UNIVERSITY OF CALGARY

Investigation into Using EPAnet Software to Design Trickle Fill Water Distribution Systems

by

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Abstract

Small rural drinking water systems in Alberta face financial challenges when supplying potable water via traditional pressurized distribution system. In many rural settings, the costs can be reduced by employing an innovative solution of distributing and delivering water via low-pressure water supply system, often called trickle fill system. This research develops a modelling approach to design the trickle fill system in Rockyview County, Alberta and investigates into EPAnet software application suggested by US Environmental Protection Agency to study and analyze system hydraulics, water quality, and energy profile. The conducted research concludes the trickle fill system design cannot be performed by EPAnet alone and suggests modeling software applications suitable for rural water development to be used in combination with EPAnet software. The study proposes options for energy optimization for Rockyview County and finds that trickle fill system implementation is the most suitable option.

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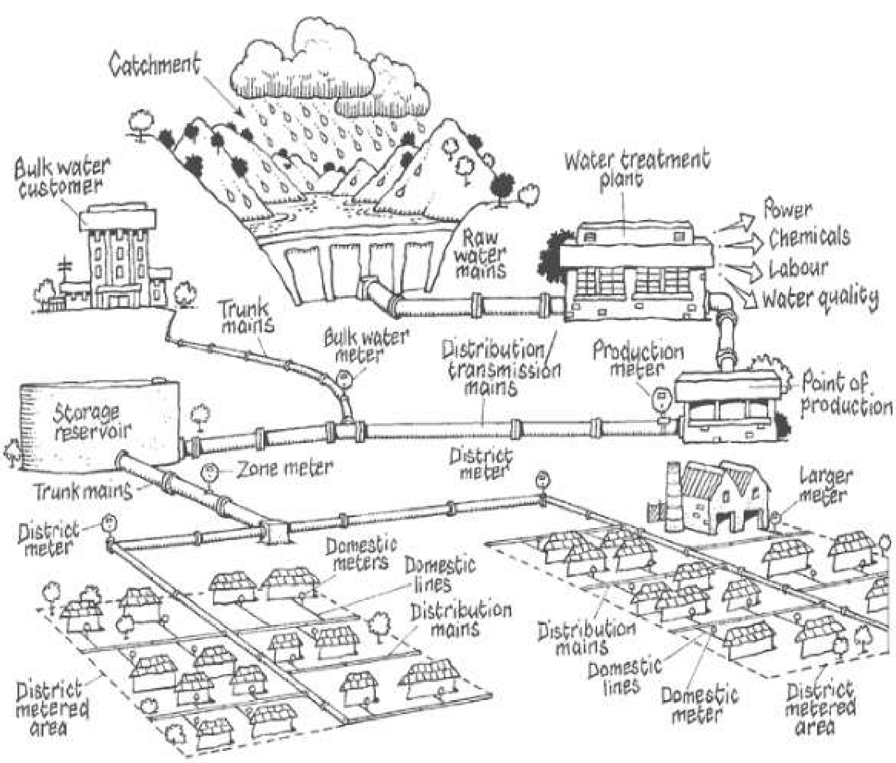
Chapter 1: Introduction

1.1 Background and Research Question

Small and rural drinking water systems in Alberta face financial challenges when supplying potable water via traditional distribution system. The access, availability and distance from a drinking water source impact the overall system costs and therefore, end user fees for small communities. Small communities do not have enough population to recover the capital costs and rely on funding and grants from the government. More than 80% of 670 regulated drinking water systems in Alberta can be classified as small, with populations less than 1,500 people. (Janzen, Achari, Langford, & Dore, 2017).

However, the costs can be reduced, and clean affordable drinking water can be delivered through regionalization which is explained in Chapter 2. Figure 1 shows a typical municipal water system from watershed to water treatment to water distribution.

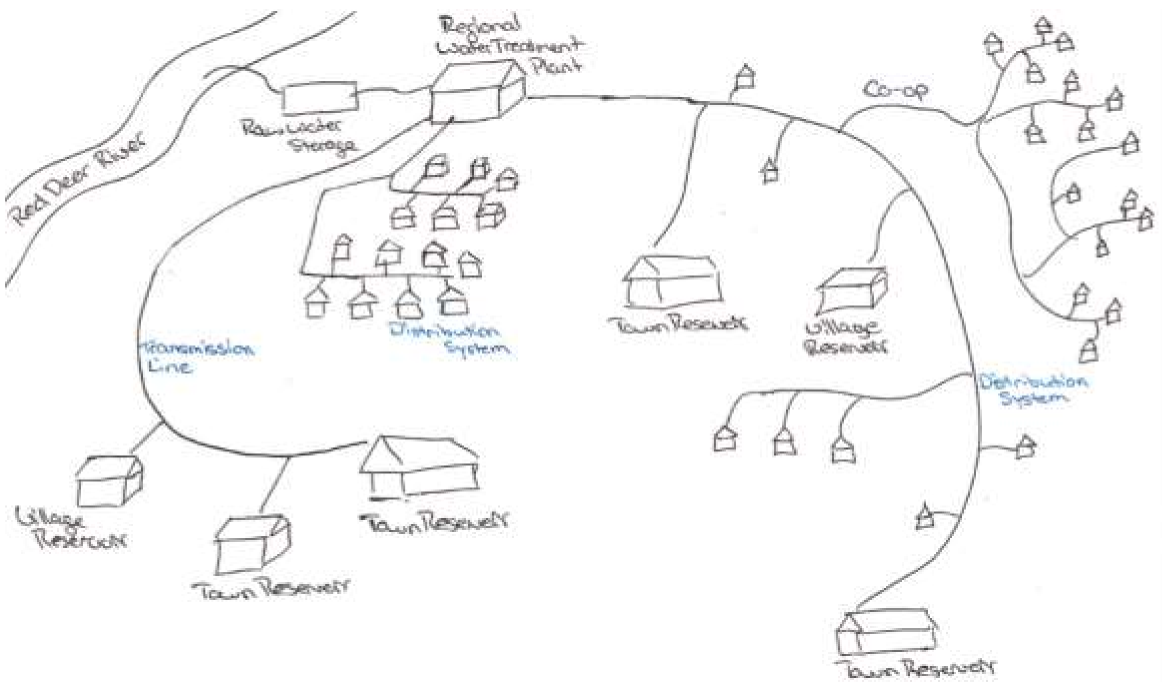
Figure 1. Water supply system



(Queensland Environmental Protection Agency and Wide Bay Water Corporation, 2004)

Figure 2 demonstrates various configurations of regional supply including network between municipalities, neighboring hamlets and rural distribution systems, and Appendix B: Locations of Drinking Water Treatment Plants illustrates locations regional water drinking systems in Alberta as of 2017.

Figure 2. Configurations of regional supply



(Roulston, March 12, 2019)

A feasibility study has been conducted and a framework developed to determine whether regionalization, through the implementation of a trickle fill system, is economically feasible for a given rural area. (Irwin, 2018). It was determined that regionalization option should be considered as it provides security with water quality and the trickle fill system supplies low-cost water. In addition, such way of delivering water is sustainable and energy efficient. However, the benefits of trickle fill system implementation are case dependent. This project expands on a technical assessment component of feasibility assessment framework for Rockyview County in Alberta initiated by Irwin (2018) and provides data needed to decide whether the trickle fill project is beneficial and affordable in the case study area.

Typically, a trickle fill system is designed to have a pipeline connected to the nearest transmission pipeline or a treated water reservoir and distributed to consumption units. The water is supplied at low pressure via high density polyethylene (HDPE) pipes to a reservoir or a tank from which it is re-pumped to fulfill end users water requirement. Therefore, trickle fill system design criterions are the pressure in the system and the water age as due to many "dead ends", there are risks of stagnation of water in pipes. There are several software applications developed to design water distribution networks. US Environmental Protection Agency (US EPA) distributes and suggests EPAnet software for water distribution modelling (United States Environmental Protection Agency, n.d.)

This capstone project investigates the usefulness of the EPAnet application to design trickle fill water distribution system and is based on a case study for an area in Rocky View County (RVC), Alberta.

The project expands on the feasibility framework developed by Irwin (2018) and is a holistic approach which analyzes environmental, economic, and energy aspects of the trickle fill implementation.

Suggested by US EPA, EPAnet application designs and analyzes water distribution system and provides energy analysis based on which the economic feasibility assessment will explain whether trickle fill implementation is the best option for the RVC to improve current situation regarding drinking water delivery.

Trickle fill distribution is a preferred method for rural water development because first, it is economical. The economic analysis and advantages of trickle fill system implementation in RVC are explained in detail in Section 1.2 and Section 2.2., and Section 2.3

Second, it is environmentally sound. Figure 3 illustrates the comparison of environmental impact difference between trucking and trickle fill water delivery methods based on 2017 metrics. Irwin (2018) compared water delivery from Conrich reservoir and pump station to Lansdowne water co-op located in RVC. It was concluded that water delivered via trickle system uses a lesser amount of energy, fossil fuels, and emits less GHG's than trucked-in water currently practiced. The impacts of water delivery methods were compared for a 20 km distance. (Irwin, 2018) The trickle fill water distribution implementation would have saved 2.3 GJ of energy consumption, 51 tonnes of fuel (fossil) consumption, 164 tCO_2eq emissions, and 35,596 water jugs refilled in the year of 2017, which is equivalent to energy savings of 25 Canadian homes and emissions of 36 average vehicles. (Irwin, 2018)

Figure 3. Environmental Impacts of water delivery methods

(a) Individual scenario calculation results

Scenario A: Trucking			VS.	Scenario B: Pumping via Trickle Fill Water Distribution		
Water delivered	3,900	m^3/yr		Water delivered	3,900	m^3/yr
From	City of Calgary (near Shepard)	-		From	Conrich Pump Station & Reservoir	-
To	Landsdowne Water Co-op	-		To	Landsdowne Water Co-op	-
Distance (one-way)	20	km		Total head (rated)	193	ft
Volume of water per truck	12	m^3/truck		Pump rated flow (imperial)	1886	gallons per min (gpm)
Truck Fuel Efficiency	40	L/100km		Combined pump & motor efficiency	60%	
SCENARIO RESULTS per unit of water delivered				**SCENARIO RESULTS per unit of water delivered**		
Energy consumed	47.73	MJ/m^3		Energy consumed	0.96	MJ/m^3
Fuel consumed	1.12	kg/m^3		Fuel consumed	0.06	kg/m^3
GHG's emitted	3.60	$kgCO_{2eq}/m^3$		GHG's emitted	0.21	$kgCO_{2eq}/m^3$
Delivery cost	10.00	$\$/m^3$		Delivery cost	9.86	$\$/m^3$

(b) Comparison results: Tricke Fill Scenario Results – Trucking Scenario Results

Key Metrics - DELTAS (trickle fill - trucking)		
Energy consumed	**-46.77**	MJ/m^3
Fuel consumed	**-1.06**	kg/m^3
GHG's emitted	**-3.39**	kgCO2/m^3
Delivery cost	**-0.14**	$/m^3

(Irwin, 2018)

Third, the trucking and bottle refilling are not preferred or convenient methods of delivering water to rural areas. It is not sustainable and reliable. Therefore, this capstone is needed to help with trickle fill realization and implementation.

This capstone develops a modelling approach and design method where the initial step starts with constructing a flow model. Further, technical data obtained from a flow model is used in EPAnet software application to examine pressure profile, analyze water quality and predict potential water quality issues within the trickle fill system network; and finally, examine energy use to suggest energy optimization options.

The technical data is based on system requirements and depends on number of communities to be connected to trickle fill network within the study area as well as elevation profile and pipelines length. The hydraulics profile is built in Google Earth Pro application. Once the required data is obtained, it is then used in flow design to estimate pipeline diameters and expected major pressure loss in pipelines. The design also considers a safety or capacity factor.

Finally, obtained flow and hydraulics data is used as input in the EPAnet case simulation to analyze pressure, water quality and potential water quality issues within the system and to examine energy use for energy optimization suggestion.

1.2 Significance and Potential Audience

Lindgren (2003) noted that a well-maintained distribution system is a critical component of a safe drinking water system. It is essential that water providers have adequate financing mechanisms in place so that their distribution systems can be properly maintained and renewed. (p.21)

Reflecting on Alberta's strategy on sustainability "Water for Life" (Alberta Environment and Parks, 2012b) goals to provide safe and secure drinking water and reliable water supply to support provincial economic development, regionalized system can qualify and receive government support as it can significantly reduce the capital costs and therefore, consumers fees. This can be up to 90% of the pipeline cost and 100% of any treatment plant upgrades needed for the regional connection. In Alberta, small communities with population less than 1,000 population are eligible for 75% subsidies to recover capital costs. (Janzen, Achari, Langford, & Dore, 2017) The subsidies do not cover operation and maintenance (O&M) costs which in addition to the capital costs represent total system costs. Both apply on to municipal systems (hamlets, villages, and towns).

The systems in the RVC case study area are not eligible for either of the municipal funding programs. Without the grant support, the systems are very sensitive to the cost of upgrades or regional connections.

The significance of this projects is in developing a staging modelling approach and to learn if the design can be performed with a single software application such as EPAnet. The design considerations from modelling approach will form a basis for economical assessment of trickle fill water supply system applications to isolated communities and be used as an opportunity to investigate into drinking water supply for indigenous communities in Alberta.

1.3 Project Scope and Objectives

Project goal was to develop a modelling approach for trickle fill system distribution system and answer research questions:

1. Can EPAnet software be used to design trickle fill water distribution system?
2. Can EPAnet software be used to predict where water quality issues will occur in a trickle fill water distribution system?
3. Can the modelling suggest energy use optimization for the case study scenario?

The system application and its economic feasibility depend on the factors such as:

1. Geophysical pipeline route,
2. Volumetric flow demand based on the community's consumption with growth factor taken in to account,
3. Reservoir/cistern design considerations,
4. System costs estimation which includes distribution piping costs,
5. Funding or support from the government,
6. End user willingness to pay.

The objective of this capstone project is to develop a modelling approach based on the above factors in the RVC case study area which further will be applied in economic assessment to ensure the affordable and sustainable delivery of clean drinking water.

The set of technical data from the feasibility assessment developed by Irwin (2018) is used as a base case scenario in the staged design process of this approach. A generalized flow model developed in this research analyzes an optimal route (pipeline length and tie-in locations) and pipeline diameter needed to perform hydraulic calculations to check pipeline pressure profile, set a design flow based on the community demand, and analyze the risks associated with process application of the water distribution via high-density polyethylene pipeline. Therefore, the project deliverables are:

1. Flow model to be used for conceptual design of trickle fill systems.

   This toolbox has a daily required volume flow per connection and water velocity as inputs and the pipe diameter and major pressure loss in pipes as outputs.

2. Investigation into EPAnet software as a suitable application for rural water development design for the following:

   2.1 System pressure analysis

   2.2 Water quality (chlorine concentration and water age) analysis

   2.3 Energy use

3. This project instigates into how suitable EPAnet software for designing a low-pressure water distribution system and makes suggestions based on findings.

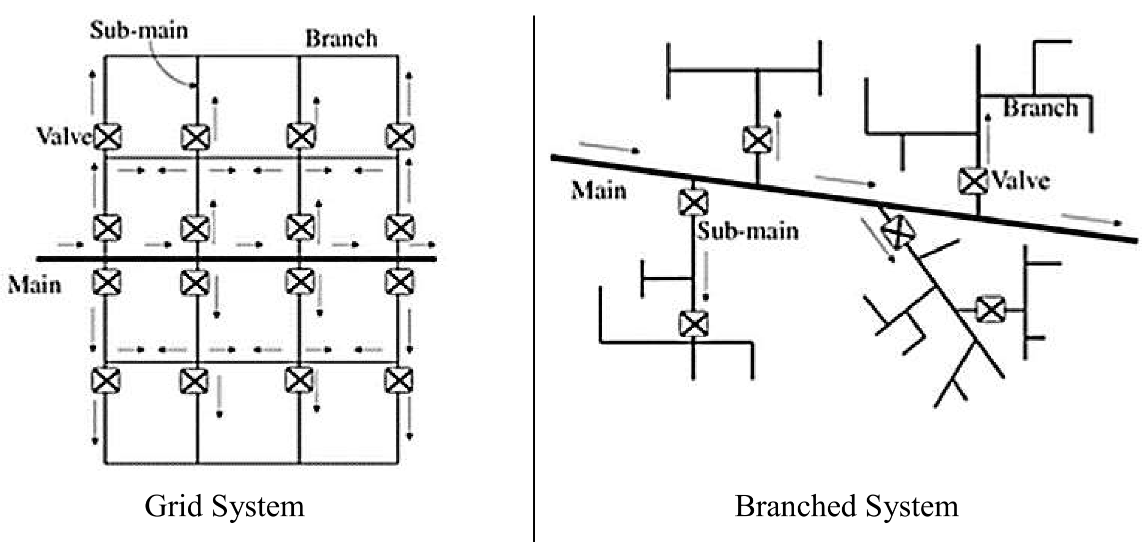
4. Energy analysis and energy optimization suggestions for the case study area.

Chapter 2: Related Literature

2.1 Low Pressure Pipeline Network

Water distribution system collects, treats, stores and distributes water between watere source and end use. There are two types of distribution networks. The first type is the grid system which represents a grid of interconnected pipelines. A grid system is suitable for a highly populated areas such as cities where it provides a stable water pressure (typically at 40 – 80 psi) even while providing fire flows at fire hydrants. In addition, as pipes are looped, there is water available during system maintenance. The second type of distribution network has a branched layout and is often called branched or "dead end" system. A trickle fill system is low-pressure system that delivers water to the end user at positive pressure (20 - 22 psi (Government of British Columbia, 2012)) and is suitable for areas with no fixed or defined pattern of roads and is used for small-capacity such as rural areas with low density population. The resulting pipe network shape is similar to a tree, in which the "trunk" is the main distribution pipeline and the "branches" are the service pipelines delivering water to end users. This type of distribution allows for smaller diameter pipes and less instruments (valves) in contrast to the grid system, and therefore, is less costly. The two network types are shown in Figure 4.

Figure 4. Types of water distribution

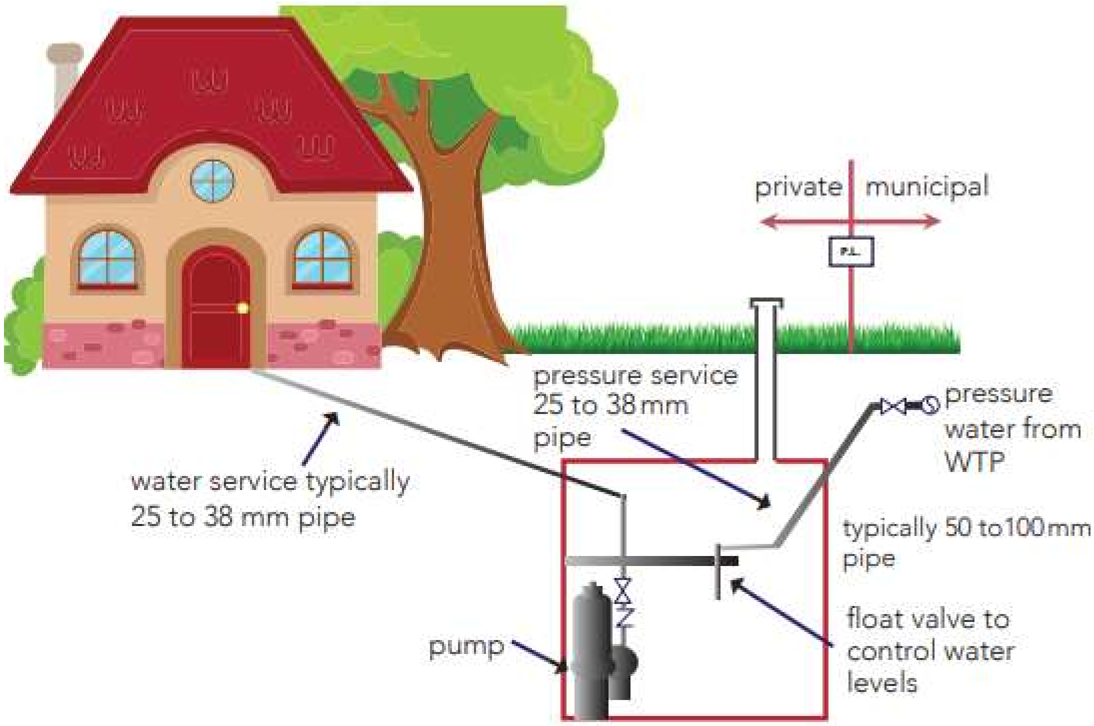


Grid System

Branched System

(Ram K. Mazumder, Abdullahi M. Salman, Yue Li, & and Xiong Yu, June 09, 2018)

Figure 5. Trickle fill distribution system



(Draper Design, 2018)

Trickle fill system (Figure 5) is a branched distribution network designed for a household use or a light commercial and is not suitable for providing the large volumes typically required by irrigation or livestock operations. Integral to its design is tht end users require on-site water storage (reservoir, tank, or cistern) to provide the peak demands and flow variation through the day. This is discussed in detail in Section 2.6.

