Mount Welcome - Hydrology Assessment

Prepared for

Pukerua Property Group LP

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Limitations:

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Pukerua Property Group LP and others (not directly contracted by PDP for the work), including Envelope Engineering Limited, BlueGreen Ecology Limited, Classic Developments Limited and Greater Wellington Regional Council. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

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Executive Summary

Pukerua Property Group LP (the Applicant) are seeking to obtain fast-track resource consent for the development of a residential subdivision near Pukerua Bay, known as Mount Welcome. The site is currently farmland, made up of a series of paddocks, small streams, wetlands, and native and indigenous vegetation. The change in land use will results in an increase in impervious surfaces and changes to the direction and intensity of surface water flow, which could potentially affect the wetlands and streams present on the site.

In order to assess the scale and potential mitigation of these possible impacts, Pattle Delamore Partners Limited has completed a hydrology assessment of the catchment with the focus being on the wetlands and downstream flows. Detailed quantitative water balance models were developed in GoldSim™ for the two catchments most affected by the development, known as the Taupo and Kakaho West catchments for the streams they discharge into. The following continuous simulations were run using local rainfall and evaporation data to assess the potential effects:

- 25 years (1991 to 2025) at a 1 day timestep to look at long-term variations in the wetland water levels under different climatic conditions;
- 1 year (July 2023 to July 2024) at a 5 minute timestep to look at the variations in surface water flow from the various catchments; and
- 24 hours at 5 minute timestep to look at the impacts of 10 and 1% annual exceedance probability rainfall events.

These scenarios were run for baseline conditions and were updated as follows and re-run for the post-development conditions:

- Changes to catchment areas and impervious surfaces;
- Locations of treated stormwater discharge; and
- Retention wetland bunds at four retention wetlands, with restricted culvert discharges and storage capacity.

The Muri Road and Kakaho East catchments are significantly less impacted by the development than the Taupō and Kakaho West catchments, so more basic water balance calculations have been completed for these parts of the site.

The results of the modelling indicate that there will be additional run-off into the majority of the wetlands post-development due to the increase in impervious surfaces. This will result in generally wetter wetlands, although some seasonal variation will still occur. In areas where the wetlands will be significantly wetter, particularly the retention wetlands, BlueGreen Ecology has developed an appropriate planting plan to cope with these conditions. Given that the current wetlands are predominantly exotic species, the planting of appropriate native

species will enhance the wetland environments and allow them to cope with any changes in hydrology.

The majority of the streams on site are ephemeral. There will be more flow in these streams post development but they will remain ephemeral for the most part. Overall, the total discharge from the site into the Taupō and Kakaho Streams will increase, but the use of retention wetlands will ensure that peak flows are lower during large rainfall events. This means that periods with no flow are likely to be reduced, but also periods of high intensity flow will also be fewer post-development. This indicates that there should not be a negative effect on the downstream hydrology.

An assessment of the changes in sediment transport indicates that the increase in average discharge from the site will not be sufficient to increase the risk of sediment mobilisation. Given the reduction in the peak velocities as a result of the stormwater design, the risk associated with sediment movement within the streams are slightly reduced post-development.

However, it is noted that the modelling undertaken is based on a number of assumptions and a limited amount of baseline data. It is therefore recommended that baseline monitoring continues until construction and the model is reviewed against this data to ensure the results are representative.

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1.0 Introduction

1.1 Project Background

Pukerua Property Group LP (the Applicant) are seeking to obtain fast-track resource consent for the development of a residential subdivision near Pukerua Bay, known as Mount Welcome. The site is currently farmland, made up of a series of paddocks, small streams, wetlands, and native and indigenous vegetation. It will be developed into approximately 950 residential lots (see Figure 1 for location).

Due to the change in area of impervious surfaces, along with change to the direction and intensities of surface water flows, the wetlands and streams on site and downstream receptors may be affected. The Applicant has commissioned Pattle Delamore Partners Limited (PDP) to complete a hydrological assessment of the effects of the proposed development on the wetlands and streams both on and off site. Envelope Engineering Limited (Envelope) have provided draft stormwater designs, demonstrating how surface water from the site will be managed. This involves a series of raingarden treatment devices discharging into retention wetlands, which use some of the existing wetlands on site to retain flow during peak events, before discharging downstream.

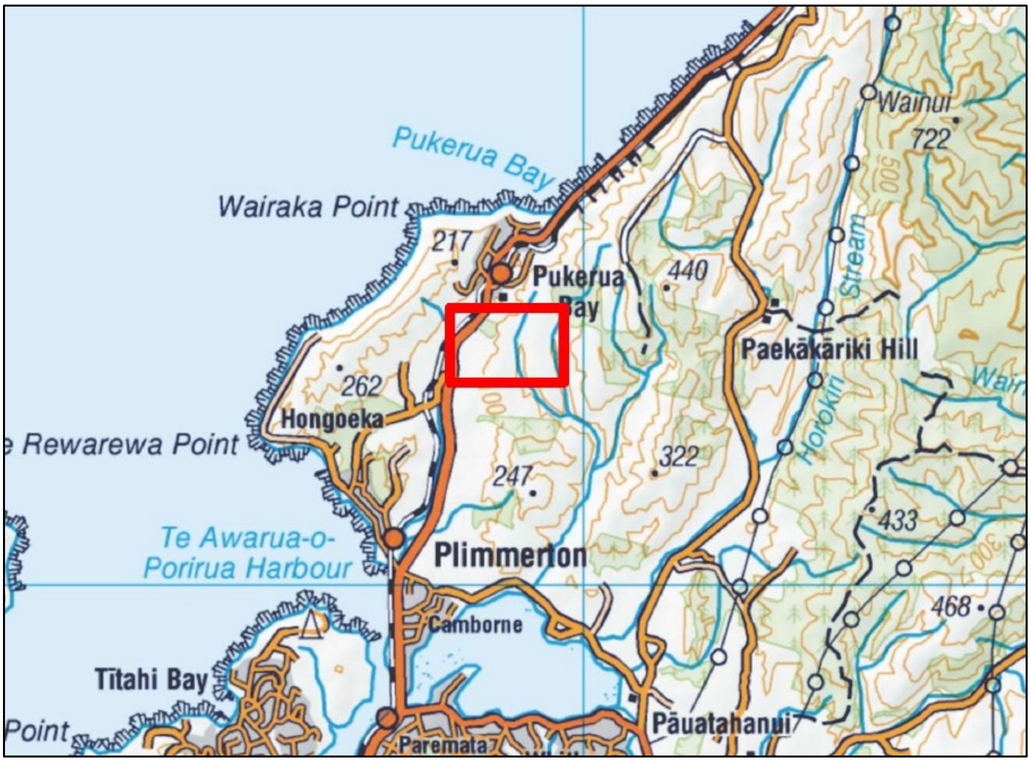

Figure 1: Site Location

1.2 Aims and Exclusions

The purpose of this report is to assess the potential effects of the development on the hydrology of:

- All the delineated retained wetland areas present at the site;
- The predominantly ephemeral streams present at the site; and
- The downstream off-site stream flows in the Taupō, Kakaho and Waimapihi Stream catchments.

Some areas of existing wetland will be removed as part of the development and will be offset elsewhere. The delineation of the wetlands and classification of watercourses within the site was undertaken by Boffa Miskell Limited and is detailed in the Mt Welcome Natural Inland Wetland Offset that was prepared during the preliminary investigation (Boffa Miskell Limited, 2023). A more detailed assessment of the wetlands has been completed by BlueGreen Ecology to support the fast-track resource consent application (BlueGreen Ecology Limited, 2025).

The purpose of this report is to assess the effects on the retained wetlands. Wetland loss and proposed offsetting have been covered in the Mt Welcome Ecological assessment (BlueGreen Ecology Limited, 2025).

The report also focuses on the assessment of the hydrological effects on the offsite streams (primarily the Taupō and Kakaho Streams) as the on-site streams are mostly ephemeral and at the very low end of ecological value (Blue Green 2025). The impacts on water quality of the retained wetlands and downstream receptors are covered in a separate report (PDP, 2025).

1.3 Report Overview

This report details the assessment of potential effects of the development on the existing hydrology of the site and includes the following:

- Site descriptions including both wetlands and streams;
- Baseline monitoring data for the wetlands and streams within the project area;
- Development plans, and how they may affect the wetlands and streams;
- Quantitative assessment methodology, including development and calibration of catchment water balance models;
- Assessment of effects on the wetland hydrology and downstream environments (e.g. the Taupō and Kakaho Streams), including:
  - Changes to catchment area;
  - Changes to stormwater run-off volumes and discharge locations;

- Changes to groundwater recharge; and,
- Mitigation and monitoring measures (where considered necessary).

2.0 Site Context

2.1 Location and Topography

The Mt Welcome site is legally described as:

- Lot 1 DP 608433, Lot 1000 DP 608433 (34 Muri Road);
- Lot 1 DP 534864 (422 SH59);
- Lot 2 DP 534864 (422A SH59);
- Lot 2 DP 89102 (422B SH59);
- Part Lot 1 DP 89102 (422A SH59); and
- SH59 corridor adjacent to the site which is legally described as Road Reserve.

The site is currently covered in pasture and managed as an active deer/cattle farm. There are small pockets of native and exotic woodland and wetland areas within the site, which will be described in more detail in Section 2.6. The site primarily comprises steep sided hills, cut by incised valleys. The ground elevation ranges from 35 m above sea level (asl) in the southwestern corner to 301 m asl on the far eastern boundary, although the highest point in the development area is 175 m asl. The lower parts of the valleys are primarily occupied by wetlands and streams (see Figure 4), with pasture also present where the gullies are wider.

The site is bounded to the west by State Highway 59 (SH59, formerly SH1), and to the north by the Muri Road block, which is currently undergoing development. The land to the south and east is occupied by pasture and used for farming.

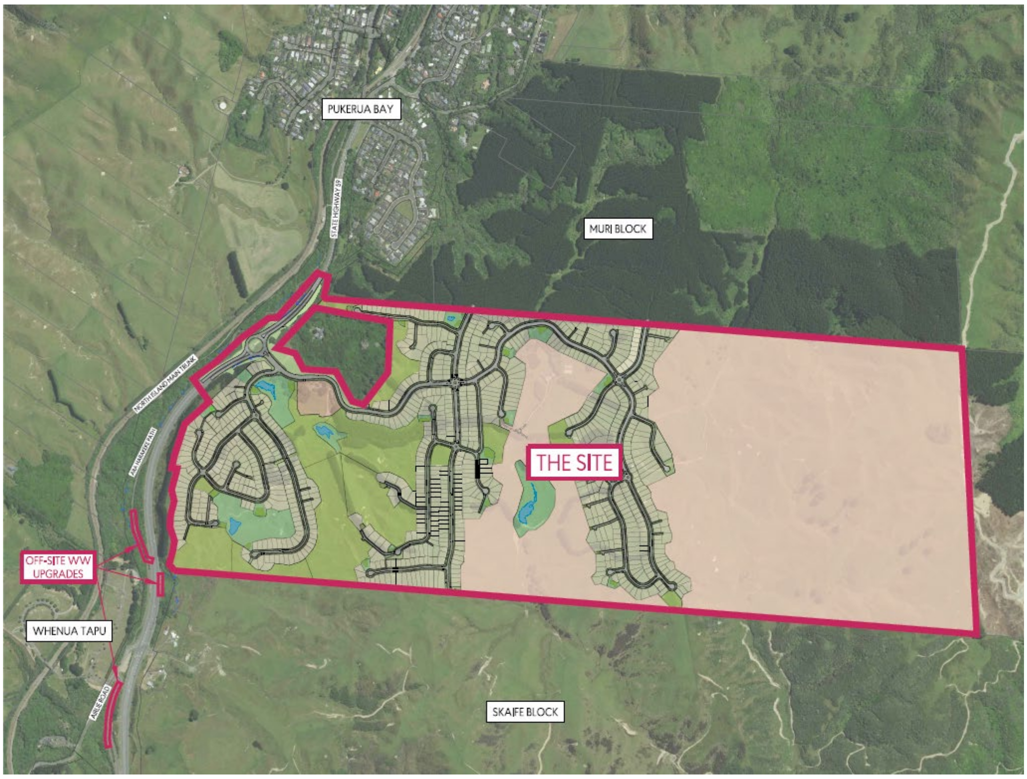

Figure 2: Proposed Site Layout (adapted from Envelope drawing 1753-02-1200-R3)

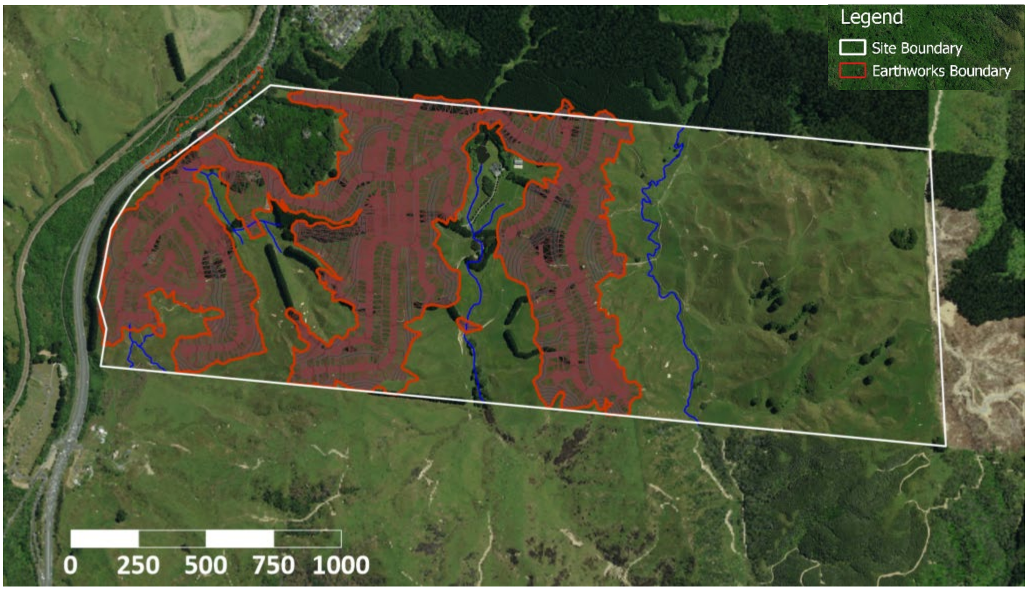

Figure 3: Earthworks Extent

Figure 4: Wetlands in Valley Floors

2.2 Climate

The annual rainfall of the Wellington region is highly variable and is largely driven by the local topography. However, with the exception of the central Tararua Range and Wairarapa Plains, the majority of the region typically experiences 1,000 to 1,200 mm/year (Chappell, 2014). In lieu of site-specific data, data collected at the closest regional rain gauge at the *Taupō Stream at Whenua Tapu* site (GWRC, 2025) indicates that the average annual rainfall in the general site area is approximately 1,040 mm/year (data available from 1991 to present) see Figure 5. Rainfall occurs year-round but is lowest between February and May (Figure 6).

A cumulative difference trend has been developed for the monthly rainfall data and is presented in Figure 7. This indicates that the area experienced a drying trend between 2000 and 2008, before there was a period of relatively stable rainfall until 2020. There was a steep wetting trend between 2020 and 2022, which is a reflection of the relatively high annual rainfall over these three years (Figure 1) before more average rainfall from 2023.

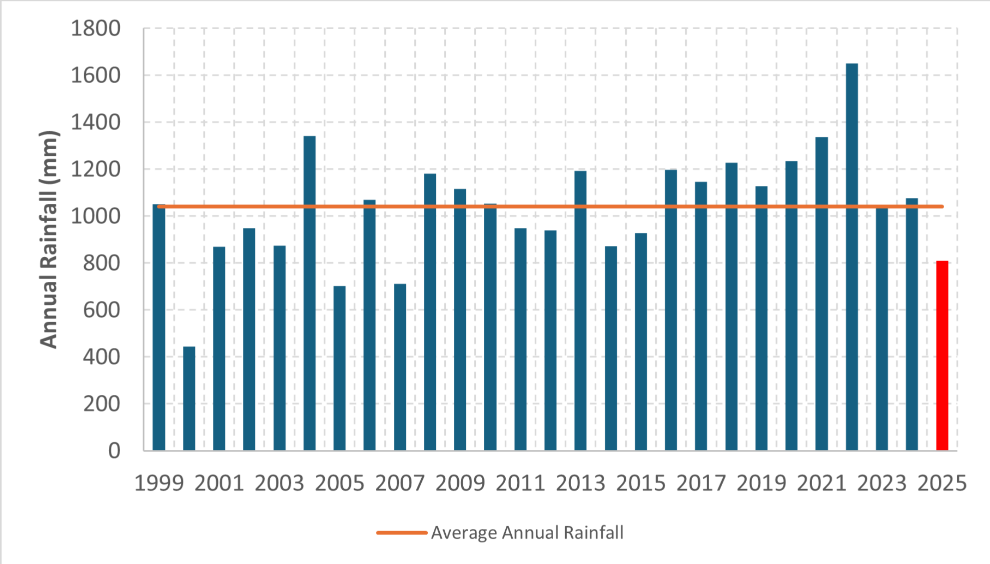

Figure 5: Annual Rainfall at Taupō Stream Whenua Tapu (red columns indicate <300 days recorded data)

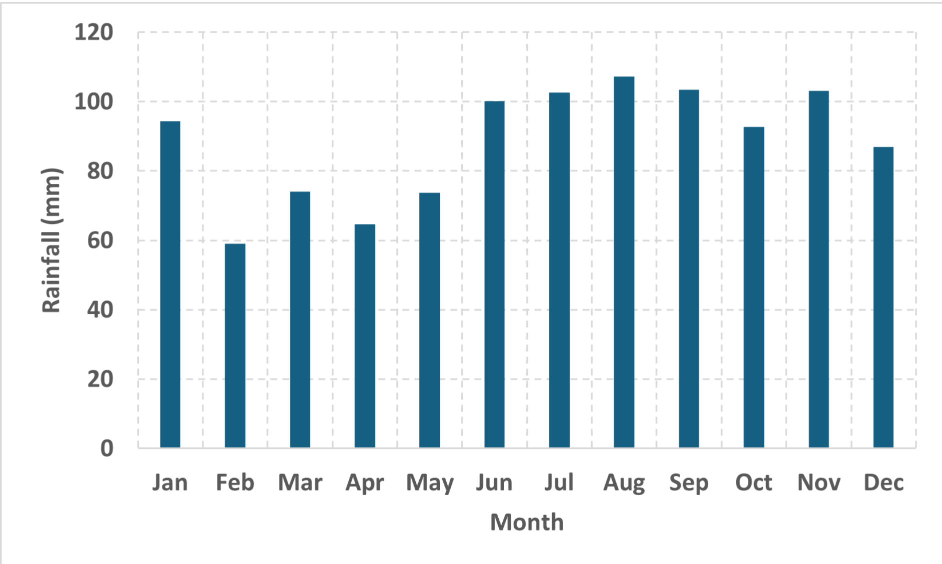

Figure 6: Seasonal Variation in Rainfall Monthly Average Rainfall (1999 - 2025)

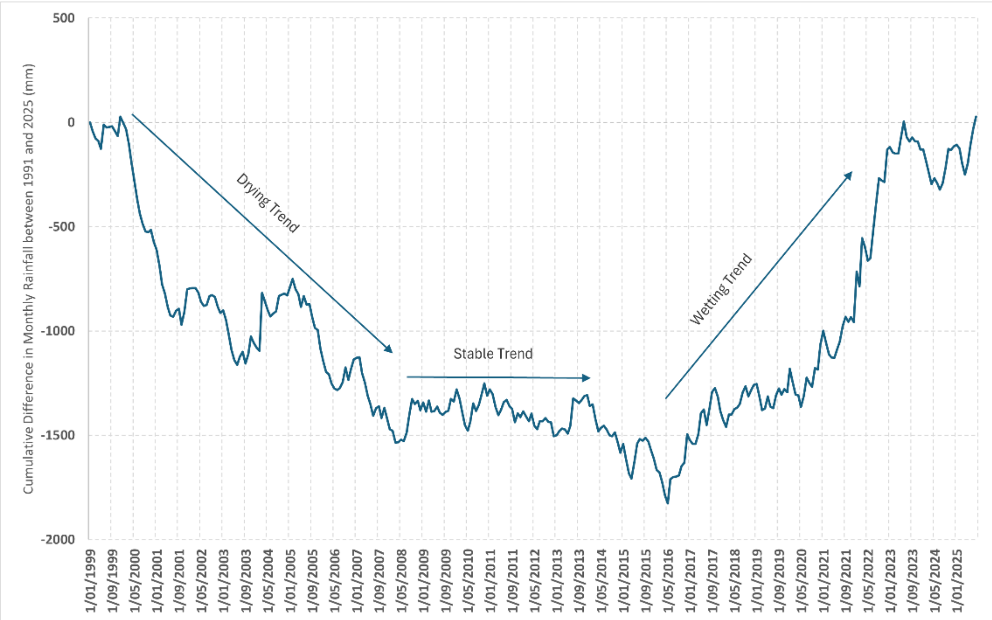

Figure 7: Cumulative Difference in Monthly Rainfall at Taupō Stream Whenua Tapu (1999 - 2025)

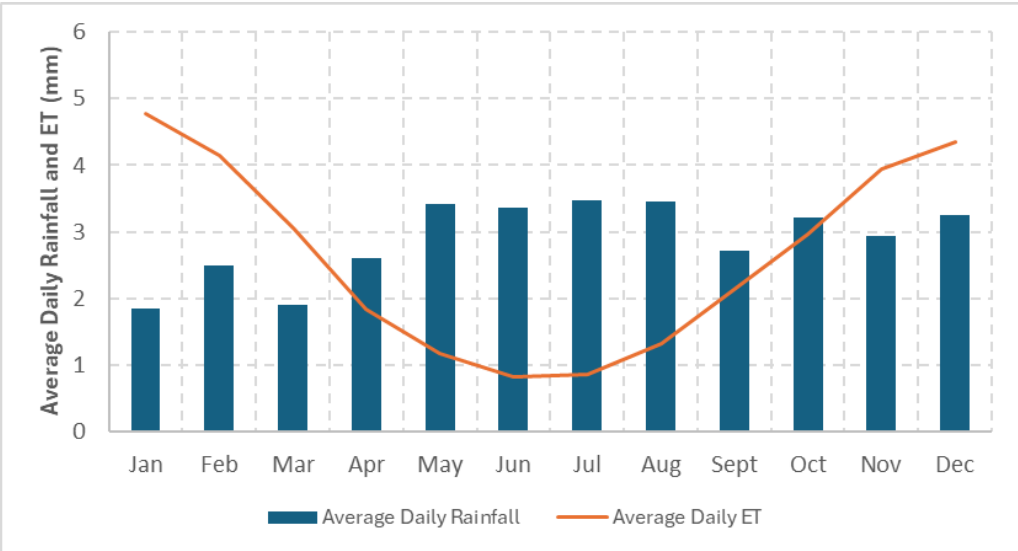

Figure 8: Seasonal Variation in Rainfall and Evapotranspiration (1999-2025)

The nearest potential evapotranspiration data is available from the Porirua Elsdon Park and Paraparaumu Aero weather stations (NIWA, 2025). The Paraparaumu record is more complete and extends from March 1993 to August 2025 so has been used for this assessment. The average annual potential evapotranspiration in the region is approximately 936 mm, which is lower than the annual rainfall. However, there is significantly more seasonal variation in potential evapotranspiration, with most occurring between September and April (Figure 8).

