WATERCARE'S CENTRAL INTERCEPTOR WASTEWATER MODEL - IMPROVING ACCURACY BY INCLUDING SEASONAL VARIATION

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ABSTRACT

Watercare Services are in the process of developing a consent application and concept level design for the Central Interceptor – a proposed sewer tunnel that seeks to address the key business drivers of asset duplication, capacity for growth and mitigation of targeted combined sewer overflows. This new sewer tunnel will extend approximately 15 kilometres under the city, replacing the existing Western Interceptor, and connect to Watercare's wastewater treatment plant at Mangere.

A crucial aspect of the Central Interceptor is optimising the wastewater system's conveyance, storage, and treatment capacities to ensure the least whole of life cost. To achieve this, Watercare is working closely with AECOM to update and enhance their trunk sewer system model – known as the Project Storm 2 model.

A key aspect of enhancing the model's accuracy is to upgrade it to better represent the significant effects of the seasonal variations in base flows. This paper will present the methods and results of this model enhancement and improved correlation to long-term flow data records.

This paper also discusses the importance of this work in ensuring an optimal configuration of the Central Interceptor and how it allows for a best-practice assessment of the upgrade requirements of the wastewater system - as an integrated unit.

KEYWORDS

Seasonal Variation, Master Planning, Regression

1 INTRODUCTION

1.1 WATERCARE SYSTEM

Watercare Services Limited (Watercare) operates the trunk wastewater network in the Auckland region, receiving wastewater from four of five city councils in the area. Currently, Watercare conveys and treats approximately 288,000 m^3 of wastewater at the Mangere Wastewater Treatment Plant (WWTP) per day. Figure 1 illustrates the service area for the plant, which includes Waitakere City, Auckland City, Manukau City and a portion of Papakura District Council. The North Shore City Council operates its own wastewater collection system and treatment facility.

