CASHMERE VALLEY, APPLYING DAM PRINCIPLES TO STORMWATER

Marcus Burrows (Stantec), Steven Woods (Stantec), Petra O'Bery (Stantec), Peter Christensen (Christchurch City Council)

ABSTRACT

Following the major earthquakes in Canterbury in 2010 and 2011, flooding of properties along the Ōpāwaho Heathcote River significantly worsened due to a combination of effects such as settlement of buildings and deposition of silt in the river. In order to respond to this change in the environment and build resilience in the stormwater system against future climate change, Christchurch City Council (CCC), amongst other flood mitigation projects, has constructed a network of significant flood detention basins and naturalised wetlands.

The construction of larger flood detention basins in urban areas is likely to be part of the flood mitigation strategies in many parts of New Zealand in the future. New Zealand is in the process of adopting new regulations that relate to dam safety of existing dams, and will come into force in May 2024. New regulations define a 'classifiable dam', which will require dam engineering principles and compliance with the legislation in the future.

Many embankments constructed to retain or detain stormwater have historically been designed using empirical methods and engineering judgement. This paper highlights CCC's newest flood storage basin, the Cashmere Valley Dam, and presents key considerations required to apply dam engineering principles to flood detention dams, in particular:

- Understanding the potential consequences of a dam failure so that a Potential Impact Classification of low, medium or high can be assigned.
- Flood modelling required to complete the consequence assessment, particularly in a highly populated urban environment.
- Using different soils through the embankment cross section to achieve seepage control and stability.
- Detailing around pipe penetrations through earth embankments to control seepage.
- Spillways designed and constructed to operate safely under significant flows.
- Construction monitoring required of engineers – where to look and what to focus on.
- The size of floods that dams are designed to safely pass, which are generally much larger than the floods considered for stormwater design.

Construction of dams requires engineering monitoring that is focused on dam engineering principles and is significantly more rigorous than what may be considered typical for earth and civil structures. The Cashmere Valley Dam monitoring and surveillance began from the ground up including foundations, fills, earthworks construction methods, and testing. Monitoring of the construction of the civil structures (reinforced concrete inlet, outlet, and pipes) required specific attention to quality and durability of concrete for flood water conveyance, and consideration of seepage paths through structures and adjacent fills.

The Cashmere Valley Dam stakeholders are diverse and considerable effort was placed on the multiple use aspect of the dam and reservoir. This paper highlights how 'softer' engineering solutions can be applied to dams in urban setting so that they integrate sympathetically with the surrounding environment and the ability to use the reservoir formed behind flood detention dams for recreation and environmental enhancement purposes.

KEYWORDS

Flood Detention Dam, Ōpāwaho-Heathcote River, Dam Safety, Regulations, Dam Design, Dam Construction.

1 INTRODUCTION

The Ōpāwaho Heathcote River catchment has a history of flooding and poor water quality. Following the major earthquakes in Canterbury in 2010 and 2011, flooding of properties along the Ōpāwaho Heathcote River significantly worsened due to a combination of effects such as settlement of buildings and deposition of silt in the river. In order to respond to this change in the environment and build resilience in the stormwater system against future climate change, Christchurch City Council (CCC), amongst other flood mitigation projects, has constructed a network of significant flood detention basins and naturalised wetlands.

This paper introduces CCC's approach to stormwater management through the Land Drainage Recovery Programme, and focuses on a critical piece of infrastructure in the Cashmere Valley Dam. The Cashmere Valley Dam is a stormwater detention dam located in the Cashmere Valley and comprises a zoned earthfill embankment 4.5m in height. The reservoir includes a naturalized wetland upstream and downstream of the dam.

The Cashmere Valley Dam is a Large Dam under New Zealand legislation and is subject to the design, dam safety, and consenting requirements of the Building Act 2004 (the Act). For more than a decade New Zealand has been considering regulation for existing dams, which has culminated in the drafting of the Building (Dam Safety) Regulations 2022 (the Regulations) coming into force on 13 May 2024.

The design of the Cashmere Valley Dam comprises a zoned earthfill dam designed in line with national and international dam design practice. Dam design considers the effects of a theoretical 'dam break', the consequences of which drive the performance criteria for technical design. Construction of the Cashmere Valley Dam began in September 2022, and was completed in February 2024. This paper presents key construction considerations of large dams and specific challenges encountered during the Cashmere Valley Dam.

2 BACKGROUND

2.1 STORMWATER NETWORK

The Ōpāwaho Heathcote River forms a key part of land drainage for Christchurch City. The river is located in the southern part of the city at the base of the Port Hills, and winds its way though urban development discharging to the Avon/Heathcote Estuary. The catchment for the river comprises some 103 km^2 of approximately 70% Holocene floodplains, and 30% Port Hills land. The river and catchment in the context of the Christchurch urban area is shown in Figure 1.

River-side roads in the Ōpāwaho Heathcote River catchment experience regular flooding and low-lying houses can be flooded in large events. The 2010/11 Canterbury Earthquakes caused settlement of land within and adjacent to the river channel, much of which is residential urban neighborhoods. This combined with catchment development and increasing sediment load has increased the flood risk for many properties.

The Council's Land Drainage Recovery Programme was formed in 2012 to investigate and alleviate the impacts on flooding risks, with the aim of returning the flooding risk to houses to pre-earthquake levels. CCC developed a floodplain and river model to improve understanding of the risks to houses on the floodplain. A key part of achieving the recovery goals was the creation of significant flood storage basins in the upper reaches of the catchment. Basins impound stormwater at times of high rainfall which can be released in a controlled manner after downstream water levels have lowered, alleviating the effects of flooding. Figure 1 presents the Ōpāwaho Heathcote River and major storage basins constructed, of which the Cashmere Valley Dam forms part.

