Water Distribution in Metro Vancouver [*]

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Abstract

Metro Vancouver has an ever rapidly growing population, this combined with severe summer droughts that are increasing in frequency give rise to the need for radical change in Metro Vancouver's water distribution systems. In this project, these systems are examined, various network models are looked at in detail and various potential solutions are provided in order to help improve the current state of Metro Vancouver's water systems. The main goal of this examination it to minimize the need to acquire water from expensive sources and attempt to maximize the coverage of current water sources across Metro Vancouver. Four different models are constructed for this task as well as three different potential networks for Metro Vancouver.

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1 Introduction

In this paper, we want to optimize total water usage in Metro Vancouver. Cities require millions of litres of water to be transported within its bounds. To optimize total water usage we want to make sure that every section of the city meets its demands for water. We have developed three different ways to transport water and a look to the future in 2020.

For our models we want to optimize the total water distribution usage in Metro Vancouver, and as such we want all of our objective functions maximize 0. The first model examined is a simplified (isolated) network where dams supply water only to the cities within their respective region. The simplified model was used as a baseline to find where exactly new pipes need to be constructed in order to prevent unnecessary construction costs. The next model considered is an interconnected network where specific cities from different regions may share water supply. The interconnected network best represents the network Metro Vancouver currently has implemented. The third model is similar to the interconnected network except that this model has the inclusion of a bidirectional pipe. This bidirectional pipe allows for water to be sent both ways so that either region can share and receive water. Following this, the interconnected network with a bidirectional pipe is tested against predicted population increases and twin tunnel completion in 2020, where the twin tunnel system connects Capilano and Seymour dams. Finally, other potential solutions are outlined for future consideration of Metro Vancouver's water systems.

2 Assumptions

The following assumptions were made to simplify the model:

1. We are only concerned with water obtained from Capilano, Seymour, and Coquitlam Lake.
2. Residental demand is the only demand of the system.
3. Water leaks from pipes are pre-emptively taken into account.
4. Water filtration is pre-emptively taken into account.
5. All water that flows through the system is used.
6. In our models, we divided the system into sections by municipality. If the municipalities are divided into subsections we assumed the population diversity is the same.
7. When dams supply are 0, it implies that the dams supply have reached an minimum acceptable level.

2.1 Additional Information

Our collected data shows that Metro Vancouver gets nearly all its water from 3 large reservoirs: Capilano, Seymour, and Coquitlam. These 3 reservoirs get their water mostly from the lakes that share their names and the melted snow from nearby mountains. It is important to note that during the winter months, the water coming into the Capilano reservoir cannot be used due to the dirt that washes in with the water [3]. Since there exists mountainous terrain between these

3 reservoirs, the construction of pipes between them is difficult and expensive. Currently, there is no connection between these 3 reservoirs. A project has been worked on for the last few years to link 2 of the reservoirs together called the Twin Tunnel Filtration System. Due to the vast system of pipelines and other water delivery systems, it is estimated that 13% of usable water is lost due to leakage throughout the system [4]. Our system takes into account all the above paramters.

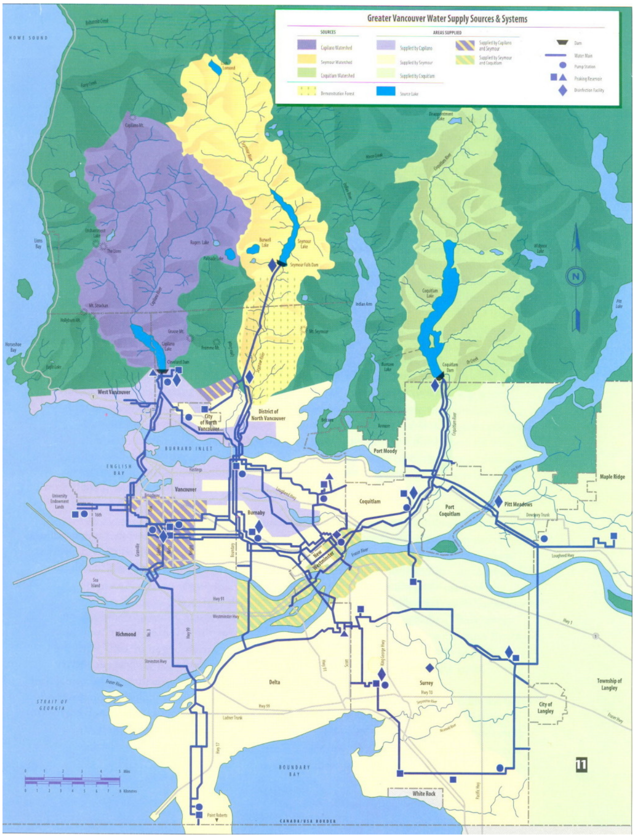

Figure 1: The purple shaded area is where the Capilano reservoir delivers its water. Likewise with for Seymour and Coquitlam with the yellow and green shaded areas respectively [8]

3 Isolated Network Model

3.1 Overview

The first model taken under consideration was an isolated network. This model is regarded as the basic foundation for networking when it comes to water transportation due to its simplicity.

