AVON RIVER STORMWATER QUALITY TREATMENT - AN INNOVATIVE GIS DESIGN APPROACH

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ABSTRACT

The Christchurch City Council Stormwater Management Plan (SMP) for the Avon Ōtākaro catchment in Christchurch considers retrofit of stormwater quality treatment devices throughout the highly urbanised catchment of 8,862 ha. The concept design for treatment utilised traditional and innovative GIS approaches and proposes a range of water quality devices and mitigation scenarios.

This paper describes the GIS identification of stormwater quality device retrofit locations which form the basis of the mitigation options. An engineering constraints approach informed a complex GIS analysis across the entire catchment. The analysis extended to sizing and costing the devices within the GIS model for two types of treatment device with the overall goal of informing a benefit-cost analysis. The GIS approach enabled easy modification and validation of the proposed retrofit locations as well as visualisation of potential options for future of stormwater management within the catchment.

KEYWORDS

Stormwater treatment, specimen / concept design, global stormwater discharge consent, GIS.

PRESENTER PROFILE

Tom Parsons is a Stormwater Engineer for Innovate Consulting Ltd. He specialises in concept design, stormwater modelling, project management and programme management. Tom has focused recently on work for Christchurch City Council and investigations into earthquake effects on the drainage network and the Avon River SMP.

1 INTRODUCTION

Christchurch City Council ('Council') is currently preparing a Stormwater Management Plan (SMP) to support a global stormwater discharge consent for the Avon River. The Avon River runs through the heart of Christchurch and is an integral part of the fabric of the city. The SMP considers the effects of existing and proposed development within the catchment (8,862 ha), the nature of discharges into the river and the effects of urbanisation on the water quality (Bartram and Ritchie 2013) and sediment quality (Gadd and Sykes 2014) in the river. The SMP also proposes modifications to the existing stormwater infrastructure (the 'Avon SMP Blueprint', Couling (2014)) within the catchment to better manage both stormwater quality and quantity over the next 35 years.

The Avon SMP Blueprint will form a chapter of the SMP and will present the options, costs and benefits of new stormwater quality infrastructure within the catchment. This paper discusses in detail a part of the method used to derive the stormwater quality infrastructure options.

2 BACKGROUND

Council has previously applied for two global stormwater discharge consents; the Styx River (Golder Associates 2012) and the South West Area Plan (Golder Associates 2011). These two consents were focused on the community's aspirations for the waterway, achieving policy directives (CCC 2009) and the effects of proposed greenfield development discharging into waterways. These earlier consents could rely on large water quality devices, such as ponds and wetlands, situated in the greenfield development areas to mitigate the effects of proposed urbanisation (Couling 2012, Golder Associates 2011a). The Avon SMP blueprint had to consider a dramatically different environment; consisting of approximately 50% existing impervious coverage (Golder Associates 2014), 550 km of existing pipework, 1,200 stormwater outfalls and very few possibilities for constructing large communal treatment devices. A different approach to the concept design for stormwater infrastructure was required; one which relied heavily on a dispersed treatment approach with a multitude of small treatment devices located across the catchment.

The concept design for the dispersed treatment device solution relied on existing guidance (CCC 2005) but also required significant effort in selecting appropriate devices (Couling 2014), establishing appropriate design criteria for them (Christensen (2014), Stone (2014), Parsons (2014)), considering specimen designs at an individual sites, across sub-catchments and the application of the site specific specimen designs across the whole catchment to provide the 'catchment wide picture'. This paper focuses solely on part of the method used to inform options for the catchment wide picture using data models within a Geographic Information System (GIS) platform.

The Avon SMP Blueprint Concept design provides realistic and robust solutions so that the community can have confidence in the proposed benefits and costs. The robustness of the design will be tested in the resource consent process where the costs of the proposed scheme are likely to be scrutinised. Council also required a design method which was both auditable and flexible so that it could easily be modified for changes in the other design elements (i.e. the specimen designs).

3 THE CHALLENGE

As described above the Avon SMP presented new challenges with the nature of the catchment, resulting in mitigation options which significantly varied from previous SMP blueprint documents (Section 2). The density of existing development, with high utilisation of existing open spaces and tight engineering constraints limited the scope for large devices. High environmental protection aspirations (CCC 2009), in conjunction with this, meant a new approach was required. The resulting design approach had to focus on the existing stormwater infrastructure, and identifying locations for retrofit of many, small, stormwater quality devices, i.e. a dispersed treatment system.