2.3 Hydrology

There are four main catchments at the site:

- Taupō Stream
- Kakaho Stream West
- Kakaho Stream East
- Waimapihi Stream

The Taupō Stream catchment can be subdivided into three sub catchments discharging west and south forming the headwaters of Taupō Stream and Taupō Swamp. The Taupō Swamp complex is a regionally significant lowland freshwater wetland of high ecological value and has been protected via a QEII covenant since 1988.

The two eastern catchments (Kakaho West and East) discharge south into the Kakaho Stream, which flows into the Pāuatahanui Arm of the Te Awarua-o-Porirua Harbour 4.6 km downstream of the site. This is a highly sensitive estuarine environment.

The site also includes a small portion of the upper reaches of the Waimapihi Stream catchment, which discharges north into the Muri Road block and flows into the sea at Pukerua Bay.

The majority of the streams on the site are ephemeral, but there are perennial reaches in the lower parts of the catchments. Stream flows are generally low, but respond rapidly to rainfall run-off from the steep catchments. The ecology assessment indicates that the streams draining west into the Taupo catchment are modified, low diversity, low functioning and in poor condition, without rarity, so classified as low value stream systems. Whilst the streams in the Kakaho catchments are in better condition, they are still modified with a of lack of shading, nutrient inputs, stock inputs, bank slumping and increased sedimentation.

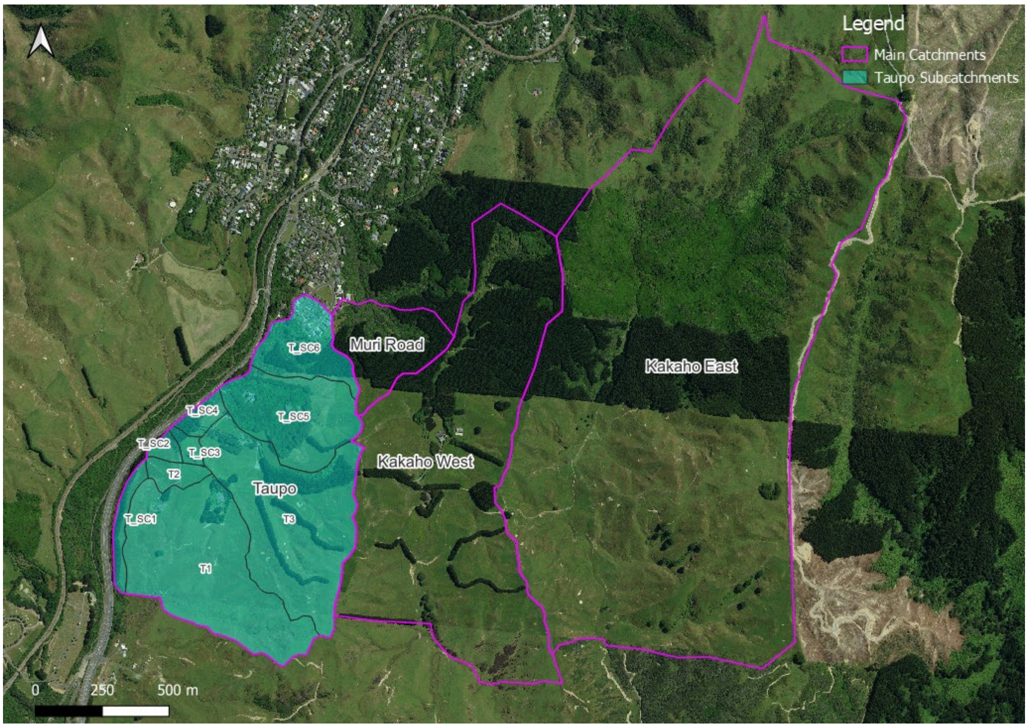

Figure 9: Key Site Catchments

2.4 Geology

The regional geological map indicates that the western part of the site is underlain by loess covered fan gravel deposits, over greywacke bedrock (Begg & Johnston, 2000). There is a small area of quaternary alluvium in the southwestern part of the site, with the remainder being greywacke bedrock of the Rakaia Terrane. The Pukerua Fault runs northeast to southwest and is located 600 m to the west of the site.

The geotechnical investigations completed at the site to date (ENGEO Limited, 2022) indicate that peat deposits up to 1.5 m thick are present in some gullies, although not likely to be laterally extensive. Minor loess and colluvium were present in some areas, but weathered greywacke bedrock was encountered at shallow depth across the majority of the site.

2.5 Hydrogeology

There is no large-scale regional aquifer present at the site, but groundwater is likely to be present in fractures and weathered horizons within the greywacke bedrock. There are no bores, or groundwater or surface water takes within the catchment. Seepages were observed in the lower parts of the gully systems, which may indicate the level of the regional groundwater table or flow within the alluvial valley deposits.

ENGEO has recently undertake further investigation and the preliminary results indicate that groundwater is relatively deep below the hills, but present at shallow depth within the alluvial deposits in the valleys. However, it's noted that the geotechnical investigations have all be undertaken in the winter season when water levels will be higher.

2.6 Wetlands

Wetlands on site have previously been identified by Boffa Miskell Limited (Boffa Miskell Limited, 2023) and during PDP's site walkover in some of the lower gully valleys, and seepages were visible during site walkover. Three classifications were made through rapid assessment by Boffa, including likely natural inland wetland, possibly natural inland, and probably not natural inland (Boffa Miskell Limited, 2023). No significant indigenous vegetation has been identified in the natural wetlands at the site, with all wetlands including only exotic wetland flora species common on farmland (BlueGreen Ecology Limited, 2025).

Significant earthworks are planned during development, leading to approximately 1.5 ha of natural inland wetland likely to be affected. The offset and enhancements proposed to mitigate this loss are detailed in the values assessment and offset calculations reported elsewhere (BlueGreen Ecology Limited, 2025).

This assessment focuses solely on the retained wetlands (Figure 10), which can be split into two groups based on the hydrology:

1. Wetlands in the upper gully systems which are fed principally by direct rainfall and run-off, and may dry out periodically in the summer months; and
2. Wetlands in the valley floors, which are fed by direct rainfall and run-off, but also have contributions from groundwater discharge and stream flow/flooding, which are likely to have more stable water levels (albeit with some seasonal variation).

At present, the wetlands are unfenced and can be accessed by cattle and deer grazing at the site.

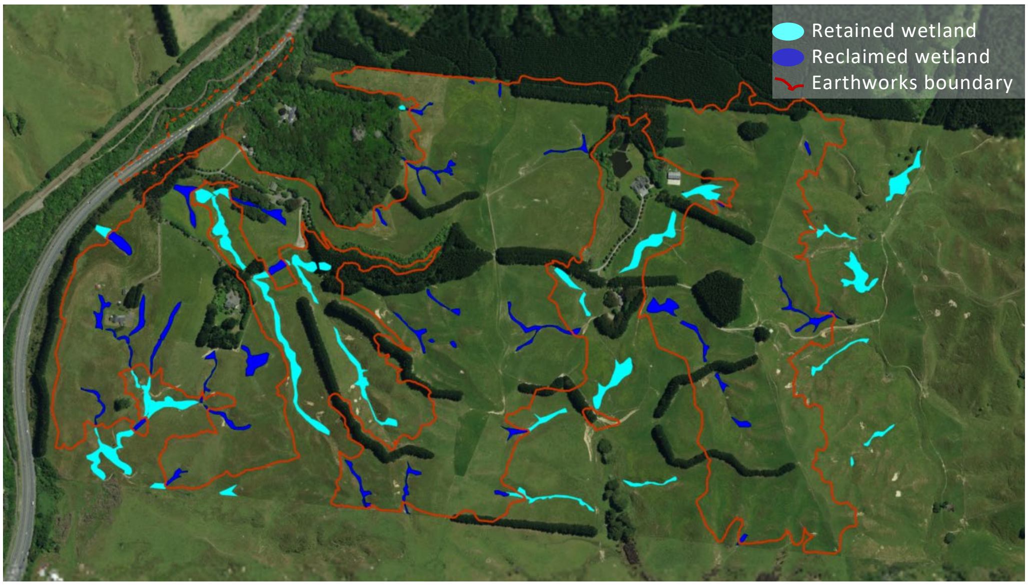

Figure 10: Wetland Extents

3.0 Planned Development

The proposed development will comprise approximately 950 lots for primarily residential use, with associated roads and infrastructure.

The proposed development will require significant earthworks (see Figure 3) and the installation of appropriate infrastructure (Envelope Engineering Limited, 2025). This will alter the catchment boundaries and, in some cases, flow paths into the wetlands. The key changes to the site that may impact the wetlands and streams are:

- Changes to catchment areas and an increase in impervious surfaces, affecting run-off and infiltration to groundwater;
- Diversion of run-off to the stormwater treatment and disposal system, which is to broadly replicate the existing catchments, but includes treatment devices (primarily rain gardens) and piping where required;
- Changes to culverts and road layouts downstream, which may affect the rate of flow from some of the wetland areas;
- Installation of retention wetland bunds to develop four of the existing wetlands into enhanced retention wetlands with permanent pools and increased ecological benefit; and
- Installation of a constructed stormwater retention pond to control the flow rate into the Waimapihi Stream catchment.

4.0 Baseline monitoring

To understand the existing hydrological conditions at the site, PDP has installed some baseline monitoring stations within the wetlands and streams discharging from the site (see Figure 11). There are:

- Three surface water monitoring locations which continuously measure stage and turbidity in the streams.
- Four wetland monitoring piezometers which continuously measure water levels in key wetland areas.

Monitoring only started in August 2025 so a limited amount of site-specific baseline data is available at this stage. The available data includes:

- One month of continuous wetland water levels from BH01, BH02, BH03, BH04;
- One-month continuous stream stage from SW01, SW02, SW03;
- One set of discrete flow discharge measurements from SW01, SW02, SW03; and
- Long-term synthetic flow discharge data estimated for SW01, SW02, SW03.

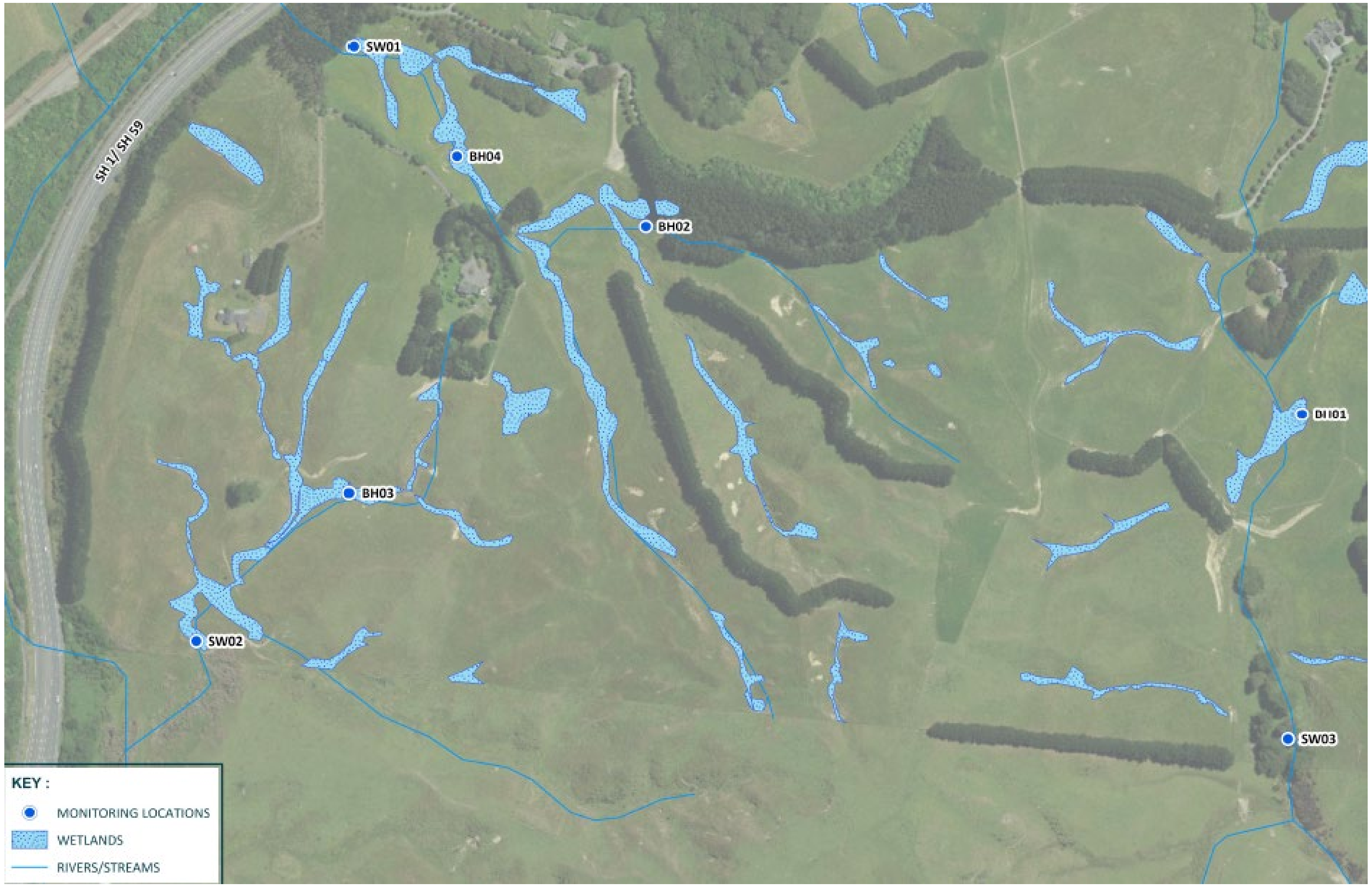

Figure 11: Monitoring Locations

4.1 Continuous wetland water levels

Wetland piezometers were installed between 23 and 28 July 2025 to measure the water levels within the wetlands. Continuous water levels are measured using pressure transducers, compensated for barometric pressure using local data and calibrated using regular manual dip measurements. The available data was downloaded on 26 August 2025 and is presented in Figure 12. It is noted that the piezometers were located for long term monitoring, so are on the edges of most of the wetlands to ensure they remain usable following the installation of the retention wetlands. The edges are more elevated than the main body of the wetland, meaning that the water levels are deeper in the monitoring points than in the central parts of the wetlands where the ground level is lower and water levels are closer to the surface.

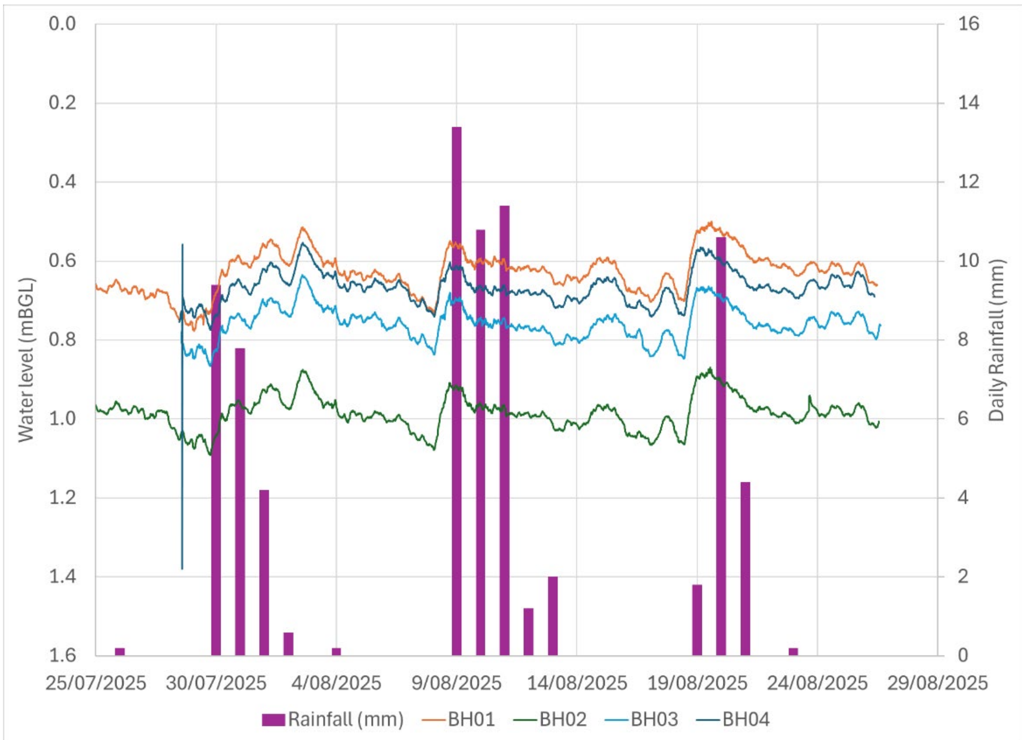

Figure 12: Baseline Wetland Water Levels

The results indicate that the water levels are relatively stable in the four wetlands monitored under winter conditions. There are small increases in water level, tied to rainfall, but none of the water levels fluctuate more than 0.2 m over the monitored period. However, it is anticipated that the fluctuations may be greater in the summer when rainfall is less frequent.

4.2 Stream hydrology and synthetic record

Level loggers were installed at each surface water monitoring point to continuously record the stage in the key streams, where they discharge from the site. As with the wetland bore monitoring sites, this water level data was compensated with local barometric pressure.

One discrete stream flow measurement was gauged at each surface water site using a FlowTracker2 on 26 August 2025. Due to the limited available data, a relationship between stage and flow could not be established so a synthetic record for each site was developed and checked against the stage readings and flow gauging results.

The long-term flow record from GWRC's Horokiri Stream at Snodgrass site was used to develop the synthetic flow record for the site, as it was the closest continuous flow monitoring station to Mt Welcome (GWRC, 2025). Using the MfE river classification database (Ministry for the Environment, 2025), the catchment area at the discharge location was found to be 39.4 times larger than SW03 catchment, 115.3 times larger than the SW02 catchment and 78.4 times larger than the SW01 catchment. The discharge record from the Horokiri Stream at Snodgrass site was then divided by 39.4, 115.3, and 78.4 for an estimated discharge record for each catchment, respectively.

To validate this synthetic record, the estimated discharge for each stream was compared to the discharge recorded from the manual flow gauging at the relative site for the same time and date. The estimated record was similar to that of the manually recorded flow, so was considered sufficient to use as calibration flow data (see Figure 13 for example). However, as the record was only able to be validated with one manual discharge data point at each site it should be treated with caution.

It is acknowledged that the gauging site on the Horokiwi Stream is in the lower parts of the catchment, whereas the Mount Welcome site is located in the upper parts of the Taupo and Kakaho catchments so flows from the site are likely to be less attenuated. However, there is no data available for similar catchments within the region and the current record on site is insufficient to accurately develop flow curves for the monitored catchments. This synthetic record has been used as a high-level check to confirm that the daily discharge from the model is of the correct order of magnitude for the period baseline monitored period. It has not been used for a more detailed calibration due to the limitations discussed.

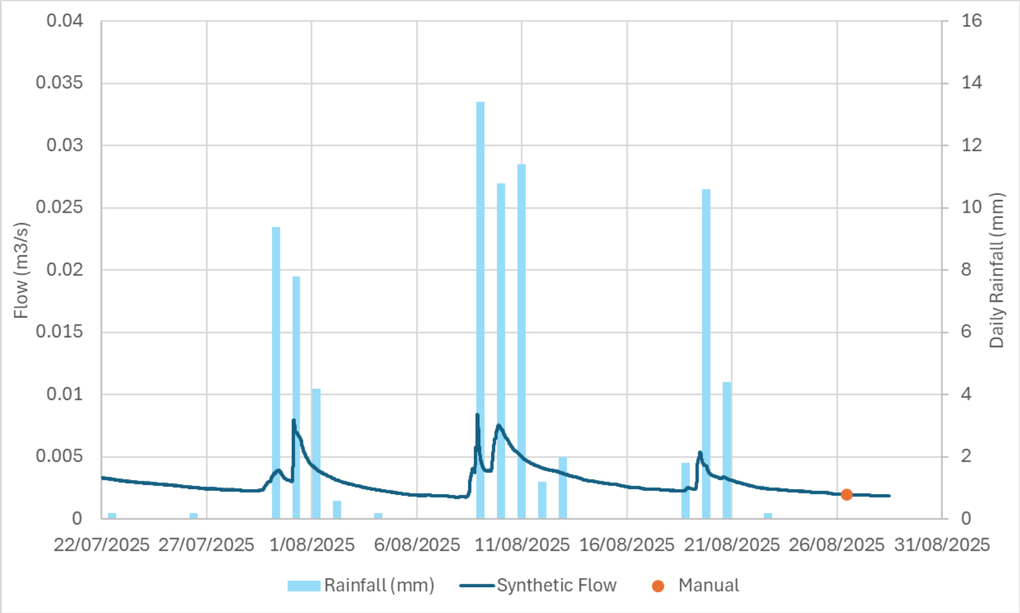

Figure 13: Estimated Baseline Flow at SW01

5.0 Conceptual Models

Figure 14 shows the basic conceptual model for the types of wetland present at the site. Based on the information provided, the limited baseline monitoring data available to date and the site walkover, it is considered likely that the majority of the wetlands are perched above the regional groundwater table although there may be some local groundwater flows within alluvial deposits and weathered bedrock in the channels. Therefore, the majority of the wetlands are likely to be of the perched upper catchment type, although the ones in the southwest corner of the site may intersect regional groundwater.

