PIPE ALIGNMENT TOOL

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ABSTRACT

Yara Valley Water in Melbourne needed a strategic wastewater plan to extend their networks to over 7,000 high-risk properties that were not serviced by the existing infrastructure. To route pipes from individual parcels to existing pipelines, this extension must consider the topology of Yara Valley as well as soil survey data. Additionally, gravity pipes must be prioritised over pressure where possible.

Traditionally, engineers would manually:

Plan potential routes,
Check the elevation data and path viability,
Identify the pipe requirements based on surface gradient, soil type, and parcels serviced by it.

Our team at Stantec developed an innovative solution involving automation and graph theory by building a connected network of all possible pipe locations based around the existing road network and resolving this into a final design through and interactively collaborative lowest cost algorithm.

Though this approach relied on engineering judgement to review and correct the cases not identified and resolved through the development of this tool, the automated process saves weeks' worth of work and can be applied internationally.

KEYWORDS

Pipelines, Strategic Planning, Innovation, Automation, Efficiency

PRESENTER PROFILE

Andrew has a background in Computer Systems Engineering which he has applied to the digital engineering ecosystem within Stantec. Branching into GIS and Data analytics within the transportation team, Andrew supports projects across all Stantec's disciplines. He uses his engineering skillset to innovative and robust design solutions to meet stakeholder requirements.

INTRODUCTION

We were engaged by Yarra Valley Water (YVW) to undertake a high-level review and desktop planning exercise—here, we developed a bill of quantities and associated cost estimates for delivering reticulated sewerage services to 7,000 high risk properties across 44 of YVW's Community Sewerage Areas (CSAs).

Further, incidental properties (unsewered properties not classified as high risk) that could be connected to the new networks should be identified and the associated additional connection costs (connection and network costs) calculated.

Figure 1 exhibits a broad overview of the study area. These unsewered regions have been left this way partially due to inaccessibility. Many of these community service areas are in hilly terrain with high costs associated with design and implementation of a functioning sewer system.

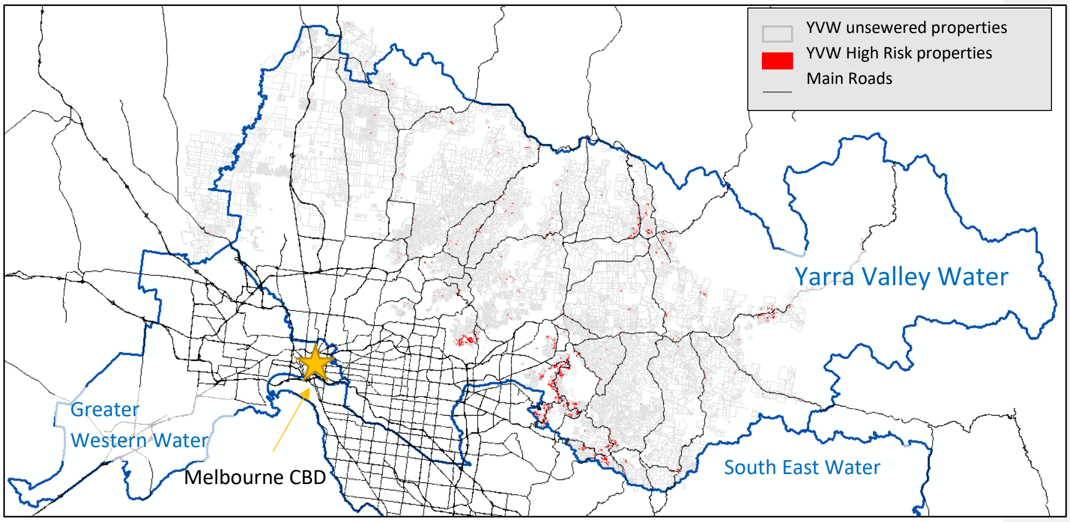

Figure 1: Study Area

DATA INPUTS

SCOPE

YVW supplied a geospatial layer containing all currently unsewered parcels organised into two categories: ">Low Risk Properties" (i.e. the High Risk properties to be considered) and "Low Risk/Possible Alignment Properties for consideration".