The specimen designs considered a number of case studies for the implementation of a dispersed treatment solution but a number of questions arose:

- How do you take a specimen designs and 'roll it out' over a large catchment?

- How much of the catchment could realistically be treated in this manner and how much would they cost?
- What does the retrofit picture look like?

These questions condensed into a goal to establish a concept for potential retrofit locations for various stormwater treatment devices. The objectives required to meet this goal were to:

1. Determine potential stormwater treatment device retrofit locations (Rain Gardens and Proprietary Filtration Devices);
2. Establish approximate catchment areas, device sizes and rough order cost estimates; and
3. Inform potential spatial combinations of treatment types to derive 'mitigation scenarios' for testing within a Contaminant Load Model.

An overarching aim was to enable the community and decision makers to engage with the proposed solution through clear representations of the scale and breadth of the proposal.

4 SOLUTION

A solution was identified to meet the goal which involved utilisation of the existing GIS data and current GIS tools to 'roll out' engineering design concepts in the form of data models. These data models would attempt to replicate the specimen design across the whole catchment which to inform the identification of a mix of potential treatment mitigation scenarios.

The same approach was then extended to develop cost estimates based upon the findings of the specimen design for each proposed treatment device. Two treatment devices were considered within the 6 values context of the Waterways, Wetlands and Drainage Guide (CCC 2003).

The GIS approach provides a clear audit trail, replicable results, adaptation to changing design and policy criteria and also provides an excellent tool for displaying results.

5 METHODOLOGY

The methodology was delivered in stages:

1. Start up and data collection: project briefing, planning and sourcing up to date GIS data from a range of sources.
2. Model development: building the data model (GIS) from a range of input data, criteria, design constraints and calculations. Development of cost estimates for each retrofit location.
3. Model validation: comparison of the model results of device locations and contributing catchments against the specimen designs done for Shirley and Addington.

4. Reporting: drafting, review and finalisation of a report.

The output from the study informed the development of potential combined treatment scenarios. These are spatial combinations of a range of treatment methods and devices into potential catchment wide mitigation scenarios. The following stage also considered development of total cost estimates for the scenarios, calculation of treated and untreated areas and the 'big picture'.

5.1 DATA COLLECTION

Georeferenced data was required to inform the identification of retrofit locations. As with any concept design a wide range in data is required. In particular information such as; stormwater network and road network data / geometry, parcel boundaries, surface elevation, groundwater depths and land use. The majority of the data was available within existing Council GIS datasets but some additional data was required from other custodians, such as; LINZ and ECan.

5.2 MODEL DEVELOPMENT

The model builder feature of ArcGIS 10.0 was used to apply the design rules to the existing datasets. This involved development of a series of inter-related models to:

1. Establish potential retrofit sites based upon design parameters and constraints;
2. Establish the catchment areas draining to the sites (allowing for bubble up sumps);
3. Calculate the dimensions of the devices based upon the contributing area; and
4. Derive cost estimates for each site.

5.2.1 POTENTIAL RETROFIT SITES

Potential retrofit sites were identified from existing stormwater network feature datasets. Rain Gardens were based upon stormwater inlets and filtration devices were based upon stormwater outlets. These full datasets were then narrowed down based upon design constraints and device specific rules.