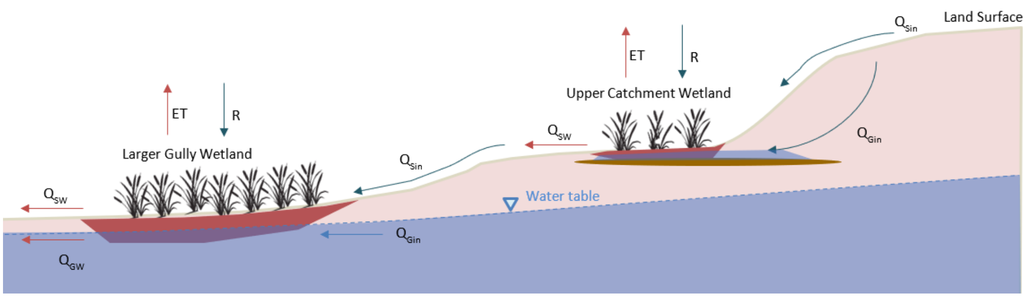

Figure 14: Wetland Conceptual Model

Discharge from the wetlands and run-off from the surrounding slopes contributes to flow in the Taupō Stream and Kakaho Stream respectively. The results of the surface water monitoring indicate that flows respond rapidly to rainfall, which is not surprising given the steep hillsides and relatively low permeability of the surface geology.

5.1 Taupō Stream Catchments

The Taupō Stream Catchment is made up of three main subcatchments (named T1, T2 and T3 for the purposes of this assessment), which comprise steep gullies with wetlands that discharge into the Taupō Stream (see Figure 9 and Figure 10).

The retained wetlands in the T1 catchment are a small area of interlinked wetlands in the southwestern block of the site, near the edge of the property boundary. These wetlands are likely to be primarily supported by surface-water run-off, although there may be some contribution from groundwater in the lower reaches where there is a small tributary of the Taupō Stream. This discharges southwest onto the neighbouring property before passing under SH 59 via culvert and joining the Taupō Stream. The T1 catchment has an area of 0.4 km^2 (Ministry for the Environment, 2025).

The T2 catchment is relatively small at approximately 2 ha and includes a small area of wetland just upstream of the culvert where it discharges below SH59 into the Taupō Stream. There is no permanent flow from this catchment and the wetland is likely to be primarily supported by run-off and direct rainfall.

The T3 catchment includes a series of long and thin gully wetlands, which are largely supported by direct rainfall, runoff and a combination of streams and farm drains. There may be a minor groundwater component in the downstream reaches where there is a small tributary of the Taupō Stream. This discharges northwest under SH59 via culvert before joining the Taupō Stream. The T3 catchment has an area of 0.9 km^2 (Ministry for the Environment, 2025).

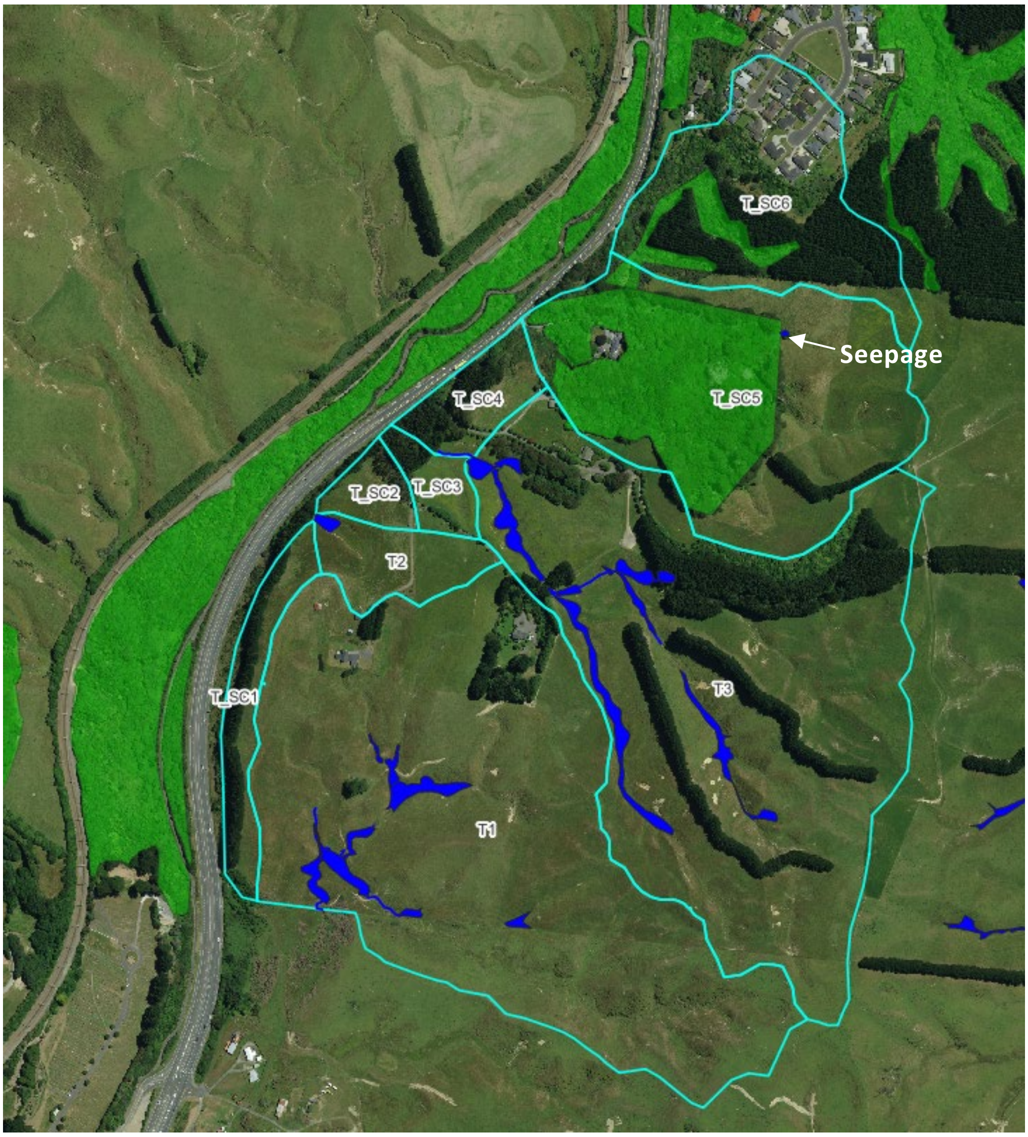

Figure 15: Taupō Stream Catchments (green areas are SNAs)

In addition to the wetland supporting catchments, there is also a catchment immediately north of T3 (designated T_SC5 in this assessment, see Figure 15) which does not include any wetlands but has a large portion of native bush designated as a Significant Natural Area (SNA) (Porirua City Council, 2022). This catchment is fed primarily by run-off, but it is understood that there is a small seep in the northeastern reach which provides some base flow (see Figure 15). This is likely to be associated with a fracture or weathering horizon rather than regional groundwater, given the elevation of approximately 90 m ASL. The catchment discharges to the west under SH59 via culvert into the Taupō Stream.

The primary vegetation within the Taupō Stream Catchments is pasture, with a small amount of pine forest and a larger area of native bush associated with the SNA.

5.2 Kakaho Stream Catchments

The two eastern catchments discharge south into the Kakaho Stream and form part of the upper catchment of this surface water system. These two catchments have been designated as Kakaho West and Kakaho East for the purposes of this assessment.

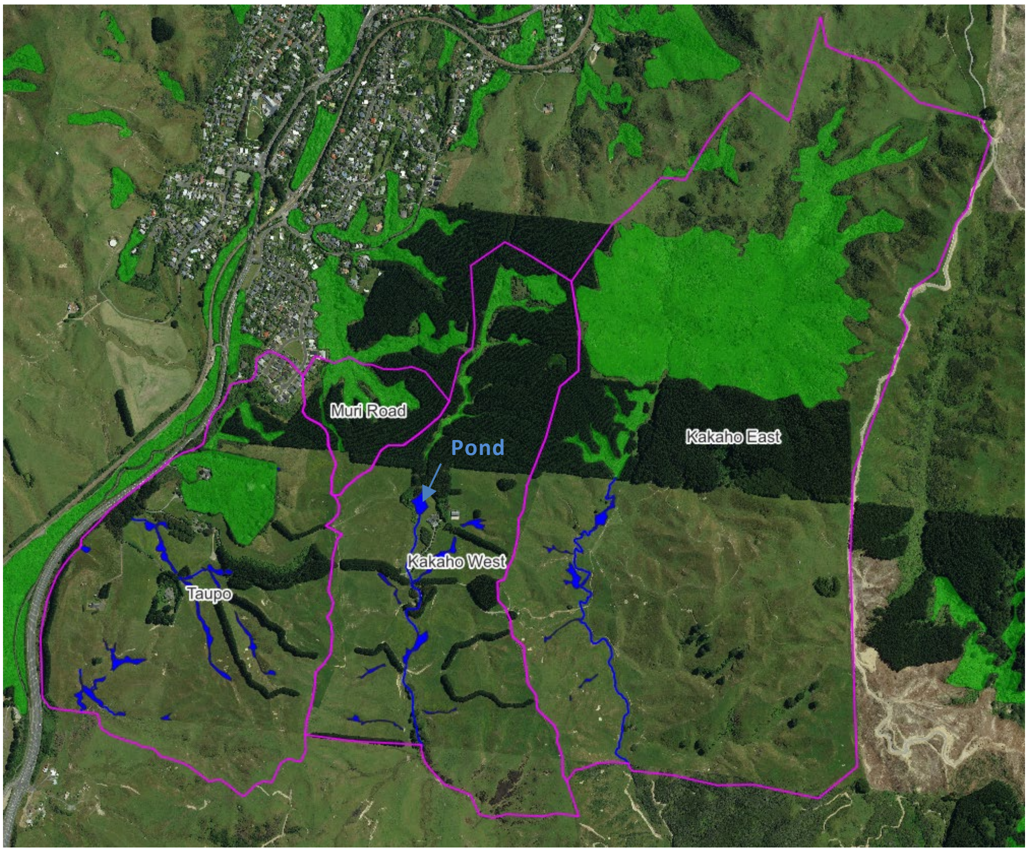

Figure 16: Kakaho Catchments (green areas are SNAs)

The Kakaho West catchment extends north of the site boundary and includes part of the Muri Road block, which is currently pine forest (although this is being cleared). The part of the catchment within the site is primarily pasture with a series of small gully seepage wetlands which all discharge into the Kakaho Stream. These gully wetlands are primarily supported by run-off and direct rainfall and are likely to dry out periodically in the summer.

There are several small wetlands on the valley floor, which are also likely to be primarily run-off supported, but may also have minor contributions from groundwater discharge and streamflow/flooding. The water level in these wetlands is likely to be more stable, but will also fluctuate seasonally to a lesser degree.

There is a man-made pond on the main stream channel near the northern boundary of the site. The lower part of the catchment includes a perennial tributary of the Kakaho Stream, in combination with a farm drain, which has a catchment area of 0.8 km^2 (Ministry for the Environment, 2025).

The Kakaho East catchment will remain mostly unaffected by the development, but the Lucas Block will result in some alterations to the western edge of this catchment so it has been included for completeness. The catchment is mostly pasture, with some pine forestry and nature bush north of the site boundary. There are several small wetlands in gullies along the western edge of the catchment, which are primarily supported by direct rainfall and run-off. These are likely to be subject to drier periods during the summer months.

There are also two wetlands on the valley floor. These are also likely to be primarily rainfall and run-off supported, but are located in proximity to the stream channel so may have contributions from streamflow/flooding and shallow groundwater. The water level within these valley wetlands may be more stable but is also likely to be subject to seasonal fluctuations.

5.3 Muri Road Catchment

A small part of the site near the northern boundary discharges north into the Muri Road block and has been designated the Muri Road catchment for the purposes of this assessment. The section of catchment within the site is pasture, but the downstream catchment comprises pine forestry and native bush. The catchment discharges into a larger wetland, known as West Wetland 1, which is located in the SNA shown in Figure 16. This wetland discharges northwest into the Waimapihi Stream which flows north through the township before discharging into Pukerua Bay, approximately 1.7 km from the site boundary.

There are no retained wetlands within the site in this catchment, but it is included in the assessment because of the potential effects on West Wetland 1 downstream.

6.0 Water Balance Model

The changes in hydrology at the site have been assessed by developing a quantitative water balance models for the two key catchments (Taupō and Kakaho West). This is considered to be a suitable method for assessing the impacts on the wetlands because for wetlands to be sustainable there can be no significant change in storage on an annual basis (i.e. a certain amount of water will need to be retained in these systems for the wetland vegetation to survive).

Given the interlinked nature of the wetlands and streams within these catchments, more refined models were developed using GoldSim™ to adequately consider the potential impacts. Details of the construction and calibration of these models are presented in this section.

The Muri Road and Kakaho East catchments are significantly less impacted by the development, so more basic water balance calculations have been completed for these parts of the site. The methodology is included in the results sections for these catchments.

6.1 Model Construction

A water balance assessment has been developed for the two main catchments, comprising a continuous simulation producing daily runoff volumes, with a run duration of 25 years. GoldSim™ models were developed for the existing wetland systems based on the conceptual models presented in Section 5.0. There were used to evaluate the potential effects of the proposed development on the wetland and surface water outflows. These outputs were used to refine the stormwater design to minimise and mitigate those effects. Details of the models construction, calibration and simulations are summarised in this section.

The modular nature of the wetlands and catchments at the site meant that it was simplest to develop a series of linked water balance models in GoldSim™. The site was divided into sub-catchments based on the wetland catchments, existing areas and proposed development area (see Figure 17). A soil moisture accounting model was developed for each sub-catchment. This is effectively a two-bucket scheme which uses empirical functions to describe evapotranspiration, surface run-off, interflow and infiltration to groundwater and was used to simulate the runoff and groundwater seepage into the wetland areas from each sub-catchment.

A water balance was calculated for each wetland area based on the following equation:

$$R - ET + Q_{Sin} + Q_{Gin} - Q_{SW} - Q_{gw} = \Delta S$$

Where:

R	=	Rainfall (directly onto the wetland)
ET	=	Evapotranspiration (from the wetland)
Q_{Sin}	=	Surface water and run-off discharge into wetland
Q_{Gin}	=	Groundwater discharge into wetland
Q_{SW}	=	Surface water discharge from the wetland
Q_{gw}	=	Groundwater discharge from the wetland
ΔS	=	Change in storage within the wetland

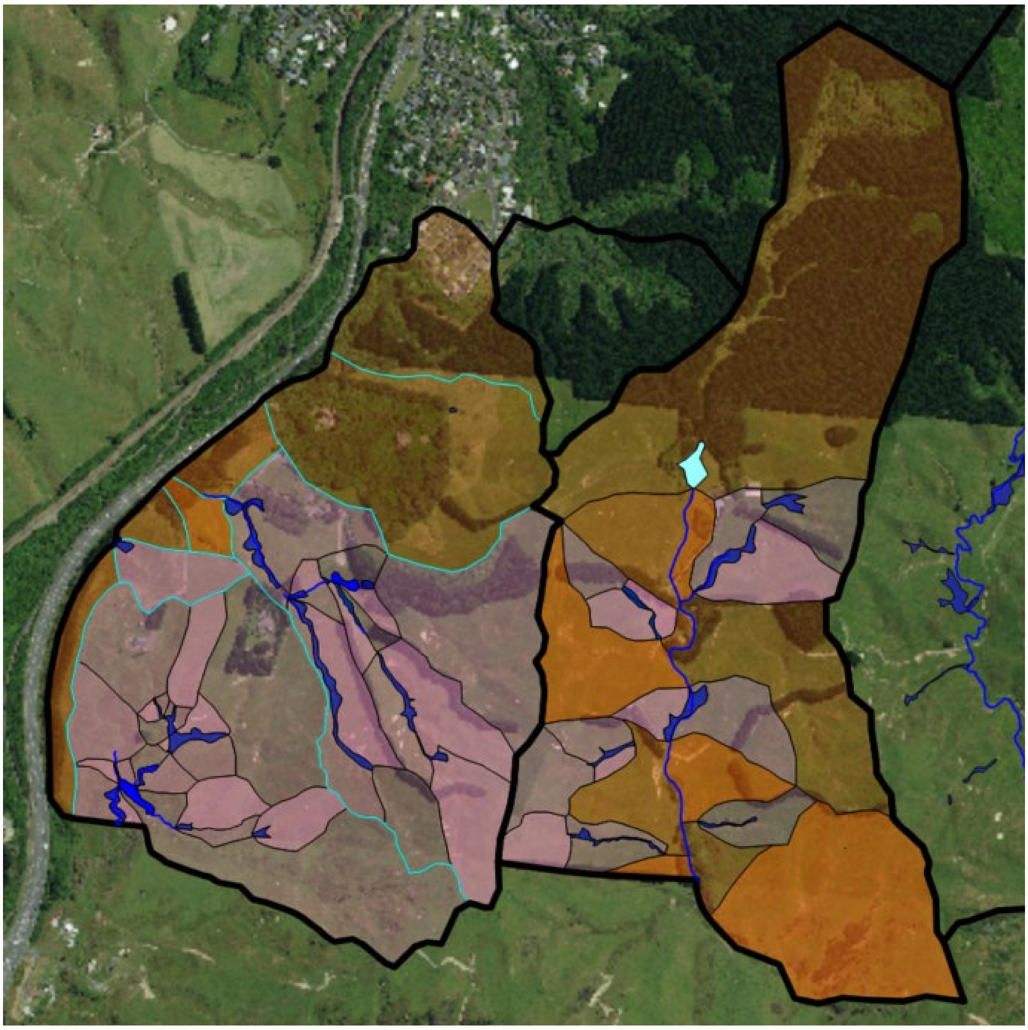

Figure 17: Catchments in Models (pink discharge into wetlands, orange directly into streams)

Examples of the model structure are shown in Figure 18 and Figure 19. The models were set up to run on a daily timestep for 25 years (1991 to 2025) and a 5-minute timestep for 1 year (July 2023 to July 2024). These two versions were used to look at the long-term implications on the wetlands and the short-term changes to peak flow velocities from the catchments.

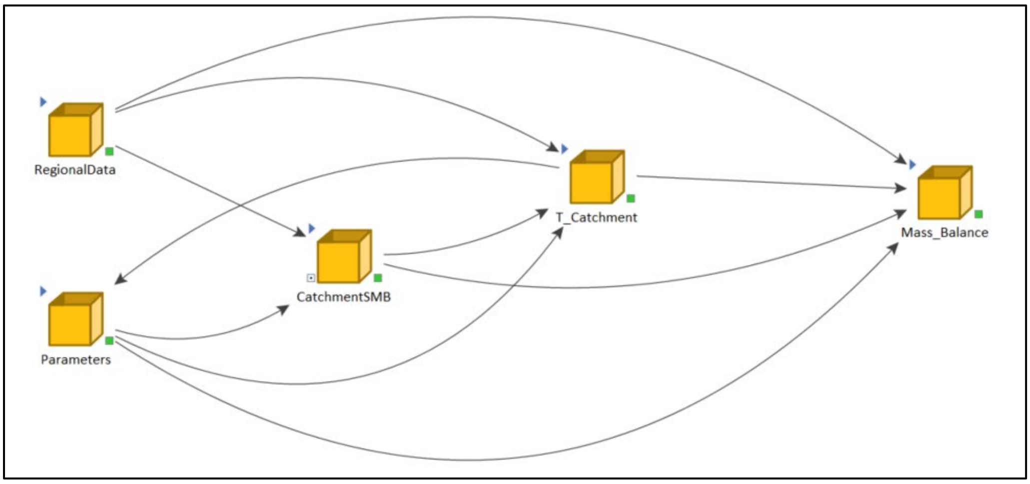

Figure 18: Example Baseline Model Construction (Taupō Catchment)

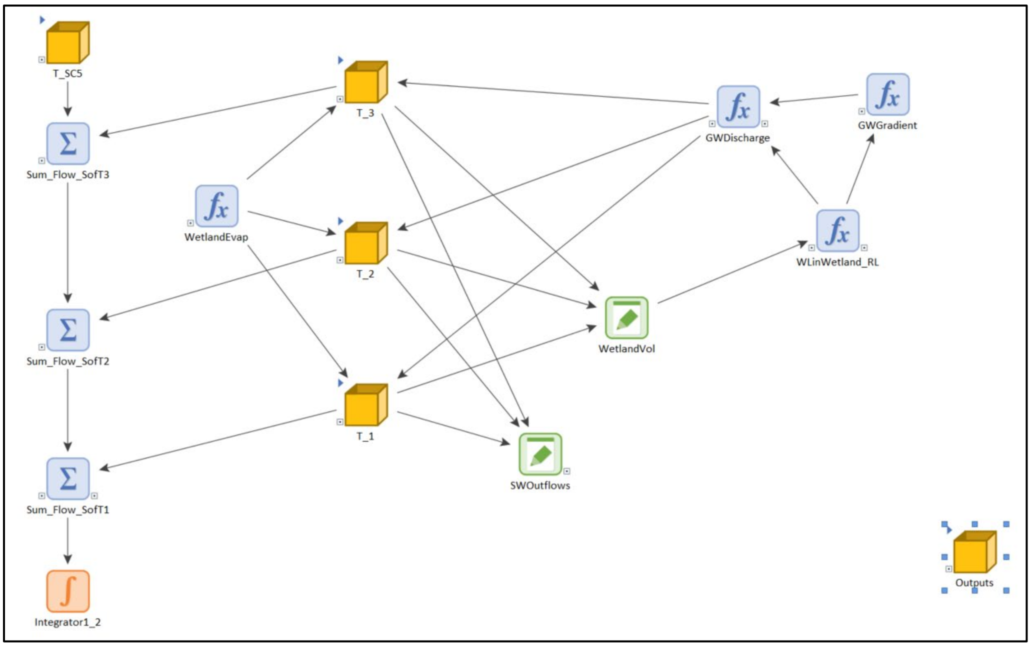

Figure 19: Details in T_catchment part of Baseline Model

6.2 Model Calibration

Due to the limited length of available site-specific baseline data (as described in 4.0), the model was calibrated to both the site-specific baseline data and the conceptual understanding of the wetlands and the results of the site walkover. PDP has previously completed similar modelling for neighbouring sites with significantly more calibration data. Due to the limited site data, the calibrated values from these models were used as the initial parameters within the Mount Welcome models and sensitivity analysis was completed to ensure the best fit with the conceptual understanding of the site. Where changes were made, more conservative parameters were used to mitigate against the effects on the wetlands being underestimated.

The model results were compared with the estimated flow discharges and water levels in the wetlands for the one month of available baseline data. Since the water levels in the wetlands were relatively consistent over this period, the focus was more on ensuring the surface water outflows were representative. However, the use of the calibrated parameters from neighbouring sites and the conceptual understanding of the wetland systems means that the modelled water level variations within the wetlands are considered to be representative of site conditions.