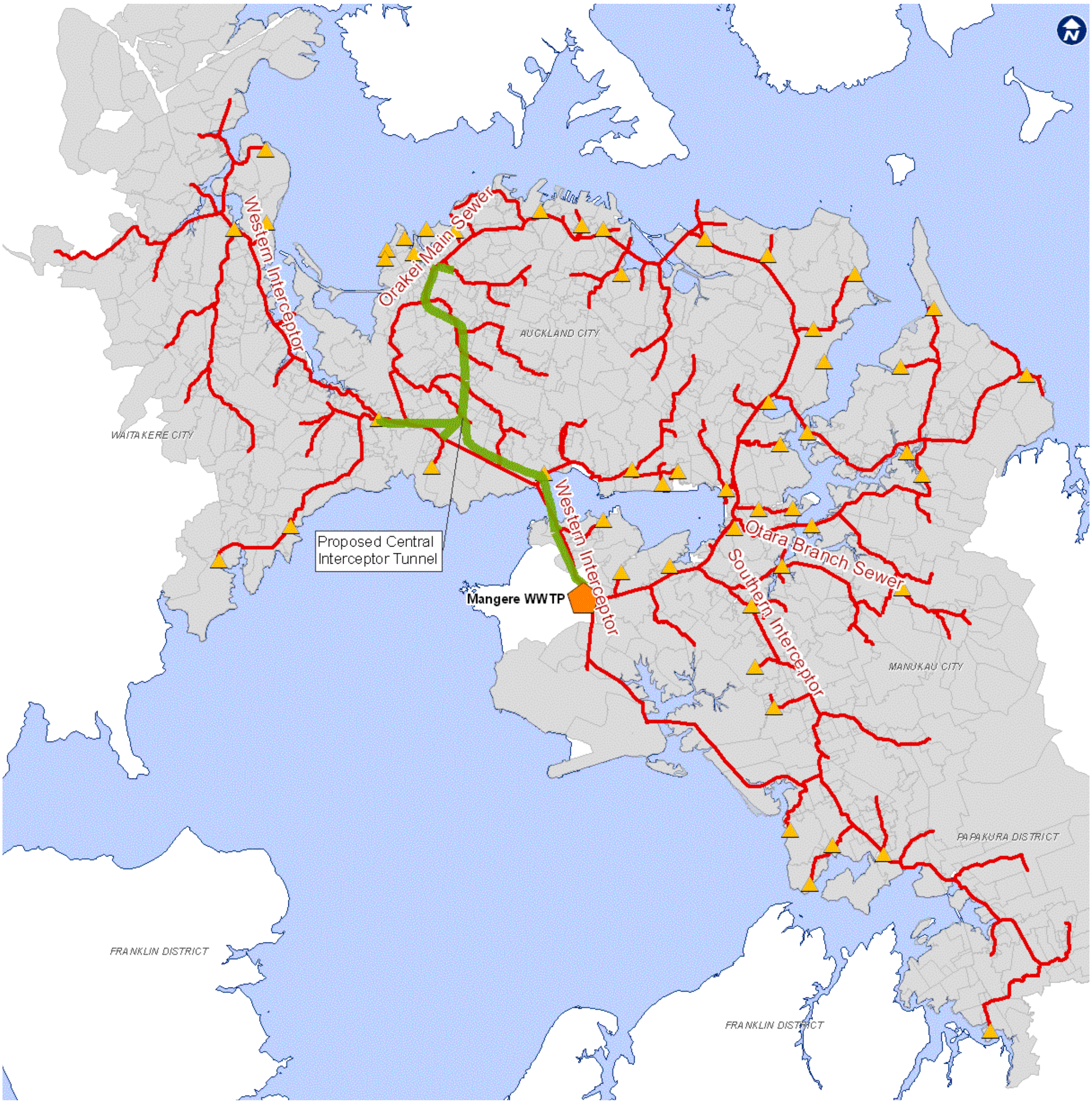
1.2 CENTRAL INTERCEPTOR SCOPE AND DRIVERS

Watercare is in the process of developing a consent application and concept level design for the Central Interceptor – a proposed tunnel that addresses key drivers of asset duplication, capacity for growth and mitigation of targeted combined sewer overflows. This tunnel will connect to Mangere WWTP and extend approximately 15 kilometres into the existing network to address these key drivers. The tunnel may provide both a conveyance and storage function, with peak flows to Mangere limited by available plant capacity at any given time. In parallel with the assessment of the Central Interceptor, Watercare are evaluating the capacity of the plant to ensure adequate treatment capacity exists to accommodate future growth and development.

A crucial aspect of the Central Interceptor Programme is optimising the balance of conveyance, storage and treatment capacities to ensure the least whole of life cost which adequately addresses Watercare's key drivers. To achieve this, Watercare is working closely with the Central Interceptor Programme Team to update and enhance their trunk sewer system model – known as the Project Storm II Model (PS2). The original PS2 model is quite advanced in terms of its level of detail and accuracy in calibration and verification – but the scope of this work focused calibrations and verifications for winter conditions based on the required conservatism at that stage of planning. A key aspect of enhancing this model accuracy further is to modify it to ensure it represents the effects of full year seasonal flow variations.

The Central Interceptor team is currently working on two simultaneous master plans: the trunk wastewater collection and the treatment systems. These have a 50 year planning period and provide opportunities to optimise the balance between the two systems and the implementation of the Central Interceptor tunnel solution.

