HAYWARDS INTERCHANGE – INNOVATIVE DRAINAGE DESIGN TO OVERCOME SITE CHALLENGES

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ABSTRACT

The SH2/SH58 Haywards Interchange Project, commissioned by NZTA, is part of the wider Hutt Corridor project for improving safety, reliability and efficiency for SH2 and SH58 users. The project has created a new grade-separated interchange for SH2 and SH58.

Dry Creek is a tributary of the Hutt River with a catchment area of approximately 92 hectares. The creek passes through a series of culverts beneath the existing SH2 and SH58, local roads, and railway line.

The revised road layout required modifications to the Dry Creek system including extension of the culvert beneath the realigned SH58 and new culverts beneath ramps for SH2. The scope of the project did not include for upgrading of the downstream network. This, and other restrictions at the site of the interchange, constrain the capacity of the Dry Creek system at the site of the interchange.

This paper explores the challenges of designing sections of the Dry Creek drainage within tight physical and hydraulic constraints, as well as providing a fish passage and ecological improvements. The challenges presented an opportunity for innovative design solutions. Features of the innovative design solution include:

- Designing for current downstream constraints as well as for future upgrade scenarios
- Providing fish baffles within new culverts and accounting for the impact of the baffles on pipe capacity. Integrating fish resting areas and adapting energy dissipation solutions for fish passage
- Providing in-pipe energy dissipation because of limited space available for conventional dissipation measures, and
- Managing hydraulic constraints within low headloss bellmouth type outlets in manholes and provision of inline flow retention to ease the flow into the downstream stormwater system.

Constructability and operational health and safety were key factors in the design and implementation of the project.

KEYWORDS

Existing Constraints, Future Ready, Hydraulics, Fish Passage, Drainage

1 INTRODUCTION

1.1 PROJECT DESCRIPTION

Downer was commissioned in 2015 by NZ Transport Agency (NZTA) to undertake the detailed design and construction of the SH2 and SH58 grade separated interchange, commonly known as Haywards Interchange, the location of which is shown in Figure 1.

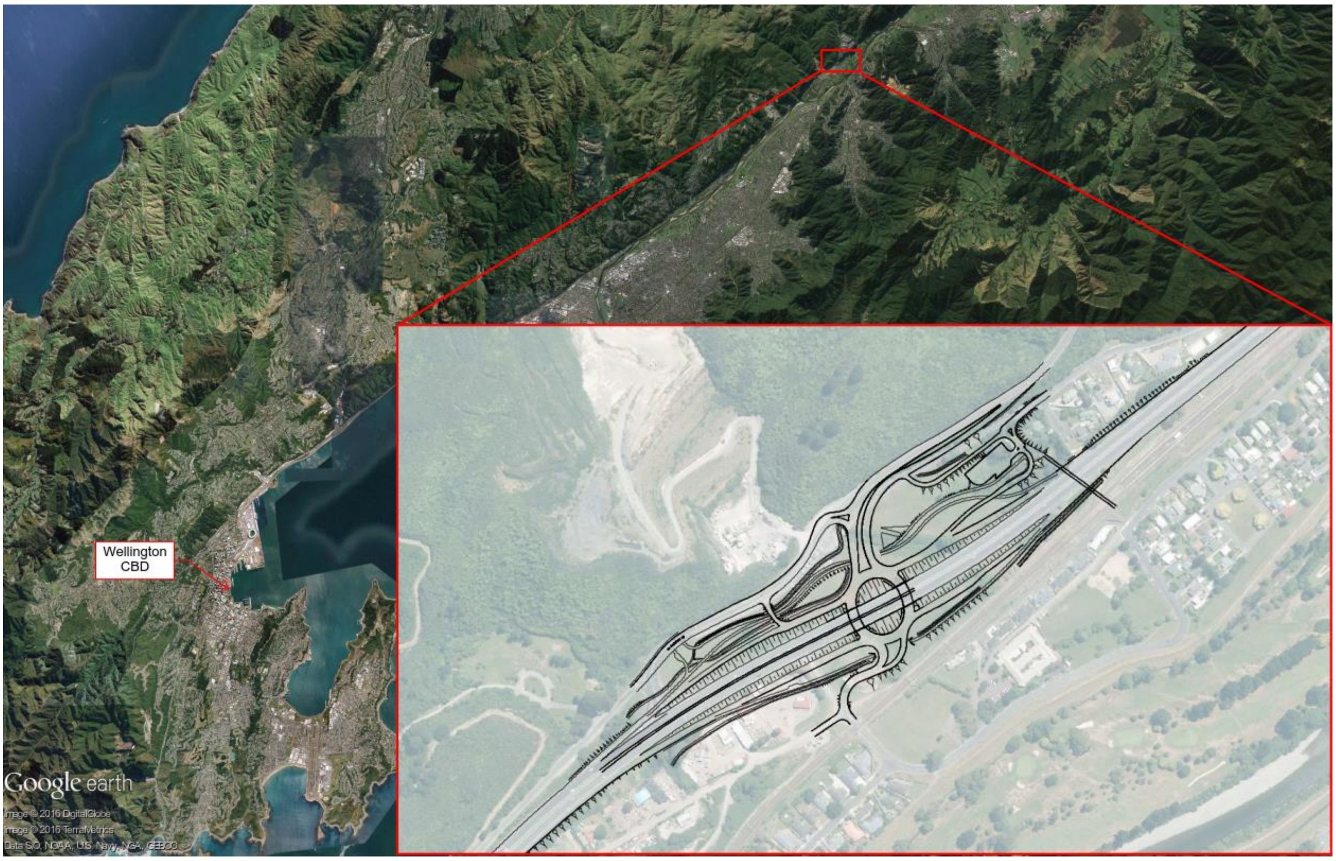

Figure 1: Location of the Haywards Interchange

The Haywards Interchange is part of the wider Hutt Corridor and aims to improve safety, reliability and efficiency outcomes for SH2 and SH58 users. A design of the Interchange and associated upgrade works was originally prepared in 2009/10 and since then has been refined. The updated design incorporates updates to various design manuals, particularly the 2014 NZTA Bridge Manual and Safe System approach, and brings in added value identified by the Design and Build team.