The Upper Ōpāwaho Heathcote River storage scheme, of which the Cashmere Valley Dam forms part, is shown in Figure 1. It comprises of six basins at four sites with remotely actuated gates that are automatically opened and closed based on remote and local river and basin levels. The purpose of this scheme is to optimise storage so that it is more available at the peak of the event, and also to allow for optimisation in both more and less frequent events. CCC is required to evaluate the effectiveness of the storage schemes against a baseline largely pre-development year of 1991. Recent modelling has shown that at the main river gauging site downstream of all the basins (Heathcote River at Ferniehurst Street), present day water levels are modelled as being 0.61 m *below* the baseline 1991 level in a 10% AEP event, and 0.39 m *below* the baseline level in a 2% AEP event. The Cashmere Valley Dam is a key part of this. This also translates in reduced floor level flooding. For a 2% AEP current climate event, without the storage scheme it was estimated that 222 floor levels were at risk of flooding, and with the scheme in place this dropped down to 37 floor levels remaining at risk.

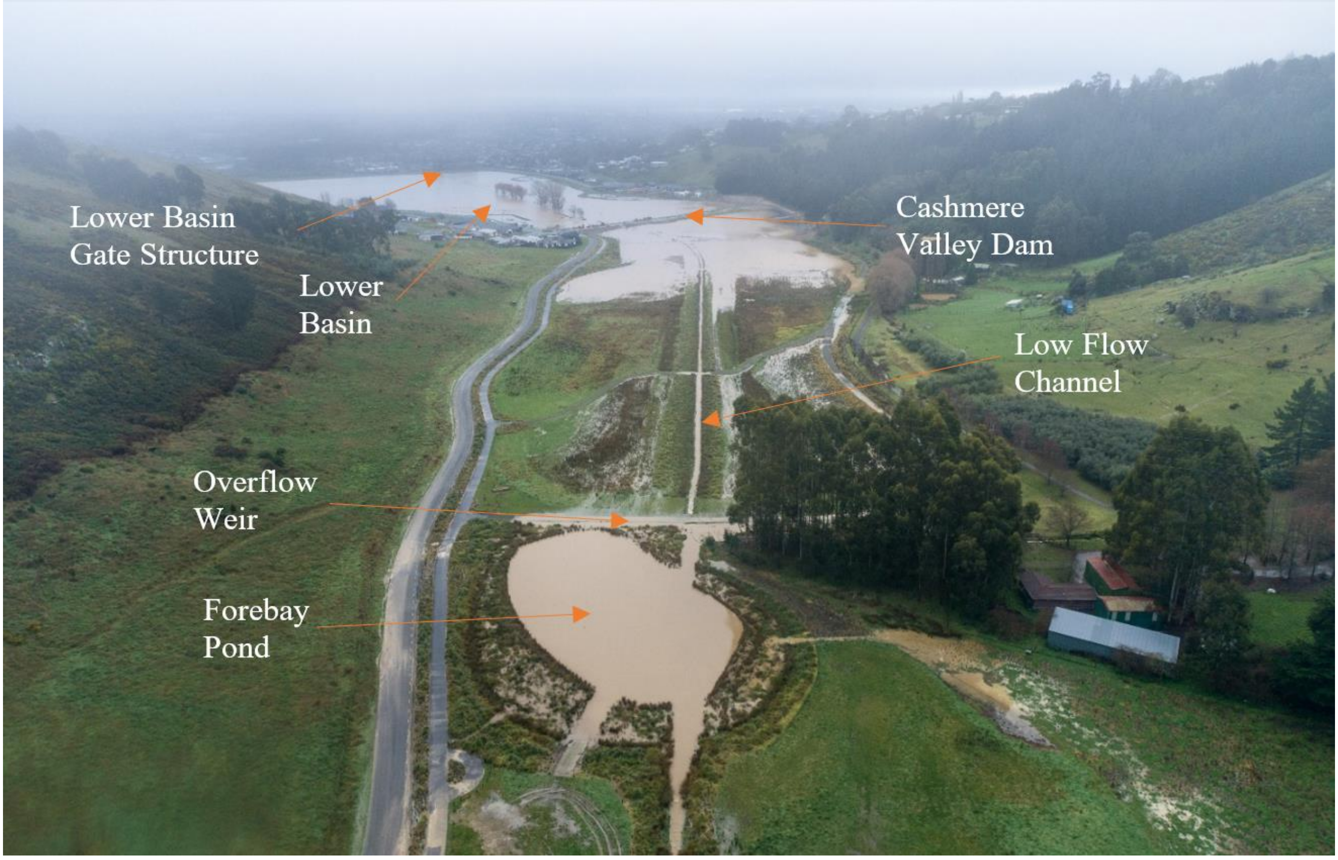
To differentiate between the terms 'basin' and 'dam' in this paper, basins are predominately in excavation i.e. water is stored below natural ground level, while dams comprise an embankment and store water above the natural ground level. Some storage systems may comprise elements of both.

Figure 1. Ōpāwaho Heathcote River and catchment overview showing approximate extents of the upper Heathcote storage scheme (based on Christchurch City Council 2022)

2.2 CASHMERE VALLEY DAM AND SITE

The Cashmere Valley Dam is a zoned earthfill embankment dam, 4.5m in height and at full capacity stores 213,000m^3 flood water or 375 million pints of beer (Stuff, 2022). Water release is controlled by a 1.8m penstock (vertical slide gate), and discharges through a reinforced concrete diversion culvert. The spillway comprises a 100m wide, reinforced grass channel located at the midpoint of the dam. Downstream of the Cashmere Valley Dam is another gated basin, adding to the flood storage capacity of the Cashmere Valley. Figure 2 presents key stormwater infrastructure within the Cashmere Valley.