Figure 1: Watercare wastewater network



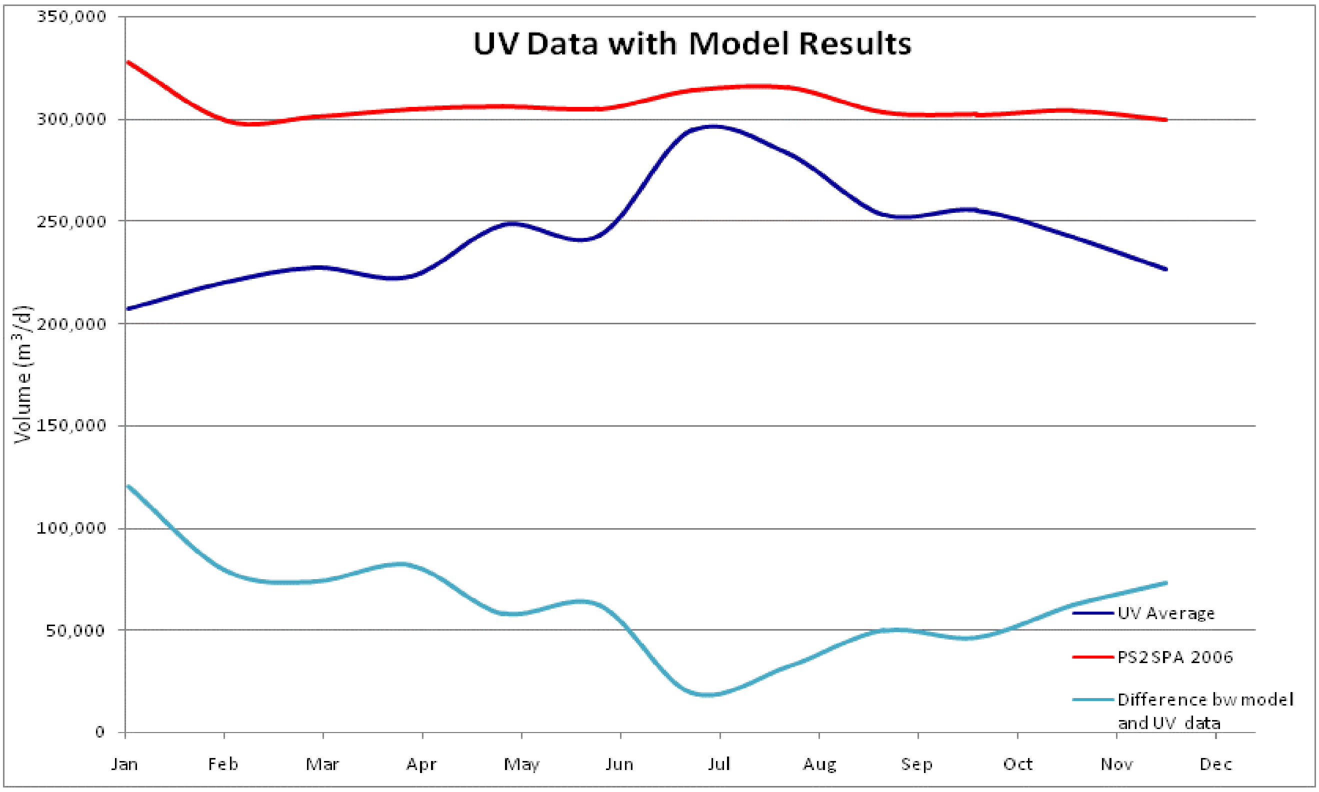
1.3 NETWORK MODEL AND MANGARE WWTP

The trunk sewer master plan is based on the current Watercare trunk sewer model, PS2. The trunk sewer model extent includes the complete Watercare wastewater system, and can be seen in Figure 1. The model was developed as a planning tool for Watercare's capital planning processes; therefore it has a high level of detail in the trunk sewer network and is calibrated to winter flows. This allows the capital planning to take a conservative approach, which is appropriate. The Central Interceptor team found that whilst this model set up is fit for the purpose it was intended for, the two master plans currently being developed require a more accurate representation of the flows arriving at the plant all year round. The seasonal variation effect means there is generally less flow arriving at the plant in summer than in winter.

Among other requirements, the plant's consent limits the annual average daily flow discharge to 390,000 m^3 per day. Figure 2 illustrates the average daily flow for dry weather flow (DWF) days measured at the plant (dark blue), compared to the model predicted flows for the same days (red). The light blue line represents the difference between the measured and modelled flows. For annual average daily flow, this difference equates to

63,000m^3, which is 16% of the plant's consent limit. Therefore, if the existing model was used, the master planning would likely be overly conservative in terms of when this consent limit would be reached.

Figure 2: Difference between recorded DWFs at Mangere and modelled DWFs



2 SEASONAL VARIATION EFFECT

2.1 CAUSES AND OBSERVED SEASONAL VARIATION

Seasonal variation in sewers refers to the observation that inflow and infiltration (I/I) flows in a sewer vary depending on the time of year. For the Auckland system, flows are higher in winter than in summer. This effect is due to less evaporation and more rainfall in winter, resulting in more I/I.

Flow data from 2006 to 2009 was analysed for annual seasonal variability. To do this, the DWF days from each month were selected and averaged to calculate an average daily dry weather volume. Dry weather flow days were those that were preceded by at least three days with no rainfall. These volumes were plotted on a monthly basis and are shown in Figure 3. The average of each month across the four years is shown as a dark blue line and the average of the minimums across the four years for each month is shown as a light blue line.