The scope of the Contract included:

- Deconstruction of the existing at-grade intersection at SH58 and Manor Park Road with SH2
- A grade separated interchange comprising an elevated roundabout over SH2 connecting SH 58, Manor Park and on and off-ramps from SH2 northbound and southbound
- Local road connections between McDougall Grove and Hebden Crescent
- Required bridge and retaining wall structures
- A new park and ride carpark

- Pedestrian and cyclist links from Golf Road to the railway station with Annabell Grove via a grade separated crossing of SH2 and the railway corridor, with connections to the park and ride facility and Belmont Regional Park

- Upgrade of the Dry Creek stormwater drainage system as well as of the adjacent Benmore Stream drainage system.

This report describes the upgrade of the Dry Creek stormwater drainage system to accommodate the interchange project and its associated constraints.

1.2 DESIGN TEAM

This Project was delivered through a Design and Build contract with Downer as the preferred contractor to NZTA. Downer employed a design team comprising Tonkin & Taylor Ltd (T+T) and Aurecon to undertake the detailed design. The design packages of geotechnical, structural, drainage, geometrics, urban design and traffic services were delivered by teams from both consultancies and were overseen by a Design Manager and a Downer Project Manager. This design team was able to collectively identify practical, constructible design solutions for a successful implementation of the project.

The drainage design package was divided up into three areas: hydrology, longitudinal drainage (parallel with the motorway) and cross drainage. Dry Creek formed part of the cross drainage package.

2 DRY CREEK – A 'FUTURE READY' DRAINAGE SYSTEM

2.1 SITE DESCRIPTION

Dry Creek is a tributary of the Hutt River with a catchment area of approximately 92 hectares. The catchment comprises relatively steep vegetated hills in the Belmont Regional Park. During a 1% annual exceedance probability (AEP) storm event, the peak discharge from this catchment into the Dry Creek network is estimated to be 7.9m^3/s. Dry Creek remains mostly a naturally formed stream until it enters the project site. The stream then enters a series of 1350mm diameter culverts passing beneath the existing SH2 and SH58 main roads, local roads, and the railway line. The system includes sections of open channel, isolated by upstream and downstream pipe lengths. The pipe system extends 200m downstream of the site and discharges into the Hutt River. This network is one of two providing drainage passage beneath SH2 within the site and collects surface drainage from the adjacent longitudinal drainage systems.

Benmore Stream is the second tributary of the Hutt River providing drainage passage beneath SH2 within the project site. This stream is located to the west of Dry Creek and has a larger catchment of approximately 334 hectares. It receives flow surcharges from the Dry Creek system. The works associated with this stream are not included in this paper.

The existing Dry Creek and Benmore Creek drainage systems along with the superimposed interchange project are shown in Figure 2. The revised road layout and associated modifications to the Dry Creek system, including extension of the culvert beneath the realigned SH58 and the installation of new culverts beneath new cycleways and on and off ramps for SH2 are also shown in Figure 2.

