2019 Aldergrove Sanitary Sewer Infiltration and Inflow Reduction Project

ENGR 481, Spring 2019

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Acronym Definitions

Acronym	Definition
I&I	Infiltration and Inflow
USD	U.S. Dollars
CIPP	Cured-in-Place Pipe
CoA	City of Arcata
MGD	Million Gallons per Day
O/M	Operations and Maintenance
LS	Lumped Sum
LF	Linear Foot
EA	Each
CY	Cubic Yard
ROW	Right-of-Way
GPM	Gallons per Minute
CCTV	Closed-Circuit Television

1. Introduction

This report presents the findings of the joint effort between a curricular course project for the Wastewater Treatment and Design class (ENGR 440) for Humboldt State University's Environmental Resources Engineering program, and the 2019 Aldergrove Inflow and Infiltration Reduction Project for the City of Arcata Engineering Department. This project and the finding's reported within' encompass the three primary objectives of this project: (1) analyze historical sanitary sewer flowrate and local water service data to quantify the magnitude of the infiltration and inflow (I&I) issue for the sanitary sewer in the West End Industrial Zone (Aldergrove sanitary sewer), (2) identify and document probable sources of I&I into the Aldergrove sanitary sewer, and (3) develop project alternatives that would reduce or eliminate I&I into the Aldergrove sanitary sewer, or projects that would reduce negative impacts of I&I. The introductory section below presents background information to understand the nature of the I&I problem that this report addresses, as well as a detailed outline of the scope and purpose of this project.

Background

This section includes discussion of the background of the problem, the project location, an overview of I&I, a description of the consequences and negative effects caused by excessive I&I into the sanitary sewer, and a brief discussion of I&I in Arcata.

Problem Background

The City of Arcata (CoA or City) developed the Aldergrove Industrial Park within the West End Industrial Zone in the 1980s, and at that time, a sanitary sewer system was installed in the area to convey wastewater to the Arcata Wastewater Treatment Facility (which is located to the south along the north shore of Humboldt Bay) (CoA 2017). Due to the hydrology of the local area, the CoA Engineering Department thinks that sanitary sewer in the Aldergrove area is frequently submerged in groundwater, which leads to extraneous water seeping into the system through cracks and other defects; additionally, there is frequent ponding of water on private property, and it is expected that this ponding water is often conveyed via direct unauthorized connections into the sanitary sewer. The City of incurs numerous problems, burdens, and additional costs due to this extraneous groundwater and stormwater runoff entering the sanitary sewer (such as increased pumping costs at sewer system lift stations) (Netra Khatri—CoA Assistant City Engineer, Personal Remarks, 2019). This project seeks to address this issue by characterizing the problem and developing potential solutions that the City could implement to reduce I&I into the sanitary sewer in the Aldergrove area.

Project Location

The Aldergrove Industrial Park is located in the City of Arcata, which is located on the north coast of California (roughly 250 miles north of San Francisco). Arcata lies on the northern shore of Humboldt Bay, and is bracketed by a rugged terrain (steep hill) to the east, farmland to the west, and the Mad River to the North (as shown in Figure 1 below). The cities residential, commercial, and industrial zones are primarily centered arround US Highway 101, which runs through the town and which is approximately 3.7 miles east of the Pacific Ocean. The Aldergrove Industrial Park is located within the West End Industrial Zone (also called West End Road Industrial Area), which is in the north-eastern corner of Arcata, and which is bracketed by a steep hillside to the east and partially to the south, US Highway 101 to the west and partially to the south, and US Highway 299 to the West and North (City of Arcata 2019a) (Google Maps 2019).

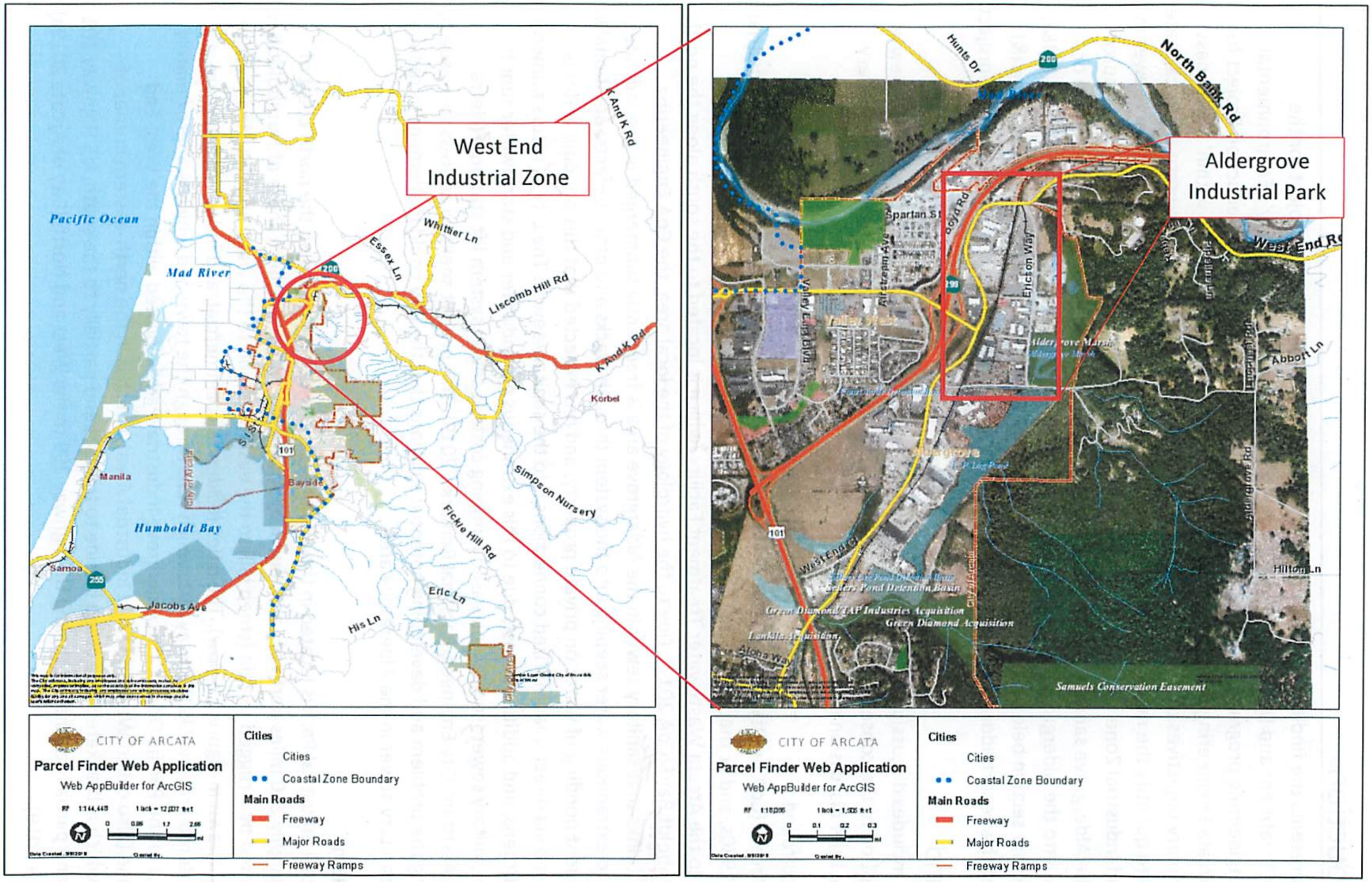


Figure 1. Overview of the City of Arcata and the surrounding area (left), and a zoomed in aerial overview of the west end industrial zone (right), which is the location of this project. Maps obtained from the City of Arcata Parcel Finder **(City of Arcata 2019a)**.

Infiltration and Inflow Overview

Infiltration and Inflow (I&I) is extraneous groundwater and stormwater runoff that enters a sewer system. Infiltration is water that seeps into the sewer from the surrounding soil matrix through cracks, joint offsets, and other defects in sewer pipes and manhole shafts; inflow is stormwater runoff that enters from direct, unauthorized connections to the sewer system. When the sewer system is a sanitary sewer, they incursion of this extraneous water is unwanted, burdensome, and costly for the City, because sanitary sewers are designed solely to convey wastewater requiring treatment (Davis 2011). Infiltration and inflow is also called "clear water" to differentiate it from dirty sanitary wastewater (even though the water may sometimes be dirty/turbid) (Xylem Inc. 2011). Understanding the differences between infiltration and inflow is important because methods to reduce/eliminate I&I are dependent upon which constituent is desired to be reduced. Listen below are example sources of I&I.

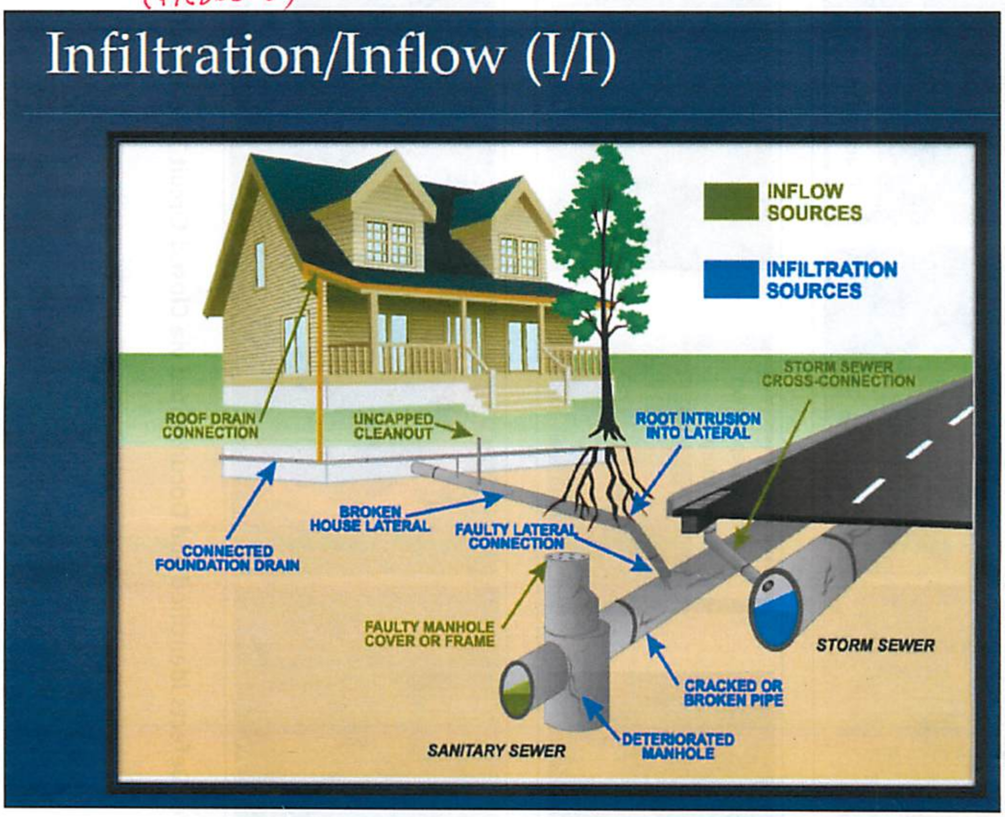


Figure 2. Sources of Infiltration and Inflow **(King County 2019)**.

Groundwater Infiltration is water that enters a sewer system from defects in manhole shafts, improper lateral connections (often where water "seeps" into the main sewer pipe about the pipes unsealed connection), cracks and joint offset in pipes, crushed pipes, side effects of improper maintenance and cleaning, and through holes/cracks caused by root intrusion (examples of said defects is shown in Figure 3). Of particular concern are sewer pipes near or beneath bodies of water or streams, or in areas where there is a high water table that submerges the pipes, because there is ample source of water to infiltrate into the sewer, (METCALF & EDDY 1991) (Xylem Inc. 2011).

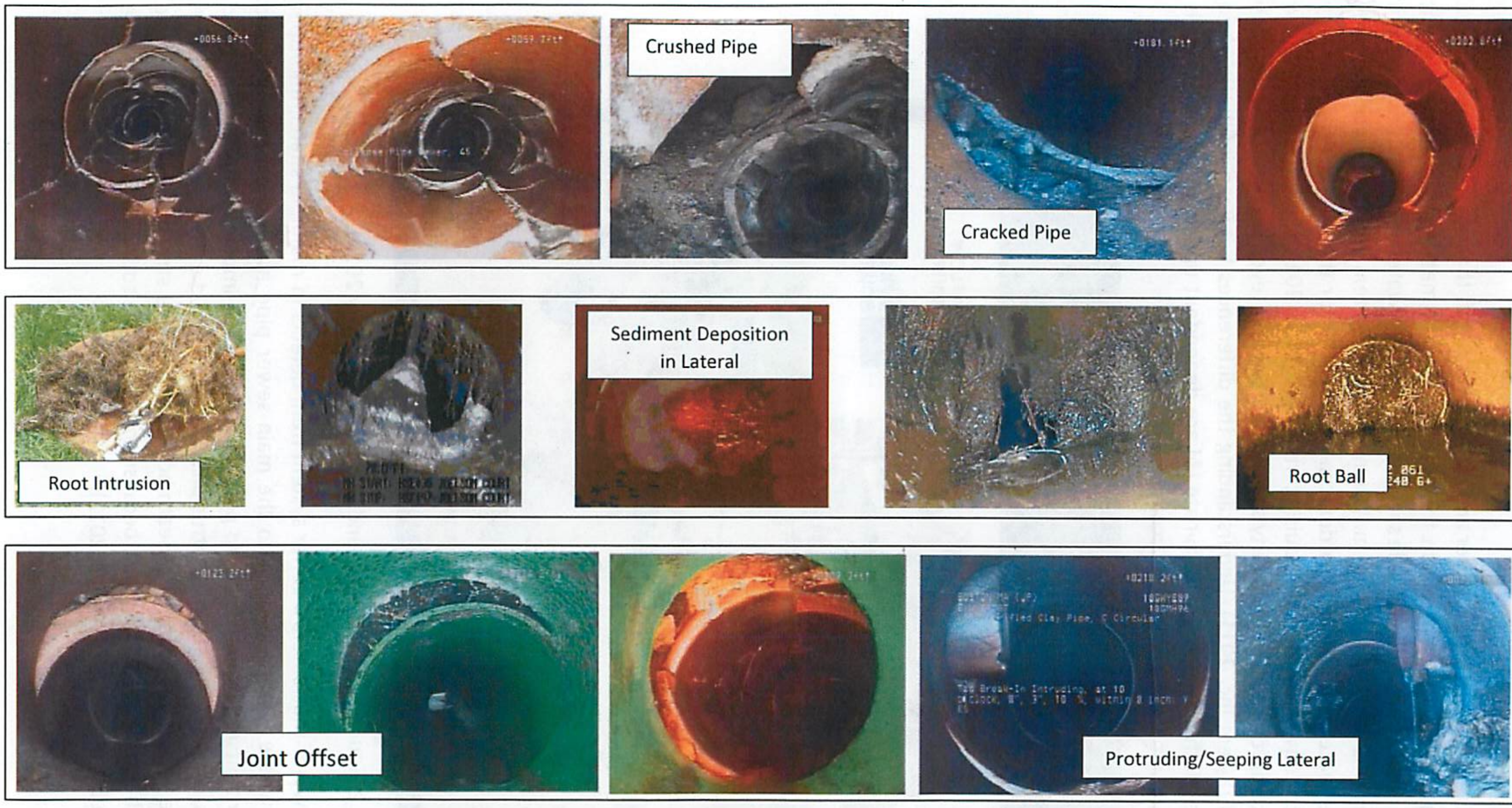


Figure 3. Common Sanitary Sewer Defects Identified and Documented via Closed-Circuit Television (CCTV) Inspection (JTV Inc. 2017).

Inflow can be categorized by three components, *steady inflow*, *direct inflow*, and *delayed inflow*.

Steady inflow is non-sanitary (is not wastewater) water that enters the sanitary sewer from a direct connection that limits the flowrate into the sewer. Examples of steady inflow sources include: basement or drop inlet sump pumps, cellar/foundation drains, and drains from swamps, springs, stormwater basins, or creeks. It is typical for steady inflow to be quantified with groundwater infiltration, as it is difficult to separate the two when analyzing sewer system flowrate data. This project lumped the quantification of steady inflow with groundwater infiltration (METCALF & EDDY 1991).

Direct Inflow is stormwater that enters the sanitary sewer from direct connections and yields a response in the sewer's flowrate almost immediately after the rainfall events occur. The response in flowrate is recognized by rapid and large increases in flowrate magnitudes immediately precipitation begins (faster and larger peaks for longer and more-intense storms). Thus, direct inflow can be separated and quantified from analysis of flowrate data by separating it from the diurnal sanitary flow and groundwater infiltration. Examples of sources of direct inflow include: sanitary sewer connections from building gutter drains, cracks/holes in manhole lids, and cross-connections from storm or combined sewers and/or retention basins/swales, yard and area drains, and sanitary sewer cleanouts (METCALF & EDDY 1991). Many sources of direct inflow are unauthorized by the City and are illegal—this water should not be entiering the sanitary sewer but rather be allowed to infiltrate into the ground or enter the storm sewer system. Direct inflow from unauthorized connection can convey significant amounts of water into the sanitary sewer; for example, a single sump pump can contribute more then 7,000 gallons in one day, which is approximately as much sanitary water is produced from 26 domestic residential connections (Xylem Inc. 2011). Stormwater runoff should not be inflow into sanitary sewers, bur should be dealt with by a separate stormwater management system. Storm sewer pipes are typically much larger than sanitary sewers, which is required to provide adequate drainage for developed watershed (EPA 1996). It was expected (at the commencement of this project) that as the base groundwater infiltration rate at the start of a precipitation event increases, so does the magnitude of the sanitary sewer's peak flowrate that is induced by the direct inflow (because there is a greater volume of water in the sewer over the short period that a large volume of water enters).

Delayed Inflow is stormwater that enters the sanitary sewer from direct connections after the end of a rainfall event, and that may take several hours or days to drain into and through the sewer system (METCALF & EDDY 1991). This inflow can sometimes be classified as steady inflow, and like it, is lumped in its quantification with groundwater infiltration (and thus steady inflow).

The 1972 Water Pollution Controls Act requires that potential recipients of many federal grants for wastewater treatment projects must first show that their sanitary sewers do not have excessive rates of I&I, and that it is not more beneficial to remediate and reduce I&I then to proceed with a treatment/capacity expansion project. Therefore, it is important to understand how I&I is defined in the eyes of federal and state governments, as they are potential sources of project funding/financing (especially as the City is in the process of a roughly $60,000,000 treatment plant upgrade project). The Federal Register defines infiltration as (Federal Register in Davis M., 2011 1974):

> The water entering a sewer system, including sewer service connections, and from the ground through foundation drains, defective pipes, joint pipes, connections, or manhole walls. Infiltration does not include inflow.

And inflow as:

> The water discharged into a sewer system, including service connections from such sources as roof downspouts (also called leaders); basement, yard, and area drains; cooling-water discharges; drains from springs and swampy areas, manhole covers; cross connections from storm sewers and combined sewers; catch basins; storm water; surface runoff; street wash water; or drainage.

Problems Caused by Excessive Infiltration and Inflow

Sanitary sewers are not designed to convey the volume of groundwater that infiltrates into them or stormwater runoff that enters via direct connections—they are designed to carry wastewater from authorized connections. There are numerous problems that result from excessive inflow and infiltration that cause a burden for the City. When excessive I&I occurs, especially over a short period of time (often caused by direct inflow), the sanitary sewers hydraulic capacity can be exceeded. This can lead to sanitary sewer overflows and can result in the Arcata Wastewater Treatment Facility (AWTF) operating at above its design limit (CoA 2018). Excessive I&I results in the dilution of the influent wastewater stream to the treatment plant, which can disrupt treatment processes (i.e. interfere with biological treatment), can result in the bypass of primary treatment, and can cause discharge violations (Xylem Inc. 2011) (North Coast Regional Water Quality Control Board 2019). Excessive I&I can cause shortened detention times for treatment plant reactor processes, clarifier short-circuiting due to increased approach velocities, and can overwhelm the treatment plants capacity and cause unauthorized discharges (Hill 2014).

Inflow and infiltration inflict monetary costs on the City in numerous ways. Sanitary sewer overflows cause fines and penalties for the City, as do discharge violations from the treatment plant (North Coast Regional Water Quality Control Board 2019). Additionally, all water entering the sanitary sewer increases operations and maintenance costs, and can accelerate the degradation of and put strain on lift station and treatment plant pumps. Excessive levels of I&I can also make municipalities (the City) ineligible for loans from numerous governmental entities. Inflow and infiltration can also add to lifetime treatment costs, increasing the degradation of sewer system and treatment facility infrastructure and equipment, as well as necessitating capacity expansions to prevent unauthorized discharges (Xylem Inc. 2011) (METCALF & EDDY 1991). Because excessive infiltration is a sign of defective pipes, there is the possibility for exfiltration of raw sewage out the sanitary sewer during periods of groundwater recession (shown in **Error! Reference source not found.**).

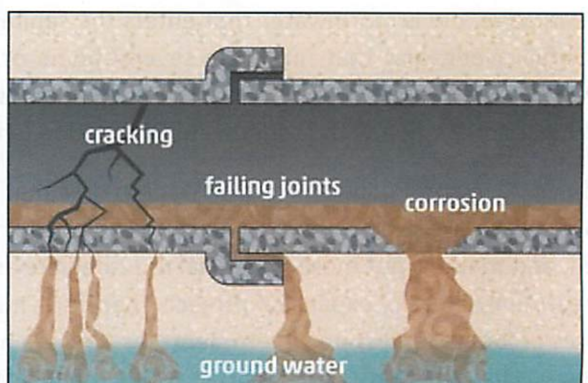


Figure 4. A depiction of potential causes and effects of exfiltration from sanitary sewers through defects (Bhatia 2017).

Excessive I&I can also result in surcharging of the sewer system, which can lead to sanitary sewer overflows; sanitary sewer overflows (SSOs) occur when a mixture of wastewater, infiltrated groundwater, and stormwater (inflow) surcharges and overflows manholes, leaving the sanitary sewer (such an even that occurred in Arcata is depicted in Figure 5) (EPA 1996).

BETTER TO NOT "WRAP" TEXT AROUND FIGURES

Figure 5. A sanitary sewer overflow occurring in Arcata **(City of Arcata)**.

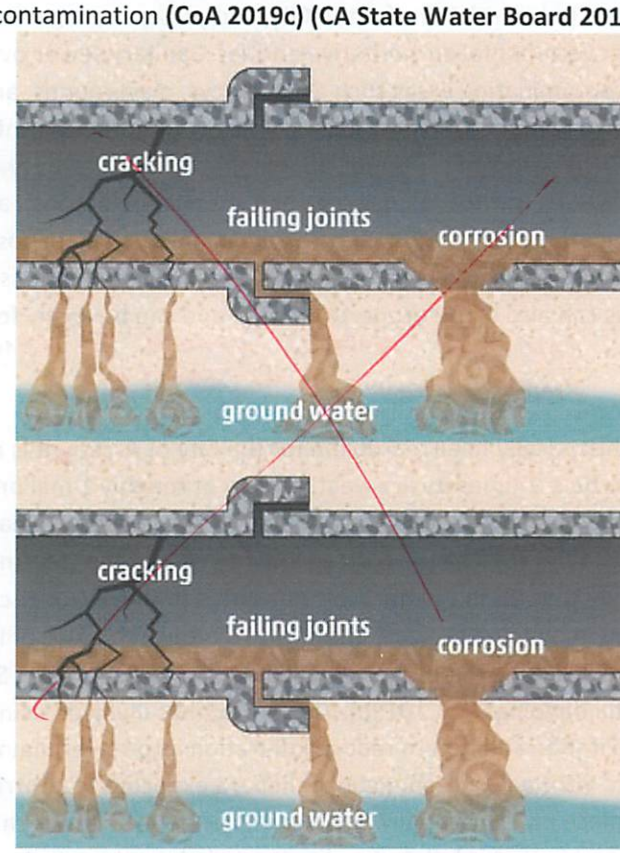
Despite the fact that this overflowed water can be fairly dilute, there is the possibility for spread of sanitary waste—this can lead to environmental contamination (contamination of surface waters), public health/safety issues, stressed public relations for the City/bad press, and legal penalties and fines imposed on the City from governmental authoritative entities. Sanitary sewer overflows can pose significant health risks by contaminating areas such as roadways, playgrounds, and parking lots with raw sewage—this wastewater can contain harmful bacteria, viruses, and other harmful organisms/contaminants. Such pathogens include: chlorea (bacteria), dysentery (bacteria), hepatitis and meningitis (virus), Gastroenteritis (protozoa), diarrhea and anemia (helminths), and Legionnaire's disease (bioaerosol), among others (EPA 1996). People and animals can be exposed to this sewage by unknowingly contacting it or consuming water (or animals, i.e. Shellfish) that has been contaminated by it. Sanitary sewer overflows can also cause property damage and can be costly for the City to clean up (EPA 1996) (CoA 2018).