While large parcels remained in the data set, YVW determined that any parcel greater than 10,000 m^2 was to be excluded from the analysis. Additionally, any incidental properties where the building offset would be greater than 100 m were also excluded.

YVW also provided a buildings outline data set which covered both high risk and other unsewered properties where there was building outline data available. This was required as the connection locations for pressure pump units needs to be adjacent to a building.

Figure 2 shows an example of the spatial layout of high risk and incidental properties.

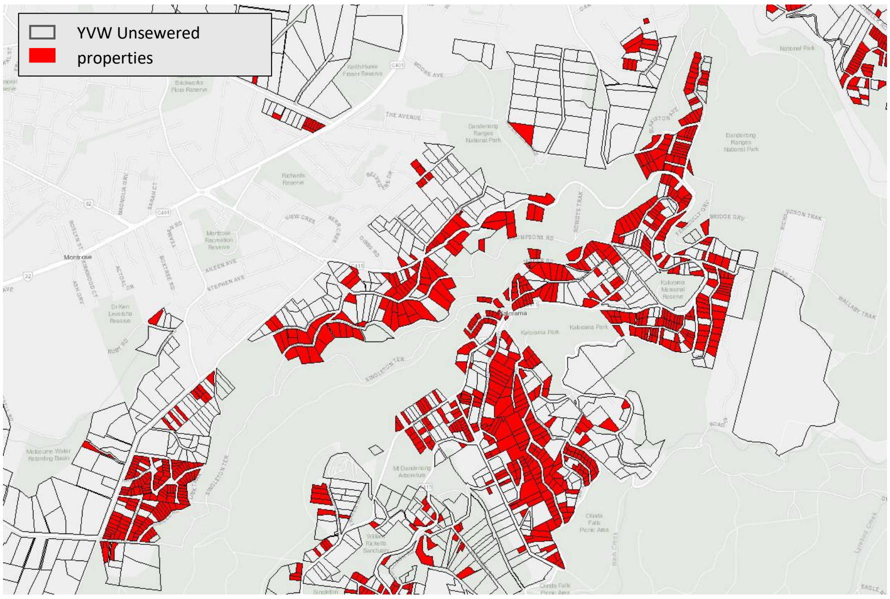

Figure 2: High risk and other unsewered properties example

COMMUNITY SEWERAGE AREAS (CSAS)

Previously, YVW had identified and grouped the original 7,000 high-risk properties into 44 CSAs—these represented groups of properties in spatial proximity with the potential to be serviced via the same network. The 44 areas were eventually grouped into 18 analysis sections due to proximity and potential for network overlap. Figure 3 displays some of the original CSA groups, with the high-risk properties coloured accordingly, as well as which ones were grouped together for cohesion.

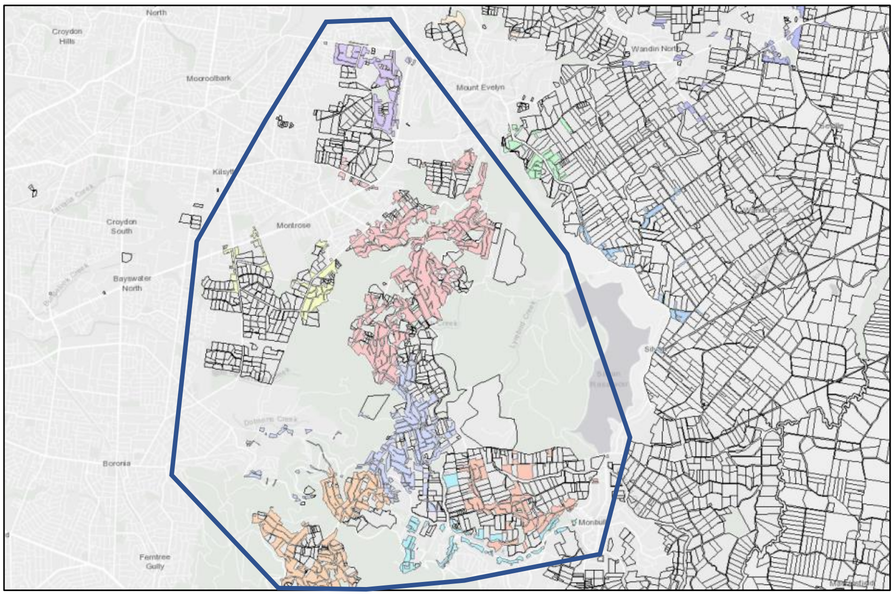

Figure 3: Example of CSA groupings (high risk and incidental alignment properties)

