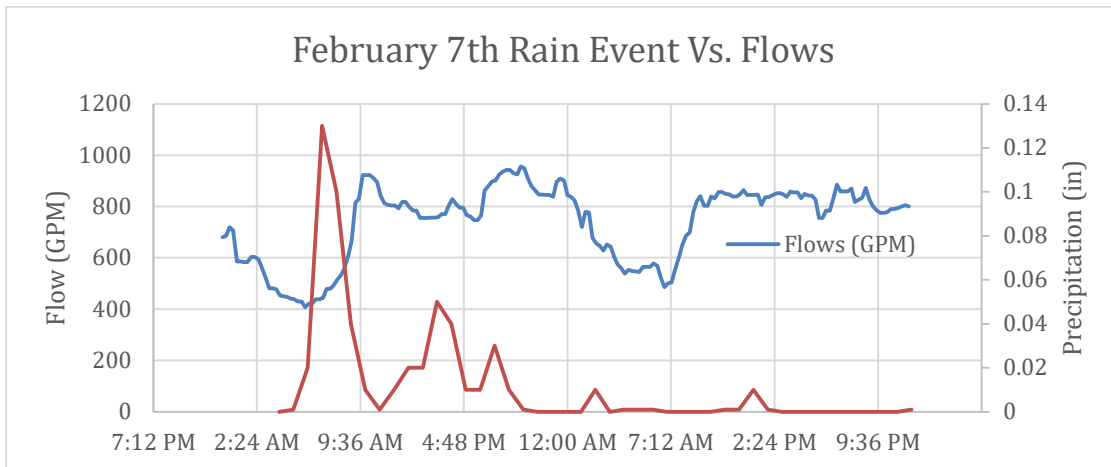
**Figure 11. Precipitation vs. Flow during November 19th Rain Event.**

Figure 11 shows data from the November 19<sup>th</sup> rain event used to calculate direct and delayed inflow into the pipe for the month. Direct inflow was calculated by subtracting the max flow within 24 hours of the rain event from the average daily flow and dividing it by the average daily flow. If flows were still elevated 24 hours after the rain event, delayed inflows were calculated by taking the highest minimum flow within 24 hours of the rain event minus the average minimum flow. Rain data was collected from the Provo Municipal Airport (see Appendix D).



**Figure 12. Precipitation vs. Flow during the January 17th rain event.**

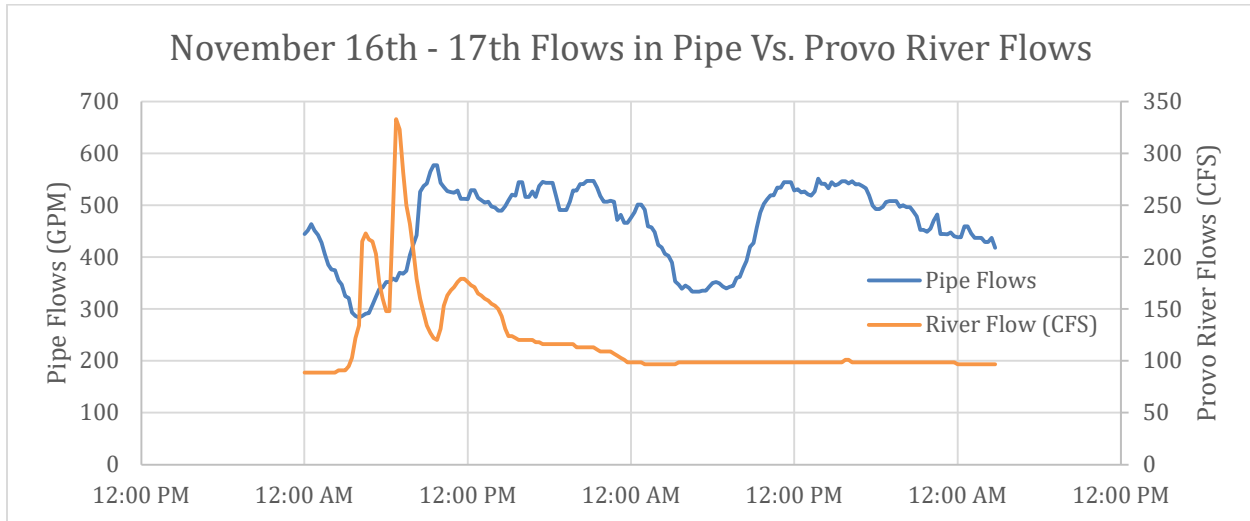
Figure 12 shows data from the January 17<sup>th</sup> rain event used to calculate direct and delayed inflow into the pipe for the month.



**Figure 13. Precipitation vs. Flow during the February 7th rain event.**

Figure 13 shows data from the February 7<sup>th</sup> rain event used to calculate direct and delayed inflow into the pipe for the month.