CAN ALSO MAKE IT HARDER TO REACH 85% BOD/TSS REMOVAL SINCE INFLUENT IS SO DILUTE

Infiltration and Inflow in Arcata

Infiltration and inflow has historically been a problem for the City of Arcata; it is not uncommon for the AWTF's influent flowrate to be 1-2 times its dry weather flow of roughly 1 million gallons per day (MGD), or for sanitary sewers overflows to occur. While few sanitary sewer overflows have occurred within the Aldergrove area specifically, numerous have occurred between it and the treatment facility (as is shown in Figure 6 below)—it is likely that I&I in Aldergrove contributes to the occurrence of SSOs elsewhere in the City. The City is involved in ongoing projects in a effort to reduce the rate of I&I into the sewer system throughout the City, including the roughly 7 million dollar 2018 Sanitary Sewer Infiltration Reduction Project that is still ongoing (CoA 2019b). This project has involved using the cured-in-place pipe trenchless pipe rehabilitation solution to reduce infiltration into sewer main lines and lateral connections (specifically old vitrified clay connections that are expected to contribute relatively high amounts of I&I). Cured-in-place pipe essentially involves inflating a fabric sock that has been impregnated with an epoxy resin that is inflated and expanded along the interior of the sanitary sewer pipes and which is heat cured to harden in place. The result is some structural rehabilitation and sealing off of the sewer pipe (CoA 2019b).

Figure 6. A sanitary sewer over flow in Arcata (left), and the locations of sanitary sewer overflow events in Arcata since 2007. The pink crosses indicate a category 1 overflow, which means the overflowed water reached surface water. The orange triangles indicate SSOs that did not result in surface-water contamination **(CoA 2019c) (CA State Water Board 2019)**.



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Project Purpose, Scope, and Objectives

This section presents the purpose of this project, the scope of the project, and the objectives that were sought at the commencement of this project.

Problem Statement

The City of Arcata (City) needs an analysis conducted of the current magnitude, sources, resulting wastewater conveyance and treatment cost increases, and other effects of the infiltration and inflow (I&I) of extraneous groundwater and stormwater runoff into the City's sanitary sewer in the West End Industrial Zone (that is associated with the current hydrologic characteristics of the local watershed and the current condition of the sanitary sewer infrastructure). Pending the results of said initial assessment, the City needs design alternatives developed that would eliminate, decrease the magnitude of, or decrease the negative effects and costs resulting from I&I into the Aldergrove sanitary sewer. This project is necessary because the City expects that there is significant I&I occurring and that it is imposing significant monetary costs and other undue-burdens on the City.

Scope of Project

The scope of this project was to assess the current (2019) and historical magnitudes of and costs imposed on the City of Arcata due to the infiltration and inflow into the sanitary sewer in the West End Industrial Zone. This project entailed analysis of available sanitary sewer flowrate data and water service (usage) data for properties in the industrial zone. The project also involved implementing methods to identify source of I&I; these processes included: sanitary sewer manhole inspections in the industrial zone, conducting a private property survey (inspections) to identify and document potential sources of I&I on the parcels in the industrial zone, and reviewing the available closed-circuit television inspection footage of the sanitary sewer in the industrial zone. Using the results and inferences made from the data analysis, field inspection work, and CCTV footage review, the engineering design processes was implemented to develop alternatives to eliminate or reduce I&I in the industrial zone. This project did not encompass or consider the redesign of the stormwater infrastructure in the area, although observations regarding the drainage in the area were made during field inspections.

Project Objective

There were three primary objectives of this project, which were: (1) analyze historical sanitary sewer flowrate and local water service data to quantify the magnitude of the infiltration and inflow (I&I) issue for the sanitary sewer in the West End Industrial Zone (Aldergrove sanitary sewer), (2) identify and document probable sources of I&I into the Aldergrove sanitary sewer, and (3) implement the engineering design process to develop project alternatives and make a recommendation of a alternative (or set of alternatives) that would effectively and efficiently reduce or eliminate I&I into the Aldergrove sanitary sewer, or projects that would reduce negative impacts of I&I in a cost effective manner.

2. Existing Facilities

The project area encompasses the West End Industrial Zone and the Aldergrove Industrial Park. Specifically, any area within the City right-of-way (ROW), or any private property with an active lateral connection to the City's sanitary sewer, is of interest and under assessment by this project. The sanitary sewer in the area consists of roughly 1.36 miles of pipeline, where more than 95% of the pipe lines are gravity sewers. There are approximately 76 live sewer lateral connections in the area, which was determined from analysis of water service (usage) records for parcels in the West End Industrial Zone for 2018 (CoA Finance Department, Unpublished Water use Data, 2019). These lateral connections consist of two parts, the "upper" lateral, which resides from the base of a building to the property line, and the "lower" lateral, which extends from the property line to the connection with the sanitary sewer (as is depicted in **Error! Reference source not found.** below). The upper lateral is the responsibility (to maintain and repair it) of the property owner, while the lower lateral is the responsibility of the City. All wastewater entering the sanitary sewer in the Aldergrove area is conveyed through the system to the Aldergrove lift station, wherefrom it is pumped to the east side of Arcata, where it then flows by gravity to the Samoa lift station, where it is then pumped to the Arcata Wastewater Treatment Facility, as was determined from analysis of the City's GIS Data (City of Arcata 2019a). This is of particular interest, because roughly 60% of all water entering Arcata's sanitary sewer is conveyed through the Samoa lift station (CoA 2010). There is one ductile iron 3-inch diameter pressure line that runs from the north end of West End RD, east across the railroad, and down through Frank Martin CT to connect with the sewer main on Erickson Way (pipe lengths, locations, and inch-miles reported in Table 1 below). The total inch-mileage of the sanitary sewer in the area is roughly 8.7; this value will be used to analyze the severity of the I&I issue into the Aldergrove sanitary sewer. The local area surrounding the sanitary sewer is frequently very wet, with many streams, ponds, and marsh's in the area (shown in Figure 8 below). The Aldergrove lift station has two 7.5-horsepower pumps (350 gallons per minute, 17 feet of required pump head, model No. T4A3-B/WW) that convey wastewater roughly 2000 feet south to a manhole where it joins with a force main from Glendale Community Services District to flow south by Gravity on West End RD (City of Arcata 2019a) (Gorman-Rupp Engineered Systems Equipment 2001). The is also a backup generator that is used to provide the pumps with power during outages.

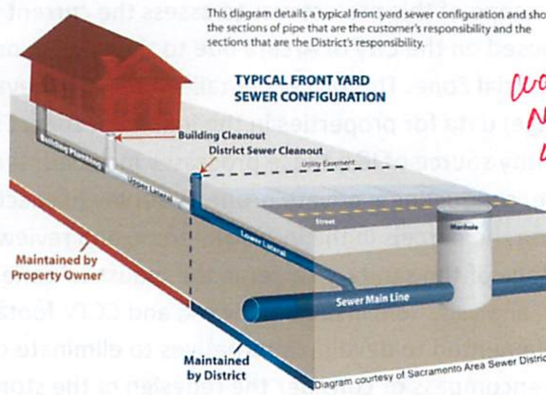

Figure 7. Typical lateral connection to the sanitary sewers in Arcata **(CoA 2019b).**

Table 1. Existing sanitary sewer pipe sections and their details in the West End Industrial Zone.

Pipe ID	Material	Type	Diameter	Length (Mile)	Inch Mile	Street
587	Ductile Iron	Pressure	3"		0.47	West End RD
571	AC	Gravity	6"	0.16	0.3	Frank Martin CT

572	AC	Gravity	10"	0.05	0.74	Frank Martin CT
1107	AC	Gravity	6"	0.07	0.42	Erickson Way
1463	AC	Gravity	6"	0.2	0.13	Erickson Way
1462	PVC	Gravity	6"	0.05	0.28	Belle Falor Ct
1109	AC	Gravity	8"	0.06	0.5	Erickson Way
486	AC	Gravity	8"	0.08	0.64	Erickson Way
481	AC	Gravity	8"	0.04	0.28	Erickson Way
1464	PVC	Gravity	6"	0.03	0.15	Erickson CT
573	PVC	PVC	6"	0.08	0.48	Erickson CT
485	AC	Gravity	10"	0.05	0.5	Erickson Way
1236	AC	Gravity	10"	0.08	0.82	Erickson Way
1404	AC	Gravity	10"	0.06	0.64	Aldergrove RD
1402	AC	Gravity	10"	0.06	0.57	Aldergrove RD
1399	AC	Gravity	10"	0.04	0.41	Aldergrove RD
1358	AC	Gravity	8"	0.02	0.17	Aldergrove RD
1405	AC	Gravity	8"	0.07	0.56	Aldergrove RD
1406	AC	Gravity	8"	0.09	0.72	West End RD
1359	PVC	Gravity	6"	0.06	0.38	West End RD
1360	VC	Gravity	6"	0.01	0.04	West End RD
Total Inch-Miles of Sanitary Sewer Pipe in Aldergrove				8.73		
Total Length of Sanitary Sewer Pipe in Aldergrove (miles)				1.36		

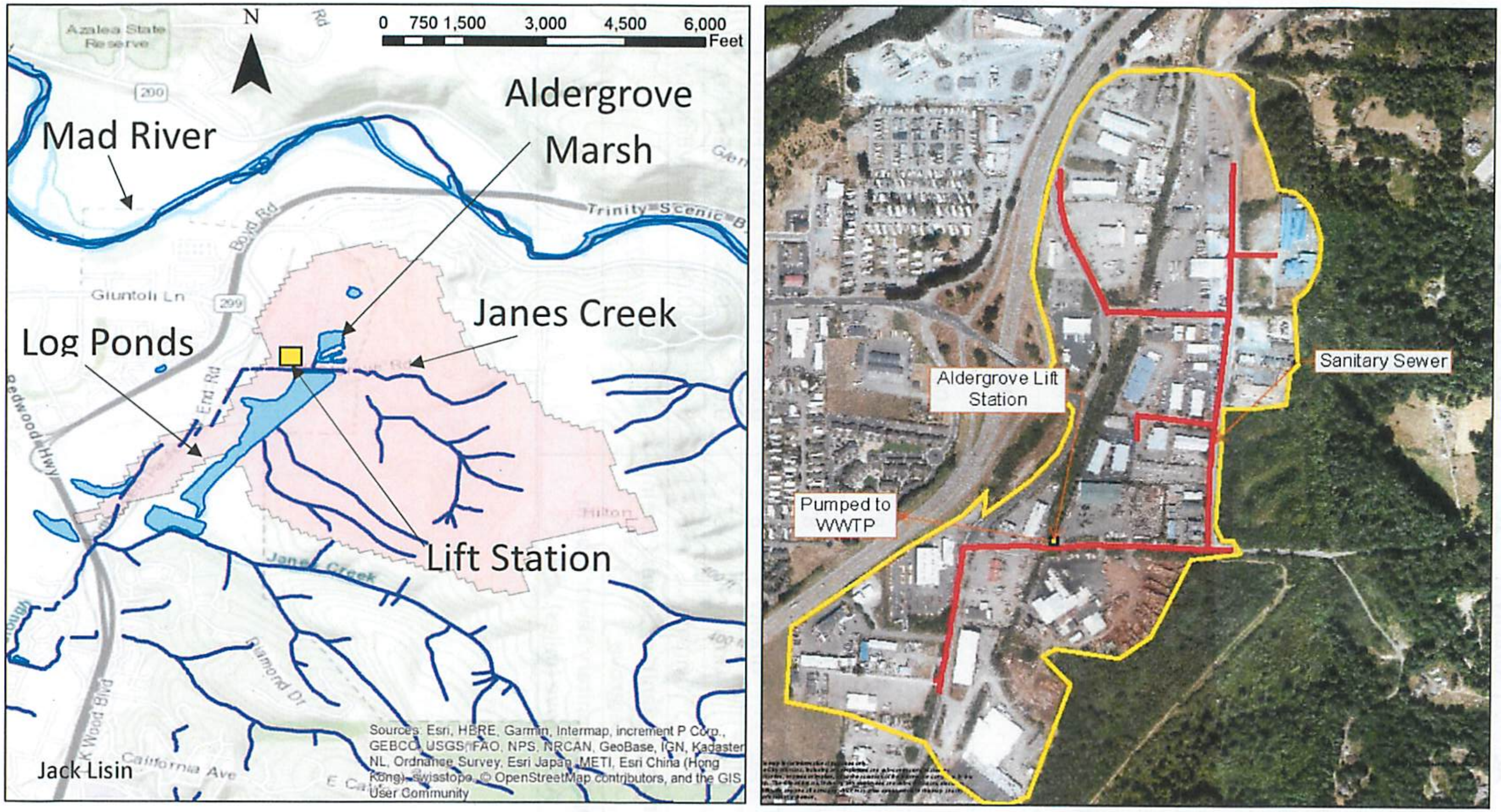

Figure 8. Hydrology of the West End Industrial Zone (left), and the sanitary sewer in the industrial zone that is analyzed by this project **(City of Arcata 2019a)**.

3. Regulatory Requirements

There are various discharge requirements stipulated by Arcata's National Pollutant Discharge Elimination System permit (NPDES No. CA0022713), which allows the Arcata Wastewater Treatment Facility (AWTF) to discharge secondary treated wastewater to Humboldt Bay, that pertain to infiltration and inflow, and this project. The NPDEs encourages and requires correction of I&I into the City's sanitary sewer system. The permit also specifies that the City is to investigate unauthorized and illicit connections to the sanitary sewer, and that the City should: perform general housekeeping and have a routine maintenance schedule to clean the sewer system; perform smoke testing of the City sewer to detect interconnections between the storm and sanitary sewers, and identify locations of pipe defects and illicit connections; to perform routine closed-circuit television (CCTV) inspection of sewer pipe lines to detect existing defects; and to develop public outreach and education programs to educate the public about the negative consequences and dangers of unauthorized and illicit connections to the sanitary sewer (CoA 2005) (North Coast Regional Water Quality Control Board 2019). These requirements regarding, I&I identification and reduction were be important to consider in the development of alternatives to reduce or eliminate I&I. The following discharge violations are prohibited by the City's NPDES permit (North Coast Regional Water Quality Control Board 2019):

A. The discharge of waste to Humboldt Bay is prohibited unless the discharge is consistent with State Water Resources Control Board (State Water Board) Order No. 79-20 and Regional Water Board Resolution No. 83-9.
B. The discharge of any waste not disclosed by the Permittee or not within the reasonable contemplation of the Regional Water Board is prohibited.
C. Creation of pollution, contamination, or nuisance, as defined by section 13050 of the Water Code is prohibited.
D. The discharge of untreated or partially treated waste (receiving a lower level of treatment than described in section II.A of the Fact Sheet) from anywhere within the collection, treatment, or disposal systems is prohibited
E. Any sanitary sewer overflow (SSO) that results in a discharge of untreated or partially treated wastewater to (a) waters of the state or (b) land and creates pollution, contamination, or nuisance, as defined in Water Code section 13050(m) is prohibited.
F. The discharge of waste at any point not described in Finding II.B of the Fact Sheet or authorized by a permit issued by the State Water Board or another Regional Water Board is prohibited.
G. The average dry weather flow of waste through the Facility shall not exceed 2.3 million gallons per day (mgd), measured daily and averaged over a calendar month.

An additional law that is important to this project is the mandatory sewer lateral inspection ordinance. Sewer laterals are thought to be significant contributors of I&I within the collection system, partially because many of them predate the sewers they are connected to and have defects that property owners may not know about. Currently, City of Arcata Ordinance 1461 mandates CCTV inspection of private property sanitary sewer laterals for buildings and homes that are more than 25 years old, when the property is being sold (or remodeling projects greater than $30,000). If the inspection indicates that repairs are needed, they must be completed prior to the house being sold (CoA 2019d).

4. Basis of Design

Data analysis was conducted of available historical flow rate data from 2007 to 2018. Due to the fact that the average wet weather flows differ substantially for the years of 2007-2010 and 2011-2018 (roughly 13,000 vs 7,000 gallons per day wet weather flow) (magnitudes shown in Figure 9 below), data prior to 2011 was rejected from further analysis. An algorithm was developed to separate infiltration and inflow from total flow rate observations, given that the base sanitary flow rate was known. The base sanitary flowrate for 2018 was estimated as 100-percent of the total water consumed, which was determined from analysis of available water use data for the Aldergrove area (City of Arcata Finance Department, 2018 Water Use Data, 2019). The methodology behind the algorithm is not reported due to time constraints (please inquire if this information is desired). However, one thing to consider is that separating infiltration from flow rate observations is more of a art then a science (although educated estimates were made with reference to statistical findings). Figure 10 shows total daily flow rate and precipitation observations for 2018, and Figure 11 shows the results of the application of the algorithm to develop a flow rate profile for 2018. This algorithm was applied to each year (2011-2018) to determine the total annual volume of infiltration and inflow respectfully for each year (shown in Figure 12). Figure 13 and Figure 14 show the lift station pump operation times for 2017 over the course of the year and with respect to I&I volumes, respectfully. These figures show that direct inflow was the primary cause of long operation times and operations and maintenance costs. To estimate the conveyance and treatment costs associated with daily infiltration, inflow, and abuse sanitary flow rate observations, a scheme was developed using the EPA's suggested value conveyance and treatment cost for wastewater of $2-$5per 1000 gallons, where increasing flows resulted in higher costs being applied (direct inflow was penalized). Information on how this was conducted and underlying data is available upon request but was not reported here due to time constraints.

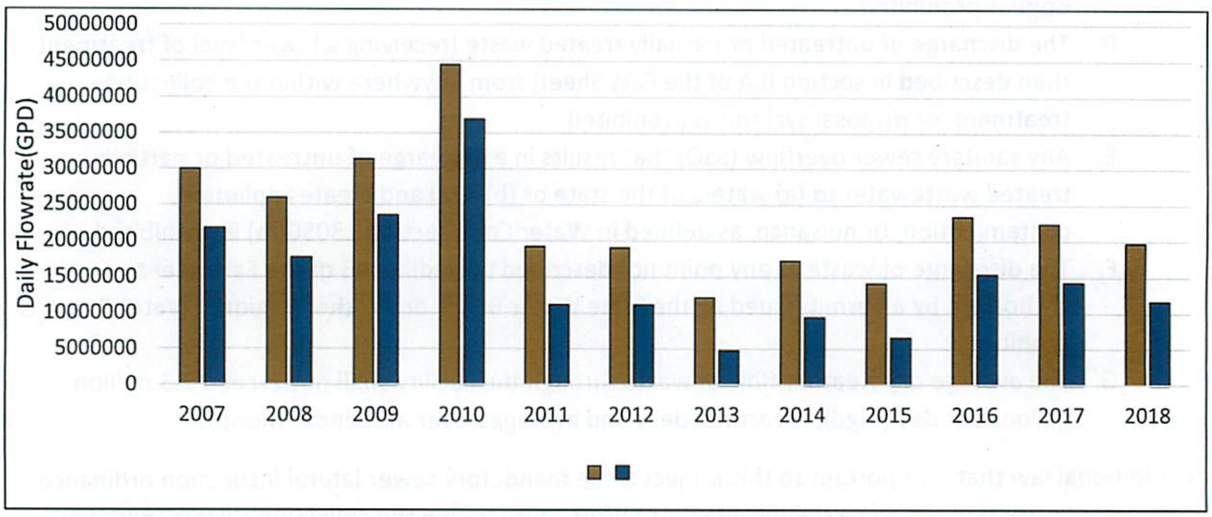

Figure 9. Average dry and wet weather daily total flow rates for the Aldergrove lift station for the years of 2010-2018.

MIGHT SAY WHY YOU SUSPECT THE DIFFERENCE. DROUGHT? REPAIRS?

NEW PAR

WHY NOT JUST USE COA ANNUAL BUDGET VALUES FOR WW AND ANNUAL TOTAL SEWAGE FLOW TO GET UNIT COST OF OPERATION/1000 GAL?

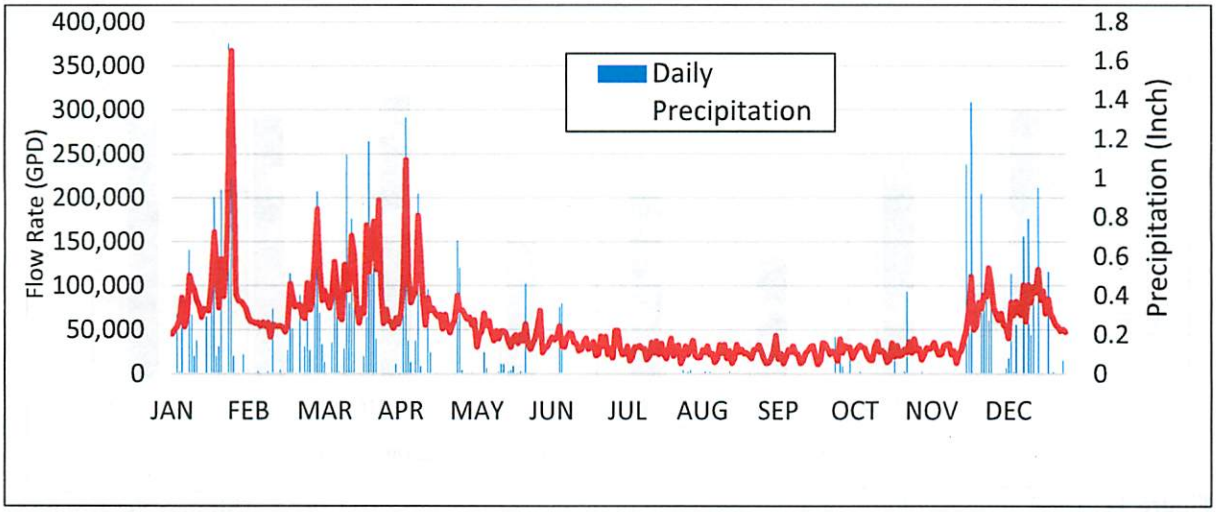

Figure 10. Total daily flow rate observations past the Aldergrove lift station in 2018.