It is simple in the sense that it lacks interconnected nodes. This means that the three watersheds, Capilano, Seymour and Coquitlam, that provides Metro Vancouver with water only distributes to its own region and the supply of water for each watershed is separate from its neighbour. Within this model, it is important to note that water is tranported by the Earth's gravitational force. This implies that the resource can flow only in the downwards direction, which differs from an interconnected network approach that is comprised of bidirectional pipes, an approach that will be discussed later in the report.

3.2 Model

Referring to the diagram below, the perception of isolation is apparent in this simplistic model. It portrays each lake at the top, then the water accumulated enters the dam and afterwards distributing to each node and finally going to the residents after going through an intense filtration system that must pass Metro Vancouver's water requirements. For example, if we look at the allocation of water for the Capilano watershed, it is quite simple. As mentioned, we start off with the Capilano Lake, and subsequently its designated dam. From there, the water is the transported to the UBC, Central Vancouver then Tsawwassen nodes then to the residents in the area particular to that node.

3.3 Formulation

Below is the inflow and outflow constraints:

Capilano Dam: $X_{Cap} - X_U - X_{CVan} - X_{Tsa} = 0$
UBC: $X_U - Res_U = 0$
Central Vancouver: $X_{CVan} - Res_{CVan} = 0$
Tsawwassen: $X_{Tsa} - Res_{Tsa} = 0$
Seymour Dam: $X_{Sey} - X_{NVan} - X_{B2} - X_{B1} = 0$
North Vancouver: $X_{NVan} - Res_{NVan} = 0$
Burnaby 1: $X_{B1} - Res_{B1} - X_{NWest1} = 0$
New Westminster 1: $X_{NWest1} - Res_{NWest1} = 0$
Burnaby 2: $X_{B2} - Res_{B2} - X_{NWest2} = 0$
New Westminster 2: $X_{NWest2} - X_D - Res_{NWest2} = 0$
Delta: $X_D - X_{S1} - Res_D = 0$
Surrey 1: $X_D - Res_{S1} - X_{S2} = 0$
Surrey 2: $X_{S2} - Res_{S2} = 0$
Coquitlam Dam: $X_{Coq} - X_C - X_{MR} = 0$
Coquitlam: $X_C - Res_C - S_{S3} = 0$
Maple Ridge: $X_{MR} - Res_{MR} = 0$
Surrey 3: $X_{S3} - X_L = 0$
Langley: $X_L - Res_L = 0$

Below is the supply and resident demand constraints for November, the rest can be found in the appendix:

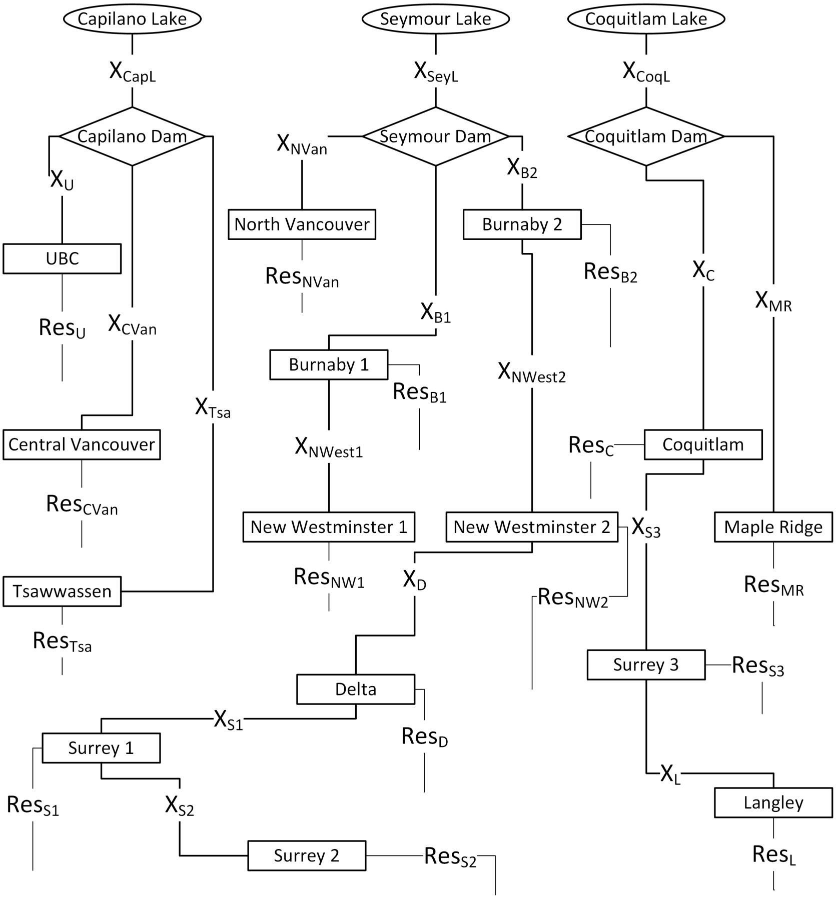

Figure 2: The network

Supply Constraints:

$X_{Cap} \leq 0$

$X_{Sey} \leq 18948.6 + 9904.34$ surplus from October

$X_{Coq} \leq 6551.1$

Resident Demand Constraints:

UBC:	$Res_U \geq 740.8368$
Central Vancouver:	$Res_{CVan} \geq 7949.5920$
Tsawwassen:	$Res_{Tsa} \geq 301.4352$
North Vancouver:	$Res_{NVan} \geq 1909.5552$
Burnaby 1:	$Res_{B1} \geq 1607.1696$
New Westminster 1:	$Res_{NWest1} \geq 475.0272$
Burnaby 2:	$Res_{B2} \geq 1607.1696$
New Westminster 2:	$Res_{NWest2} \geq 475.0272$
Delta:	$Res_D \geq 1438.0272$
Surrey 1:	$Res_{S1} \geq 2340.432$
Surrey 2:	$Res_{S2} \geq 2340.432$
Coquitlam:	$Res_C \geq 2720.03424$
Maple Ridge:	$Res_{MR} \geq 1350.5472$
Surrey 3 :	$Res_{S3} \geq 2340.432$
Langley:	$Res_L \geq 1500.1488$

3.4 Results

The simplicity of this network allows for easy construction and management. However, it there are some drawbacks. This simplistic approach is built on the concept that each watershed is responsible for supplying water to its own region due to the absence of links between the nodes. Another advantage is the type of energy used in the process of transporting water. As mentioned previously, the force of gravity moves the resource from node to node which is cost free since the pipes do not have to be built with a pump or use electricity to trigger the process. It is also crucial to understand that each watershed generally does not depend on its neighbouring watersheds, with an exception to certain months where there is a deficit in the amount of water obtained. The only feasible months are September, June, July, and August. For example, during the winter Capilano actually doesn't acquire any water (see the diagram below). This deficiency causes a decrease in supply and an increase in demand which results in some downsides. One of the downsides is that since Capilano is not receiving any water, water must be obtained from its neighbours, Seymour and Coquitlam, which may cause the aggregate water levels to drop below its standard threshold. Secondly, this might also initiate water restrictions on the citizens of Metro Vancouver. Generally, average water usage levels decrease throughout the winter months, nevertheless, there are still residents who contribute to activities such as washing their car, or power washing their house, driveway, etc. Additionally, the importation of water is also something taken into account. This solution however, is the worst case scenario since transporting large amounts of water is costly and also time consuming.

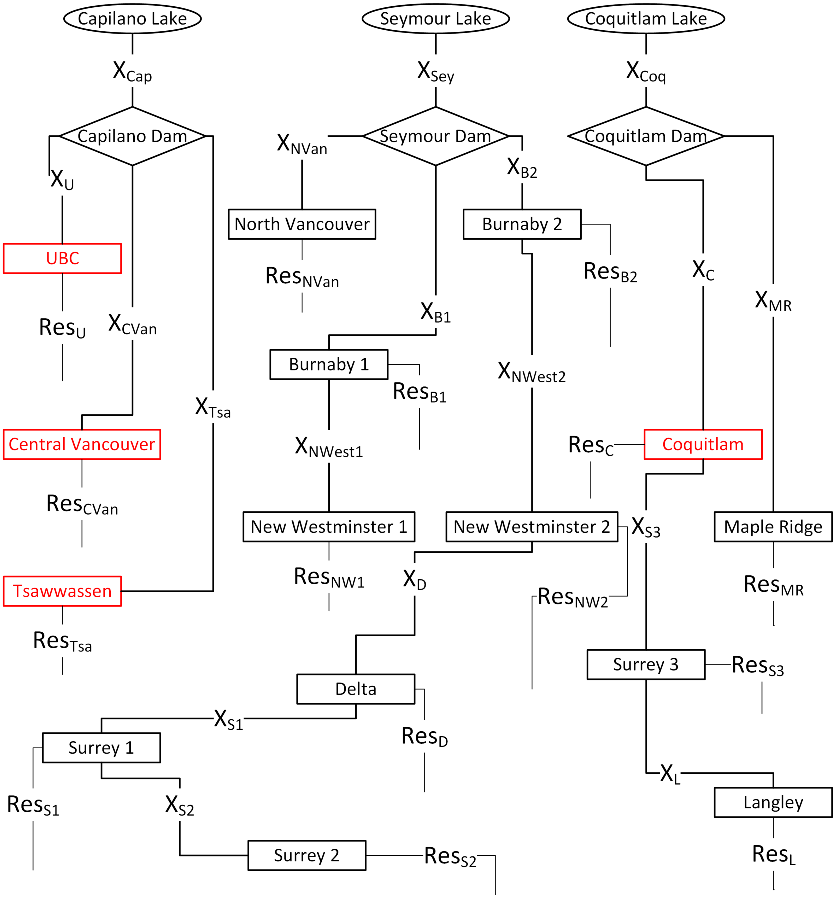

Figure 3: Results of November's Model

4 Interconnected Network Model

4.1 Overview

The second model covered is an interconnected network of three regions in Metro Vancouver; Capilano, Seymour and Coquitlam. In this network, some nodes, city reservoirs, from different regions are now connected by a pipe. This allows a region in excess to share water with a region in deficit if such a case arises. Note that in this model, water flows with gravity so a node with higher elevation will not receive water from a lower elevated node. The interconnected model best represents the network that Metro Vancouver currently has implemented as a water system.

The reason behind constructing the interconnected model is to determine whether connecting city reservoirs from separate regions helps increase the number of feasible nodes, meaning a node's demand is met.