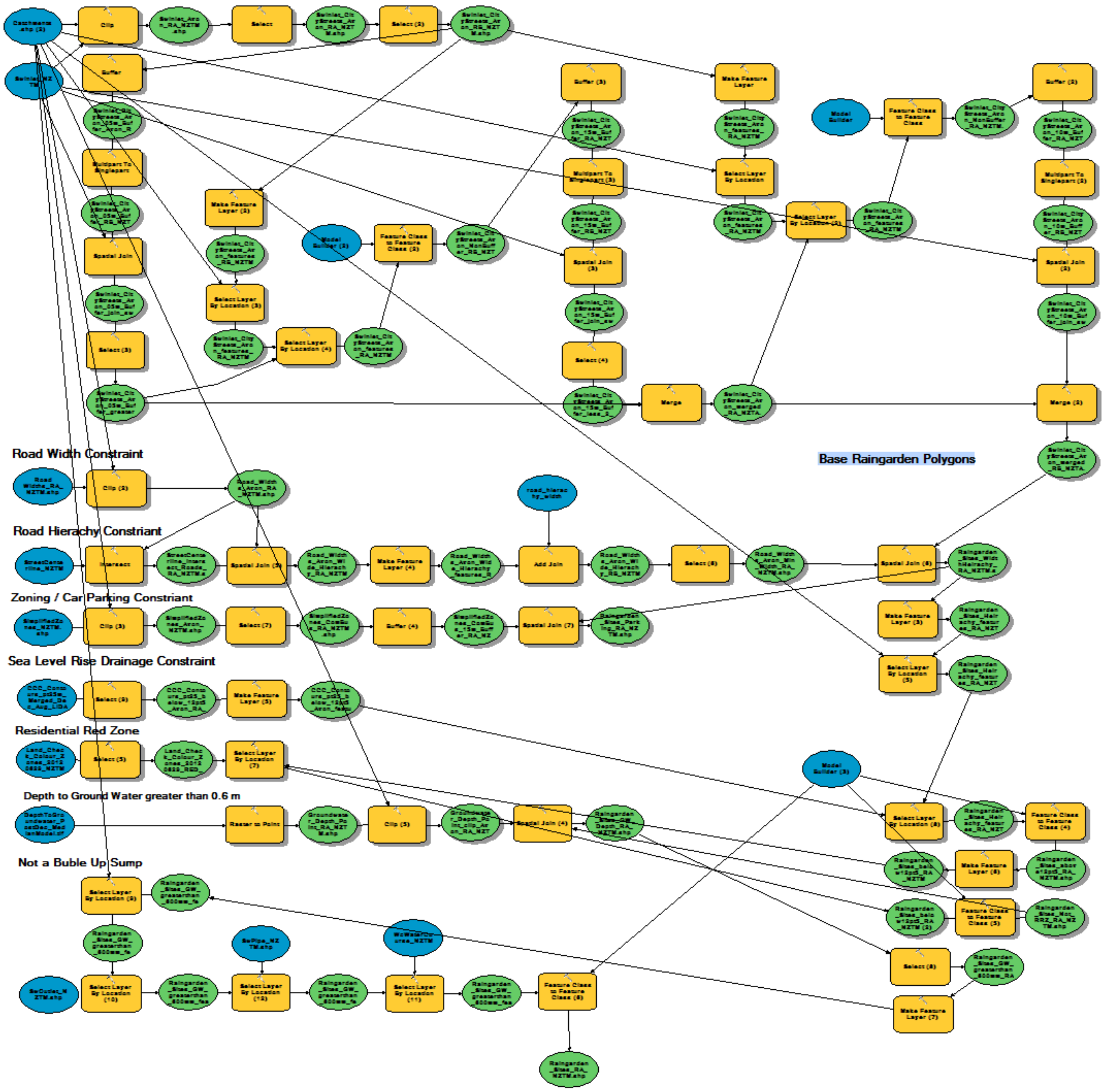
A number of constraints limited the placement of all types of stormwater treatment devices, such as; location within the road reserve or adjacent to a waterway (e.g. not within schools, parks or heritage sites), ground levels must be greater than 11.85m RL (to account for future sea level rise and the impacts on the stormwater drainage network) and median groundwater depths must be greater than 0.6m (Thomas 2013) were applied. Areas outside of the constraints were considered for potential retrofit locations through the application of device specific rules. These rules were based upon the thinking applied when developing the specimen designs, i.e. the data model attempted to replicate, at least in part, a traditional design approach. For example; rules were used to identify relevant assets within the datasets, test proximity to other features, consider topography and network geometry. The design rules applied for the identification of Rain Garden sites included:

- Established in service sumps, owned by Council and suitable inlet types;
- Merged close proximity sumps located on the same side of the same street;
- Established if there were sufficient width in the road reserve to site a device depending on the hierarchy of the road; and

- Were based upon a bubble up sump feature.

Figure 1 shows the graphical representation of the data model developed for the Rain Garden retrofit site locator, where blue oblongs represent input data, orange squares represent actions or processes and green oblongs represent output.

Figure 1: Rain garden retrofit site model build process diagram



The design rules applied for the identification of filtration device sites included:

- Outlets with a connected pipe greater than 600 mm in diameter; to target larger catchments;
- Outlet within 30 m of a waterway; to identify pipes discharging to the receiving waterway and not an internal network connection;

- Re-routing of the network for pipes along one bank of a watercourse for pipe delivering equivalent flow as a 600 mm pipe and within approximately 30 m of each other; and

- Outlets not connected to arch culverts.

For the filtration devices some manual correction (typically, removal of devices working in series) was required at the end of the automated processing to produce a realistic result.