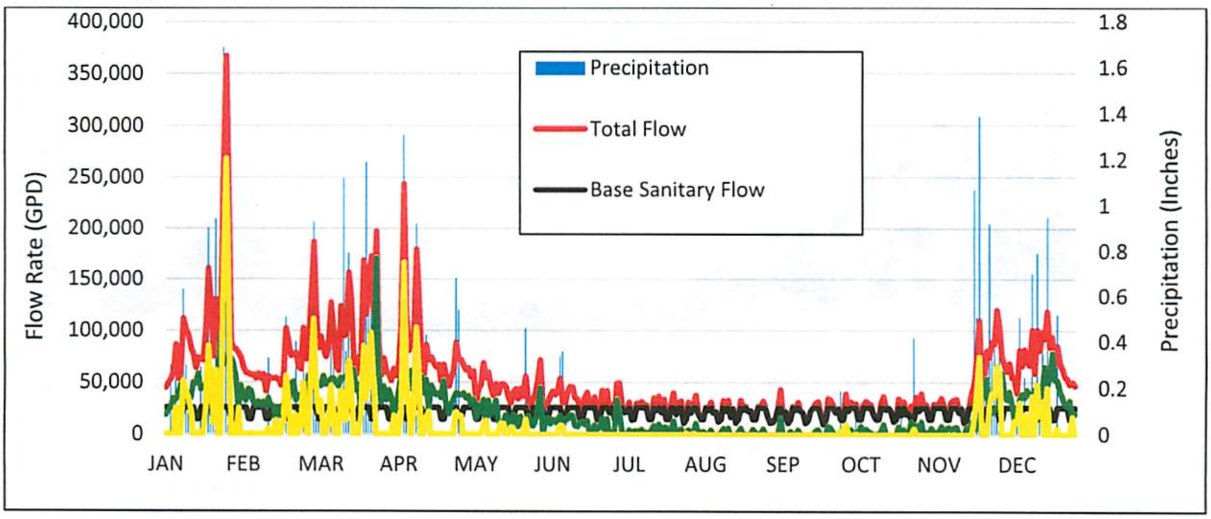

Figure 11. Results of the application of the developed algorithm to develop a flow rate profile for 2018.

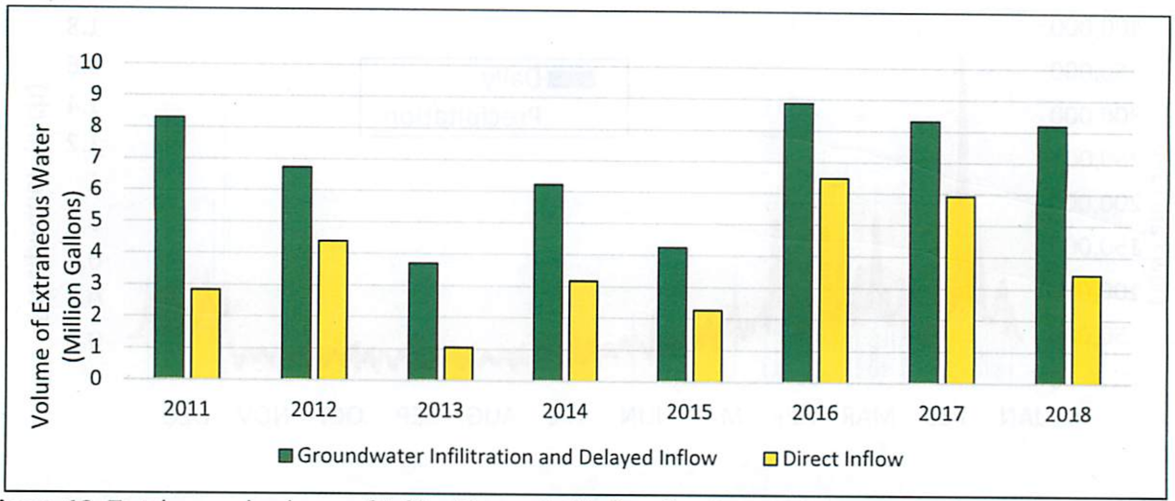

Figure 12. Total annual volume of infiltration and of inflow for the yars 2011-2018. This was determined by developing a flow rate profile for each year(reported in the Appendix) and summing total flow observations.

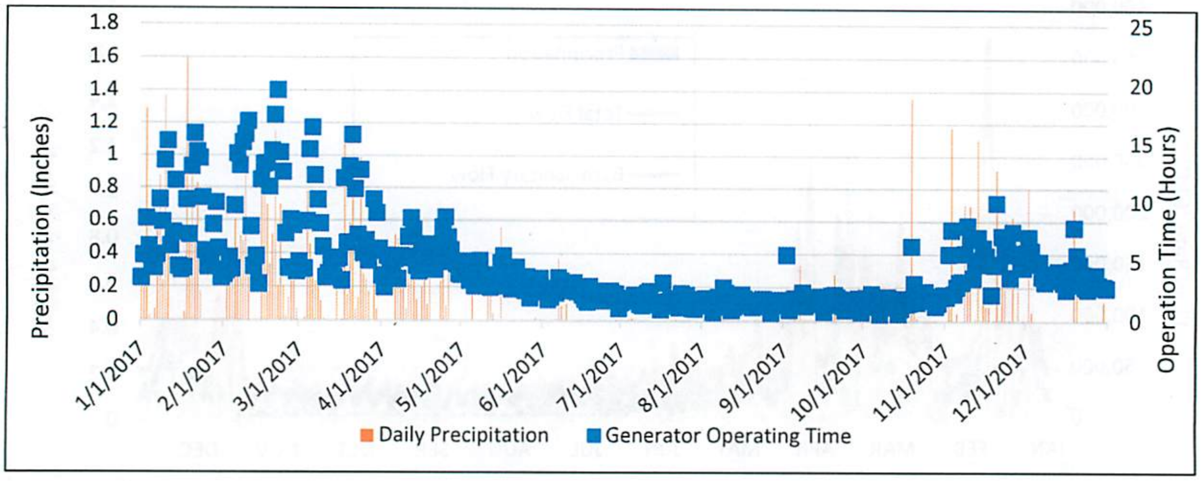

Figure 13. Lift station operation time over the course of 2017 (blue squares) and daily precipitation (orange bars).

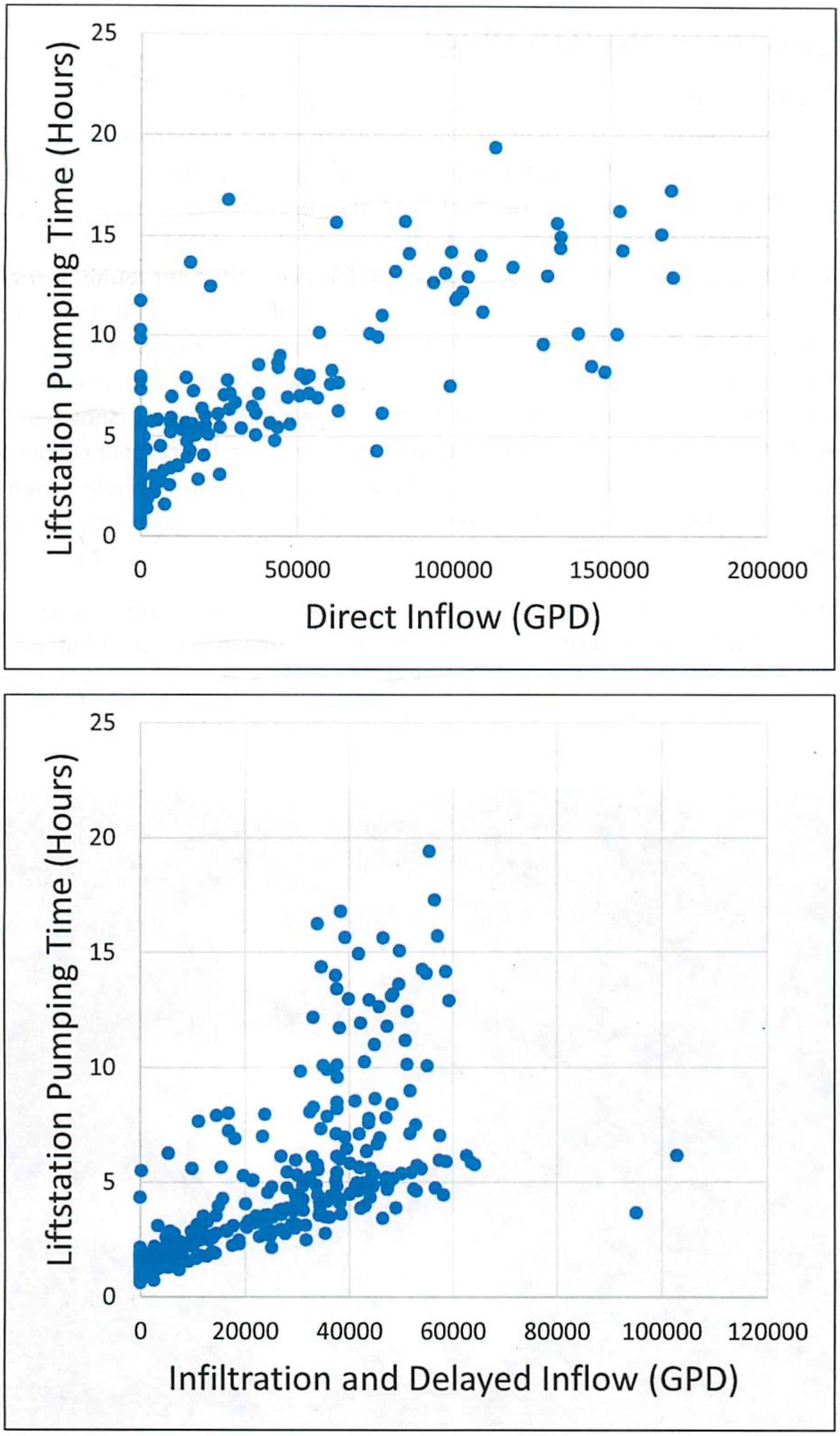

Figure 14. Lift station operation time (pumping hours) with respect to the daily volume of inflow and infiltration (bottom)

5. Identification of Sources of I&I

Manhole Inspections

(Figure 15)

Inspection were conducted of 8 of the 19 manholes connected to the Aldergrove sanitary sewer. This involved opening the manhole, obtaining a depth invert, photographing the manhole, and looking for obvious defects and signs of infiltration (~~example shown in~~ ~~**Error! Reference source not found.**~~). The results of this inspection work yielded numerous findings, and indicated that 11 of the 18 manholes inspected are in need of rehabilitation (~~shown in **Error! Reference source not found.** below~~) (Figure 16). It was suspected that between manholes 1 and 2 there is some source of inflow or infiltration (Terry Barney, personal comments, 2019). To confirm this, Manhole 2 was pugged, and the flow response in Manhole 1 at the Aldergrove lift station was observed; this showed that when the upstream manhole (2) was plugged, there was still a considerable amount of water coming into Manhole 1 (~~shown in~~ Figure 17 ~~below~~). Review of CCTV inspection footage showed that there were no lateral connections between manholes, which indicts that the observed water that was still coming into manhole 1 even when 2 ~~wsa~~ was plugged is likely infiltration or inflow. One possibility is that during heavy rain events Janes Creek raises ~~aid~~ and causes increases rates of either direct inflow or infiltration in the immediate area.

These manhole inspections also yielded discoveries of other defects, such as cracks, ponding water of manhole lids, effluent pipes, infiltration/seepage into manholes (~~shown in~~ Figure 18 ~~below~~), crumbling/crushed manhole walls or influent (~~shown in~~ Figure 19 ~~below~~). These defects contribute to infiltration into the sanitary sewer and were indicative that manhole rehabilitation is necessary. Photos reported in this section were taken by Jack Lisin.

Figure 15. Observed constant groundwater infiltration through crack in Manhole IP6.

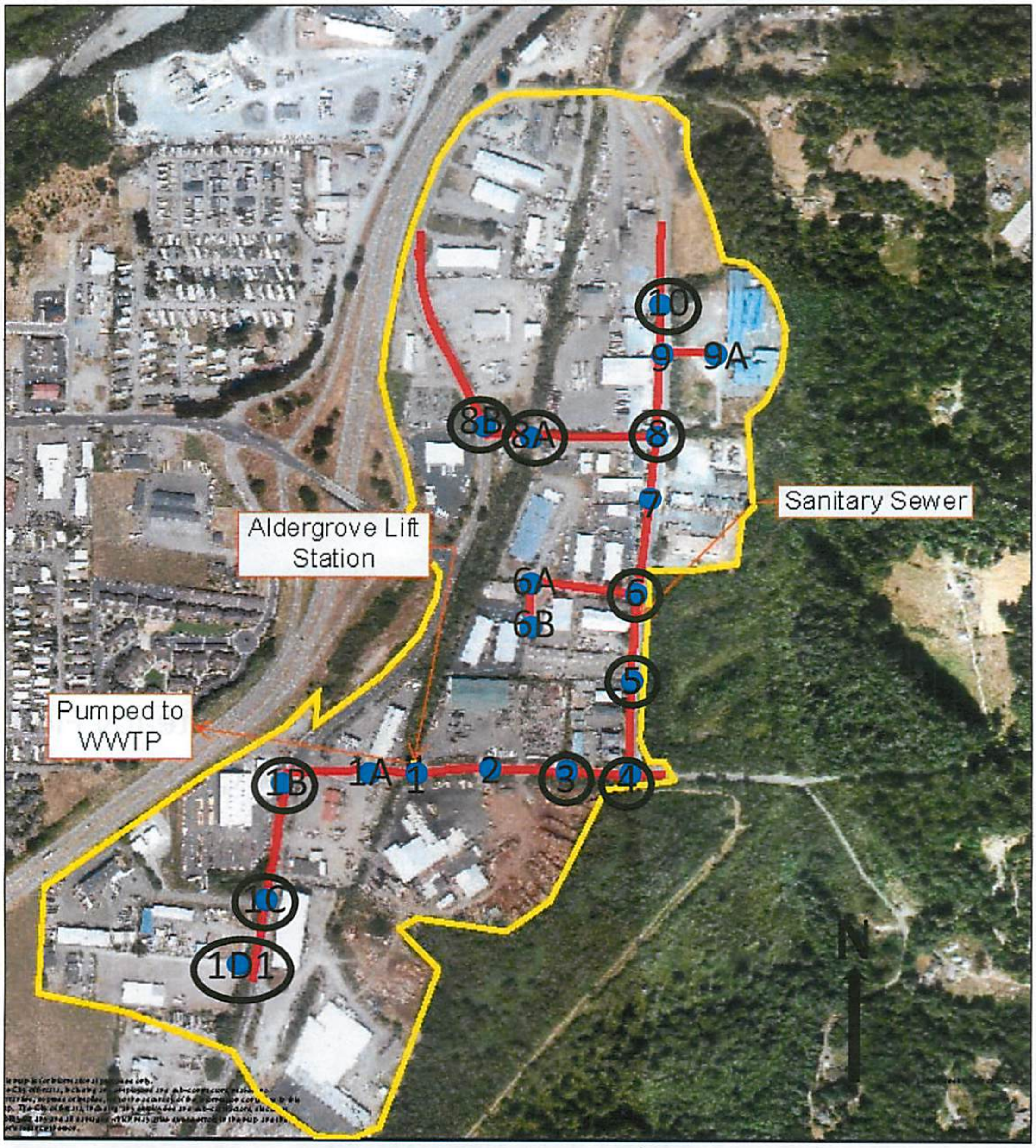

Figure 16. Manholes requiring rehabilitation as indicted from observations made when doing field inspections of them **(City of Arcata 2019a)**.

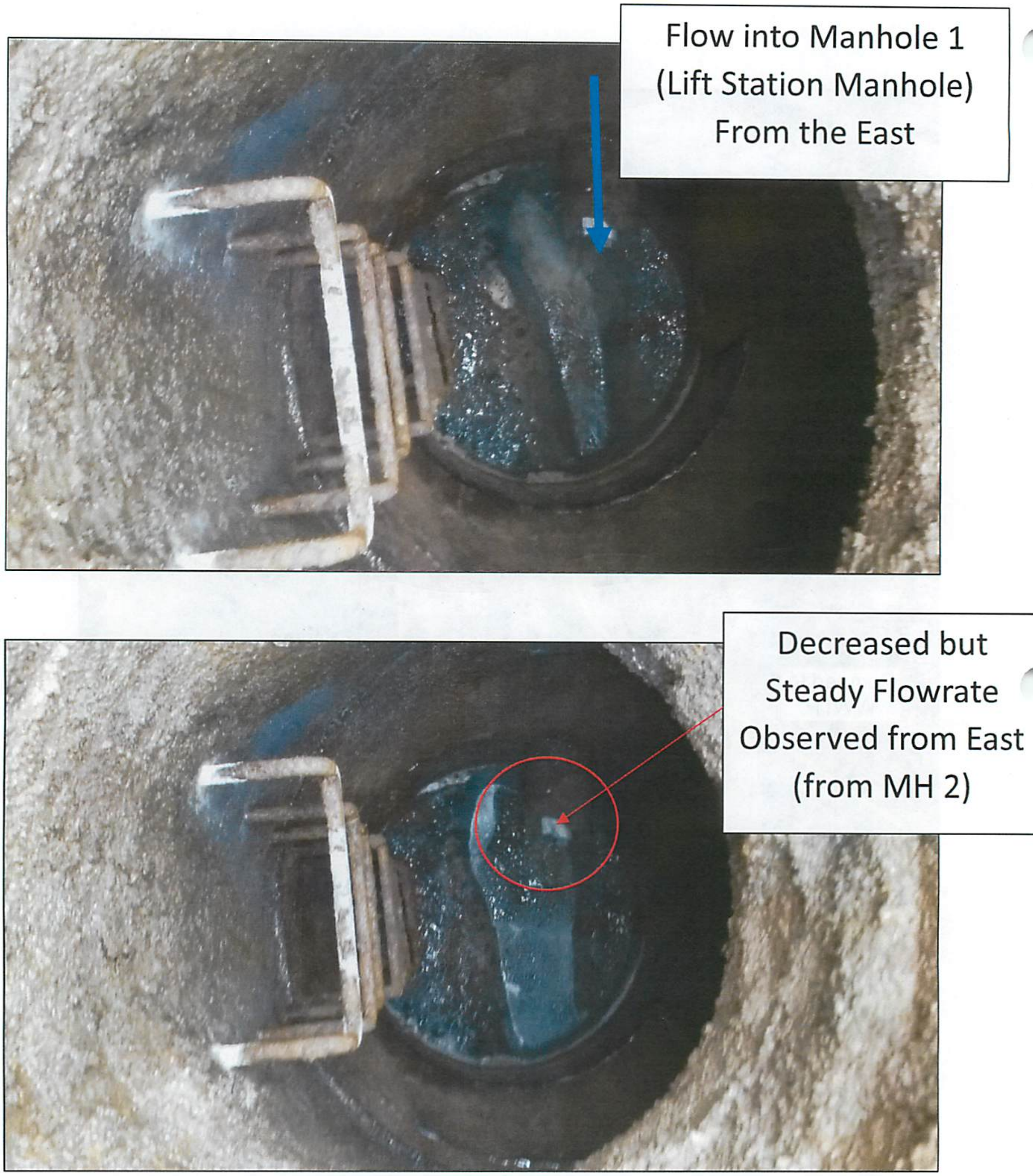

Figure 17. Observed flow response in Manhole IP1 (lift station manhole) when manhole 2 was not plugged (top), and when it wsa plugged (bottom). Shows that there was still significant flow coming from the pipe down stream of Manhole 2 even though flow into Manhole 2 was plugged.

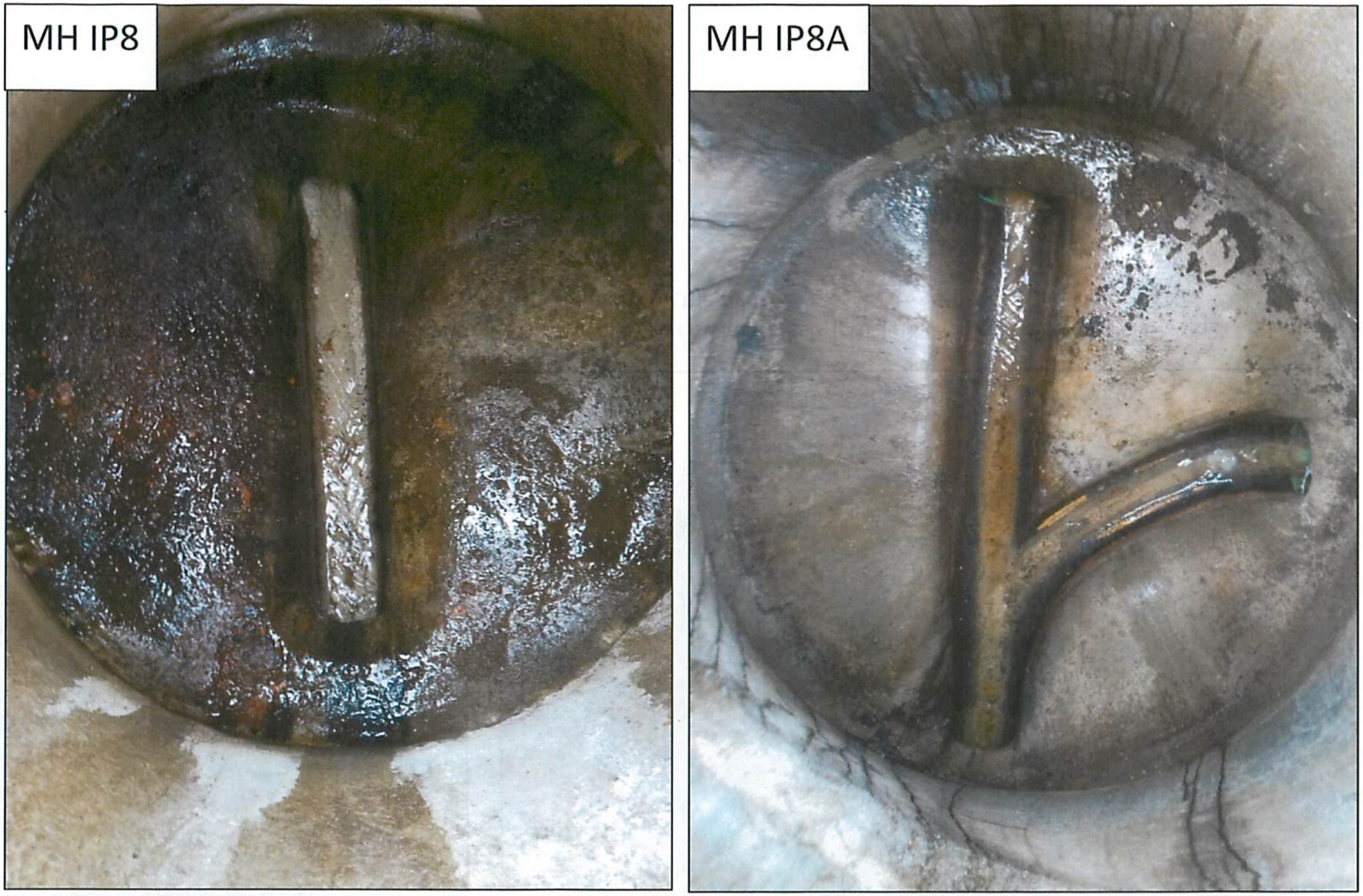

Figure 18. Sanitary sewer manholes connected to the Aldergrove sewer showing signs of infiltration.