2.1.1 Examples of Trickle Fill Around Alberta

There are several examples of communities that have employed the trickle fill system to supply drinking water. In Alberta, 20% of rural municipalities have at least one trickle fill water distribution system (Irwin, 2018). These include Kneehill County, County of Newell and Wood

Buffalo. The projects performed under standards leading design, preparation, and plans specifications
for construction of trickle feed water distribution systems and low-pressure sanitary sewer systems in the Rural Service Area of the County of Grande Prairie and South Peace Region. (Aquatera Water Earth Innovation, 2018) The standards are in compliance with requirements of:

1. Alberta Environment, Standards and Guidelines for Municipal Waterworks,
2. Wastewater and Storm Drainage Systems
3. Municipal Safety Codes
4. Municipal Government Act
5. Water Act
6. Public Lands Act
7. County of Grande Prairie - Design and Construction Manuals
8. County of Grande Prairie - Levies Policy and Bylaw
9. Town of Sexsmith- Levies Policy and Bylaw
10. South East Area Servicing Study
11. North Industrial Park Servicing Study
12. Aquatera Utilities Inc - Design and Construction Manuals (ADCM)

2.1.2 Examples of Trickle Fill in Canada

In Ontario, there is a Carlsbad Trickle Feed System located on the outskits of the city of Ottawa. (Infrastructure Policy Group, 2014) In Saskatchewan, there are examples of both raw and treated water trickle feed which are the Melfort Rural Pipeline Association and the Coteau Hills Pipeline Association. Both pipelines delivered water to groups of farmsteads and agricultural enterprises. (Univesity of Saskatchewan, SK Association for Rural Water Pipelines and PFRA, Agriculture and Agri-Food Canada, 2002)
In Manitoba, Lasalle South Water Supply trickle system was considered, but the Drinking Water Safety Act rules that any piped water distribution system with more than 15 connections is designated as a "public water system", which by law must conform to all regulatory requirements.

(Cochrane Engineering Ltd., 2004) The trickle-feed system concept was not approved for public systems due to qualifications of source-to-tap water concerning quality assurance.

2.1.3 Examples of Trickle Fill Internationally

Trickle fill projects are successfully employed worldwide. Trickle Feed Systems have been applied in South America since the early 1970's and in the South Pacific island country of Kiribati since 2001. (Albetis, 2003) The Nondayana pilot project is one of the examples of supplying and distributing safe drinking water to 180 households that is approximately 1800 people in Nondayana, Kwazulu-Natal, South Africa. (R. Scott, 2001)

2.2 Capital Costs, Grant Funding

Since the implementation of Water for Life strategy in 2003, supported by funding, many water transmission lines have been installed and water plants upgraded (Alberta Environment and Parks, 2012b). According to Water Grant Fact Sheet (Government of Alberta, May 2017), the Government of Alberta is contributing $131 million in grants over a four-year period starting from 2017 to support small water and waste water projects in small rural communities under the Water for Life and Alberta Municipal Water/Wastewater Partnership (AMWWP) applications. The funding is pay-on-progress based and depends on the construction time.

Regionalizing allows adding more users to the existing regional systems which currently operate below capacity levels. (Irwin, 2018) Supplying treated water trough trickle fill distribution will maximize existed regional system utilization by increasing system capacity levels and also will help small rural communities sruggling to supply affordable and clean drinking water. In addition, regional systems have advanced water treatment and can hold competent operations and maintenance (O&M) staff (Langford M., Daviau J. & Zhu D.Z., 2012). Therefore, trickle fill water distribution through regionalization for small rural communities not only will improve the drinkable water quality, but also will ensure long-term sustainable and reliable service.

Table 1 below illustrates grants and fundings available for regionalized systems. It can be observed that small rural communitites and coops are not eligible for any. Hence, the costs of supplying water should be paid upfront. This is a huge obstacle for rural house owners. Thus, water network / distribution design and its impact on capital costs is needed to determine whether it is feasible to deliver water via trickle fill distribution. At this point, a stage modelling approach is nessessary. This will give sets of data which will be used for economical feasibility assessment and will make a better estimation of end users' costs. As an example, Janzen et al. (2017) summarized costs of trickle fill system implementation shown in Table 2 for the County of Newell and Kneehill County in Alberta. A comparison between Kneehill County, County of Newell, and Rockyview County's costs reveals that the highest $1,824,941 in subsidies (Irwin, 2018) is required to reach the affordability of $165 /month/home cost of delivered water.

Table 1. Alberta water infrastructure grant programs based on project category

Example	**Years**	**Length of HDPE pipe installed**	**Capital Cost**	**Water Treatment Cost**	**Average annualized cost per connection**
Kneehill County	2009 - 2011	240 km	$58,000/km	$2.88/m3 + $9.75/month	$1,730/year
County of Newell	2011 - 2016	1,215 km	$42,700/km	$2.73/m3 + $26/month	$1,560/year
Data sourced from Janzen et al. (2017)					

(Irwin, 2018)

Table 2. Calculated cost metrics for existing trickle fill systems in rural Alberta

Example	Years	Length of HDPE pipe installed	Capital Cost	Water Treatment Cost	Average annualized cost per connection
Kneehill County	2009 - 2011	240 km	$58,000/km	$2.88/m3 + $9.75/month	$1,730/year
County of Newell	2011 - 2016	1,215 km	$42,700/km	$2.73/m3 + $26/month	$1,560/year
Data sourced from Janzen et al. (2017)					

(Irwin, 2018)

Irwin (2018) calculated the upfront costs for the Rockyview County represented in Table 3 below:

Table 3. Upfront costs calculated for RVC

Total Capital Cost for the Project	**$ 6,586,296.24**
Average capital cost per km	$ 79,766.21/km
Average capital cost per new connection	$ 29,014.52/connection
Average capital cost per home equivalent	$24.41/month/home equivalent
Total System Connection Fees for the Project	**$ 11,702,357.50**
Average system connection cost per month per home	$ 46.15/month/home
Total Upfront Costs	**$ 18,288,653.74**

(Irwin, 2018)

2.3 Water Rates

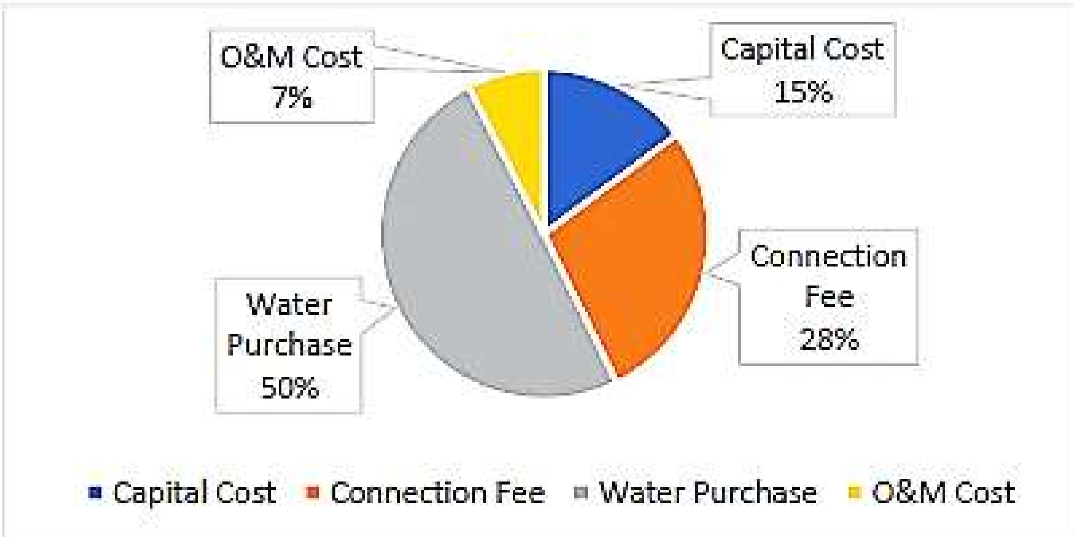
There is a significant difference in end costs between single residential and non-single-residential connections, for example, water co-op distribution centers or commercial customers. According to Feasibility Framework developed by Irwin (2018), the projected daily consumption for connections to commercial customers has a significant impact on the system connection fees. As per the RVC master rates bylaws, system connection cost for the non-residential connections is determined by multiplying $18,050 by the expected average daily flow in m3/day, whereas a single residential connection has a fixed rate of $17,150 (Rocky View County, 2018). Figure 6 presents the average breakdown of monthly cost of water, from which the major portion of the total cost is allocated to water purchase. The water costs for Rockyview co-op are presented in Table 4. Irwin (2018) summarized that for a single residential customer the monthly cost could vary from $110.24 to $191.06 per month per home and for a commercial customer depending on whether it is a school or a campground, water cost ranges from $687.79 to $22,142.67 per month. To better understand the values of water costs, the comparison of single-family home average monthly costs for drinking water is illustrated in Table 5.

Table 4. 2019 Treated water rates for Rockyview Water Co-op Ltd.

East Rocky View Water Services		
Residential Water Fees	$15.00 + $3.915/m3	Monthly fixed fee and consumptive charges per residential connection.
Non-residential Low Volume Water Fees	$20.00 + $3.915/m3	Monthly fixed fee and consumptive charges per non-residential connection use of 0 to 49 cubic meters per month.
Non-residential Medium Volume Water Fees	$50.00 + $3.915/m3	Monthly fixed fee and consumptive charges per non-residential connection use of 50 to 499 cubic meters per month.
Non-residential High Volume Water Fees	$150.00 + $3.915/m3	Monthly fixed fee and consumptive charges per non-residential connection use of 500 and over cubic meters per month.
Water Use Overage Fee	7.83 /m3	Per cubic meter of water delivered during a month which exceeds the annual maximum alloted quantity calculated on a pro-rata basis.
Residential Water Connection Fee		Per residential connection (if not previously paid/recovered) plus applicable off-site infrastructure borrowing costs calculated to the date of connection fee payment.
	$15.210.00	East Balzac Service Area
	$17.150.00	Conrich Service Area

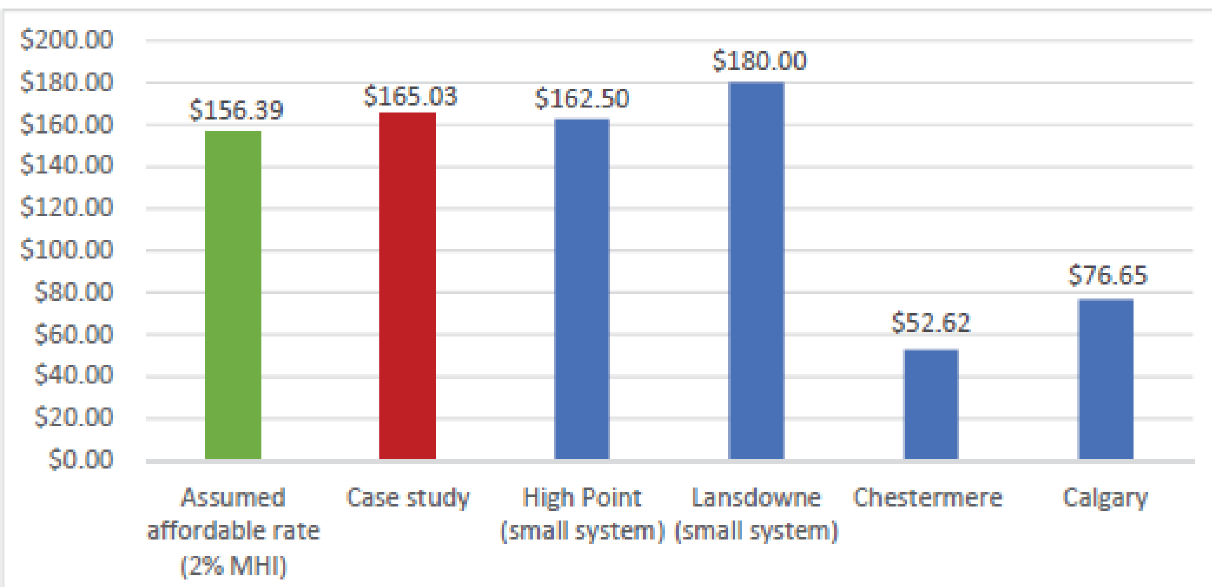
(Rocky View Water Co-op Ltd., 2019)

Figure 6. Average breakdown of monthly cost of water when the capital costs are amortized over 25 years.



(Irwin, 2018)

Table 5. Comparison of single-family home average monthly costs for drinking water per home

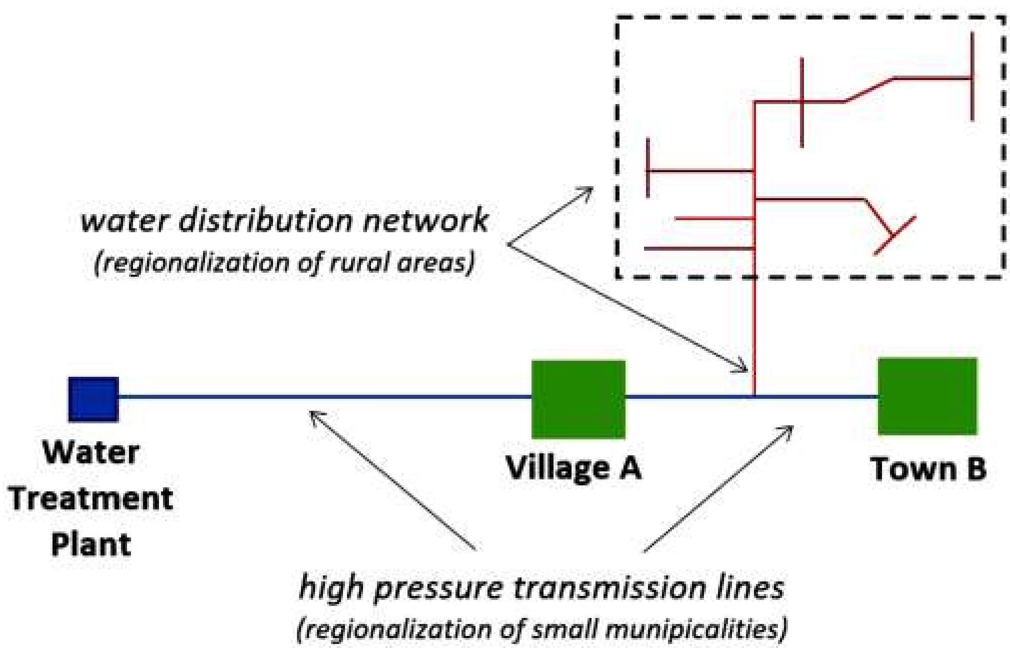


(Irwin, 2018)

2.4 Design Criteria

As pointed earlier in this study, clean and affordable drinking water can be delivered to small rural communities through regionalization. Regardless of a method of regionalization, system amalgamation is a preffered option of supplying water to small rural areas. (Janzen, Achari, Langford, & Dore, 2017) Traditionally, regionalization is grouping of two or more municpalites. This is shown in Figure 7 with the blue lines running from the Water Treatment Plant to Village A and Town B. Regionalization of small water distribution network for rural communities is shown in the red. These are typically trickle fill water distribution systems. Rural regionalization is done by connecting water sub-main pipeline to regional pressurized transmission line and distributing it at low pressure to end users' water storage units via small diameter service pipes. Service pipes can deliver water to a community reservoir or to a house cistern, or tank. The development of design criteria for the trickle fill system considers both options.

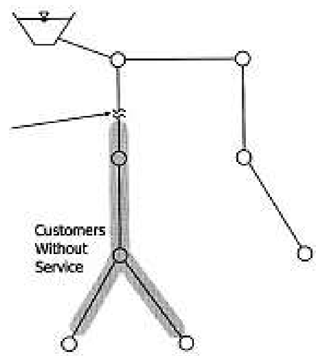
Figure 7. Regionalized water distribution network



(Irwin, 2018)

As explained in Chapter 2.1, trickle fill system has a larger-diameter main water pipeline and series of smaller-diameter pipelines branching-off to consumption units and it is one - directional flow. Such configuration has potential risks associated with loosing a service for consumption units located downstream of pipeline (Figure 8) in case of any break or maintenance work until the the pipeline problem is fixed. However, the risks are alleviated in the trickle fill scenario by installing onsite water storage, for instance a reservoir or a cistern which is described in Section 2.6.

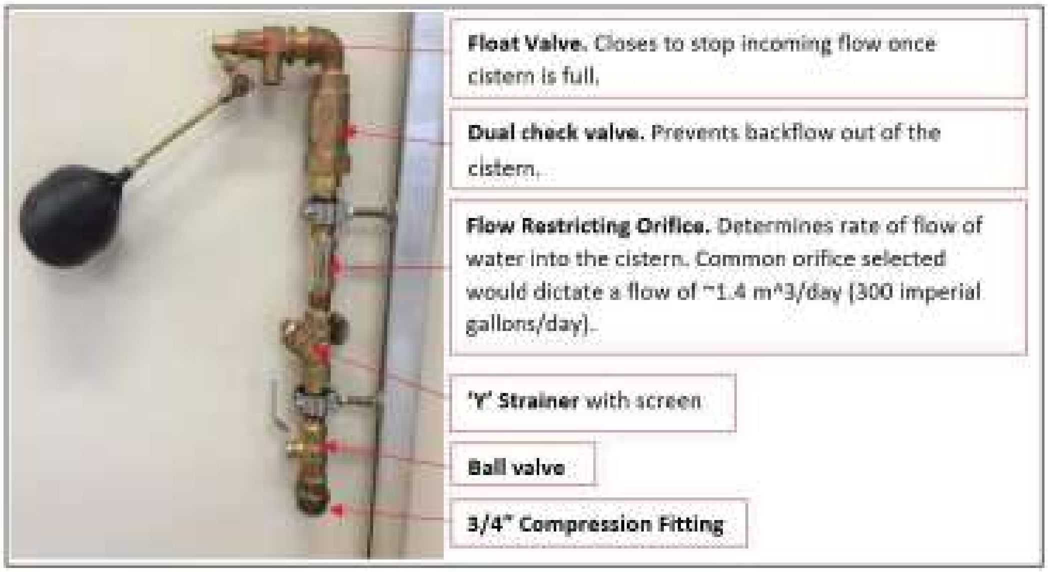
Figure 8. Network failure



(Pitt R., 2010)

The water control (Figure 9) is performed by flow emitter instruments and has a very simple sequence where the valve opens when the float drops and the water inflows in at a set rate by the restricting orifice; when the float reaches the high level, the valve closes, and the water inflow stops. (Regional Municipality of Wood Buffalo, 2018) The water restricting orifice what makes a system trickle fill flow as it only allows a set daily volume into the cistern over the course of the day. The water restricting orifice is where the term trickle fill originates. A cistern is equipped with automatic booster pump to supply pressure to the premises. Trickle fill system components and its functions are summarized in Table 6. The system is designed to supply water via high density polyethelene (HDPE) pipelines. HDPE material is leak proof, lightweight, impact, corrosion, and chemical resistant, and easy to install. (Fabco Plastics). Depending on load and geographical location such as elevation, valves and booster pumps may be required to control the pressure.