Figure 3: Seasonal variation effect at Mangere WWTP 2006 - 2009

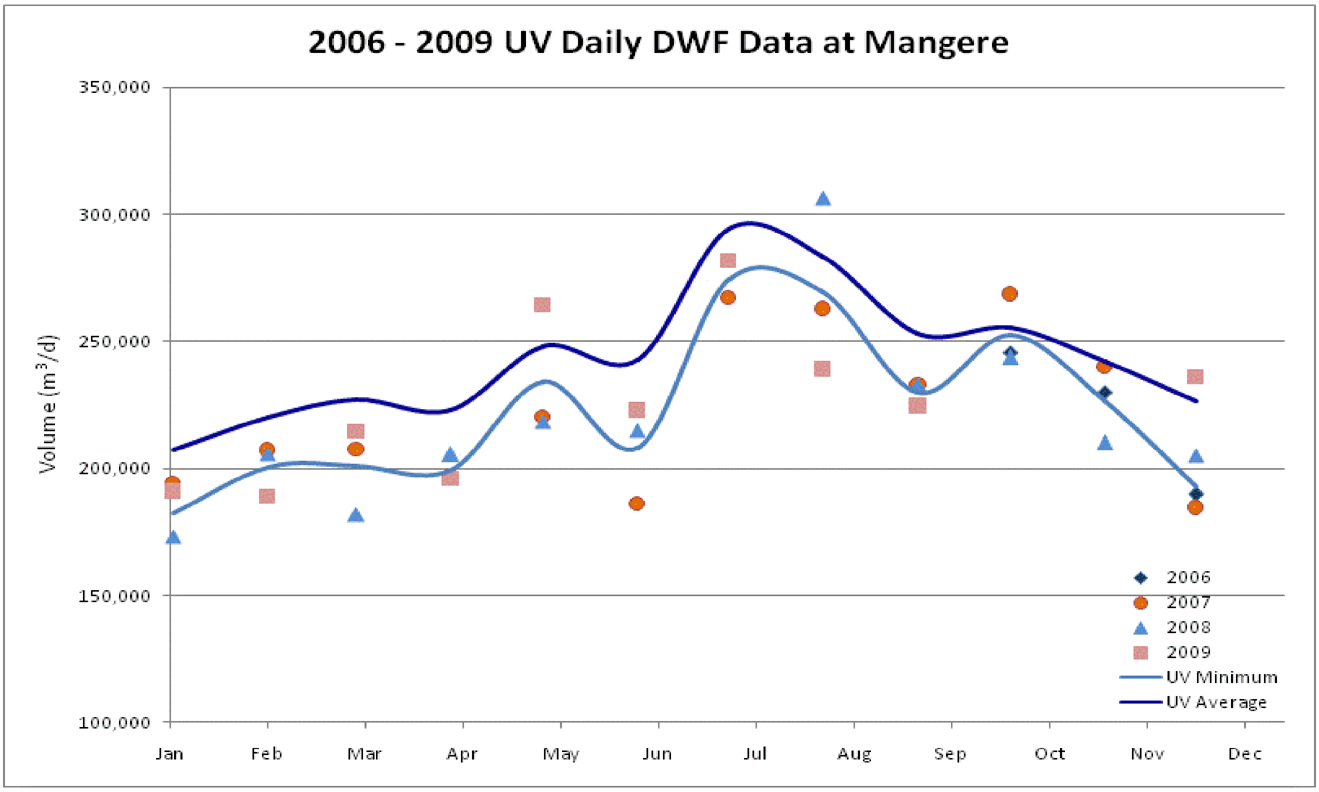


Figure 3 shows the effect of seasonal variation in Auckland, with DWF days in the winter months (May – October) having an average daily volume of up to 80,000 m^3 higher than the summer months. This figure also shows the average of the minimum DWF flow plotted for each month. A similar seasonal pattern is observed, with lower volumes. These results indicate that the volume of wastewater at Mangere for 'DWF Days' is affected by antecedent rain, despite the three days dry weather lead time.

2.2 IMPACT OF SEASONAL VARIATION ON THE WATERCARE MASTER PLANS

Figure 2 shows the difference between the modelled flow, calibrated for winter months, and the recorded flows through the plant. On average across the year this difference equates to 63,000m^3, which is 16% of the current consent for discharge at Mangere. This volume is equivalent to an increase of 315,000 serviced people in the Auckland region.

With the assumption that the wet weather effect will remain consistent in the future, when the population is projected forward the model predicts that the plant consent limits will be exceeded in 2018. After incorporating seasonal variation, the model predicts consent limits will not be exceeded until 2035 - 17 years later. The cost savings of deferring possible upgrades to Mangere or even Rosedale WWTPs for 17 years are significant. Additionally, the incorporation of seasonal variation means that the planned capital work programme is more realistic.

3 RETROFITTING MODEL TO REPRESENT THE VARIATION

3.1 PROJECT STORM II MODEL

Although the PS2 model was not built to take seasonal variation effects into account, it is well calibrated to the winter. The ways in which the seasonal variation could be applied without affecting the calibration, or having to recalibrate the model to a full year of data, were limited.

The PS2 model was built and calibrated using InfoWorks CS software. To estimate the flows through the system the whole year round, including seasonal variation effects, this model could be calibrated using the groundwater module built into InfoWorks CS. As the original purpose of the model was as a high-level tool for CAPEX planning, a conservative approach was used of calibration to winter conditions. For the Central Interceptor project it is more appropriate to assess year-round flows.

In terms of retro-fitting seasonal variation, the ground water module cannot be changed in the model without affecting the calibration. An evaporation time series was added to the rainfall in a bid to simulate the seasonal variation as the evaporation has a seasonal effect also. However, the effect on the model was not as pronounced as the effect recorded by the meters at Mangere WWTP. Therefore, either a new calibration or an alternative approach is required.

In this case the alternative approach chosen was to put the seasonal variation into the model by adjusting the base flow with monthly factors. This method reduced the groundwater infiltration during the summer months but did not affect the calibration during the winter. This is described further in Section 3.4.

3.2 AVERAGE SEASONAL VARIATION CURVE FOR THREE YEARS

Because seasonal variation is heavily influenced by previous rainfall it is not accurate to apply the pattern as derived from the 2006 – 2009 years in Figures 2 and 3. Figure 3 illustrates that while the overall yearly pattern is similar, each month can vary widely between years. Each year will have its own distinct pattern, depending on the rain patterns of that year.

Accurate gauging data at Mangere is only available for the years 2006 – 2009. When running the model for system performance, it is likely that other years will be used. The same seasonal variation pattern cannot be applied to these other years as it is heavily influenced by the rainfall.