**Table 6 Column 8 Calculations**

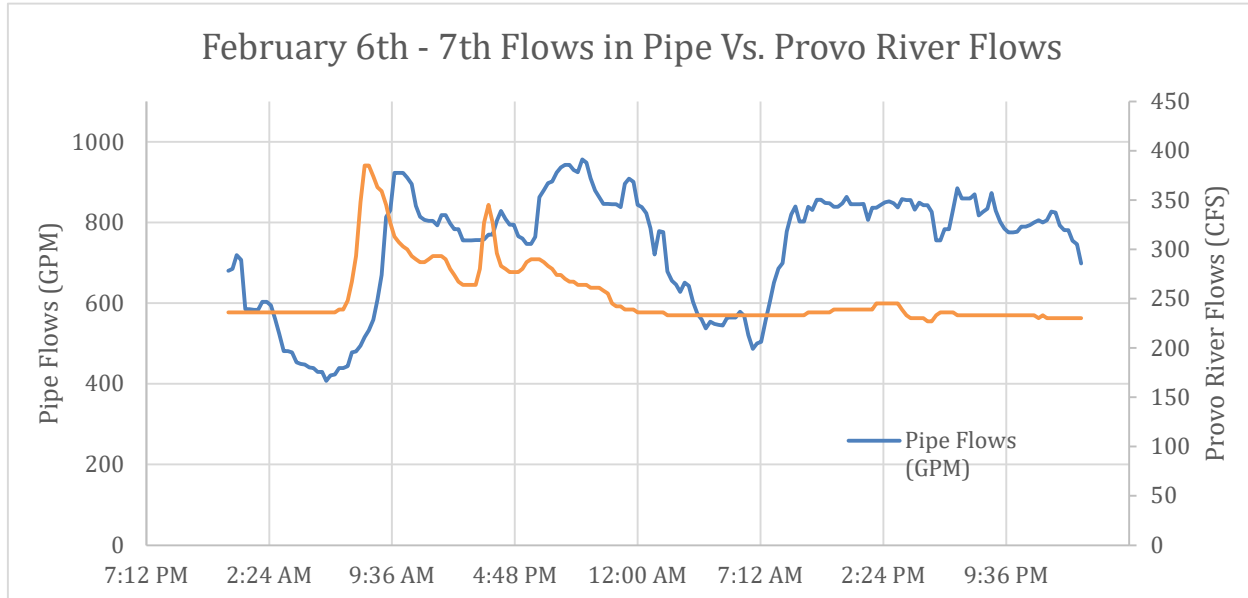


**Figure 14. Flows in Pipe Vs. Flows in Provo River November 16th – 17<sup>th</sup>**

Figure 14 shows the flows during a November significant flow period used to calculate infiltration from the Provo River. The infiltration from the river was calculated when the river had a significant increase in flow.

$$\text{Provo River Infiltration \%} = \frac{(\text{Elevated night flow} - \text{Average night flow})}{\text{Average night flow}} \times 100$$

It is important to note that there was no significant flow period in January from the Provo River. Flow data was collected from the CUAHSI website (see Appendix D) for the Provo River.



**Figure 15. Flows in Pipe Vs. Flows in Provo River February 6th – 7th**

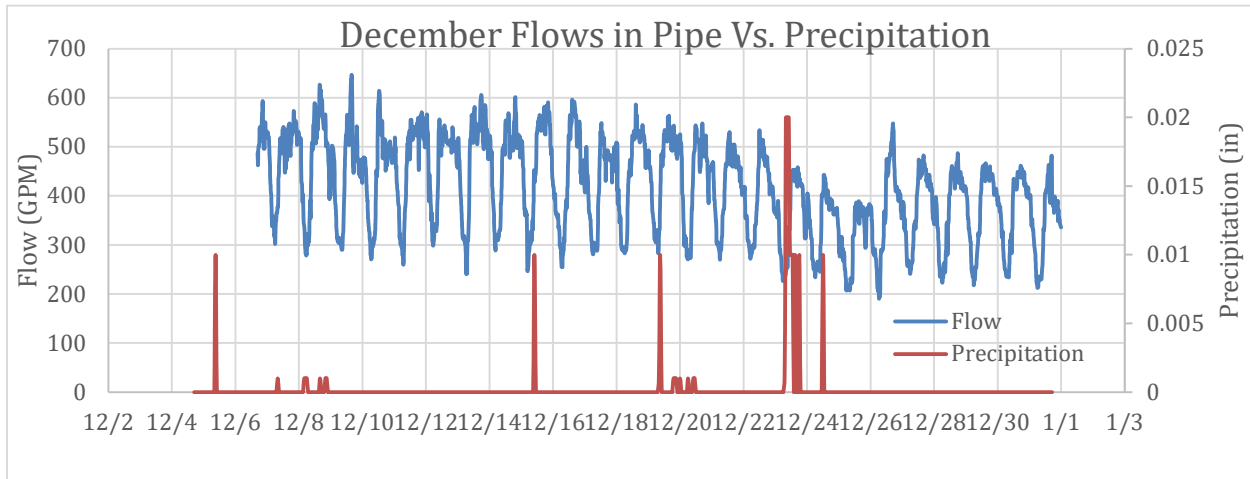
Figure 15 shows the flows during a significant flow period in February used to calculate infiltration from the Provo River.

$$\text{Provo River Infiltration \%} = \frac{(\text{Elevated night flow} - \text{Average night flow})}{\text{Average night flow}} \times 100$$

**Table 6 Column 9 Calculations**

Irrigation infiltration calculations are done by comparing the minimum flow in the pipe before and after the irrigation season. The period of the audit occurred before the irrigation season began, so these were not calculated.

**December Calculations**



*Figure 16. December Flows in Pipe Vs. Precipitation*

Calculations in December differed due to a decrease in flow after December 21<sup>st</sup>. This decrease in flow affected inflow and Provo River infiltration calculations. This was likely due to BYU winter break beginning December 22<sup>nd</sup>, during which many students leave. This may have caused a significant decrease in daytime flows.

### **GIS Analysis**

Provo City provided their GIS-based sewer utility network for analysis. Using ArcGIS Pro, the sewer basin that drains into the point of analysis was delineated. This was done using Utility Network tools, including Trace. Using Census block data downloaded from the Utah Geospatial Resource Center, it was determined that 6,633 people lived in the analysis area during the 2020 Census. Utah Administrative Code Section R317-3-2 states that sewer systems “shall be designed based on an annual average daily rate of flow of 100 gallons per capita per day (0.38 cubic meter per capita per day) unless there is data to indicate otherwise. The per capita rate of flow includes an allowance for infiltration/inflow.”

Based on this information, the minimum daily rate for which this sewer system should be designed is approximately 663,300 gallons per day or 0.66 million gallons per day. This does not consider the flow coming from other land uses in the analysis area, including commercial lots and new apartment developments. As stated above, there is already a large volume of sewage flowing through the sewer at this location. This discrepancy is likely due to the increased population and the nonresidential land use in the sewer shed.