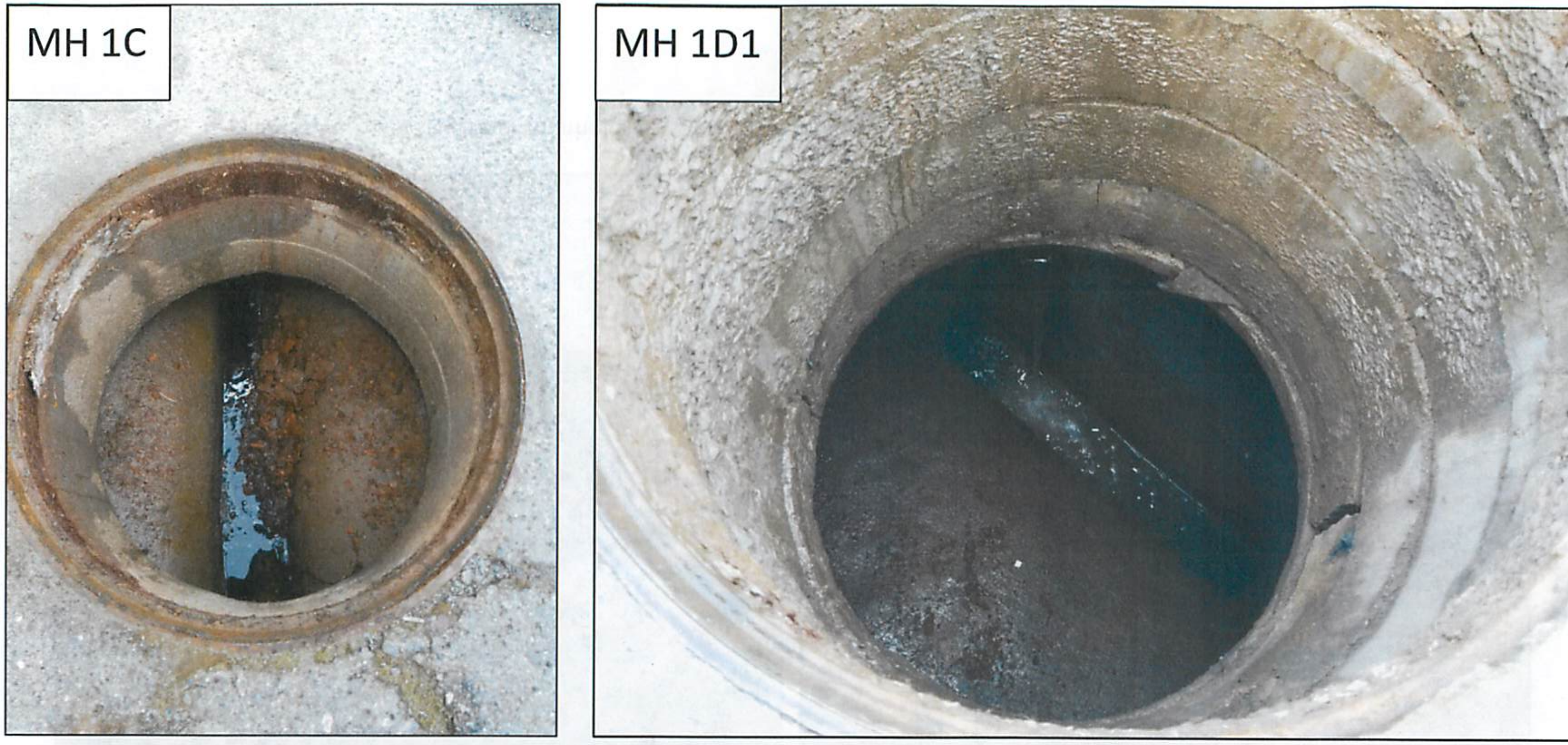

Figure 19. Sanitary sewer manholes connected to the Aldergrove sewer with defects (crushed vitrified clay pipe on left, crack and suspected inflow on the right).

Private Property Inspection

Five private property inspection (shown in Figure 20) were conducted in an attempt to identify and document sources of inflow and infiltration. The documented findings and developed inspection reports are to be shared with the City of Arcata but are not listed in this report due to time constraints. The manhole findings of this inspection work was that Janes creek frequently backs up on from the Mill yard which spills west over Janes creek into McCullough Constructions property (shown in Red in Figure 20). This is interesting because there is suspected infiltration into the sanitary sewer between manholes 1 and 2 in that area, it is possible that these two issues are related. The other significant finding was observed evidence of direct or delayed inflow of stormwater into the sanitary sewer. This was observed when inspecting manhole IP1C, as the system began surcharging after what is assumed to be a sump pump or septic tank pump kicked on (the flow rate approximately quadrupled in magnitude from a already steady flow from a lateral connection from the west into manhole 1C). The observed influent flow (shown in Figure 21) is fairly clear and is high in magnitude. From the property inspections it was determined that the parcel in green likely is not the cause of this high levels of flow because the have sinigang stormwater infrastructure.

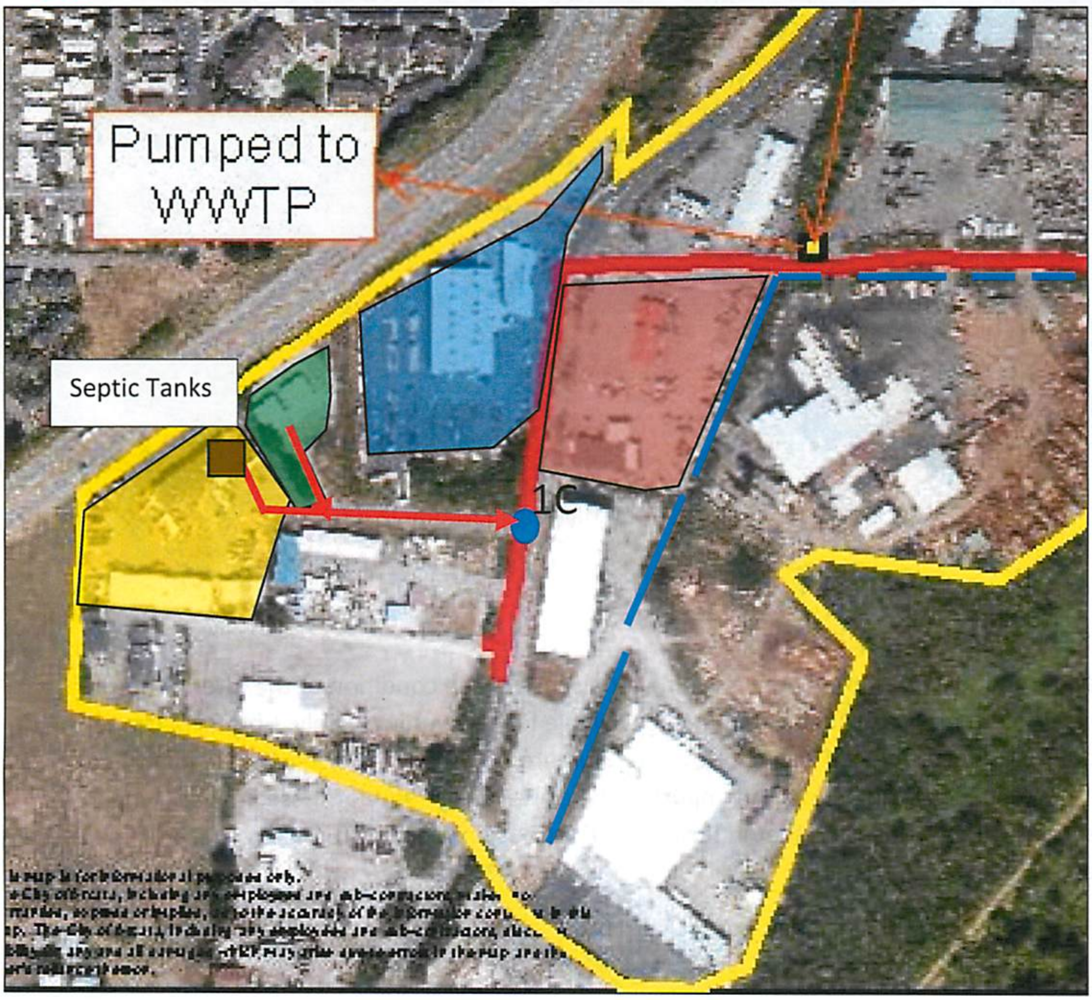

Figure 20. Private property parcels inspected during the inflow identification survey.

SEPTIC TANKS MAY LEAK AND COLLECT G.W.

Two septic tanks on the parcel in yellow (Figure 20)were found to intercept wastewater from the property prior to it being pumped to the sanitary sewer. It is expected that the source of the suspect inflow could be into those septic tanks, where the pump is activated by a float switch valve, which would trigger a response if extraneous stormwater is entering the pipe. When the footage shown in Figure 21 wsa obtained it was fairly wet out. Additionally, the same phenomena were observed a few weeks later when it wsa a lot drier, and the pump kicked on again, except the observed flow was much lower. This is taken of evidence of direct inflow into the sanitary sewer from private property, which is important to consider with respect to the developed design alternatives (in Section 7 below).

Figure 21. Observed surcharging in Manhole IP6.

CCTV Inspection Footage Review

CCTV footage from 2010 was briefly reviewed to get a sense of the condition of the interior of sanitary sewer pipes. While there was roughly 6-hours of available footage, only roughly 2-hours of it was reviewed due to project time constraints. However, numerous cases of infiltration were identified (examples shown in Figure 22 below). An important take away is the date of these images (June in 2010). This lends tot eh conclusion that infiltration is a serious problem, as it is likely much worse in the wintertime.

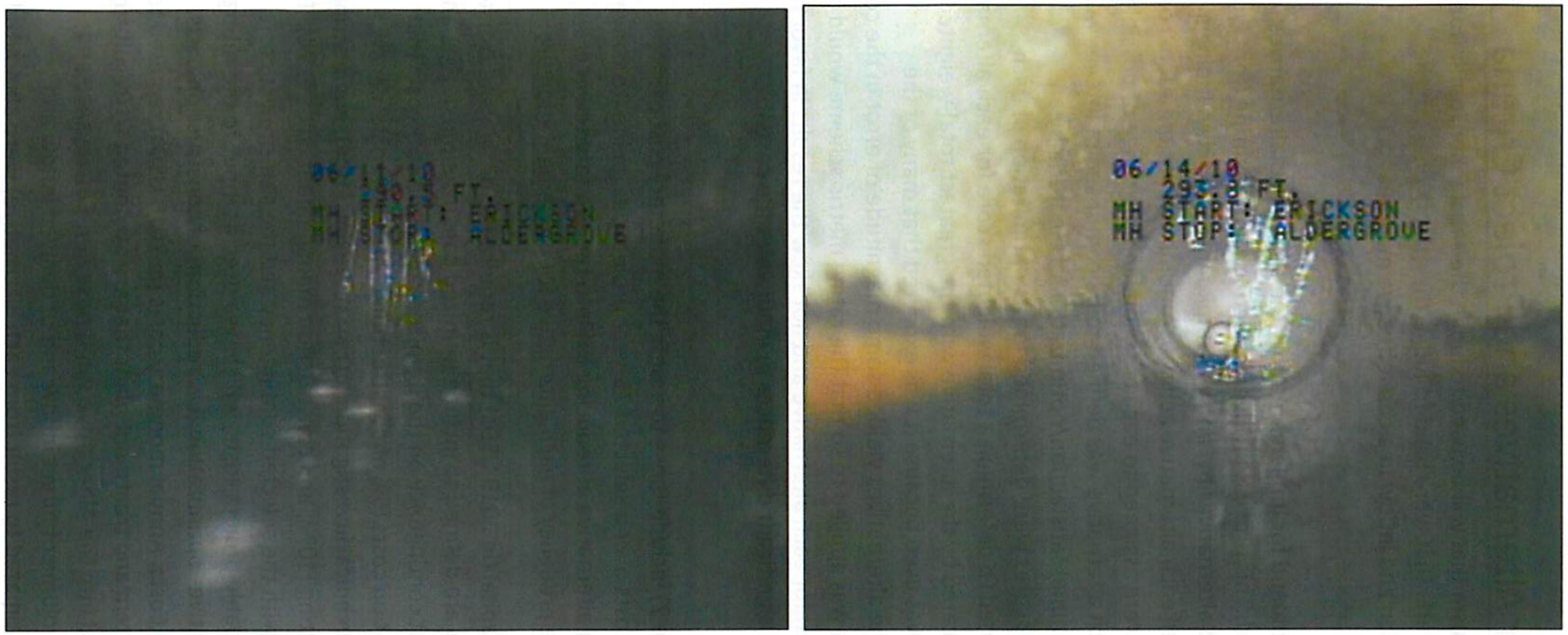

Figure 22. CCTV inspection footage of infiltration into pipes in the Aldergtove sanitary sewer during an inspection in June 2010.

6. Screening Mechanism for Alternatives and Project Criteria

This section presents the screening mechanism that will be used to judge the satisfaction/optimization the criteria by each alternative, and the criteria that were used to judge the effectiveness of the developed alternatives at reducing infiltration and inflow in a cost-effective manner. 04

Screening Mechanism

To determine prudent alternatives to recommend for implementation, the developed alternatives were evaluated and screened via a Delphi method. This process involved selecting and weighting (for significance) criteria to judge the developed alternatives by, and was implemented by developing a point-based rating scheme to score how well each alternative achieves/optimizes each criterion. For this project, numerical weights of either 1 or 2 were assigned to each criterion, and the range of possible scores applied to each of the criteria for each alternative was defined to be comprised of integer values from 0 to 2 (where a score of 0 indicates minimal satisfaction/optimization of a criteria by an alternative). For each alternative, weighted scores were determined for its optimization of each criterion; these weighted scores were summed to determine a total weighted score for each alternative. The 'winner' of the Delphi method was indicated by the alternative with the greatest total-weighted score. A small range of weights and scores was used because it was expected that many of the assumptions made in the cost analyses of the alternatives yielded some magnitude of error in the cost estimates; therefore a small range of scores was applied to so that the rating metric scheme would cover a large range of input values (i.e. costs) for each alternative and not skew the results in favor of one alternative over another unless there is significant differences in input vales (i.e costs).

Project Criteria

The criteria developed for this project (Table 2) include those to assess the monetary cost of implementing the project, the subsequent costs over a selected 25-year project design life (to convey and treat I&I), and the effectiveness of each alternative at reducing I&I into the sanitary sewer. Specifically, the criteria used to evaluate the prudency of each alternative for implementation are:

- *Construction Costs*: The monetary capital (in 2019 USDs) that is required to design and construct the project alternative. Capital costs are defined to include itemized construction, design, and material costs, a selected 30-percent contingency on the itemized costs, and soft costs that include, if prudent: legal/administration costs (5% of construction costs with contingency), land/Right of Way acquisition, geotechnical investigation (10%), surveying (10%), engineering design (15%), environmental permitting (10%), and construction management costs (15%). The sum of the total construction costs with the selected contingency and the soft project costs yielded the total opinion of the probable project costs, which wsa used as input to the rating metric scheme to score each alternatives optimization (I.e. reduction) of construction costs.
- *Operations and Maintenance (O/M) Costs*: Annual monetary costs (in 2019 USDs) required to operate and maintain the sewer system and treatment plant that are attributed to (result from) the conveyance and treatment of I&I into the Aldergrove sanitary sewer. Conveyance and treatment costs (for the estimated volume of direct inflow and of delayed inflow and groundwater infiltration that was estimated to result from each alternative) were computed

AGAIN, SUGGEST USING ARCATA COSTS

from a cost range of $2.00-$5.00 per 1000 gallons conveyed and treated, which was suggested from available literature (US EPA 2014).

- *Lifetime Project Costs*: Total costs of the alternative over the selected 25-year design life. These include: the predicted first-year (2019/2020) O/M (including conveyance and treatment) costs resulting from the implementation of a specific alternative spread out over a 25-year lifetime (assuming a interest rate of 1%), and the cost of upgrading the capacity of the Arcata Wastewater Treatment Facility resulting from the fraction of influent to the treatment facility attributed to I&I from the Aldergrove sanitary sewer. This lifetime cost includes the construction cost of the project.
- *Reduction in Direct Inflow:* The percent reduction in direct inflow resulting from the implementation of a specific alternative. Values for this parameter for each alternative were estimated using critical thinking/judgement and with reference to available literature on the effectiveness of the method. This direct inflow reduction criterion is assigned a weight of 1 because, while important for various reasons (i.e. it contributes to SSOs), it is not defined specifically in terms of monetary units, which is expected to be the primary driver of the City's actions.
- *Reduction in Groundwater Infiltration:* The percent reduction in extraneous groundwater entering the sanitary sewer that results from the implementation of a specific alternative. Values for this parameter for each alternative were estimated using critical thinking/judgement and with reference to available literature on the effectiveness of the method. This groundwater infiltration reduction criterion is assigned a weight of 1 because, while important for various reasons (i.e. increases magnitude of peak discharge events when direct inflow occurs), it is not defined specifically in terms of monetary units, which is expected to be the primary driver of the City's actions.

NOT SURE I UNDERSTAND THIS. A REDUCTION IN I/I LEADS TO A DIRECT SAVINGS IN OPERATIONAL COSTS IN THE COLLECTION SYSTEM (PUMPING) AND TREATMENT PLANT (PUMPING & CHEMICALS)

Table 2. Criteria Weights and the Rating Scheme Implemented to Score the Effectiveness of Each Alterative at Optimizing the Stated Criteria

Criteria	Weight (1-2)	Rating/Scoring Metric	Criteria Rating/Scoring Scheme (1-3)		
			0	1	2
Construction Costs	2	Monetary Capital Required for Project Construction and Implementation (2019 USDs)	≥ $2,000,000	$500,000 — $2,000,000	≤ $500,000
Annual O/M Costs	2	Annual Operations and Maintenance Costs for the Project, Including Conveyance and Treatment Costs for I&I (2019 USDs)	≥ $30,000	$25,000 — $30,000	≤ $25,000
Lifetime Project Costs	1	Total Project Costs over a 25-Year Design Life (USD)	≥ $6,000,000	$3,000,000 — $6,000,000	≤ $3,000,000
Reduction in Direct Inflow	1	Estimated Percent Reduction in Direct Inflow (Relative to the Current Annual Average of 3.7 Million Gallons)	Minor Reduction ≈0%—10%	Moderate Reduction ≈10%—50%	Significant Reduction ≥ 50%
Reduction in Infiltration	1	Estimated Percent Reduction in Infiltration (Relative to the Current Annual Average of 6.8 Million Gallons)	Minor Reduction ≈0%—10%	Moderate Reduction ≈10%—50%	Significant Reduction ≥ 50%

7. Description and Analysis of Project Alternatives

This section presents the developed project alternatives, included is: a description of what the alternative would entail, an estimate of the effectiveness of the project at reducing groundwater infiltration and direct/delayed inflow, an estimate of what the required capital costs would be to implement/construct the alternative (in 2019 USDs), an estimate of the annual operations and maintenance costs associated with the project (which includes conveyance and treatment costs for the resulting annual average volume of I&I entering the sanitary sewer), and an estimate of the total lifetime costs of the project over the selected 25-year design life.

(TOO) VERY A LONG SENTENCE.

Alternative A: Do Nothing / No Action

Description of Alternative

This alternative would entail taking no corrective action to reduce or eliminate infiltration or inflow into the Aldergrove sanitary sewer. If this alternative is implemented, it is assumed that in the future the average annual volume of I&I entering the sanitary sewer would be approximately equal to the historical average annual volume of 11 million gallons, which was determined from daily-total flow rate observations from 2011 to 2018.

Estimated Effectiveness

Since no corrective action would be taken to reduce or eliminate I&I, there would be no reduction in the average annual volume of I&I entering the sanitary sewer. This alternative would not be effective at reducing I&I, or reducing the conveyance and treatment costs associated with it. The rate of I&I into the sewer will continue to fluctuate, increasing in magnitude with increasing precipitation. Continued issues resulting from extraneous water entering the sewer would likely include: occasional, rain-driven sanitary sewer overflows; exceedance of the sanitary sewers hydraulic capacity and pipe/manhole surcharging; potential to cause ware-and-tear and increase degradation of pipes, pumps, and other sanitary sewer or treatment facility infrastructure; increased lift station and treatment facility pumping requirements; increased treatment costs; contributing to the treatment facilities influent flow exceeding the treatment facilities capacity; and contributing to overflow discharges from the treatment plant, among other issues.

Construction Costs

Since no corrective action would be taken, there would be no capital costs associated with the implementation of this alternative.

Alternative B: Inflow Dampening

Description of Alternative

This alternative would involve constructing a off-line flow equalization basin that would be able to absorb some of the direct inflow that enters the sanitary sewer after heavy precipitation evets [events]. The purpose of the constructed equalization basin would be to dampen out the significantly high peak flows caused by direct inflow by reducing their magnitude by 50% (shown in Figure 23). This would help alleviate some peak-flow capacity requirements of the sanitary sewer section that receives wastewater from the Aldergrove lift station. It was estimated that the required equalization basin size is ?

MISSING REST OF SENTENCE (THE PUNCHLINE)

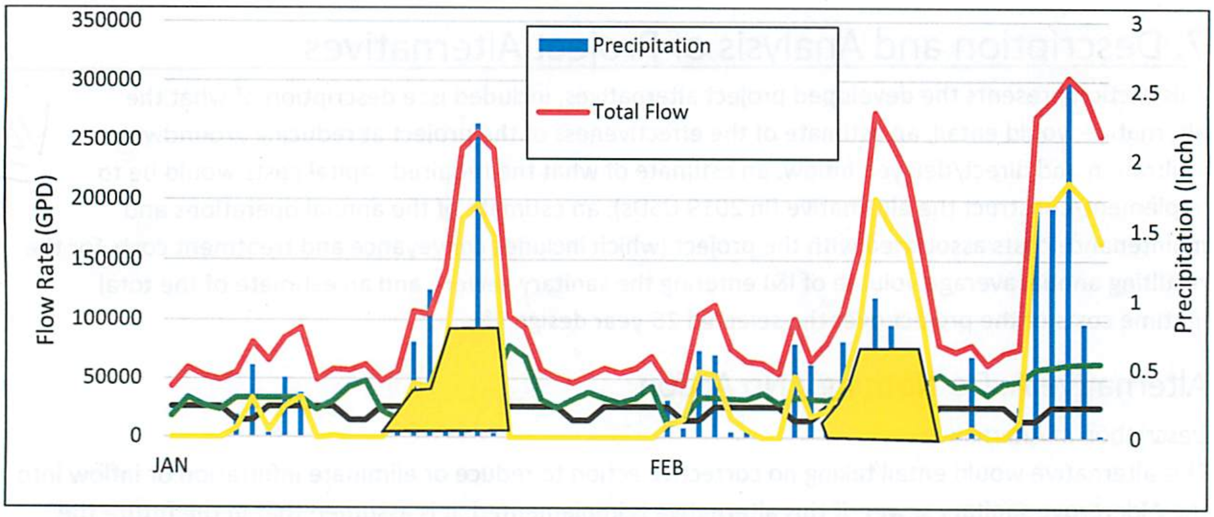

Figure 23. 2019 flowrate profile for the Aldergrove lift station. The volumes of direct inflow filled in yellow is approximately equal to the required volume of the equalization basin to dampen down the peak flowrates by approximately 50%.

Estimated Effectiveness

Using the developed algorithm to separate inflow and infiltration from total daily flow rate observations (given the base sanitary flowrate), the impact of adding a equalization basin was assessed. Data for the year of 2018 was taken as a model case. Modeling the impact of the basin was achieved by distributing the volume of direct inflow that occurred during heavy precipitation events over subsequent days after the precipitation ends—this model the storage of direct inflow. This analysis indicated that a equalization basin would decrease the annual O/M costs by roughly $5,000 (2019 USDs).

Construction Costs

The primary construction costs for this alternative is the equalization basin itself. These costs were estimated from costs for other treatment plants that were reported in available EPA literature. The basin-cost data points were, unfortunately, below the range of the basin size required for this alternative. However, the developed equation was used none the less by extrapolating to estimate the lumped-sum cost of an offline equalization basin. Using the estimated cost in 1974 dollars that was computed from the regression equation in Figure 24, the cost of a offline flow equitization basin in 2019 was computed by multiplying it by a factor computed via the future cost given present cost factor formula (ENGR 313 Course Notes, unpublished notes, 2017), assuming a interest rate of one-percent. Using the computed itemize cost for the construction of a equalization basin the total project costs for this alternative was computed (total cost estimate reported in Table 3).