The variations in wetland water levels and surface water flows for both models were considered in line with the conceptual understanding of the site and sensible conservative parameters have been used. However, when more baseline data becomes available the models will be checked to ensure that the results are representative of site conditions. Whilst significant changes are not anticipated, it will be important for the development of trigger values for use during construction monitoring. The final parameters and catchment areas used in the model are presented in Appendix A.

6.3 Proposed design scenario

The models were updated to reflect the proposed development. The following changes were made to the model:

- The catchment areas were adjusted in accordance with the new earthworks and stormwater design catchments provided by Envelope Engineering (see Figure 20, noting that the off-site catchments are unchanged in extent).
- Impervious cover was updated for each catchment, based on 75% impervious surfaces within the residential lots, 85% impervious surfaces within the roads, and 90% impervious surfaces within the commercial lot.
- Raingardens and treatment devices were not included in the model as these will be lined so they have no significant retention potential. However, it has been assumed that all stormwater run-off from the development area will be treated before discharge into the wetlands. It is understood that flow will be dissipated via the use of scruffy domes and peak flow diversions to ensure the risk of increased channelisation is minimised.
- Four wetland areas (T1W2, T3W1, T3W4 and K1W4) will be developed into stormwater retention wetlands. These wetlands will have a permanent body of standing water in the centre with excess flows discharging downstream via culvert, which restricts the maximum

discharge from these areas. If water levels exceed the height of the retention wetland bunds, excess flow will be discharged over a spillway in extreme discharge events. These have been modelled based on the design details provided by Envelope Engineering, including the volumes and flow ratings curves. Key details are presented in Appendix A and refer to the stormwater design for further information.

The parameters used for the post development models are presented in Appendix A. An example of one of the retention wetlands within the model layout is presented in Figure 21.

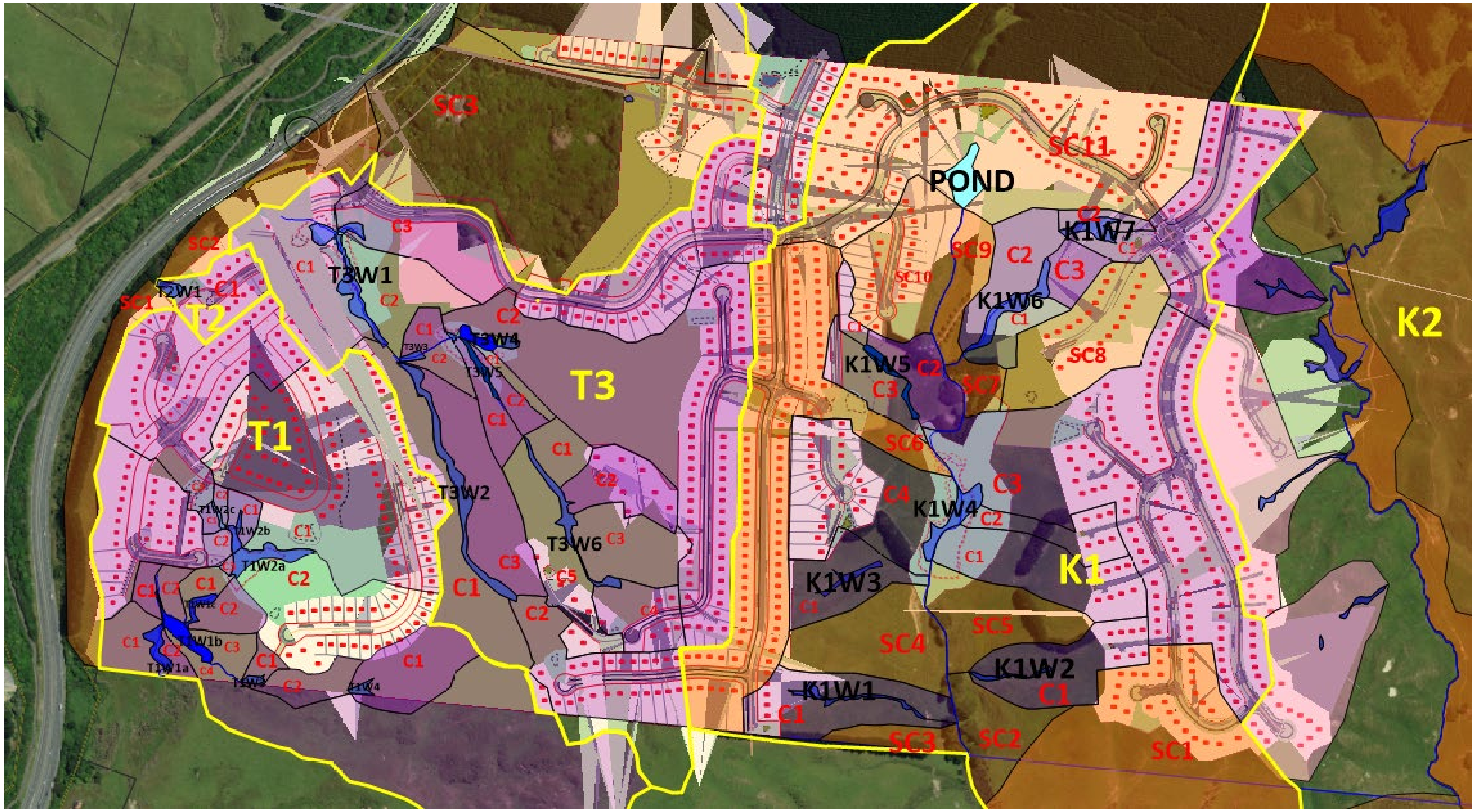

Figure 20: Post-development Catchments in models

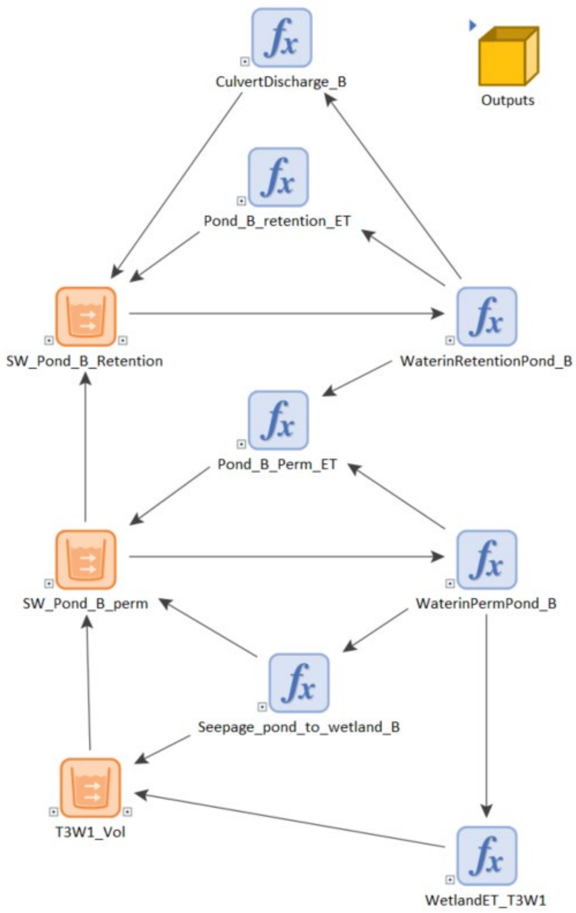

Figure 21: Stormwater Retention Wetland in Model

7.0 Assessment of Effects – Wetlands

7.1 Taupō Catchments

7.1.1 T1 Catchment

The results of the 25-year baseline model for the T1 catchment are presented in Figure 22. Please note that wetlands T1W1 and T1W2 have been split into three linked sections for the purposes of modelling, to account for the different branches, discharge locations and catchments of these wetlands. The results indicate minor seasonal water level variations occur in all the wetlands, with drying periods every summer although the water level variations are relatively limited.

Water levels do respond to rainfall, increasing during heavy rainfall and decreasing during dry periods. This supports the conceptual model that the wetlands are largely run-off supported, rather than groundwater supported, and is supported by the ecological understanding (BlueGreen Ecology Limited, 2025).

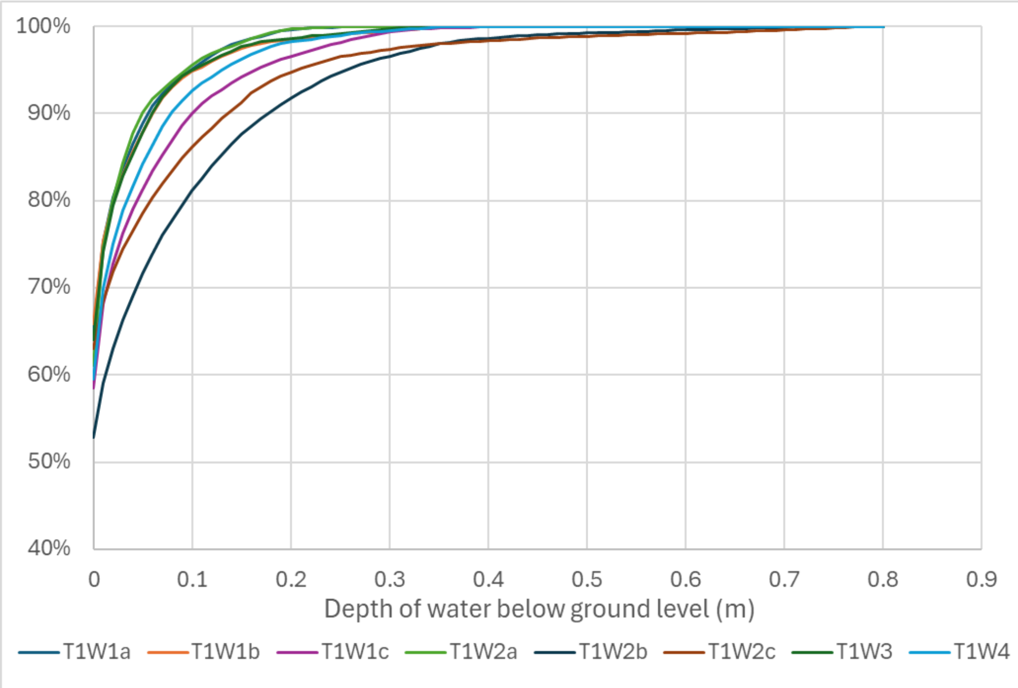

Figure 22: Modelled Baseline Water Level Duration Curves for T1 Wetlands

The modelled water levels within the wetlands post-development are presented in Figure 23. There is less seasonal variation although most of the wetlands still show some decline in water levels during the summer albeit less severe than under baseline conditions. The increased run-off from smaller rainfall events as a result of the impervious surfaces means that there is likely to be more water in the wetlands post development. It should be noted that the lack of variation in T1W2a post development is due to the presence of the permanent standing water in the retention wetland at this location.

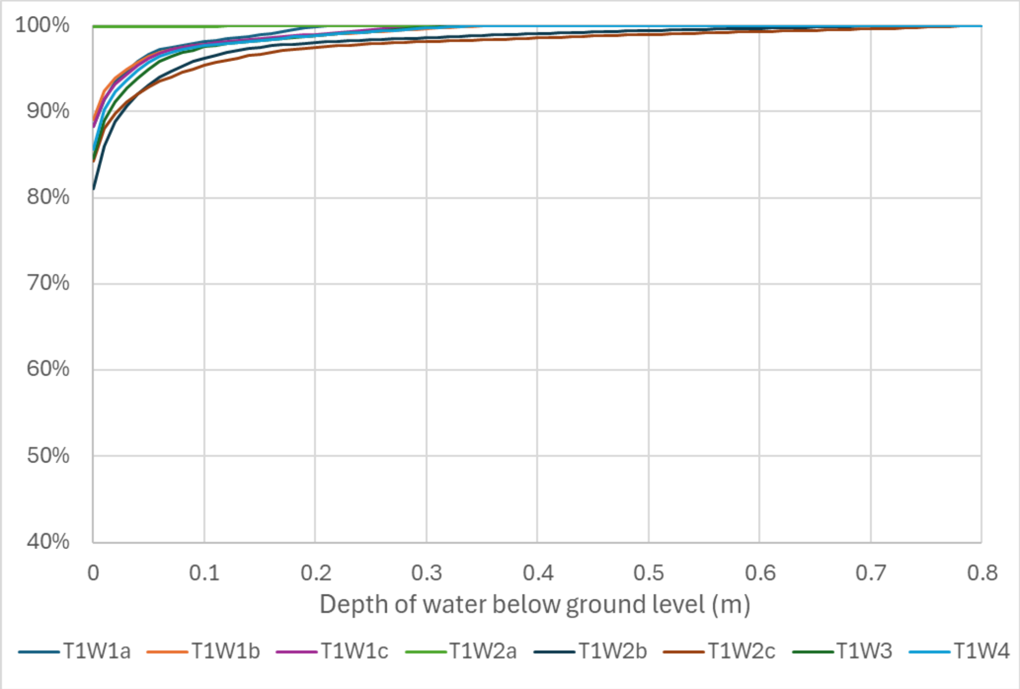

Figure 23: Modelled Post Development Water Level Duration Curves for T1 Wetlands

Table 1: Changes to wetland water levels under post development conditions – T1

	T1W1a	T1W1b	T1W1c	T1W2a	T1W2b	T1W2c	T1W3	T1W4
All Data								
Wetter (%)	7%	8%	14%	10%	23%	16%	6%	12%
Drier (%)	0.02%	0%	0%	0%	0%	0%	0.2%	0.01%
Same (%)	93%	92%	86%	90%	77%	84%	94%	88%
Summer Data (December to May)								
Wetter (%)	7%	8%	14%	10%	23%	16%	6%	12%
Drier (%)	0.02%	0.04%	0%	0%	0%	0%	0.2%	0.01%
Same (%)	93%	92%	86%	90%	77%	84%	94%	88%

Notes:

1. *Only considered variations greater than 0.05 m from the baseline as significant.*

The percentage of time that the water levels will be wetter or drier than the baseline conditions is presented in Table 1. Unsurprisingly the changes are concentrated in the summer, with fewer periods where the wetland water levels decline significantly. For example, wetland T1W2 had water level declines of up to 0.7 m over summer periods under baseline conditions. Post-development these declines are significantly reduced due the construction of the retention wetland bund transforming T1W2 into a retention wetland.

The retention wetland at T1W2 is known as retention wetland A in the Infrastructure report (Envelope Engineering Limited, 2025). Figure 24 shows the estimated variation in water levels within this area over the 25-year model period. It is clear from this that there will be some permanent water present within this wetland year-round, which is a significant change from the baseline conditions. However, this change has been considered in the wetland planting plan so it is anticipated that the wetlands in this area will be sustainable provided appropriate species are established effectively.

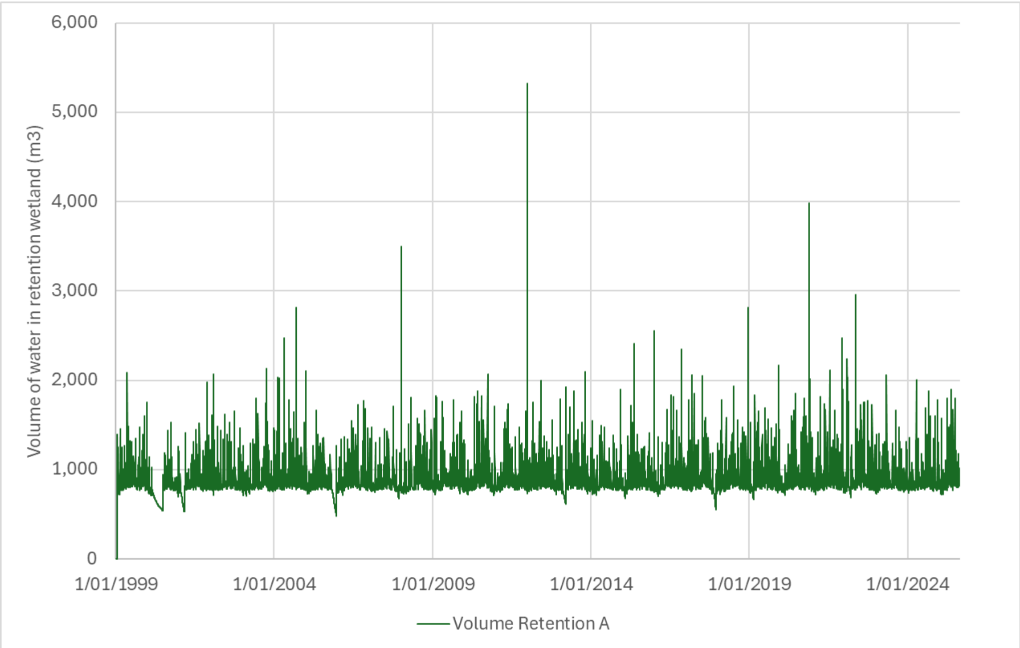

Figure 24: Modelled volume of retention wetland A (T1W2)

Whilst some of the changes are considered significant, the modelling suggests that the wetlands will be similar or wetter post-development. Given the proposed enhanced planting proposed for the lower wetlands (BlueGreen Ecology Limited, 2025), it is considered unlikely that there will be negative impact on the wetland health in the T1 catchment post-development and any risks can be managed through monitoring and mitigation strategies.

7.1.2 T2 Catchment

The baseline and post-development modelled water levels are presented in Figure 25. The results show that the water levels within this wetland vary seasonally by between 0.1 and 0.4 m, which is to be expected for a small, perched wetland with limited groundwater seepage. Post-development the seasonal fluctuation continues but is usually less extreme except in very dry periods.

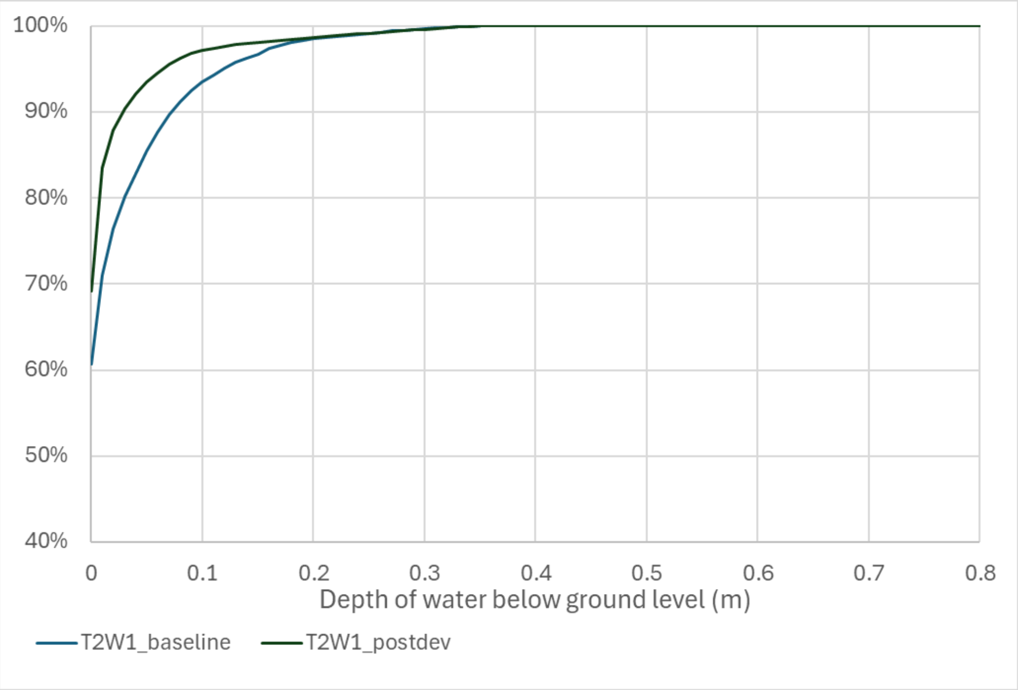

Figure 25: Modelled Water Level Duration Curves for Wetland T2W1

The differences between the pre and post development scenarios are included in Table 4 in the following section and indicate that the wetlands will be the same or wetter 99.7% of the time post-development. This suggests that the development is unlikely to have a significant effect on the wetland hydrology of T2W1.

7.1.3 T3 Catchment

The results of the baseline modelling of the T3 catchment wetlands are presented in Figure 26. The results are similar to the other Taupō catchments, with seasonal variations associated with dry periods and rapid response to rainfall events. This is unsurprising given the conceptual understanding of these wetlands as being predominantly run-off fed, with potentially a minor groundwater component in the lower reaches.