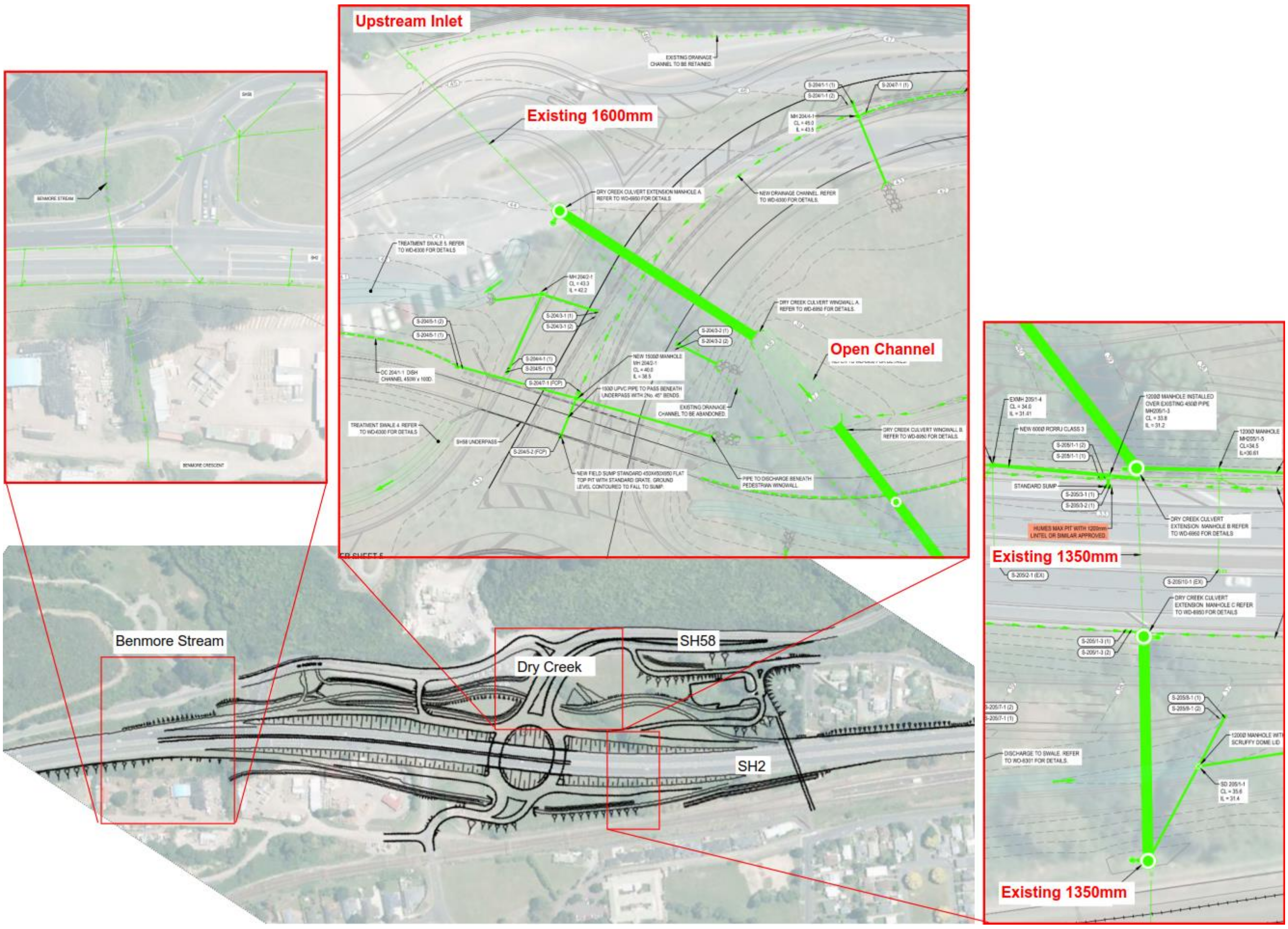

Figure 2: Haywards Interchange and locations of Dry Creek and Benmore Stream

2.2 DESIGN CRITERIA

The key requirements for the Dry Creek drainage system included:

Hydraulic Design

All culverts/pipes are required to have sufficient capacity to:

- Accommodate the 1% AEP flow without ponding outside of the road designation, NZTA owned land, or existing/future riparian margins
- Ensure design flows can pass with a minimum of 500mm freeboard below road surfaces
- Ensure 10% AEP flows can pass without headwater level exceeding inlet soffit level

To mitigate and offset environmental impacts, the culverts/pipes may be oversized to incorporate fish passage.

Erosion Protection

- Erosion protection must be provided to mitigate erosion at the interface between open streams and culvert headwalls or energy dissipation structure
- Energy dissipation must be incorporated into the design to facilitate transition to natural channel flow and sized for the design storm event

- Any hydraulic jumps must be confined within the culvert or outfall stilling basin

Other requirements

- Fish passage to be provided for climbing fish species in all culverts/crossings of natural perennial water courses

- A length of open channel to be provided between SH58 and the onramp to SH2 to mitigate and offset environmental impacts by keeping some natural amenity

2.3 DESIGN CHALLENGES

2.3.1 INTRODUCTION

The key technical challenges throughout the design were primarily the hydraulic constraints, the provision of a fish passage and the inclusion of an open channel section.

2.3.2 EXISTING CONSTRAINTS

The Project did not include a full upgrade of the existing Dry Creek drainage system because of economic constraints. However, the Project had to be 'future ready,' i.e. ready for further, complete upgrade of the stormwater system in the future. At the same time the Project had to function adequately now, which is further termed the 'intermediate design case.'

Catchment analysis and investigation of the existing Dry Creek system showed that the existing network components, upstream inlet and downstream culvert sizes, are capable of conveying storm flows up to the 10% AEP event. Flows in excess of this become overflow and are conveyed to the west along SH58 and Hebden Crescent to the Benmore Stream. The design criteria for the new system requires conveyance of the 1% AEP storm event.

The components of the existing system excluded from the upgrade works and which created hydraulic constraints along the Dry Creek system are:

- The upstream culvert entrance adjacent to Dry Creek quarry

- The existing 1350mm diameter culvert under SH2

- The existing 1350mm diameter culvert under the railway at the downstream end of the site

- The 200 m long downstream section of the Dry Creek culvert system.

These constraint locations are shown in Figure 2. The current upgrade works are limited by these existing constraints and constitute the intermediate design case. New elements of the upgrade works have been designed for the 1% AEP event. The existing constraints will be upgraded to 1% AEP capacity in the future. Until then, the project has to manage stormwater runoff in a satisfactory manner with reference to the design criteria. In some cases, a relaxation of the criteria was required.

The most significant challenge was how to lower the hydraulic grade line to avoid surcharging at manholes and causing overflows onto adjacent road carriageways. The overflows most likely to occur were adjacent to the state highways, namely, at the upstream inlet on the northern side of SH58 and at the manhole on the northern side of SH2 (refer Figure 2). This led to the need to minimise head losses where possible throughout the system to provide hydraulically smooth, efficient conveyance elements. The solutions are described in section 2.4.2.