Figure 9. Flow control instruments



(Irwin, 2018)

The pressure is the system performance indicator. In the trickle fill system design, the minimum operating pressure (OP) must be kept above 150 kPa at every distribution point (Alberta Environment and Parks, 2012a) to avoid contamination from outside sources, especially in the event of a pipeline failure.

The design considerations (Table 7) in terms of equipment and pipeline sizing are made on a basis of daily volume demand which is set to 1.14 m3/d (2.3 l/min or 0.5GPM) where a typical average daily use of water per household in Alberta is 0.9 m3/d (Irwin, 2018); hence, the design volumetric flowrate has 20% of safety factor and accounts for future growth. However, the growth capacity factor is case dependent. A secondary feed pipeline may be considered as an option, if the peak hour on maximum day demand exceeds the future normal operating conditions presented in Table 8. A failure condition is defined by the normal flow demand on the winter day. (Infrastructure Policy Group, 2014) The pipe diameters range is from 40 mm (1.5 in) to 150 mm (6 in) with recommendation to be 50 mm (2 in). (Langford M., Daviau J. & Zhu D.Z., 2012) The smaller diameters are one of the key factors that make these systems economically viable. (Janzen, Achari, Langford, & Dore, 2017).

Considering the trickle fill system layout and settings, the main design criteria are the minimum pressure within the system and the water age.

Water age can be regulated by number of flushing. With the existing guidelines for indication of maximum water age (Table 8), it makes it challenging to accurately simulate water age and quality, if considerations are made for future growth which would then change the system volumetric flow capacity. Hence, another key design criterion is the change in the water age and possible risks associated with water quality within the system. In consideration for factors which can contribute to the change in water quality or age, the flushing requirements should be articulated. Increased water will decrease flushing requirements. While the trickle fill system design excludes water flows needed for firefighting, operational flushing may still be needed to deal with system upsets and to improve water age by flushing dead ends and low use areas.

The design should account for the future demands and depends on pipe characteristics, network configuration, spatial distribution of demands. The pipeline capacity largely depends on its diameter and roughness (C factor) which are correlated. HDPE pipe material has high C factor in combination with other technical characteristics which makes it ideal material to carry the water. C factor for HDPE varies from 115 to 150 depending on pipe diameter, the larger the diameter, the larger the factor. Water speed in pipes at operating conditions can be in laminar and/or transient regime depending on the elevations and length of the pipeline, but the design should aim to maintain the hydraulic integrity of the pipelines or in other words, keep the pressure constant avoid water hammering effect and pipes bursting especially at the locations closest to pumps and valves. (National Research Council, 2006a)

Table 6. Trickle fill system components

OWNER/ OPERATOR	**COMPONENT**	**NOTE**
Utility	Connection to potable water supply	Example: tie-in to regional transmission main
Utility	Small diameter HDPE piping	Routed to minimize cost and negative environmental impact
Utility	Pressure control valves, esp. at high elevation points	To maintain system pressure
Utility	Pressure reducing valves at high pressure points	To safeguard design pressure exceedance
Utility	Local booster pumps at lower pressure points	To provide required pressure, especially during maximum daily demand
Utility	Isolation/shut-off valves (distribution system)	To isolate for maintenance/inspection
Utility & Customer	Flow emitter assembly per cistern	To moderate the flow into each cistern, critical for maintaining system pressure. Ownership depends on system's organization & design
Customer	On-site potable water storage cistern for each property	To store water onsite. Sized to support peak flow through respective connection.
Customer	On-site pressurization system for each property	To deliver water from cistern to end-use-point at each customer's property.

(Irwin, 2018)

Table 7 Pipeline characteristics

Daily volume demand per connection	1.14 m3/d (2.3 l/min or 0.5 GPM)
Pipe diameters range	40 mm to 150 mm (1.5 in to 6 in)

(Langford M., Daviau J. & Zhu D.Z., 2012)

Table 8. Water age evaluation

Summary of water age evaluations			
Population Served	**Miles of Water Mains**	**Range of Water Ages within System (Days)**	**Method of Determination**
750,000*	1,100	<1 – 3	Fluoride Tracer
800,000	2,750	3 – 7+	Hydraulic Model
87,900*	358	> 16	Chloramine Conversion
24,000	86	12 – 24	Hydraulic Model

*Estimated by using 2.5 multiplier on number of customers served.

(U.S. Environmental Protection Agency, 2002)

A general values of plastic pipes C factor against the guidelines are presented in Table 9. The C factor value 130 was used in this study and is explained in detail in Section 3.1. (Saskatchewan Environment, 2004)

Table 9. HDPE roughness coefficient (C factor)

Pipe Diameter	Guidelines	1999-2000 Testing Program
75	N/A	118-122
100	N/A	125-127
150	100	N/A
200	110	144

(Infrastructure Policy Group, 2014)

The system capacity depends on network configuration and spatial distribution of demands. The higher density of population will require higher system capacity. However, regardless of volume of water required, upstream demands of the system can be accommodated easier because of the bigger diameter of the pipeline network and the smaller pressure loss as they are closer to the head of the pipeline as to compare to the downstream demands. Hence, the operating condition must address and be designed to accommodate the downstream system demands to achieve a long-term system performance. The key demand criteria are presented in the Table 10.

Table 10. Key design criterion

Design Criterion	Demand Set	Indicator
Peak Demand Capacity	Peak Hour on Maximum Day	Minimum System Pressures
Flushing Requirements	Average Day	Water Age

(Infrastructure Policy Group, 2014)

2.5 Risks

As compared to existing ground water sources, there are systems associated with system hydraulics as well as public perception of a new water source from a pipeline.

As in any process related to fluid flow transfer, there are many major risks associated with the system hydraulics. Maintaining hydraulic integrity of the system is critical to ensure the water quality and quantity is delivered at satisfactory levels. As mention above, the key parameter of the system is water pressure. Water delivery can be impaired due to breaks, significant leakage, excessive head loss at the pipe walls, pump or valve failures, or pressure surges which are caused by loss of pressure in the pipe. In addition to technical problems, the loss of pressure can cause the contamination in the pipe through intrusion.

Another factor is time period the water stays in the distribution system. Low water volumetric flows can result in loss of disinfectant residual. In addition, some sediments can collect, and microbes can grow and be protected from disinfectants. Also, sediments will increase pipe roughness which will reduce hydraulic capacity.

Table 11. Comparison of water co-op and regional system water quality parameters

Parameter	**High Point[1,2]**	**RVC System[3]**		**Canadian Guidelines[4,5,6]**
		EBWTP output	**Better than High Point?**	
E coli	absent	absent	comparable	MAC of none/100 mL
Total coliforms	absent	absent	comparable	MAC of none/100 mL
Sulphate	**784.4 mg/L**	87.8 mg/L	yes	500 mg/L (AO, taste)
Manganese	0.0183 mg/L	0.005 mg/L	yes	0.05 mg/L (AO, taste, staining)
Chloride	112.2 mg/L	24.6 mg/L	yes	250 mg/L (AO, taste, corrosion)
Haloacetic acids	0.024 mg/L	0.058 mg/L	no, but both < MAC	0.08 mg/L (MAC, carcinogen)
Trihalomethanes	0.075 mg/L	0.054 mg/L	yes	0.1 mg/L (MAC, carcinogen)
pH	8.5	7.0	yes	7-10.5 (AO, treatment, corrosion)
True Colour	5	< 5	yes	15 (AO)
TDS	**1909 mg/L**	295	yes	500 mg/L (AO, equipment scaling)
Turbidity	**43.5 NTU**	<0.10 NTU	yes	less than 0.1/0.3/1 NTU
Dissolved sodium	**695.2 mg/L**	<1 mg/L	yes	200 mg/L (AO, taste)
Fluoride	1.05	0.082 mg/L	yes	1.5 mg/L (MAC)
NOTES: (1) Data source: High Point Estates (2017); (2) Bolded readings exceed AO or MAC guidelines; (3) Data source: ALS Environmental (2018); (4) Data source: Health Canada (2017a); (5) AO = Aesthetic objective; (6) MAC = Maximum Acceptable Concentration				

(Irwin, 2018)

Finally, adequate mixing and inflow rates in storage facilities should be maintained. This is an important component of hydraulic capacity. Short circuiting and pockets of stagnant water with depleted disinfectant residual can be created if the mixing and flow rates are insufficient. (National Research Council of The National Academies, 2006b)

There is a risk of public perception of a new water source form a pipeline does not match the reality. Several of existing groundwater sources have quality issues. Table 11 summarizes the water quality table of ground water in RVC and compares it with the water that communities will receive once switched to the trickle fill treated drinking water and compares it to the quality per Guidelines for Canadian Drinking Water Quality (Health Canada, 2017). The table shows that treated water has higher quality and hence better health benefits. Through regionalized trickle fill system which can afford an effective water treatment, turbidity of drinking water is low meaning an improvement against microbial pathogens.

2.6 Water Storage Consideration

Potable water management is substantial for small rural communities suffering from water shortages and water quality issues. Storing water in end users' tanks and/or cisterns allows the design trickle fill system for smaller flow rates, and smaller diameters which is economical and can supply sufficient amount of water for a period of one day to three months. Typical water storage tanks are designed to store water for up to two days and hold about 700 to 1500 liters of water. Larger storage tanks are not recommended for a household water storage because of the space, cost and water quality considerations. Cisterns are designed to store water for one to three months, and therefore, require additional filtration and disinfection due to possible deterioration of water quality in storage. (E. Scott, 2006)

The CSA Group recently published and specified water system requirements standard for treating potable water in B126 SERIES-13. This standard helps to ensure a proper design and installation for drinking water storage systems, to minimize health risks of contamination and accidents. As this standard is implemented, it will provide guidelines, codes and best management practices to use systems locally. (Canadian Standards Association (CSA), 2013)

Water storage tanks, reservoirs and cisterns store water for domestic and consumptive purposes. Cisterns are used in households to store potable water which is not available in the community. A cistern consists of the reservoir, access hatch for the inspection and maintenance, air vent, fill port to prevent contaminants from entering the cistern, withdrawal pipe with screen to connect between the dwelling and reduce the possibility of sediment that collects at the bottom from entering the plumbing system. The size of cistern depends on volume and is based on household size, water demand, and water delivery frequency. A float switch and alarm can be installed to warn about a

Figure 10. Household tank

Figure 11. Household cistern

(E. Scott, 2006)

low water level. The flow control is described in detail in Section 2.4. There are no regulatory requirements for cistern placement. (Manitoba Conservation and Water Stewardship, 2014).
According to a Water Policy Review report prepared for First Nation Training Services Advisory Group, Health Canada's Environmental Health Officers and Community Health Representatives

do not monitor private cisterns or wells, expect where five connected households are linked to water supply. (Solstice Environmental Management, 2018) Since cisterns are a homeowners' responsibility just like maintaining a furnace, many Public Health Agencies have provided information and guidance on how to clean and disinfect a private cistern. Appendix A: Cleaning and Disinfection Guideline for Private Cisterns after a Drinking Water Advisory presents one of a Public Health Agency's guidance on cistern cleaning following a Drinking Water Advisory.

2.7 Planning

Planning includes capital investment decisions to identify and prioritize capital improvements to meet projected growth or to replace aging infrastructure. Also, it includes the development of water system to schedule, stage, locate, and size new facilities to support projected growth. In addition, the planning is needed to analyze the interconnection of existed systems for emergencies and to identify and prioritize water mains that need to be lined, paralleled or duplicated, or replaced.

As mentioned in the Section 2.4, accounting for the future growth is one of the key design factors. Normally, engineers do not estimate population growth. In addition, each area has its own growth factor due to local and regional social-economic conditions which can be best estimated by comparing a historical data. Further, the water demand in small communities can vary due to recruitment of external work force from different types of industry which makes an impact on the population. There are different models exist to estimate the growth factor. The most commonly used are the arithmetic and exponential methods. (Pitt R., 2010) Arithmetic method uses the constant change in the population over time, and exponential growth assumes a rate of increase which is proportional to population.

There is a technical component to planning stage related to routing. Planning for future connections will allow better planning of pipeline routes which impacts system hydraulics (lengths and elevation profile and required equipment to maintain the pressure in the system) as well as economics of the project. Routing for future connections should be considered and installation methods should be evaluated in the early stage of the project. This will allow to better estimate capital costs and design for system expansion.

2.8 Learnings from Trickle Fill Feasibility Assessment Project

A study has been conducted which developed a feasibility assessment tool for low pressure drinking water supply systems based on the case study area in Rockyview County, AB and concluded that supplying drinking water to the rural areas via trickle fill system is a sustainable way of delivering water. (Irwin, 2018)

What I learned from the assessment development study and the reasons why this project was performed are:

1. Trucking and bottle refilling are expensive and not convenient or preferable ways of supplying drinking water,
2. Many small rural water treatment plants are older and need a replacement,
3. Many small rural water systems struggle to meet water quality standards,
4. There are current and future source water quality and quantity concerns.

These are real life problems many rural or remote communities currently in Canada and around the world face. With the example of RVC area, the concept of sustainable water distribution can be applied to any remote communities in Canada and what is very important to indigenous communities that have been suffering for a very long time.

I have learnt and explained in Section 1.1, that switching to trickle fill system is beneficial as the system has the less energy and environment footprint compare to the water supply systems currently in place (Table 12).

Table 12. Energy and Environment Impacts of Switching to Trickle Fill Scenario

OVERALL SCENARIO TOTALS *(concept scenario impacts – existing scenario impacts)*		
Energy consumed	-2.3	GJ/yr
Fuel consumed	-51	tonnes/yr
GHG's emitted	-164	tCO_{2eq}/yr
Number of jug refills	-35,596	#/yr

(Irwin, 2018)

Supplying water via trickle fill distribution is economical because it is designed for smaller flowrates, the system uses small diameter pipes and inexpensive pipe material (HDPE). However, the affordability depends on many factors which require further research.

Irwin (2018) made several recommendations for further research regarding framework improvement which would strengthen the assessment process, that are to provide best practice concept design modelling recommendations such as default flows, piping diameters, pipe material roughness coefficient, cistern sizes, and how to incorporate long-term planning. These aspects framed this research.

Chapter 3: Methodology

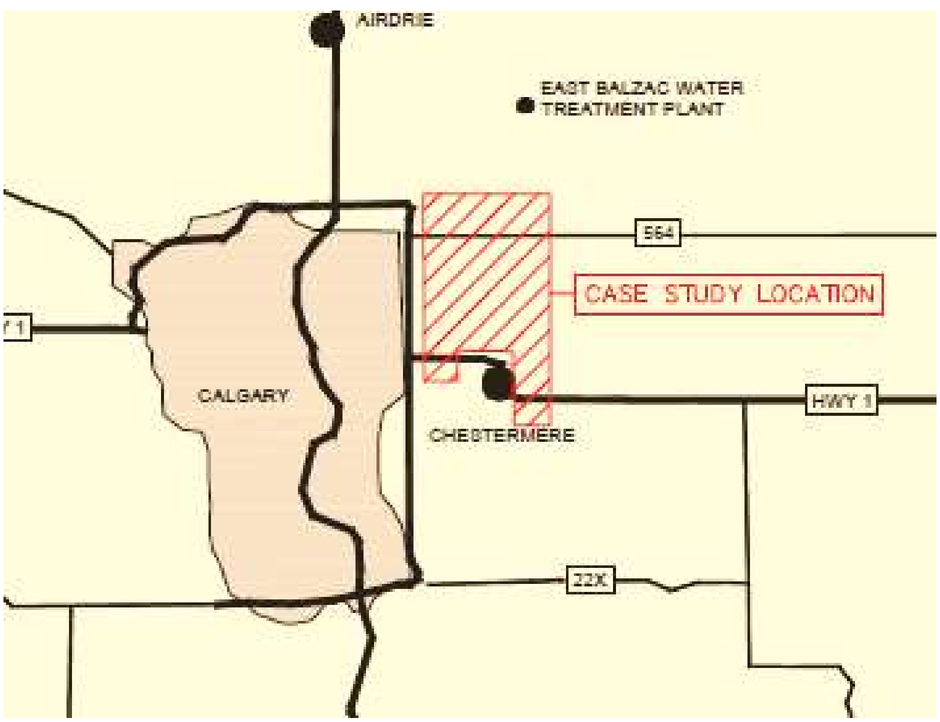
3.1 Design Basis Development

The system distribution design is based on the following criteria which were developed from a report by Infrastructure Policy Group (Infrastructure Policy Group, 2014):

1. Water quality should be kept throughout distribution;
2. Capability of supplying water at all planned connections with enough pressure;
3. System should be water-tight to avid losses due to leakage;
4. Connections are limited to flow (growth factor should be accounted for but is case dependent).

Modelling approach represents a staged process for the trickle fill system design and is based and relies on technical data from feasibility assessment developed by Irwin (2018) and topography profile obtained from Google Earth Pro application illustrated in Appendix C: RVC Trickle Fill Elevation Profile (Google Earth Pro). East Rockyview County study case (Figure 12) represents

Figure 12. East Rockyview County Case Study Location



(Irwin, 2018)

an existing residential, commercial, and industrial properties, properties under development, and future development areas to be connected via trickle fill network illustrated in Appendix D: Rockyview Trickle Fill Distribution Model . The treated water is supplied from the existed East Balzac Water Treatment Plant (EBWTP) to the Conrich Reservoir and Pump Station (CRPS) and is further to be distributed via trickle fill network north and south of RVC. The lengths of main pipelines from EBWTP and CRPS are summarized in Table 13.

Table 13. Technical specifications for piping mains

Pipeline	**Route**		**PVC Pipe**			**Design Operating Conditions**
	From	**To**	**km**	**Size (mm)**	**Pressure (kPa)**	**Max Flow (m^3/day)**
Conrich Transmission Main	East Balzac WTP	Conrich Pump Station	22.6	300 (12 in)	1,282 (186 psi)	2,938
Feeder Main	Conrich Pump Station	Buffalo Hills Subdivision & CN Calgary Logistics Park	2.4	600 (24 in)	515 (75 psi)	1,950
Data sourced from MPE Engineering Ltd. (2013)						

(Irwin, 2018)

The trickle fill distribution network connects nearly 1700 people which represents 704 homes, 227 of new connections, 7 distribution hubs/centers, 217 single residential and 3 commercial connections (Irwin, 2018). This makes the total length of approximately 83 km based on Google

Earth Pro application (Author, 2019). The servicing pipelines lengths are also based on Google Earth Pro application and correspond to technical data from feasibility study by Irwin (2018). The lengths of pipelines to each location are illustrated in Appendix H: Technical Data for RVC Case Study Design. As the initial stage of this project, I analyzed the hydraulic profile obtained from Google Earth Pro which is further required to build a model in EPAnet simulation.

