IMPACTS ON STORMWATER MANAGEMENT ARISING FROM SUBDIVISION MODIFICATIONS DURING DEVELOPMENT

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ABSTRACT

The red-zoning of significant portions of eastern Christchurch as a result of the Canterbury earthquakes has seen the proliferation of new subdivision developments on greenfield sites around Christchurch and other satellite towns in the Canterbury Region.

This paper will focus on the authors' recent experience during the development of a large subdivision in North Canterbury. During the planning and consenting phase of this development, an initial stormwater design which met the requirements of the subdivision was prepared and the system was later constructed. However, market demands, requirements for infrastructure improvements and the incorporation of additional development area resulted in modifications to the subdivision design well into the construction phase. These modifications have entailed changes to the initial stormwater system design and variations to the stormwater discharge consent.

The challenge was to provide an efficient stormwater system, in terms of both treatment requirements and space availability, while working within the constraints of a site where space had already been allocated for sections and internal roads.

KEYWORDS

Stormwater Management, Treatment, Consenting, Residential Development

PRESENTER PROFILE

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1 INTRODUCTION

In the wake of the Canterbury earthquakes significant portions of residential land was red-zoned, including areas around both eastern Christchurch and Kaiapoi. Consequently, there has been a rise in new subdivision developments throughout Christchurch and other satellite towns in the greater Canterbury Region. The majority of these subdivisions are being developed on 'greenfield' sites, some of which have required privately initiated Plan Changes to the relevant District Plan to change the zoning of development areas from rural to residential.

1.1 SILVERSTREAM ESTATES RESIDENTIAL SUBDIVISION

Silverstream Estates (Silverstream) is a 42 hectare residential subdivision located in the Waimakariri District to the north of Christchurch, in West Kaiapoi. It was one of the first greenfield developments approved under the Canterbury Earthquake Recovery Act, with the once rural land being rezoned to Residential 7 and Business 4 in November 2011. Approval for development under this Act bypassed the need for a private Plan Change to the Waimakariri District Plan.

Although the land was approved for development, it was still necessary to obtain the relevant consents. With respect to stormwater related activities, consents were required from Environment Canterbury. The requisite resource consent application and assessment of environmental effects were prepared and consents were granted for the stormwater discharges from Stages 1 to 4 of Silverstream to the Kaiapoi River in 2012. The location of the subdivision is shown in Figure 1.