## **Related Issues**

The audit of the sanitary sewer line and its associated tributaries addresses interrelated issues that extend beyond the sizing assessment of the wastewater treatment facility. The audit has implications for public health, safety, welfare, global concerns, social dynamics, environmental stewardship, and economic stability. It addresses not only the immediate need for efficient wastewater treatment but also contributes to sustainability within the community. This project not only mitigates health risks associated with untreated wastewater but also safeguards against safety hazards and supports economic stability by avoiding costly damages. Moreover, it aligns with global efforts to promote environmental sustainability by preventing pollution of natural water bodies and preserving ecosystems.

### 1. Public Health:

The audit of the sanitary sewer line and its correlating tributaries directly influences public health by ensuring the proper treatment and management of wastewater. Inadequate sizing or malfunctioning of the wastewater treatment plant and the sewer system can result in the discharge of untreated or partially treated wastewater, posing a risk to public health. Waterborne diseases, contamination of local water sources, and the potential spread of pathogens can be averted through examination and correction of the sewer system.

### 2. Safety:

Safety considerations are also an important aspect of the audit. An improperly sized sewer system can lead to overflows, blockages, or even structural failures that jeopardize supporting infrastructure. Additionally, the audit itself required the implementation of standard safety procedures for the successful installation of the Flo-Dar sensor and subsequent data retrieval.

3. Welfare:

The welfare of the community is directly linked to the efficiency of wastewater treatment. The audit contributes to community welfare by guaranteeing that the wastewater treatment and the associated sewer system operate optimally, minimizing disruptions, and ensuring a consistent and effective treatment process. A well-functioning sanitation system positively impacts the lives of residents, providing them with a cleaner and healthier living environment.

4. Global Factors:

While the project primarily addresses local infrastructure, its indirect contribution to global factors lies in its alignment with broader environmental sustainability goals. Proper wastewater management on a local level prevents pollution of natural water bodies, supporting global efforts to maintain clean water sources and ecosystems. The new wastewater facility for which this audit was performed was largely created to treat water contaminated with phosphorus, a major pollutant present in Utah Lake.

5. Social Factors:

The project positively influences social factors by mitigating potential negative consequences of inadequate wastewater management. A well-maintained and properly sized sewer system contributes to functional infrastructure that benefits the local community.

6. Environmental Factors:

The sewer audit safeguards the environment by preventing the discharge of untreated wastewater into local bodies of water. The protection of aquatic ecosystems, flora, and fauna contributes to overall environmental health.

7. Economic Factors:

The project is also related to financial stability within the community. By avoiding the costs associated with emergency repairs and environmental remediation due to malfunctions, the project contributes to economic sustainability. A thorough sewer audit prevents potentially extensive and costly damages.

## Lessons Learned

This project was an excellent opportunity for the team to learn how to effectively work on real-world engineering projects. Throughout the project, the team compiled weekly status reports detailing challenges and resulting solutions. The challenges encountered, team solutions implemented, and lessons learned from those challenges are listed below:

1. At the start of the project, the team was still adjusting to working with one another—an official line of communication between team members had not yet been established and regular meetings had not been set. The team needed to choose a team lead and make delegations for assignments. The main problem encountered at this stage was understanding what was to be expected from the team and what the project would entail. Because that understanding came slowly, the first few weeks of the project were slower. While the project was in its infancy, solutions to encountered challenges were simple and it was easier to reach a team consensus. An iOS group chat was created for the sake of communication, weekly meetings were set for 2:00 p.m. on Wednesdays in a standard location on campus (4:00 p.m. on Mondays during the second semester of the project), Bennett Price was chosen to be the team lead, and designated tasks came gradually as further understanding of the project was established. From the initiation of the project, we learned that it can be difficult to get started and to know what a project will entail. In practice, an engineering firm may take on a project, but there will likely need to be much more communication at the beginning for the company and client to be on the same page with plans and for those plans to commence. We also saw how starting in any new group can look.
2. In the first semester of the Capstone class, the team was meant to engage in team-building exercises that included giving constructive criticism to help one another

develop the ability to work within a group and interact professionally. It was a challenge to give relevant feedback that would be beneficial to the team. In a weekly meeting, the team held a discussion where each member shared strengths and weaknesses about each other which wound up being very formative and useful for building team rapport. In civil engineering practice, it is often necessary to give feedback or commentary on work performed which is critical for delivering quality results to clients. In the instance above and throughout the project, we learned more about how to give constructive criticism and how to encourage one another to produce the best work which is useful in real-world practice.

3. At the commencement of the project, there was a kick-off dinner. Unfortunately, our faculty mentor, Dr. Woodruff Miller, was unable to be present, but we were able to meet Lane Pierce, our sponsor from Provo Public Works. The weekly reports for this project were also submitted to our mentor, Dr. Miller, allowing us to tell him how the kick-off dinner went. The weekly status reports likewise allowed us to inform Dr. Miller of the progress we were making. From experiences such as this, we saw the importance of keeping those in managerial-type positions informed of the work performed. This allows for feedback where needed and helps the overall flow of work. By working with Lane Pierce for the past two semesters, we saw how important it is to establish a good relationship with clients. Our project was largely facilitated by our ability to communicate openly with Lane.
4. One of the major challenges throughout the project was budgeting time. Each member of the team was pushed for time—taking full-time credits both in the Fall semester of 2023 and Winter 2024. Furthermore, each member of the team worked throughout the project, and several were studying for and taking the FE exam. While time often became a constraint, it never inhibited the progress of the

project. Each team member made time to complete designated tasks or to help make up for another team member if they were unable to be present, whether for a meeting or in collecting data from the Flo-Dar sensor. The team also set deadlines for itself outside of the regular deadlines for the capstone class to stay on top of progress. Balancing our schedules helped us practice time management which will be critical in future careers. Practicing professionals are often balancing multiple projects on top of their personal lives. The ability to set aside dedicated time to complete a task is a useful skill and this project was an opportunity to practice that.

5. One small, but significant, challenge that the team faced was file sharing and being able to collaborate on files. The team used Microsoft Teams to share files and work on them simultaneously. File sharing is important within civil engineering as there are often very specific ways that companies will organize their files and collaborate, especially for interdisciplinary work. Understanding the significance of sharing and editing files correctly will be helpful in future careers.
  