Figure 2. Cashmere Valley stormwater detention system (in flood during dam construction, 2023)



Cashmere Valley Dam forms part of a multistage stormwater storage and treatment system. The key elements of this system as shown in Figure 2 are:

- A forebay pond which stores water when stream flows exceed approximately 100 l/s. The purpose of the forebay pond is to drop out coarse sediment within a confined area that can readily be cleaned out.
- A 100m long overflow weir that discharges water at low depth across vegetated ground to further remove sediment as water enters the Cashmere Valley Dam reservoir.
- A series of footpaths through the reservoir that cross an engineered low flow channel act as small check dams to cause further ponding and removal of sediment.
- Cashmere Valley Dam, which stores water by closing a slide gate at the upstream end of the 1.8m diameter culvert.
- The lower basin, which stores water by closing two bottom hinged flap gates.

The Cashmere Valley Dam forms the main focus of this paper. The general arrangement and locations of key infrastructure are shown in Figure 3.

Figure 3. Cashmere Valley Dam general arrangement

2.3 DAM REGULATIONS

Dams are subject to specific regulation in New Zealand. Key parts of the regulatory framework are:

- Building Act 2004 (the Act) - construction of new Large Dams, or modification of existing Large Dams requires compliance with the Act, including building consent.
- Building (Dam Safety) Regulations 2022 (the Regulations) – regulations for existing Classifiable Dams

A Large Dam is defined in the Act as *"a dam that has a height of 4 or more meters and holds 20,000 or more cubic meters volume of water or other fluid"*. There are no prescriptive design standards for dams and the path for compliance with the Act uses alternative solutions. Designing a dam in accordance with international guidance and recommended good practice in the New Zealand Dam Safety Guidelines (NZSOLD, 2023) is one way of complying. The design also generally needs to go through a peer review process.

The Regulations were introduced in May 2022 and come into effect on 13 May 2024 after which date, owners of Classifiable Dams will have specific engineering and dam safety obligations. Classifiable dams were defined in May 2022 as a dam that is either:

1. 4 or more metres and stores 20,000 or more cubic metres volume of water, or other fluid; or

2. 1 or more metres and stores 40,000 or more cubic metres volume of water, or other fluid.

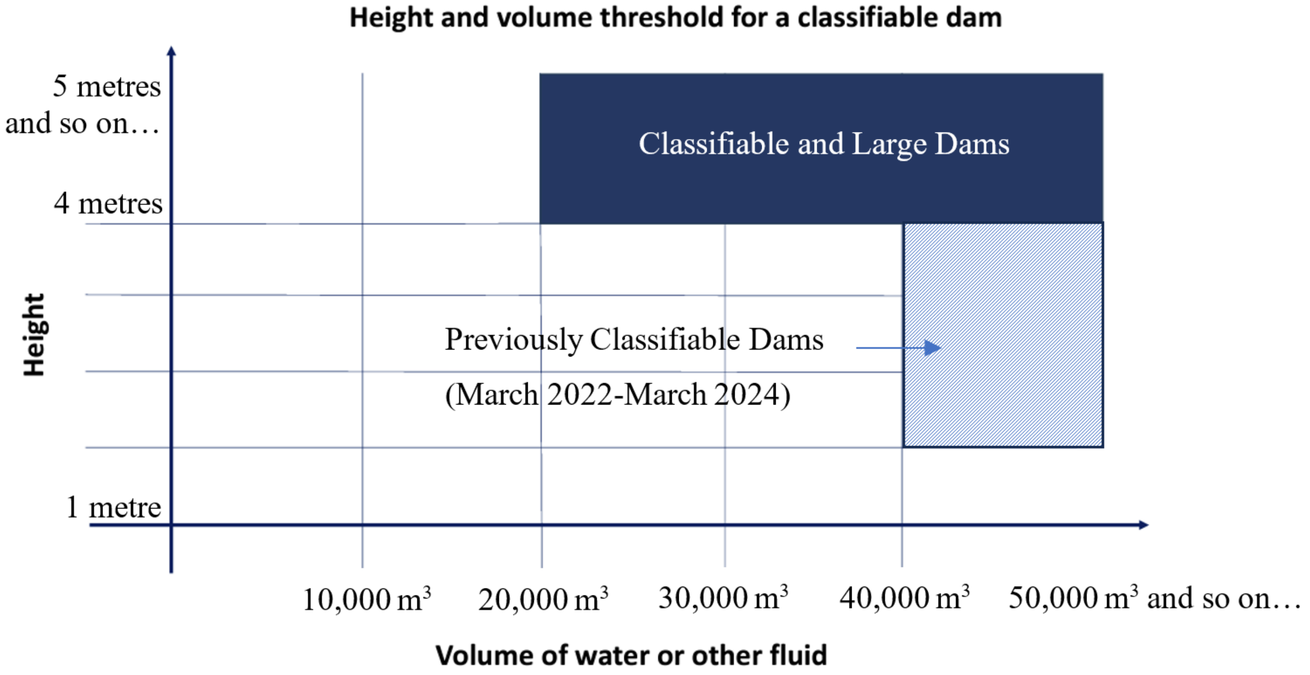
An update to the Regulations in March 2024 has removed item 2 from the definition, meaning that a Classifiable Dam is now defined using a single height and volume threshold of 4 metres or higher and 20,000 or more cubic metres of stored liquid. The Regulations intentionally do not include stopbanks.