It is possible to predict how the rainfall will affect the flow at Mangere and therefore the seasonal variation for each year, and use that to calculate a unique seasonal variation pattern for each year. This can be done using multiple regression equations.

3.3 MULTIPLE REGRESSIONS ON RAINFALL DATA

The rainfall/flow multiple regression method uses rainfall and flow monitoring data to derive a relationship between rainfall and flows. It assumes this relationship is linear and can be expressed as an equation.

Multiple regression was applied to the five-minute rainfall data and flows from 2000, but unfortunately no relationship was derived between the rain and flow response. The method was then simplified by averaging the flow and rain data to a daily average which proved to be successful.

3.3.1 MULTIPLE REGRESSION METHODOLOGY

The following steps were taken to develop the predictive equations used:

1. The flow data was averaged on a daily basis
2. Rainfall data up to 60 days preceding each daily flow were summed for incremental periods: For example, 0-1 days, 1-2 days, 2-3 days, 3-4 days,4-5 days, 6-10 days, 11-20 days, 21-30 days and 31-60 days
3. Multiple linear regression is performed on the correlation between the rainfall sum and the measured flow to determine the regression coefficients (C_i) for each rainfall sum. Regression equations are in the form of:

$$\text{Average Daily Flow} = C_1{*}Rain_{0\text{-}1days} + C_2{*}Rain_{1\text{-}2days} + C_2{*}Rain_{2\text{-}3days} + C_2{*}Rain_{3\text{-}4days} + C_2{*}Rain_{4\text{-}5days} + C_2{*}Rain_{6\text{-}10days} + C_2{*}Rain_{11\text{-}20days} + C_2{*}Rain_{21\text{-}30days} + C_8{*}Rain_{31\text{-}60days} \quad (1)$$

4. Once the regression coefficients have been calculated, other periods of rainfall can be applied to verify the predicted flow against actual measured data
5. Because the seasonal variation is not solely affected by rain, several sets of equations may be necessary to predict the seasonal influences of antecedent conditions. In our case, two equations were derived, one for the summer months and one for the winter months.

3.3.2 MULTIPLE REGRESSION RESULTS

Figure 4 shows 2007 flows measured at the plant and the prediction with the multiple regression. Whilst this match is not perfect, particularly in the winter peaks, it is only the dry weather days we are interested in for the purpose of our analysis. Figure 5 shows a good relationship between the regression prediction and the monthly average daily DWF volumes.

Figure 4: Multiple regression flow prediction compared with metered flows at Mangere