5.2.2 CATCHMENT AREAS

In order to calculate the size of the treatment devices the contributing catchment areas needed to be established. Typically the catchment for a small treatment device, such as a Rain Garden, in a smaller event (i.e. up to the water quality storm (Christensen 2014)) is controlled by road and curb geometry, roof connections and general topography. Utilising a tool based upon the terrain would require a very detailed resolution of the terrain to represent fine features, (e.g. road curbs), with consequential computational effort. In order to avoid this, a data model was developed (Figure 2). This model utilised the road boundaries, sump locations, parcel boundaries, and a coarse topographic model (based on LiDAR data) as base data. A series of catchment delineation rules were applied, but in principle involved:

1. Dividing the road into very small segments;

2. Associating the small segments with the closest, lower sump;

3. Associating parcels with the closest road; and finally

4. Merging all segments and parcels draining to common sumps.

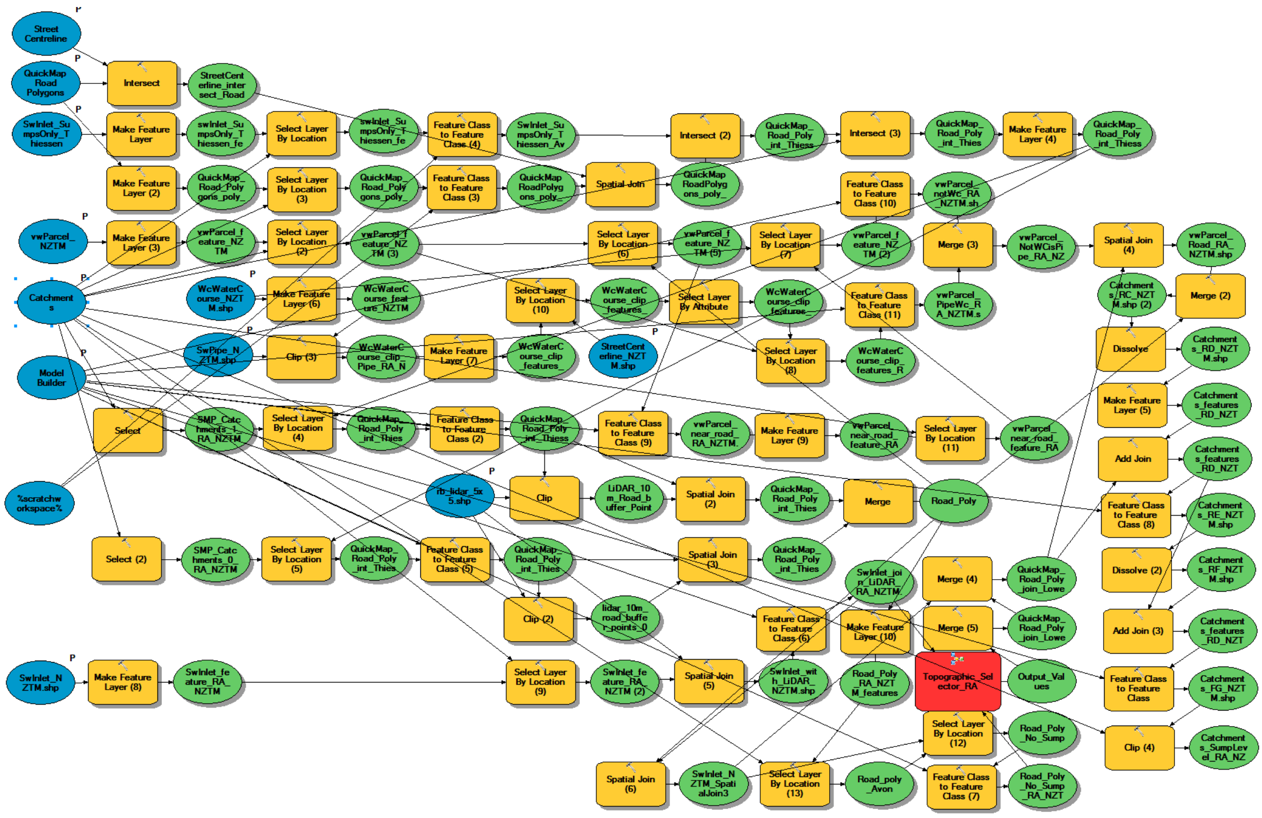
Other rules included testing:

- Parcel proximity to a waterway; to identify parcels which may drain directly to a watercourse or open channel, but not piped waterways;

- Sump function; identifying bubble up sumps which will drain to other network sumps; and

- Sump status; identifying sumps in service.