The second step which is the flow modelling was to determine the required piping diameters for each of the pipelines in the scenario. To do this, I used the pressure drop diagram, application of which is described in Section 3.2. It should be noted that my modeling approach relied on available data obtained from East Balzac Water Plant and Conrich Reservoir and Pump Station and supported drawings as well as the data obtained from ArcGIS software utility files for Rockyview County illustrated in Appendix B. With having flowrates (demands), velocities, and pipeline diameters, as well as equipment data sheets (pumps) estimated, I had enough data to build EPAnet simulation case for RVC area.

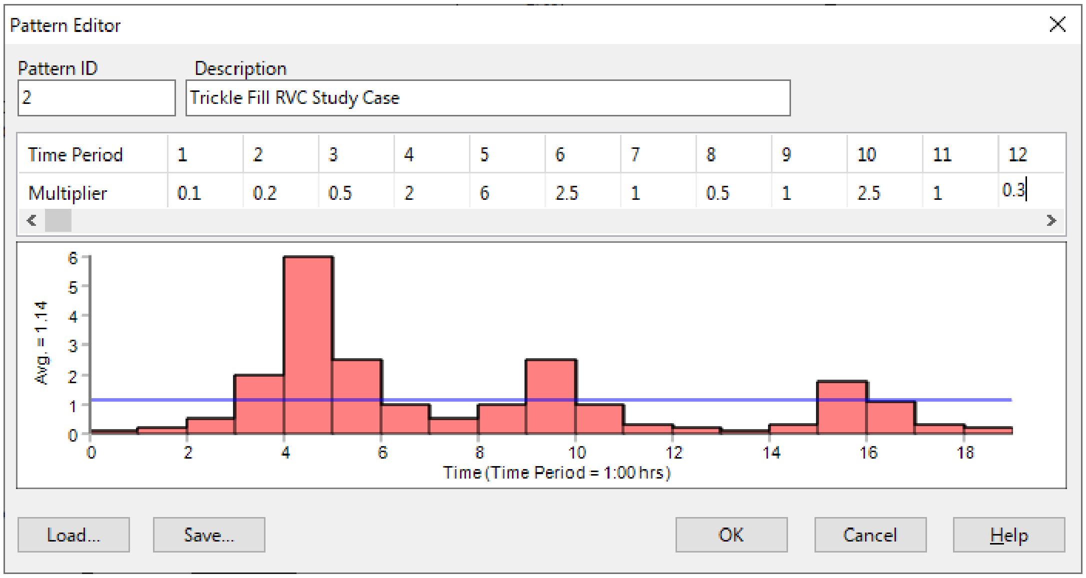
3.2 Water Flow Model

The design flow demand per connection set to 1.14 m^3/day was used for calculations. (Irwin, 2018) The typical flow pattern is presented in Figure 13 and is set to represent peaks of water usage during the morning, lunch, and in the evening. The design flow includes 26% safety factor added to 0.9 m^3/d a typical water demand for rural household in Alberta per day and considers growth factor. (Irwin, 2018) The initial step in the modeling approach was to estimate pipe diameters required for a specific demand of each community within the study area represented in Table 14. For that purpose, I used pressure drop diagram suitable for HDPE pipes (The Engineering Toolbox, 2003) illustrated in Figure 14. The trickle fill system design parameters are set within the purple envelope inside the diagram where the pipe dimeter ranges from 40 to 150 mm and the suitable velocity of water in pipes should be between 0.6 m/s and 1.5 m/s based on Hazen-William equation:

$V = 0.849\ C_{hw} R^{0.63} S^{0.54}$ (Saskatchewan Environment, 2004);

where V is velocity; C_{hw} is Hazen-Williams Friction coefficient, $C_{hw} = 130$ (For PE pipes with nominal diameter up to 150 mm); R is the hydraulic radius; S is the slope of the total head line. As mentioned in Section 2.1, the C factor value is critical for calcualtion of pressure loss due to friction.

Figure 13. Flow Pattern, m³/day



(Author, 2019)

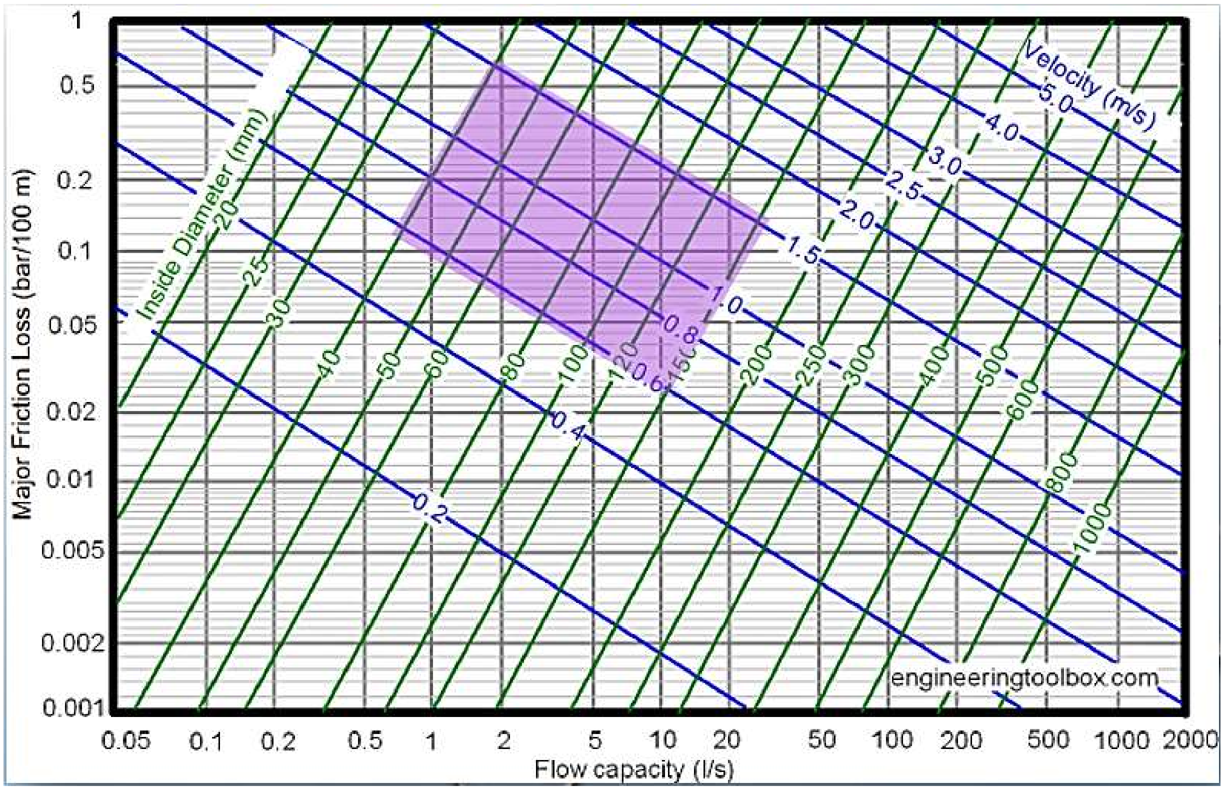
With having a specific demand for a new connection, the pipe diameter and the pressure loss per each 100 meters of pipeline can be easily estimated. This toolbox is very easy to use and should be applied for a quick estimation of a pipe diameter needed for example if a new connection to be added to the system. To explain using RVC case study, starting with a demand of 100 m^3/d (Mountain View Campground (2 buildings, 176 RV Sites) which corresponds to 1.16 l/s and the flow velocity of 0.8 m/s, the pressure drop diagram shows that a 40 mm diameter pipe would be adequate.

Table 14. Flow Demand, m3/day

Community	**Demand, m^3/day**
Cambridge (190 homes) (EPEA 240354)	145
Prince of Peace (90 homes, Senior Living Facility) (EPEA 290049)	100.9
Mountain View Campground (2 buildings, 176 RV Sites)	100
Rural Grouping #1 (78 homes)	46.8
Rural Grouping #2 (12 homes)	7.2
Rural Grouping #3 (85 homes)	51
High Point (30 homes) (EPEA 148701)	22.8
Chestermere High School (907 occupants)	14.3
Landsdown (25 homes) (EPEA 390719)	9.1
Serenity (EPEA 249788) (30 homes)	17.6
Georgian Del-Rich (EPEA 184220) 30 homes	17.9
East Prairie Royale (EPEA 76554) 30 homes	17.8
Spaghetti 20” (25 homes)	15.0
Delacour (17 homes)	10.2
Kathryn School (189 occupants)	2.9

(Irwin, 2018)

Figure 14. Pressure Drop Diagram Showing a Typical range of Pipe Diameters in a Trickle Fill Application



(The Engineering Toolbox, 2003)

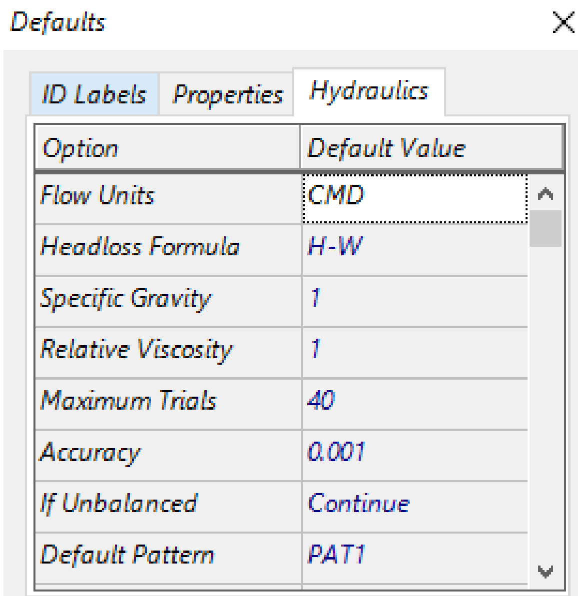
3.3 EPAnet Software

I used EPAnet software to design and develop a model for rural water distribution system. EPAnet is the most widely used free software for simulation of pressurized water networks; it is available to public and recommended by US Environmental Protection Agency's Water Supply and Water Resources Division for modelling water distribution systems. (US Environmental Protection Agency, 2019) EPAnet software is designed to model water distribution network, adjust pumping and tank schedules to lower water age, to use or foresee booster disinfection stations, improve hydraulic performance, help with equipment and instruments location and sizing, and perform energy minimization.

To build a simulation case in EPAnet software, a network must be first drafted in AutoCAD software, and then the file should be converted to EPAnet using EPACAD software. (Universitat Politècnica de València, 2019). As a first-time user, I was not aware of this, and due to time constrains, I manually built a distribution network in EPAnet software. Therefore, the network was not scaled, hence, to build a hydraulic profile and reflect on topography, I manually entered the overall elevation loss or gain for each segment of pipelines as well as assigned the lengths. Next, I had to set project defaults which will be used for modeling the case. For pressure loss calculations, I used Hazen-William's equation, described in the flow model section, and the units were set to CMD (or m^3/d). The project defaults are presented below in Figure 15. The pump curves used for the EBWTP and CRPS are represented in Figure 16, Figure 17, and Figure 18 respectfully and are the pump curves of the existed pumps illustrated in the Appendix E and Appendix F. The pipe diameters were estimated by using the pressure drop diagram for the trickle fill system and then entered into model. The case study model was then built in the EPAnet Software. The original case file is presented in Appendix E: RVC Trickle Fill EPAnet Original Case.

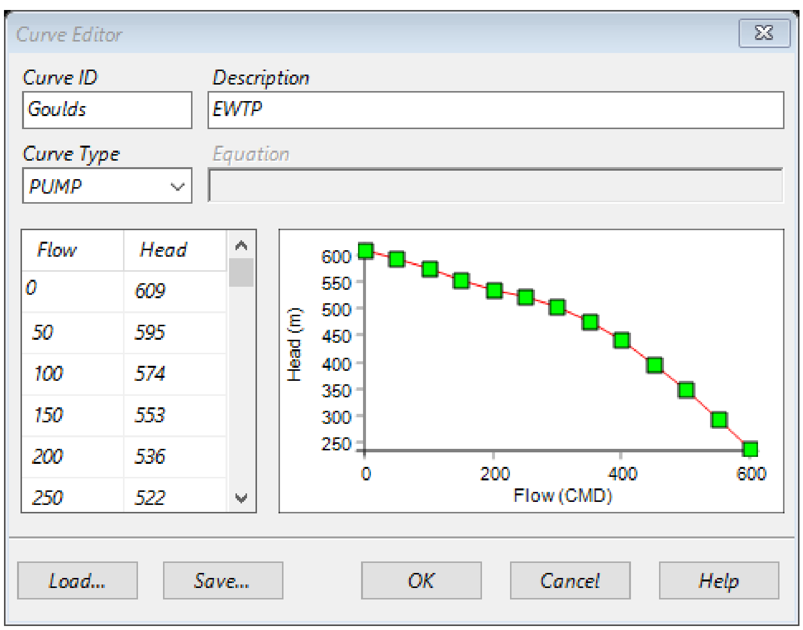
Initially, the case study model did not simulate. The systems calculated errors were related to negative pressure at the pumps or the initial flow of the pumps in the system. After numerous attempts to adjust the flowrate of the water coming through the pumps and adding more storage tanks at the end of lines, by using different sizes of the storage tanks, the software showed the same errors. I came to the conclusion that there are two possible problems. First, the pumps that were used for the simulation case are not suitable. Second, the software is not capable or built to design or model the equipment. The solution was found in estimating and setting the required hydraulic head (pressure) at the EBWTP and CRPS pumps, so the water is delivered to all the communities in RVC trickle network at pressure close to a trickle fill system requirement.

Figure 15. Project Defaults



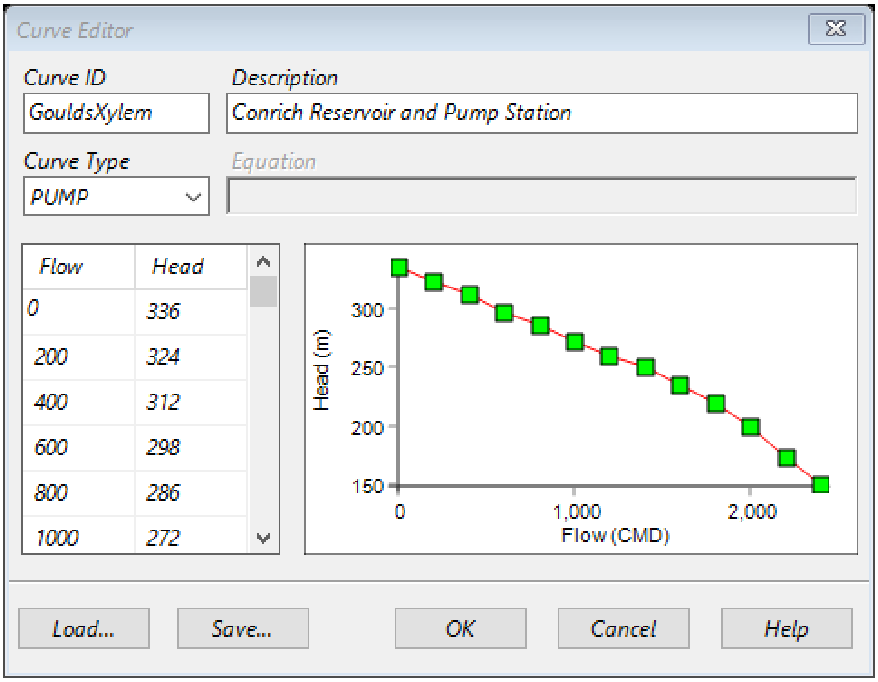
(Author, 2019)

Figure 16. EBWTP Pump Curve



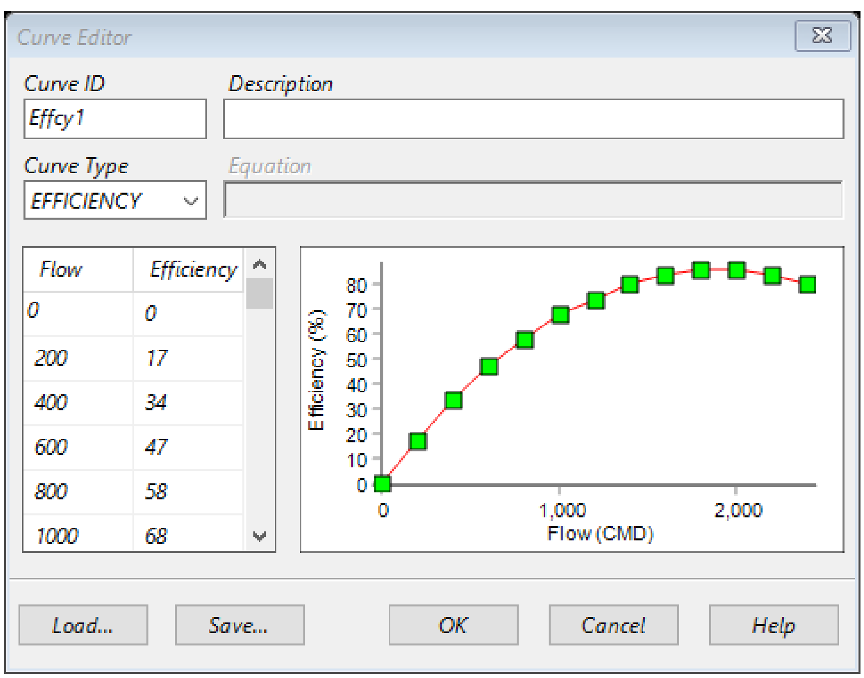
(Author, 2019)

Figure 17. CRPS Pump Curve



(Author, 2019)

Figure 18. CRPS Pump Efficiency Curve



(Author, 2019)

In addition, due to the EPAnet software configuration, EBWTP and reservoirs at CRPS were represented as tanks. When the CRPS was presented as a reservoir, the software assumed that at curtain conditions, it was the source or a starting point of delivering water throughout the distribution network. After implementing the changes described above the case was simulated and results were obtained; however, the overall pressure in the system was higher than allowed for the trickle fill system (Table 15). The pressure was in the range for pressurized grid systems described in Section 1.1.

Chapter 4: Results and Analysis

4.1 EPAnet Design Analysis

When getting errors in the simulation about negative pressure at the pumps suctions and initial flowrates, I checked if other EPAnet users and modelers had similar problems when simulating low-pressure systems or gravity flow systems. I discovered that the errors I had are very common because EPAnet is constructed to model pressurized water distribution systems. (Ingeduld, 2008)

4.1.1 Hydraulic Design

EPAnet software is designed to simulate a fixed demand model and not pressure-dependent and cannot be relied for in terms of designing the system around pressure. The systems settings are such that at low pressure and low flowrate which represent trickle fill system, some flow control valves will close. Therefore, valves cannot be used in the software for this type of system simulation for example to reduce pipe diameters due to valve closure settings in case of intermittent flow pattern application (peak flows and taps off). The same problem with equipment functioning occurs because some pipes are not constantly full or pressurized.

In addition, to set a hydraulic profile that is scaled and represents the true elevation profile as in topographical map, trickle fill network should be drafted in a secondary software and then converted to EPAnet. As RVC case was not properly set in terms of elevations, the system was not scaled, and the hydraulic profile cannot be relied on. The results obtained by the simulation can give a preliminary answer to whether booster stations or additional pumps are required to ensure sufficient pressure at the end of lines.

The pressure in EPAnet simulation is measured in meters of water and is used to calculate the pressure at connections or in other words a nodal pressure, a user must subtract the calculated value from the elevation (meters). The results I obtained by modifying the parameters in the system (head pressure at EBWTP and CRPS), are presented in the Table 15 below.