WHAT IS THE SIZE?

WHAT ABOUT AVOIDED COSTS OF FINES, OVERFLOWS?

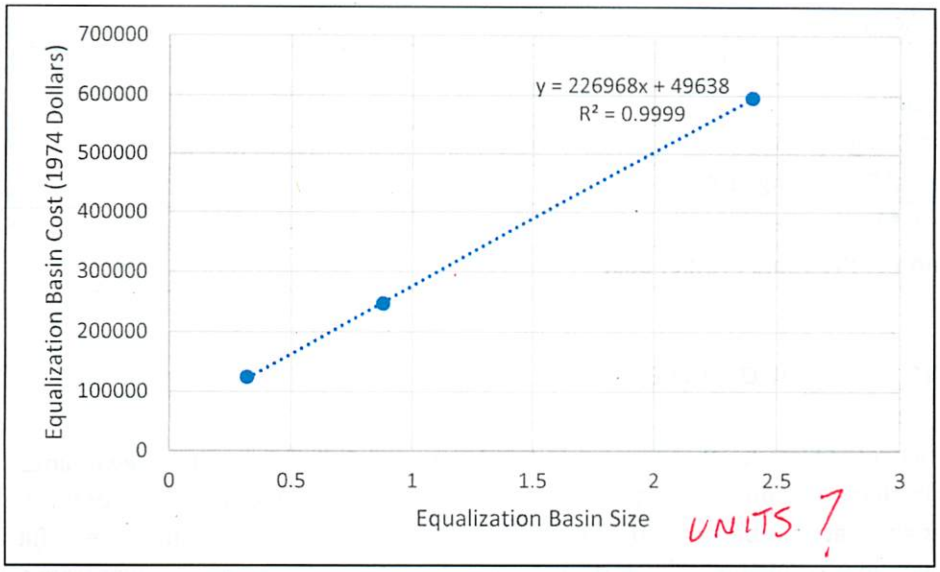

Figure 24. Equalization basin size and corresponding cost data **(EPA 1974)**.

$$Factor = (1 + i)^n \quad (1)$$

Where:

F	=	Future Cost given Present Cost
i	=	Intrest rate
n	=	Time period

Table 3. Estimated Monetary capital required to construct/implement the inflow dampening alternative.

Item #	Item Description	Approx. Quantity	Unit	Unit Price	Total Item Price
1	Mobilization and Demobilization	1	Each (EA)	$50,000.00	$50,000.00
2	Traffic Control	30	DAYS	$2,500.00	$75,000.00
3	Erosion and Sediment Control	1	Lumped Sum (LS)	$25,000.00	$25,000.00
6	Offline, Underground, Flow Equalization Basin (EPA 1974)	1	LS	$1,498,322.00	$1,498,322.
Construction Subtotal					**$1,648,322.**
Contingency (30%)					$494,000.0
Opinion of Probable Construction Cost					**$2,142,322.**
Legal/Admin (5%)					$107,000.0

DON'T USE CENTS

Land/ROW Acquisition	$100,000.0
Geotechnical Investigation (10%)	$214,000.0
Surveying (10%)	$214,000.0
Engineering Design (15%)	$321,000.0
Environmental Permitting (10%)	$214,000.0
Construction Management (15%)	$321,000.0
Total Opinion of Probable Project Cost	**$3,633,322.**

Alternative C: Dig and Replace

Description of Alternative

This alternative would involve the removal and replacement of all main sanitary sewer lines, and all lower laterals, that are connected to the Aldergrove sanitary sewer (the sewer that drains to the lift station). This alternative is based on the idea that the best way to reduce groundwater infiltrations into the main sewer lines would be to "restart" and reconstruct the entire sanitary sewer from scratch. Asbestos cement has a useful life expectance of roughly 70 years, so while that age has not yet been reached (the system was installed in the 1980s), it will eventually need to be replaced, regardless of the alternative implemented (although some alternatives may extend the life expectancy). One option is to complete this inevitable replacement right now, which would also provide a opportunity to reconstruct the sanitary sewer system in accordance with modern engineering design and construction standards—this would likely considerably decrease the rate of I&I into the system.

This alternative would involve the excavation of the existing sewer infrastructure within the City right-of-way. This would require the removal and eventual backfilling and regrading/surfacing of affected roadway surfaces, as most of sewer lines in the area are beneath roads (with typical inverts to the flow line of 6 to 10 feet from the manhole lid) (Jack Lisin, field inspection work, 2019). This alternative would also involve the reconstruction of all existing (19) sanitary sewer manholes attached to the Aldergrove sanitary sewer.

Estimated Effectiveness

It is thought that because this alternative would allow for the installation of modern sewer conveyance piping that would be constructed to modern engineering design standards, that there would be a considerable reduction in I&I into the sanitary sewer within the ROW. Therefor, it is estimated that up to 60% of the annual-average volume of groundwater infiltration into the Aldergrove sanitary sewer could be reduced, where the other 40% is assumed to come from lateral connections outside the ROW). This project would not have a significant impact on the rates of direct inflow, because inflow is though to primarily occur from sources on private property.

Construction Costs

There are significant and extensive construction costs associated with this project. Pursuant to the scope of this project, a detailed cost analysis of every aspect of this work is not conducted. Rather literature values for typical costs of excavation, trenching and shorting, and sanitary sewer main line removal and replacement were referenced and used to conduct this cost estimate. Excavation was estimated on a per-volume basis by approximating the volume of earthen material that would need to be removed to access the sewer pipe lines (this would be used as backfill after the replacement), and the cost per cubic

CHEAP CONSIDERING ROAD PAVING

yard was assumed to be $200 (Home Advisor 2019b). From a review of numerous literature sources, and reviewing past cost-estimate values used by the City of Arcata, the cost to the City of removal and replacement of sanitary sewer main lines was estimated to be $100 per linear foot (LF) of pipe removed. An estimate of the price to reconstruct an existing sanitary sewer manhole in 2017 was found to be $6,500 per manhole (City of Helotes 2017). To account for inflation and to add a minor contingency, a price of $7,500 per manhole was assumed for this project.

Table 4. Estimated Monetary capital required to construct/implement the dig and replace alternative.

Item #	**Item Description**	**Approx. Quantity**	**Unit**	**Unit Price**	**Total Item Price**
1	Mobilization and Demobilization	1	EA	$50,000.00	$50,000.00
2	Traffic Control	90	DAYS	$2,500.00	$225,000.00
3	Preliminary CCTV Inspection	1	LS	$5,000.00	$5,000.00
4	Manhole Reconstruction	18	EA	$7,500.00	$135,000.00
5	Main Line Excavation	15,253	CY	$200.00	$3,050,663
6	Trenching and Shoring	6,864	LF	$20.00	$137,280.00
7	Sanitary Sewer Main Line Removal and Replacement	6,864	LF	$100.00	$686,400.00
8	Sanitary Sewer Lateral Reconstruction	76	EA	$10,000.00	$760,000.00
9	Post Lining CCTV Inspection	1	LS	$5,000.00	$5,000.00
					$0.00
Construction Subtotal					**$5,054,343**
Contingency (30%)					$1,516,000.00
Opinion of Probable Construction Cost					**$6,570,343**
Legal/Admin (5%)					$329,000.00
Geotechnical Investigation (10%)					$657,000.00
Engineering Design (15%)					$986,000.00
Environmental Permitting (10%)					$657,000.00
Construction Management (15%)					$986,000.00
Total Opinion of Probable Project Cost					**$10,185,343**

Alternative D: Chemical Grouting

Description of Alternative

This alternative would involve injecting a chemical grouting agent into the soil matrix surrounding manhole and sewer pipe defects. This grouting agent would expand, fill air voids in the soil, and harden, which would prevent water from infiltrating into the sewer through defects. Chemical grouting would also prevent root intrusion in treated areas. Significant reduction in root intrusion has been observed for at least two to three years. Some chemical grout may end up on the inside of the sewer pipes, but would eventually break loose and be washed down the sewer system to the AWTF. Chemical grouting can be used to restore join offsets where they are not significantly large. Large offsets would require reconstruction (dig and replace) or rehabilitation with a liner to restore the pipes structural integrity. The life expectancy of chemical grout (length of time it provides infiltration elimination/reduction) is roughly 20 years. Manhole/sewer pipe rehabilitation involves drilling through the manhole/pipe wall at locations of observed defects and infiltration, and injecting grout into the surrounding soil matrix; for sewer main lines, this can be accomplished with a robot that can make the repairs and maneuver through the sewer system (as is shown in Figure 25 below) (NAASCO 2019).

Estimated Effectiveness

It was roughly estimated/assumed that chemical grouting would decrease infiltration rates by 40%.

Construction Costs

The process of applying chemical grout to sewer defects is less expensive then installing a liner. The cost per linear foot of pipe inspected for defects and grouted if they exist was assumed to be $10, which was selected with reference to literature values stipulated by the National Association of Sewer Service Companies. The cost of rehabilitating manholes was assumed (with reference to available literature values to be $1000 per manhole rehabilitated via chemical grouting (NAASCO 2019). A cost of $500 per lower lateral rehabilitated via chemical grouting was assumed with reference to a value specified in the literature of $300 (a contingency was added as actual costs vary from lateral to lateral).

Table 5. Estimated monetary capital required to construct/implement the chemical grouting alternative.

Item #	**Item Description**	**Approx. Quantity**	**Unit**	**Unit Price**	**Total Item Price**
1	Mobilization and Demobilization	1	EA	$50,000.00	$50,000.00
2	Traffic Control	30	DAYS	$2,500.00	$75,000.00
3	Preliminary CCTV Inspection	1	LS	$5,000.00	$5,000.00
4	Manhole Rehabilitation by Chemical Grouting	11	EA	$1,000.00	$11,000.00
5	Sanitary Sewer Main Line Rehabilitation by Chemical Grouting	6,864	LF	$10.00	$68,640.00
6	Sanitary Sewer Lateral Rehabilitation	76	EA	$500.00	$38,000.00
7	Post Grouting CCTV Inspection	1	LS	$5,000.00	$5,000.00
Construction Subtotal					**$252,640.0**
Contingency (30%)					$76,000.00
Opinion of Probable Construction Cost					**$328,640.0**
Legal/Admin (5%)					$16,000.00
Geotechnical Investigation (10%)					$33,000.00
Engineering Design (15%)					$49,000.00
Environmental Permitting (10%)					$33,000.00
Construction Management (15%)					$49,000.00
Total Opinion of Probable Project Cost					**$508,640.0**

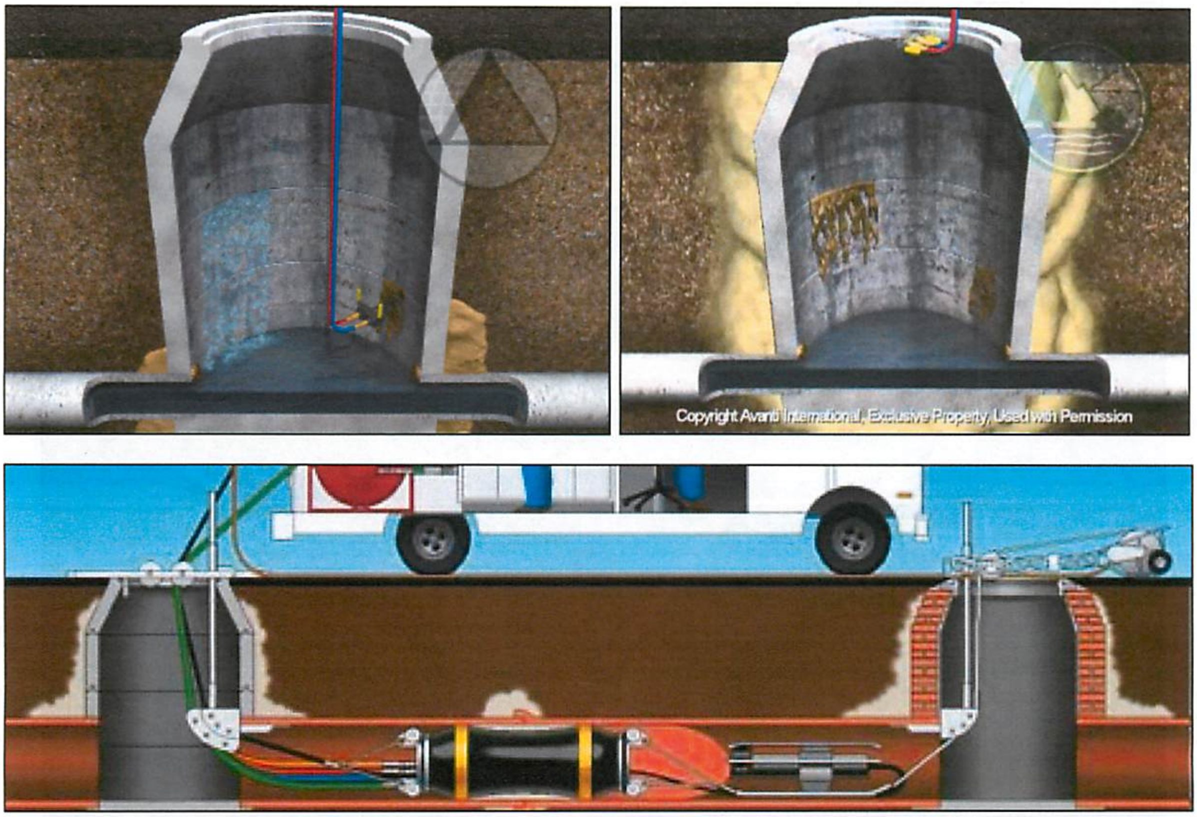

Figure 25. Conceptual overview of the chemical grouting process for manhole rehabilitation (top) and sanitary sewer main line rehabilitation (bottom) **(Amazon 2019) (BlueBook 2019)**.

Alternative E: CIPP Lining

Description of Alternative

This alternative would be a infiltration reduction project that would also serve to restore the structural integrity and functionality of rehabilitated manholes, sanitary sewer main lines, and sanitary sewer laterals; the project would involve the rehabilitation of 11 of the 19 manholes connected to the Aldergrove sanitary sewer, the rehabilitation of all sanitary sewer laterals for the 76 parcels with active connections, and the rehabilitation of the 1.46 miles of sanitary sewer main lines with cure-in-place pipe-within-a-pipe. Cured-in-place pipe essentially involves inflating a fabric sock that has been impregnated with an epoxy resin that is inflated and expanded along the interior of the sanitary sewer pipes and which is heat cured to harden in place (process shown in Figure 26). The result is some structural rehabilitation and sealing off of the sewer pipe. Sanitary sewer laterals would be rehabilitated using T linters that protrude up into sanitary sewer laterals, sealing the connections and preventing infiltrations/seepage through the joint, as well as providing structural rehabilitation and infiltrations reduction for the lower lateral (CoA 2019b).

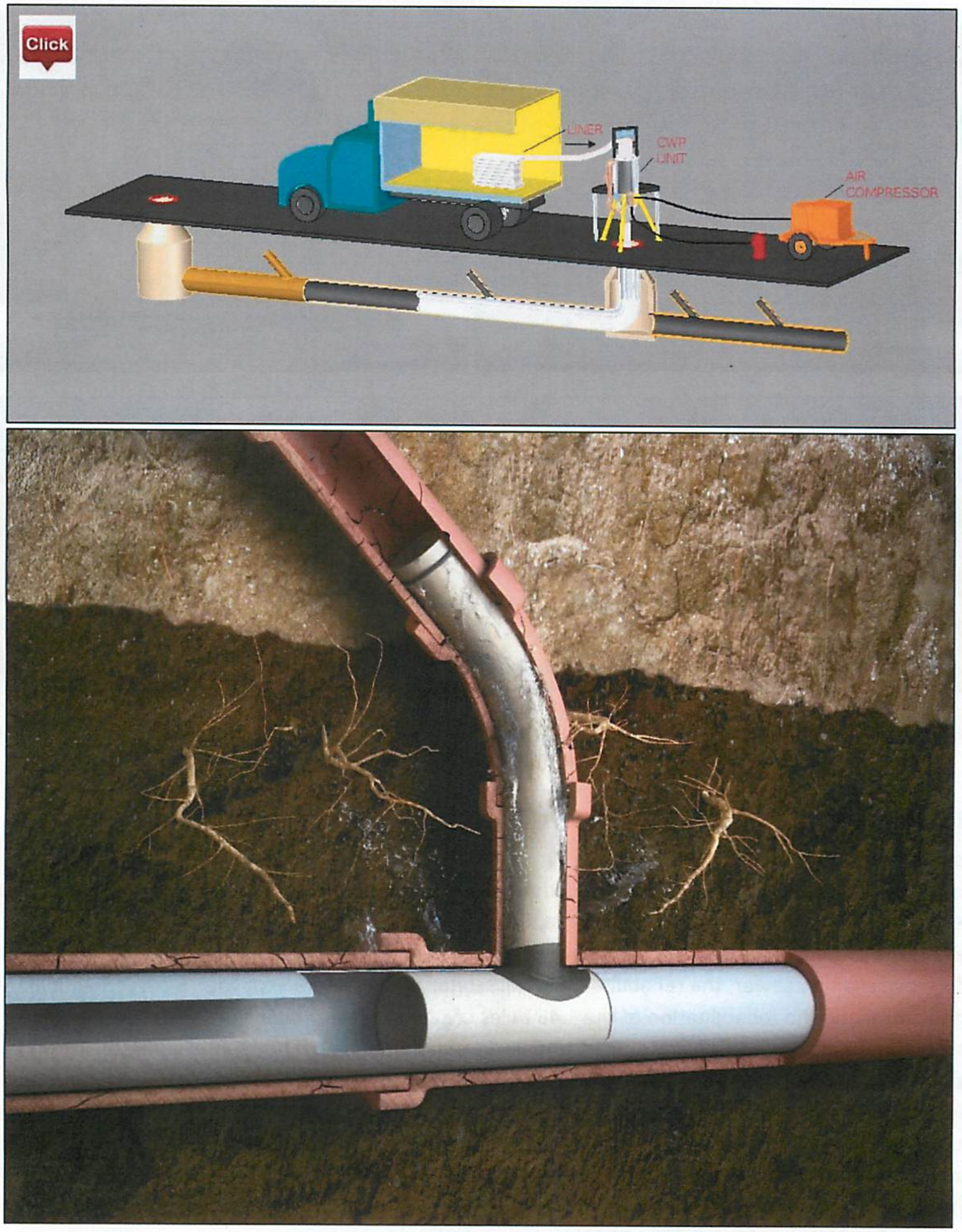

Figure 26. Schematic of the process of lining sanitary sewer pipe lines with cured-in-place pipe (CoA 2019b).

Estimated Effectiveness

Manhole and sewer pipe lining usualy is more effective at reducing infiltration compared to grouting, because the entire length of pipe is rehabilitated and sealed off by the liner. It was assumed that lining would produce a slightly greater percent reduction in groundwater infiltration then grouting would, and would produce a reduction slightly less then the dig and replace alternative. Therefore, it was assumed the if this alternative were implemented, annual infiltration rates would be reduced by 50-percent.

Construction Costs

Costs were assumed to be roughly 5 times that of chemical grouting on a per-linear foot basis, as was suggested in referenced literature sources (NAASCO 2019) (Heinselman 2019). So, it was assumed that sanitary sewer mainline rehabilitation by cured-in-place-pipe (CIPP) lining would cost approximately $50 per linear foot lined. Likewise, manhole rehabilitation were assumed to cost $5000 per manhole rehabilitated (as shown in the itemized cost list in Table 6).

Table 6. Estimated monetary capital required to construct/implement the infiltration reduction by cured-in-place pipe lining alternative.

Item #	**Item Description**	**Approx. Quantity**	**Unit**	**Unit Price**	**Total Item Price**
1	Mobilization and Demobilization	1	EA	$ 10,000	$ 10,000
2	Traffic Control	15	DAYS	$ 2,500	$ 37,500
3	Preliminary CCTV Inspection	1	LS	$ 5,000	$ 5,000
4	Manhole Rehabilitation by CIPP Lining	11	EA	$ 5,000	$ 55,000
5	Sanitary Sewer Main Line Rehabilitation by CIPP Lining	6,864	LF	$ 50	$ 343,200
6	Sanitary Sewer Lateral Rehabilitation by CIPP Lining	76	EA	$ 2,500	$ 90,000
7	Post Lining CCTV Inspection	1	LS	$ 5,000	$ 5,000
				Construction Subtotal	**$ 645,700**
				Contingency (30%)	$ -
				Opinion of Probable Construction Cost	**$ 645,700**
				Legal/Admin (5%)	$ 32,000
				Geotechnical Investigation (10%)	$ 65,000
				Engineering Design (15%)	$ 97,000
				Environmental Permitting (10%)	$ 65,000
				Construction Management (15%)	$ 97,000
				Total Opinion of Probable Project Cost	**$ 1,001,700**

Alternative F: Private Sewer Lateral Replacement

Description of Alternative

This alternative would involve the City of Arcata rehabilitating (paying for it) all 76 private property sewer lateral connections in the West End Industrial Zone. The primary objective of this project would be to reduce/eliminate infiltration into the sanitary sewer from degraded private property laterals, which would not otherwise be repaired (at least in a timely manner).

Sewer laterals can degrade overtime and defects can form which can lead to groundwater infiltrating into them and entering the sanitary sewer. It is thought that a significant portion of the inflow and infiltration that occurs in Arcata comes from private sewer laterals, primarily because the City has not historically conducted routine inspections and maintenance of them. Sewer laterals, like main sewer lines, can corrode, crack, an suffer root penetration. It is not uncommon for defects in sewer laterals to be present, with or without the property owner's knowledge, for long periods of time after they form.

Currently, City of Arcata Ordinance 1461 mandates CCTV inspection of private property sanitary sewer laterals for buildings and homes that are more than 25 years old, when the property is being sold (or remodeling projects greater than $30,000). If the inspection indicates that repairs are needed, they must be completed prior to the house being sold (CoA 2019d). This mandate may prove effective, but it will take time for changes to be realized. One option is for the City to take on the burden of paying for the repair of all lower and upper private property sewer lateral connections in the West End Industrial Zone. It is expected that the structural integrity of many lateral connections in Aldergrove is defective, as many of them date to the time before the sanitary sewer was installed in the 1980s (when the few developed private property's in the area had individual septic systems). Therefore, cured-in-place pipe should be an effective solution to both restore the structural integrity of the lateral, and prevent groundwater infiltration into the lateral. It is likely that some laterals would need to be replaced entirely, possibly due to extreme pipe sags, which would limit the ability to line the pipe.

Estimated Effectiveness

It is estimated/assumed that roughly 40% of groundwater infiltration occurs through private sewer laterals. To confirm this estimate, pinpoint flow analysis would need to be conducted, which is beyond the scope and time constraints of this project.

Construction Costs

Required construction costs to rehabilitate or replace the 76 live (actively contribution wastewater to the sanitary sewer) private property sewer lateral connections include contractor and equipment mobilization and demobilization, traffic control (estimated 60 days to do all 76), preliminary and post-work CCTV inspection of every lateral, and sanitary sewer lateral reconstruction. Each lateral connection differs in length, diameter, material type, type (pressure vs gravity), and severity of defects. This variation will create variation in the required capital to reconstruct/rehabilitate each lateral—not all will cost the same. However, as no CCTV inspection footage was obtained or reviewed for the individual laterals, a refined/accurate estimate for each lateral is impossible to obtain. To obtain an average cost estimate that could be applied to each lateral, a review of the available literature on the matter was conducted; this review indicated that the range in costs was roughly between $5,000 and $25,000 to rehabilitate and/or repair sanitary sewer laterals (repairing being more expensive). (Express Sewer and Drain 2019) (Home Advisor 2019a) (Cost Helper 2019). To make a conservative cost estimate, the upper limit of this range was selected as the cost of rehabilitation or replacement that was applied to each of the 76 lateral connections, which yielded a required capital of almost two million dollars to rehabilitate or repair all of the laterals. These itemized costs are reported in Table 7.