COST RATES AND ASSUMPTIONS

Cost rates were provided by YVW which factored in asset cost, installation, and maintenance/operation over a 25-year lifecycle. Pipes were priced per meter for gravity, pressure, and rising mains with cost adjustments for different soil types and pipe sizes. While no additional cost factors were provided for the depth of pipe, this was applied as a percentage markup on the base cost of any pipe.

Other assets which were priced up included booster pump stations, rising main pump stations, manholes, and property-based pressure pump units. The connection costs were also included for each parcel based on the plumbing required to install a gravity sewer compared with pressure.

GROUND CONDITIONS

The costing for different pipe installations varied based on ground conditions. To apply these costs, the The VicMap Geology Layer GEOL250 data set was used to identify ground conditions across the study area. While this layer contained a large set of soil types, they were condensed into three categories to simplify and align with the YVW cost schema: Granite, Siltstone, and Clay.

LIDAR (DIGITAL TERRAIN MODEL)

To measure ground elevation, YVW provided a digital terrain model dataset containing high-resolution LiDAR data. Here, accuracy was essential to ensure that the property connections were at appropriate elevations, the pumping units

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could supply enough pressure to crest the highest elevations, and gravity flowed downhill.

In some areas where no LiDAR was available, lower resolution contour data (sourced from Vicmap) was used to set the ground levels. Figure 4 exhibits the coverage of the LiDAR data across the study area and the area where contour data was used.

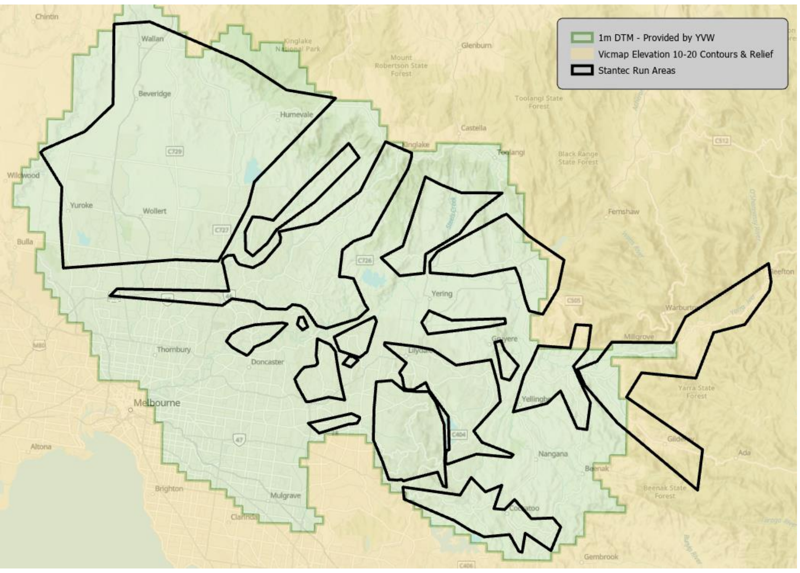

Figure 4: LiDAR coverage

OPTIMISATION APPROACH AND ENGINEERING RULES

SCOPE

Our team formulated an efficient methodology that both determined the sewerage servicing strategy for all CSAs and developed feasible networks to connect each high-risk property to the existing sewerage network. To this end, we utilised a collaborative 'lowest cost' algorithm through which we identified a sewerage servicing strategy for each CSA. The following provides a breakdown of the steps that made up our approach:

- Identify feasible connection points to existing sewer (manual selection or automated)
- Ground level analysis to identify property connections
- Using the road network data (GIS) network trace from each property to connection points
- Iterate and adjust cost factors based on network usage to encourage a collaborative network design.

SEWER CONNECTION POINTS

The sewer connection points we considered in the analysis were identified based on the sewer maintenance hole layer provided by YVW. Filtered for each of the study areas, the layer only included the connection points within reasonable proximity. The layer was limited to gravity network nodes and, for the purposes of this exercise, the current capacity and utilisation of the network downstream of these nodes were not included as factors.