Table 15. EPAnet network table

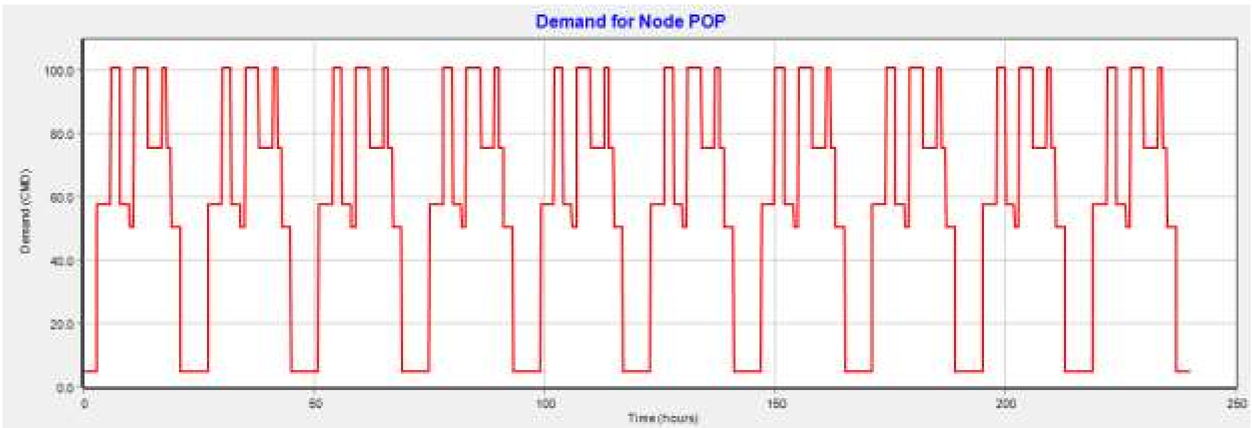
Network Table - Nodes at 239:53 Hrs

Node ID	Elevation m	Base Demand CMD	Head m	Pressure m	chlorine mg/L
Junc E	74	11.3	93.57	19.57	0.21
Junc Delacour	24	10.2	93.56	69.56	0.07
Junc RGP#2	0	7.2	93.55	93.55	0.00
Junc KathrynSchool	-0.98	2.9	93.55	94.53	0.00
Junc CambridgeEst	55	145.0	93.53	38.53	0.55
Junc RG#3	39	51.0	93.49	54.49	0.42
Junc HighPoint	25	22.8	93.45	68.45	0.23
Junc J11	72	17.8	93.57	21.57	0.34
Junc POP	63	100.9	93.50	30.50	0.53
Junc J13	69	46.8	93.54	24.54	0.22
Junc J14	72	17.9	93.57	21.57	0.23
Junc J15	60	15.0	93.56	33.56	0.12
Junc MountView	54	100	93.51	39.51	0.63
Junc ChestHSchool	24	14.3	93.45	69.45	0.23
Junc Landsdown	26	9.1	93.45	67.45	0.20
Junc J22	60	15.0	93.57	33.57	0.19
Tank Conrich	60	#N/A	93.59	33.59	0.00

(Author, 2019)

The EPAnet table shows that the pressure in the system is very high compared to the trickle fill pressure of 140-150 kPa which corresponds to about 15 meters of water. This tells that pressure control and reducing valves must be implemented but cannot be due to the trickle fill configuration explained earlier in this study. In addition, for the trickle fill system, not the whole amount of available water coming to the CRPS shall be used. To recall, the water required for firefighting is excluded from the design. To implement that, the pumps should be sized before the EPAnet case simulation and installed in the simulation to control the amount of water needed for trickle fill network. This can be performed by Aspen HYSYS software and/or applications such as VMG as the total estimated water demand for all connections is known. Due to time constrained and a lack of access to HYSYS or VMG software, in addition to the fact that the issue was discovered after some time spent on EPAnet simulation, the pumps sizing was not performed as a part of this study. To present the results obtained from simulation, the demand for the Prince of Peace was taken as an example and is illustrated in Figure 19.

Figure 19. Base demand for Prince of Peace, RVC



(Author, 2019)

Figure 20. Hydraulic options

Hydraulics Options

Property	Value
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	PAT1
Demand Multiplier	1
Emitter Exponent	0.5
Status Report	Yes
CHECKFREQ	2
MAXCHECK	10
DAMPLIMIT	0

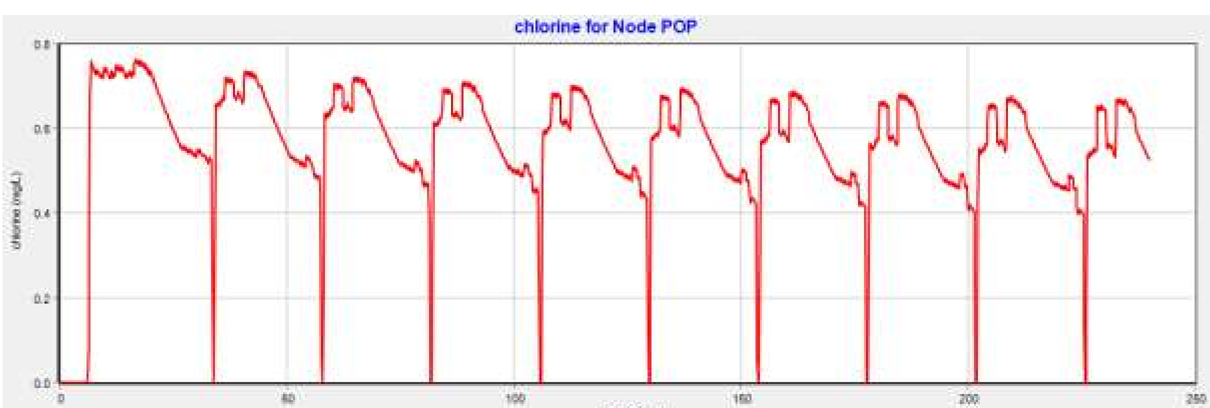
(Author, 2019)

The demand has peaks and falls that correspond to a typical water flow pattern. If the water demand changes (i.e. increases in the future due to new connections), it can be adjusted and predicted by using software hydraulic option called demand multiplier. Another application of demand multiplier option is to calculate the change in water demand value for example to account for an increased maximum water demand. For example, in Prince of Peace, where the base demand is 100.9 m3/d and the peak demand is 302.7 m3/d. The demand multiplier would have a value of 3 instead of 1 (Figure 20). Therefore, the system can be designed considering all possible variations of water demand including future possible connections.

4.1.2 Water Quality

EPAnet predicts water quality expressed through chlorine residual concentration for each node or a connection. The output results are dynamic and color-coded; hence the user can see how the water quality changes with time and analyze where additional disinfection is required. To better understand this, I showed the chlorine residual results from simulation for RVC case study in the Appendix J: RVC Chlorine Concentration Results, Day 2 and Day 9. If to look at a node in the network, user can see different values of concentration and different color changing with time. Each node can be also analyzed individually by looking at the chlorine residual change within the designed period of time.

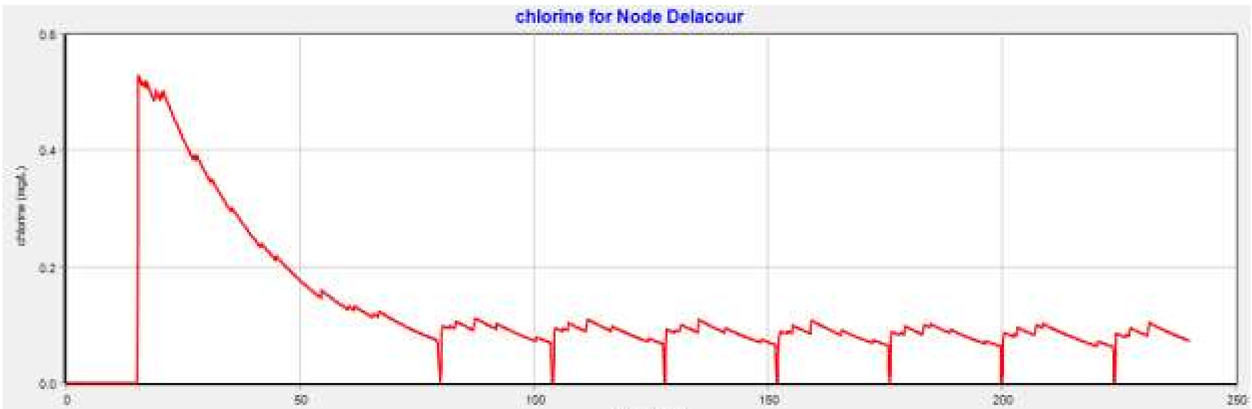
Figure 21. Prince of Peace chlorine residual



(Author, 2019)

In my model I used 10 days period. The chlorine residual concentration values change within 10 days for Prince of Peace and Delacour are shown in Figure 21 and Figure 22 respectfully.

Figure 22. Delacour chlorine residual



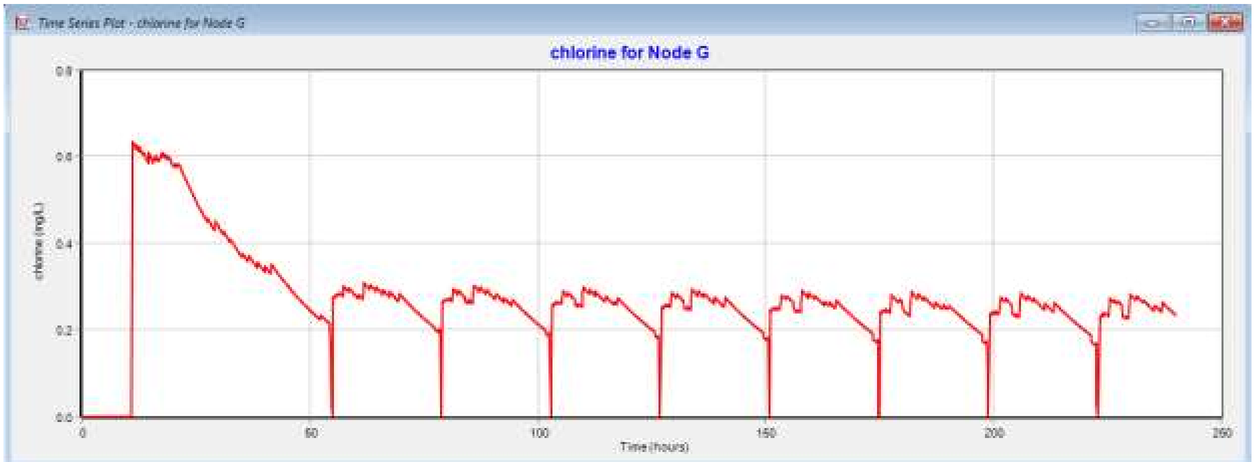
(Author, 2019)

Graphs of chlorine residual have peaks and falls that correspond to taps on/off flow pattern. At constant flow regime, graphs would have more gradient and smooth change in value. For the purpose of study, peaks and drops can be disregarded. Ignoring the peaks and drops, the chloride residual for Prince of Peace location varies between 0.5 to 0.7 mg/l, but for the Delacour it drops below 0.2 mg/l.

Per Alberta Environment and Parks (AEP) guideline, free chlorine residual concentration in drinking water should be minimum 0.2 mg/l (Alberta Environment and Parks, 2019). It can be concluded that additional disinfection is required somewhere before Delacour location or the whole system would need to be operated at a higher average chlorine residual level. Below are the graphs of chlorine residual for locations Spaghetti 20, node G and node G' upstream of Delacour (Figure 23, Figure 24) from which it can be analyzed and concluded that additional disinfection would be required after node G which is "Spaghetti 20" location in the RVC map (Figure 23) because at that node residual concentration drops just below 0.2 mg/l.

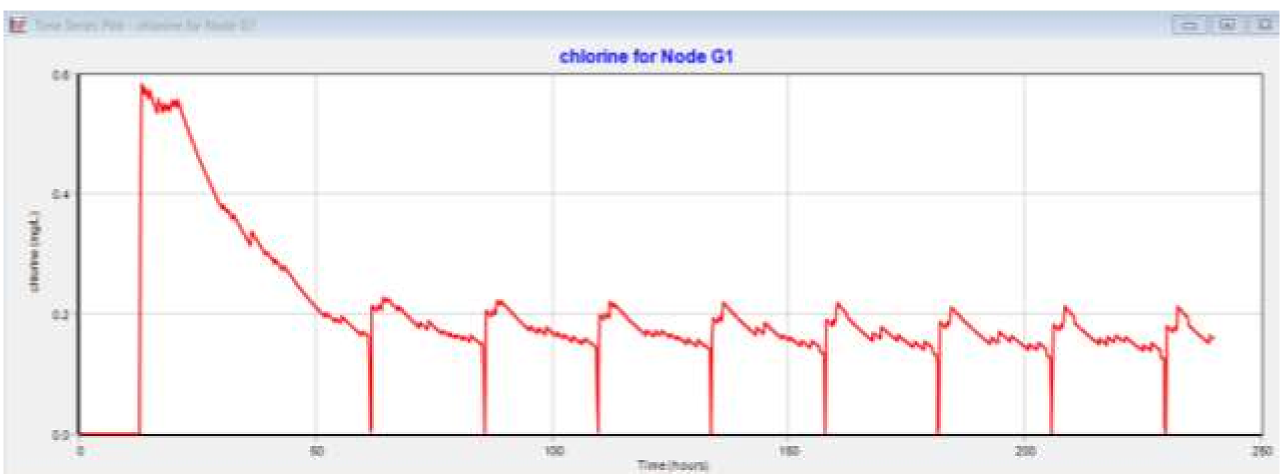
As with all modelling results the actual chlorine residual concentration may deviate from predicted, since the EPAnet case simulation does not (and cannot) include all the details of the actual system. These includes factors such as system sizing, pumps, air entrapment, valves, condition of the water of pipes and reservoirs.

Figure 23. Chlorine Residual for Spaghetti 20 (Node G), RVC



(Author, 2019)

Figure 24. Residual concentration for Spaghetti 20 (Node G'), RVC



(Author, 2019)

4.2 Energy Analysis

EPAnet provides energy analysis based on the pumps in the system; however, because the existed pumps (EBWTP and CRPS) are not suitable for trickle fill simulation in EPAnet, the energy analysis cannot be performed by the software.

To analyze energy use, I calculated the volumetric energy consumption of pumps that is presented in Table 16 which shows that the energy consumption of the water treatment plant pump is double of what a typical pump uses and the consumption of the CRPS pump is just over it. That means that the pumps are sized for future growth/system expansion, by currently do not operate at full capacity, which is:

1. This is not economical;
2. Not operating at full capacity creates hydraulic risks (described in detail in Section 2.5), wears off the equipment and instruments in the system faster and requires higher pressure.
3. This creates more risks of deteriorating water quality (described in detail in Section 2.5) and requires higher number of flushing to avoid water stagnation in pipes.

There are two ways to improve current system situation. First is to implement trickle fill water distribution. By adding more connections / customers to the existed system, it will significantly increase the capacity. Trickle fill network was estimated to add up to 1717.1 m3/d of water flow. (Appendix H: Technical Data for RVC Case Study Design) In addition, trickle fill distribution system is economical compare to a full pressure system as it requires inexpensive pipe material, less piping and instruments such as pressure control valves which have major impact on capital costs. Finally, trickle fill system implementation will reduce hydraulic and water quality associated risks. The second way to improve the situation is implementation of jockey pump also known as maintenance or fire pump (Figure 25). This is a small pump designed to maintain/stabilize pressure and to protect the pipeline from sudden pressure change such as a drop or jump in case of fire in the fire flow water system. Jockey pumps are typically small multistage centrifugal pumps. How would this pump work for the current system? The water pressure inside the pipes reduces due to pressure loss. The jockey pump is designed to sense it, and to fill it up to normal pressure.

Table 16. Volumetric energy consumption

Equipment	Typical pump consumption	EBWTP pump at 83 m^3/h (rated capacity) (Appendix F: East Balzac Water Treatment Plant Pump Curve)	CRPS pump at 428 m^3/h (rated capacity) (Appendix G: Conrich Reservoir and Pump Station Pump Curve)
Volumetric energy consumption, kWh/m^3	0.2 kWh/m3 (Irwin, 2018)	0.52 kWh/m^3	0.23 kWh/m^3

(Author, 2019)

Figure 25. Jockey pump

(DESMI, n.d.)

Hence, this pump would ensure the water is delivered at the required pressure and would be applied to control pressure in the line rather than setting it to the large CRPS pump level. Since jockey pump would control pressure in the system, it will also lead to energy and equipment savings. I performed the energy and environment analysis where the jockey pump is assumed to be installed at CRPS against the pump currently in operation. As an example, I chose Landsdowne Estates consisted of 25 houses and has 3900 m3/year of water demand. Landsdowne (node V) is located 15 kilometers south of CRPS (node M) and is shown in the Appendix D: Rockyview Trickle Fill Distribution Model. Due to time constrain, I assumed a jockey pump flowrate would be 2 GPM (or 10.7 m3/d) which corresponds to the water demand.

I also assumed that the volumetric energy consumption of the jockey pump is 0.2 kWh/m^3 that is a typical pump consumption as explained earlier. To make it consistent with the energy and environment analysis of trickle fill system against trucking water delivery methods described in Section 1.1, I assumed that a power plant efficiency of 35%, electricity is generated from natural gas, and GHG emissions intensity of 790 gCO2eq/kWh. (Irwin, 2018) I also assumed a pumping cost of $0.15/kWh which is the same as was used in energy analysis by Irwin (2018) of trickle fill system versus trucking water delivery. Pumps efficiency of 84% is taken from pump curve/test presented in the Appendix F. Total pump head for the jockey pump is assumed to be the same as for the CRPS. As point of my interest, I calculated energy and emissions data for the EBWTP pump as it would transfer the same amount of water as a jockey and CRPS pumps. The calculation spreadsheet is presented in Appendix L: Energy and Environment Analysis for Jockey Pump. The energy metrics delta calculated for a unit of water delivered is shown in the Table 17 from which it can be concluded that the jockey pump installation is a better option rather than running system on current CRPS pumps as it saves the equipment, energy, and has a smaller environmental footprint, however, the difference is not that big. However, if to represent it on annual basis which is shown in Table 18, the difference is significant. For example, the energy of 1.1 GJ/yr that could be saved if the jockey pump is installed would be equal to the energy savings of 12 Canadian homes. (Statistics Canada, 2017)

To conclude, there are benefits to energy and environment if to install a jockey pump. Such option for RVC will be better than using current pumps, and implementation of jockey pump will save some energy and equipment, but such option should be considered as a temporary solution.

Table 17. Energy and environment analysis for a jockey and CRPS pumps per unit of water delivered

Equipment	Jockey pump option, 0.45 m^3/h	EBWTP pump at 83 m^3/h (rated capacity)	CRPS pump at 428 m^3/h (rated capacity)	**Energy Metrics Delta between jockey and CRPS pumps**
Volumetric energy consumption, kWh/m^3	0.2	0.52	0.23	**-0.030**
Energy consumption, MJ/m^3	0.686	1.644	0.961	**-0.274**
Fossil fuel consumption per unit of water delivered, kg/m^3	0.04	0.10	0.06	**-0.017**
Greenhouse gas emissions per unit of water delivered, $kgCO_{2eq}/ m^3$	0.151	0.361	0.211	**-0.06**

(Author, 2019)

Table 18. Energy and environment analysis for a jockey and CRPS pumps - annual basis

Equipment	Jockey pump option, 0.45 m^3/h	EBWTP pump at 83 m^3/h (rated capacity) (Appendix E)	CRPS pump at 428 m^3/h (rated capacity) (Appendix F)	**Energy Metrics Delta between jockey and CRPS pumps**
Energy consumed for pumping annually, kWh	743	1780	1041	**-297**
Energy consumed for pumping annually, GJ	2.7	6.4	3.7	**-1.1**
GHG's emitted due to pumping, $kgCO_{2eq}$	587	1407	822	**-235**
Fuel consumption, tonnes /yr	0.156	0.390	0.234	**-0.078**
Annual cost of pumping, $	111	267	156	**-44.60**

(Author, 2019)

Chapter 5: Conclusion

5.1 Assumptions and Limitations

This study had many assumption and limitations related to case simulation using EPAnet software and are presented in Appendix M: Case Study Assumptions and Limitations.