2.3.3 FISH PASSAGE

The installation of fish passage in the Dry Creek system was a design requirement and another component of the future-ready design. The Dry Creek system prior to the upgrade works had significant drops at the culvert outlets into the open channel sections. The open channel sections were also isolated due to existing upstream and downstream pipes without fish passage provisions. Both of these are impassable to the majority of New Zealand river fish species. The future-ready design included the elimination of the excessive drops and the provision of a fish passage within the sections of new culverts. This will enable fish to migrate through the system when the remaining pipe lengths are upgraded in the future.

The inclusion of the fish passage within the new culverts added to the hydraulic challenge of the project, namely, in quantifying the hydraulic effect of the fish baffles on the flow in the pipes. The provision of fish rest areas along the length of the system and the allowance for a wetted margin for climbing fish to traverse outside the main line of flow also created design challenges. The solutions are described in section 2.4.3.

2.3.4 OPEN CHANNEL

The design required a length of open channel between SH58 and the northern cycleway to maintain some of the original open channel and to offset the ecological effects of the increased length of piped flow.

The length of open channel is short and relatively steep and located between two steep (8% slope) sections of new pipe. The exit velocity from the upstream pipe with no dissipation measures was calculated to be 9m/s, too high for an unprotected channel. An energy dissipation structure would normally be required since riprap lining of the channel alone would not be sufficient to dissipate the flow energy. The construction of an energy dissipation basin was not practical due to the channel’s short length. Alternative methods of energy dissipation were investigated. The selected solution of internal energy dissipation is described in section 2.4.4.

2.4 DESIGN SOLUTIONS

2.4.1 INTRODUCTION

The design challenges required innovative engineering solutions. These solutions included flood attenuation, bellmouth type outlets at manholes, special fish baffles and internal energy dissipation within pipes. This section describes these solutions.

2.4.2 HYDRAULIC GRADE LINE MANAGEMENT

The Dry Creek system is shown in Figure 3. The system comprises lengths of new 1800mm diameter concrete pipe with sections of existing 1350mm diameter pipe and open channel remaining. The original design allowed for box culverts and manhole structures with the focus on fish passage rather than hydraulic efficiency. The hydraulic constraints favoured the use of pipes and more typical manholes. Downer also expressed desire for the use of circular pipes instead of box culverts for cost efficiency and construction ease. These pipes also had the benefit of more efficient seals between pipe sections.

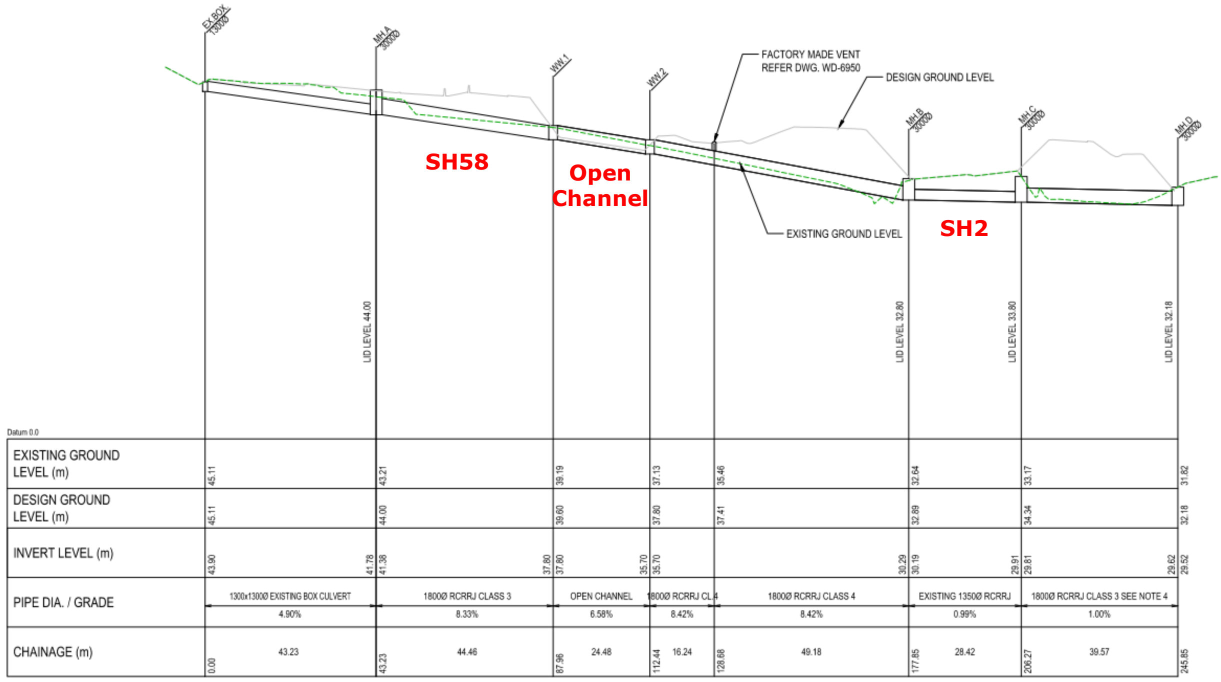

Figure 3: Dry Creek long section

The hydraulic grade line of the system was modelled using the 12D software and with a hand check calculations for verification. Initial grade line calculations of the hydraulically improved piped system still indicated surcharging at manhole B adjacent to SH2 (refer Figure 3) and capacity issues with the downstream, flatter gradient sections of pipe. In addition, the increased flow from the longitudinal drainage discharging into manhole B on the upstream side of SH2 substantially increased the head loss at this manhole. As discussed in section 2.3.2, the existing 1350mm outlet pipe from this manhole under SH2 could not be upgraded to match the new 1800mm inlet pipe. Eliminating surcharging in storm events and consequent flooding of SH2 via this manhole was a priority.