Figure 1: Location of Silverstream Residential Subdivision

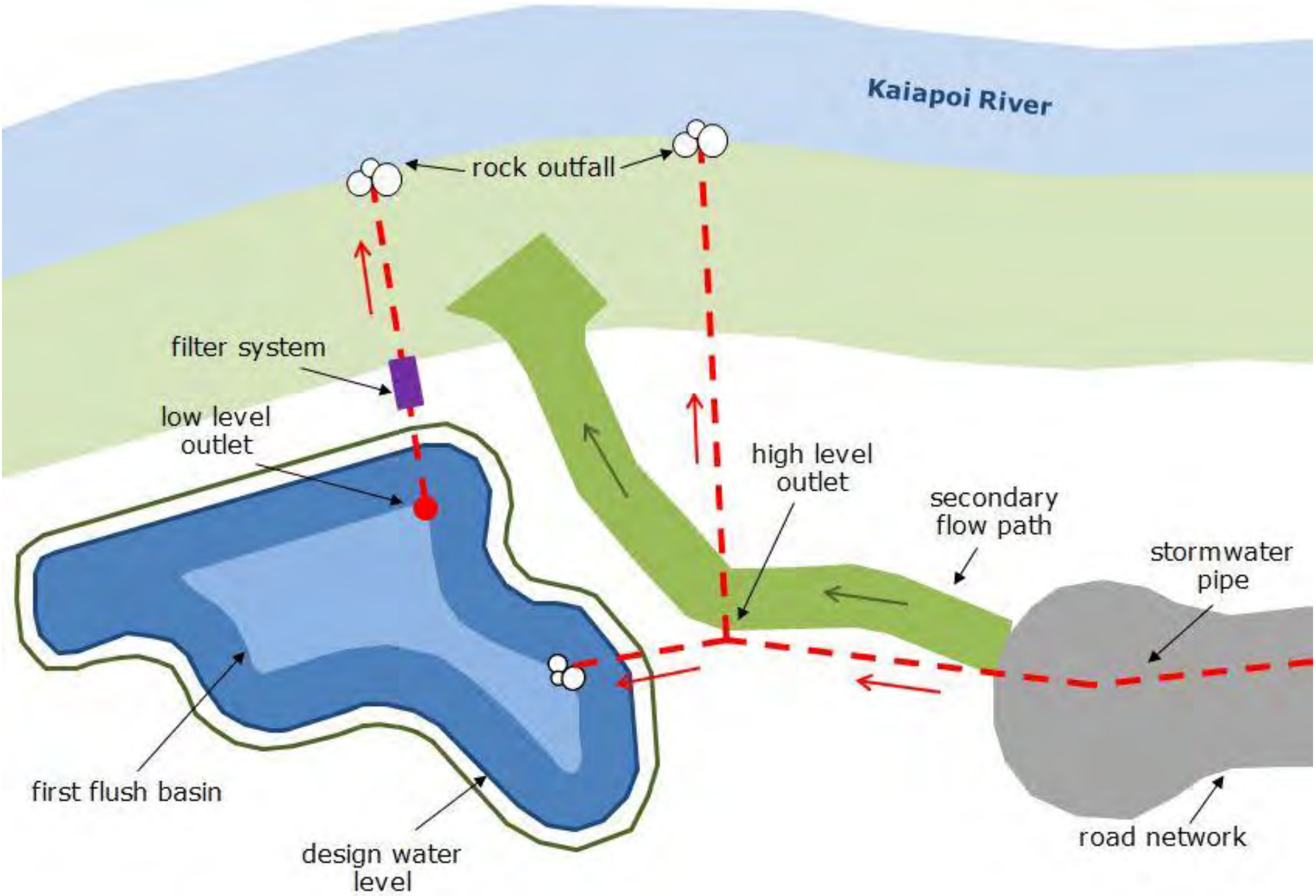
2 OVERVIEW OF INITIAL STORMWATER SYSTEM DESIGN

Each stage of the subdivision represents a separate stormwater catchment area. Runoff from roofs, roads and other hardstand areas (driveways, footpaths etc.) is directed to sumps, via kerb and channel in the roading system, and conveyed by a piped network to a dry first flush basin. Each basin has been sized to collect, store and provide primary treatment for the runoff from the first 25 mm of rainfall over its respective catchment.

To achieve an average detention time of 24 hours in each basin, a restricted outlet, in the form of an orifice, was installed on the outlet pipe. Proprietary filter systems are utilised to provide additional treatment of the first flush volume before it discharges to the Kaiapoi River, which is spring-fed at this location. These filters have been sized to accommodate the respective maximum design outflow rate from each first flush basin.

For rainfall events where runoff exceeds the capacity of the first flush basin, excess stormwater will discharge directly to the Kaiapoi River, bypassing the filter system via a secondary pipe and outlet structure. The conceptual system design is shown in Figure 2.

Figure 2: Conceptual Stormwater System Design for Each Basin



2.1 STORMWATER QUANTITY

A hydrologic model to assess the volume and rate of stormwater runoff from the development was created using HEC-HMS (US Army Corps of Engineers, 2011). Inputs to the model included the areas for different land types (roads, commercial areas and residential areas – high, medium and low density) and the percentage of impervious cover of each.

The results of this model gave the first flush volume for each stage of the subdivision development, upon which each first flush basin was sized. Given the layout of the subdivision, the first flush basins for Stages 1 and 4 are located on the edge of the river. Runoff from Stages 2 and 3 is directed to two interlinked first flush basins located between the two stages with an outlet pipe discharging to the Kaiapoi River.