6. Another challenge that the team faced during the project was in terms of data access. The team was given access to use the City of Provo's ArcGIS data but the access was not initially shared correctly. The challenge then was to coordinate with the correct individuals who could provide access to the data. The team made sure to be communicative both in requests and in asking for clarification as needed. This allowed the team to work through communication difficulties that can often inhibit progress. It is good practice in technical communication to have open dialogue to prevent miscommunications. Redlines, commentary letters, and other forms of technical communication are critical in civil engineering projects. It is therefore important to ensure transparency and full disclosure.

7. In writing code for one of the project deliverables, the team found that various aspects of the code that were written by different team members were difficult to compile due to incompatibility. The solution to this was for one team member to take all the code that had been written and make it compatible with the other lines of code. This made it possible for the code to work together seamlessly. Work done by separate individuals can lead to inconsistencies that make it challenging for that work to be put together. This underscores the necessity of good collaboration and the ability to adapt to others' work. This is especially true when doing interdisciplinary projects as other professions may have varying practices or methods in formatting and organization.
  
8. One aspect of the project that was difficult to understand was backwater within the pipe. Upon comparing measured data to the anticipated Manning's equation flow, we found that they didn't line up as expected and it was found that the backflow was not being considered for calculation. To understand backwater, the team consulted with faculty members at BYU. The team then integrated backwater considerations into the code for output analysis. Many of the problems encountered in the field of civil engineering will be different than what was learned in a classroom setting. Backwater for sanitary sewers is not something that members of the team had encountered before given that most of our exposure to fluid mechanics dealt with clean water. Sanitary sewers contain solids and other materials that can affect flows and that need to be accounted for when doing sewer audits.
  
9. In completing the sewer audit, the team was challenged with interpreting the infiltration analysis results. The team found that there seemed to be infiltration but

interpreting the output charts and analyzing the significance of apparent infiltration was initially unclear. Once again, the team met with BYU faculty members to discuss the implications of the findings from the infiltration analysis. We also met with our sponsor to discuss the matter. It was found that though there was data suggesting infiltration, it was insignificant to the pipe sizing based on existing developments in the sewer basin area. From this, we saw how important a skill sifting through information is. In practice, civil engineers must think intuitively about their findings even if results would suggest otherwise. This critical thinking is what sets professionals apart.

## Conclusions

The audit conducted by F.M. Williams and Price on the sewer pipe located in Provo provided insights into the operational functions of the sewer line. Manning's analysis justified the utility of the Flo-Dar sensor for infiltration calculations. This process was simplified by an Excel VBA program that processes sensor data. This program's ability to generate figures and tables helped in the data interpretation process and can be used in future projects utilizing the Flo-Dar sensor technology. Plotting the measured sensor data against Manning's curve has ensured alignment with theoretical pipe flow trends, with consistent  $R^2$  values indicating the reliability of the Flo-Dar data and its representativeness of actual flow conditions within the pipe segment.

The infiltration analysis aimed to estimate inflows of groundwater, precipitation, and other sources of water into the system, assuming minimal nighttime flow for infiltration calculations. Initially, higher levels of infiltration and inflow were observed, but further investigation revealed the influence of nighttime sewage flows, likely inflating infiltration percentages. Adjustments made for this factor suggest that infiltration levels are likely negligible. Even with some apparent inflow, the pipe remained well below its capacity. This emphasizes the importance of accounting for all variables for inaccuracies in system assessment.

Moreover, our GIS analysis, leveraging Provo City's sewer utility network and Census block data, highlighted a significant sewage flow. A discrepancy is attributed to factors such as population growth and nonresidential land use, emphasizing the need for infrastructure adjustments to accommodate changing demographics and land use patterns.

Throughout the project, various assumptions and limitations inherent in analysis were addressed. Adjustments made for factors like backwater, Manning's n value, and rainfall data sources enhanced the accuracy and reliability of the audit. By acknowledging these limitations and refining methodologies, it ensured accurate interpretation of the results, informing recommendations in sewer system management and future audits. The project underscores the importance of monitoring sewer flow, GIS analysis, and data processing to understand sewer system dynamics and inform sustainable infrastructure development strategies.

The findings indicate that the sewer pipe operated within the expected parameters. In the interest of maintaining optimal functionality and preventing potential issues, the team recommends that annual audits be conducted (see Recommendations).

## **Recommendations**

From the results of this sanitary sewer audit, it was found that the facility was sized appropriately with acceptable flow levels and infiltration. Based on our analysis, our recommendations to Provo City Public Works are as follows:

1. It is recommended that a yearly audit be performed in conjunction with other sewer laterals entering the treatment plant to ensure that infiltration does not become a problem with time due to age and wear.
2. It is also recommended that in the event of future major developments or redevelopments within the area of the delineated sewer basin, an audit of the sanitary sewer system should be performed to ensure system stability with additional anticipated flow contributions.

**Appendix A Resumes**

# Bennett Price

(385) 332-6046 · jabenacount@gmail.com · <https://www.linkedin.com/in/bennett-price-9898441b9/>

## EDUCATION

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### Brigham Young University

April 2025

Bachelor of Science/Arts: Civil Engineering

Provo, UT

- GPA 3.50
- Membership in BYU's Global Engineering Outreach, ASCE, and ITE
- Classes Taken or enrolled in: AutoCAD, Fluid Dynamics, Hydrology Structures, Transportation, Soils, Computer Methods (a course in VBA and Microsoft Excel)

## PROJECTS

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### BYU Capstone: Provo City Sewer Audit

November 2023 – Present

*Team Leader*

- Manually calculate flow of sewer pipe in Provo and compare Calculation to Flodar machine.
- Analyze 5 months of data, and check for infiltration by checking flow at night and after precipitation
- Organize Weekly team meetings and lead out the tasks for each week