The solution developed comprised flood attenuation upstream to reduce the downstream flow and the use of bellmouth type outlets at the manholes, which reduced the manhole head losses. These combined measures lowered the hydraulic grade line to an acceptable level.

2.4.2 (a) PEAK FLOOD FLOW ATTENUATION

The open channel section of the system is located upstream from SH2 (as seen in Figures 2 and 3). This section of the system was utilised for inline attenuation to reduce the peak flood flow reaching SH2. The attenuation was achieved by the inclusion of an orifice plate on the downstream pipe inlet and providing sufficient attenuation volume in the channel (refer Figure 4). The open channel and area around the open channel was modelled as a basin, with the storage volume dictated by channel slopes and available space.

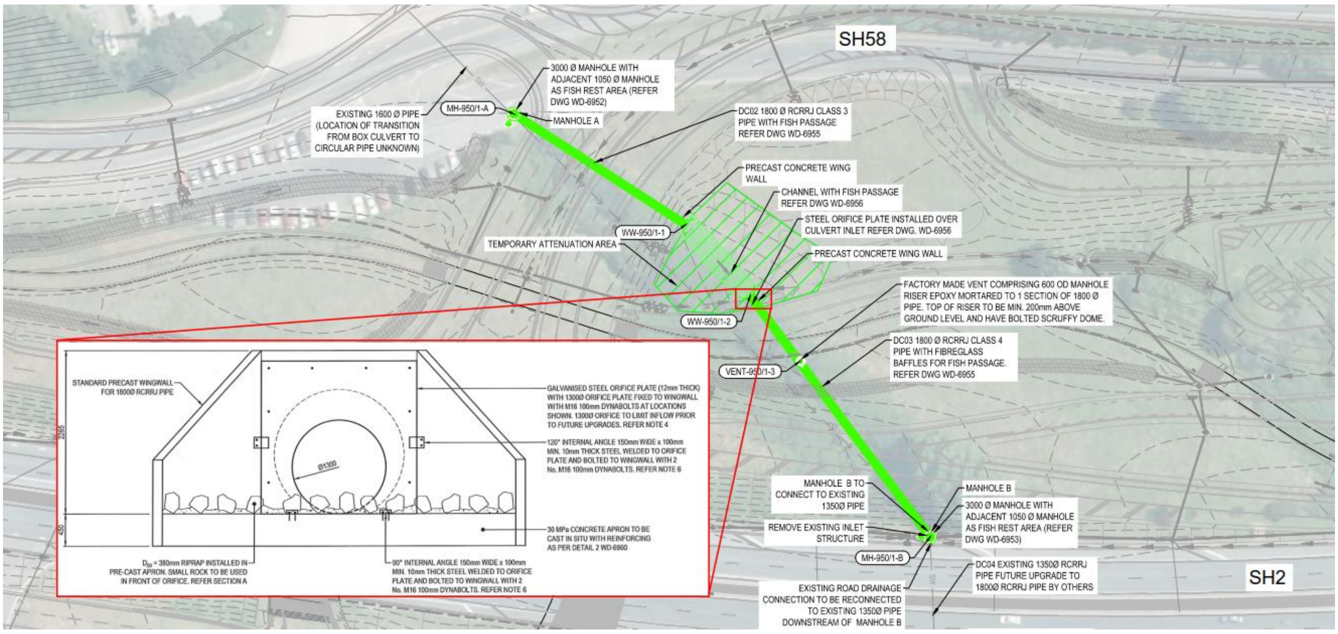

Figure 4: Flood attenuation area and orifice detail

Initial pond and orifice plate sizing was undertaken with the use of the US Environmental Protection Agency's Storm Water Management Model (SWMM). Following this the system was checked with flood routing calculations undertaken in a model created in Microsoft Excel. This sheet modelled the different sections of the system, including the flood attenuation section, enabling the input of several different storm durations and intensities.

Rational method inflow hydrographs were developed for the catchment and input into the model. The storage curve of the open channel and the orifice diameter were able to be adjusted in the model to optimize the storage design. This enabled the effect of the flood attenuation area on peak flows at each manhole downstream of the open channel to be determined. The peak flows were then used to check the hydraulic grade line of the system. The storage volume and orifice sizing were adjusted until the combined downstream peak flows were low enough to prevent surcharging. This process was iterative and, with the limited storage space and minimal freeboard below SH2, the system proved to be very tightly constrained. Our design predicts that in the intermediate design case the pond will fill up to approximately 200mm below the level of the downstream cycleway. The secondary overflow path is towards the north to an adjacent scruffy dome that discharges back into the downstream pipe network.

The future upgrade works to the Dry Creek system will allow the orifice plate to be removed. The inline attenuation will still be utilised in large storm events approaching 1% AEP due to inlet control at the downstream pipe inlet. Design freeboard will be provided in this case.