Often located on or near to the road, these connection points were linked into the road network via the shortest path.

PROPERTY CONNECTIONS

We used the high-risk properties parcel layer, building footprint layer, and LiDAR data were to identify property connection locations and ground level information for each property. Subsequently, each property was setup with two connection point options for the optimisation to consider. The following engineering rules and costs were applied accordingly:

Pressure connection

1. Connection point was located at lowest point along the building footprint on the parcel.
2. If there was no building location information, the connection point was located at the centroid of the parcel.

Gravity connection

1. For full lot control, the lowest point on the parcel was adopted.

Once these connection nodes were identified, they were attached to the nearest boundary of the parcel, offset by 1 m. It is worth noting that properties with multiple equally low points posed multiple connection options. Additionally, the low point around the building outline may be the same as the parcel low point—this would result in one connection location for both pressure and sewer.

An internal buffer of 1 m around the parcel was used to provide a route for these connection nodes to reach any edge of the parcel. To allow the sewerage multiple options through which to exit the parcel, the parcel's internal buffer was connected to all roads within 50 m. An example of this lot connection is shown in Figure 5 below.

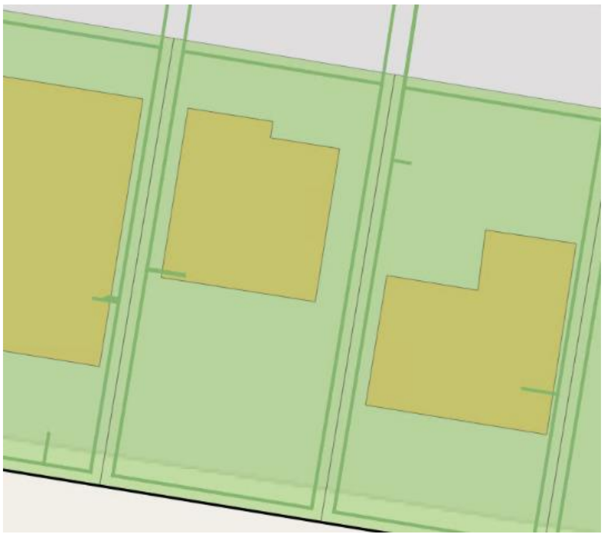

Figure 5: Lot Connection Example

PIPELINE SETUP

Our team used the VicMap road network data to the identify feasible pipeline routes that would form the basis of the analysis. The connected and routable network could be used as the basis for shortest path navigation across Yarra Valley. Based around this road network, we constructed the connected network links layer.

The connected network links layer was made up of short sections, with nodes inserted at regular intervals to ensure the changes in elevation along the road were observed. Moreover, the network was also broken up by nodes which were inserted where the property and sewer connections intersected. To complete the connected network, the property and sewer links we created were merged with the road layer. Using this combined network, paths could be calculated from all property nodes to all sewer nodes, based on lowest cost. However, the network was still lacking a cost function use for the 'lowest cost' path, as well as variables to utilise.

The first constraint we needed to consider was elevation. This would be the greatest determining factor between where a gravity-based system can flow and, in many cases, whether or not a property would be able to connect into the network using gravity at all. Based on the LiDAR data provided, we assigned an elevation to every node along the network. This was then passed into the network links which were assigned start and end elevations.

Another key factor at play was soil consistency and the effect of pipeline construction through different ground types. Using the dataset and lookup tables provided, we assigned a simple soil classification to each network link. As this was directly correlated to the costings of each pipe type, the according cost rates were also applied to each link.

To leverage the power of existing routing algorithms, this network needed to be reformatted into a graph. The network was triplicated into gravity, pressure and rising main exclusive networks—each with their own distinct cost per link, plus additional links added at every node to connect the three networks together.