4.2 Potential Improvements Versus Isolated Model

As an example of the potential improvements of the interconnected model versus the old model, North Vancouver, which is in Seymour's region may now receive water from Capilano Dam if North Vancouver is in deficit and Capilano has excess supply. This transfer of water flow will not work the other way around, so if North Vancouver has access to additional water and Capilano Dam is in need of water, North Vancouver still cannot send excess water to Capilano Dam.

4.3 Model

In Figure 4, the Y arcs represent pipes that are not present in the isolated network. The majority of Y arcs are pipes that supply water from one region to another, excluding a select few, arcs Y_D and $Y_{NWest2A}$ that supply water to cities within the same network.

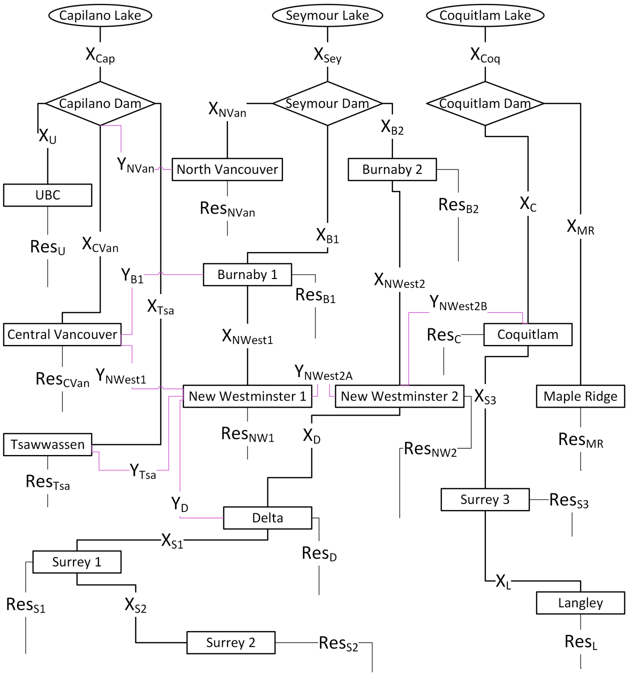

Figure 4: The interconnected network, purple links denote the new pipes added compared to the previous model

4.4 Formulation

The formulation is similar to the previous models with the minor difference of adding or subtracting Y arcs. Below is the inflow and outflow constraints:

Capilano Dam: $X_{Cap} - X_U - X_{CVan} - X_{Tsa} - Y_{NVan} = 0$
UBC: $X_U - Res_U = 0$
Central Vancouver: $X_{CVan} - Res_{CVan} - Y_{B1} - Y_{NWest1} = 0$
Tsawwassen: $X_{Tsa} - Res_{Tsa} + Y_{Tsa} = 0$
Seymour Dam: $X_{Sey} - X_{NVan} - X_{B2} - X_{B1} = 0$
North Vancouver: $X_{NVan} - Res_{NVan} + Y_{NVan} = 0$
Burnaby 1: $X_{B1} - Res_{B1} - X_{NWest1} + Y_{B1} = 0$
New Westminster 1: $X_{NWest1} - Res_{NWest1} + Y_{NWest1} - Y_{NWest2A} - Y_D - Y_{Tsa} = 0$
Burnaby 2: $X_{B2} - Res_{B2} - X_{NWest2} = 0$
New Westminster 2: $X_{NWest2} - X_D - Res_{NWest2} + Y_{NWest2B} + Y_{NWest2A} = 0$
Delta: $X_D - X_{S1} - Res_D + Y_D = 0$
Surrey 1: $X_D - Res_{S1} - X_{S2} = 0$
Surrey 2: $X_{S2} - Res_{S2} = 0$
Coquitlam Dam: $X_{Coq} - X_C - X_{MR} = 0$
Coquitlam: $X_C - Res_C - S_{S3} - Y_{NWest2B} = 0$
Maple Ridge: $X_{MR} - Res_{MR} = 0$
Surrey 3: $X_{S3} - X_L = 0$
Langley: $X_L - Res_L = 0$

Since there is the same amount of demand and supply as in the previous model, the demand and supply constraints remain the same. To see the full formulation, refer to the appendix.

4.5 Results

September, June, July, and August are still the only months where all cities received enough water to supply their respective demands. The feasible months remain the same as the months feasible for the isolated model, but there is a noticeable difference in the deficits of infeasible months. The interconnected model managed to distribute supply better than the simplified model. Figure 5 shows the feasibility of each city results in November for the interconnected model.