### Global Engineering Outreach Navajo Nations Trip

March 2023

*Service Volunteer*

Navajo Nations

- Constructed a 12'x25'x10' rain catcher for a 3 families in the Navajo Nations to supply water for cattle
- Installed insulation for an Elderly woman's House to help her move into her own house for the first time
- Designed propelled boat out of trash as engineering projects for children to build at a local Elementary School

## EXPERIENCE

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### BYU Central Food Stores

August 2021-Present

*Transportation Student Lead*

Provo, UT

- Direct the transportation of food goods across BYU Campus, acting as student supervisor and lead over 5 other drivers
- Deliver food, and food supplies to 11 different locations on BYU's Campus, including the BYU Creameries, the Cougar eat, and the Missionary Training Center

### TricorBraun: Price Container & Packaging

April 2021-August 2021

*Assistant Logistics Coordinator*

Ogden, UT

- Aided in directing 2 Company Drivers travel across the Country to pick up product from 2 locations in California, and one in Texas
- Communicate with Client and Driver to schedule pickup times, usually resulting in a full semitruck of product, about 26 – 30 pallets of plastic bottles, pails, or steel drums

## VOLUNTEER EXPERIENCE

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### Church of Jesus Christ of Latter-day Saints

August 2018 - March 2020

*Volunteer Service Member*

Mexico City, Mexico

- Conducted weekly training meetings for 5-10 other volunteers
- Planned and executed 6 – 10 meetings with friends of the Church

## SKILLS /ABILITIES

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- Conversationally Proficient in Spanish, lived in Mexico for 2 years, BYU courses in Spanish
- Proficient in both Microsoft Excel and Microsoft Word

## SKILLS/INTERESTS/ACHIEVEMENTS/ABILITIES

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- Running: Casual runner, has run one half marathon and is currently training for second
- Backpacking: Avid backpacker, have done one 35 mile backpacking trip and 10 – 12 seven mile trips

# Ian Mathews

Phone: (719) 433-1968 – Email: [ian@prceng.com](mailto:ian@prceng.com) – LinkedIn: [ian-mathews-m328](https://www.linkedin.com/in/ian-mathews-m328)

185 E 300 N Provo, UT, 84606

## Education

### **Bachelor of Science in Civil Engineering**

Brigham Young University, Provo, UT, 84602

3.63 GPA

**January 2020 – December 2024**

## Skills and Experience

- Civil3D
- ArcGIS Pro
- VB for Applications
- Pix4D
- Revit
- Bluebeam
- Adobe
- HEC-RAS
- MHFD Hydrology
- Python
- Construction Documents
- Plan Review
- Grading and Erosion Control

## Job History

### **PRC Engineering**

**January 2016 – February 2024**

- Drafted and designed 100+ water-resource and transportation-based systems using CAD software for private sector, city, and federal projects
- Trained four new hires and conducted basic plan/project reviews to ensure learning and project success
- Created new pipe networks in Civil3D that saved 200+ hours in project redesign
- Maintained IT infrastructure by setting up printers, networks, workstations, and servers for the company and new hires
- Proficient in remote work, collaborating with teams over Zoom, sharing projects, and delivering presentations

### **BYU Carpentry Shop**

**June 2023 - September 2023**

- Demolished, framed, and renovated existing buildings on BYU Campus
- Read construction documents to ensure proper building procedures

## Volunteer

### **Mountain Communities Fire Department Missionary Service**

**September 2011 – August 2013  
October 2017 – October 2019**

- Led proselyting areas of upwards of 30 missionaries in Ghana Kumasi West Africa, for The Church of Jesus Christ of Latter-day Saints

# Bryan M. Williams

Blodgett, TX | [williams.bryan.mark@gmail.com](mailto:williams.bryan.mark@gmail.com) | (903) 931-2574 | [LinkedIn](#)

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## EDUCATION

### Brigham Young University

GPA: 3.68 – BS Civil Engineering

- Relevant Coursework:

Drafting w/ CAD apps, Computer Methods, Sustainable Infrastructure, Geomatics, Structural Analysis, Fluid Mechanics, Soil Mechanics, Intro to Transportation Engineering, Hydrology, Geometric Design of Highways

- Scholarships:

Henrietta P. Clyde Scholarship 2023 (College of Engineering),

H. Burke Peterson Scholarship 2023 (College of Engineering – Civil & Environmental Engineering)

- Clubs:

American Society of Civil Engineers (A.S.C.E.)

BYU student chapter

December 2024

Provo, Utah

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## SKILLS

**Proficient:** Civil 3D, Bluebeam, Microsoft Office, Soils lab equipment

**Moderate:** Autodesk Revit, ARC GIS Pro, Conversational Russian, Python

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## WORK EXPERIENCE

### BYU Department of Civil and Construction Engineering

Teacher's Assistant (Intro to Transportation Engineering) – part time

January 2024 – Present

Provo, Utah

### PRC Engineering

Computer Aided Design (CAD) Technician – Internship

September 2022 – February 2024

Remote

- Design the implementation of proposed grading and erosion control measures for private redevelopments based on existing conditions.

- Design the placement of new utilities for proposed buildings.

- Assist in the design of storm sewer plans.

- Write up detailed legal documents detailing projects (Stormwater Management Plans).

### BYU Auxiliary HVAC Maintenance

HVAC Technician – part time

August 2022 – September 2022

Provo, Utah

- Maintained heating, ventilation, and air conditioning systems in on-campus housing.

### Utah Department of Transportation (U.D.O.T)

Quality Control Materials Technician – Internship

April 2022 – August 2022

Spanish Fork, Utah

- Collected asphalt samples from client companies to run soils tests in the lab and verify that the asphalt met design standards such as void ratios and composition

- Collected aggregate samples from suppliers and ran soils tests.

- Delivered concrete cores to central lab for crush tests.