Table 7. estimated monetary capital required to construct/implement the private sewer lateral replacement alternative.

Item #	Item Description	Approx. Quantity	Unit	Unit Price	Total Item Price
1	Mobilization and Demobilization	1	EA	$50,000.00	$50,000.00
2	Traffic Control	60	DAYS	$2,500.00	$150,000.00
3	Preliminary CCTV Inspection	1	LS	$5,000.00	$5,000.00
8	Sanitary Sewer Lateral Reconstruction	76	EA	$25,000.00	$1,900,000.00
9	Post Lining CCTV Inspection	1	LS	$5,000.00	$5,000.00
					$0.00
Construction Subtotal					**$2,110,000.0**
Contingency (30%)					$633,000.00
Opinion of Probable Construction Cost					**$2,743,000.0**
Legal/Admin (5%)					$137,000.00
Geotechnical Investigation (10%)					$274,000.00
Engineering Design (15%)					$411,000.00
Environmental Permitting (10%)					$274,000.00
Construction Management (15%)					$411,000.00
Total Opinion of Probable Project Cost					**$4,250,000.0**

Alternative G: Direct Inflow Reduction

Description of Alternative

This alternative would involve the implementation of a project to identify, document, and remove unauthorized and illicit connections to the sanitary sewer. Possible illicit connection sources include gutter drains (depicted in Table 11), lateral cleanouts, drains, and sump pumps (see Section 1 for more details on sources of direct inflow). This project would entail a professional work crew (possibly City staff or a contractor) conducting CCTV inspection of all sewer lines and private property sewer lateral connections in the area, as well as smoke testing of all sewer and lateral lines in the area, dye testing near probably locations of storm-sanitary sewer cross connections, and private property inspections to identify and document existing storm, water service, and sanitary sewer infrastructure and connections. Detailed maps and inspection reports would be developed for each parcel and provided to the City for record keeping. Pending approval from the Arcata City Council, cease and desist orders would be sent out by the City's Environmental Services department, which would

Figure 27. Photo of an Arcata resident disconnecting a storm drain that was connected to the sanitary sewer **(CoA 2019e)**.

mandate that private property owners disconnect the identified and documented illicit/unauthorized connections. Other defects discovered would be documented for the Engineering departments consideration. Follow up CCTV and smoke testing would be conducted to ensure property owner compliance with the cease and desist order.

Estimated Effectiveness

It is hard to estimate what fraction of direct inflow comes from private property sources. For this project, it was assumed that roughly 80% of all inflow could be reduced with detailed and thorough property inspection aided by CCTV review of sewer lateral connections and smoke/dye testing.

Construction Costs

Based off of the limited property inspections conducted during this project, it is estimated that it would take roughly 120 manhours to conduct the private property and smoke testing for all 76 parcels in the West End Industrial Zone. It was assumed that any required CCTV inspection or smoke/dye testing work that could impact traffic (and require traffic control) could be conducted in 5 days. A review of online retail providers indicated that a smoke test machine would cost roughly $1500, and a total liquid-smoke cost of $500 (Rental Tools Online 2019).

Table 8. Estimated monetary capital required to implement the direct inflow reduction alternative.

Item #	Item Description	Approx. Quantity	Unit	Unit Price	Total Item Price
1	Mobilization and Demobilization	1	EA	$10,000.00	$10,000.00
2	Traffic Control	5	DAYS	$2,500.00	$12,500.00
3	Preliminary Review of Building Plans / As-Builts	40	HRS	$60.00	$2,400.00
4	Smoke Test Machine	1	LS	$1,500.00	$1,500.00
5	Liquid Smoke Source	1	LS	$500.00	$500.00
6	Inspection & Smoke Testing Work	120	HRS	$40.00	$4,800.00
7	Post Inspection Documentation of Determined Information	40	HRS	$60.00	$2,400.00
8	Follow Up Inspection and Smoke Testing	60	HRS	$40.00	$2,400.00
					$0.00
				Construction Subtotal	**$36,500.00**
				Contingency (30%)	$11,000.00
				Opinion of Probable Construction Cost	**$47,500.00**
				Legal/Admin (5%)	$2,000.00
				Total Opinion of Probable Project Cost	**$49,500.00**

O/M and WWTP Upgrade Contribution Cost Estimation

Reported below is discussion of the methodology and implementation of estimating what the annual operations costs would be for each alternative, given their estimated percent reductions in infiltration and inflow. Also computed was the fractional contribution to the cost of expanding the capacity of the AWTF of I&I from Arcata.

Annual Operations and Maintenance Cost Estimate

To approximate annual O/M costs for different estimated average annual volumes of I&I (which were obtained from the percent reduction in infiltration or inflow and the average annual volumes for said parameters that were determined from historical data), the average annual conveyance and treatment costs for the I&I that occurred in the years from 2011 to 2018 was estimated, and then was plotted with respect to the corresponding average annual volume of I&I (estimated from the historical flowrate analysis). The annual conveyance and treatment cost estimates for the historical flowrate data was based upon the EPA suggested cost per 1000 gallons of \$2-5\$ dollars (application discussed in Section 4). There is an approximately linear relationship between the two parameters (as is shown in **Figure 28** below); therefor the obtained regression equation was used to approximate the resulting annual O/M costs (in 2019 UDSs) corresponding to given percent reductions in the average-annual I&I volume (due to the implementation of a given design alternative). This analysis shows that the do nothing alternative, which corresponds to the average-annual I&I volume of roughly 10.5 million gallons (based on historical lift station flowrate data), has an estimated annual O/M cost of approximately \$35,000—this was the baseline cost that the scoring metric for the annual O/M criterion was based upon (see Section 6 below) and the baseline the other alternatives were judged from. This cost analysis quantified the resulting annual volume (from the implementation of a alternative) of groundwater infiltration separately from the volume of direct and delayed inflow (lumped together). As the estimate for the baseline (do nothing) average-annual I&I volume was based on delayed inflow and groundwater infiltration lumped together, an assumption had to be made about the fraction of said estimate that's comprised of delayed inflow (vs groundwater infiltration). This method of estimating the O/M costs was implemented because the different alternatives were estimated to reduce inflow (direct and delayed) and groundwater infiltration by different percentages. Therefore, the O/M cost estimate had to be based on inflow and based on infiltration separately.

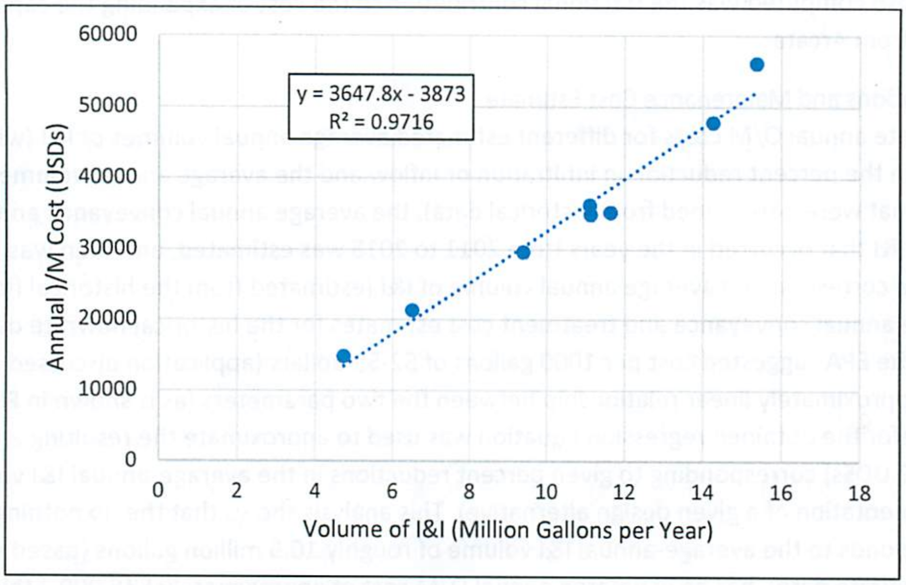

Figure 28. Total annual O/M costs with respect to average-annual volume of infiltration and inflow (volumes lumped together). Developed from historical total-daily flowrate data for the Aldergrove lift station from 2011-2018. Monetary O/M costs in 2019 US dollars.

Monetary Contribution to Arcata Wastewater Treatment Facility Capacity Upgrade Project

The estimate of the fractional contribution to the cost of the upcoming capacity upgrade for the Arcata Wastewater Treatment Facility is based on an analysis of 2018 influent flowrate data to the AWTF, which determined that the annual-total influent flow was 627 million gallons. In 2018, the annual volume of I&I in Aldergrove was approximately 11.5 million gallons. This corresponds to a fraction of approximately 0.02; this is the basis for the assumption that 2% of the required capital cost for the upcoming AWTF capacity/treatment system upgrade project is attributed to inflow and infiltration into the sanitary sewer in Aldergrove. Interestingly, the length of sewer line in Aldergrove is roughly 2% of the total length of sanitary sewer line in the City. The estimate of the contribution to the required treatment plant capacity upgrade was based on the assumption that said project would cost approximately $60,000,000 dollars. Using this outlined methodology and the regression equation in Figure 11, the annual O/M costs and treatment plant capacity upgrade contribution cost was estimated for each alternative (results of the application reported in Table 9).

Table 9. Inputs and outputs to the cost analysis scheme (regression equation reported in Figure 11 above) to estimate annual O/M costs, spread those costs out over the 25-year design life to obtain lifetime O/M costs, and an estimate of the fractional contribution of the average annual volume of I&I that would result from the implementation of the stated alternative to the roughly = $60,000,000 dollar cost of upgrading the AWTF.

Alternative	**Inflow Percent Reduction**	**Infiltration Percent Reduction**	**Estimated Annual Volume of Inflow (Million Gallons)**	**Estimated Annual Volume of Infiltration (Million Gallons)**	**Total I&I Volume**	**Total I&I Cost**	**Lifetime O/M**	**Contribution to WWTP Expansion Cost**
	Input	Input	Output	Output	Output	Output	Output	Output
Do Nothing	0	0	5.40	5.10	$11	$34,429	$3,725,000	$1,380,000
Inflow Dampening	0	0	5.40	5.10	$11	$34,429	$3,735,000	$1,380,000
Direct Inflow Reduction	80	0	1.08	5.10	$6	$18,670	$2,000,000	$803,828
Chemical Grouting	0	40	5.40	3.06	$8	$26,987	$2,920,000	$1,071,770
CIPP Lining	0	50	5.40	2.55	$8	$25,127	$2,720,000	$1,004,785
Dig and Replace	10	60	4.86	2.04	$7	$21,297	$2,300,000	$870,813
Private Sewer Lateral Replacement	10	40	4.86	3.06	$8	$25,018	$2,700,000	$1,004,785

6. Application of Alternative Screening Mechanism

The Delphi method (discussed in Section 4) was applied to the 8 developed alternatives to evaluate and assesses the achievement and optimization of the project criteria by each alternative. Using the developed criteria weighting scheme (reported in Section 6), the alternatives were scored a value of 0-2 for their optimization of the alternative (based off of the defined scheme Table 2). The inputs to this method were obtained from the estimated I&I reduction efficiencies and cost estimates for the developed alternatives (and are reported in Table 10 below). Multiplying the alternatives scores for each criterion by the weight of each alternative yielded weighted criterion scores for each alternative. These values (for each criterion for each alternative) were summed (as is reported in Table 11 below) to obtain total weighted scores for each alternative. The alternative with the highest weighted score was defined as the 'winner' of the Delphi method and thus the recommended alternative for implementation, pending final/other considerations. Application of the Delphi method using the estimated percent reductions in infiltration and inflow by each alternative, and the estimated capital, O/M, and treatment plant capacity expansion contribution costs (all as inputs to the criteria scoring scheme), indicated that Alternative G: Direct Inflow Reduction is the winning alternative with a weighted score of 12. This is 4 points higher than the next-best (or highest scored) alternative, which is chemical grouting. Chemical grouting and lining, while relatively cheap in capital, were not nearly as cheap as the direct inflow reduction alternative—yet they had similar impacts on reducing annual O/M and thus lifetime O/M costs. Interestingly, the do nothing alternative earned a weighted score of 5, while the direct inflow dampening scored a zero in all categories. This (low score) is caused by the large required capital costs ($3.7 million), and the only minor reduction in annual O/M costs. The dig and replace, while requiring lots of capital, was deemed to be a better option the do nothing alternative—likely due to the estimated significant reduction in annual O/M costs. The private sewer lateral replacement scored the same as the dig and replace alternative, likely due to the high initial capital required, and the only 40% estimated reduction in infiltration rates. What is notable about this alternative, however, is that it is the only alternative that would address infiltration into upper sewer laterals on private property. The other alternatives max out at infiltration reduction efficiencies of 60%, due to the assumptions made by this project. If the remaining fraction of infiltration into the sanitary sewer were to be addressed, Alternative G (private sewer lateral replacement) would need to be implemented. The reason the direct inflow alternative ~~won~~ received the greatest weighted score by the Delphi method is because of its low capital costs ($50,000) and corresponding low in O/M costs ($19,000 opposed to $35,000 for the do nothing alternative and $25,000 for CIPP lining, and $27,000 for chemical grouting). Also, the lifetime costs associated with Alternative G ($3,000,000) are much lower than those for all other alternatives (CIPP lining and chemical grouting are tied for second lowest lifetime costs at $4,500,000 over 25 years). Therefor, the results of the efficiency and cost analysis, and application of the Delphi method, indicate that the most prudent alternative for implementation, due to its high cost-effectiveness, is Alternative G: Direct Inflow Reduction.

MAKES SENSE
PUTS MOST OF THE "COST" ON THE PROPERTY OWNER
WITH THE CITY GETTING ALL OF THE BENEFITS.

Table 10. Input Values for the Rating Metric Scheme (Implemented in Table 4) for the Stated Criteria and Alternative

Alternative	Construction Costs	Annual O/M Costs	Lifetime Project Costs	Reduction in Infiltration	Reduction in Inflow
Do Nothing	$0	$35,000	$5,000,000	No Reduction	No Reduction
Inflow Dampening	$3,700,000	$30,000	$9,000,000	No Reduction	No Reduction
Dig and Replace	$10,000,000	$21,000	$13,000,000	60% Reduction	10% Reduction
Chemical Grouting	$500,000	$27,000	$4,500,000	40% Reduction	No Reduction
CIPP Lining	$1,000,000	$25,000	$4,500,000	50% Reduction	No Reduction
Private Sewer Lateral Replacement	$1,300,000	$25,000	$5,000,000	40% Reduction	10% Reduction
Direct Inflow Reduction	$50,000	$19,000	$3,000,000	No Reduction	80% Reduction

Table 11. Scores and Weighted Scores (Underlined) for Each Project Alternative's Optimization of the Stated Criteria

Alternative	**Score and Weighted Score for the Stated Alternatives Optimization of the Stated Criteria (with the Stated Weight)**										**Total Weighted Score of the Stated Alternative**
	Construction Costs (2)		Annual O/M Costs (2)		Lifetime Project Costs (1)		Reduction in Infiltration (1)		Reduction in Inflow (1)		
Do Nothing	2	_4_	0	_0_	1	_1_	0	_0_	0	_0_	5
Inflow Dampening	0	_0_	0	_0_	0	_0_	0	_0_	0	_0_	0
Dig and Replace	0	_0_	2	_4_	0	_0_	2	_2_	0	_0_	6
Chemical Grouting	2	_4_	1	_2_	1	_1_	1	_1_	0	_0_	8
CIPP Lining	1	_2_	1	_2_	1	_1_	2	_2_	0	_0_	7
Private Sewer Lateral Replacement	1	_2_	1	_2_	1	_1_	1	_1_	0	_0_	6
Direct Inflow Reduction	2	_4_	2	_4_	2	_2_	0	_0_	2	_2_	**12**

Recommendations and Conclusions

It is recommended that the City implements the winning alternative of the Delphi method, Alternative G: Direct Inflow Reduction, because of the combination of its low capital costs, low resulting O/M costs, and low lifetime costs. However, in consideration of the ongoing 2018 City of Arcata Sanitary Sewer Infiltration Reduction project, and the potential for decreased legal, mobilization, and other project costs, it is also recommended that the City implements alterative E: CIPP lining. While the required capital cost of lining makes the alternative less attractive over the 25-year lifetime then the direct inflow reduction alternative (as shown in Figure 1), the fact that it would rehabilitate the structural integrity of the sewer and likely extended its lifetime makes it an attractive alternative. Because the City is currently involved in a large scale CIPP lining project, it may be prudent for the City to seek lining of the Aldergrove sanitary sewer during or immediately the construction/implementation of the 2018 infiltration reduction project, as the capital costs may be cheaper at that time then others (since the contractors are already mobilized in the City).

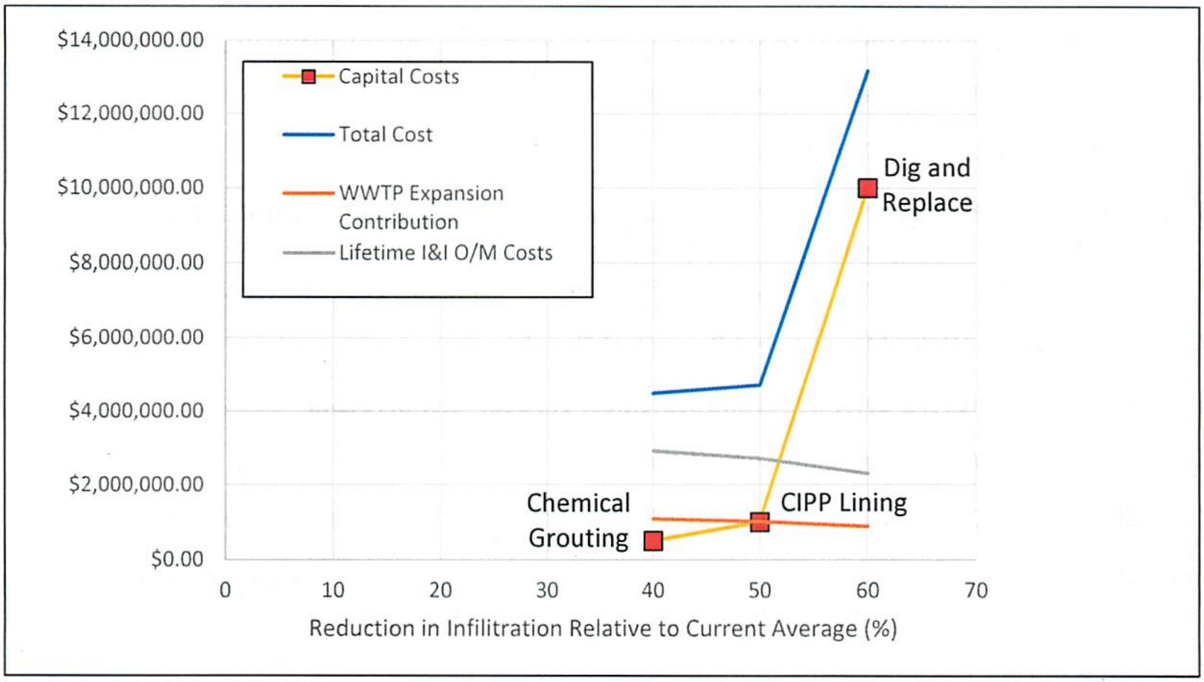

Figure 29. Cost curves for the different components of alternative costs for the three stated sanitary sewer main line infiltration reduction alternatives.

This report showed that inflow and infiltration into the Aldergrove sanitary sewer is a significant problem that results in high operations and maintenance (conveyance and treatment) costs for the City, and that it is economical for the City to pursue a variety of options to attempt to reduce rates of infiltration and inflow. The project showed that while infiltration is a serious issue that should be addressed, direct inflow poses a greater danger in terms of the potential to exceed the hydraulic capacity of the sewer and cause overflows, and the fact that peak flows require increases it maximum capacity limits for the entire sewer system, lift station pumps, and the wastewater treatment plant. Development of design alternatives and analysis of their cost and effectiveness indicated that the City has numerous viable options to address I&I, and that reducing direct inflow via property inspections and reducing infiltration either via cured-in-place pipe lining or chemical grouting would be cost-effective methods to reduce I&I.