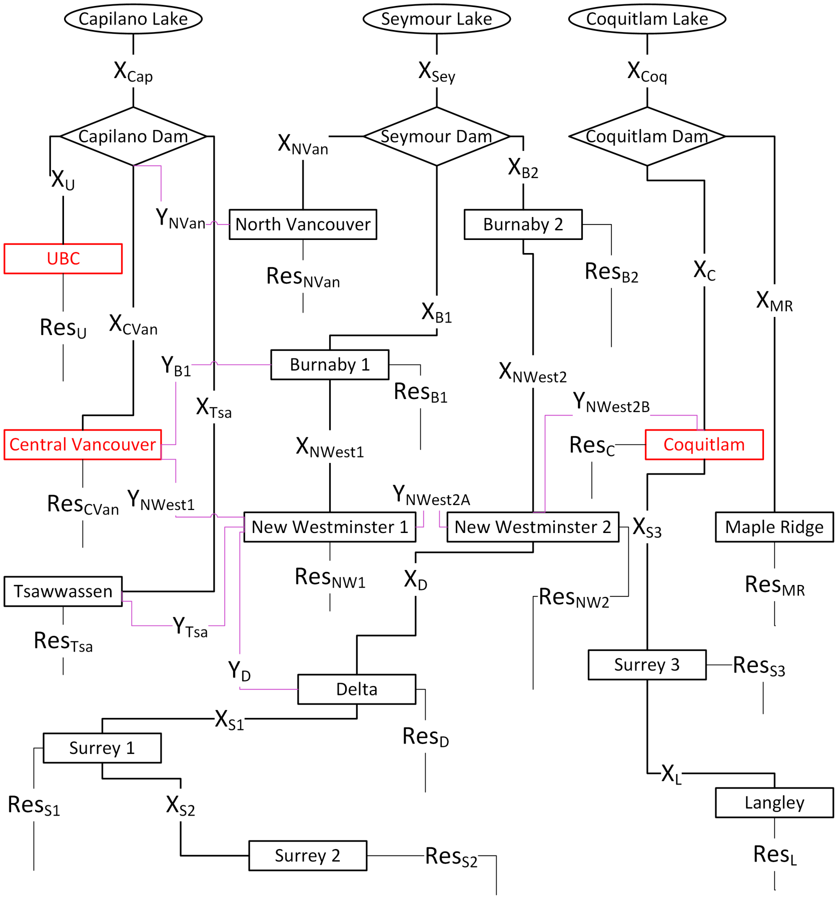

Figure 5: November's results with red nodes denoting nodes where the demands are not met

5 Interconnected Network with Bidirectional Pipe

5.1 Overview

The second model covered is an interconnected network of the three regions in Metro Vancouver; Capilano, Seymour, and Coquitlam. In this network, some nodes denoting city reservoirs from different regions are now connected by a pipe and one bidirectional pipe. This excess pipe allows water to flow to previous nodes in a higher elevation. This pipe is able to do this by a pump powered by electricity or by some other means.

5.2 Potential Improvements Versus Previous Models

For example, North Vancouver, which is in Seymour's region, may now receive water from Capilano Dam if North Vancouver is in deficit and Capilano has excess supply which also works the other way around with this new bidirectional pipe.

5.3 Model

In Figure 6, the Z arcs represent the bidirectional pipe which can flow water both to a higher and lower point in the system.

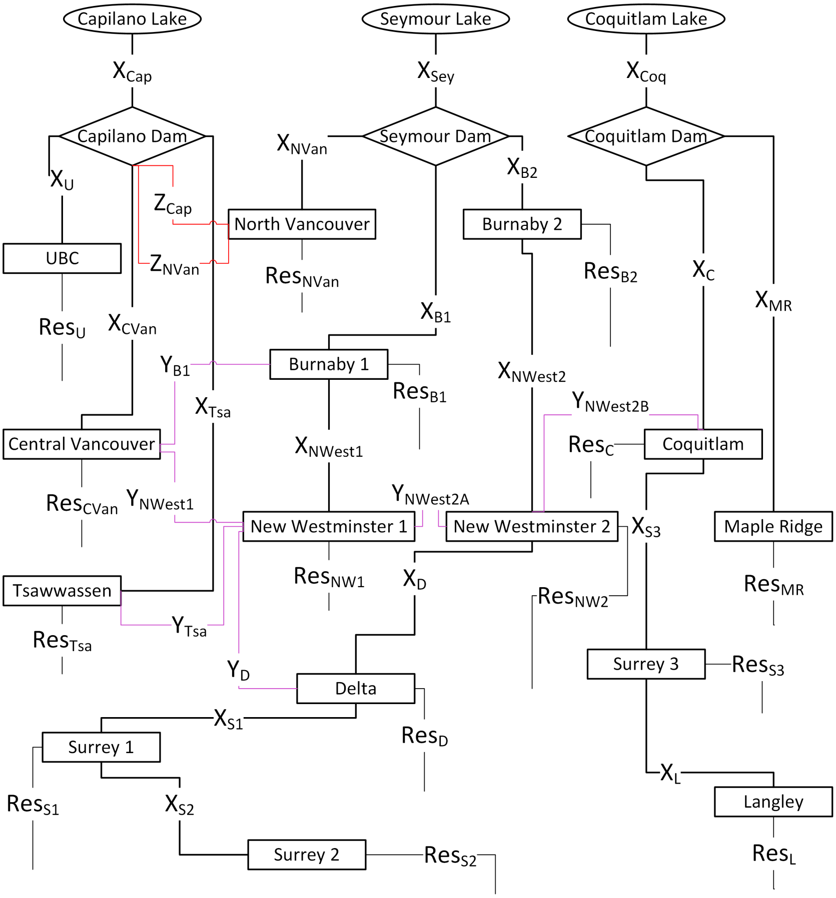

Figure 6: The bidirectional network, purple arcs denote the new pipes added compared to the isolated network, and red arcs denote the new bidirectional pipe

5.4 Formulation

Again each node is formulated in the same way as previous models except with the addition and subtraction to appropiate constraints regarding the bidirectional pipe. Below is the inflow and outflow constraints:

Capilano Dam: $X_{Cap} - X_U - X_{CVan} - X_{Tsa} - Y_{NVan} - Z_{NVan} + Z_{Cap} = 0$
UBC: $X_U - Res_U = 0$
Central Vancouver: $X_{CVan} - Res_{CVan} - Y_{B1} - Y_{NWest1} = 0$
Tsawwassen: $X_{Tsa} - Res_{Tsa} + Y_{Tsa} = 0$
Seymour Dam: $X_{Sey} - X_{NVan} - X_{B2} - X_{B1} = 0$
North Vancouver: $X_{NVan} - Res_{NVan} + Y_{NVan} + Z_{NVan} - Z_{Cap} = 0$
Burnaby 1: $X_{B1} - Res_{B1} - X_{NWest1} + Y_{B1} = 0$
New Westminster 1: $X_{NWest1} - Res_{NWest1} + Y_{NWest1} - Y_{NWest2A} - Y_D - Y_{Tsa} = 0$
Burnaby 2: $X_{B2} - Res_{B2} - X_{NWest2} = 0$
New Westminster 2: $X_{NWest2} - X_D - Res_{NWest2} + Y_{NWest2B} + Y_{NWest2A} = 0$
Delta: $X_D - X_{S1} - Res_D + Y_D = 0$
Surrey 1: $X_D - Res_{S1} - X_{S2} = 0$
Surrey 2: $X_{S2} - Res_{S2} = 0$
Coquitlam Dam: $X_{Coq} - X_C - X_{MR} = 0$
Coquitlam: $X_C - Res_C - S_{S3} - Y_{NWest2B} = 0$
Maple Ridge: $X_{MR} - Res_{MR} = 0$
Surrey 3 : $X_{S3} - X_L = 0$
Langley: $X_L - Res_L = 0$

Since there is the same amount of demand and supply as in the previous model, the demand and supply constraints remain the same. To see the full formulation, refer to the appendix.

5.5 Results

September, May, June, July and August are still the only months where all cities received enough water to supply their respective demands. The number of feasible months are increased from the previous model compared to this model, in this model we have the additional month of feasibility in May. This model was able to distribute water in better ways than the previous models since it was able to push water where it was needed more adequately.

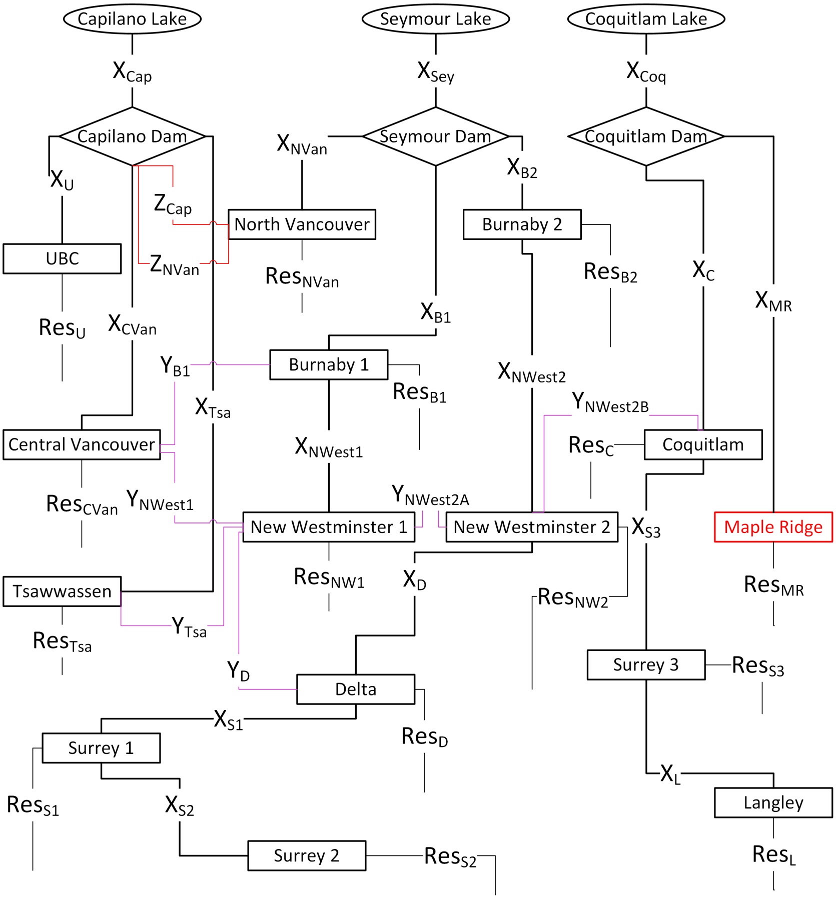

Figure 7: The bidirectional network's results for November with red nodes denoting nodes where the demands are not met

6 Looking to the Future

6.1 Infrastructure

As mentioned earlier, there is currently a project that has been worked on for over 10 years, set to finish spring of 2015. It is called the Twin Tunnel Filtration system, this project eliminates the issue of the Capilano reservoir not providing any water due to the dirt washing in during the winter months. It sends the water from Capilano through one tunnel to the large filtration plant in Seymour. This will provide an estimated 300 million more liters of water per day.