ASSIGNING RULES AND COST

The first and simplest rules the assign are around the limitations of a gravity Unless a pump station is introduced, sewage in a gravity system can only flow downhill. To reflect this in the graph, the easiest approach would remove any links from the gravity network that ended at a higher elevation then they began. However, these elevations were based on surface level LiDAR; they did not take into consideration the potential to dig a trench where a pipe continues to reduce in elevation while the surface rises. To address this problem, a series of links and nodes were generated for each primary link and node, reflecting possible pipes of various depths beneath the road surface. The nodes were generated at 500 mm intervals from a depth of 1.2 m to 5 m below the surface. Thus, links were generated to connect each of these nodes to all other nodes of an equal or lower depth. These deeper links were assigned a cost multiplier to reflect the cost of digging a deep trench. Figure 7 shows an early concept drawing of the planned network.

Though a gravity network cannot connect to a low-pressure network, a low-pressure network can discharge into gravity. The discharge of pressure into gravity was already accounted for: these three networks were connected at every node. However, to reflect this constraint, the gravity to pressure links were removed from the graph along with the rising main to pressure links.

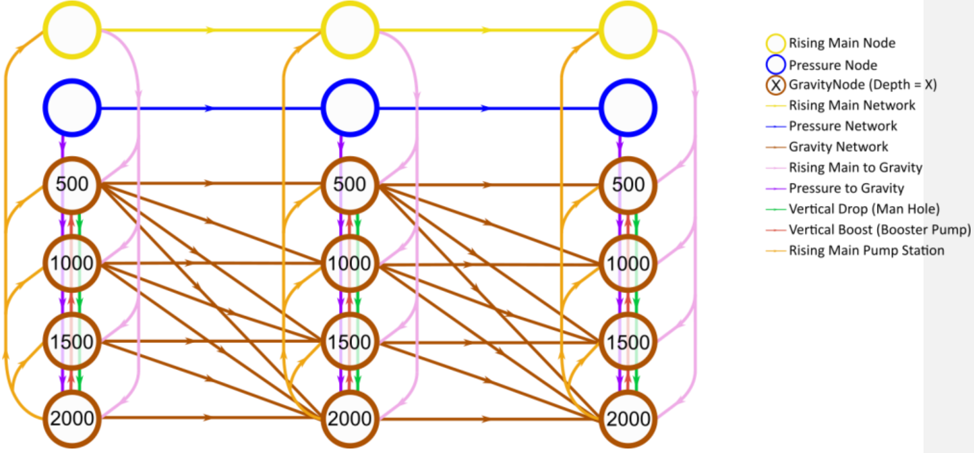

Figure 6: Sewer type and depth optimisation concept

Next, we addressed the costs associated with the links connecting gravity to rising main. These links were assigned the cost of a rising main pump station; for YVW, a ballpark cost of $400K was determined.

To the links where the property connection nodes join to the property boundary, we assigned the specific installation cost. Gravity incurred only a small plumbing cost, yet a pressure connection included the CAPEX and OPEX costs of a property pump unit, approximately $30k in total. While this is a high price point, it should be noted that the cost per meter of a gravity pipe was slightly less than four times the price of a pressure pipe. Therefore, over a certain distance it would become cheaper to install pump and pressure pipes rather than utilise a gravity sewer connection over a distance of around 50 m. Additionally, these measurements apply to a single property connecting and using the pipeline. In an example with two properties, the cost of the pipe would be split, while a pump is required each for a pressure connection. This Increases the cost threshold to almost 200 m.

Finally, we tackled the costing and rules associated with booster stations. In the initial development of this tool, booster stations had been included in the network to allow the gravity system to gain a small amount of elevation at each nod. These were coding as links vertically between gravity nodes at the same location. Though high in price, there are cases where booster stations may have been more economical then developing a pressure network for an area and where a rising main was not required. However, it was determined later in the design process that this use of booster stations was not in line with the design practices of the area and were thus removed. Fortunately, with this automated approach, the removal of these links and entire network re-creation was an overnight hands free exercise, rather than the weeks of manual re-edits that may have been required using a traditional approach.

Later, there was a different type of booster station that was required to boost the pressure of a low-pressure network. By design, the units are only capable of about 50 m worth of pressure. Given the hilly terrain of some of the study areas, several of these pressure systems are required to pump up 50 to100 m. Unit placement was decided in a post-processing exercise, though cost was simulated by applying a proportional cost increase on the pressure lines based on their elevation gain.

We created a custom adaptive cost function based on the measures above alongside evolving modifiers that encouraged collaboration between properties. This was useful in selecting an effective network that identified a low community-based cost.