2.2 STORMWATER QUALITY

Contaminant concentrations present in stormwater runoff from the development will be typical of that from modern residential subdivision in a Canterbury environment, for which specific monitoring has been carried out in the past (Brough et al., 2012).

3 PLANNING MATTERS

The discharge of stormwater to water requires resource consent under Section 15 of the Resource Management Act 1991 (RMA). Regard must be given to the rules of the relevant regional plan when assessing the activity.

As the receiving environment for the discharge is located in the Waimakariri River catchment, the activity is covered by the Waimakariri River Regional Plan (WRRP) which has been operative since 2005. Where the proposed activity is addressed in a catchment specific plan such as the WRRP, it is the governing plan and no other regional plans apply.

The stormwater discharge was assessed against the rules in the WRRP and classified as a discretionary activity. Resource consent was therefore required from ECan and this was granted in November 2012.

4 FLOODING RISK

Being located adjacent to the Kaiapoi River, which is a tributary of the Waimakariri River, the site is subject to flood risk. The development area is an old flood plain of the Waimakariri River and has also been identified as a flood hazard in scenarios where the Ashley River breaks out of its riverbed. As such, it was necessary to assess the flooding risk for Silverstream during 2% Annual Exceedance Probability (AEP) events.

Due to the flat nature of the site and complexity of the overland flow paths, a linked 1-D/2-D TUFLOW hydraulic model was developed to estimate the flood levels on the site.

The modelling indicated that flood levels will not increase as a result of the Silverstream development. However, as the flood levels in the Kaiapoi River reach similar levels to the design water levels in each dry first flush basin, the modelling demonstrates that no discharge will occur from the basin during extreme rainfall events. This effectively provides some additional detention storage above the first flush capacity in such circumstances. Non-return valves will be included in the outlet pipes to prevent any backflow into the stormwater system in times of high water levels in the Kaiapoi River.

Flood modelling of the development included setting floor levels for the development that would reduce the flooding potential of residential properties in 2% AEP events. Minimum ground levels for the development were set above the 2% AEP flood event level with minimum floor levels set 300 mm higher or above the 0.5% AEP event – whichever gives the higher floor level. The minimum floor level requirement for the development was set through consultation with Waimakariri District Council (WDC).

This resulted in ground levels across the development being set at 4.2 – 4.5 m above mean sea level, approximately 0.8 – 0.9 m higher than the original level of the land. As such the development areas would need to be raised.