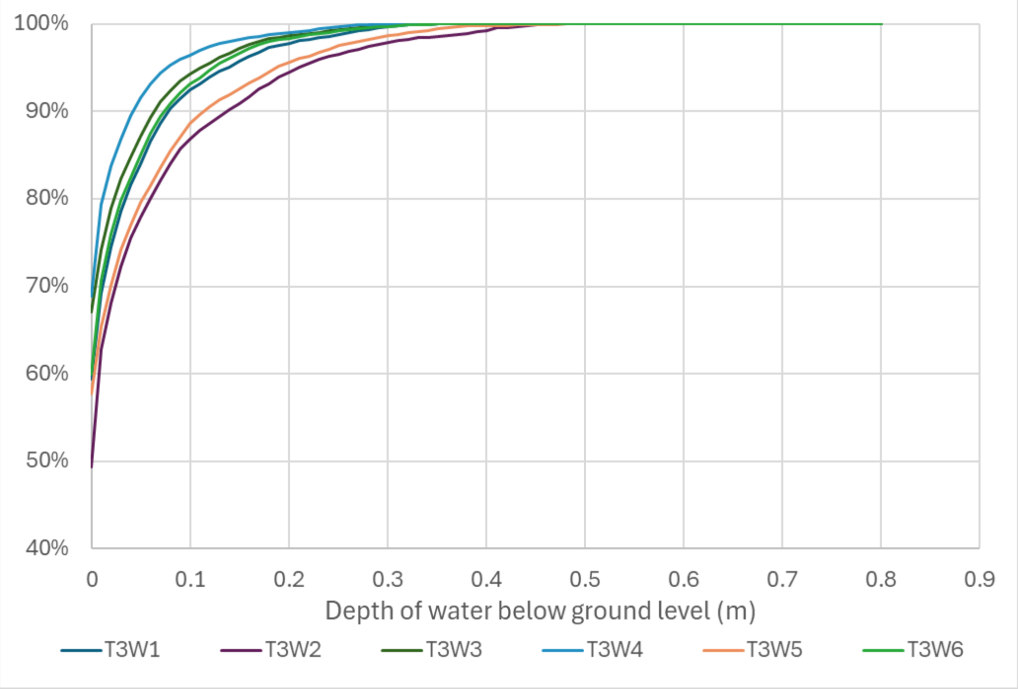

Figure 26: Modelled Baseline Water Level Duration Curves for T3 Wetlands

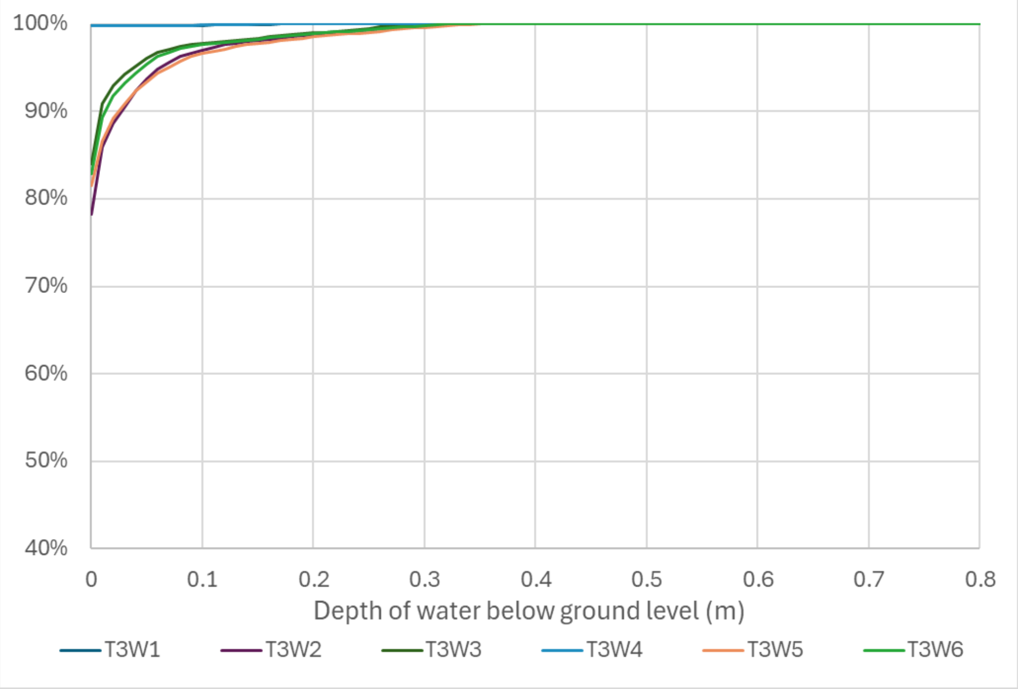

Figure 27: Modelled Post Development Water Level Duration Curves for T3 Wetlands

The post-development results show a more muted seasonal variation, probably caused by the increased run-off associated with summer rainfall events due to the greater imperviousness of the post-development catchments. Wetlands T3W1 and T3W4 are developed into retention wetlands post-development and maintain some standing water, which is why there is significantly less seasonal variation in these wetlands in Figure 27.

The changes in the wetland water levels for the T2 and T3 catchments are presented in Table 2 below. The results indicate that the T3 wetlands are the same or wetter 99.8% of the time post-development. As with the T1 catchment, the majority of the changes between the baseline and post-development scenarios occur during the drier summer months, see example presented in Figure 28. This indicates that the wetlands are less likely to be susceptible to prolonged drying periods post-development due to the increased run-off.

Table 2: Changes to wetland water levels under post development conditions - T2 & T3

	T2W1	T3W1	T3W2	T3W3	T3W4	T3W5	T3W6
All Data							
Wetter (%)	8%	16%	17%	8 %	8 %	14%	10%
Drier (%)	0.3%	0%	0.1%	0.01%	0%	0.2%	0.01%
Same (%)	92%	84%	83%	92%	92%	86%	90%
Summer Data (December to May)							
Wetter (%)	8%	16%	17%	8 %	8 %	14%	10%
Drier (%)	0.2%	0%	0.1%	0.01%	0%	0.2%	0.01%
Same (%)	92%	84%	83%	92%	92%	86%	90%

Notes:

1. *Only considered variations greater than 0.05 m from the baseline as significant.*

The retention wetlands in the T3 catchment are designated as retention wetlands B (T3W1) and C (T3W4) in the infrastructure report (Envelope Engineering Limited, 2025). Figure 29 shows the estimated variation in water levels within these areas over the 25 year model period. It is clear from this, that retention wetland C will have a more variable water level, with fewer large peak and periods where water levels decline, although some standing water is likely to be present year-round. Retention wetland B also has permanent standing water but receives more water from the wider catchment, so will have periods of higher water levels and need to be planted to cope with this variation.

The presence of permanent standing water in these areas is a significant change from the baseline conditions. However, this alteration has been considered in the wetland planting plan so it is anticipated that the wetlands in this area will be sustainable provided appropriate species are established effectively.

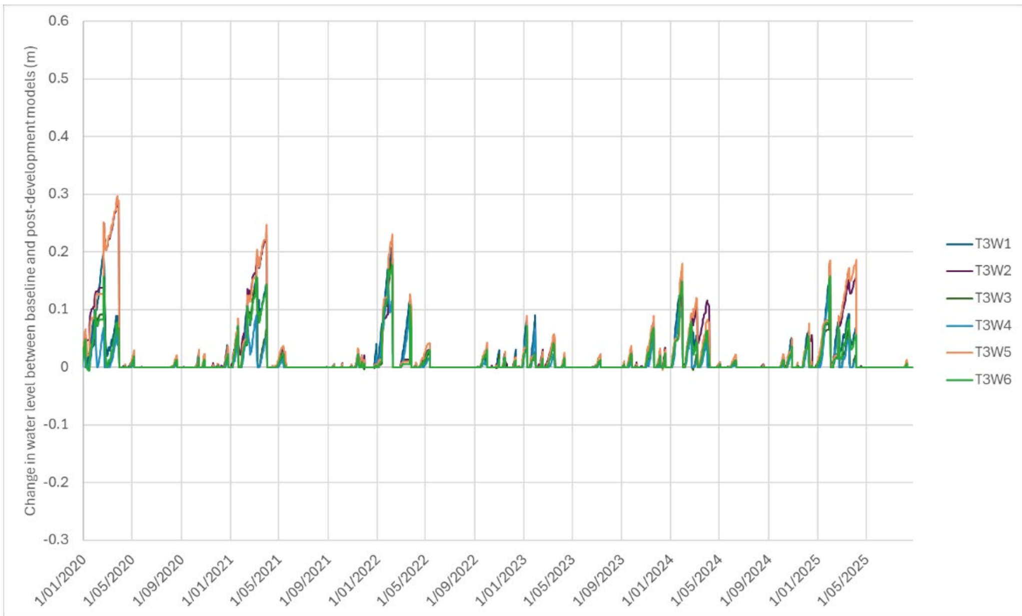

Figure 28: Difference in wetland water level in T3 catchment

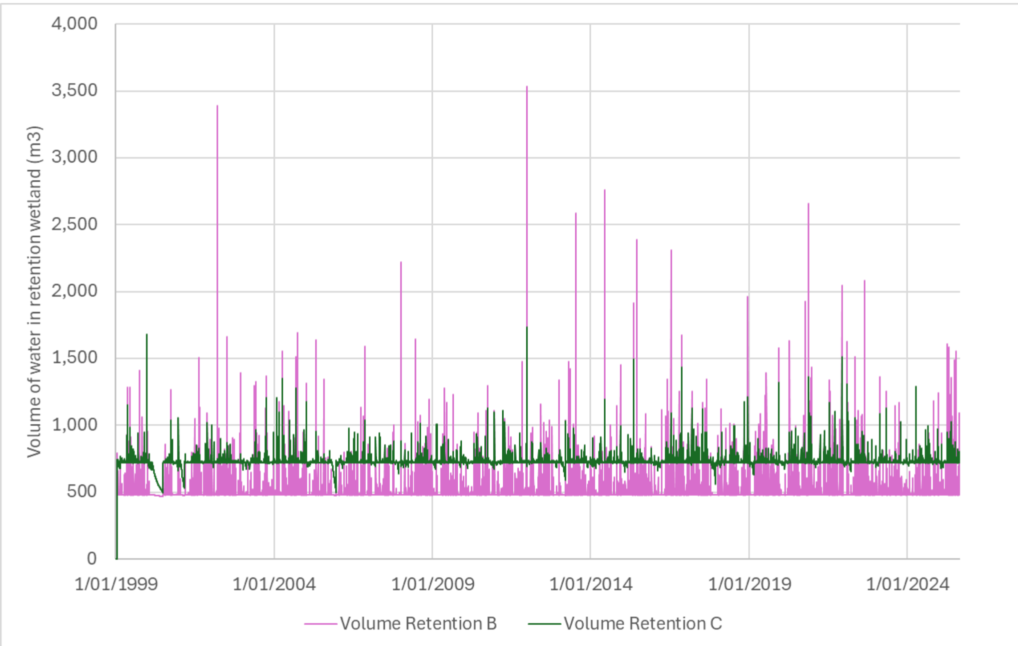

Figure 29: Modelled volume of retention wetlands B (T3W1) and C (T3W4)

Given the proposed enhanced planting proposed for the lower wetlands (BlueGreen Ecology Limited, 2025), it is considered unlikely that there will be negative impact on the wetland health in the T3 catchment post-development and any risks can be managed through monitoring and mitigation strategies.

7.1.4 Wetland Water Balance

The average annual water balance for each Taupō catchment wetland is presented in Appendix B and a summary for the total Taupō wetland catchments is presented in Figure 30, note the log-scale. As noted previously the increase in impervious surfaces does increase the run-off into the wetlands and the surface water discharge from these systems. The increase in the groundwater inflow component does not represent regional groundwater discharge, but rather the sub-surface/interflow component of run-off from the catchments. The other components of the water balance are unchanged by the development.

The increase in groundwater inflow is not uniform across the wetlands and occurs for the following reasons:

- Changes in catchment area,
- Higher water levels in upstream wetlands causing additional groundwater inflow into downstream wetlands post development, and
- Reduction in losses to evaporation within the catchment.

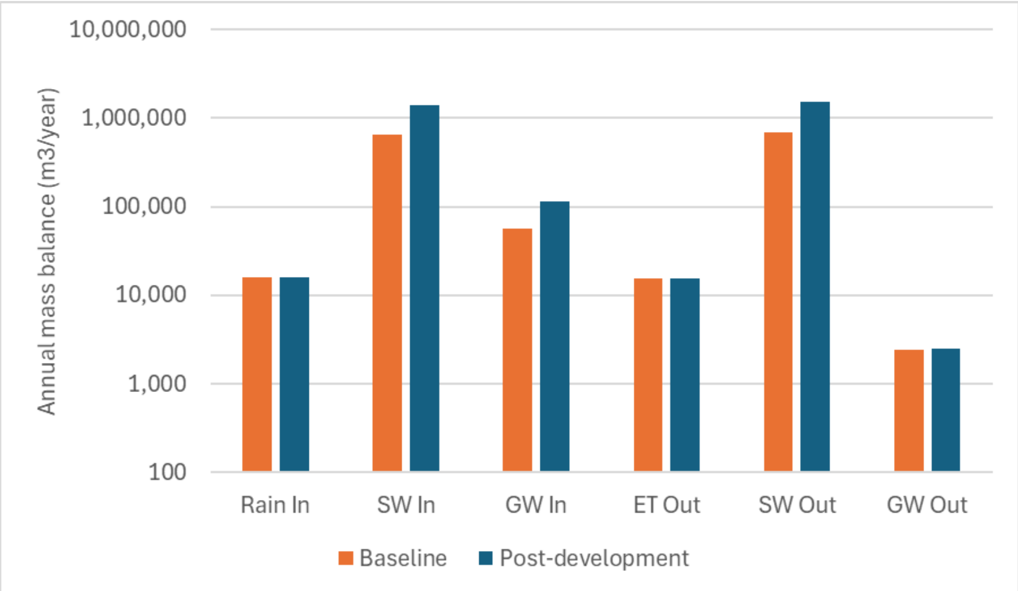

Figure 30: Taupō Catchment Wetlands - Annual Water Balance

7.2 Kakaho Catchments

7.2.1 Kakaho West

The modelled baseline water levels in the wetlands in the Kakaho West catchment are presented in Figure 31. These indicate that the wetlands' water levels fluctuate seasonally, declining over the summer months and rebounding in the wetter parts of the year. The pond is less variable due to the large volume of this water body, but does also show a decline in water level during particularly dry summers.

The water levels within the wetlands react rapidly to rainfall events and are primarily supported by run-off. The decline in water levels over the dry months is in accordance with the ecological assessments for these wetlands, which can cope with periods of drying (BlueGreen Ecology Limited, 2025).

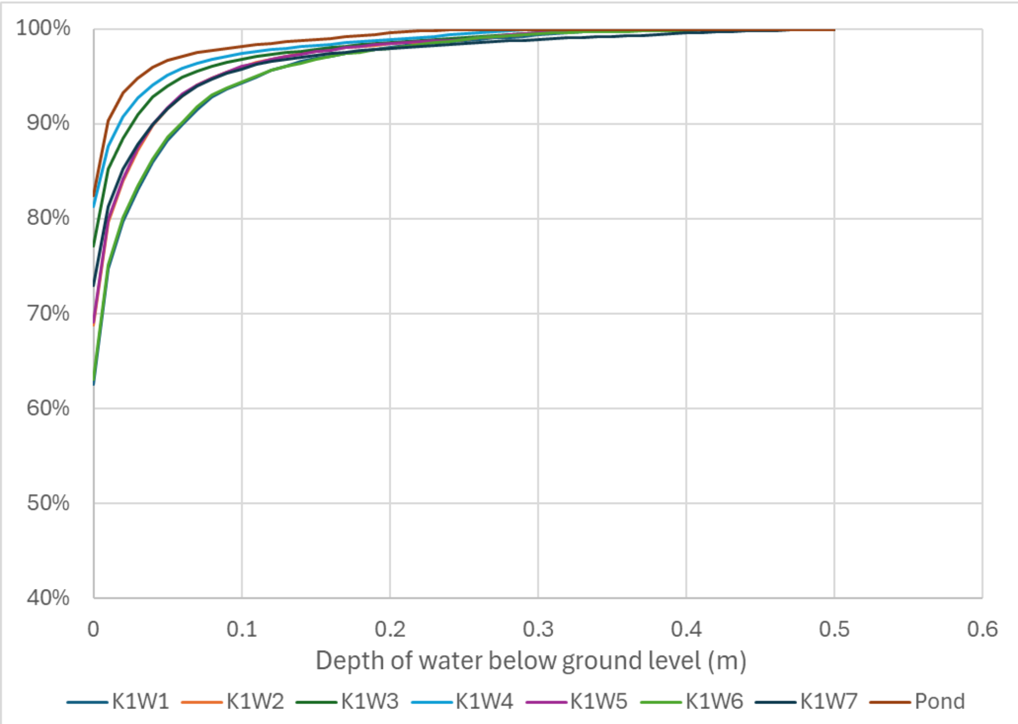

Figure 31: Modelled Baseline Water Level Duration Curves for Kakaho West Wetlands and Pond

The effects on the Kakaho West wetlands are less pronounced that the changes seen in the wetlands in the T1 and T3 Taupō catchments, apart from K1W4 (see Figure 33 and Figure 33). This wetland will be developed into retention wetland E post-development (Envelope Engineering Limited, 2025), with some permanent standing water, and will have to cope with short periods where the water level is significantly higher than the baseline conditions. The planting plan has been designed to ensure the wetland will thrive under these conditions (BlueGreen Ecology Limited, 2025).

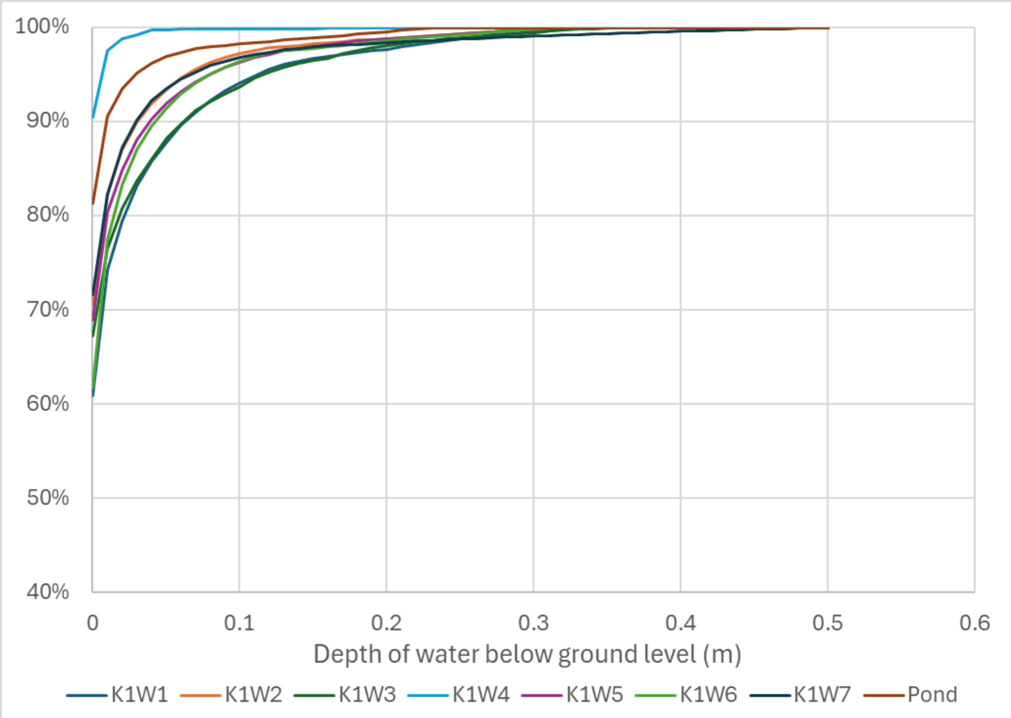

Figure 32: Modelled Post Development Water Level Duration Curves for Kakaho West Wetlands and Pond

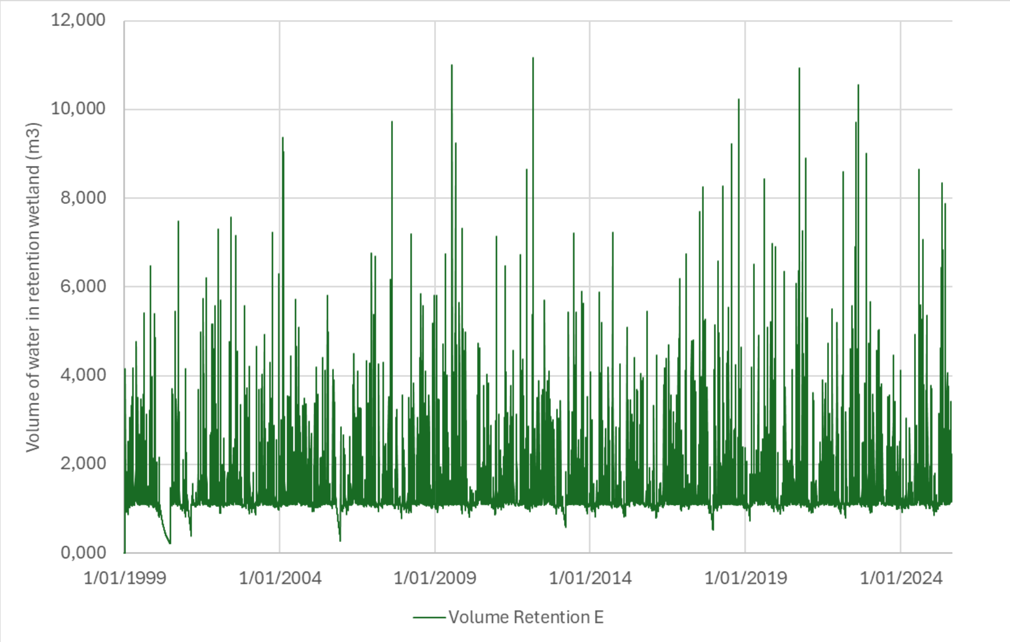

Figure 33: Modelled volume of retention wetland E (K1W4)

Table 3: Changes to wetland water levels under post development conditions – K

	K1W1	K1W2	K1W3	K1W4	K1W5	K1W6	K1W7
All Data							
Wetter (%)	1.3%	1.9%	0.1%	4.3%	0.7%	3.1%	2.2%
Drier (%)	1.2%	0.0%	5.0%	0.0%	0.3%	0.0%	0.1%
Same (%)	97.5%	98.1%	94.9%	95.7%	99.0%	96.9%	97.8%
Summer Data (December to May)							
Wetter (%)	1.3%	1.9%	0.1%	4.3%	0.7%	3.1%	2.2%
Drier (%)	1.2%	0.0%	5.0%	0.0%	0.3%	0.0%	0.1%
Same (%)	97.5%	98.1%	94.9%	95.7%	99.0%	96.9%	97.8%

Notes:
1. *Only considered variations greater than 0.05 m from the baseline as significant.*

Table 3 indicates that wetland K1W3 is likely to be drier on average post-development. This is because the catchment area is reduced as a result of the development, and no additional stormwater discharge is being diverted into this gully. However, these gully wetlands are used to coping with dry periods and a minor increase in the number and/or duration of these periods is unlikely to have a negative effect on the wetland health at these locations.

The remaining wetlands will be the same or wetter post-development, 98% of the time.

The water level variations mostly occur in the summer months, and the vast majority of the differences between the pre- and post-development scenarios are less than 0.1 m so are unlikely to have a significant effect on wetland health. It is therefore considered that the effects of the development are likely to be limited to the wetlands in the Kakaho West catchment. However, strategic monitoring of wetland water levels and health is recommended to ensure this given the limited baseline data available for model calibration.

7.2.1 Kakaho West Wetland Water Balance

The average annual water balance for each wetland in the Kakaho West catchment is presented in Appendix B and a summary for the total wetland catchments is presented in Figure 34 below, note the log-scale. There is an increase in run-off due to the increase in impervious surfaces, with a corresponding increase in surface water discharge. The model seems to have an imbalance associated with the retention wetland at K1W4, with on average approximately 6% more water leaving the retention wetland than enters it. It is thought this is a result of how the water levels and discharge from the culvert are calculated which should be addressed once more calibration data is available and detailed design of the retention wetland has been completed. However, the excess discharge means that the estimated effects on the wetland water levels and downstream flows are conservatively assessed within this report.