Figure 2: Catchment delineation data model process diagram



The catchment delineation relied on a number of key assumptions:

1. Houses/parcels connect to the closest road; this may be inaccurate as topography and stormwater connections will dictate the actual discharge location;

2. Thiessian polygons have been used as one of the ways to divide the road segments. This infers a proximity based relationship independent of topography. In reality topography will dictate and catchments may be inaccurate;

3. Sumps within the divided road segments drain the segment, with similar consequences to item 2 above; and

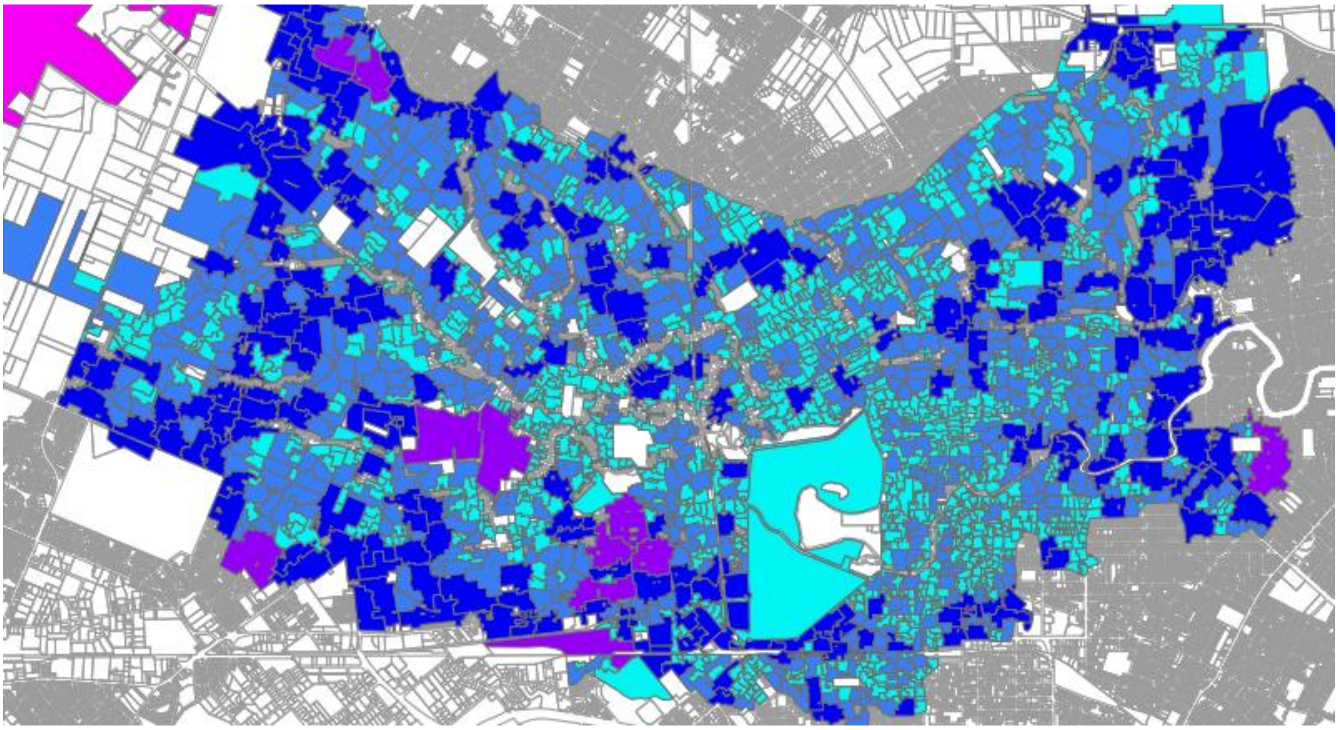
4. If there is no sump within a road segment then topography is considered in a simplified form, i.e. the closest sump which is lower than the level set by equation (1). The 250 mm allowance included in equation (1) is for the averaging effects of the LiDAR grid development (i.e. curb height and road cross fall).

   (The maximum level within the road segment + the minimum level within the road segment) / 2 + 250 mm (1)

5.2.3 DEVICE DIMENSIONING AND COST ESTIMATION

Utilising the contributing catchment characteristics for each device location permitted the estimation of the device size and also the presentation of the treatment coverage. The sizing of the device relied upon the design guidance and cost curves prepared by Christensen (2014). Effectively the data model was used as a spreadsheet to calculate the foot print and consequential cost of each device. The contributing catchments could then be mapped by size of the device (Figure 3), where lighter colours are smaller devices.