Owners of a Classifiable Dam will have specific obligations under the Regulations, including:

- Provision of a dams Potential Impact Classification (PIC) to the Regional Authority.
- If the dam PIC is medium or high, provision of a Dam Safety Assurance Programme (DSAP).
- Provision of an annual compliance certificate confirming compliance with the DSAP.

The PIC, DSAP, and annual compliance certificate are required to be audited and certified by a Recognised Engineer. The Cashmere Valley Dam is both a Large and Classifiable Dam under the Act and Regulations and is subject to the requirements above, among others.

Figure 4. Height and Volume Thresholds for Large and Classifiable Dams (adapted from MBIE, 2024)



The development of the Regulations, and subsequent revision of definitions are presented in this paper to highlight potential impacts to stormwater infrastructure to the reader. Regulations and guidelines will continue to advance and be updated to incorporate good practice and balance the risk and cost of compliance.

In the future it is possible that the Regulations may revert back to the previous definition of a Classifiable Dam, or some other classification threshold (height and/or volume). The Authors recommend that new water detention structures utilise the previous definition of a Classifiable Dam and that such structures are designed using the same design framework applied to Large Dams. Our opinion is that as stormwater detention structures are often located in urban settings, there is higher potential to impact people, property, and the environment should an uncontrolled release of impounded water occur. Adopting dam design principals in future stormwater infrastructure will also safeguard against the situation where the Regulations are updated in the future, or potentially return to the 2022-2024 Classifiable Dam definition, requiring PIC, DSAP, and annual compliance. The way in which that framework is applied to Cashmere Valley Dam is described in the following section.

3 CASHMERE VALLEY DAM DESIGN

3.1 DAM BREAK AND CONSEQUENCES

Design criteria for large dams is driven by the hypothetical effects of a dam failure. This process is commonly referred to as a dam break study. NZSOLD (2023) sets out the process required for undertaking such a study, and may generally be summarized by:

- Defining of the catchment hydrology and inflows;
- Modelling immediate release of a full reservoir under various conditions ‘dam break’;

- Assessing the damage level of a hypothetical dam break to buildings, infrastructure, historic/archeological sites, and the natural environment;
- Estimating the Population at Risk (PAR) and Potential Loss of Life, of a dam break; and
- Assigning a Potential Impact Classification (PIC) for the dam.

A dam break study normally considers two conditions, namely:

- A 'sunny day' scenario where the failure occurs during normal flow conditions.
- A 'rainy-day' scenario where the failure occurs during flood conditions.

As the Cashmere Valley Dam is a flood detention structure, it does not store water under normal flow conditions, therefore, the sunny day scenario is not considered. For a rainy-day scenario, the **incremental** effects of the dam break event on top of natural flooding were considered. The selection of hydrologic conditions for the dam break should therefore be to create the scenario that creates the largest incremental effect due to the dam break. In order to have confidence that the worst-case incremental effects were being assessed, three different natural floods were considered with superimposed dam break effects.

The Cashmere Valley Dam impact assessment is complicated by the urban setting of the dam, and the presence of the downstream lower basin. In order to assess the effects of a dam break an existing DHI Mike Flood model of the Ōpāwaho Heathcote River and its floodplain was utilized. For each of the flood conditions considered the following process was followed:

- The natural flood with the dam operating normally was modelled to establish flood levels throughout the flood plain.
- The flood level data was post processed in GIS and compared to floor level data held by CCC to work out the number of houses flooded above floor level.
- A hydrograph that represents a dam break event was inserted into the model and the same processing steps as above were repeated.
- The results of the two runs were compared to give the incremental effect of the dam break i.e. the additional number of houses flooded were estimated.
- Based on the number of additional houses flooded, typical occupancy rates and the criteria set out in the NZSOLD Dam Safety Guidelines, the Population at Risk could be estimated.

Based on the incremental Population at Risk, the Incremental Potential Loss of Life could be estimated. This is a statistically derived estimate of hypothetical fatalities based on the depth and velocity of flow and uses data collected from historical flooding events.

The result of the worst-case incremental effect for the Cashmere Valley Dam is shown in Figure 5. Flow from a hypothetical failure would first fill the lower basin causing it to overflow a road embankment (Worsleys Road) and then flow into an additional ponding area downstream of the road. Water then flows largely down the main channel of the Ōpāwaho Heathcote River.

Figure 5. Extent and additional depth of flooding due to dam break

Downstream of the road embankment the increase in depth due to the dam break event was modelled as less than 0.3m and velocities were low due to the extent of ponding. Due to the limited height of water and low velocities the incremental Potential Loss of Life assessed was essentially zero.

The Population at Risk for the Cashmere Valley Dam was assessed according to NZSOLD (2015) and concluded to be zero persons. The theoretical damage from a dam break was assessed to be an additional five houses flooded to less than 0.5m above floor level, or moderate incremental damage. Based on an assessment of zero incremental population at risk, essentially zero potential loss of life and moderate incremental damage, the PIC was assessed as Low. Some changes have been made to the details of the PIC assessment process in recent 2023 updates to the NZSOLD Dam Safety Guidelines, however, the process is similar to the 2015 version and result would be the same for the Cashmere Valley Dam.