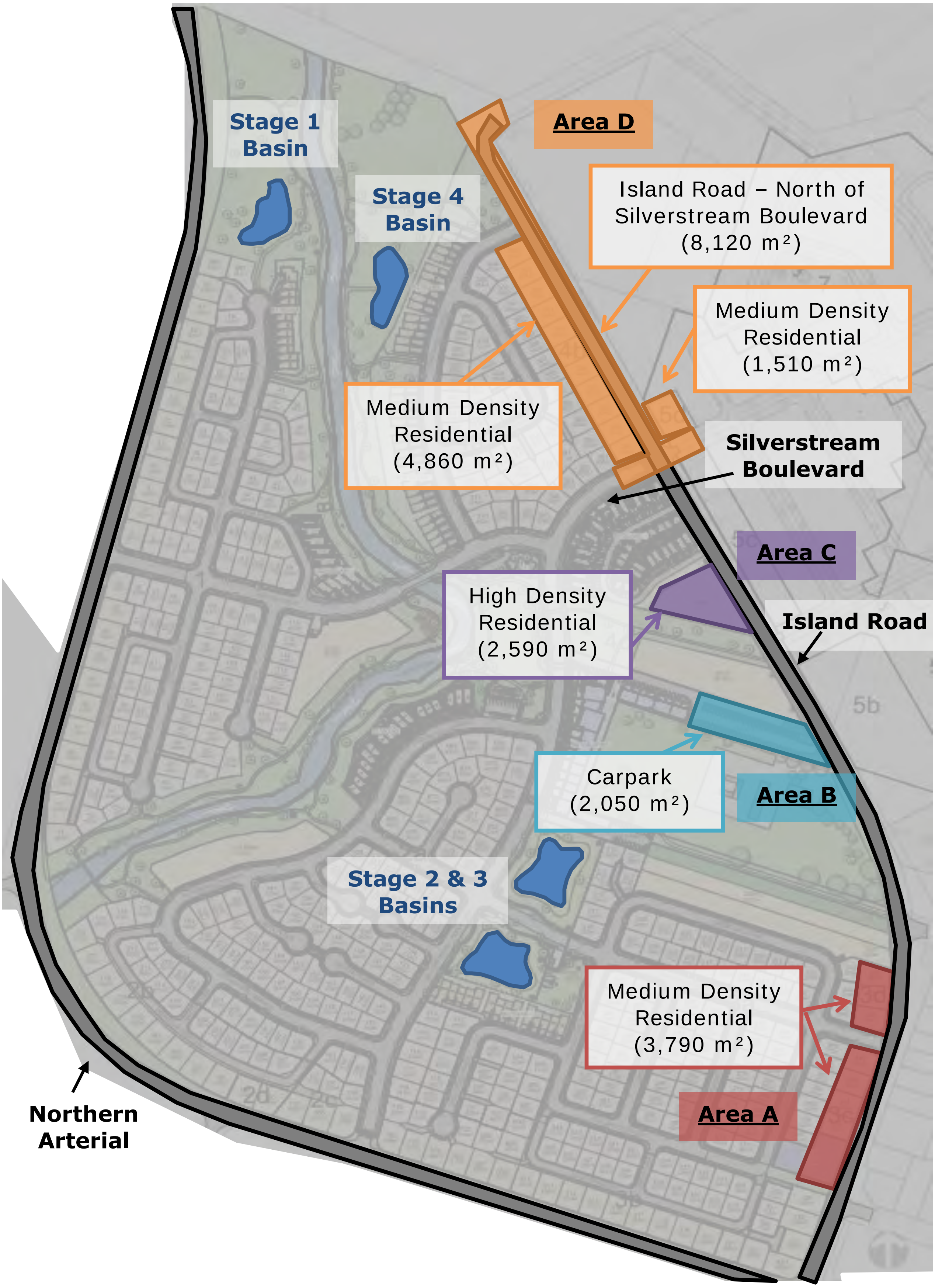
5 CHALLENGES DURING CONSTRUCTION

Construction of the Silverstream subdivision began in mid-2012, with all Stage 1-4 earthworks completed in late 2014. Several complications arose during the course of this work in mid-2014 and it was necessary to find a solution while working within the constraints of an active construction process.

Earthworks at the site predominantly involved raising the land by 0.8 – 0.9 m to meet the finished floor levels set as a result of the flood modelling. This filling of the site affected portions of the original stormwater design, which was based on the assumption that all stormwater runoff would drain via gravity towards each respective basin. Stage 1 was unaffected. After more detailed engineering work was carried out for Stages 2 to 4, it was found that not all this area could discharge to the basins and variations to the stormwater system design as outlined in Figure 3 were required.

In many cases, detailed site design is not completed prior to lodging and obtaining the stormwater discharge consent. This means that if site design changes, the stormwater design may need to be altered. Sometimes, as in this instance, this results in a variation being required to the resource consent.

Figure 3: Silverstream Stages 1-4 Showing Areas that Require Changes to Stormwater System (image courtesy of Morgan Pollard Associates)



Areas A and B

Stage 3 contains residential lots and a carpark area that border Island Road. Expected runoff from this area was included in the sizing of the Stage 2 and 3 first flush basins. Given the height difference between Island Road and the raised ground level of the subdivision, these lots and the carpark have to be sloped towards Island Road as this is the point of access. Any stormwater runoff from these areas would therefore flow via gravity to the road, and not back towards the first flush basins. The only way for stormwater runoff from these areas to reach a basin was if it were pumped there, which was not considered a viable option.