6.2 Projection

Since infrastructure in the water industry takes a significant amount of time, it is important to plan ahead. Metro Vancouver's population is set to increase from 2.3 million in 2014 to 2.8 million in 2025 [1] [5]. This means demand will inevitably be rising along with the population. However, Vancouver has always made an effort to be one of the greenest places to live in. The 2006 estimated water consumption is 583 litres per person per day. In 2013, 5 years later, it was estimated that we have reduced that water usage to 480 L per person per day. The projected consumption is 390 L per person by 2020 [7].

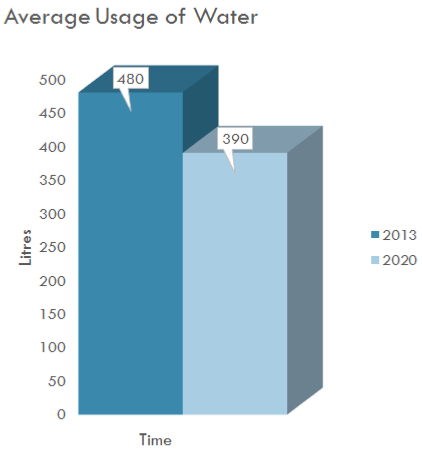

Figure 8: Water usage decrease per day per person

6.3 Formulation

We are testing whether the increase in population demand can be met by increased water consumption efficiency. Formulation for this projection is quite simple. The formulation of the interconnected nodes system including a bidirectional node was used, with changes to three data points: the population constants, water usage data, and demand data. A simplification was made to adjust the population size as the ratio of overall population increase, 2.3 million to 2.8 million, is applied to each city and municipality.

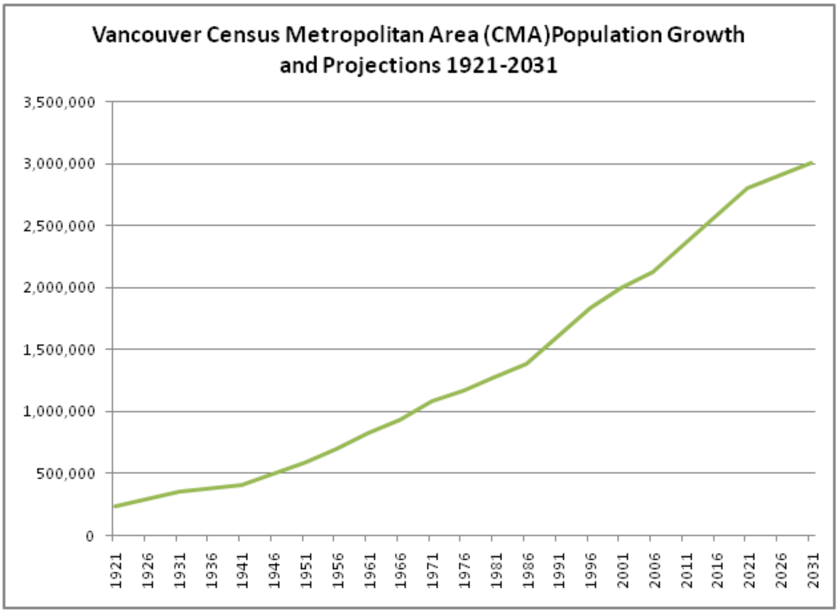

Figure 9: Projected population increase [1] [5]

Since we are using the same network for the population growth model, the inflow and outflow constraints remain the same.

Below is November's demand and supply constraints, the remaining models can be found in the appendix:

Resident Demand Constraints:
UBC: $Res_U \geq 740.8368$
Central Vancouver: $Res_{CVan} \geq 7949.5920$
Tsawwassen: $Res_{Tsa} \geq 301.4352$
North Vancouver: $Res_{NVan} \geq 1909.5552$
Burnaby 1: $Res_{B1} \geq 1607.1696$
New Westminster 1: $Res_{NWest1} \geq 475.0272$
Burnaby 2: $Res_{B2} \geq 1607.1696$
New Westminster 2: $Res_{NWest2} \geq 475.0272$
Delta: $Res_D \geq 1438.0272$
Surrey 1: $Res_{S1} \geq 2340.432$
Surrey 2: $Res_{S2} \geq 2340.432$
Coquitlam: $Res_C \geq 2720.03424$
Maple Ridge: $Res_{MR} \geq 1350.5472$
Surrey 3: $Res_{S3} \geq 2340.432$
Langley: $Res_L \geq 1500.1488$

Supply Constraints:
$X_{Cap} \leq 4477.02$
$X_{Sey} \leq 17018.07 + 7095.108\, surplus\ from\ September$
$X_{Coq} \leq 7821.3 + 300.3966\, surplus\ from\ September$

The network model for population growth is the same as it was for the bidirectional network since the inflow and outflow constraints are the same.

6.4 Results

The observed result of the formulation is that there is actually a significant improvement in demands being met. This means that the estimated water usage efficiency surpasses the projected population growth. Solving this model gives us a feasible solution in a greater number of months than previous models see the table below. In addition, infeasible months are quite close to being feasible, with only very small deficits. This result shows that there is not an urgent need for additional infrastructure. The supply will be able to keep up with the demand. However, this trend must be continually monitored; decrease in water consumption due to efficiency has a limit, while population growth continues indefinitely.