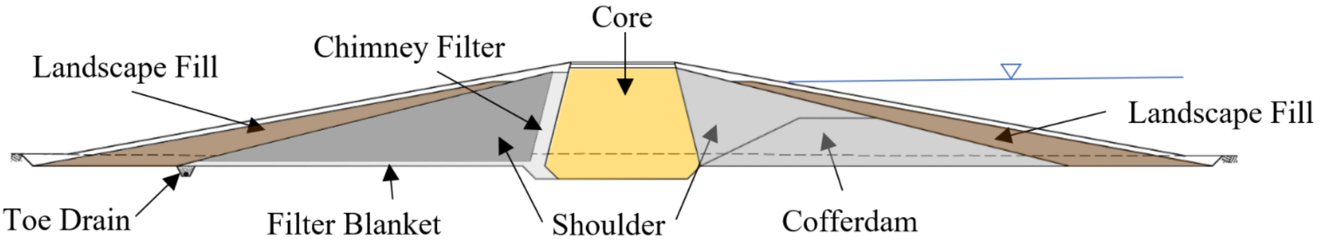
3.2 EMBANKMENT DESIGN

The Cashmere Valley Dam embankment is the critical water-retaining structure for stormwater detention and comprises zoned earthfill. Zones within earthfill dams refer to areas where different materials are located. Each zone has a specific role in the function of the dam, through stability, erosion protection, permeability, seepage, or drainage. As shown in Figure 6, the Cashmere Valley Dam embankment comprises:

- Central core – the key water retaining element of the dam constructed from locally available silt from the reservoir excavation.
- Filter chimney and blanket - a protection element that prevents the core fill from migrating downstream in the event of concentrated seepage along cracks in the core.
- Shoulders constructed from imported gravel to provide strength and stability to the structure and allow fill placement to progress in a range of weather conditions.

- Toe drain at the downstream extent of the embankment to collect seepage water from the chimney and blanket drains.
- Landscape fill that allowed the embankment to be shaped to a landform that was more sympathetic with the existing topography.

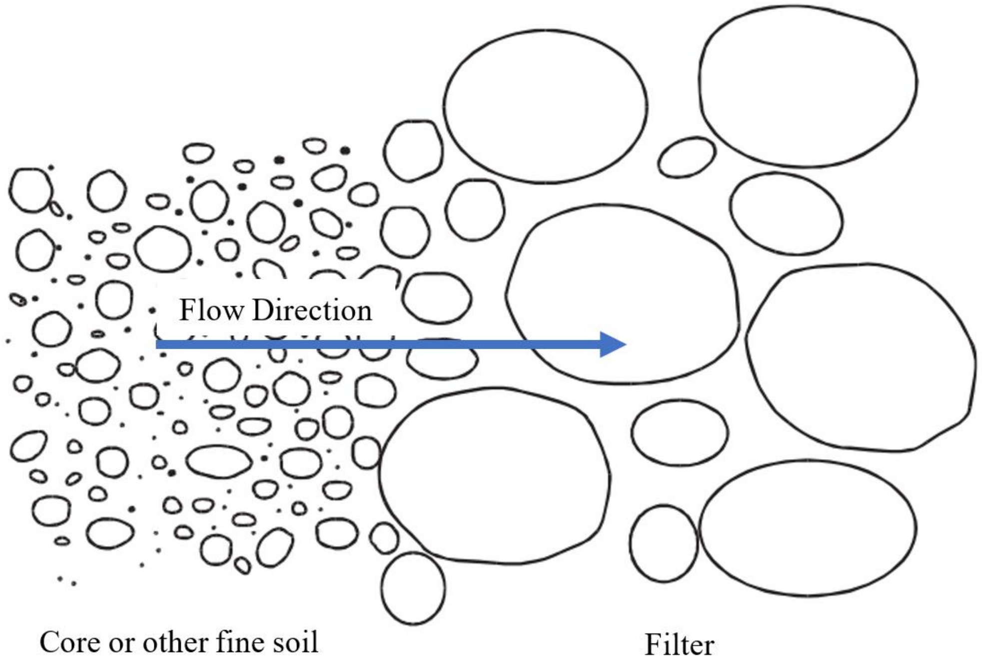
Figure 6. Cashmere Valley Dam embankment zones.



Design of filter and drainage zones is a critical part of embankment design. The role of a dam filter is to prevent fine soil particles migrating with water seepage while allowing drainage. This requires careful assessment and consideration of abutting soils particle sizes, and in some cases may require more than one filter zone. The Cashmere Valley Dam uses a narrowly graded gravelly sand envelope in both the chimney and filter drains to prevent migration of fine material and internal erosion of the core and foundation. A graphical representation of the core-filter interface is presented in Figure 7.

Homogenous earthfill embankments where the entirety of the embankment is constructed of the same material are commonplace in existing stormwater bunds and dams. Embankment zoning is a key aspect of defensive design against internal erosion or piping. Research shows for dams in Australia, USA, Canada and New Zealand constructed after 1930, 90% of dam failures were related to internal erosion and piping (Fell et al. 2015).

Figure 7. Graphical representation of the core filter interface adapted from Fell et al. 2015



Embankment and foundation material parameters such as strength, permeability, and erodibility were defined by insitu geotechnical investigations and testing, laboratory tests, and assessed using interpretative methods. The embankment was modelled under various operational conditions including full reservoir, empty reservoir, end of construction, and reservoir rapid drawdown after a flood event. Different load cases incorporating earthquake shaking and temporary loads are also considered. Modelling of the Cashmere Valley Dam was undertaken using finite element seepage and limit equilibrium stability modelling software (Geostudio, 2020) for the full range of scenarios.