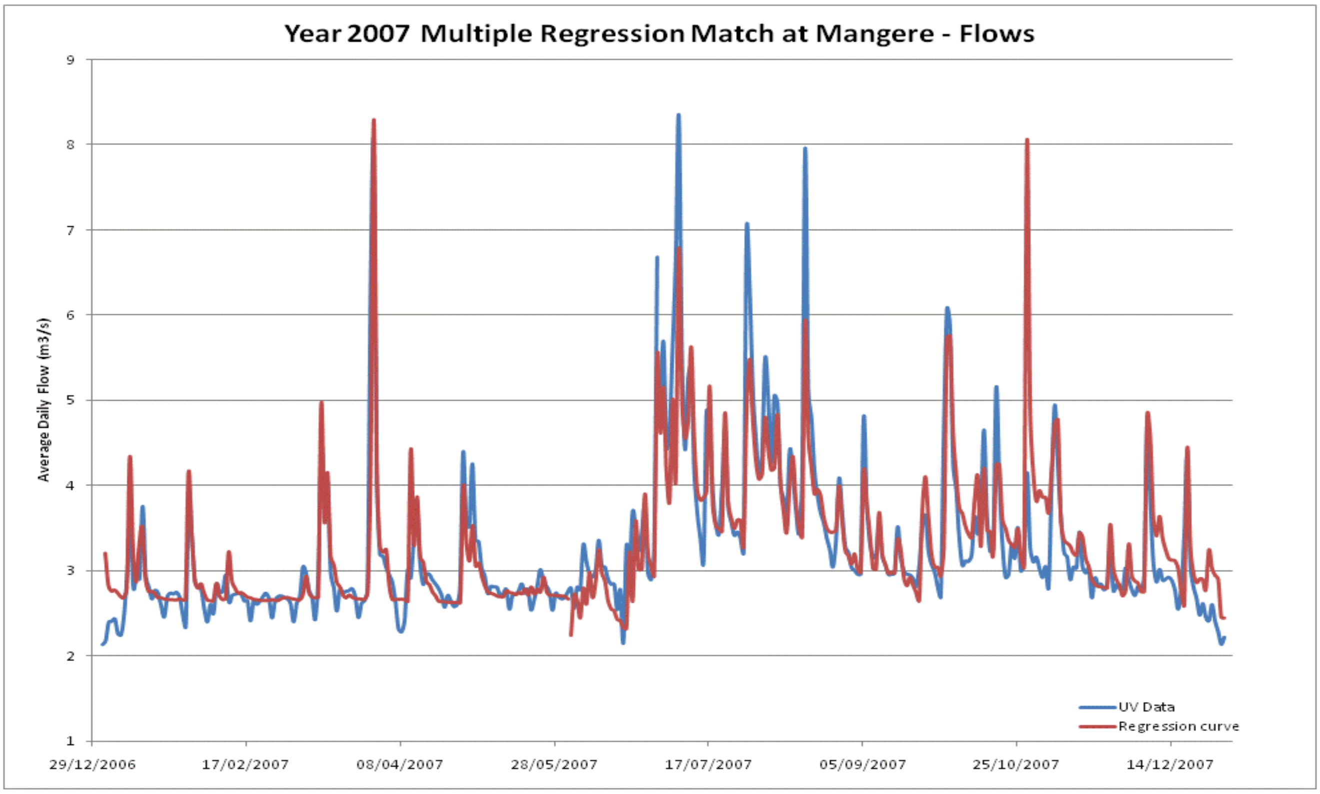
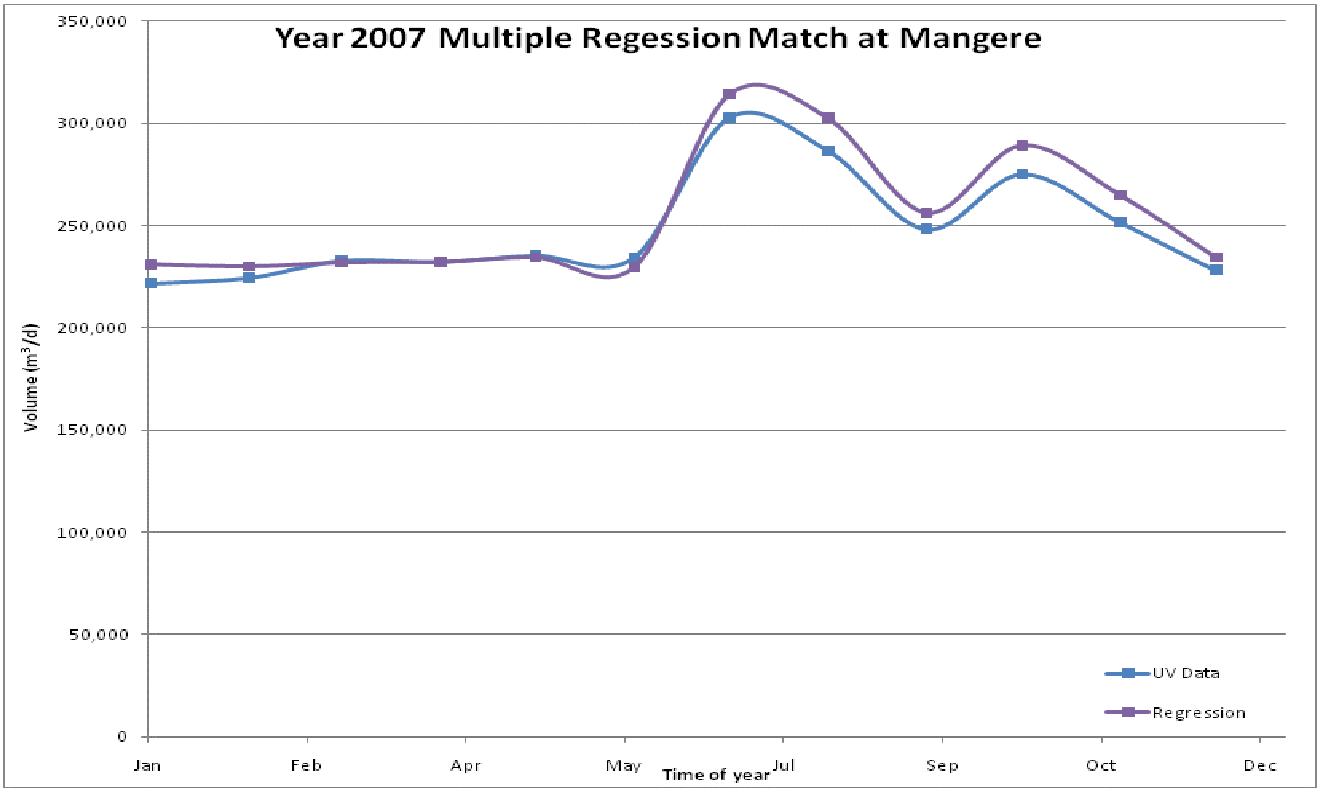
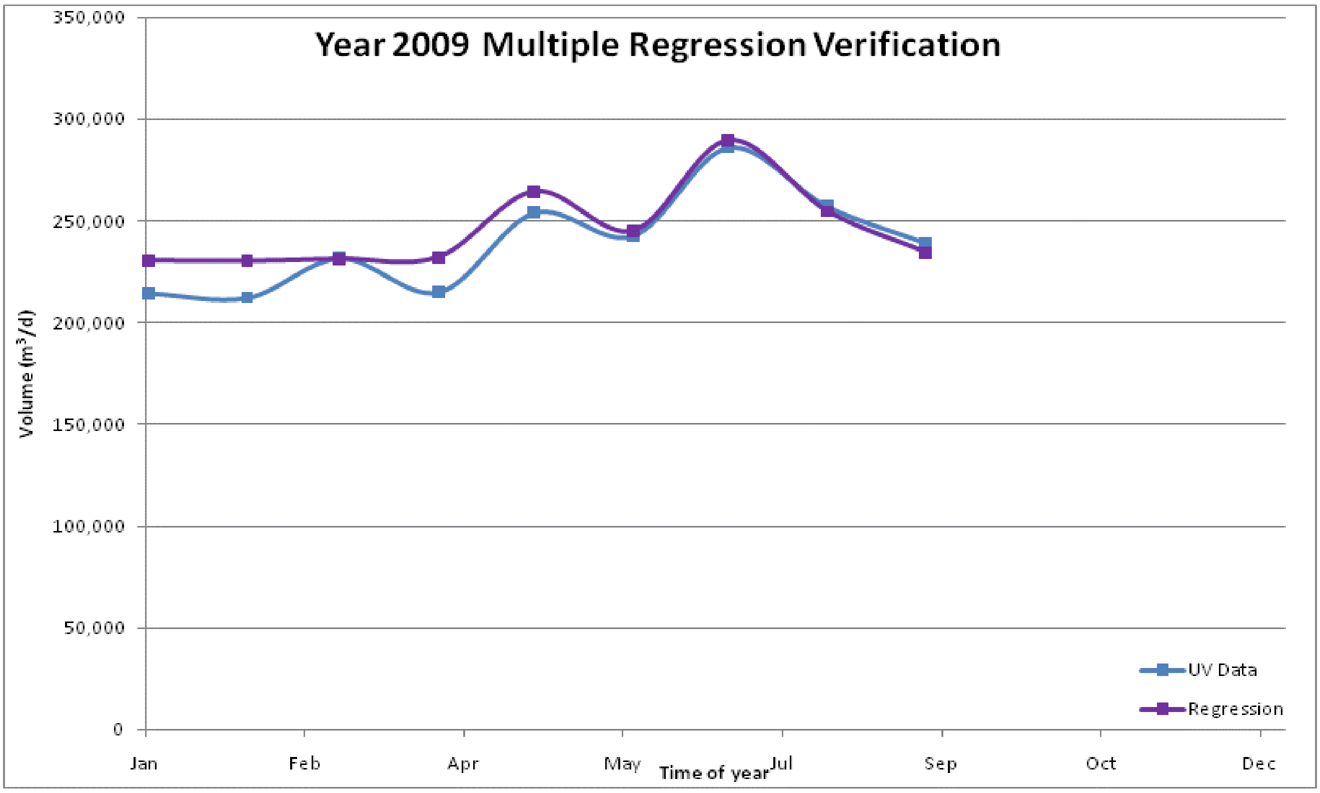