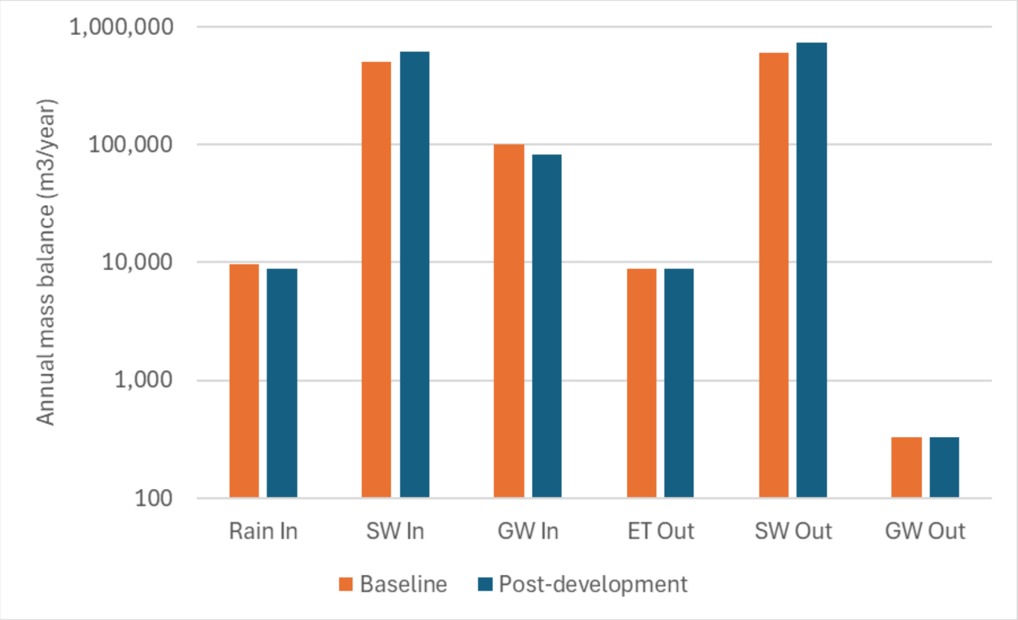

Figure 34: Kakaho West Catchment Wetlands - Annual Water Balance

7.2.2 Kakaho East Catchment

A detailed water balance model has not been developed for the Kakaho East catchment, due to the limited number of wetlands and the relatively small changes to land-use within this catchment. However, an assessment in the change in area and percentage impervious surfaces has been completed for each catchment (see Figure 35 for catchments). The results are presented in Table 4 and indicate that the wetlands in the gully floor (K2W3 and K2W5) will be unaffected by the development due to their location and the fact that they are more supported by stream flow then local run-off.

The stormwater design means that significantly more water will be discharging into wetlands K2W1, K2W2 and K2W4 post development. However, it should be noted for K2W2, that only low flows will be diverted into the wetland from the catchment to the north. High flows will be discharged outside the wetland catchment, so the change in area is an overestimate of the potential effects.

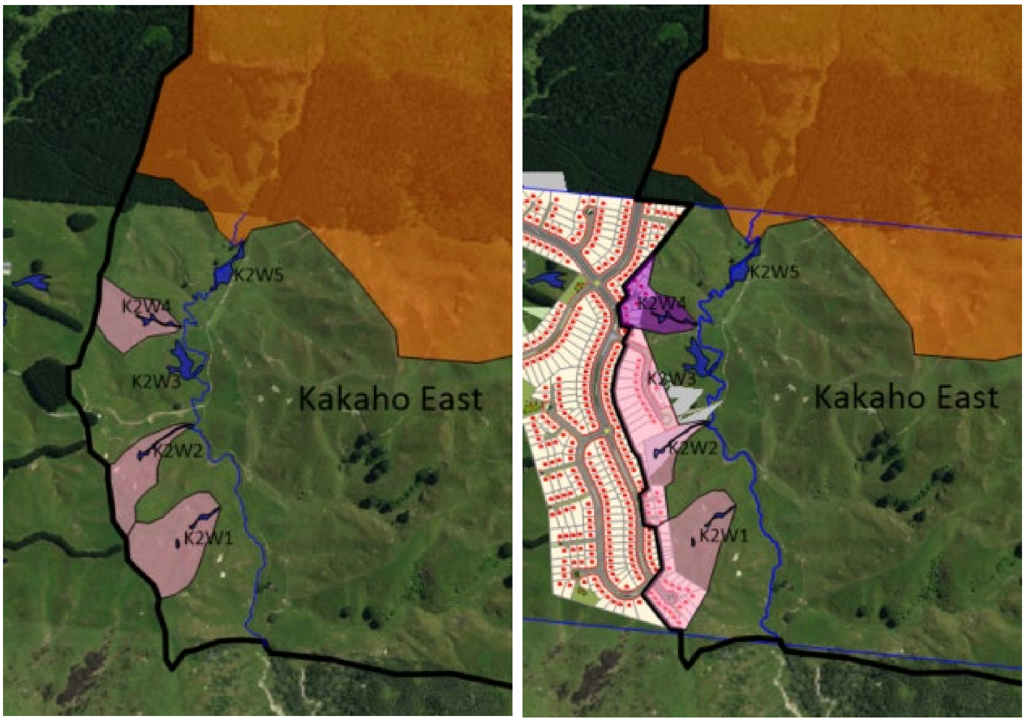

Figure 35: Pre- and post-development K2 wetland catchments

Table 4: Kakaho East Wetland Catchment Assessment

Wetland	Change in catchment area		Change in impervious surfaces (%)	Effects
	m²	%		
K2W1	+4,730	+19	+23	Wetter
K2W2	+17,140	+112	+30	Wetter
K2W3	-21,260	-1	+0.2	No effects
K2W4	+4,210	+28	+16	Wetter
K2W5	0	0	0	No effects

These wetlands are currently subjected to regular drying periods under baseline conditions. The changes associated with the development are likely to reduce the number and duration of the dry periods, but given the location and nature of these wetlands it is considered unlikely that they will remain permanently wet year-round, even with the increased run-off. Consultation with the project ecologist (BlueGreen Ecology Limited) indicates that these wetlands would benefit from the increased discharge into these catchments and the increase in flow in is unlikely to negatively affect the wetlands. It is therefore considered that any effects on the wetlands in the Kakaho East catchment are likely to be minimal or potentially beneficial.

7.3 Muri Road Catchment

A small part of the site discharges north into the Muri Road block. This section flows north into a large wetland and SNA known in the Muri development as West Wetland 1. This wetland discharges into the upper parts of the Waimapihi Stream catchment. The changes in the catchment area from baseline (green) to post-development (pink) are shown in Figure 36, with an increase in catchment area of 6% and an increase in imperviousness of 11% across this catchment. This is likely to result in increased run-off into the Muri Road catchment and subsequently the West Wetland 1. However, the stormwater from the section of the catchment within the site boundary will be diverted into a stormwater retention basin near the northern boundary (Figure 36). This will regulate flow rates to ensure that they are within the pre-development range.

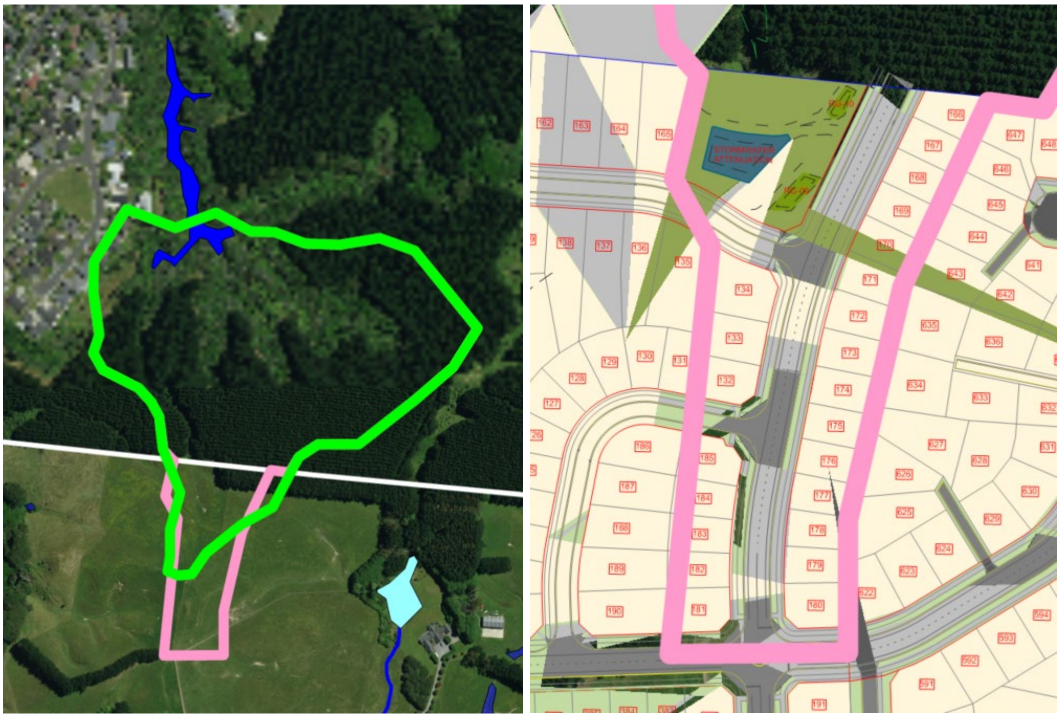

Figure 36: Pre- and post-development Muri Road catchments

The West Wetland 1 is a significantly larger wetland than those present within the Mount Welcome block. It is predominantly flax and the seasonal water level fluctuations in this wetland are likely to be smaller due to the larger available storage volume within the wetland. It is considered likely that this wetland can accommodate the additional discharge from the site provided the flows are regulated by the stormwater attenuation pond. Given the relatively small change in catchment area and the regulation measures included in the stormwater design, the effects of this development on West Wetland 1 are likely to be less than minor.

8.0 Stream Discharge Assessment of Effects

The stormwater modelling and design has been completed by Envelope Engineering Limited and is not presented here. The purpose of the hydrology modelling results discussed below is to consider the day-to-day changes within the on-site and downstream hydrological environments as a result of the proposed development and the installation of the retention wetlands. The stormwater discharge events used by Envelope Engineering to design the stormwater infrastructure have also been modelled to cross-check the accuracy of the hydrology model outputs and check the estimated changes in peak velocity.

8.1 Taupō Catchment

8.1.1 Total discharge

The total discharge and peak flow velocities from the site into the Taupō Stream have been estimated by combining the outflows of the T1, T2, T_SC1, T_SC2, T_SC3, T_SC4, T_SC5 and T_SC6 catchments within the model (see Figure 9 for details of the catchment boundary modelled). Whilst the 25-year model with the 1-day timestep is useful to assess variations in the long-term, a 1-year model with a 5-minute timestep is more useful to assess flow variations within the catchment because it provides more granularity to the flow and discharge results. A year with average rainfall has been used to provide representative conditions and the results are summarised in Table 5.

It is clear from the results that the flows from the site are slightly higher on average, except for the maximum flow which is 33% lower. The difference can be seen in the flow duration curve (Figure 37), with 90% of flows being less than 1L/s pre-development and only 65% being below post-development, although even post-development 80% of the flows are less than 5 L/s.

However, the total discharge per day is higher post-development, with the mean per day being 40% greater post development. This can also be seen in Figure 38, which shows the distribution of discharge per day. This change is a result of the increased impervious surfaces and changes to catchment areas, which result in greater run-off and less infiltration and canopy capture, and will be more significant in wetter years.

Table 5: Statistics for flows from site into Taupō Stream

Parameter	Peak Flow (L/s)		Daily Discharge (m^3/day)	
	Baseline	Post-Development	Baseline	Post-Development
Minimum	0	0	0	0
Lower quartile	0.02	0.05	2.1	6.4
Mean	13.6	19.2	1,181	1,654
Median	0.11	0.44	15.7	61.0
Upper quartile	0.42	1.69	127	753
Maximum	5,579	3,737	53,833	61,262

Notes:

1. *Based on 1 year model with 5 minute timestep under average rainfall*

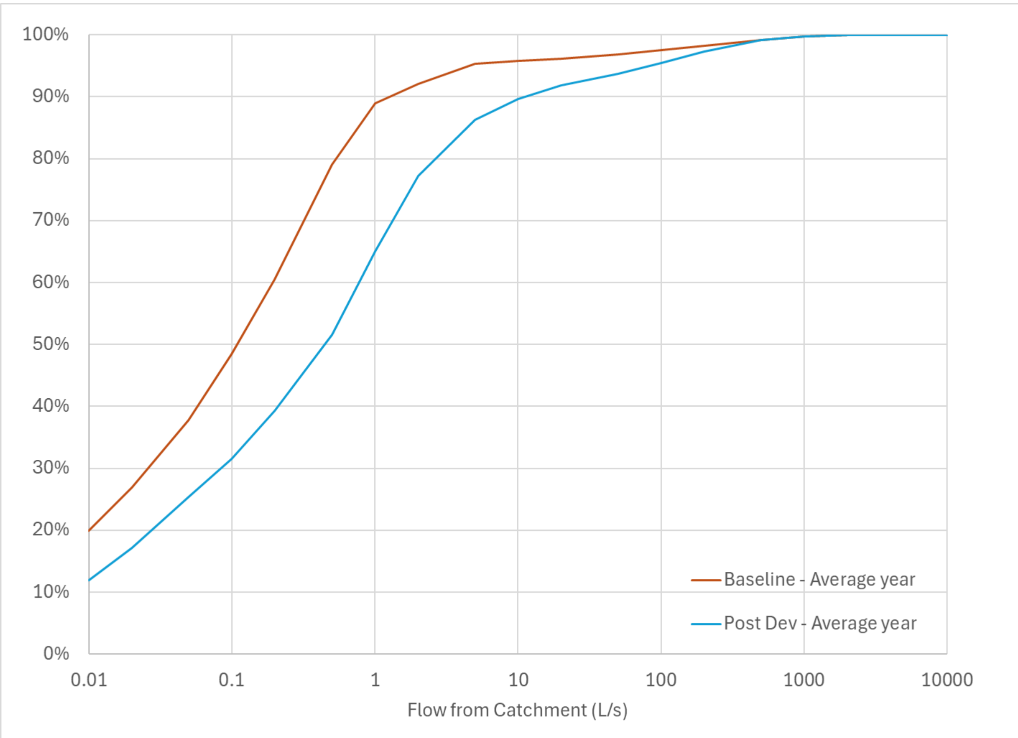

Figure 37: Flow duration curve - Taupō Catchment

The key to managing the impacts of this change in flows on the downstream Taupō Stream and Swamp is the use of the retention wetlands to control the peak flows and maintain them at or below the baseline level. A more detailed assessment of the changes these devices make to the flows out of the T1, T2 and T3 catchments during storm events is presented below.

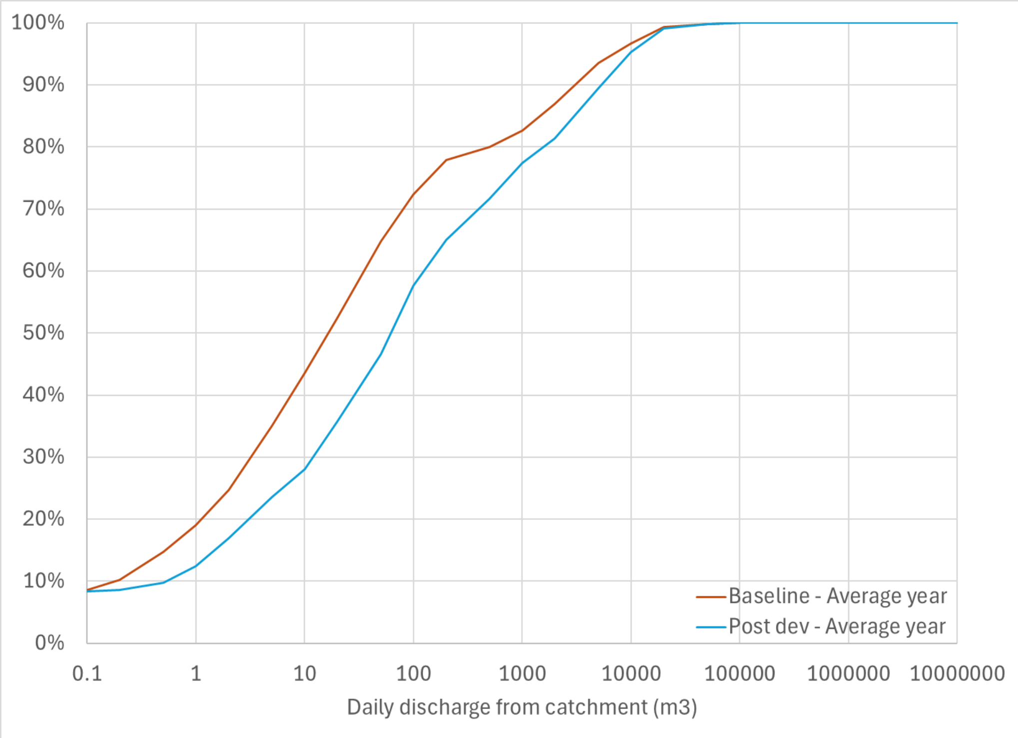

Figure 38: Discharge duration curve - Taupō Catchment

8.1.2 Storm discharge

The discharge from the catchments was assessed for the following rainfall events (data provided by Envelope Engineering Limited):

- 10% Annual Exceedance Probability (AEP) event of 79.8 mm over 720 minutes; and
- 1% AEP event of 117 mm over 720 minutes.

It was conservatively assumed that the wetlands were full at the start of the modelling period and the permanent pools associated with the retention wetlands were also full. The results are presented in Table 6 and Figure 39 and indicate that the peak flows from the development catchment will be reduced by approximately 15% post development. The T3 catchment is the most effected with the two wetland retention areas significantly smoothing the flow during the 1% rainfall event.

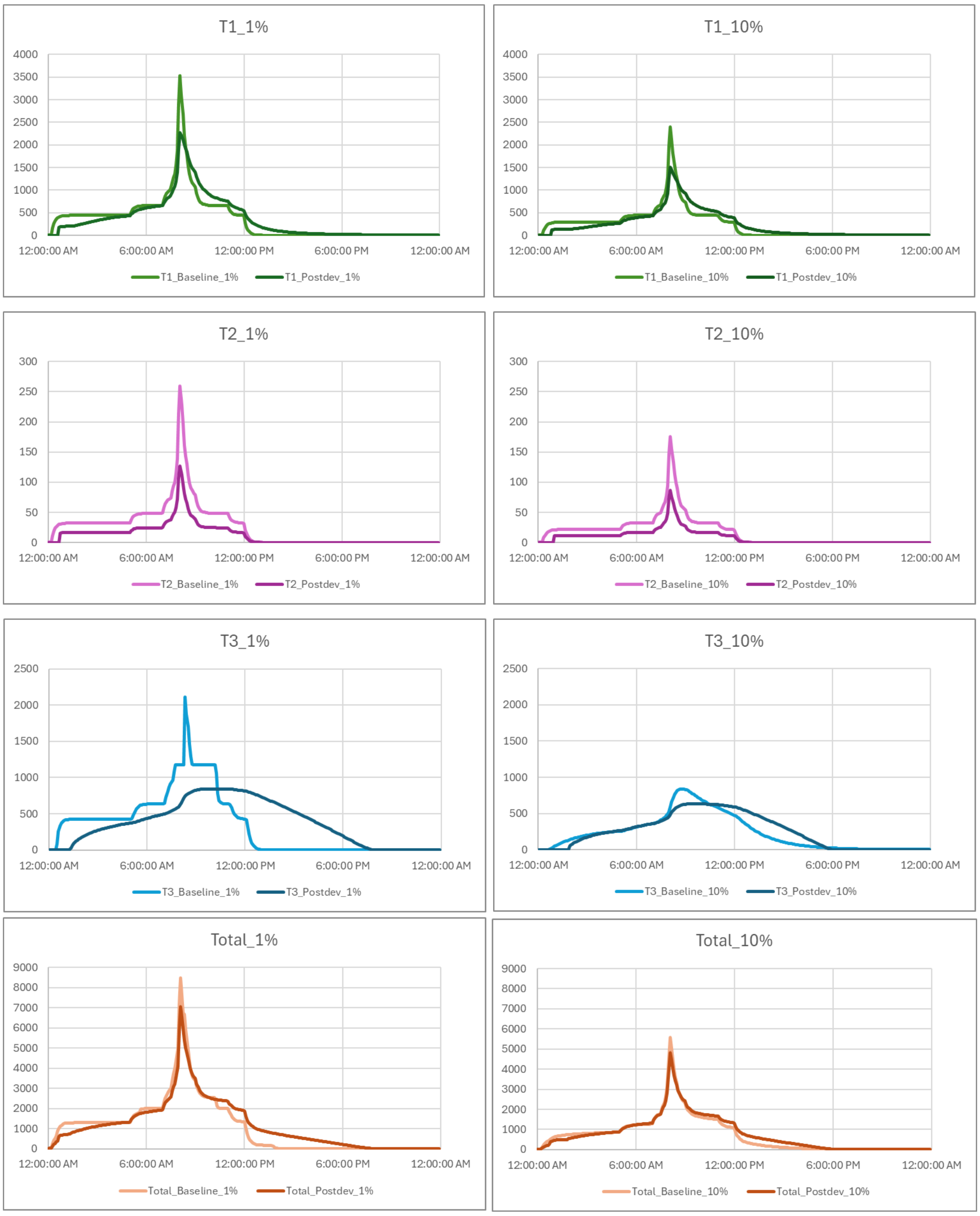

Figure 39: Taupō catchment AEP flows in L/s

The results have been compared with the outputs from the stormwater design modelling to check for accuracy and tally reasonably well with the outputs estimated. It is therefore considered that the effects of the development on peak flows will be positive, smoothing the discharge into the Taupō Stream and reducing the peak flow velocity.

Table 6: Storm event peak flows – Taupō Catchments

Catchment	10% AEP		1% AEP	
	Baseline peak flow (L/s)	Post-development peak flow (L/s)	Baseline peak flow (L/s)	Post-development peak flow (L/s)
T1	2,403	1,510	3,534	2,270
T2	176	87	259	127
T3	840	636	2,110	842
Total	**5,566**	**4,806**	**8,497**	**7,046**

8.1.3 Sediment Transport

Whilst the retention wetlands reduce the peak flow velocity of streams discharging into the Taupo catchment from the site, the total volume of discharge increases as a result of the increase in impervious surfaces. The potential effect on downstream sediment transport has been assessed using the outputs from the modelling to develop a basic coupled sediment transport model for the section of stream immediately downstream of the site (see Figure 40).