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Appendix A: Historical Flow Analysis Results

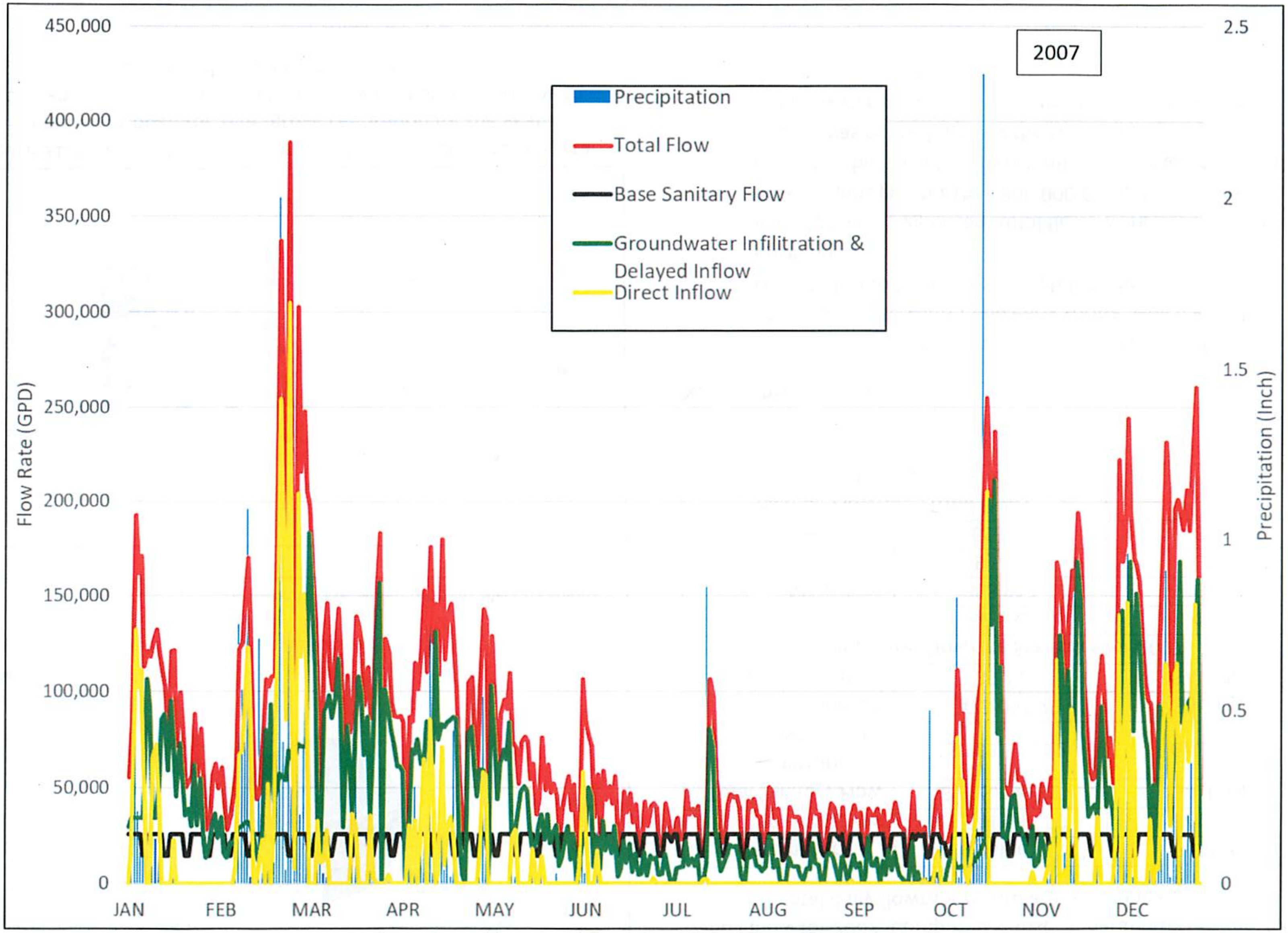
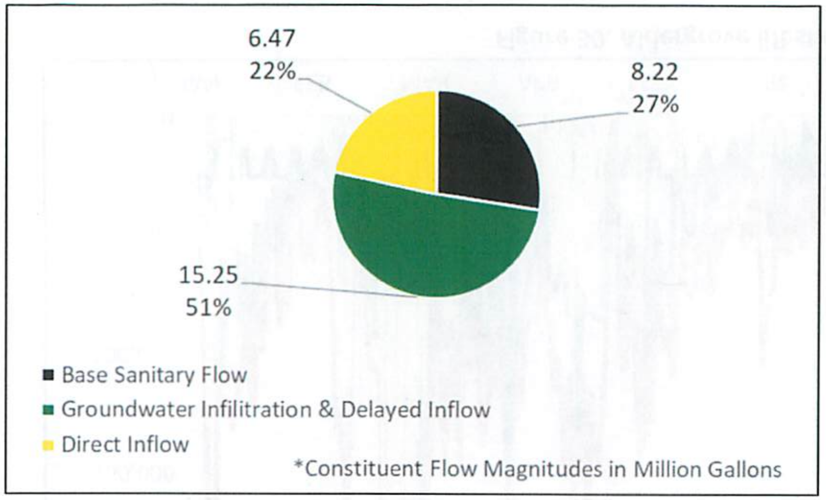


Figure 30. Aldergrove lift station flowrate profile for 2007

Sample flow analysis results for 1-year



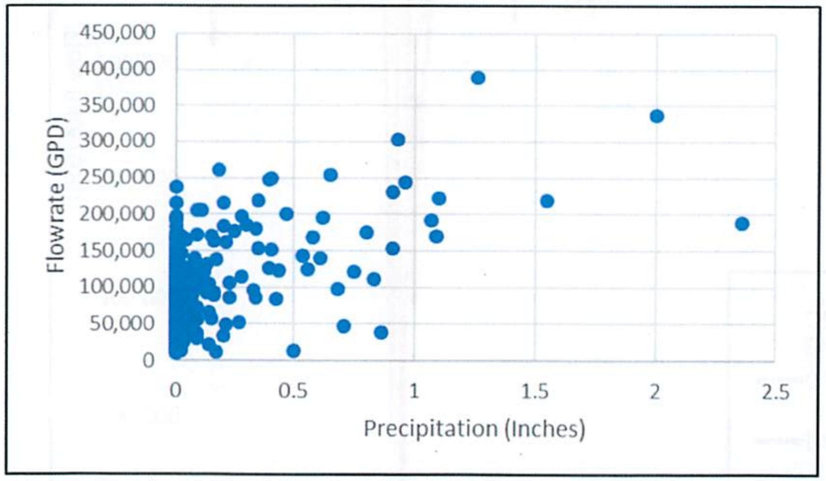


Figure 31. Flow contributions from constituent sources to the total flow pumped through the Aldergrove Lift Station for the year 2007 (top), and a scatter plot of total daily flowrate observations with respect to daily precipitation (bottom).

Table 12. Estimated volumes of sanitary baseflow and infiltration and inflow for 2007. Computed statistical parameters of the 2007 total daily flowrate record are reported as well.

Parameter	Value	Units
Total Flow	29,941,646.50	GALLONS
Total Sanitary Flow	8,215,180.59	GALLONS
Total Infiltration & Delayed Inflow	15,253,371.12	GALLONS
Total Inflow	6,473,094.79	GALLONS
Total Precipitation	35.11	GALLONS
Daily Total Flowrate Statistics for 2007		
Average	82,032	GPD
Maximum	388,913	GPD
Minimum	9,553	GPD
Standard Deviation	61358	GPD
Rainfall-Flowrate (Total Flow) Correlation Coefficient		0.55

Notes/Observations:

- Significant rates of infiltration and/or delayed inflow occurred in late winter and early spring, which greatly contributed to the observed high total flowrate observations.
- In early march, significant total flows were observed (three observations greater than 300,000 GPD). These were caused by high levels of direct inflow; the magnitude of the impact was exacerbated by the simultaneous high groundwater infiltration rate (which was approximately 75,000 GPD at that time).