### Weld North Education / Imagine Learning

Tier I Product and Customer Support Agent – part time

July 2021 – November 2021

Remote

### BYU Store

Warehouse Clerk – Receiving Team – part time

May 2021 – April 2022

Provo, Utah

# DYLAN FITT

(442) 218-6686 ◊ dnelsonfitt@gmail.com ◊ linkedin.com/in/dylan-fitt

## EDUCATION

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### **Brigham Young University**

Bachelor of Science, Civil Engineering

Overall GPA: 3.38

Relevant coursework: Urban Transportation Planning, Geometric Design of Highways

*Provo, UT*

December 2024

## SKILLS/INTERESTS

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- Programs: ArcGIS Pro, Microsoft Access and Excel
- Programming: Python, L<sup>A</sup>T<sub>E</sub>X
- Proficient in Spanish
- Active Contributor Member of the OpenStreetMap Foundation

## RELEVANT EXPERIENCE

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### **American Fork City**

*Engineering Intern*

*Provo, UT*

January 2024–Present

- Generated exhibits and CAD designs of collector and arterial roads to be presented to city council and used as part of funding applications
- Contacted residents of the city to inform them of upcoming projects and to coordinate land purchases

### **Brigham Young University Department of Civil Engineering**

*Research Assistant*

*Provo, UT*

April 2023–August 2023

- Collected real-world data from vehicle emissions in Utah from over 10,000 vehicles using roadside equipment
- Troubleshooted problems with emissions detection equipment, including generators and programs running in DOS
- Created a new process to import data into Microsoft Access to accelerate data processing

### **Los Angeles Department of Water and Power**

*Summer Maintenance Crew Member*

*Independence, CA*

June 2018–August 2018

- Maintained waterways, work yards, and other department property in a team of five students
- Worked in teams of 4–10 people to complete daily tasks safely and effectively

## ADDITIONAL EXPERIENCE

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### **Provo Missionary Training Center**

*Media Technician*

*Provo, UT*

August 2021–Present

- Trained less-experienced media technicians about the expectations and procedures of the media department
- Led and directed devotional productions with teams ranging from three to ten people for audiences with hundreds of attendees
- Developed written instructions to describe technical processes involving audio, video, and broadcasting

### **The Church of Jesus Christ of Latter-day Saints**

*Full-time Volunteer*

*Puebla, Mexico and Dallas, TX*

June 2019–June 2021

- Led and motivated groups of 6–8 volunteers by conducting weekly training meetings to increase unity and effectiveness

## Appendix B Calculations & Code

Sample Mannings code. Used in module 5 of the Excel program deliverable.

Sub CalculateManningsEquation()

```
' Declare variables for output (not included due to length)
' Get values from cells B4, C4, and D4
n = Range("B4").Value
d = Range("C4").Value / 12
S = Range("D4").Value
E = Range("E4").Value / 12
' Output header titles in row 6
Range("H30").Value = "Velocity (fps)"
Range("I30").Value = "Flow (cfs)"
Range("J30").Value = "Depth (in)"
' Calculate Manning's equation for a depth of blackwater inches
h = d - E ' Depth of backwater inches converted to feet
r = d / 2
y = d - h
If y <> 0 Then
    theta = (2 * WorksheetFunction.Acos((r - y) / r))
    sinTheta = Sin(theta)
    A = (1 / 8) * (theta - sinTheta) * (d ^ 2)
    P = 0.5 * d * theta
    rh = 0.25 * (1 - (sinTheta / theta)) * d
    T = Sin(0.5 * theta) * d
    dh = (1 / 8) * ((theta - sinTheta) / Sin(0.5 * theta)) * d
' Calculate flow using Manning's equation
Q1 = (1.49 / n) * (A) * (rh ^ (2 / 3)) * (S ^ 0.5)
' Calculate velocity (V) using Q = AV
velocity = Q1 / A
```

```
End If
' Loop through increments of 0.1 from 0 to full depth
For h = 0 To d - E + 0.0001 Step 0.025
    ' Calculate intermediate values
    r = d / 2
    y = d - h
    If y = 0 Then
        Exit For
    End If
    theta = (2 * WorksheetFunction.Acos((r - y) / r))
    sinTheta = Sin(theta)
    A = (1 / 8) * (theta - sinTheta) * (d ^ 2)
    P = 0.5 * d * theta
    rh = 0.25 * (1 - (sinTheta / theta)) * d
    T = Sin(0.5 * theta) * d
    dh = (1 / 8) * ((theta - sinTheta) / Sin(0.5 * theta)) * d
    ' Calculate flow using Manning's equation
    Q = (1.49 / n) * (A) * (rh ^ (2 / 3)) * (S ^ 0.5) - Q1
    ' Calculate velocity (V) using Q = AV
    velocity = Q / A

    ' Output results in columns underneath B4, C4, D4, and E4
    valueInF1 = Q
    Range("H30").Offset((h / 0.025) + 1, 0).Value = velocity
    Range("I30").Offset((h / 0.025) + 1, 0).Value = Q
    Range("J30").Offset((h / 0.025) + 1, 0).Value = (d - h) * 12
Next h
End Sub
```

**Ground Water (GW) Infiltration Calculations:**

GW Infiltration % = (Minimum flow / Average flow) \* 100

November GW = (206/435) \* 100 = 47.356 about 47%

December GW = (191 / 424) \* 100 = 44.99 %

January GW = (179 / 473) \* 100 = 37.88%

February GW = (314 / 596) \* 100 = 52.73%

**Direct Inflow Calculations:**

Direct Inflow % = (Max flow – Average flow) / Average flow \* 100

\*\* Max flow within 24 hours of rain event and Average flow during recent dry days

November (11/19/23 rain event) Direct Inflow = (627 – 506)/506 \* 100 = 24.16%

January (01/17/24 rain event) Direct Inflow = (685 – 598)/598 \* 100 = 14.55%

February (02/07/24 rain event) Direct Inflow = (956 – 812)/812 \* 100 = 17.7%

**Delayed Inflow Calculations:**

Delayed Inflow % = (Increased night flow – Average night flow) / Average night flow \* 100

\*\* Increased nighttime flow within 24 hours of the rain event, may substitute average nighttime flow with average nighttime dry flows near the rain event

November (11/19/23 rain event) Delayed Inflow = (352 – 289) / 206 \* 100 = 14.48%