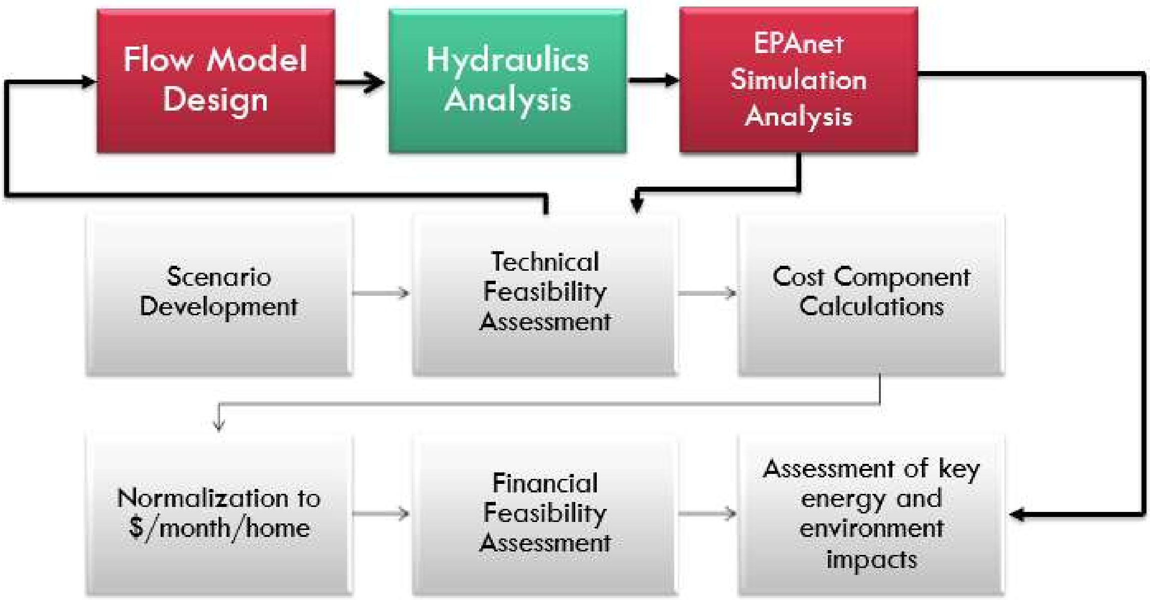
5.1.1 Modelling Software Discussion

There are three stages in the developed modelling approach where suitable software must be used to obtain precise and reliable outcomes which are critical for trickle fill system assessment, as the results have direct impact on costs, energy, and environment components of the project. Figure 26 illustrates the imput of this study in the trickle fill system assessment process developed by Irwin (Irwin, 2018).

The first stage that is the flow model design requires use of HDPE pressure drop diagram application (described in Section 3.2). The hydraulic analysis should be characterized as a separate stage in the modelling approach and performed before the water modeling software application. At this stage, hydraulic study is required to evaluate pressure profile in the system and make a preliminary equipment and flow and pressure control instruments. This can be obtained by using software like PIPESIM (Schlumberger Limited, 2019) or PIPE-FLO® (Engineered Software Inc., 2019). Once the hydraulics are analyzed and the required equipment is unidentified, it should be sized. This can be performed by Aspen HYSYS (Aspen Technology, Inc., 2019) or VMGsim software (Virtual Materials Group Inc., 2019) applications.

The final stage of the approach requires water modelling software application suitable for rural water systems that is branched distribution. For this study, I used EPAnet software as US EPA recommended software (US Environmental Protection Agency, 2019). This software is advanced in modelling pressurized systems that are applicable for urban areas. However, I learnt that this software alone is not capable to model or design trickle fill system and summarized the advantages and concerns that I observed in Table 19.

Figure 26. Trickle Fill System assessment modification



(Based on Development of Feasibility Framework by Irwin (2018))

(Author, 2019)

Table 19. EPAnet software application for Rural Development

Advantages	Concerns
Models different water use patterns (taps on/off)	Designed for pressurized water systems
Considers demand fluctuations at each node	Assumes pipes are full and pressurized
Models pressure dependent flows	Modelling/sizing cisterns or break pressure tanks
Results are easy to read and analyze	Pump selection for simple pumping systems

(Author, 2019)

There are several modeling software applications suitable for rural water development listed in Table 20. Each software as it can be seen from the figure has its advantages and disadvantages, but I found recommendations about using GOODwater software (Good, 2008).

Table 20. Rural water distribution software

	Air In Pipes	NeatWork	EPANET	Reents'	GOODwater
General Attributes					
Stand Alone Program		✓	✓		
Useful Resources Available		✓	✓		
Add-Ons Available			✓		
Supported Design Capabilities					
Materials Lists				✓	✓
Project Scheduling					✓
Site Assessment					✓
Valve Placement	✓		with add-ons		
Pump Modeling			✓		
Water Quality Modeling			✓		
Conduction Line Design	✓		✓	✓	✓
Distribution Network Design		✓	✓	✓	✓
Capital Costs Optimizer	✓	✓			✓
Tank Size Calculator				✓	✓
Airblock Diagnosis	✓				✓
Pipe Diameter Optimization		✓	with add-ons	✓	✓
Grid System Ability			✓		
Post Processing Functionality					
Simulation Capabilities	✓	✓	✓		✓
Plan-View Visual Representation			✓	✓	
Budgeting Tools	✓	✓		✓	✓
Report Generator		✓	✓	✓	✓
Sustainability Assessment					✓

(Mortenson Center in Global Engineering, 2008)

GOODwater software has some options that EPAnet does not offer such as tank sizing which is critical for a dead-end distribution system and cost optimization; and last but not least important, GOODwater software is the only software among compared that offers sustainability analysis. This concludes, that EPAnet should be used in combination with another software suitable for rural water development. I recommend using EPAnet and GOODwater to model trickle fill distribution system as these applications complement each other in terms of general attributes, design capabilities, and post processing functionalities, and the results obtained by both applications can be compared against each other for errors in values.

5.2 Recommendations

As this research is a continuation of the Development of a Feasibility Framework for Trickle Fill Water Distribution Projects study done by Irwin (2018), my recommendations add to a list of the original study suggestions. Regardless of case study limitations and difficulties with using EPAnet modelling software, the modelling approach developed in this capstone for RVC case study area brings valuable points based on which the trickle fill project development can be carried out further. I propose to make changes to the project development illustrated in Appendix J:

1. The Environmental Assessment which should include wildlife, wetlands, and vegitation assessments, erosion and sediment control plans, fish and fish habitat assessment, ECO plan, and Phase 1 ESA, should be performed in the assessment process on the project definition stage of development as well as the project should be checked against Water Act (water supply licence), COP water course crossing notifications, Historical Resource Act, and Public Lands.

2. In the design stage of the project, geotechnical study should be performed (for rock allowance, should horizontal directional drilling (HDD) be used for construction), road allowance (private roads crossings analysis), depths at pipeline connections (for HDD or plowing methods of pipeline installation).

A hydraulic analysis should added as a separate step in the design stage as it plays a key role in overall assessment. The hydraulic analysis is recommended to be performed by a suitable software such as PIPESIM or PIPE-FLO. The equipment and instruments (control valves, air pressure relieve valves) sizing shall be the next step and can be performed by Aspen HYSYS or VMG software. Finally, a water modelling software should be applied, and I recommend to use EPAnet in combination with GOODwater applications.

3. In the preparation stage of the project, once the design conditions are checked and satisfied, the construction methods should be evaluated (plow, HDD, trenching/open cut, or combination of it), and cost analysis performed.

5.3 Conclusion

Rural water distribution modeling is an interesting and not an easy project because such distribution systems are not fully pressurized and operate at very low pressures. In addition, emptying and refilling of water pipelines due to water storage requirements at the end of lines makes it challenging to design using EPAnet standard hydraulic modelling software because of such working parameters in addition to data availability, and possible hydraulic and water quality related risks. Therefore, the system modelling approach must ensure the appropriate service delivery, otherwise it can diminish the work and effort of regionalized communities currently facing financial challenges when supplying potable water. It is critical for the water distribution system to be sustainable that is to be technically, economically, social, and environmentally sound. That means that the system should use appropriate technology (be equally accessible to upstream and downstream users), use local materials, and should be flexible (consider population growth).

Rural water distribution economics differs from an urban system in a way that the costs should be paid upfront. Hence, community education plays a key role, and the trickle fill network customers' needs should be considered and incorporated. The communities shall participate in the water system distribution planning and development to make it work.

There are many software programs designed to help with system modelling and optimization. EPAnet software used in this research study was found to be insufficient to design the RVC trickle fill system alone and should be used in combination with another modelling software suitable for rural water development such as GOODwater. EPAnet is suitable for water quality analysis and for prediction of possible water quality issues within the system; however, it is not appropriate for energy optimization as EPAnet energy analysis is based on the equipment put in the model. EPAnet hydraulic modeling is also based on the equipment in the system, and therefore all the equipment and instruments should be sized by a suitable software such as Aspen HYSYS or VMGsim prior to EPAnet software application. The hydraulic model should be tested and analyzed prior EPAnet software application. This can be done by PIPESIM or PIPE-FLO software designed for hydraulic modelling and optimization. With all of this in mind, EPA is concluded to be suitable for water and energy analyses but should be used in combination with other software to model trickle fill distribution system.

In conclusion, under given situation in RVC, the trickle fill distribution network is strongly recommended as a sustainable water distribution compare to other options of delivering drinking water such as trucking or bottle refilling. Not only trickle fill system will deliver a clean treated water to rural communities in Rockyview county, it will also be the most economical and forward-thinking way for RVC to improve the situation with pumps at the East Balzac water treatment plant and Conrich reservoir and pump station currently not operating at full capacity thus wasting a lot of energy and water which is not economical. Through regionalization of communities, trickle fill system will bring more customers which will maximize the system capacity and eliminate risks associated with system hydraulics and water quality deterioration. Trickle fill distribution is economically feasible and environmentally sound and as studied in this paper can be easily designed with suggested software. This ensures the treated drinking water supply to users reliable in a more sustainable and timely manner as a long-term plan.

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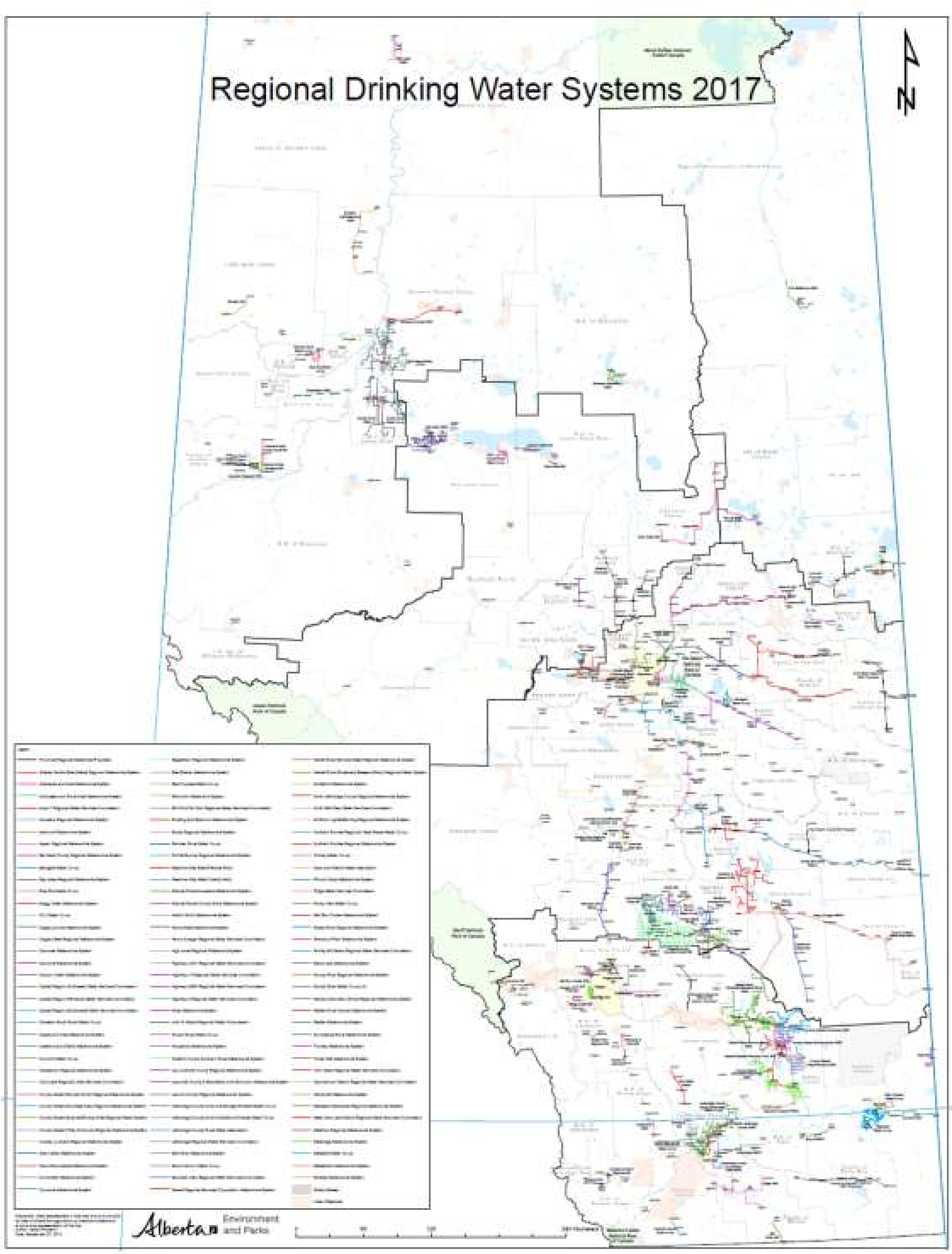
Appendix A: Cleaning and Disinfection Guideline for Private Cisterns after a Drinking Water Advisory

Cleaning Procedure	1. Drain the drinking water cistern completely. Do NOT use a sewage hauler to pump out the drinking water cistern. 2. Wash all internal surfaces. Use a pressure washer with a mild, food-grade detergent to remove all dirt from the interior of the drinking water cistern (see Safety Note below). 3. Examine all seals, surfaces and the floor for signs of cracks and leaks. 4. Rinse the inside of the cistern with potable drinking water to remove the remaining dirt, debris and detergent residue. 5. Discard all rinse water. 6. Follow the disinfection or sanitization procedures below.
Disinfection Procedure	1. Disconnect all water treatment equipment such as water filters and softeners from the cistern. 2. Fill the cistern half full of potable water. 3. Add chlorine to the cistern to achieve a 20 mg/L chlorine solution strength in the water. • If using unscented household bleach (5.25%), add 400 ml (1 ½ cups) of unscented household bleach into the cistern for every 1000 L (220 imp gal.) of water cistern total volume. • If using industrial strength chlorine (12%), add 200 ml (3/4 cup) of industrial strength sodium hypochlorite into the water cistern for each 1000 L (220 imp gal.) of water cistern total volume. 4. Add more potable water to the cistern until it is full. 5. Run water through the taps until you can smell the chlorine. Do not run chlorinated water through certain types of water treatment equipment (e.g., softeners, carbon filters, reverse osmosis systems). For specific information contact your equipment dealer or the manufacturer.

	6. Leave the chlorinated water in the cistern and piping for 24 hours. Water MUST NOT BE CONSUMED during this process. This water should not be used for laundry or bathing. An alternative supply of drinking water, such as bottled water, should be used during this time. 7. After 24 hours, drain the chlorinated water from the cistern and flush the drinking water system with potable water. 8. See below for “Disposing of Heavily Chlorinated Water”. 9. Fill the cistern with potable water.
Disposing of Heavily Chlorinated Water	Flush the tank or cistern by pumping the water through an outside hose. Dispose of the chlorinated water away from grass, shrubs, trees and other sensitive plants until the strong smell of chlorine disappears. Make certain that the water does not enter a natural watercourse. Do not dispose of rinse water or heavily chlorinated water in an onsite wastewater treatment system. Consult a public health officer (see below) for acceptable disposal options of significant volumes (i.e. more than household use) of highly chlorinated water.