Figure 3: Rain Garden catchment with device footprint



5.3 MODEL VALIDATION

The results of the analysis were compared against a number of sites throughout the city, including, Grahams Road and the Shirley and Antigua Catchment specimen designs (that were undertaken to inform the Avon SMP Blueprint). There were some differences in catchment boundary, size and device location at the individual treatment device level, overall however, there was a reasonable correlation between the two methods (Figure 4).

Figure 4: Grahams Road Design Validation

6 RESULTS

Figure 5 shows the results of the data model for Rain Gardens which identified approximately 5,000 potential retrofit sites across the catchment.

Figure 5: Potential Rain Garden retrofit locations

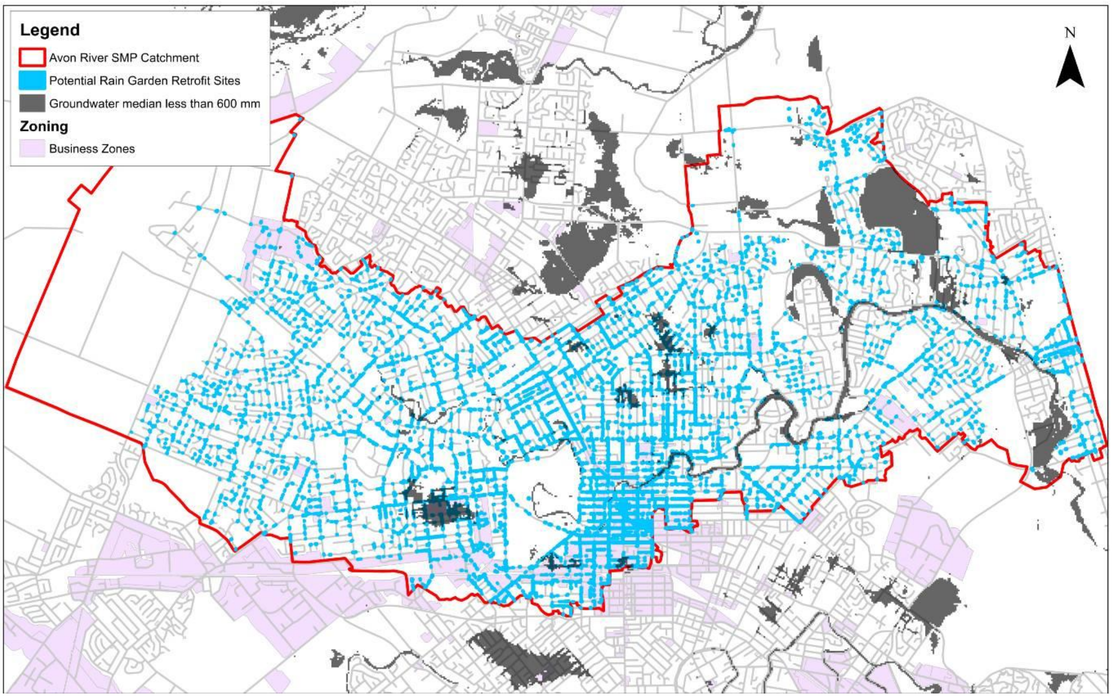
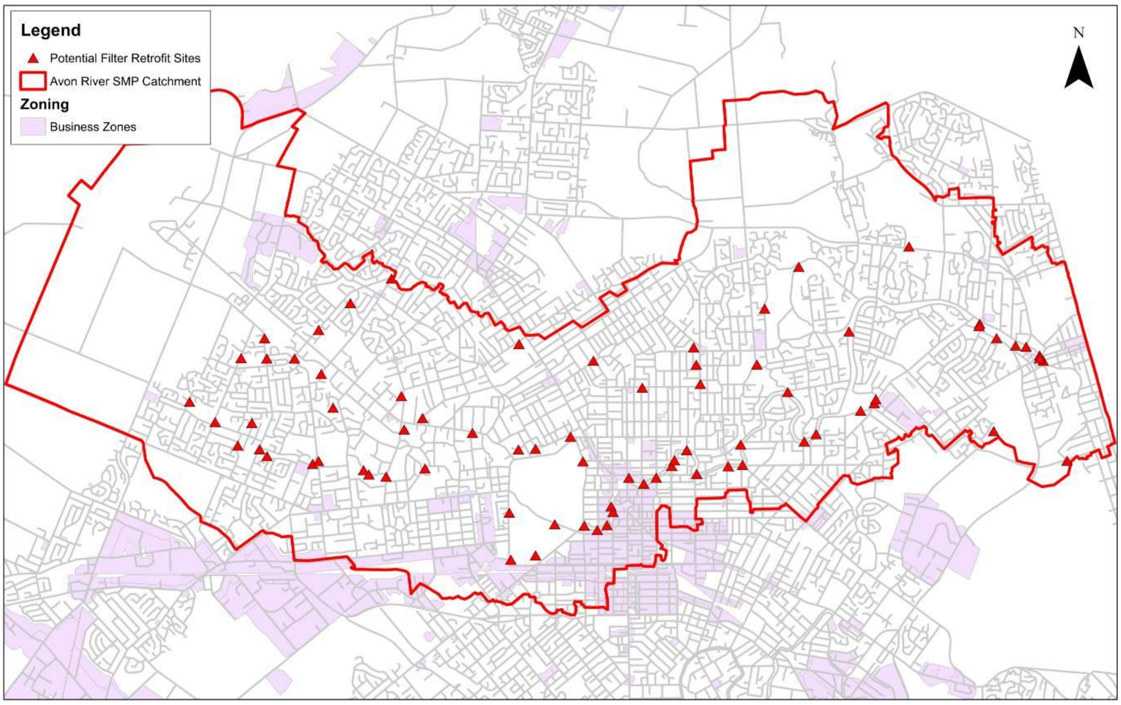