January (01/17/24 rain event) Delayed Inflow = (426 – 382) / 382 \* 100 = 11.52%

February (02/07/24 rain event) Delayed Inflow = (580 – 495) / 495 \* 100 = 17.17%

Provo River Infiltration % = (Increased night flow – Average night flow) / Average night flow \* 100

\*\* Increased nighttime flow within 24 hours of the rain event, may substitute average nighttime flow with average nighttime dry flows near the rain event

November (11/17/23 significant flow period) Provo River Infiltration =  $(333 - 284) / 284$

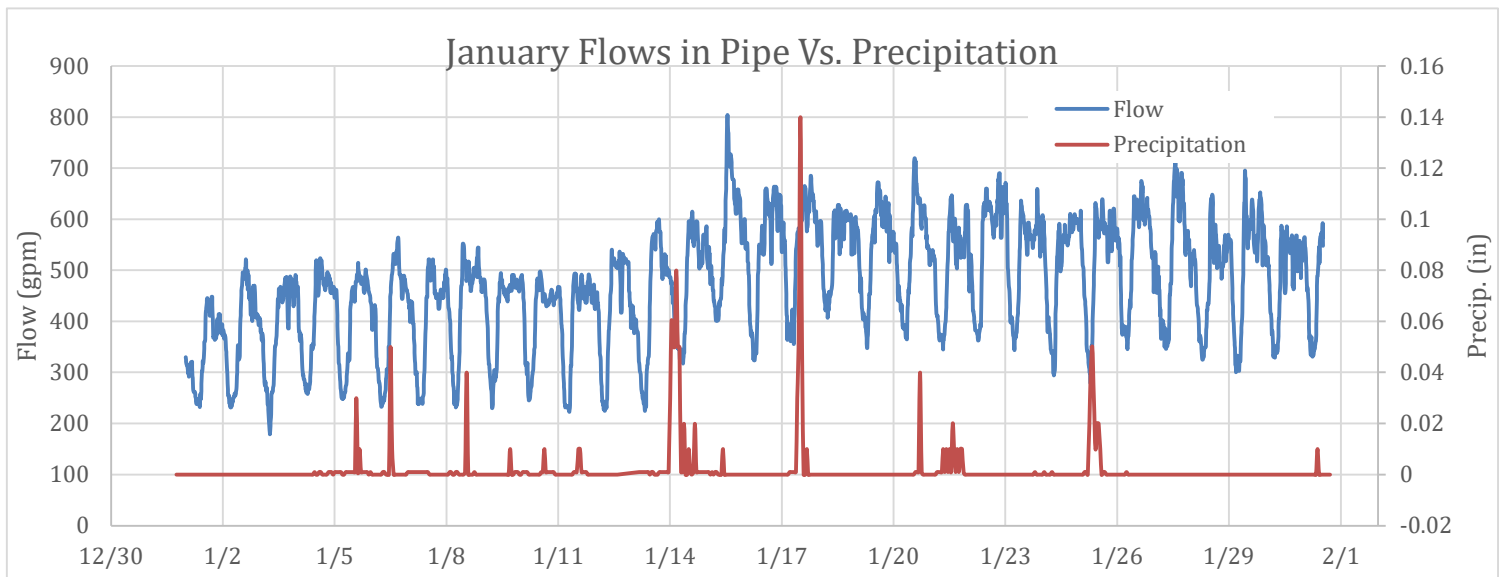
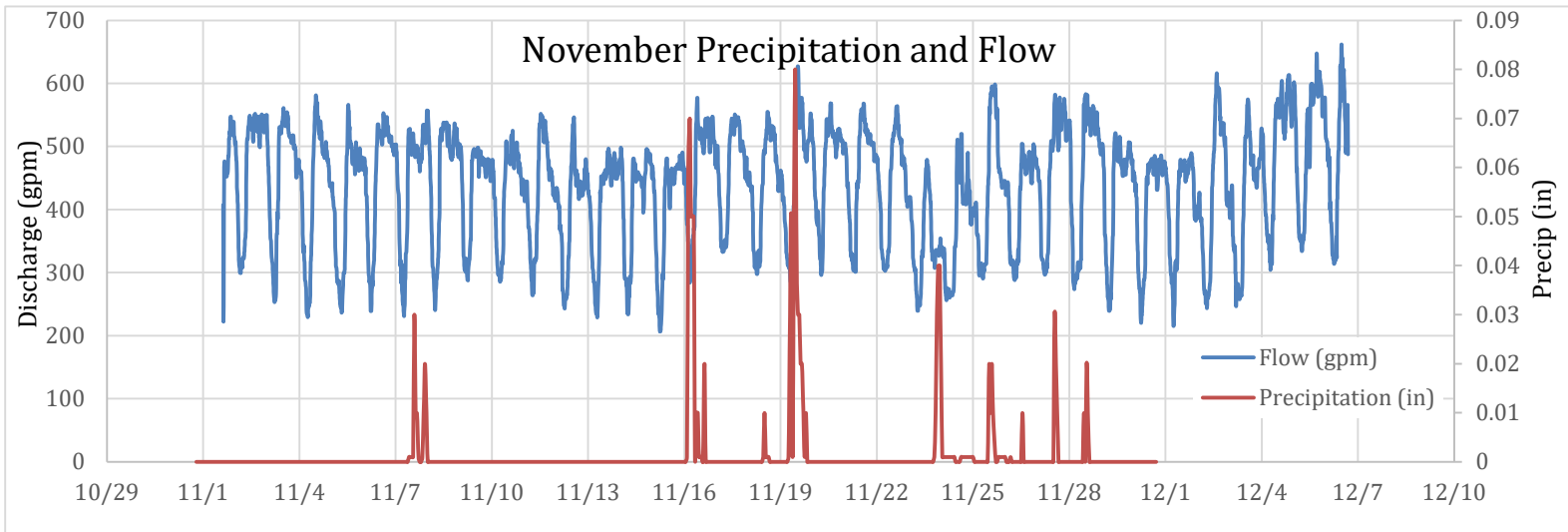
\* 100 = 17.25%