Area C

After the original stormwater consent had been granted in 2012 for Stages 1-4 of the subdivision, additional land bordering Island Road was obtained and included in the development. Originally this section consisted of one residential dwelling. To be incorporated into Stage 4 of the development, the land use would be changed to high density residential, with a series of apartment blocks envisaged for the area, increasing the percentage of impervious cover for the area and therefore the expected runoff. Stormwater runoff from this area needed to be included in the Stage 4 stormwater system.

Area D

Stage 4 also contains residential lots that border Island Road. It was not possible to grade a stormwater system to allow runoff from this area to flow via gravity to the Stage 4 first flush basin. There is also a small additional area on the eastern side of Island Road which needed to be incorporated into the design. These areas therefore required a separate stormwater treatment system to the original consented design.

Island Road is to be upgraded as part of the development, involving the installation of kerb and channel, footpaths and a new road surface. When the Northern Arterial is constructed (envisaged to be in 2016/2017), Island Road will be closed where it crosses the Kaiapoi River and, instead of being used as a thoroughfare for those travelling to North Canterbury, it will become a local road for the subdivision. Stormwater runoff from the northern portion of Island Road (north of Silverstream Boulevard, as shown in Figure 3) is therefore to be included in the stormwater system.

5.1 COUNCIL REQUIREMENTS

5.1.1 REGIONAL COUNCIL

As the original stormwater system design had been consented by ECan, any changes to the stormwater system required a variation to this consent.

5.1.2 DISTRICT COUNCIL

The existing stormwater system in Island Road is managed by WDC. Stormwater collected in Island Road (south of Silverstream Boulevard) is conveyed via a network of pipes and open drains to the Parnhams Drain pump station. From there it is discharged into the Kaiapoi River, approximately 1.5 km downstream of the last discharge from the subdivision, as shown in Figure 4. For any stormwater runoff from the subdivision being discharged into this network, the discharge requires acceptance from WDC. Acceptance from WDC is also required for the upgraded Island Road stormwater system (north of Silverstream Boulevard), as WDC is to take over the management of this system upon construction.

Figure 4: Island Road Stormwater System – WDC Network

6 OPTIONS ASSESSMENT

Changes to the original stormwater system design were required for the areas of the subdivision outlined in Figure 3. These areas accounted for 2.3 ha out of the entire 42 ha subdivision, however a variation to the stormwater discharge consent was required.

To determine the environmental effects of the proposed changes, a contaminant load assessment was carried out to evaluate different stormwater treatment scenarios for Areas A-D. The overall aim of the assessment was to provide a revised stormwater treatment concept for these areas that provided the best level of treatment possible within the space available. The assessment compared each treatment scenario to the original design, to determine any changes in the contaminant profile in the first flush volume of the overall stormwater discharge, and assess its effects on the Kaiapoi River. Only runoff from the land areas outlined in Figure 3 was taken into account, as these were the only areas of the subdivision where there was a change in either runoff volume or discharge location compared to the original consented design.

The first flush runoff volume for each land area was calculated for the original and varied scenario which, when multiplied by the expected contaminant concentrations, gave a contaminant load for each land type. The contaminant loads are then reduced by the treatment efficiencies for different treatment trains considered in order to give a final contaminant load entering the Kaiapoi River. The expected contaminant concentrations and treatment efficiencies used in the assessment are described in Sections 6.1 and 6.2, with the results of the options assessment discussed in Section 6.3.

6.1 CONTAMINANT CONCENTRATIONS

The contaminant concentrations expected to be entrained in stormwater from roofs, driveways and other hardstand areas on residential land are given in Table 1. These values are representative of new residential dwellings where the roofing material is not galvanised steel and no copper spouting is used.