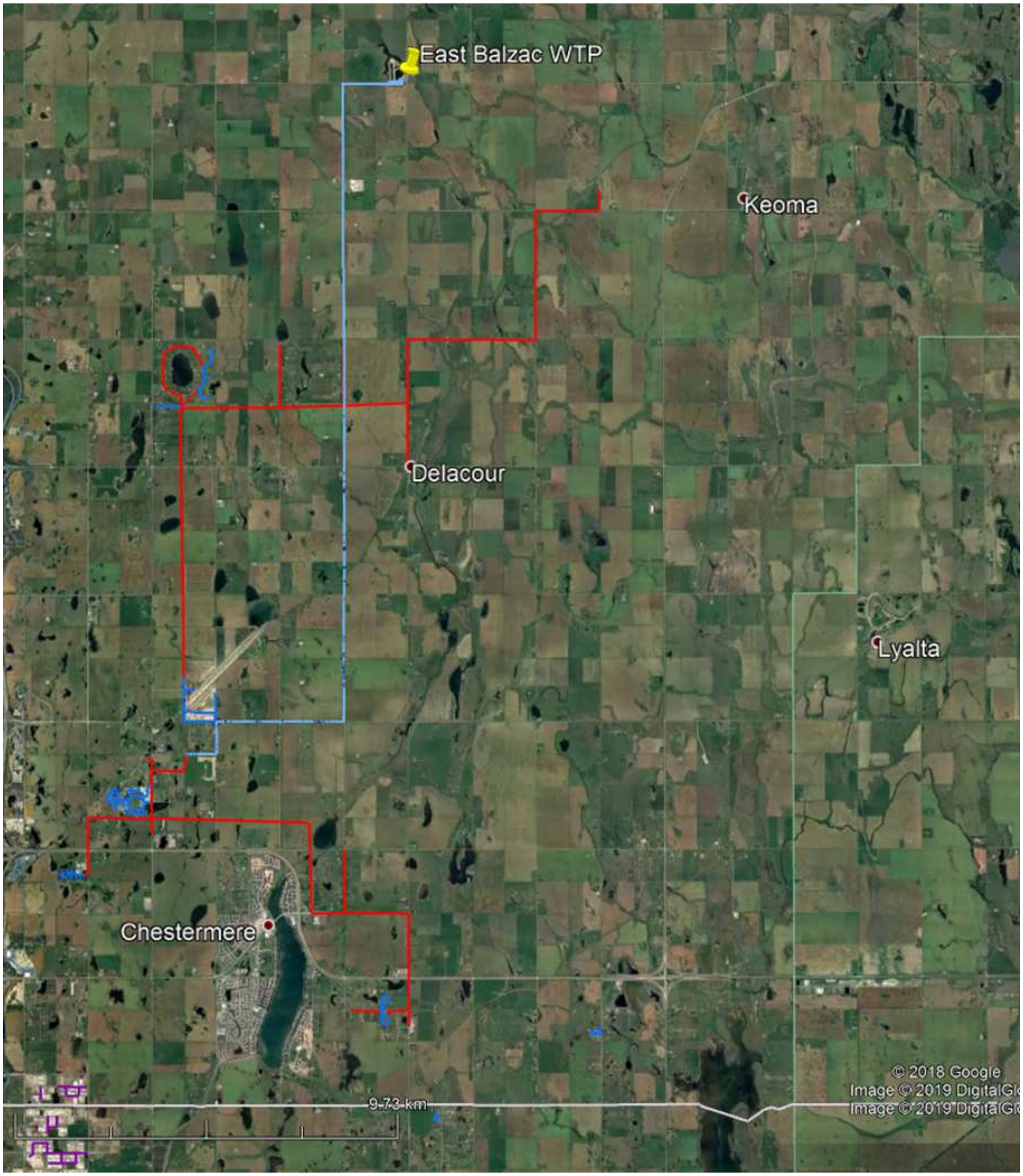
(Government of Saskatchewan, 2014)

Appendix B: Locations of Drinking Water Treatment Plants



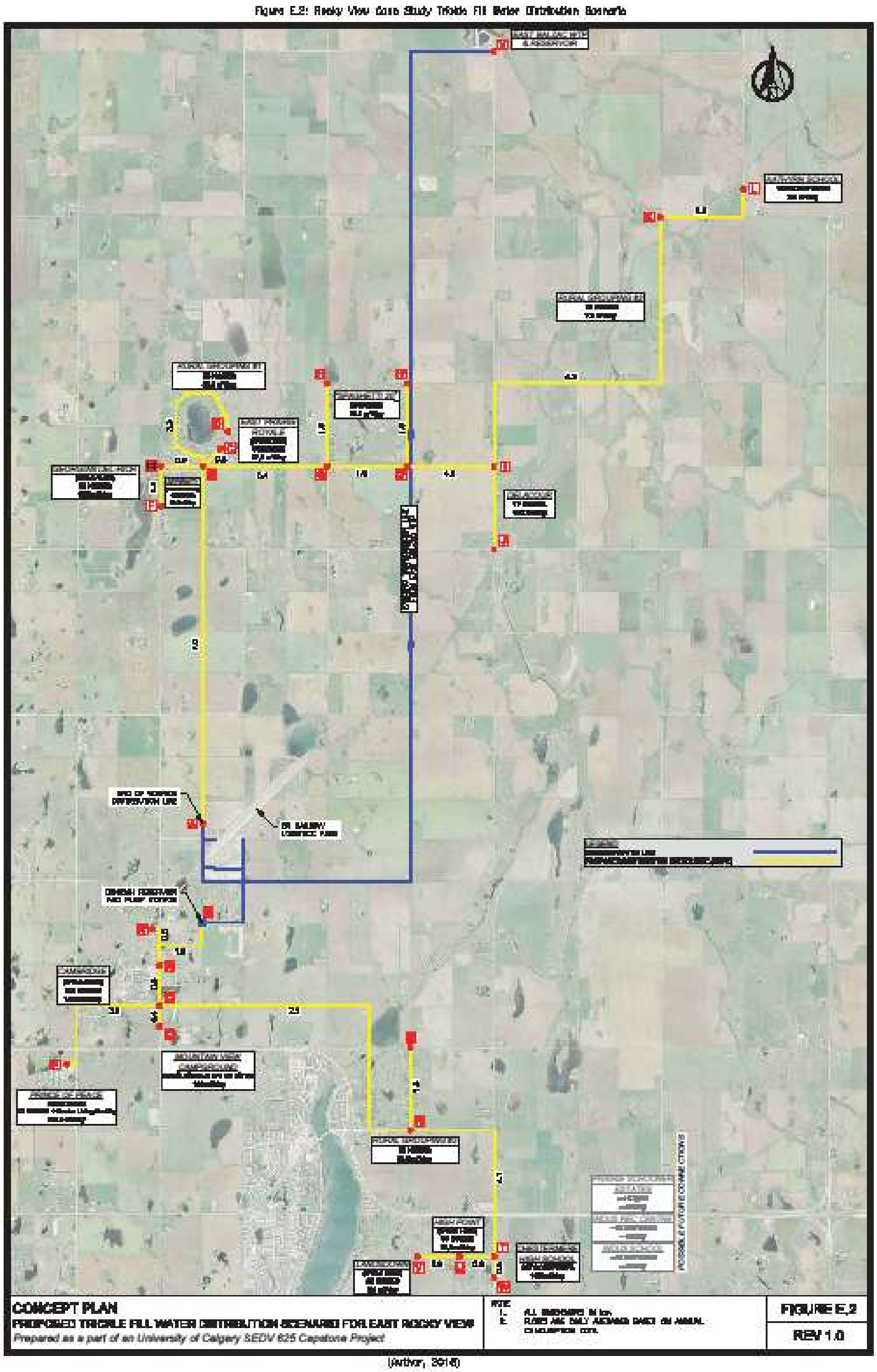
(Janzen, Achari, Langford, & Dore, 2017)

Appendix C: RVC Trickle Fill Elevation Profile (Google Earth Pro)



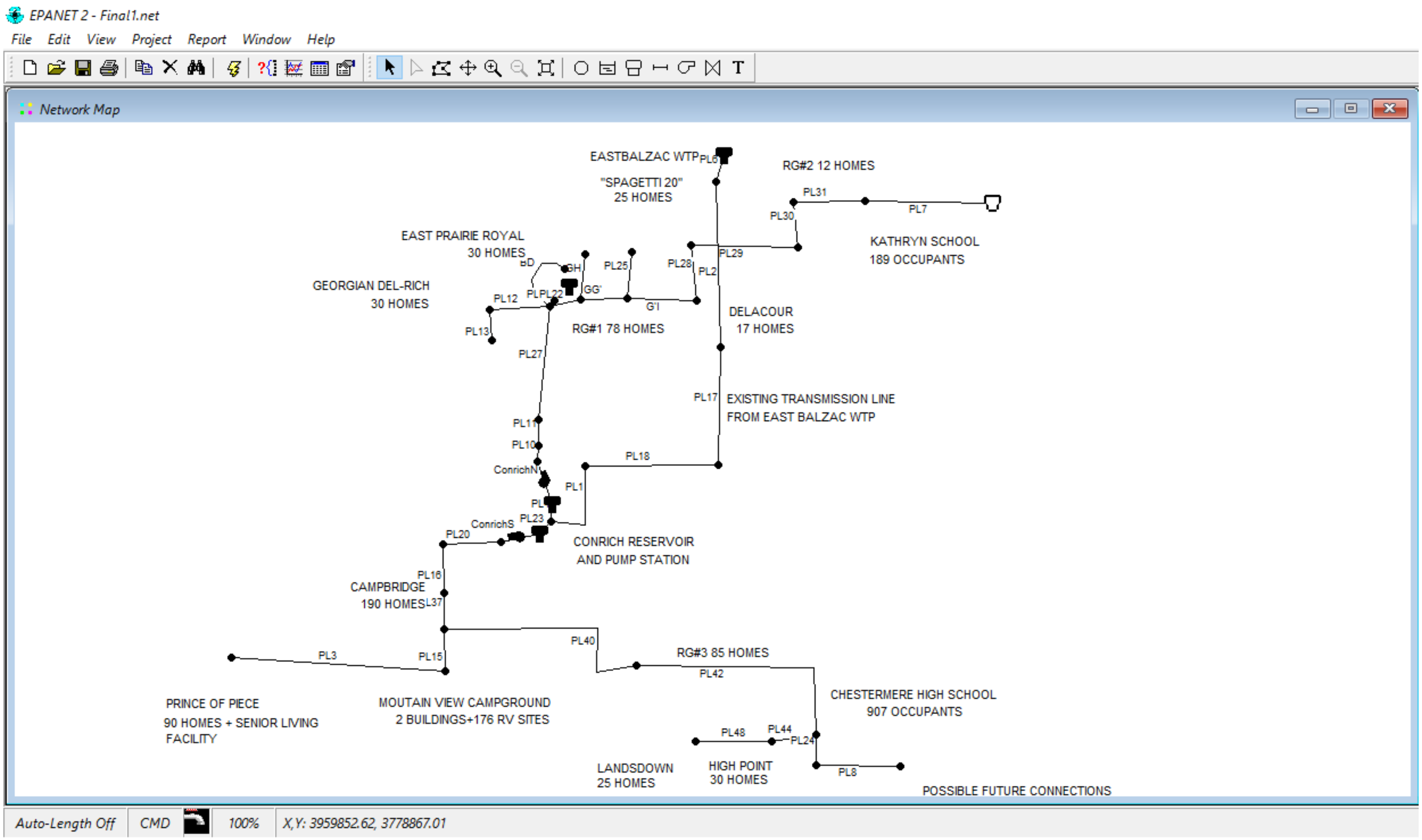
(Author, 2019)

Appendix D: Rockyview Trickle Fill Distribution Model



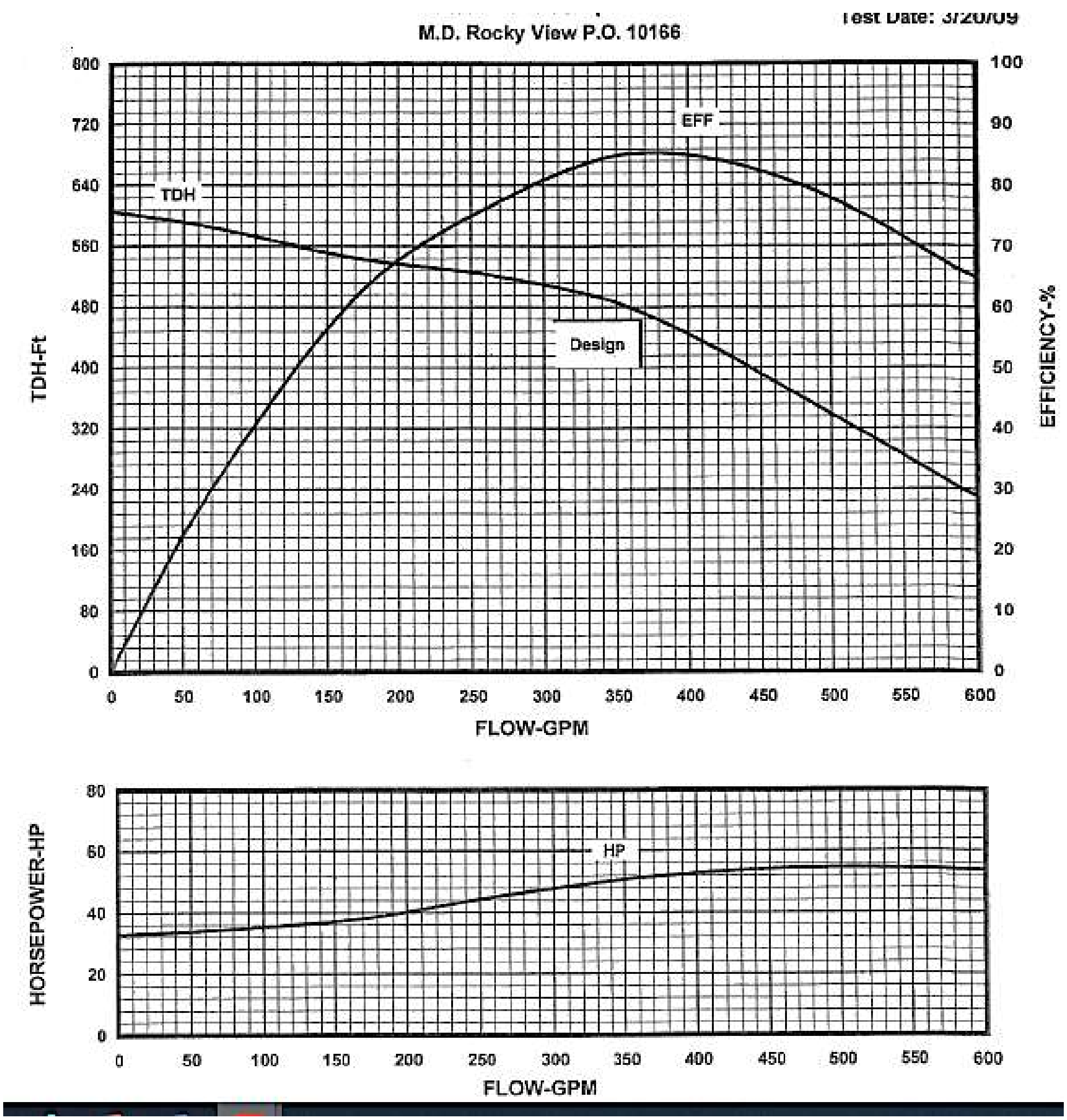
(Irwin, 2018)

Appendix E: RVC Trickle Fill EPAnet Original Case



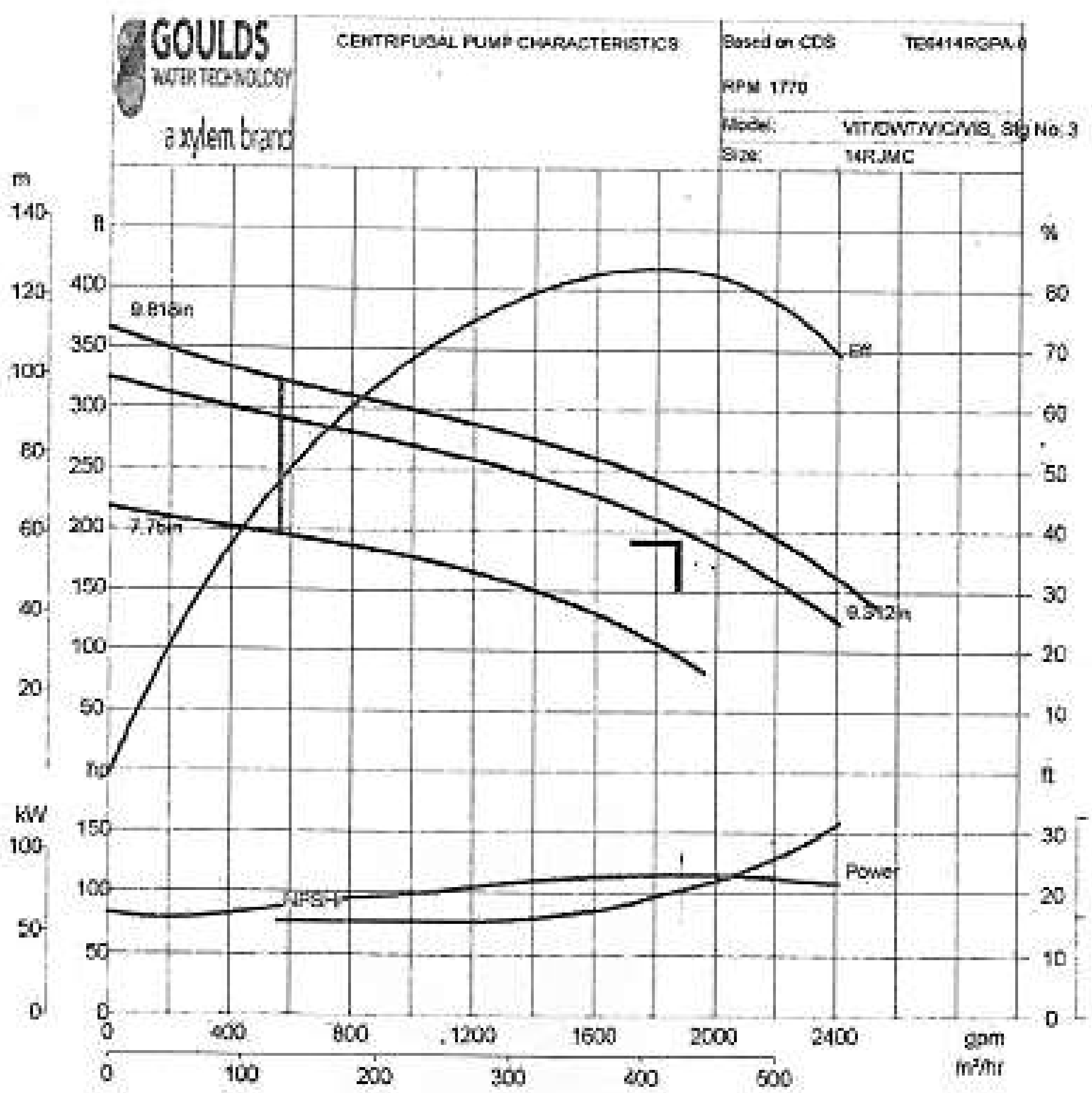
(Author, 2019)

Appendix F: East Balzac Water Treatment Plant Pump Curve



(Personal Communication)

Appendix G: Conrich Reservoir and Pump Station Pump Curve



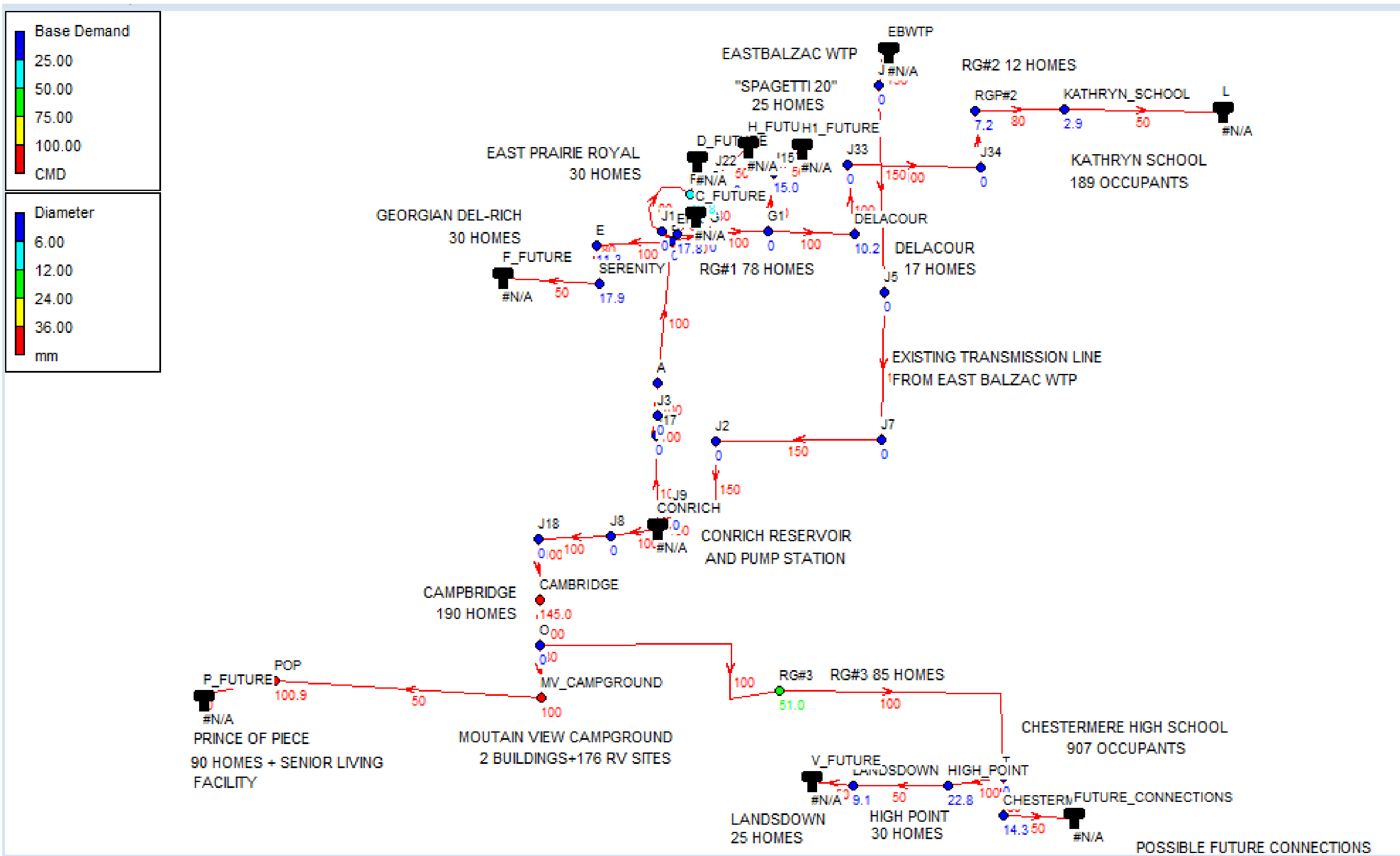
(Personal Communication)