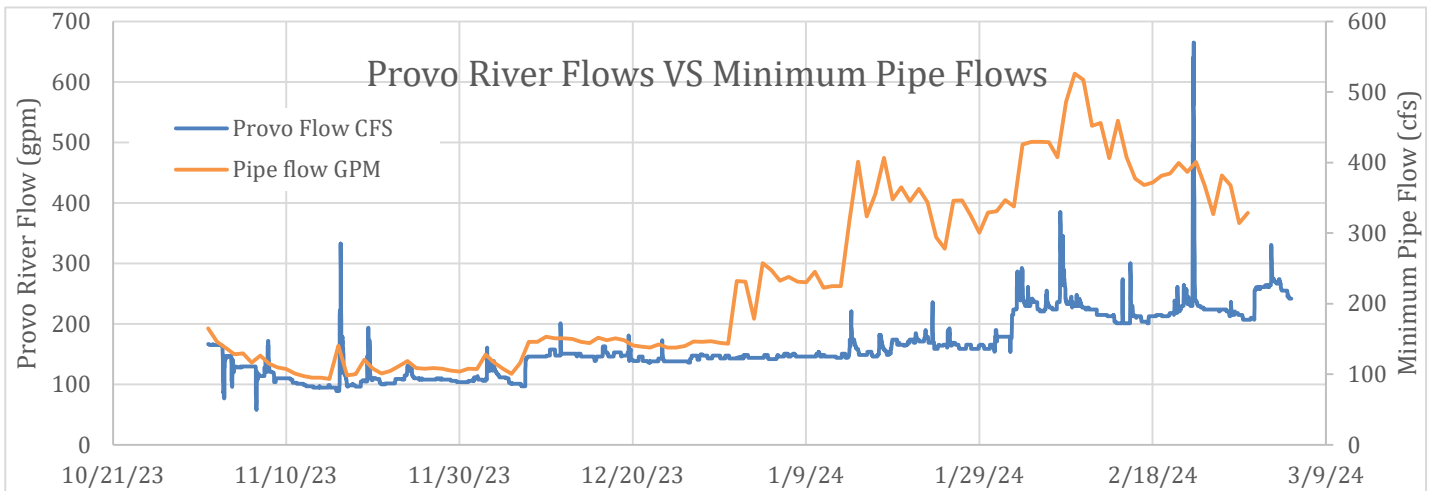
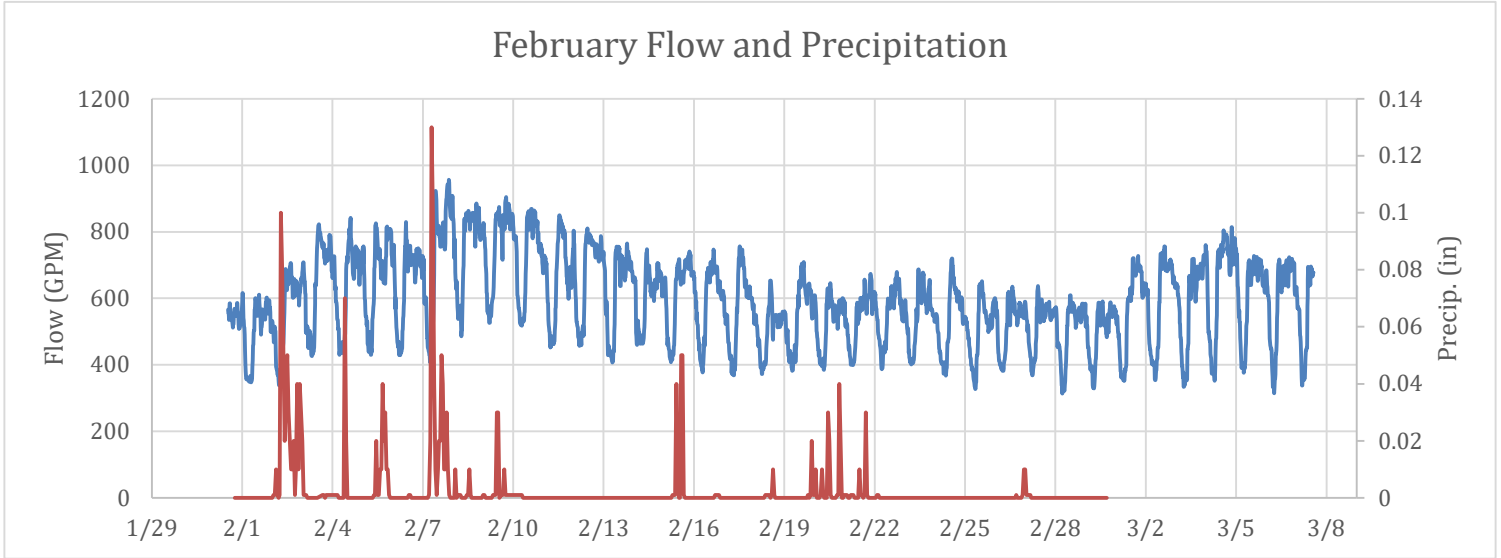
February (02/08/24 significant flow period) Provo River Infiltration =  $(486 - 407) / 407$  \*

100 = 19.41%

## Appendix C Supplementary Infiltration Data

Infiltration graphs used to determine peak rain events and peak flow events in Provo River





## **Appendix D References**

1. <https://www.weather.gov/wrh/timeseries?site=KPVU>  
(Precipitation data from the National Weather Service, an agency within NOAA)
2. Contract Documents for the construction of the Provo City Exchange Park Sewer Upgrade Project. BID NO. PROVOEN202115489 Prepared for Provo City, prepared by Bowen Collins & Associates, dated 05/25/2021.
3. <https://data.cuahsi.org/>  
(Provo River Flow data from CUAHSI downloaded from the PROVO RIVER AT PROVO, UT site.)
4. <https://www3.epa.gov/region1/sso/pdfs/Guide4EstimatingInfiltrationInflow.pdf>  
(Environmental Protection Agency Guide to Estimating Infiltration and Inflow)