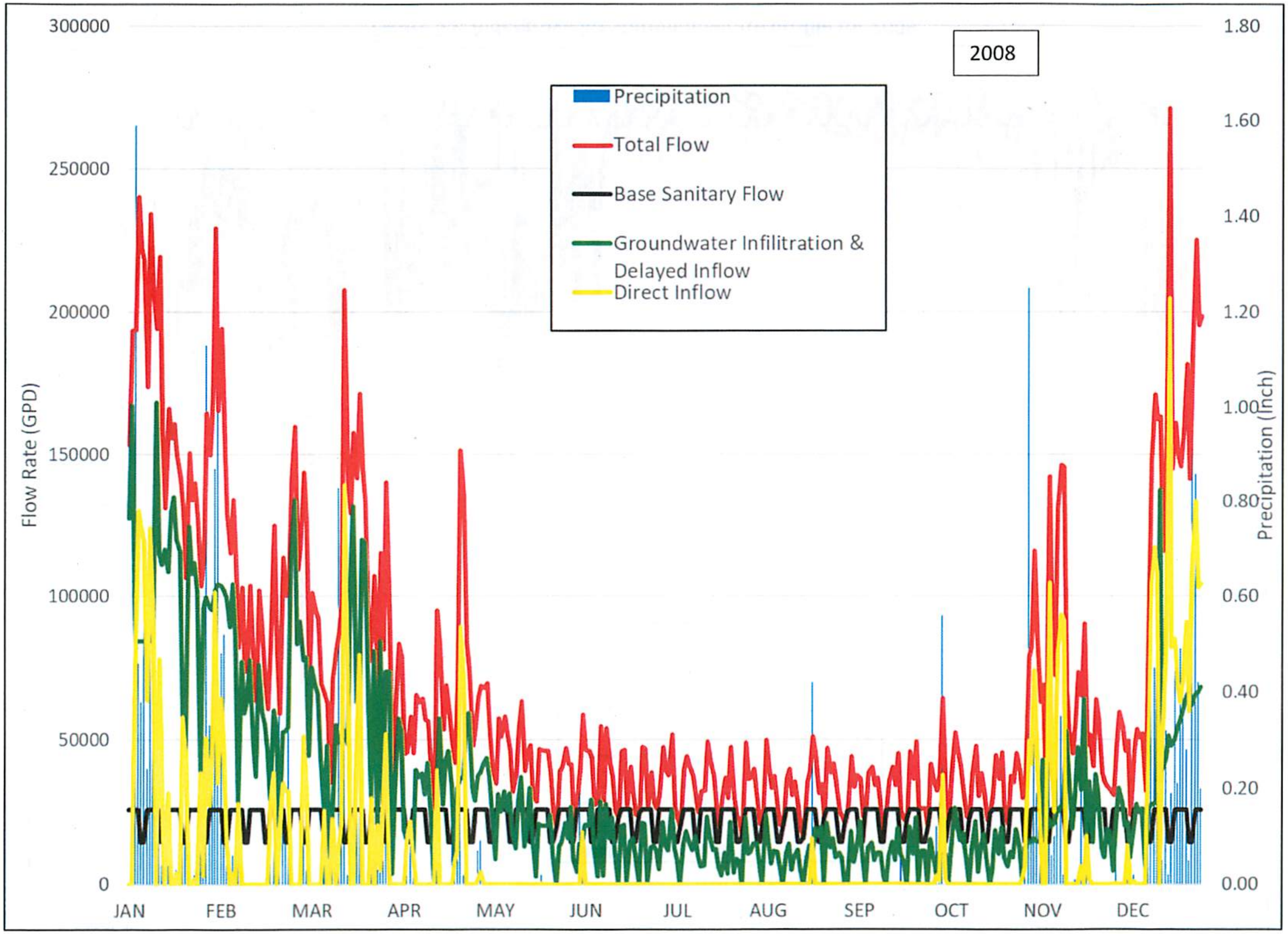


Figure 32. Aldergrove lift station flowrate profile for 2008

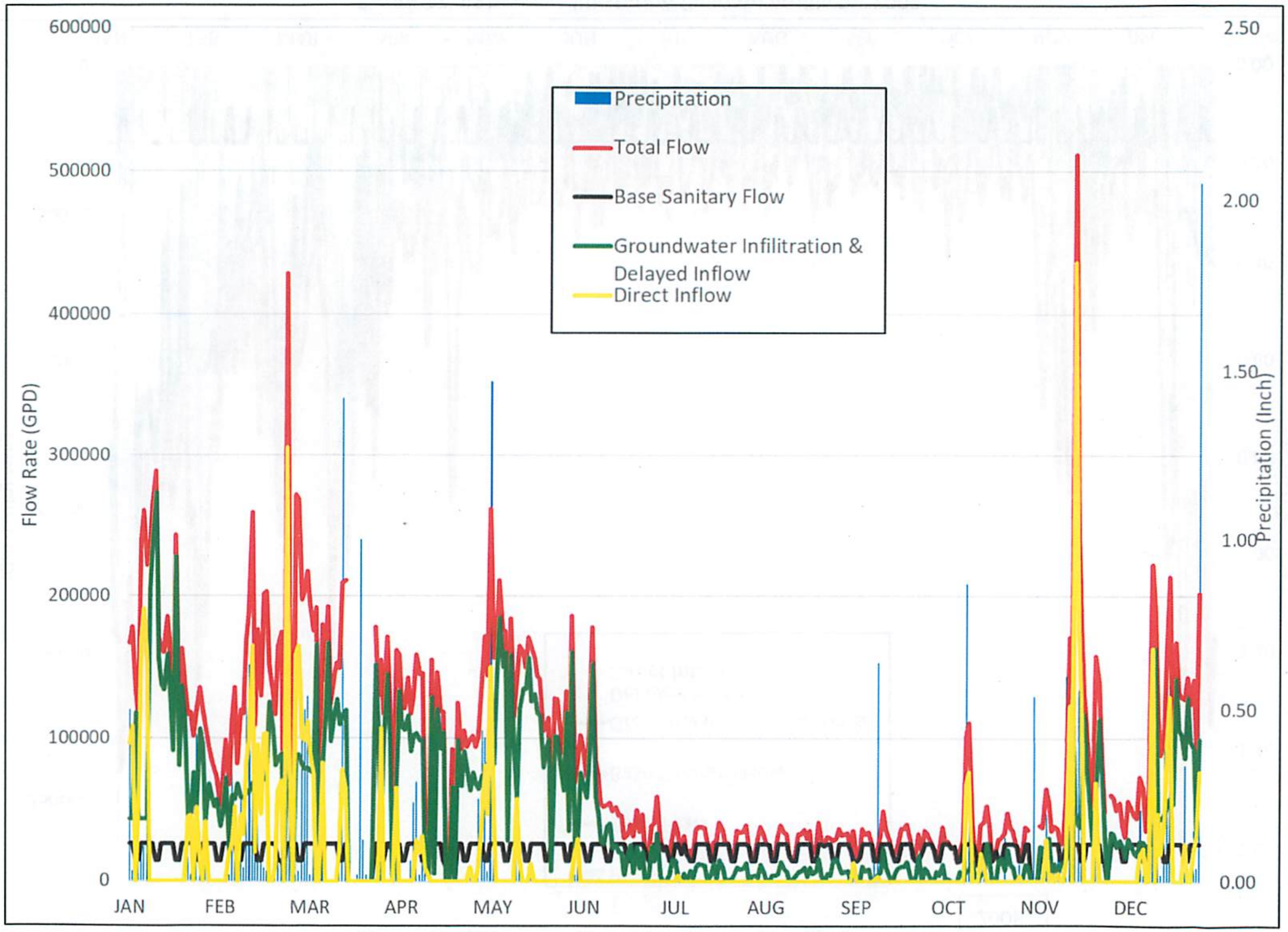


Figure 33. Aldergrove lift station flowrate profile for 2009

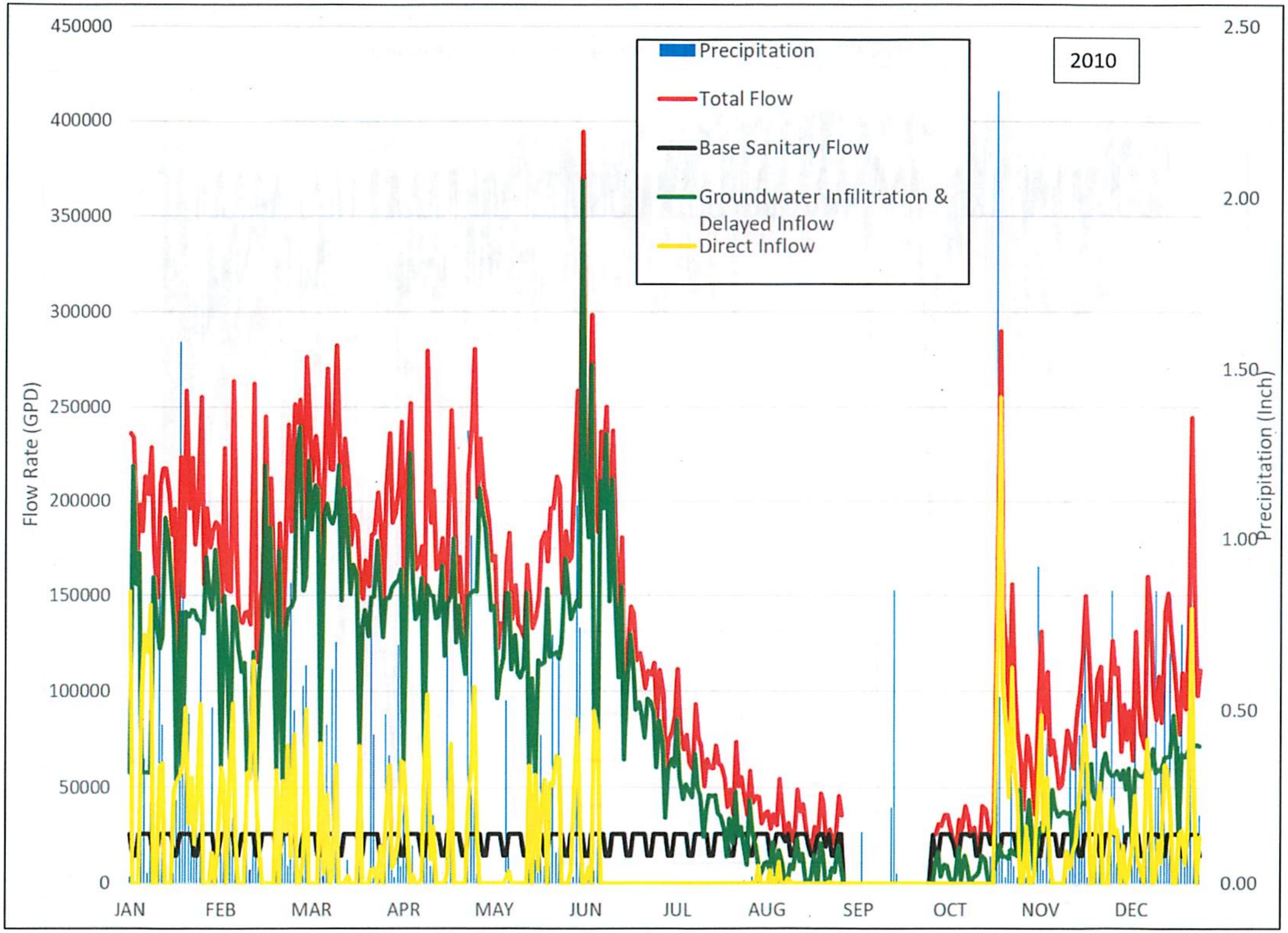


Figure 34. Aldergrove lift station flowrate profile for 2010

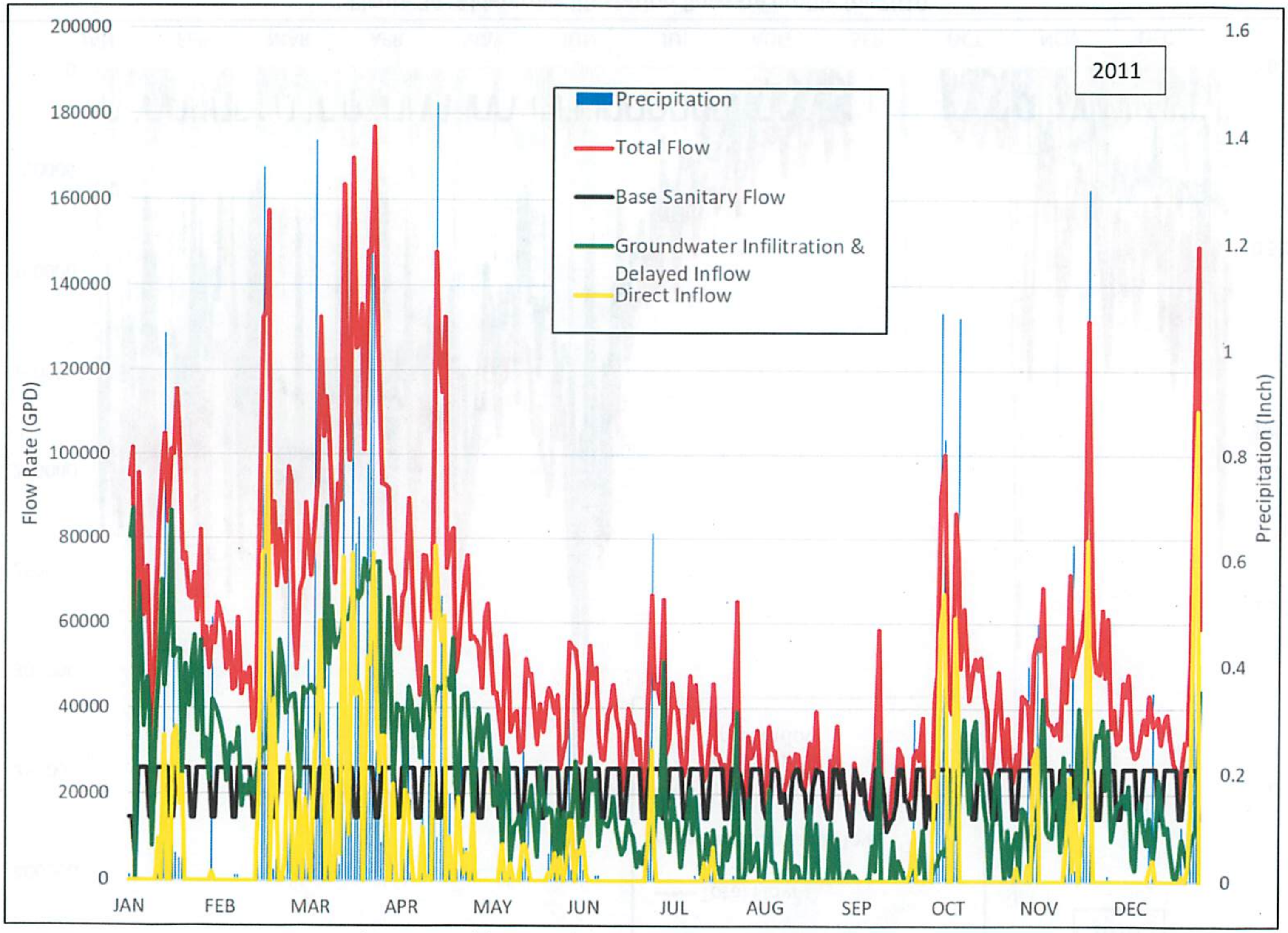


Figure 35. Aldergrove lift station flowrate profile for 2011

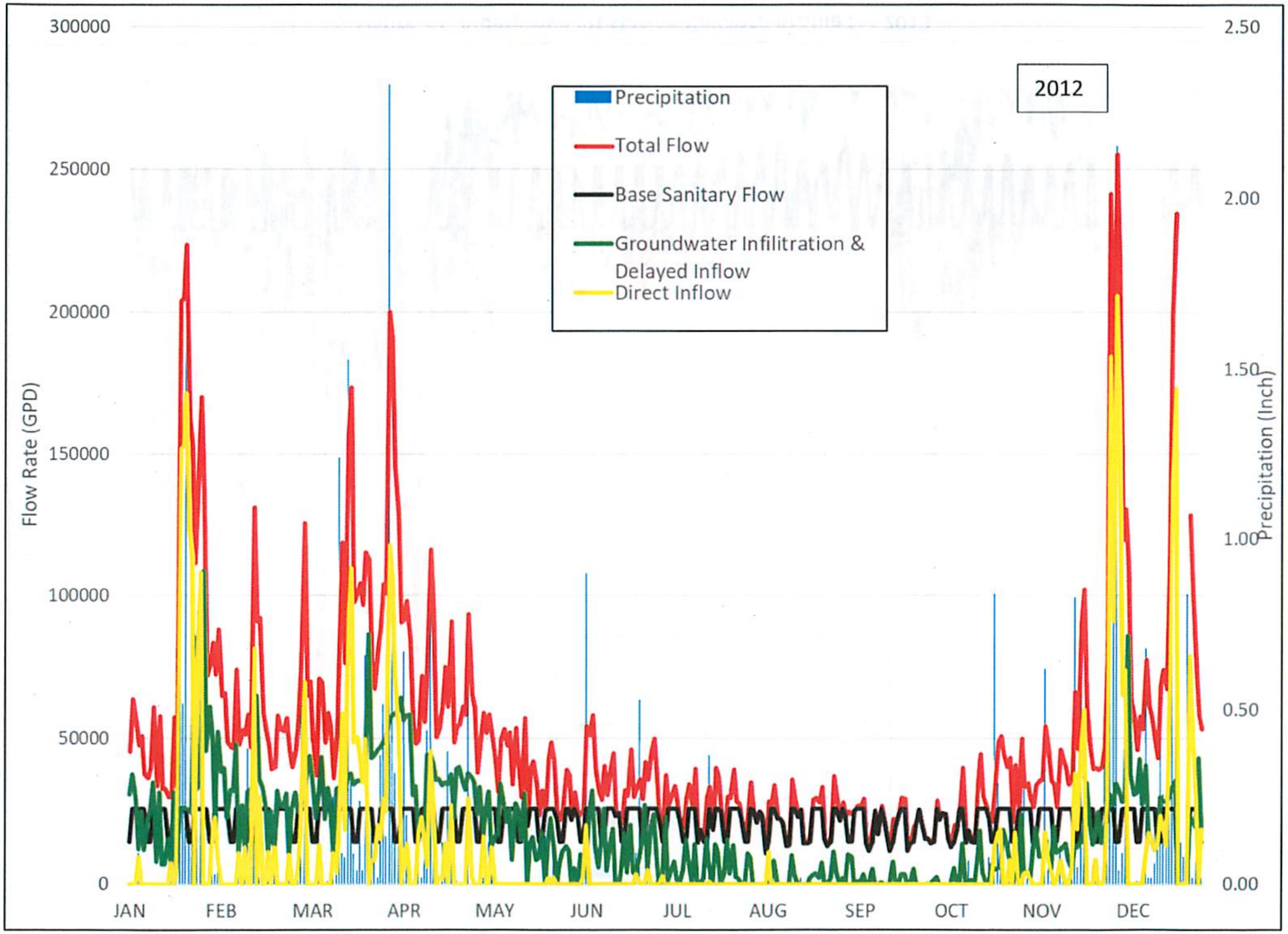


Figure 36. Aldergrove lift station flowrate profile for 2012

Figure 37. Aldergrove lift station flowrate profile for 2013

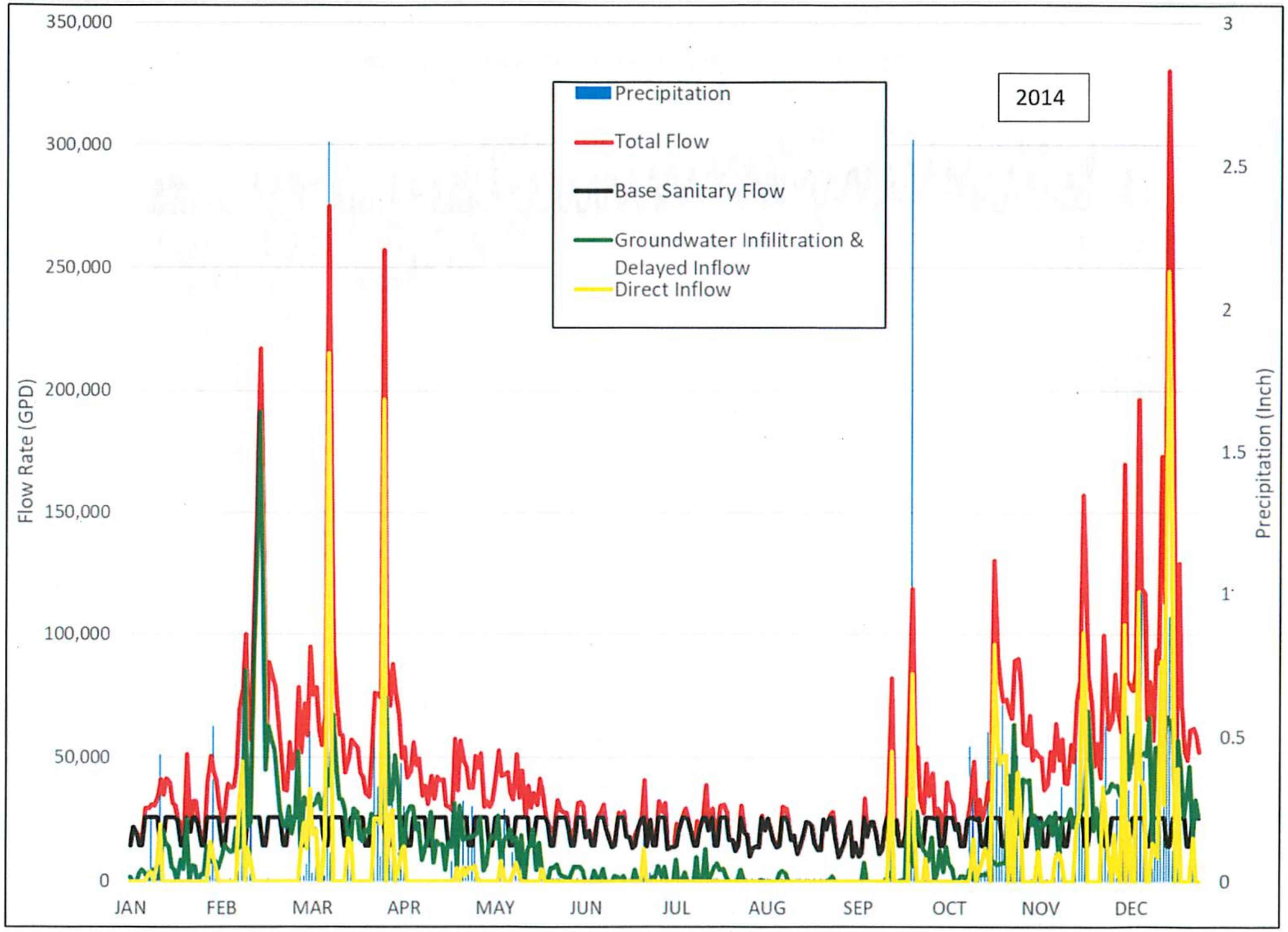


Figure 38. Aldergrove lift station flowrate profile for 2014.

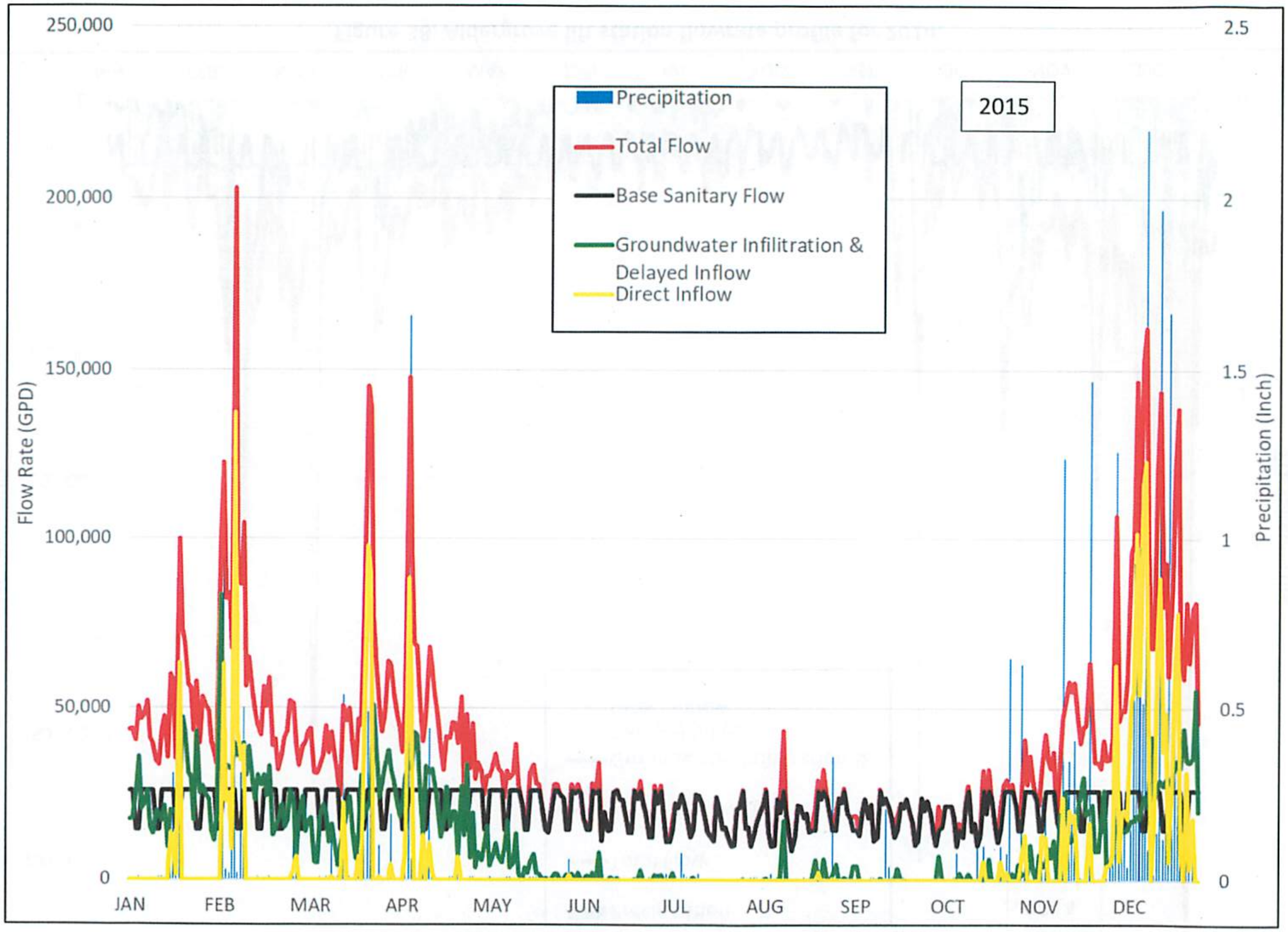


Figure 39. Aldergrove lift station flowrate profile for 2015.

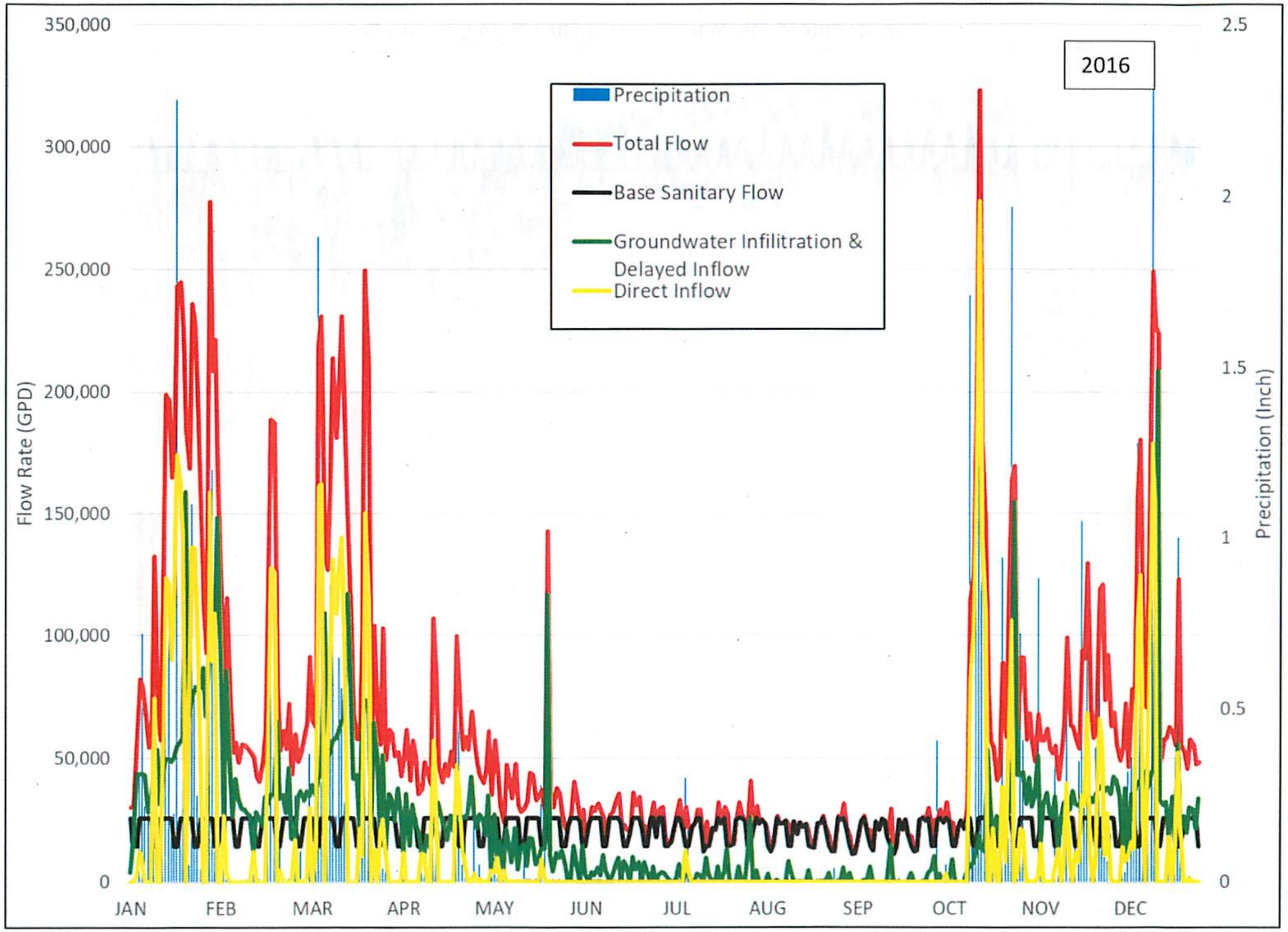


Figure 40. Aldergrove lift station flowrate profile for 2016

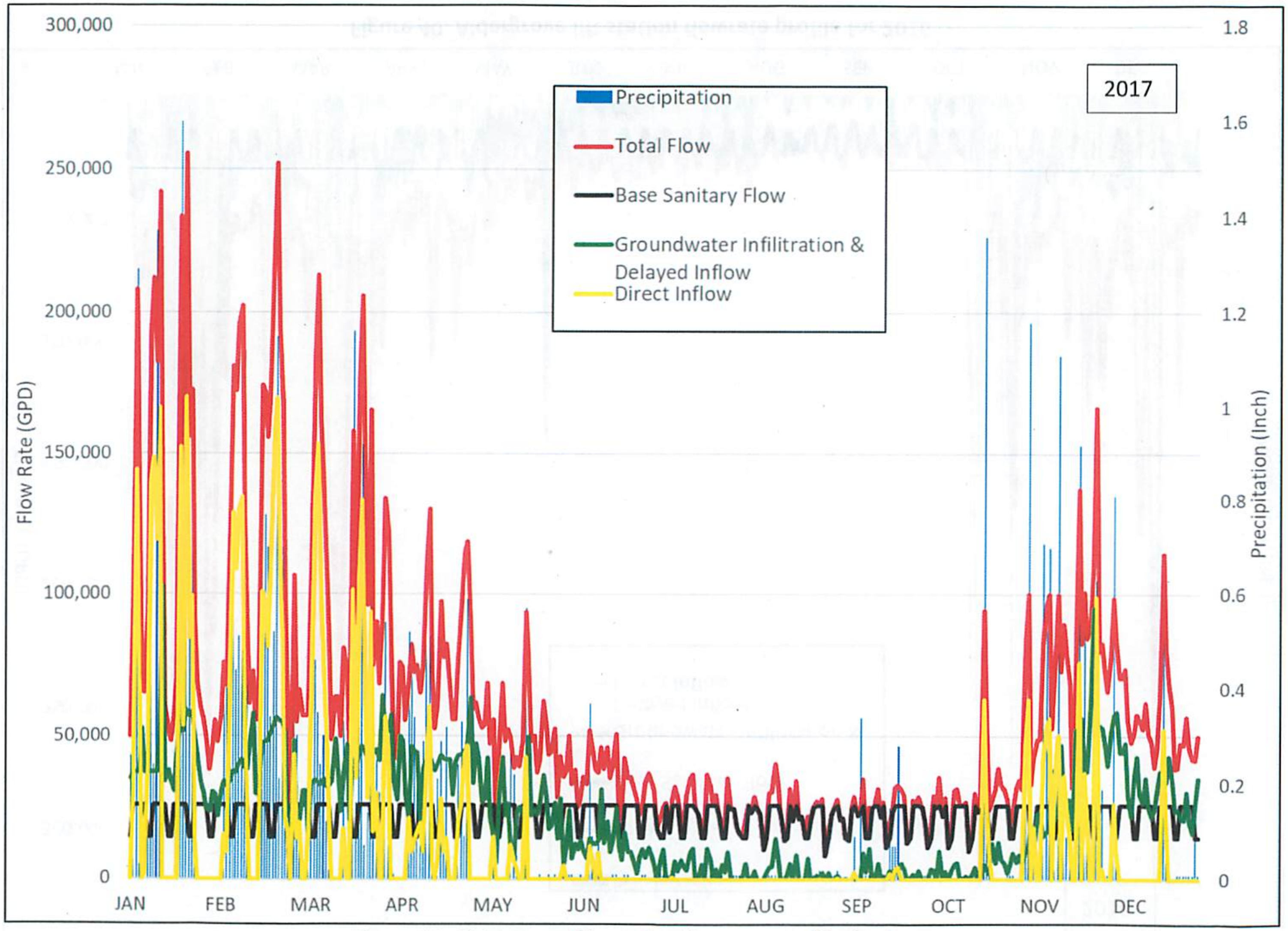


Figure 41. Aldergrove lift station flowrate profile for 2017

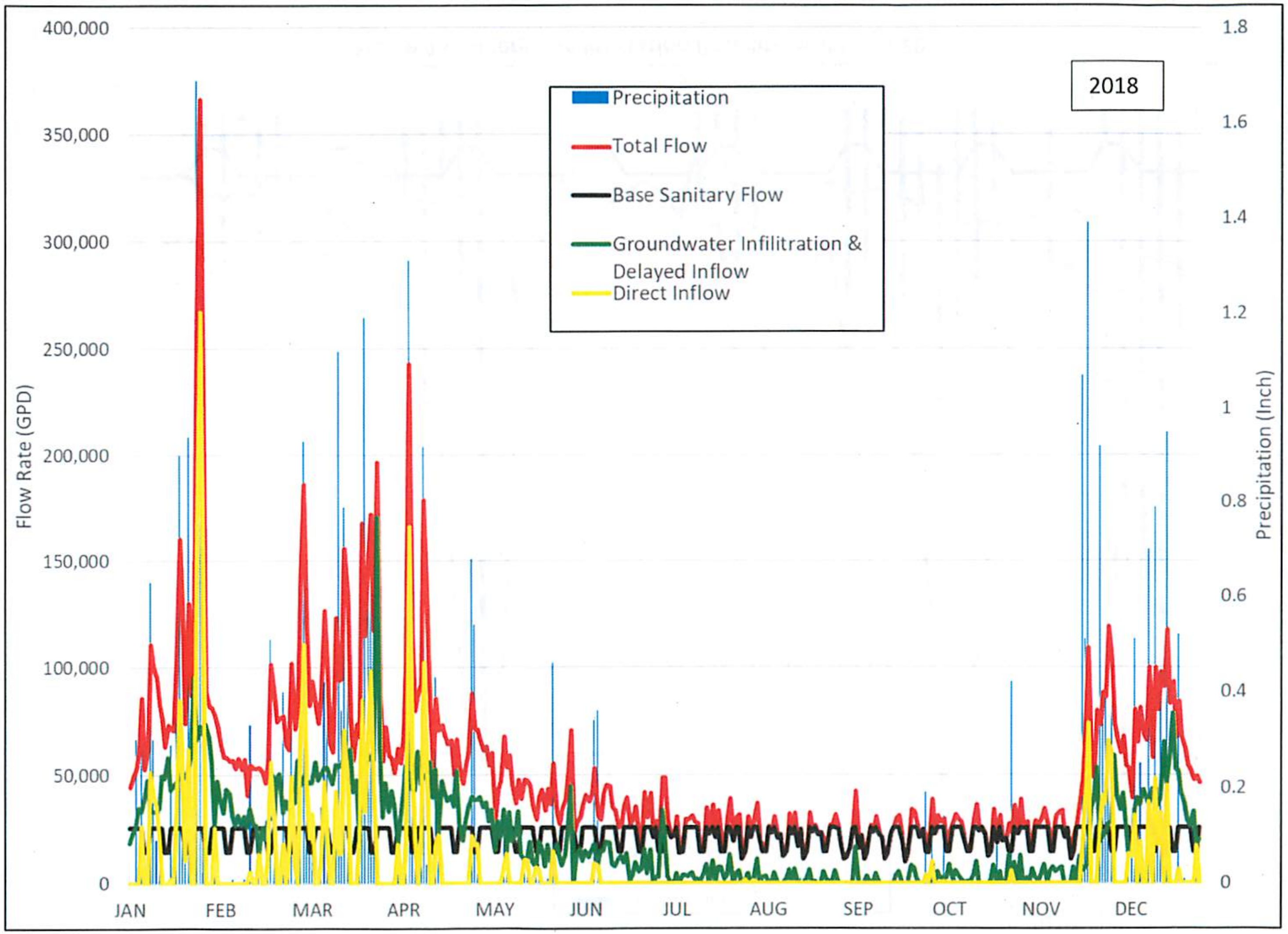


Figure 42. Aldergrove lift station flowrate profile for 2018

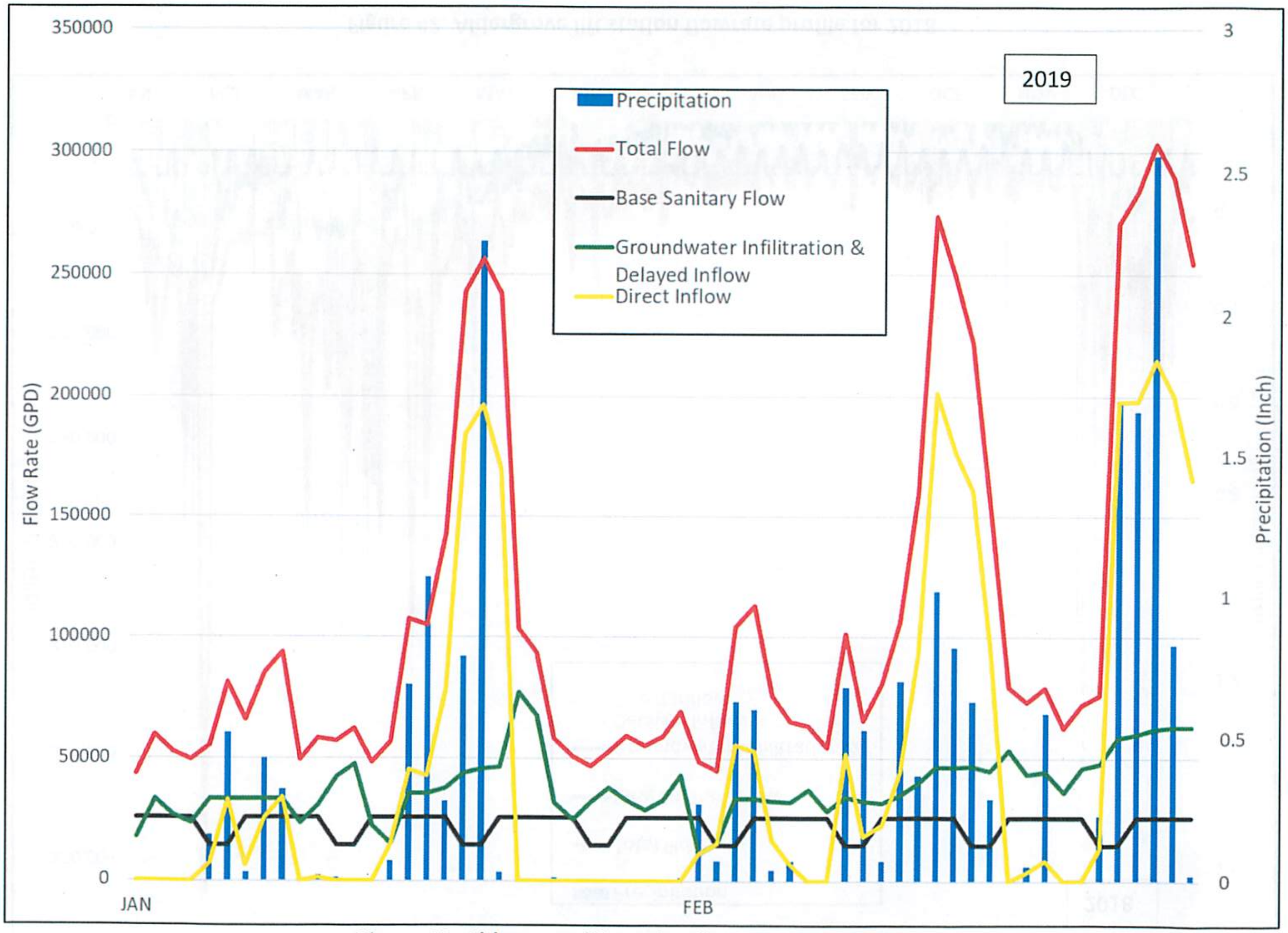


Figure 43. Aldergrove lift station flowrate profile for 20