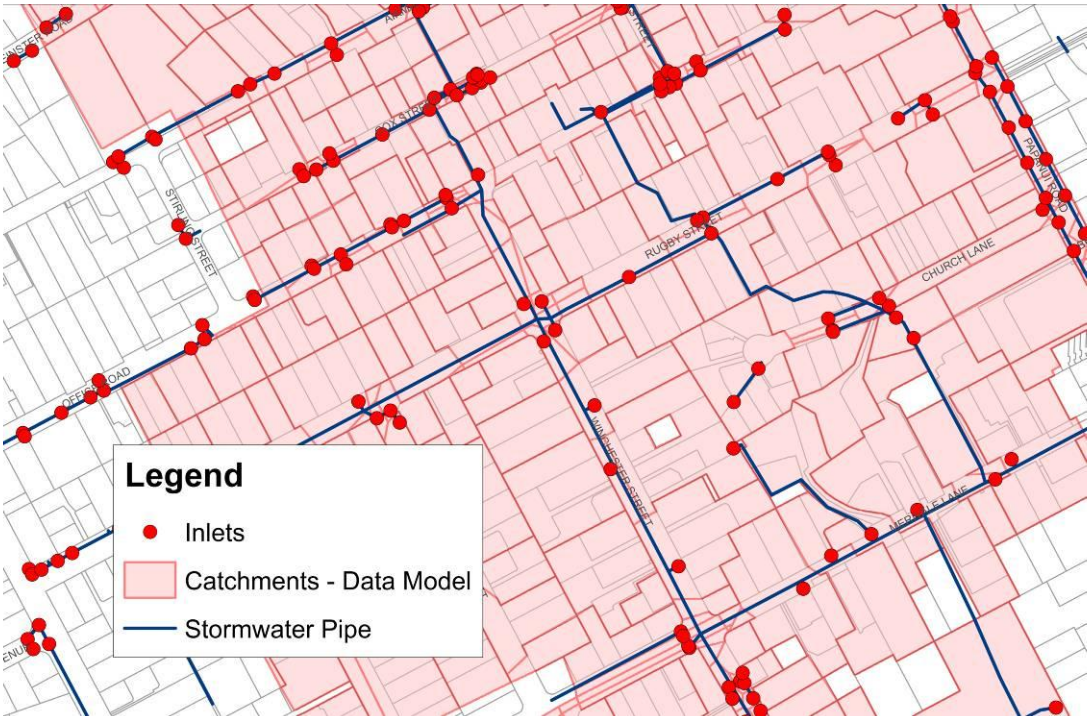
Figure 6 presents a similar figure for the 78 potential filtration device locations identified.

Figure 6: Potential filtration device retrofit locations



The catchment delineation model produced a large number of small catchments (Figure 7) which were suitable for approximate sizing of devices and the identification of treated areas.

Figure 7: Catchment Generation



7 DISCUSSION

7.1 MEETING THE GOAL

The goal to establish potential locations for retrofit stormwater treatment devices at a concept level was achieved through meeting the project objectives (Section 3). Locations were identified for both Rain Gardens and Filtration Devices and these were validated against other design processes. The proposed locations could be used to develop catchment wide mitigation strategies.