Figure 5: Multiple regression prediction compared with observed monthly average DWF volumes for 2007



The regression was also checked against the flows and the average monthly volumes for 2008 and 2009 and a similar match was found. Figure 6 shows the verification for the available months in 2009. It was held that the regression equations derived for 2007 would be a good match for the other years in the long term time series.

Figure 6: Regression verification for available data in 2009



3.3.3 MULTIPLE REGRESSION LIMITATIONS

There are some variables that may affect the quality and consistency of the regression, which modellers should be aware of when undertaking similar work. These are outlined below:

- **A linear relationship must exist between rainfall and flows.** A linear relationship does not always exist as the percentage of rainfall varies. For example, debris or surcharging in the system and system operation as well as large changes to the system which change flows for reasons other than rainfall.
- **Good quality flow and rain measurements throughout the regression period.** It is important to graph the data for the whole period and check for anomalies and drop outs as these can affect the regression equations.
- **Spatial variability of rainfall.** Variability results in differences in flow rates, volumes and timing. For this regression, we have analysed and taken a representative rain gauge, but then checked the regression equations by running them with several other rain gauges to check for large differences. No large differences were found in any of the years which we applied the regression to.
- **Antecedent conditions.** RDII predicted by regression equations will be most accurate when applied to periods of similar storm patterns and antecedent conditions to those used to generate the equations.
- **Model assumptions.** Depending on these, the system flows may not correspond to rain with a multiple linear relationship.

Regressions should always be checked carefully and used only on systems where no large changes have occurred. In terms of a model, the same network should be used.

3.4 ADJUST MODEL BASED ON REGRESSIONS

As mentioned in Section 3.1, there are limited ways to adapt a model to replicate the seasonal variation effect without overly affecting the calibration. The model was adapted to vary the base flow by month, according to the results of the regression analysis. The model was first adjusted for seasonal variation on a global basis, but then refined to reflect variation at two upstream locations. The number of locations where this could be applied is only restricted by the number of long term gauges in any collection system.