POST PROCESSING ANALYSIS

Pipe Sizing

The pipelines were sized based on the number of upstream connections. As part of the optimisation, the number of upstream connections in the network was calculated for each connected network group. The pipe size was determined based on the following table of number of connections and pipeline sizes. Further, the values for gravity sewers are based on a conservative assumption of slope/grade for the pipe size and are not adjusted to allow for increased properties—this was chosen to simplify the optimisation problem and reduce the algorithm run time with little change in overall cost. Costs were then calculated for each link based on size, length, network type (pressure/gravity), and ground conditions identified for that link.

Table 1: Pipeline Size Rules

Network Type	Pipeline Size	Number Connections
Gravity	150 mm	< 173 lots
	mm	173 to 496 lots
	300 mm	>=496 lots
Pressure / Rising Main	63 mm	< 125 lots
	90 mm	125 to 400 lots
	125 mm	>=400 lots

Booster Station Placement

Our placement of booster stations was determined by the properties with the highest elevation gain over a pipeline. We identified and flagged 50 m increments in elevation gain as locations where booster stations were required.

Next, these locations were reviewed and calibrated by our engineers to ensure they were both cost-effective and feasible.

Incidental Analysis

Our iterative solution was first tested using only the high-risk properties. Once the network was designed, we ran the solution again—this time including any property that was adjacent to the planned pipeline. Here, we could identify how these properties would connect , if there was any shift to the network design (from pressure to gravity or vice versa), and how to re-evaluate the pipe sizing if required.

OUTPUTS

Of the 7,190 high risk properties, our methodology proposes a connection strategy for 6,419. During this study, many properties were flagged as outliers and could not be sensibly included in the connection strategy due to factors such as geographic isolation or service costs required.

The vast majority of the property connections exhibited by this strategy utilised pressure units. While it was communicated by YVW that gravity is their preferred servicing option (which was expressed by the small cost modifier added to all pressure assets) the mountainous terrain of the study area made many of the properties very costly to route using gravity only. Often, the connection locations were significantly below road level. The combination of properties requiring a pressure connection to reach the road level, and the price difference between gravity and pressure connections resulted in more properties connecting via pressure. In the end, 6,289 of the 6,419 properties were identified to be best serviced by a pressure system.

Our automated process traced over 621 km worth of sewer pipe across Yarra Valley, connecting these 6,419 high risk properties to 300 existing manholes. The completed network included 130 gravity connections, three rising main pump stations, and 13 booster stations—these booster and pump stations were reviewed, and their locations refined by the wastewater engineering team. Moreover, the digital outputs of this approach can be efficiently imported directly into hydraulic modelling tools to review and further refine the design.

In addition, we were able to connect another 3,934 unsewered properties that were not classed as high risk but were adjacent to the planned pipeline.

The results of a sample area are shown in Figure 7 while the overall network is shown in Figure 98. Though the outcome was imperfect and required continual calibration to reflect the engineering judgement the at comprises these exercises, it granted a baseline for our engineering teams to work from when delivering the complete network.