The current vehicle movements along Island Road have been measured at 6,900 vehicles per day with predicted future movements at approximately 6,000 vehicles per day (Abley Transport Consultants et al., n.d.). It is expected that, as Island Road will become a local road in the near future as a result of the construction of the Northern Arterial, the number of heavy vehicles utilising Island Road will reduce. It is reasonable to expect that lighter vehicles will generate lower contaminant concentrations than heavy vehicles. However, contaminant concentrations from road runoff, as derived from monitoring data, does not differentiate between heavy and light vehicles. Therefore it is considered that the data presented in Table 1, for road runoff, probably represents conservatively high concentrations of contaminants in road runoff.

For the purpose of this assessment, the expected contaminant concentrations from the carpark area are assumed to be equivalent to those for road runoff.

Table 1: Expected Contaminant Concentrations in Residential and Road Stormwater Runoff

Contaminant	Concentration	
	Residential Runoff	Road and Carpark Runoff
Total Suspended Solids (TSS)	70 mg/L [1]	75 mg/L [2]
Copper	2.8 µg/L [2]	18 µg/L [3]
Lead	8.3 µg/L [2]	15 µg/L [4]
Zinc	80 µg/L [1]	76 µg/L [3]
Total Petroleum Hydrocarbons (TPH)	0.213 mg/L [2]	2.5 mg/L [2]
Polycyclic Aromatic Hydrocarbons (PAH)	0.085 µg/L [2]	1 µg/L [2]

Notes:

1. *(Brough et al., 2012)*
2. *(Pattle Delamore Partners Ltd, 2012a)*
3. *(Moores, 2011)*
4. *(Kennedy, 1999)*

6.2 TREATMENT EFFICIENCIES

The expected treatment efficiencies from different stormwater systems used in this assessment are given in Table 2.

Table 2: Expected Contaminant Removal Efficiencies for Given Stormwater Treatment Systems

Contaminant	Average Removal Efficiency (%)				
	Swale [1]	Dry Basin [1]	Wet Basin [1]	Wetland [1]	Filter System [2]
Total Suspended Solids (TSS)	40	60	70	70	70
Copper	40	40	60	60	45
Lead	40	60	70	70	67.5
Zinc	40	50	65	65	55

Notes:

1. *(CCC, 2003)*
2. *(Pattle Delamore Partners Ltd, 2012a)*

For this assessment, it was assumed that TPH and PAH have the same treatment efficiency as TSS given that the majority of hydrocarbons readily bind to sediment.

Treatment efficiencies also assumed the following particulate and dissolved states of heavy metals (Brough et al., 2012):

- Copper: 50% particulate; 50% dissolved
- Lead: 95% particulate; 5% dissolved
- Zinc: 70% particulate; 30% dissolved.

The primary form of treatment provided by swales and basins, both dry and wet, is the settling of sediments. The treatment efficiency varies depending on influent concentrations, the nature of the sediment and design parameters such as residence time. Swales are perhaps the least effective in terms of treatment but provide conveyance. Both dry and wet basins provide temporary stormwater detention and add landscape and recreational value to a community. Wet basins are generally more efficient at stormwater treatment as the permanent body of water provides a longer residence time for the settling of finer particles.

For a wetland, treatment of stormwater comes in the form of settling, filtration and the removal of dissolved contaminants through biological uptake from the wetland plants. Wetlands are among the most effective when it comes to treating stormwater runoff. They also add aesthetic value however, they require a significant footprint compared to other treatment devices.

The main form of treatment for a proprietary filter system is physical filtration, although some sorption onto the media does occur. Filter systems are generally compact and located underground.

Each stormwater treatment device has their advantages and disadvantages depending on site specific factors and what the ultimate goal of the stormwater system is.

6.3 OPTIONS CONSIDERED

A range of stormwater treatment devices, and treatment trains, were considered to add to the existing stormwater system to treat runoff from the different land areas highlighted in Figure 3. The aim was to improve or maintain the overall contaminant load entering the Kaiapoi River as a result of the variation to the stormwater system design.

Feasibility and space availability were two major factors in determining what option would be chosen to essentially retrofit the existing design. Much of the construction works, in terms of setting out lots and completing the roading and underground services, was already complete. This placed certain constraints on what options could be chosen, as the contouring of the subdivision had been completed and stormwater generally relies on gravity flow. Furthermore, the upgrade of Island Road was waiting on the variation being accepted by ECan so work could get underway, adding time pressure.