Appendix H: Technical Data for RVC Case Study Design

Grouping/Organization	EPEA #	Number of homes	Average flow (m^3/day)	Peak Flow (m^3/day)	Total new PL length (km)
East Prairie Royale Estates Co-Op	76554	30	17.60	52.80	7.5
Rural Grouping 1 (Prairie Royale)	n/a	78	46.80	140.40	7.15
Serenity Estates	249788	15	11.30	33.90	0.85
Georgian Estates and Del-Rich	184220	30	17.90	53.70	0.8
"Spaghetti Twenty"	n/a	25	15.00	45.00	8.45
Delacour	n/a	17	10.20	30.60	5.7
Rural Grouping 2 (south of Kathryn)	n/a	12	7.20	21.60	14.17
Kathryn School	n/a	n/a	2.90	8.70	2.2
Cambridge	240354	190	145.00	435.00	2.25
Prince of Peace	290049	168	100.90	302.70	3.5
Mountain View Campground	n/a	n/a	100.00	300.00	1.2
Rural Grouping 3 (RR 281 & TWP 243)	n/a	85	51.00	153.00	22.75
High Point Estates	148701	30	22.80	68.40	4.7
Lansdowne Estates	390719	25	9.45	28.35	0.85
Chestermere High School	n/a	n/a	14.30	42.90	0.5
TOTALS	**n/a**	**704**	**572.4**	**1717.1**	**82.57**

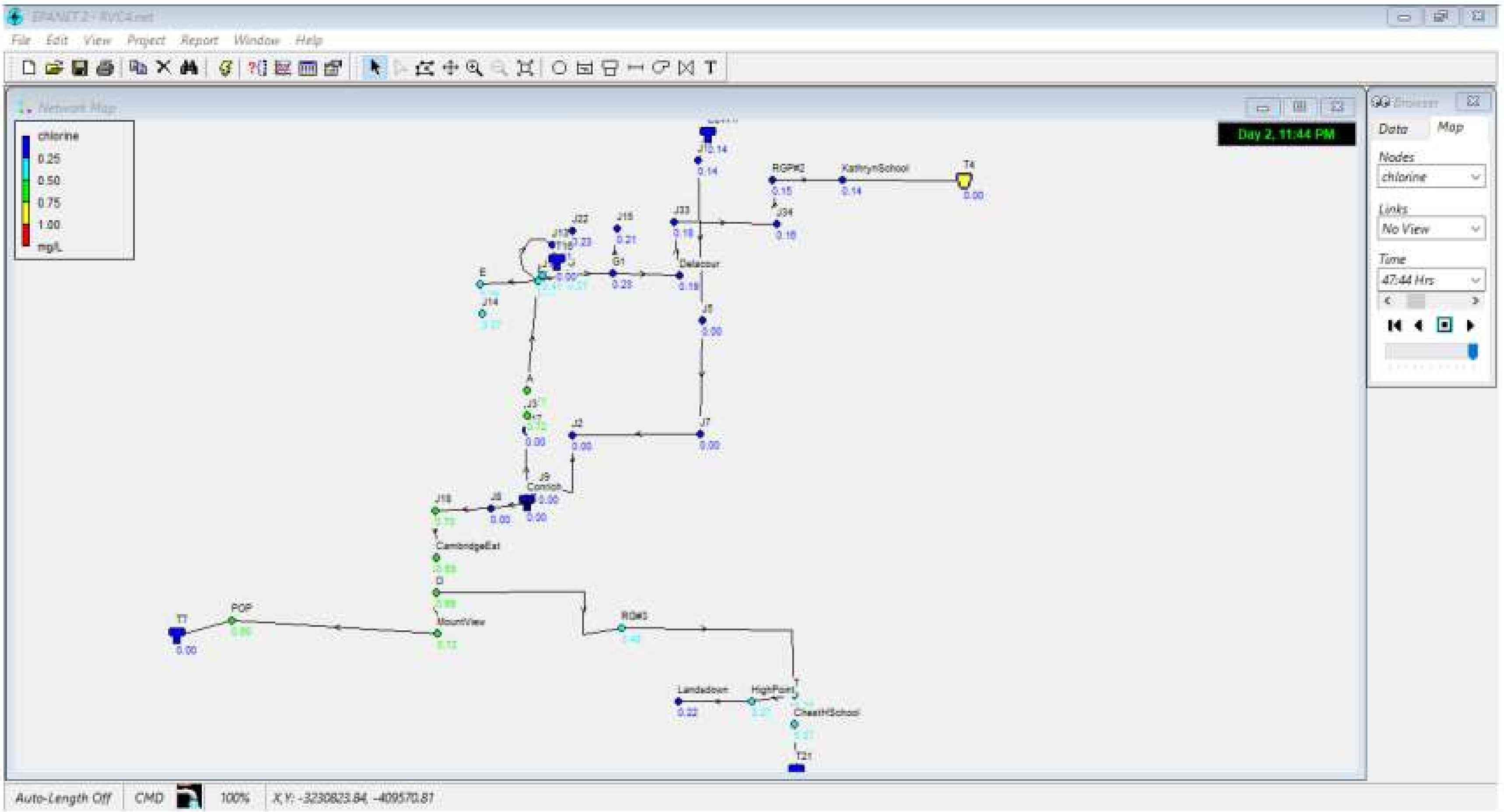
(Irwin, 2018)

Appendix I: RVC Trickle Fill EPAnet Simulated Case



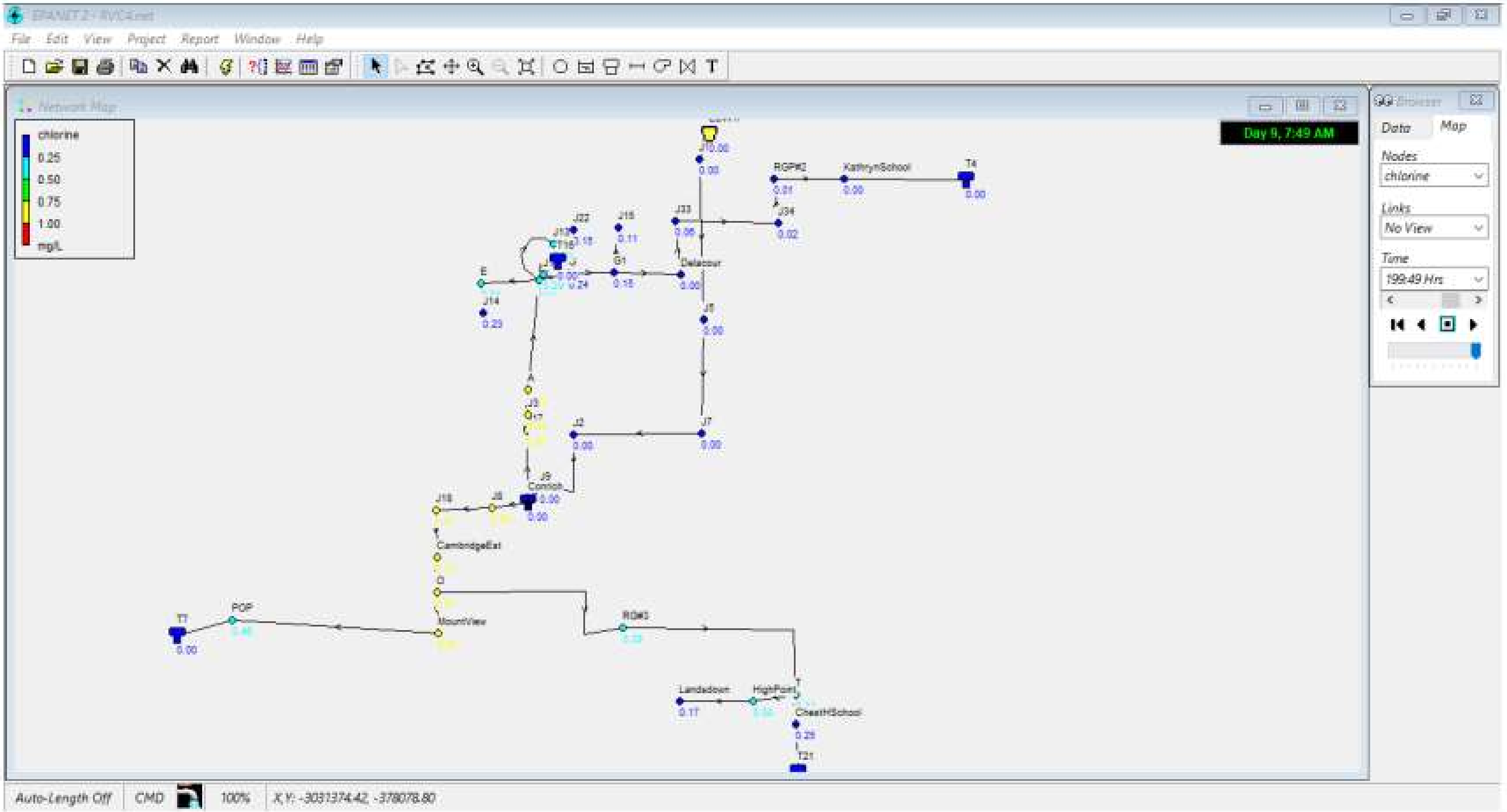
(Author, 2019)

Appendix J: RVC Chlorine Concentration Results, Day 2



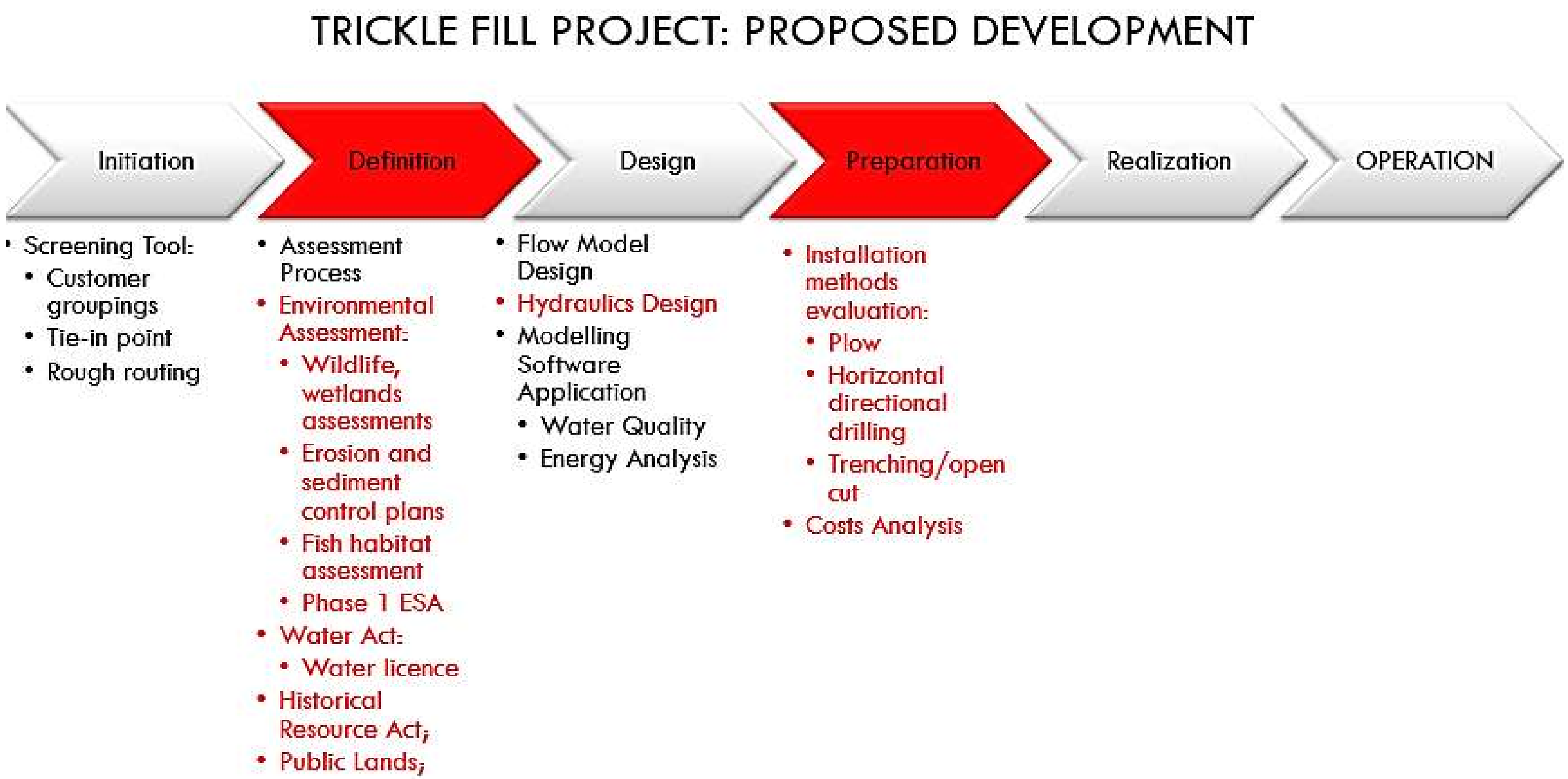
(Author, 2019)

RVC Chlorine Concentration Results, Day 9



(Author, 2019)

Appendix K: Trickle Fill Project Proposed Development



(Author, 2019)

Appendix L: Energy and Environment Analysis for Jockey Pump

Parameter			Input/Value	Unit
From	Conrich Pump Station & Reservoir via jockey pump	East Balzac Water Treatment Plant to Conrich Reservoir and Pump Station	Conrich Pump Station & Reservoir	-
To	Lansdowne water co-op		Lansdowne water co-op	-
Distance	15	22.4	15	km
Pumping costs	0.15	0.15	0.15	$/kWh
Pump Type	electric	electric	Electric	
Pump rated flow (imperial)	2.00	367.00	1886.00	gallons per min (GPM)
Total head (rated)	193.00	462.00	193.00	ft
Combined pump & motor efficiency assumed	0.84	0.84	0.84	
Water delivered annually	3900.00	3900.00	3900.00	m^3/yr
Pump rated flow (metric)	0.45	83.00	428.36	m^3/h
Time pump would run in 1 year	8585.62	46.99	9.10	hrs/yr
Energy pump would use in one year	743.27	1780.48	1040.58	kWh/yr
Pumping energy input - Specific energy	0.191	0.457	0.27	kWh/ m^3
Energy consumed for pumping annually	743	1780	1041	kWh/yr

Energy consumed for pumping annually (in GJ)	2676	6410	3746	MJ/yr
GHG's emitted due to pumping annually	587	1407	822	$kgCO_{2eq}$/yr
Annual cost of pumping	111.49	267.07	156.09	$/yr
Energy consumed per unit of water delivered	0.686	1.644	0.961	MJ/ m^3
Fuel consumed per unit of water delivered	0.04	0.10	0.06	kg/ m^3
GHG's emitted per unit of water delivered	0.151	0.361	0.211	$kgCO_{2eq}$/ m^3

(Author, 2019)

Appendix M: Case Study Assumptions and Limitations

Assumption/Limitation	**Application**
Case study technical data	The technical data used in this case study is based on the technical feasibility assessment developed for RVC in 2018. (Irwin, 2018) and the available data collected from the RVC Utility Department via personal communication also based on 2018 system performance.
Case study elevation profile and lengths	Trickle fill service pipelines routing was obtained from manual transferring ArcGIS utility files for RVC in Google Earth Pro application. By doing this, I was able to locate the main transmission and feed lines from EBWTP to CRPS from which I built branched distribution pipes; hence, the exact lengths of pipelines in reality may slightly vary from the ones used in this study. For each built pipeline, I checked the elevation profile to obtain the elevation gain or loss in meters to be further considered in nodal (connections) elevations in EPAnet case simulation.
Design water flowrate safety factor	There are different values of safety factor used for process design depending on application. In general, 110% (121% for the fire case) of normal flowrate is used as design flowrate. For this case, based on literature review and future growth consideration, a design flowrate of 1.14 m^3/d was calculated against water storage tanks inflow rates rather than against 0.9 m^3/d of typical daily water usage per single family in Alberta (described in Section 3.2) which corresponds to 126% factor.

EPAnet software	As a first time EPAnet user, I worked with the base model configuration of EPAnet and did not have any knowledge of software extensions that may exist to simulate low-pressure / gravity flow / intermittent flow models. Though, it must be noted that EPAnet requires for a user / modeler to have a knowledge of fluid mechanics including fluid flow in pipes (dynamics) and hydraulics.
EPAnet case initiation	Initially, distribution network must be drafted in AutoCAD software and then converted to EPAnet software by using EPACAD software application which I was not aware of as a first-time user, and due to time constrains and no access to the required software applications, neither AutoCAD, nor EPACAD were used.
EPAnet case initiation	The built network is not scaled because it was built manually.
Water flow pattern and water quality analysis	For the purpose of study, the overall chorine residual pattern change was analyzed disregarding the peaks and falls repeated in every certain period of hours which represents the water flow (water demand at different hours in a 24-hour period) pattern.
East Balzac Water Treatment Plant and Conrich Reservoir and Pump station vessels	The reservoirs could not be input in the simulation as “reservoirs”, and thus were presented as tanks. The reason for this is if, for example, the water holding reservoirs were shown as they are, at certain time and pressure, the system would treat it as nodal connection with its water demand, and instead of supplying the water from reservoir it would supply water to it. In other words, the flow direction would be reverted and

	directed to the source where in reality, it is the other way around. For this reason, the reservoirs were presented as tanks, and their sizes were very roughly estimated to hold the amount of water required for the trickle fill system only excluding the water flow required for firefighting. Such settings impacted the number of flushing required that would be estimated different from what it is in reality. The pump volumetric energy consumption is calculated using rated flows taken from performance test curves which are illustrated in Appendixes E and F. The calculations were done so because of time constrains and data availability and limitations for pumps performance.
EPAnet Pumps sizing	As I learnt through EPAnet simulation process, the software does not size the equipment. The theoretical total dynamic head (TDH) pressure required for pumps at EBWTP and CRPS was assumed to simulate the case by assigning high nodal elevations different from the actual ones.
EPAnet energy analysis	Energy analysis is based on pumps, flowrate of which would be controlled by the water storage tanks required inflow and which would stop the pumps once the tanks are full at the end nodes and this would significantly decrease the energy and water by reducing number of flushing. However, the existed pumps could not be applied in the simulation and therefore energy analysis was not performed by the software.

Case study results	The results are general and simplified as they represent a holistic approach case study. To obtain precise and reliable results, another study should be conducted and dedicated to process design basis development and shall include process design and equipment and instruments sizing performed prior to a water modelling software application.

(Author, 2019)