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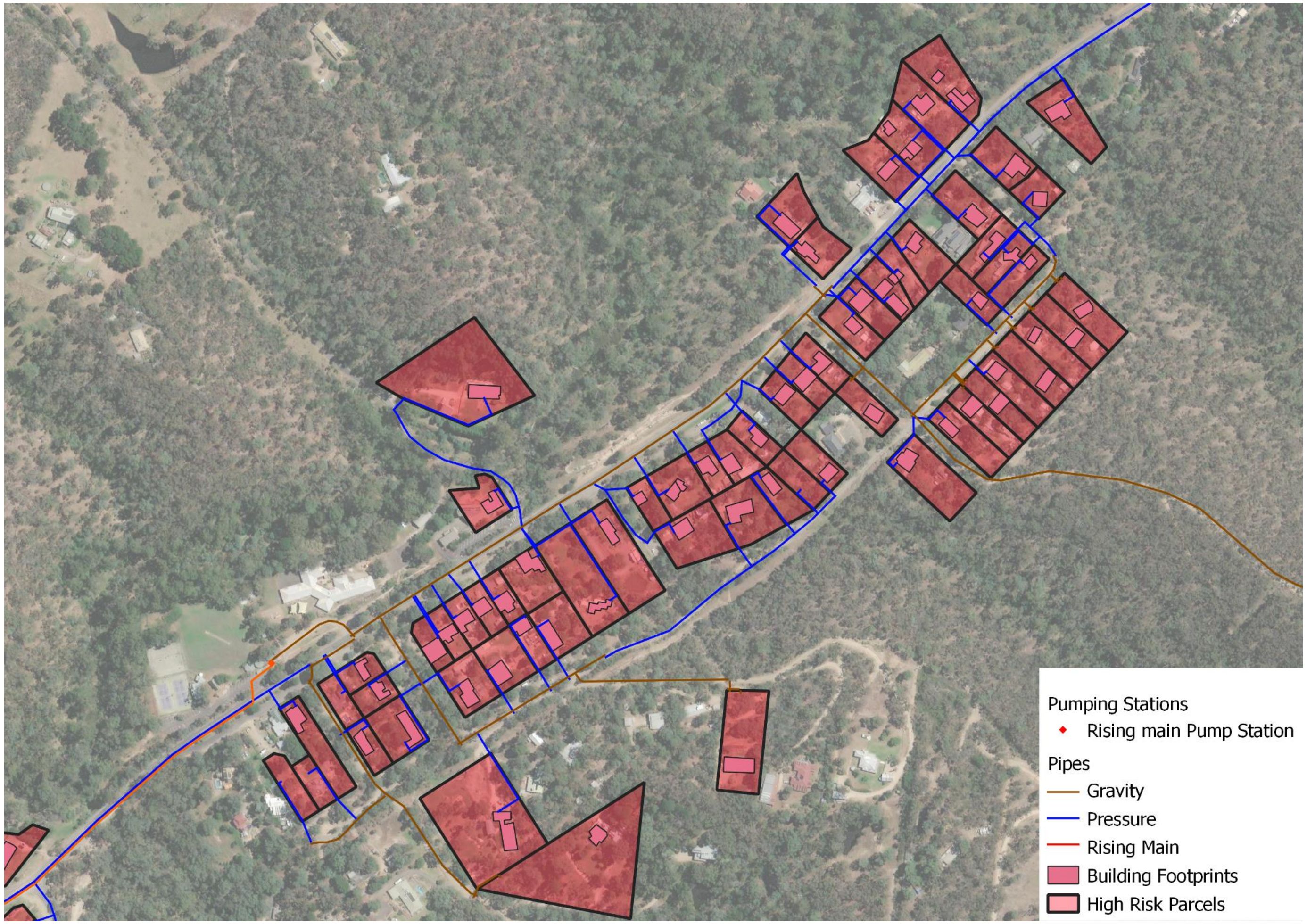