2.4.2 (b) MANHOLE BELLMOUTH TYPE OUTLETS

Inline flood attenuation on its own was not sufficient to eliminate the risk of surcharging at manhole B adjacent to SH2. Losses at the junctions between new 1800mm pipe and existing 1350mm pipe at manholes were high. As a solution, bellmouth type outlets were provided at the manholes which significantly reduced the losses. These outlets created lower exit velocities and an associated reduction in manhole head loss. The 'bellmouths' were created by constructing eccentric pipe tapers.

A combination of inline flood attenuation and pipe tapers was sufficient to lower the hydraulic grade line to an acceptable level to prevent surcharging on to SH2 for the design event. The pipe beneath SH2 will run under pressure during large storm events and there is little freeboard available between water level in the manholes and the road level. The risk of flooding will therefore still exist for large events until the future upgrade of the Dry Creek system is completed.

2.4.2 (c) FUTURE UPGRADE PHASE

The hydraulics of the 'future design case' were also assessed to ensure the system would meet full design requirements once the future upgrade to the Dry Creek system is competed. This case includes the upgrade of the existing 1350mm diameter pipes under SH58, SH2 and the railway being upgraded to 1800mm to match the new sections of pipe installed in this project. The hydraulics of the piped system after the future upgrade phase will be greatly improved, with the surcharging risk greatly reduced.

2.4.3 FISH PASSAGE

Fish passage design requirements included the provision of measures for the intermediate and future design cases to complete the ability for fish to travel from the Hutt River downstream to the upstream reaches of Dry Creek. This system is currently isolated, and unlikely to be reachable in the intermediate case by fish until the upgrade of the downstream pipe system is completed in the future. Therefore no post construction monitoring for effectiveness of the constructed fish passage is required at this stage.

The fish passage is for climbing fish species only. Therefore the key components of the design for the fish passage were to ensure wetted margins for fish to traverse out of the main line of flow along with periodic break pools for the fish to rest following their 'burst'-like swimming technique. Other considerations were to eliminate any drop structures from the system and ensure flow velocities are within acceptable limits for climbing fish species.

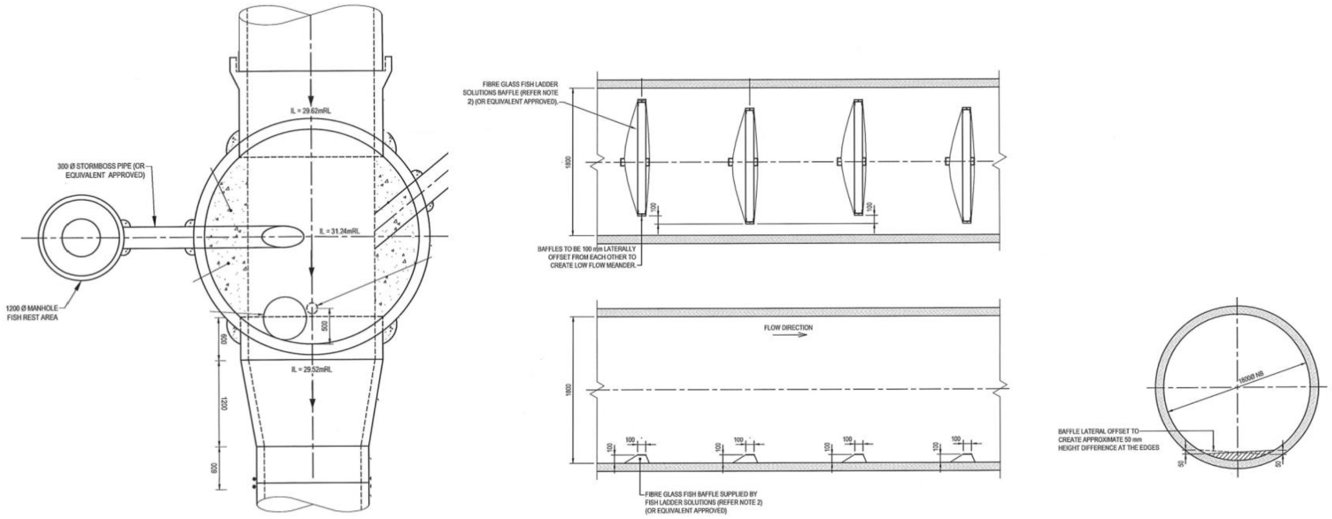

Figure 5: Fish offline rest area example and pipe baffles

The fish passage system comprised three main components: precast fiberglass baffles (supplied by Fish Ladder Solutions), and offline and online rest areas (refer Figure 5). The baffles were installed along the new lengths of pipeline with a lateral offset of 100mm between baffles i.e. the centerline of each baffle alternates 50mm either side of the pipe invert line. The role of the baffles is threefold: i) to create a sheltered area immediately downstream of each baffle in low flows to enable fish to rest by diverting the main line of flow around either side the baffle, ii) to create a low velocity meander in the invert of the pipe in low flows, and iii) to increase the wetted margin on the sides of the pipe to provide a wider pathway for the climbing fish outside the high flow velocity zone of the pipe system.

Offline fish pools were included adjacent to each of the five manholes along the system. These pools were formed in the base of 1050mm diameter manholes connected to the main line of flow with a 300mm diameter pipe. The pipe inlet is shaped to match the manhole benching as to minimise disruption during high flows and is located to one side of the manhole invert, easily accessible in low flows. The inlet being located in the invert of the benching encourages flushing flows to occur and prevent stagnant water conditions developing in the fish pools. The open channel is rock lined (refer section 2.4.4) with a wide base and shallow sides allowing for small pools outside of the main line of flow to form. A larger pool was also created prior to the downstream wingwall.