InfoWorks CS allowed us to vary the base flow by creating dummy catchments with no area and no population for all the locations where base flow is in the model. The base flow values were then moved to the trade flow in the new dummy subcatchments. The dummy subcatchments were given a prefix to denote that these catchments were used to incorporate seasonal variability in the base flow.

A yearly pattern with monthly factors was then specified in the trade flow group to scale the base flow of the dummy subcatchments up or down to match the observed seasonal variation. The monthly factors were attained by trial and error until the model replicated the desired variation during the DWF days.

This must be done separately for each year to match the corresponding regression flows during the correct rainfall. Therefore the factors are specific to each year, so if there are 10 years in a long term time series, 10 trade flow groups would be expected.

4 OUTCOME

4.1 PURPOSE OF THE MODEL

The trunk sewer master plan model serves a dual purpose: master planning of Watercare's conveyance assets, and input into the wastewater treatment plant master plan. These two master plans are related as they both aim to alleviate Auckland's growth related wastewater problems.

The purpose of incorporating seasonal variation into the model was to accurately simulate the flows reaching the plant, and therefore allow an accurate assessment of the flows with respect to the consent limitation. Having higher model accuracy with the seasonal variation means that the effect of growth within the Auckland region can be understood, and the year that the consent limit is reached can be better defined. It also allows for more accurate sizing of the Central Interceptor tunnel, which can mean significant savings in capital costs to Watercare.

4.2 LIMITATIONS OF VARYING THE BASE FLOW GLOBALLY

4.2.1 GLOBAL APPLICATION LIMITATION

The main limitation is when looking at detail in the model, as I/I is not uniform throughout the service area. This approach has applied the seasonal variation almost evenly throughout the region. In our case, the global application was altered to give a better match to the three interceptors tributary to the plant. However, no further detail was necessary; the reason for this is that the main focus of the model is to attain more accurate flows at the plant, where the consent limit applies.

When looking at specific overflow data which is further up in the system, care should be taken to assess if the seasonal variation application is correct for that area.

4.2.2 BASEFLOW LIMITATION

Seasonal variation affects both base flow and wet weather storm response. For example, 30mm of rain in the winter will generally produce more RDII than 30 mm of rain in the summer. The base flow adjustment method described in this paper to represent seasonal variation does not vary the wet weather response over the year. It is possible to match WWFs in summer and winter by using the groundwater infiltration module during calibration of the model, if the purpose had been to predict year-round flows accurately. At this stage, this limitation is acceptable as the key driver of the annual average flow volume at Mangere is the dry weather flow.

5 CONCLUSIONS

Watercare is in the process of developing a consent application and concept level design for the Central Interceptor as well as developing master plans for Mangere WWTP and the trunk sewer network.

A crucial aspect of the Central Interceptor Programme is optimising the balance of conveyance, storage and treatment capacities in the system to ensure the least whole of life cost which adequately addresses the system's key drivers. A key aspect of this is to enhance Watercare's existing model accuracy by modifying it to represent the effects of full year seasonal variations on flows.

This work was achieved with the following conclusions:

- An analysis of the available 2006 - 2009 UV data indicates significant seasonal variation is apparent at the plant during dry weather.
- Comparison of the PS2 model with the observed seasonal variation indicates that the model does not simulate seasonal variation and is calibrated for winter conditions. As a result, the model over-predicts the average daily flow by an average of 63,000 m^3/day. For the purpose of the Central Interceptor project, this means the model will predict the volumetric consent limit at Mangere (annual average daily flow) will be exceeded significantly earlier than in fact will occur, and the consequent master planning will be inaccurate.
- Converting the model to simulate base flow as trade flow with monthly adjustment factors is an effective method for simulating observed seasonal variation. It should be noted that the method is not predictive and must be calibrated for each time period simulated.
- Because the method is not predictive, it follows that the monthly adjustment factors determined from the available 2006 - 2009 UV data are not appropriate to use as a design condition for other years.
- Multiple linear regression can be used to determine a relationship between the antecedent rainfall and the flows in the system for any period.
- The model can be successfully adapted to simulate the seasonal changes in base flow, and now shows a significant improvement to the representation of total flows received at Mangere. This means the model can be applied to accurately simulate the flows at the plant and optimise the year for upgrade and the Central Interceptor sizing.
- Certain limitations apply to the use and application of this method. Because the changes are made to represent seasonal variation effect only in the base flow and apply to dry weather flow only, the model may still over predict the volume and duration of wet weather effects in summer.

Overall, incorporating the seasonal variation effect into the modelled base flow provides Watercare with a significant improvement to the estimated flows at Mangere WWTP. This allows for a more accurate estimation of the upgrade requirements and timing.

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