The delivery of the project relied on a mix of engineering and GIS skills. The project goal could not have been achieved without; an understanding of the data (and its limitations), knowledge of the capability of GIS, knowledge of the full design process and what a realistic outcome could be. A considerable amount of 'trial and error' was required in development of the models as not all the parameters within the traditional design process could be automated and other techniques were required. The trial and error highlighted the benefits of the approach as initial design parameters could be altered, and the models re-run without the need to repeat intermediate processing steps manually.

In application, the design parameter selection requires careful consideration, with testing of appropriateness and effectiveness, i.e. constantly asking the question: does this analysis approach produce realistic locations? The practicality of individual retrofit site selections accumulates to the practicality of the whole concept design. The practicality of the overall concept design was a key driver. What is proposed has to be achievable or else the SMP could potentially fail, with time, through either the establishment of overly restrictive consent conditions (as a result of an optimistic evaluation of potential retrofit sites) or by limiting the potential benefits of the receiving waterway (as a result of a pessimistic evaluation of potential retrofit sites or an overestimate in costs).

7.1.1 ACCURACY

The model validation did provide some certainty in the derivation of the sites and the overall cost estimates. The estimates for each individual site were not considered accurate given the dependence on the catchment area as the primary factor for device sizing (which were generated with only partial consideration of topography). However, the overall cost estimates were in the same magnitude as preliminary estimates undertaken by the design team.

The models are also reliant on the input data accuracy. If the built network is not accurately represented by the GIS datasets; either through inclusions or exclusions (e.g. new infrastructure being built and not included or old infrastructure being abandoned or unsurveyed), then the accuracy of estimates of treatment coverage could be affected. For example, if a length of existing pipework was not in the GIS data then a portion of the catchment could drain to a river without passing though a treatment device and the number of treatment devices could be underestimated.

Sampling of the accuracy of the base data sets was not undertaken during the project. However, the method does permit 're-running' of the models as new data emerges, if required.

7.1.2 ADVANTAGES

There are significant benefits with the approach, including:

- The data model provides an audit trail, repeatability and consistency. A traditional design approach relies on the individual designer and their interpretation of the data provided. This approach clearly identifies the process for which sites were selected, rightly or wrongly, and allows third parties to see how the output was derived.

- The development of the retrofit site location data models could occur in parallel with the specimen design work, so that if the specimen design changed then the big picture could respond without significant rework.

- The facilitation of sensitivity testing. Given that the based design rules could be altered and models re-run the designers could gain an appreciation of how their rules affected costs or treated areas.

- Future flexibility. The models developed for the Avon could easily be modified for other catchments with similar datasets or as more up to date datasets are supplied/derived.

These benefits were obtained in applying this method, which took a similar quantum of effort to deliver as estimates for the traditional design approach.

A very similar approach could be used for any number of applications where GIS data is available.

7.1.3 DISADVANTAGES

There are disadvantages with utilising a data model approach, including:

- More specific skill sets are required to develop the data models. The models require a reasonable level of GIS competence in parallel with engineering knowledge. This makes the approach less accessible to engineers, and harder to review (i.e. both the model and the output require review, potentially by different people).
- The models need accurate and extensive electronic spatial data (not just hardcopy plans). The models require greater complexity as the reliability of the data decreases. More 'data cleaning' steps are required in poor data, which is both time consuming and adds risk of model failure.
- The initial startup time is longer. A detailed understanding of the data is required to develop a model, and in conjunction with any data cleaning leads to longer periods before first delivery of output. Also, the progress in producing the output is harder to track than a traditional design as the design does not progress geographically.

8 NEXT STEPS

The potential retrofit locations will be used to establish catchment wide treatment solutions based upon a spatial mix of devices. Retrofit locations included in these catchment wide options will then be prioritised and programmed so that more detailed cost estimation can occur.

At the next stage of design the feasibility of each site will be considered with consideration given to services. The specimen design work (Christensen 2014) found that services tended to add complexity and cost to the design but did not exclude them completely. Services were not tested in the methodology due to the complexity in the analysis.

9 CONCLUSIONS

Software and hardware tools are now widely available which can be used to analyse large spatial datasets with (relative) ease. The software tools are both powerful and flexible and are only constrained by the imagination of the designer and operator. These tools permitted the identification of potential retrofit sites for a distributed treatment scheme within a large catchment. However, these tools could be used for any number of purposes.

GIS data is typically available in urban areas for topography and infrastructure so the approach outlined in this paper could readily be adapted to other cities.

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