Area A

Runoff from the medium density residential area in Stage 3, which borders Island Road, was originally planned to be treated via the dry pond and filter system. However, these lots had to be sloped towards Island Road and therefore would drain that way, eventually discharging into the Kaiapoi River via the Parnhams Drain pump station. A swale was considered to provide some treatment before runoff entered the WDC system, however there was no space for a swale in the road reserve design plans. A filter system was also considered as this could be located under the road reserve, however this filter system would then also be treating road runoff from Island Road, and this was not practical. Ultimately, the only option was to discharge this runoff untreated into the WDC network. It was considered that the treatment of the northern section of Island Road now included in the development would compensate for this untreated runoff.

Area B

Runoff from the carpark area bordering Island Road, which is to serve a light commercial area, was originally planned to contribute to the Stage 2 and 3 basins and therefore be treated by a dry basin and filter system. However, due to the grade of this area runoff can now only flow to Island Road (south of Silverstream Boulevard) and enter the WDC stormwater network that discharges to Parnhams Drain pump station. There is space in the reserve for a short swale; however this option does not provide sufficient treatment, given the high contaminant load expected from this land use type. There is no space available for a basin or any other additional treatment device. A proprietary filter system, on the other hand, provides sufficient treatment and is located underground; therefore space availability is not a constraint. This was the chosen option for the carpark catchment. It has a slightly increased contaminant load (the original load being 40-60% of the new load) due to the removal of the dry pond from the treatment train. In accordance with WDC requirements, the filter system was sized to treat 95% of all rainfall falling on the catchment and had to be approved for removing more than 75% of TSS (in accordance with Auckland Regional Council's TP10). Submerged sumps in the carpark will not only trap floatable pollutants, specifically hydrocarbons, but also provide a level of containment in the event of a spill of fuel or other contaminant in the carpark area.

Area C

The additional area now included in the development originally consisted of low density residential land. To fit into the development plans, it is to be converted to high density residential land. This will increase the first flush volume significantly due to the increase in impervious area and therefore increase the contaminant load. However, under the original scenario, this area was discharged untreated to the WDC stormwater network in Island Road. This area can be directed into the Stage 4 first flush basin, so treatment will be provided in the dry basin and filter system. The contaminant load for the new scenario ranged from 20-50% of the original load that would enter the river in every first flush volume. The Stage 4 basin has the capacity to accept this runoff volume as it is less than the volume from the medium residential lots bordering Island Road which are no longer contributing to this catchment.

Area D

After analysis of the lay of the land, it was decided that Island Road north of Silverstream Boulevard, the Stage 4 medium density residential land bordering Island Road to the west, and the medium density residential land on the eastern border of Island Road would be treated as one catchment. In the original scenario, Island Road runoff was discharged untreated, and the residential areas were to be treated in first flush basin followed by a filter system, providing a high level of treatment.

Options considered for this catchment consisted of a swale, a swale and a dry pond, and a swale, dry pond and wetland treatment train. The option including the wetland provided the highest level of treatment for this catchment, with the resulting contaminant load ranging from 5-14% of the original load entering the Kaiapoi River from this catchment for the first flush volume. Although the best option in terms of treatment, it required the most space. As the lots for Stage 4 had already been set out, and there was already a first flush basin in the reserve area, space was limited, and it was this major constraint that ruled out the use of a dry pond and a wetland. A swale on its own resulted in a contaminant load 50-60% of the original load, but was considered the best option in terms of space availability and feasibility. Having the swale discharge to a soakpit, where stormwater would infiltrate through the soil and be diluted by groundwater, before entering the river through seepage was considered to reduce the contaminant load further. Once soakage tests were carried out, however, it was clear that this would not be practical due to a poor infiltration rate of in-situ gravels.