Figure 7: Sample Area

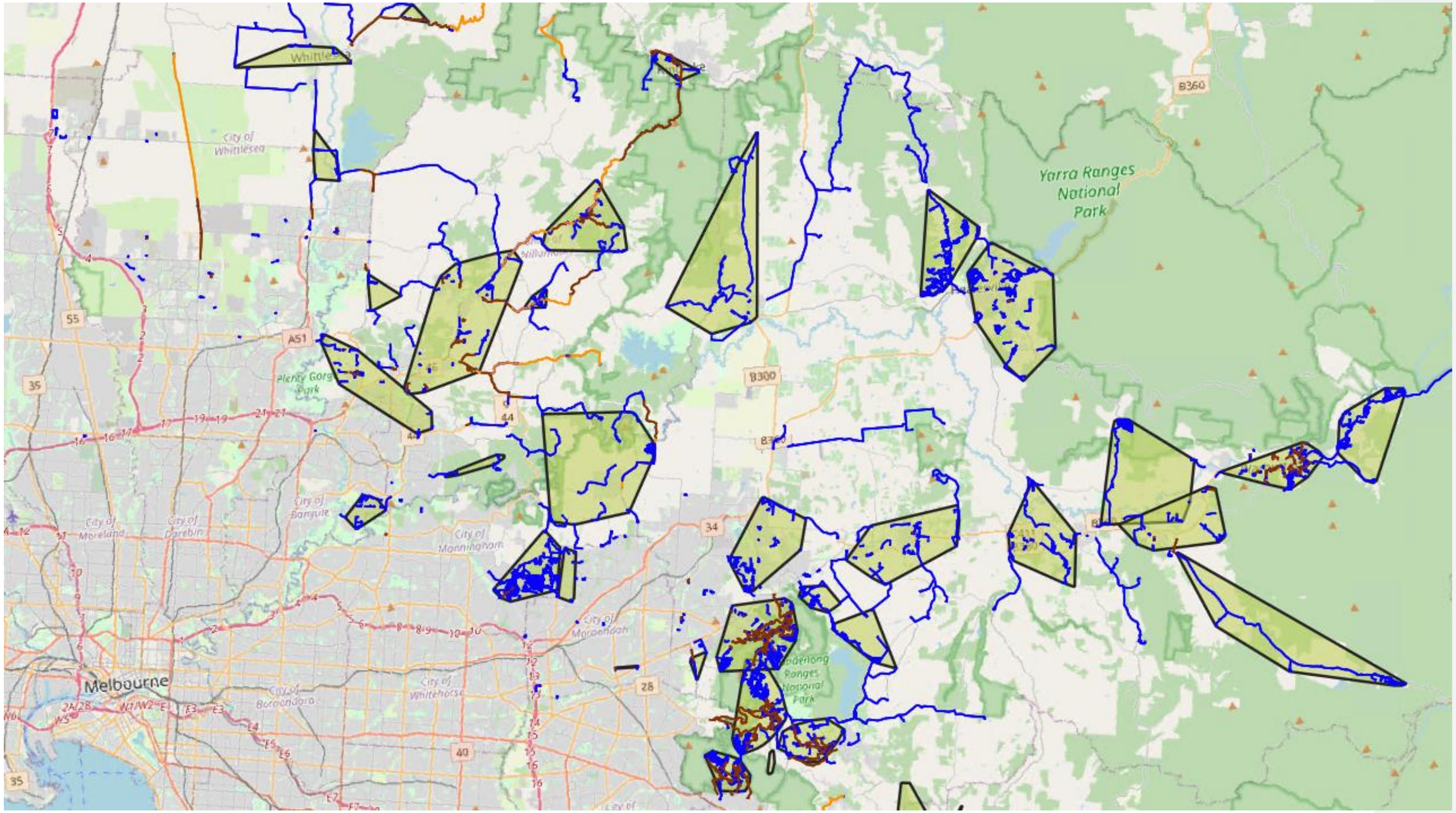

Figure 98: Overall Network

CONCLUSION

On behalf of Yarra Valley Water (YVW), our team developed an optimisation algorithm and process to automate concept designs of sewer networks to service approximately 7,000 high risk properties across the YVW catchment.

In developing solutions to service these properties, we identified connection types (pressure or gravity) for each property as well as feasible sewer networks made up of pressure sewer, gravity sewer, rising mains, pumping station, and booster pump stations to connect each property to an existing sewer network. Our optimisation algorithm searched for near optimal solutions based on 'lowest cost' paths while accounting for ground elevations, capital and operating costs, and surrounding properties. The optimisation follows an iterative process to refine routes, sewer type, and sewer size per iteration.

The solutions we developed grouped each property into a CSA (Community Sewerage Area) based on network connectivity and/or proximity of properties. This has allowed YVW to assess both costs per CSA and costs per connection per CSA and prioritise areas for further development and construction.

Within this project, unsewered properties along the proposed pipe alignments were also pinpointed. These were categorised as 'incidental alignment' properties. The additional costs to connect these properties was calculated to provide YVW with a quantifiable cost for extending the network as well as the overall impact on cost per property within the CSA group.

Conclusively, this project has delivered a concept design to connect over 10,000 unsewered properties within YVW's service area to existing sewer networks. We have also provided the associated cost estimates (full cost breakdown of pipelines, pumps, connection costs, OPEX, and customer plumbing connection costs). Moreover, the GIS layers of the proposed new assets, CSA groups, connected properties as well as network maps for each CSA were additional outputs of this work.

ACKNOWLEDGEMENTS

Yarra Valley Water, for the support of a new approach to strategic wastewater design.