Earthquake shaking is a driving design consideration for New Zealand dams. Like other disciplines, the level of seismic loading applied in design is specific to the importance of the structure, in this case, a dam. NZSOLD, 2023 sets out return period and seismic loading considerations to be applied in design based on PIC. Design earthquakes for dams are defined as:

- Operating Basis Earthquake (OBE) – The earthquake for which a dam is designed to remain operational, with any damage being minor and readily repairable following the event.
- Safety Evaluation Earthquake (SEE) – The earthquake that would result in the most severe ground motion which a dam without uncontrolled release of the reservoir.

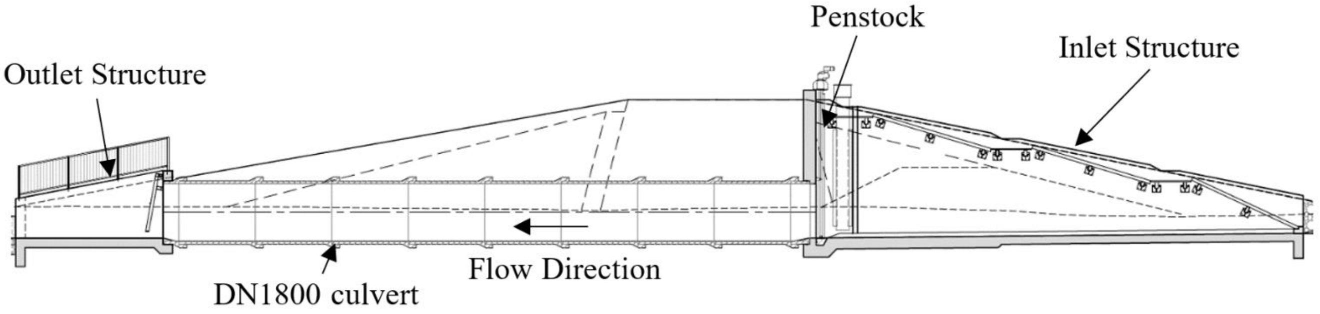
The Cashmere Valley Dam, as a flood detention dam, infrequently stores water in the reservoir. Consideration was given to a coinciding flood event and large earthquake. Design guidance requires the Cashmere Valley Dam to be sufficiently operational after a large earthquake to handle a moderate flood.

3.3 STRUCTURES AND SPILLWAY DESIGN

The Cashmere Valley Dam diversion structure comprises a 1.8m diameter reinforced concrete conduit with an upstream penstock (slide gate). Reinforced concrete inlet and outlet structures train water into and out of the conduit. Trash rack screens cover the inlet and outlet to the diversion.

The interface between the concrete structures and embankment fill requires specific attention for dams. Seepage of water tracking along the soil-structure interface and eroding soil is a common mode leading to dam failure. The Cashmere Valley Dam implements defensive design against this erosion mechanism by surrounding the conduit downstream of the core with a filter material, which, in the case there is contact seepage, will collect and positively drain to the toe drain outlets.

Figure 8. General arrangement of the Cashmere Valley Dam diversion structures



The Cashmere Valley Dam spillway is a centrally located, 100m wide, reinforced grass spillway. Design flood inflows for dams are established dependent on the PIC, for Low PIC dams guidance recommends between 1/100 and 1/1,000 AEP event. The Cashmere Valley Dam is designed for a 1/500 AEP flood event, and spillway operational flow up to 22 m^3/s and velocity of 3 m/s. Water is spread evenly across the spillway by a reinforced concrete nib weir. Due to the soft and compressible foundation conditions, the dam will continue to settle for a number of years after construction. As such, design includes provision for a batten-style attachment to allow the nib elevation to be maintained until settlement subsides. The Enkamat™ reinforced grass covering fits into the aesthetic of the naturalised wetland detention area, and provides resilience up to 50 hours of continuous operation (CIRIA, 1987).

4 CASHMERE VALLEY DAM CONSTRUCTION

Construction of dams differs from other embankments and structures due to their water retaining and conveyance role, and the potential impact of a dam failure. The zoned earthfill embankment and reinforced concrete diversion structures specific to the Cashmere Valley Dam required focus on areas that may lead to a dam failure. The following sections outline critical items for the Cashmere Valley Dam construction.

4.1 DAM FOUNDATION

The foundation of the Cashmere Valley Dam comprises soft to firm silt. It is typical for dam foundations to be geologically mapped during construction to provide a record of soil or rock and rock mass defects, however, the homogenous nature of the Cashmere Valley Dam geology meant that such mapping was largely redundant. In order to follow best practice, each exposed area of the foundation was inspected prior to placement of fills. Any areas that may provide preferential flow-paths, organic materials, or extremely weak materials were removed from the foundation. This included historic field drains, areas of granular road fills, and tree root systems. Figure 9 and 10 show exposed foundation as inspected prior to placement of fill.

Figure 9. Exposed foundation prior to placement of core fill

Figure 10. Exposed foundation at a scheduled inspection

4.2 FILLS

The character, placement, and compaction of all fills for the embankment were carefully monitored throughout construction. Silt won from the reservoir and used for the dam core was selectively mined from the large on-site stockpile, and underwent laboratory testing to establish particle size distribution, permeability, and compaction requirements. Gravelly sand filter material required investigation of several quarry sources before a material consistent with the specification was obtained. The filter material was frequently tested for conformance with the narrow distribution envelope prior to importing to the dam site. The gradation of the filter is critical to prevent internal erosion of the dam core, so stockpiled material falling outside the envelope was rejected as dam fill.

Gravel shoulder material comprised local ‘pitrun’ outwash gravel, the gradation of this material was broader and there were no issues with the character of this material during construction. The placement of gravel was completed in staggered runs to prevent coarse material accumulating at the end of each run, resulting in higher permeability areas through the shoulder. Regular inspections of the material were undertaken and if coarse areas were identified, they were removed and replaced with well graded material.