The fish baffles take up minimal cross sectional area of the pipes, but have an effect on the hydraulics of the pipe flow. Guidance for quantifying this effect is provided in the California Department of Transportation's (Caltrans) 'Fish Passage Design for Road Crossings' where experimental results for various culvert and baffle configurations have been used to develop calculations for effective pipe roughness. The methods provided enabled estimation of a Manning's roughness coefficient value for various flow depths (refer Figure 6).

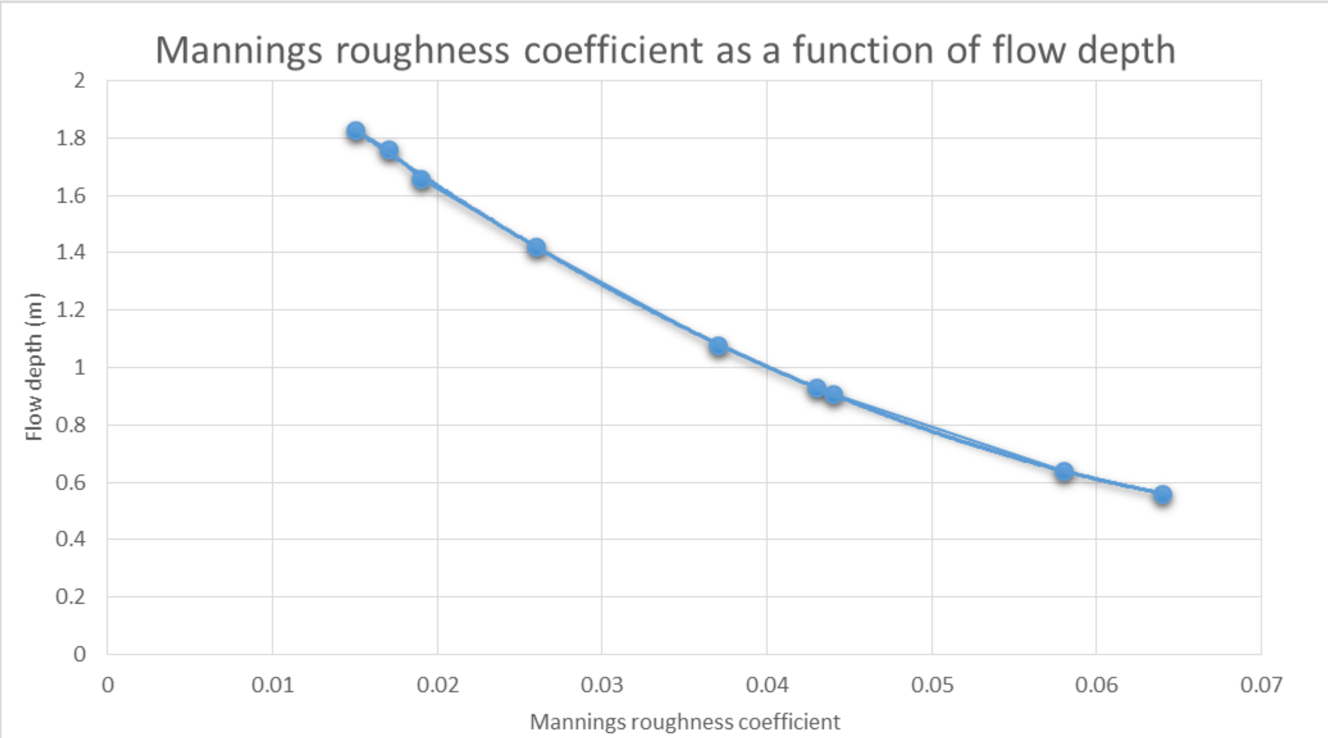

Figure 6: Mannings roughness coefficient determined from the Caltrans Guidelines

As flow depth increases, the effect of the baffles on the flow decreases. The baffle dimensions investigated and presented in the Caltrans guidelines are similar to, but not the same as, the baffles which were installed in this system. Thus this method was able to provide guidance towards the effect of the baffles but the results could not be relied on alone in design. The results from the Caltrans method were compared with a more basic, weighted circumferential estimation of Manning's roughness coefficient to give a comparative figure and the volumetric capacity reduction on the pipe was calculated as another means of quantifying effect of the baffles on the pipe capacity. The results from these methods were used to undertake a sensitivity analysis on the pipe sizing to ensure the baffles would not result in a capacity reduction too great for the specified pipe size. As allowed for in the project design criteria, the pipes were oversized for the hydraulic flow to account for the uncertainty in estimating the effect of the baffles on the flow behavior.

2.4.4 ENERGY DISSIPATION

Energy dissipation within the pipe was necessary to reduce the flow velocity exiting the pipe such that the riprap lined channel could manage the residual flow energy.

Internal roughness elements to increase resistance (in the form of dissipation rings) in combination with rock apron was the design solution to reduce flow velocities to acceptable levels. The energy dissipation rings increase internal pipe roughness to induce partial tumbling flow over the last section of pipe. This method of energy dissipation is described in the Hydraulic Engineering Circular Number 14, 'Hydraulic Design of Energy Dissipaters for Culverts and Channels,' a reference document listed in the design criteria for the project.