F: Feasible NF: Not Feasible

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Isolated Dams	F	NF	NF	NF	NF	NF	NF	NF	NF	F	F	F
Interconnected	F	NF	NF	NF	NF	NF	NF	NF	NF	F	F	F
Bidirectional	F	NF	NF	NF	NF	NF	NF	NF	F	F	F	F
Population	F	F	NF	NF	F	NF	NF	F	F	F	F	F

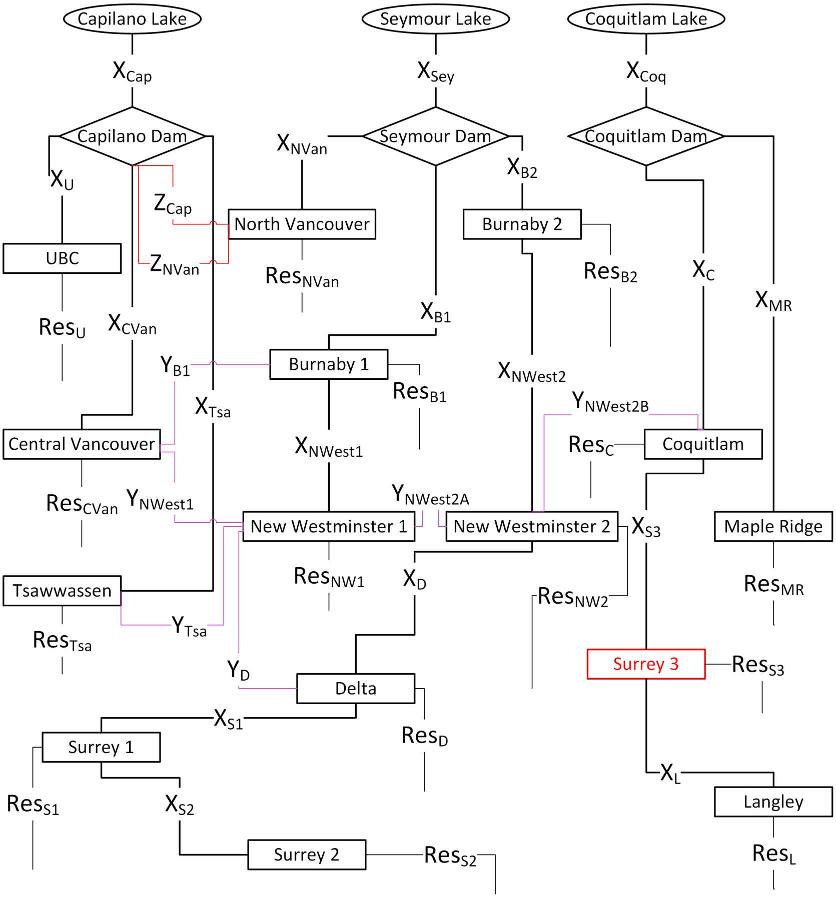

Figure 10: The population network results for November with red nodes denoting nodes where the demands are not met

7 Other Possible Models and Formulations

7.1 Rain Barrels

In contrast to larger solutions, smaller scale solutions can also be taken in consideration. The first being the mandatory implementation of rain barrels. These barrels would be implemented to each residential home limiting one per family and can hold up to 280L of water. The rainwater captured will not be used as drinking water but used for things such as watering plants and lawn, or washing the car, etc. An example of such a barrel can seen in Figure 11 which can be purchased as the local recycle depot for approximately $30.00. Although rain barrels are quite inexpensive, the concern was that even though it is mandatory, people might be unwilling to implement it or slow it due to things such as aesthetics or space.

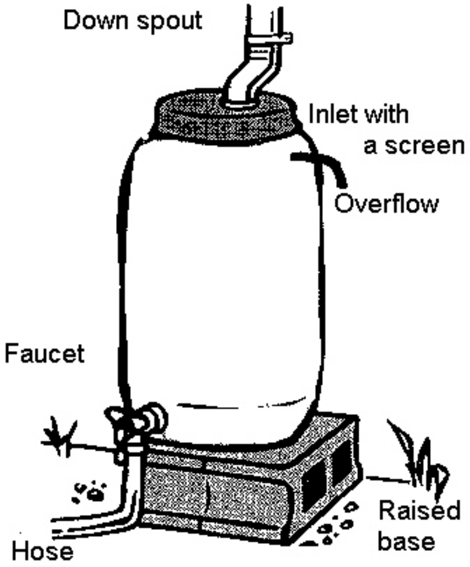

Figure 11: Example of a possible rain barrel [6]

8 Conclusion

Our extensive research and multidimensional models and formulations has shown that water distribution systems is not a simple model. Just within the area of Metro Vancouver, it is evident that there are numerous ways to create a system that is both financially affordable and efficiently functional. Metro Vancouver is fortunate to receive heavy rainfall throughout most of any given year. Even so, there were many obstacles that needed to be cleared in order to ensure the water demands of its many cities and municipalities are met. Furthermore, not only must the current situation be considered, it is critical to monitor the constantly changing situation; weather and population trends, technological development, and fluctuating economy are among the many things that can affect a water system. Aside from just the major pipelines and systems, there are numerous ways of collecting and conserving water that can be implemented, even within individual households. Promotion of these water efficient methods as well as regular improvements made to the large system are essential to maintaining a balanced and competent water system.

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