Compaction trials were conducted for all material to establish methodologies, including plant, that could effectively and consistently achieve the specification requirement. Moisture conditioning (drying) of the fine-grained silt core was frequently required and achieved by spreading in thin layers, and overturning regularly to expose all material to the sun and wind. The placement of the chimney filter was achieved by an over-placement and cut back method. This comprised placement of shoulder fills over the last filter layer to provide protection, then excavated in a shallow trench at the required width and a filter layer placed.

All fills were tested for insitu density by Nuclear Densometer (NDM) and assessed according to specification requirement for each fill type. Fail results were investigated, and were typically caused by higher than optimum moisture content. A successful method for remediating areas of low compaction was established and comprised scarifying, moisture conditioning (drying), and recompacting.

Figure 11. Placement of core and shoulder fills prior to trenching back to place filter fills.

Figure 12. Trenching for chimney filter and placement of filter material.

4.3 SOIL-STRUCTURE INTERFACE

Specific attention was given to fills immediately adjacent to the concrete structures in order to prevent the contact seepage and erosion failure mode. A low strength flowable grout (2 MPa) was used to encase the conduit to above the springline. This removed the need for time consuming placement and difficult compaction of conventional fills in the pipe haunch zone.

Compaction of core fills in close proximity to the concrete structures was completed by a 1.6T remote controlled sheepsfoot roller, hand propelled mechanical tamper, and plate compactor. Mechanical tamping along the immediate soil-structure interface provided effective compaction where the roller drums could not access. The lighter, highly maneuverable remote-control roller proved an excellent methodology for compaction of fills close to the structures to avoid damage with large compaction plant.

Placement of the gravel fill up to the structures by conventional spreading techniques presented the situation where larger gravel clasts accumulated against the structure walls. A method of dumping fill immediately against the wall and spreading away from the walls with controlled excavator movements was developed and effectively mitigated this. Excavation of the foundation immediately adjacent to structures required specific attention to ensure undisturbed, native material was encountered. It was common to have to remove additional material at this location due to disturbance or contamination from the structure building activities. A clean, competent, native foundation was exposed in all cases for the Cashmere Valley Dam.

Control of water in the structure interface area was difficult as it was the lowest lying area on the construction site. Surface water runoff combined with near surface groundwater required removal of standing water, and was effectively achieved by strategically placed temporary sumps and frequent pumping.

Figure 13. Compaction of core fill close to structures.

4.4 WETLAND CONSTRUCTION ENVIRONMENT

The Cashmere Valley Dam's location in a wetland environment, and highly erodible soils presented a challenge for the construction team. Discovery of eels and inanga within isolated ponded areas, often elevated within stockpiled material, required planning, trapping, and other methods to effectively relocate.

Erosion and sediment control for the approximately five-hectare site was achieved by various methods. Cutoff 'clean water' channels were established to intercept surface water and divert around the site. A large sediment settlement pond was established early in the work to which areas of standing water were pumped prior to discharge. Low bunds around construction work were extensively utilized, both to keep sediment laden water within the site, and clean water out of the site. Stabilisation of areas with jute matting, erosion resistant polymer, and hydroseeded clover were all used with varying degrees of success.

Nesting of protected native birds in the valley was common during spring-time construction. Construction proceeded with expert ornithological oversight to ensure construction activities complied with all legal requirements, and did not disturb nesting birds. Diversion of the existing waterway was undertaken at a time of very low flow, and minimal over-pumping was required. Compliance with resource consents was front of mind throughout the project, and successfully achieved by the project team.

5 AMENITY AND ENVIRONMENTAL BENEFITS

As well as achieving the key project outcomes of a safe flood detention dam and facilitating sediment deposition, the project also highlights how 'softer' engineering solutions can be applied to dams in urban setting so that they integrate sympathetically with the surrounding environment and facilitate recreational and environmental enhancement purposes.

The dam is located in a new residential area, along the main route to the popular Christchurch Adventure Park, and is visible from a popular route over the Port Hills. As such, the dam needed to blend into the landscape and not have a strong visual footprint. Figure 14 below shows the dam from the route to the Adventure Park. The dam is the grassed surface in the middle of the image, and even though landscape plantings around it are yet to be established, blends into the landscape. This has been achieved by using a shallow batter slope and picking the most 'natural' part of the valley for it to be located in, appearing to be an extension of the natural ridges.

Figure 14. Dam in the mid-ground demonstrating how it blends into the landscape.

The valley is a popular recreational destination, and so consideration of the needs of recreational users was a key part of the project. The dam itself offers a convenient means for pedestrians and cyclists to cross from one side of the valley to the other (offering a shortcut to the adventure park). Paths through the basin provide further access, while also acting as low check dams to increase sediment deposition. The paths also provide maintenance access throughout the facility. 'Natural' seating was provided for moderate cost by re-using logs felled from gum and macrocarpa on the site. This increases the community connection to the area, facilitating ongoing care and maintenance of the facility.

Figure 15. Informal seating provided through materials harvested on the site.

Consideration for the non-human occupants of the valley was also an important consideration. Although pest species were a challenge in establishing planting in the valley, it is an important area for native birds, fish and lizards. While lizards might not be associated with a flood detention dam (and a natural ponding area), they were identified through pre-construction ecological surveys. An opportunity to provide better habitat (rather than the assumed climbing of fence posts during flood events previously) on the sides of dam detention area. Rocks and suitable shrub species were added along the north-facing side of the upper basin, ideal habitat for lizards (Figure 16).