The spacing and height of the five rings are the key factors to velocity reduction of the flow. The ring design is based on each ring extending around the circumference of the inside of the pipe. However, if the rings were constructed like this they would create a barrier for fish passage. The design method allows for an adjustment to the calculated dissipation effect on the flow based on the ratio between ring length and pipe circumference. Gaps were constructed in the rings of approximately a quarter of the pipe circumference to one side of the pipe invert line (refer Figure 7). As it can be seen, these gaps were designed to alternate each side of the invert line between each consecutive ring. This way a low flow meander is created between the rings allowing for fish passage. The size and spacing of the rings was adjusted so the rings were still effective at reducing the flow velocity.

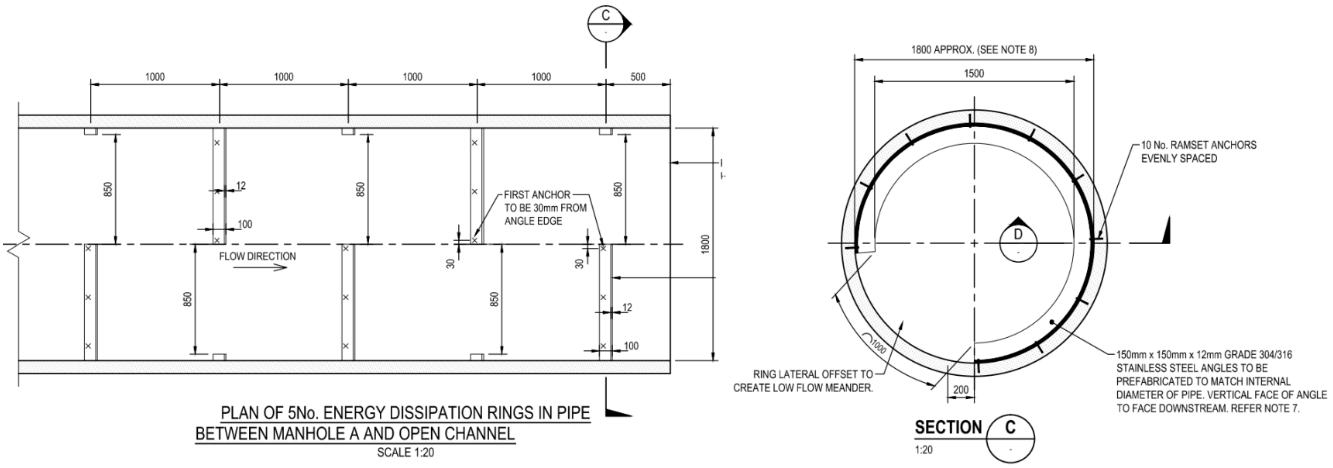

Figure 7: Energy dissipation rings

The dissipation rings were calculated to reduce the flow velocities from 9m/s to 3.7m/s by the time the flow reaches the outlet of the pipe. This is a significant velocity reduction allowing a riprap apron to become an effective means of protection following the pipe outlet. The invert of the upstream half of the open channel was designed for further energy dissipation using a 500mm riprap size followed by a smaller 380mm riprap size in the second half of the channel.

A root reinforcement mat was used in channel banks above the riprap level to stabilize the banks in the event of large flows when this stream is utilised for flood attenuation.

2.5 SAFETY IN DESIGN

Over and above the hydraulic and fish passage design challenges, operational safety was a key consideration of the design process.

To increase safety where maintenance is required, manhole locations were shifted outside of road medians to increase both safety during construction and of any future maintenance access. Maintenance over the asset life is intended to be low with the use of durable materials and smooth pipe transitions reducing the need for future access to confined spaces. Access rungs have not been provided in the large manholes to discourage entry without appropriate safety gear.

Safety during construction was considered with proprietary precast elements being used where possible to minimise construction time within excavated areas. Pipe grades were designed so to minimise excavation depth where possible and batter slopes of 1V:3H deployed during construction to increase worker safety in trench depths over 1.5m.

2.6 CONSTRUCTION AND PERFORMANCE

Construction of the Dry Creek system commenced in April 2016 and was completed by August 2016. Figure 8 shows various components of the completed system.

Figure 8: Photographs showing constructed open channel, fish baffles and energy dissipation rings

In November, following completion of the works, the site experienced a 12.5% AEP storm event. Evidence from debris lines following this event shows that the flood attenuation area around the open channel filled up to approximately 0.8m below the top of the downstream wingwall (refer Figure 9). This indicated performance in line with design expectations. There was also no surcharging of any of the manholes along the length of the system.

Figure 9: Photographs showing the debris line following the November 2016 storm event

3 CONCLUSIONS

The SH2/SH58 Hayward's Interchange was undertaken by a Design and Build team that utilised the combined engineering and contractual experience of consultants and contractors to deliver a successful product. The Dry Creek system is one of two cross drainage paths through the site of the interchange and provided a complex hydraulic challenge due to existing sections of the system being undersized for the design flow. The result was the development of two design solutions, intermediate and future, to manage the increased flow through the system arising from the construction of the interchange. The design challenges were heightened by the need for a short open channel section and for a fish passage. These challenges led to innovative engineering solutions including inline flood attenuation, internal energy dissipation and bellmouth manhole outlets to reduce head losses and provide acceptable surcharge risk. The Dry Creek system has been tested since construction with evidence showing its performance is in line with design expectations.

ACKNOWLEDGEMENTS

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Photos courtesy of Simon Grundy