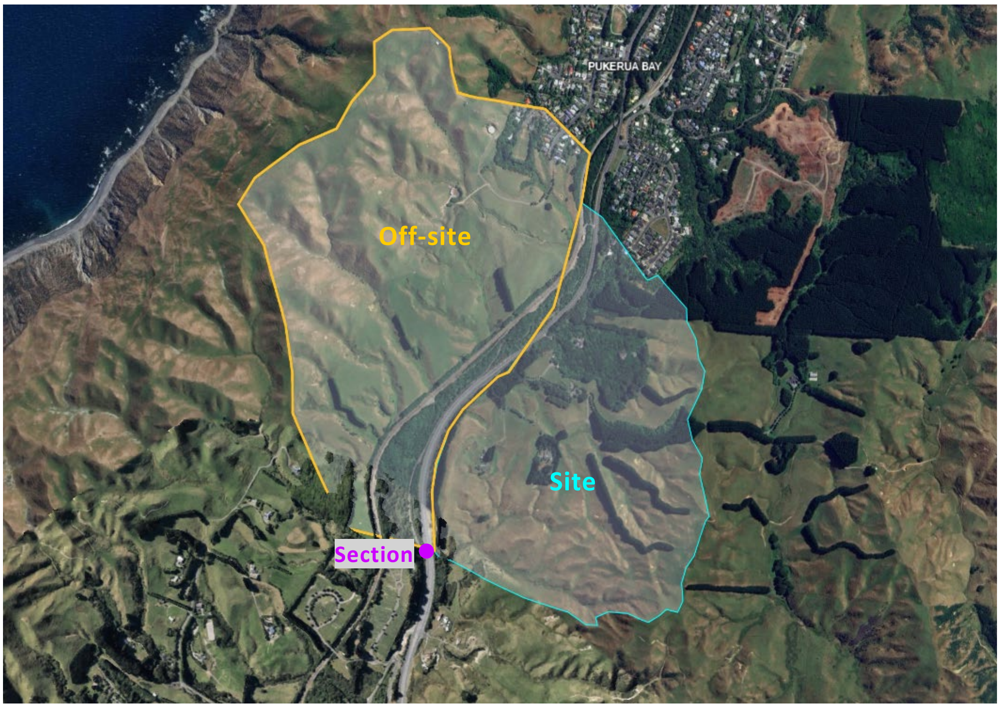

Figure 40: Sediment transport model catchments

The assessment was completed for the median and upper quartile discharge flows and the 1% and 10% AEP peak flows. These scenarios were selected to assess the impacts of the peak velocities, when most sediment transport occurs, and the changes to sediment transport outside these peak flow events.

The model results were used for the site, but it was necessary to estimate the contribution of flow from the off-site catchment (see Figure 40) by scaling the model results proportionally based on the difference in catchment area. This was cross-checked for the median and upper quartile by calculating the same statistical parameters for the Taupo Stream at Flax Swamp measurements (GWRC, 2025) and scaling based on catchment area. The results were then combined to provide the estimated discharge rates presented in Table 7.

Table 7: Total discharge at section

Scenario	Discharge (m^3/s)	
	Baseline	Post-development
Median discharge	0.017	0.024
Upper quartile discharge	0.034	0.047
10% AEP peak flow	16.5	15.7
1% AEP peak flow	25.2	23.7

Water depth and stream velocity are the input parameters used estimate the sediment transport loads and were calculated using Manning's equation and assuming a Manning factor of 0.04 (in accordance with GWRC Flood Hazard Modelling Standard, May 2025) and a stream width of 1 m. For the peak flow scenario, the stream channel alone could not accommodate the total discharge, so the flow was distributed across a composite cross section comprising the stream channel and an additional 4-meter-wide floodplain component.

Once flow velocity and water depth had been calculated for all scenarios described above, the sediment load assessment was performed using the widely recognized Van Rijn empirical equations for estimating both bed load and suspended sediment transport (Van Rijn, 1984). The equations used are provided in Appendix C. The results are summarised in Table 8 below.

Table 8: Estimated Sediment Load – Taupo Stream

Scenario	Water depth h (m)	Velocity V (m/s)	Sediment Load q (kg/s)			
			Bedload		Suspended	
			Fine	Coarse	Fine	Coarse
Baseline						
Median discharge	0.04	0.002	0	0	0	0
Upper quartile discharge	0.06	0.004	0	0	0	0
10% AEP peak flow	2.49	2.42	5.34	5.40	58.7	1.96
1% AEP peak flow	2.92	2.46	5.48	5.52	62.1	2.08
Post-development						
Median discharge	0.05	0.003	0	0	0	0
Upper quartile discharge	0.07	0.01	0	0	0	0
10% AEP peak flow	2.45	2.41	5.33	5.38	58.3	1.95
1% AEP peak flow	2.86	2.45	5.46	5.51	61.6	2.06

Notes:

1. *Fine sand (median particle size of 0.0001m)*
2. *Coarse sand (median particle size of 0.002m)*

The results were evaluated for plausibility by comparing them with literature values ranging from 1 to 10 g/L for flood events at the calculated peak discharges and were found to be satisfactory. However, it is important to note that this is a simplified analytical assessment and the dynamics of sediment transport processes are influenced by many factors. Therefore, the values presented in the tables should be interpreted as indicative estimates of the expected transport magnitude, rather than precise measurements. Nevertheless, it is possible to draw some conclusions based on this assessment.

As expected, the total mass of sediment is much higher in the case of fine sand, as it is easily suspended when turbulence exceeds settling velocity. Suspended load dominates during peak flows, particularly when there is high erosion potential in the streambed and adjacent slopes.

What is immediately evident is that the pre- and post-development scenarios for the median and upper quartile flows do not result in significant sediment transport. This is because the critical velocity required for particle motion or suspension is not reached. Whilst the discharge from the site increases, this results in a relatively minor changes in stream depth and velocity so, outside of extreme events, the effects of the increase in discharge into the Taupo Stream are estimated to have a minimal effect on sediment transport.

For significant storm events (1% and 10% AEP), the construction of the retention wetlands reduces flow velocities, which in turn leads to a slight decrease in the total quantity of sediment transported. This effect is particularly notable for the 10% AEP event, where the post-development peak flow is significantly lower than the pre-construction value.

In conclusion, the sediment mobilisation in the Taupo Stream downstream of the site is expected to be lower than it was prior to construction. The increase in base flow outside major rainfall events is unlikely to result in greater sediment transport. Furthermore, sediment transport during major rainfall events, which are widely recognized as the primary drivers of sediment suspension and movement, is reduced due to the presence of on-site retention wetlands.

8.1.4 Retention devices

The stormwater and development design does not include the use of tanks for harvesting and re-using stormwater run-off from roofs. However, given the increase in discharge into the Taupo catchment, a post-development scenario was assessed for this catchment using the 25-year water balance model for comparative purposes. This was based on the following assumptions:

- 2 m^3 tank installed on all residential lots in Taupo catchment,
- Roof area is assumed to be 175 m^2, based on average lot size of 350 m^2, with 75% of roof run-off going to the tank,
- 2.5 people per lot using 66 L per person per day, equates to 175 L/day indoor use,
- 0.1 m^3 used outdoors per lot when the 10-day average rainfall is less than 0.1 mm/day, and
- Full tank contents can be used (i.e. no dead storage).

The results indicate that the use of tanks would reduce the total discharge from the site into the Taupo Catchment by approximately 21,600 m^3/year on average, which is a relatively small change in the total discharge of 3%. This equates to a 1% reduction in annual discharge into the upstream end of Taupo Swamp, when the contribution from the rest of the catchment is considered. Therefore, the effect on stormwater retention of installing rainwater re-use tanks on the lots within the Taupo catchment is likely to be minimal.

8.2 Kakaho West Catchment

8.2.1 Total discharge

The total discharge and peak flows from the site into the Kakaho West tributary have been estimated for from the catchment area shown in Figure 41, including catchments K_SC1, K_SC2 and K_SC3. Whilst the 25-year model with the 1-day timestep is useful to assess variations in the long-term, a 1-year model with a 5- minute timestep is more useful to assess flow variations within the catchment. A year with average rainfall has been used to provide representative conditions and the results are summarised in Table 9.

Table 9: Statistics for flows from site into Kakaho West Tributary

Parameter	Peak Flow (L/s)		Daily Discharge (m^3/day)	
	Baseline	Post-Development	Baseline	Post-Development
Minimum	0	0	0	0
Lower quartile	0.01	0.01	1.4	1.7
Mean	14.3	15.9	1,236	1,369
Median	0.15	0.11	24.7	30.3
Upper quartile	0.73	0.70	151	269
Maximum	8,311	2,655	54,261	59,334

Notes:

1. *Based on 1 year model with 5 minute timestep under average rainfall*

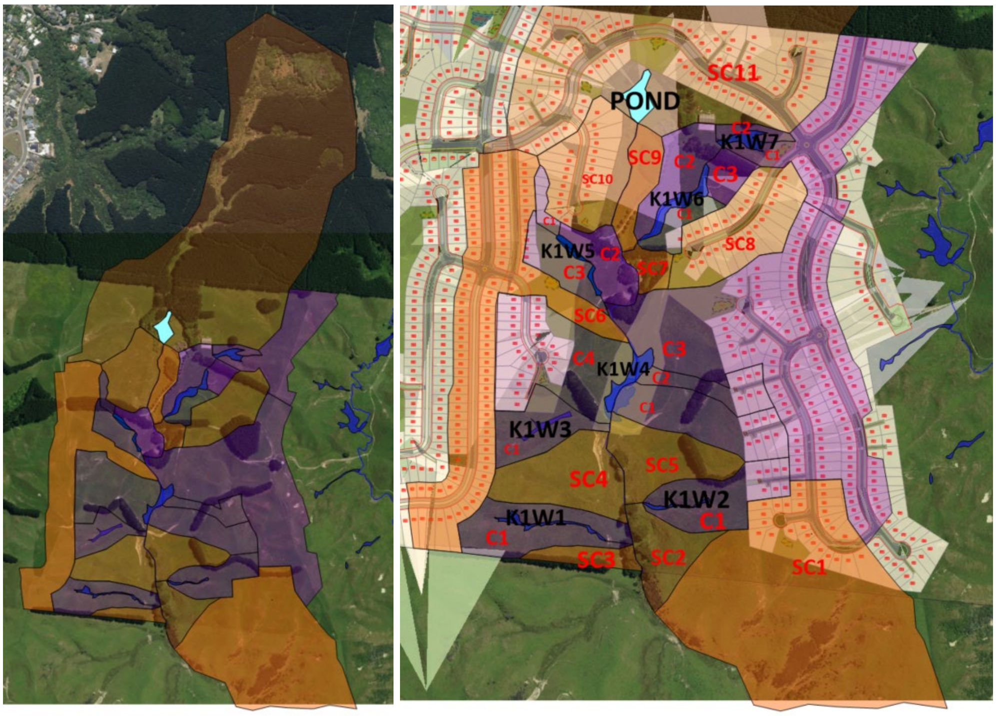

Figure 41: Post-development Kakaho West catchments

It is clear from the results that the flows from the site are generally lower post-development, except for the average flow which is slightly higher. The differences can be seen more clearly in the flow duration curve (Figure 42). Whilst both pre- and post-development scenarios have approximately 80% of flows at 1 L/s or less, post-development there are more flows in the 1 to 100 L/s bracket whereas pre-development the peak flows are greater.

The catchment is relatively large and steep sided so short duration high intensity flows are to be expected. Post-development the peak flows will be retained in the retention wetland at K1W4 reducing the peak flow rate, but increasing the duration of moderate flows from the catchment.

However, the total discharge per day is higher post-development, with the mean per day being 11% greater post development. This can also be seen in Figure 38, which shows the distribution of discharge per day. The changes are less than in the Taupō catchment because more of the catchment remains undeveloped and therefore the proportion of impervious surfaces is less.

The key to managing the impacts of this change in discharge on the Kakaho Stream is the use of the retention wetland to control the peak flows and maintain them at or below the baseline level, see section 8.2.2 for details.

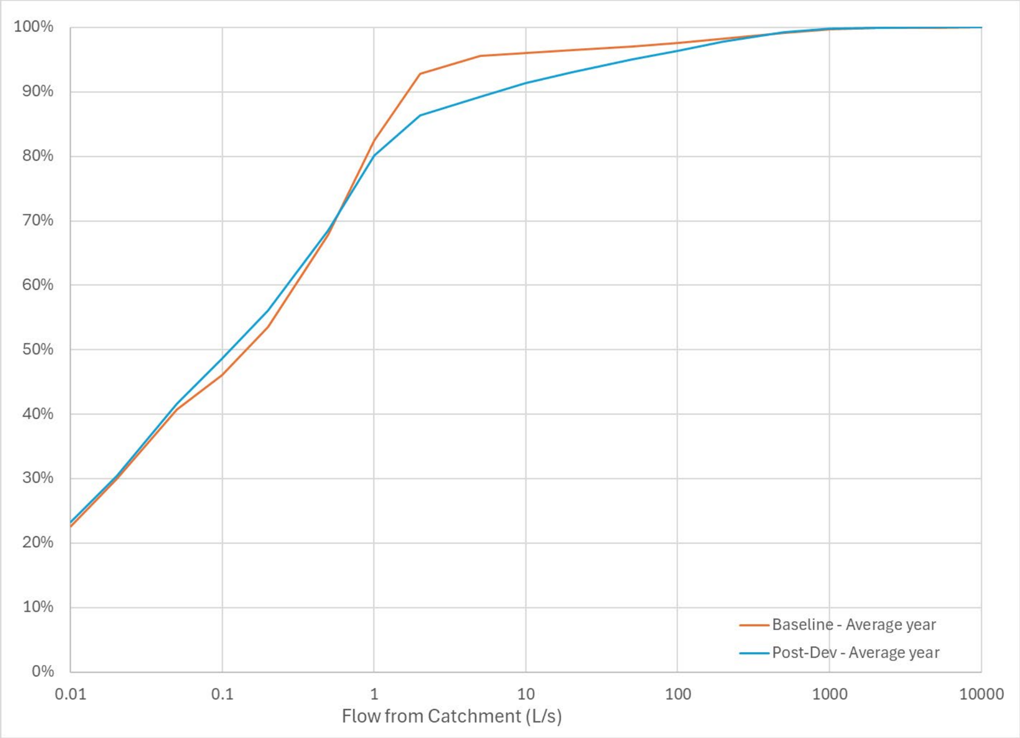

Figure 42: Flow duration curve – Kakaho West Catchment

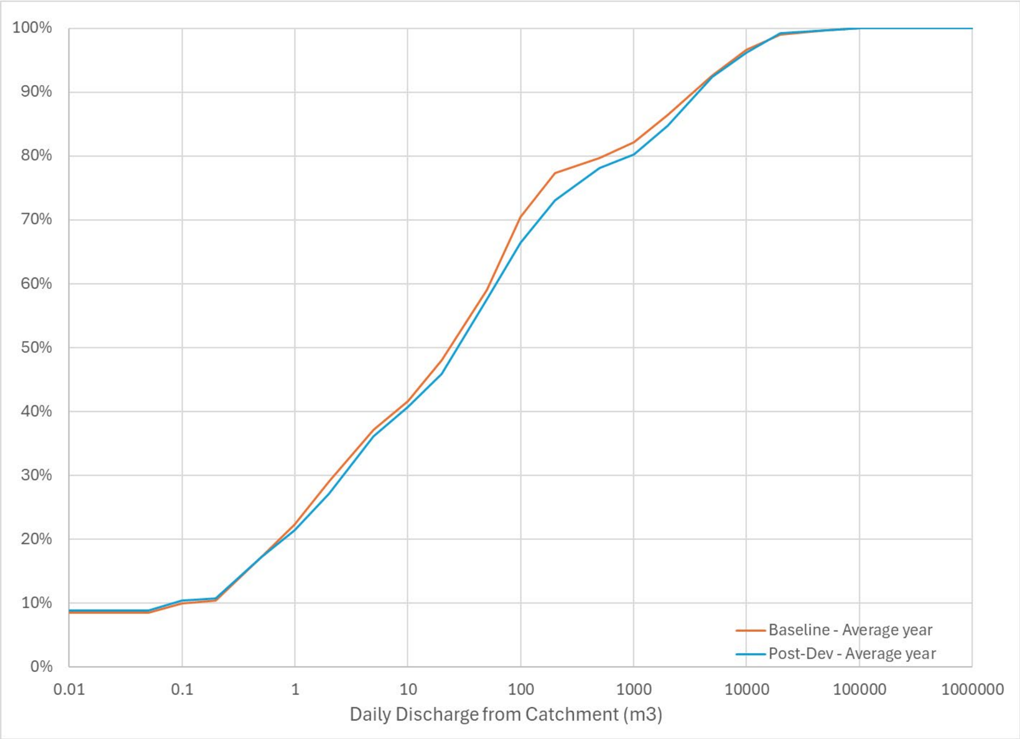

Figure 43: Discharge duration curve – Kakaho West Catchment

8.2.2 Storm discharge

The discharge from the Kakaho West catchment was assessed for the following rainfall events (data provided by Envelope Engineering Limited):

- 10% Annual Exceedance Probability (AEP) event of 79.8 mm over 720 minutes; and
- 1% AEP event of 117 mm over 720 minutes.

It was conservatively assumed that the wetlands were full at the start of the modelling period and the permanent standing water in the retention wetland was also full. The results are presented in Table 10 and Figure 44 and indicate that the peak flows from the development catchment will be reduced by approximately 40% for the 10% AEP and 4% for the 1% AEP.

The results have been compared with the outputs from the stormwater design modelling to check for accuracy and the results show a similar order of magnitude in the percentage flow reduction. However, the flow rates estimated within this model (both pre- and post-development) are higher than estimated for the stormwater modelling. Further calibration of this model will be required once sufficient baseline data is available. However, it considered that the higher flows estimated are potentially more conservative for the assessment of effects.

Based on the results of the assessment it is considered likely that the effects of the development of discharge into the Kakaho Stream will be less than minor, but as noted, further calibration is recommended when data becomes available to confirm that the assumptions are realistic. Whilst it is not anticipated that significant changes to the model will be required, it will be important for setting effective trigger values for monitoring during construction.

Table 10: Storm event peak flows – Kakaho West Catchment

Catchment	10% AEP		1% AEP	
	Baseline peak flow (L/s)	Post-development peak flow (L/s)	Baseline peak flow (L/s)	Post-development peak flow (L/s)
Total	7,411	4,342	10,900	10,418

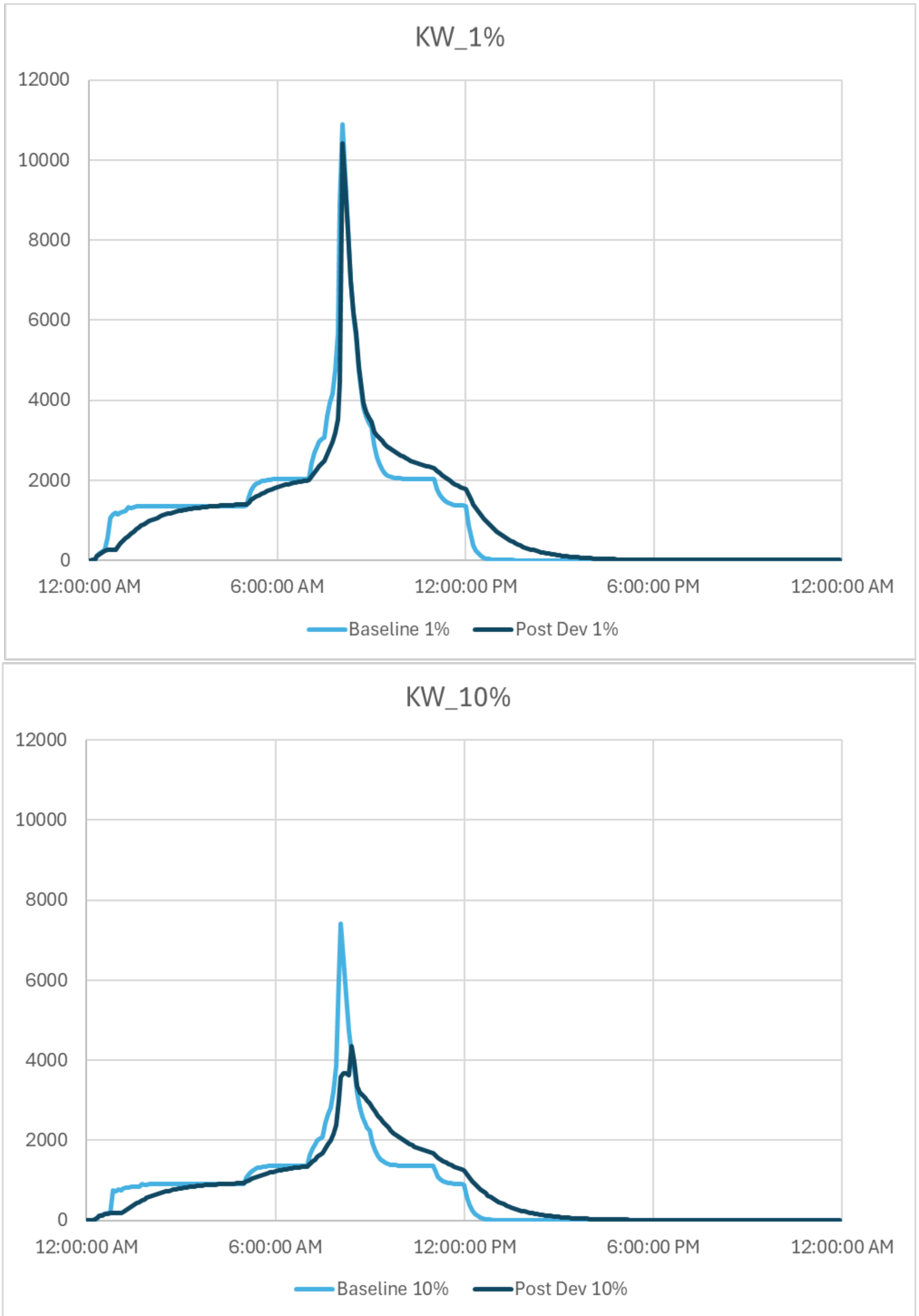

Figure 44: Kakaho West catchment AEP flows in L/s

8.2.3 Sediment Transport

Whilst the retention wetland at K1W4 reduces the peak flow velocity of the Kakaho West stream, the total volume of discharge does increase slightly as a result of the increase in impervious surfaces. The potential effect on downstream sediment transport has been assessed using the outputs from the modelling to develop a basic coupled sediment transport model for the section of stream immediately downstream SW03 (Figure 11for section location).