Ultimately it was decided that runoff in this catchment would be collected in the kerb and channel of the upgraded Island Road, conveyed along a swale following the western edge of the road and discharged directly into the Kaiapoi River. The swale is primarily a treatment swale, which was designed according to the requirements of Auckland Regional Council's TP10 to achieve a minimum residence time of 9 minutes (ARC, 2003). A rock headwall and back flow preventer was included on the entry point to the treatment swale. Given the distance to the river, the swale actually has a length double what is required to meet the 9 minute residence time. This extra length is essentially proving additional treatment, although this value was not quantified in the assessment.

6.4 OUTCOME OF OPTIONS ASSESSMENT

The first flush runoff volume for each land area was calculated for the two scenarios, which when multiplied by the expected contaminant concentrations gave a contaminant load for each land type. The contaminant loads are then reduced by the treatment efficiencies for the relevant treatment train, and divided by the total first flush volume to give the final contaminant concentration entering the Kaiapoi River.

Table 3 gives the expected contaminant concentrations entering the Kaiapoi River in every first flush volume of stormwater runoff based on the parameters and changes described in Section 6.0.

Table 3: Contaminant Load Entering Kaiapoi River from Stormwater

Contaminant	Contaminant Concentrations in First Flush Runoff (mg/L)	
	Original Design	**Variation**
Total Suspended Solids (TSS)	35	40
Copper	0.007	0.005
Lead	0.006	0.006
Zinc	0.04	0.05
Total Petroleum Hydrocarbons (TPH)	0.81	0.60
Polycyclic Aromatic Hydrocarbons (PAH)	0.0003	0.0002

The main potential effect of the variation to the stormwater system design is the difference in surface water quality of the Kaiapoi River. The variation aimed to compensate for a level of reduced treatment or no treatment for several residential areas that could not physically drain to the first flush basins by instead treating runoff from a large section of Island Road that originally discharged to the Kaiapoi River untreated.

Overall, the contaminant load for the varied stormwater system design resulted in a slightly higher increase in total suspended solids and zinc entering the Kaiapoi River than in the original scenario. However, these increases are minimal and taking into account dilution and mixing of the discharge once it enters the river, the potential adverse effects on water quality were deemed no more than minor by ECan. Approval for this varied system was also given by WDC, who would take over the maintenance upon completion of construction.

7 LESSONS LEARNT

Although flood modelling was carried out prior to the consenting of the original stormwater system and it was clear that the site needed to be raised, final ground levels for each stage were set during negotiations with WDC during the building consent process. It was the setting of these final ground levels that resulted in the requirement for variations to the stormwater system for portions of the development area. It should be noted that, for the majority of the site, the original stormwater system design was retained.

Ideally, final ground levels should be set prior to the final design and consenting of the stormwater system as typically conveyance of stormwater runoff relies on gravity flow. Generally, each stage in a subdivision is its own stormwater catchment area as each stage is developed at different times. However, consideration should be given to fact that one stage may require two or more separate stormwater systems depending on the grade of the land.

Feasibility and space availability were the two major constraints during the retrofit of the stormwater system at Silverstream. More emphasis should be placed on stormwater in new developments. Although the size of some treatment devices may compromise the number of lots available, and initial cost may be high, the aesthetic value of certain stormwater management areas, when included in the landscape planning of a development, should be given more consideration. Dry basins can double as reserve areas, while wet ponds and wetlands attract wildlife and a connection with nature, and both contribute to the recreational value of a subdivision. Swales require additional area within the road reserve; however they not only provide conveyance but also primary treatment of stormwater, as well as aesthetic value, as opposed to a piped network hidden underground.

8 CONCLUSIONS

It is not uncommon for issues to arise during construction of large residential developments. It can be difficult, however, to retrofit stormwater systems as many treatment devices require significant space – something generally quite limited in new subdivisions. Although possible, it can lead to compromises on the quality of treatment provided by the stormwater system, leading to additional adverse effects on the receiving environment. Taking an integrated planning approach during the initial phase of the development, which puts an emphasis of stormwater management as an essential component, could help to resolve potential problems during construction.

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