Figure 16. Educational signs about lizard habitat.

Lizards live here

We've created this rocky area as a home for native lizards.

What makes a great home for sun-loving skinks and night-stalking geckos?

- Tall grasses
- Warm rocks to sunbathe on
- Plenty of places to hide from predators

Geckos and skinks are protected under law. That means it's against the law to disturb, catch or injure our native lizards. You can attract native lizards to your garden by making it lizard-friendly.

Did you know?

New Zealand has over 110 diffe
native lizards. We have geckos
not found anywhere else in th
lizards are fully protected an
habitat as a place for them t

How to spot a lizard

You have to very patient and quiet, as these little guys are very shy. On a warm day (at least 18 degrees, as lizards don't like being outside in the cold), grab some bin
to look for skink

Consideration was also given to improving stream conditions for migrating fish. Prior to the project Cashmere Valley Drain had a highly variable invert, leading to fish stranding. The new engineered low flow channel has a more even grade, and the vertical transition between the forebay pond and the low flow channel was engineered in accordance with NIWA (2018) Guidelines which provide areas of respite from the high velocities.

Figure 17 Two sections of the low flow channel. Leftlooking upstream towards forebay pond and transition. Right engineered grade transition between forebay pond and low flow channel during a small flood

6 CONCLUSION AND RECOMENDATIONS

Stormwater detention infrastructure is likely to be increasingly required in urban areas in the future to mitigate the impacts of climate change. It is important that such infrastructure is designed in a rational manner that accounts for the potential consequences of failure.

Water retaining embankments that are above the Large Dam threshold require a building consent, and will via this process be designed in accordance with the New Zealand Dam Safety Guidelines. The Authors further recommend water retaining embankments meeting the 2022-24 definition of Classifiable Dams are also designed in accordance with dam design practice. Whilst this may not be a legal requirement, following dam design practice gives asset owners confidence that good practice has been followed. It also ensures, should future revisions to the Regulations be made the Potential Impact Classification is defined and any subsequent design, documentation and management decisions are commensurate with this classification. The Authors are aware that an update to the New Zealand Dam Safety Guidelines is due in 2024 that will offer improved guidance around the design of flood detention dams.

The Cashmere Valley Dam demonstrates good practice in design and construction of a stormwater detention system. The design is considerate of the impact of a theoretical dam break failure, and incorporates robust defensive design measures. The investigation and design of embankment, structures, spillway, and mechanical plant follows national and international practice to achieve the appropriate alternative solution required for building consent. Construction of the Cashmere Valley Dam was carefully monitored, and inspections and testing completed to ensure sound construction whilst keeping dam failure modes front of mind. Cashmere Valley Dam also illustrates that in conjunction with flood detention dams it is possible, and desirable, to incorporate features within the reservoir that enhance biodiversity and recreational values.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge CCC for their collaboration in producing this paper.

REFERENCES

Christchurch City Council (2022). *Heathcote Catchment.* Available at https://ccc.govt.nz/services/water-and-drainage/stormwater-and-drainage/stormwater-projects/heathcote-catchment (Accessed 9 April 2024).

Fell, R., MacGregor, P., Stapledon, D., Bell, G. and Foster, M. (2015). Geotechnical Engineering of Dams, Taylor & Francis Group, London, 498 & 568.

Harvie, W. (2022). $31 million Cashmere Dam to ease Heathcote river flooding. *Stuff.* Available at https://www.stuff.co.nz/the-press/news/129381767/31-million-cashmere-dam-to-ease-heathcote-river-flooding 28 June 2022.

Hewlett, H. W. M.; Boorman, L. A.; Bramley, M. E (1987). Design of Reinforced Grass Waterways. Construction Industry Research & Information Association (CIRIA), London, UK. ISBN 10: 0860172856.

Ministry of Business, Innovation, and Employment (2004). Building Act 2004. Public Act: 2004 No 72. Date of assent: 24 August 2004. Version as at 23 December 2023.

Ministry of Business, Innovation, and Employment (2022). Building (Dam Safety) Regulations 2022. Date of assent: 09 March 2022.

Ministry of Business, Innovation, and Employment (2024). Guide to complying with the Dam Safety Regulations, Version 3, 22.

National Institute of Water and Atmospheric Research (2018). New Zealand Fish Passage Guidelines for structures up to 4 metres. Version 1.2.

NZSOLD (2023). New Zealand Dam Safety Guidelines. ISBN: 978-0-473-69764-8

Stantec New Zealand (2021). Cashmere Valley Flood Storage Dam Detailed Design Report. Prepared for Christchurch City Council.

NOMENCLATURE

PIC	Potential Impact Classification
Dam Break	Assessment of the uncontrolled release of impounded water from a dam reservoir
PAR	Population at Risk
The Act	Building Act 2004
The Regulations	Building (Dam Safety) Regulations 2022
NZSOLD	New Zealand Society on Large Dams
DSAP	Dam Safety Assurance Programme
Classifiable Dam	Dam 4 m or higher with 20,000 m^3 or greater in storage volume (water or fluid)
Recognised Engineer	Engineer registered under the Regulations to audit and certify dam PIC, DSAP, and annual compliance certificates.
Core	Low permeability soil at the centre of a dam embankment
Filter	Internal erosion protection material in a dam embankment
Shoulder	Protective dam embankment material supporting the core.
Toe drain	Subsoil drain at the downstream extent of a dam embankment
Spillway	Channel to pass flood water
Penstock gate	Slide gate controlling water discharge
NDM	Nuclear Densometer