As with the Taupo catchment, the assessment was completed for the median and upper quartile discharge flows and the 1% and 10% AEP peak flows, to assess the changes to sediment transport during and outside peak flow events.

It was possible to use the model results for this assessment as it included the entire upstream catchment (see Figure 9 for catchment area) and the estimated discharge rates presented in Table 11.

Table 11: Total discharge at SW03

Scenario	Discharge (m^3/s)	
	Baseline	Post-development
Median discharge	0.0002	0.0007
Upper quartile discharge	0.0015	0.0087
10% AEP peak flow	7.4	4.3
1% AEP peak flow	10.9	10.4

Using the known stream cross section at SW03 (width: 0.75 m), water depth and stream velocity for the scenarios presented in Table 11 were calculated using Manning's equation, following the same methodology applied to the Taupo Stream. A Manning's coefficient of 0.04 was assumed and a 4 m wide flood plain was also included. The sediment load assessment was completed using the Van Rijn empirical equations for estimating both bed load and suspended sediment transport (Van Rijn, 1984), see Appendix C. The results are summarised in Table 12 below.

Table 12: Estimated Sediment Load – Kakaho West Stream

Scenario	Water depth h (m)	Velocity V (m/s)	Sediment Load q (kg/s)			
			Bedload		Suspended	
			Fine	Coarse	Fine	Coarse
Baseline						
Median discharge	0.002	5.3×10^{-6}	0	0	0	0
Upper quartile discharge	0.01	1.0×10^{-4}	0	0	0	0
10% AEP peak flow	2.0	2.26	3.3	3.3	34.4	1.1
1% AEP peak flow	2.2	2.28	3.3	3.3	35.5	1.1
Post-development						
Median discharge	0.009	1.0×10^{-4}	0	0	0	0
Upper quartile discharge	0.03	1.1×10^{-3}	0	0	0	0
10% AEP peak flow	1.8	2.23	3.2	3.2	33.0	1.0
1% AEP peak flow	2.2	2.28	3.3	3.3	35.3	1.1

Notes:

1. *Fine sand (median particle size of 0.0001m)*
2. *Coarse sand (median particle size of 0.002m)*

Whilst this is a simplified assessment, it does provide insight into the risks associated with sediment transport the in the Kakaho stream as a result of the change in land-use at the site. As with the Taupo catchment, the total mass of sediment is much higher in the case of fine sand with suspended load dominating the transport mechanism during peak flows.

Similarly there is little change in sediment transport outside of major rainfall events pre- and post-development because the critical velocity required for particle motion or suspension is not reached. The change in stream depth and velocity for the median and upper quartile flow events are relatively small so effects on sediment transport will be minimal.

The construction of a retention wetland at K1W4 reduces the peak flow velocities for significant storm events, which in turn leads to a slight decrease in the total quantity of sediment transported. Based on this assessment it is considered that development will slightly reduce the risk of significant sediment transport within the Kakaho West catchment from the pre-development baseline.

8.3 Kakaho East Catchment

A detailed assessment of the potential changes in flows in the Kakaho East catchment has not been completed because the changes in this catchment are limited. The catchment is 216 ha in area and the development area occupies only 7.5 ha (3%) of this extent. Whilst the development will result in a 2% reduction in catchment area, it will also increase the impervious area from 0% to 1% so the change in overall run-off is likely to be minimal. Given the size of the catchment, it is considered unlikely that the development will have a significant effect on the flows out of this catchment.

8.4 Muri Road

As noted in Section 7.3, the flows into the Muri Road catchment from the site will be regulated by a stormwater retention basin. This will ensure that flows remain no higher than pre-development, despite the increase in catchment area and impervious surfaces. The changes only affect a relatively small part of the total catchment so whilst there is likely to be a greater volume of water discharged from the site post-development, it is considered that the catchment can accommodate this change provided the peak flows are similar to baseline conditions. The flows will go through West Wetland 1, which is a reasonably large wetland with significant attenuation capacity, before discharging into the Waimapihi Stream. It is therefore considered that the effects surface water discharges into the Muri Road block and subsequently into the Waimapihi Stream will be less than minor.

9.0 Climate change

Review of the Greater Wellington Regional Council climate change scenario maps indicates that the following changes have been modelled for the site area by 2100, conservatively based on results for Regional Climate Model (RCP) 6.0 (Greater Wellington Regional Council, 2025):

- 8 to 10 more dry days (<1 mm rainfall) per year
- 1 to 2 more very wet days (>25 mm rainfall) per year
- 3 to 5% more rain per year

- 10% increase in the magnitude of extreme rainfall events
- 9 to 11 more hot days (>25°C) per year
- 11 to 13 more days per year with soil moisture deficit

These mean that there will potentially be hotter, drier summers and more extreme rainfall events. This can impact the site in the following two ways:

- Decreased water levels in wetlands in the summer for longer periods; and
- Higher peak discharges from the site during extreme rainfall events.

Given the increased run-off post-development and the nature of the wetlands, it is considered unlikely that slightly longer drier periods will have a significant effect on wetland hydrology. The wetlands on average will be wetter post-development due to more run-off from smaller rainfall events, even if the summers become drier.

The stormwater retention has been designed by Envelope Engineering to cope with at least a 1% AEP. Whilst the frequency of this scale of event will increase, this will not alter the ability of the system to regulate the peak flows discharging from the site. It is therefore considered that the effects of climate change can be managed under the current stormwater and wetland planting designs.

10.0 Monitoring

As noted previously there is very limited site-specific data for model calibration, which has meant this relied more on the conceptual understanding and experience in similar local catchments. However, site-specific data will always allow for a more accurate calibration.

It is therefore recommended that the current monitoring at the site continues until construction commences. This will provide more detailed information on how the water levels within the wetlands vary under low rainfall conditions and also provide a more detailed record of surface water flows from the site.

The model results should be cross-checked against the baseline data to confirm that the assumptions are realistic and representative. This is standard practice when modelling complex systems as more data becomes available.

Monitoring should also continue during and for at least three-year post-development and planting to ensure there are no impacts on the wetland hydrology from the development.

11.0 Conclusions and recommendations

The results of the modelling indicate that there will be additional run-off into the majority of the wetlands post-development due to the increase in impervious surfaces. This will result in generally wetter wetlands, although some seasonal variation will still occur. In areas where the wetlands will be significantly wetter, particularly the retention wetlands, BlueGreen Ecology has developed an appropriate planting plan to cope with these conditions. Given that the current wetlands are predominantly exotic species, the planting of appropriate native species will enhance the wetland environments and allow them to cope with any changes in hydrology.

This additional run-off means that the on-site streams will flow more regularly, but will mostly remain ephemeral in nature. Overall, the total discharge from the site into the downstream catchments will increase, but the use of retention wetlands will ensure that peak flows are lower during large rainfall events. This means that periods with no flow are likely to be reduced, but also periods of high intensity flow will also be fewer post-development. This indicates that there should not be a negative effect on the downstream hydrology.

However, it is noted that the modelling is based on a number of assumptions and a limited amount of baseline data. It is therefore recommended that baseline monitoring continues until construction and the model is reviewed against this data to ensure the results are representative. Whilst significant changes to the model are not anticipated, it will be important for setting effective trigger values for monitoring during the construction.

12.0 References

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Appendix A: Wetland Water Model Parameters

Appendix A: Water Balance Model Parameters

Table A1: Taupō Swamp Catchment Areas – hectares

Wetland	Baseline						Post-development					Total % Change
	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	
T1W1a	0.7	0.1	-	-	-	-	0.6	0.1	-	-	-	-9 %
T1W1b	0.2	0.1	1.7	7.9	0.3	-	0.2	0.2	0.3	7.9	-	-15 %
T1W3	1.2	0.3	-	-	-	-	0.2	0.5	-	-	-	-55 %
T1W4	1.2	-	-	-	-	-	1.2	-	-	-	-	1 %
T1W1c	0.2	0.5	-	-	-	-	0.2	0.5	-	-	-	-2 %
T1W2a	0.0	0.4	0.7	6.3	-	-	6.5	2.5	-	-	-	21 %
T1W2b	0.2	0.1	-	1.2	-	-	0.2	2.3	-	-	-	57 %
T1W2c	0.1	0.1	3.0	0.0	-	-	0.1	0.1	3.7	-	-	21 %
T2W1	2.0	-	-	-	-	-	0.9	-	-	-	-	-51 %
T3W1	3.3	0.5	-	-	-	-	2.4	1.2	5.2	-	-	120 %
T3W2	1.9	1.7	1.3	-	-	-	2.0	2.1	1.8	-	-	19 %
T3W3	0.3	0.3	-	-	-	-	0.3	0.3	-	-	-	0 %
T3W4	0.6	7.8	0.4	-	-	-	0.2	7.5	-	-	-	-13 %
T3W5	0.3	0.4	-	-	-	-	0.4	0.3	-	-	-	-1 %
T3W6	2.6	2.8	1.1	-	-	-	0.5	1.0	1.2	0.9	1.5	-20 %
T (SW)	2.1	0.9	1.0	1.7	13.5	7.7	1.9	1.9	10.8	5.4	10.5	-55 %

Table A2: Kakaho West Catchment Areas – hectares

Wetland	Baseline			Post-development			Total % Change
	C1	C2	C3	C1	C2	C3	
K1W1	0.8	1.1	0.4	1.8	-	-	-24 %
K1W2	1.4	-	-	1.6	-	-	16 %
K1W3	0.2	1.7	0.9	1.2	-	-	-57 %
K1W4	0.7	2.3	-	1.9	0.8	9.1	363 %
K1W5	0.8	0.8	0.4	0.2	0.9	0.8	-8 %
K1W6	1.1	2.4	-	0.5	1.1	0.5	-39 %
K1W7	2.0	-	-	2.9	0.2	-	58 %

Table A3: Kakaho West Surface Water Catchment Areas – hectares

Surface Water Catchment	Baseline	Post-development
K_C1	11.3	10.6
K_C2	1.2	1.2
K_C3	0.5	0.5
K_C4	2.5	2.0
K_C5	2.1	1.7
K_C6	4.4	6.3
K_C7	7.7	0.4
K_C8	3.1	2.4
K_C9	0.8	0.8
K_C10 (Pond, baseline)	32.1	2.2
K_C11 (Pond, post-development)	N/A	31.1

Table A4: Model Parameters – Taupō Swamp Catchment

Parameter	T1W1a	T1W1b	T1W1c	T1W2a	T1W2b	T1W2c	T1W3	T1W4	T2W1	T3W1	T3W2	T3W3	T3W4	T3W5	T3W6	T_SW	Notes
Regional Data																	
Daily Rainfall (mm)	Daily total rainfall from GWRC Taupō Stream at Whenua Tapu rain gauge																Assigned across model
Daily ET (mm)	Daily total evapotranspiration from NIWA Paraparaumu Aero weather station (CLIFLO database)																Assigned across model
Wetland Parameters																	
Wetland extent (ha)	0.09	0.14	0.05	0.18	0.05	0.02	0.02	0.03	0.05	0.29	0.35	0.03	0.11	0.06	0.17	N/A	Taken from BlueGreen Ecology shapefiles
Wetland depth (m)	0.8	0.8	0.4	1	1	0.8	0.6	0.8	0.8	1	1	1	1	1	0.9	N/A	Estimated from available geological information
Wetland surface (mRL)	35	35.5	36	40	42.5	45	45	55	50	58	65	65	65.5	66	75	N/A	Estimated from lidar contours, taken from near downstream end of wetland.
Wetland porosity (%)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	N/A	Estimated from soil logs
Downstream distance (m)	460	1	1	30	1	1	50	120	72	110	20	20	40	1	58	N/A	Measured distance between end of wetland and place where downstream gradient will be controlled.
Downstream groundwater level (mRL)	26	T1W1a	T1W1b	T1W1c	T1W2a	T1W2b	T1W1b	T1W3	45	52	T3W2	T3W2	T3W3	T3W4	T3W5	N/A	RL of groundwater downstream of wetland. Calculated or set to sea level
Downstream hydraulic conductivity (m/s)	1.00E-06															N/A	Permeability of aquifer downstream of wetland (estimated and calibrated)
Wetland mouth width (m)	18	30	13	15	14	8	15	17	16	24	17	15	15	9	10	N/A	Width of mouth of wetland, measured from Google Earth shape files
Mean Annual Low Flow (L/s)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Min SW discharge, estimated from site monitoring and conceptual understanding.
Catchment Parameters																	
Canopy Evaporation Ratio	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Set as 1 for all
Canopy Storage Capacity (mm)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1 or 3	Set as 1 for all, except SNA in T_SC5 which is 3 mm
Initial Soil Moisture Content (%)	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	Assumed value for day 1. Applies to all catchments
Soil porosity (%)	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	Estimated from soils and calibrated during modelling. Applies to all catchments
Groundwater percolation rate (mm/d)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	Calibrated during modelling. Applies to all catchments
Soil maximum infiltration rate (mm/d)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	Calibrated during modelling. Applies to all catchments
Crop factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Using ET so set to 1 as not relevant
Evaporative power	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Calibrated values. Applies to all catchments
Percolation power	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Calibrated values. Applies to all catchments
Soil Thickness (mm)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	Estimated from geological logs
Run-off Lag (d)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Calibrated in model
Groundwater Lag (d)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Calibrated in model
Impervious percentage (%) - Baseline	0	0	0	2	0	3	0	0	0	5	0	0	0	0	0	2	Calculated based on aerial photos. Most 0, some catchments have existing houses and sheds.
Impervious percentage (%) – Post-development	0	0	0	6	0	66	65	68	68	47	24	0	49	0	32	13	Calculated based on 85% for roads and 75% for lots

Table A5: Baseline Parameters – Kakaho West Catchment										
Parameter	**K1W1**	**K1W2**	**K1W3**	**K1W4**	**K1W5**	**K1W6**	**K1W7**	**K_Pond**	**K_SW**	**Notes**
Regional Data										
Daily Rainfall (mm)	Daily total rainfall from GWRC Taupō Stream at Whenua Tapu rain gauge									Assigned across model
Daily ET (mm)	Daily total evapotranspiration from NIWA Paraparaumu Aero weather station (CLIFLO database)									Assigned across model
Wetland Parameters										
Wetland extent (ha)	0.11	0.04	0.04	0.20	0.06	0.23	0.03	0.22	N/A	Taken from BlueGreen Ecology shapefiles
Wetland depth (m)	0.8	0.4	1	1.6	1	1.6	1.2	2	N/A	Estimated from available geological information
Wetland surface (mRL)	90	95	100	95	96	100	110	105	N/A	Estimated from lidar contours, taken from near downstream end of wetland.
Wetland porosity (%)	70	70	70	70	70	70	70	100	N/A	Estimated from soil logs
Downstream distance (m)	160	190	61	260	110	180	40	370	N/A	Measured distance between end of wetland and place where downstream gradient will be controlled.
Downstream groundwater level (mRL)	85	85	K1W4	85	K1W4	K1W4	K1W6	K1W4	N/A	RL of groundwater downstream of wetland. Calculated or set to sea level
Downstream hydraulic conductivity (m/s)	1.00E-06								N/A	Permeability of aquifer downstream of wetland (estimated and calibrated)
Wetland mouth width (m)	9	13	14	25	12.5	25	14	35	N/A	Width of mouth of wetland, measured from Google Earth shape files
Mean Annual Low Flow (L/s)	0	0	0	0	0	0	0	0	0	Min SW discharge, estimated from site monitoring and conceptual understanding.
Catchment Parameters										
Canopy Evaporation Ratio	1	1	1	1	1	1	1	1	1	Set as 1 for all
Canopy Storage Capacity (mm)	1	1	1	1	1	1	1	1	1	Set as 1 for all, except SNA in T_SC5 which is 3 mm
Initial Soil Moisture Content (%)	50%	50%	50%	50%	50%	50%	50%	50%	50%	Assumed value for day 1. Applies to all catchments
Soil porosity (%)	20%	20%	20%	20%	20%	20%	20%	20%	20%	Estimated from soils and calibrated during modelling. Applies to all catchments
Groundwater percolation rate (mm/d)	4	4	4	4	4	4	4	4	4	Calibrated during modelling. Applies to all catchments
Soil maximum infiltration rate (mm/d)	5	5	5	5	5	5	5	5	5	Calibrated during modelling. Applies to all catchments
Crop factor	1	1	1	1	1	1	1	1	1	Using ET so set to 1 as not relevant
Evaporative power	1	1	1	1	1	1	1	1	1	Calibrated values. Applies to all catchments
Percolation power	1	1	1	1	1	1	1	1	1	Calibrated values. Applies to all catchments
Soil Thickness (mm)	100	100	100	100	100	100	100	100	100	Estimated from geological logs
Run-off Lag (d)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Calibrated in model
Groundwater Lag (d)	1	1	1	1	1	1	1	1	1	Calibrated in model
Impervious percentage (%) – baseline	0	0	0	0	0	5.2	0	7.2	0	Calculated based on aerial photos. Most 0, some catchments have existing houses and sheds.
Impervious percentage (%) – Post development	14	19	0	47	13	3	64	0	23	Calculated based on 85% for roads and 75% for lots

Table A6: Retention Wetlands

Parameter	A – T1W2a	B – T3W1	C – T3W4	E – K1W1
Permanent pond volume (m^3)	770	480	720	1090
Retention pond volume (m^3)	4,930	10,220	6,230	10,560
Culvert RL (mRL)	41	54.3	64.5	91.4

Appendix B: Wetland Water Balances

Table B1: Baseline Wetland Water Balance – Taupō Catchments

Wetland	In (m^3)			Out (m^3)			In – Out (m^3)	% Difference
	Rain	Surface water	Groundwater	Evapotranspiration	Surface water	Groundwater		
T1W1a	869	107,402	1,317	859	108,718	9	1.9	0.00%
T1W1b	1,329	92,973	12,238	1,314	104,853	370	3.2	0.00%
T1W1c	509	47,765	887	503	48,582	75	0.2	0.00%
T1W2a	1,729	43,248	2,348	1,709	45,548	62	4.7	0.01%
T1W2b	453	19,018	887	447	18,871	1,038	1.2	0.01%
T1W2c	154	10,775	3,680	152	13,973	483	0.4	0.00%
T1W3	242	10,066	1,813	239	11,829	52	0.4	0.00%
T1W4	302	3,875	1,441	298	5,284	35	0.7	0.01%
T2W1	453	6,206	2,308	448	8,491	27	1.1	0.01%
T3W1	2,766	106,802	4,356	2,734	111,142	40	7.6	0.01%
T3W2	3,373	15,509	5,768	3,335	21,306	0	9.3	0.04%
T3W3	268	71,521	661	265	72,184	0	0.8	0.00%
T3W4	1,061	59,185	10,571	1,049	69,760	6	3.2	0.00%
T3W5	550	30,355	891	544	31,117	133	1.5	0.00%
T3W6	1,689	20,485	7,618	1,670	28,075	43	4.4	0.01%
Total	**15,745**	**645,186**	**56,784**	**15,567**	**699,734**	**2,374**	**40.8**	**0.01%**

Table B2: Post-development Wetland Water Balance – Taupō Catchments

Wetland	In (m^3)			Out (m^3)			In – Out (m^3)	% Difference
	Rain	Surface water	Groundwater	Evapotranspiration	Surface water	Groundwater		
T1W1a	873	235,772	2,643	860	238,418	9	2.3	0.00%
T1W1b	1,336	205,056	27,536	1,315	232,230	375	7.7	0.00%
T1W1c	511	144,718	2,227	503	146,872	81	0.9	0.00%
T1W2a	1,738	130,680	10,733	1,711	141,339	63	37.9	0.03%
T1W2b	455	55,471	3,289	448	57,680	1,085	1.7	0.00%
T1W2c	155	31,822	3,900	152	35,229	494	1.0	0.00%
T1W3	243	13,305	2,137	239	15,392	53	0.8	0.00%
T1W4	303	6,409	3,646	299	10,023	35	1.3	0.01%
T2W1	455	7,667	952	448	8,597	28	1.1	0.01%
T3W1	2,780	235,137	14,845	2,737	250,470	41	-485.8	-0.19%
T3W2	3,390	35,741	14,081	3,338	49,863	0	11.6	0.02%
T3W3	269	120,442	1,758	265	122,203	0	1.0	0.00%
T3W4	1,066	105,153	12,575	1,050	117,706	6	32.1	0.03%
T3W5	553	47,510	2,290	545	49,669	138	1.9	0.00%
T3W6	1,698	32,984	11,041	1,672	44,002	44	6.1	0.01%
Total	**15,825**	**1,407,868**	**113,654**	**15,583**	**1,519,691**	**2,452**	**-378.4**	**-0.02%**

Table B3: Baseline Wetland Water Balance – Kakaho West Catchments

Wetland	In (m^3)			Out (m^3)			In – Out (m^3)	% Difference
	Rain	Surface water	Groundwater	Evapotranspiration	Surface water	Groundwater		
K_1W1	1,171	9,038	3,602	1,067	12,735	7	2.9	0.02%
K_1W2	438	5,453	2,173	399	7,657	8	0.6	0.01%
K_1W3	379	10,959	4,368	345	15,323	36	1.6	0.01%
K_1W4	2,114	306,471	29,532	1,926	336,130	48	12.6	0.00%
K_1W5	613	7,764	3,094	559	10,907	4	2.0	0.02%
K_1W6	2,357	24,323	5,351	2,147	29,839	35	10.2	0.03%
K_1W7	283	7,694	3,066	258	10,653	131	1.3	0.01%
K_Pond	2,318	126,690	49,206	2,111	176,019	60	23.5	0.01%
Total	**9,674**	**498,392**	**100,391**	**8,812**	**599,262**	**328**	**54.6**	**0.01%**

Table B4: Post-development Wetland Water Balance – Kakaho West Catchments

Wetland	In (m³)			Out (m³)			In – Out (m³)	% Difference
	Rain	Surface water	Groundwater	Evapotranspiration	Surface water	Groundwater		
K_1W1	1,075	7,206	2,593	1,075	9,789	7	2.9	0.03%
K_1W2	402	7,213	2,267	402	9,471	8	0.9	0.01%
K_1W3	348	3,801	2,035	348	5,799	35	1.4	0.02%
K_1W4	1,941	405,285	21,869	1,941	456,665	49	-29,559	-6.89%
K_1W5	563	7,476	2,734	563	10,204	4	2.1	0.02%
K_1W6	2,164	31,560	3,454	2,164	34,970	35	10.2	0.03%
K_1W7	260	23,048	1,937	260	24,853	131	1.3	0.01%
K_Pond	2,128	131,431	44,791	2,128	176,137	60	26.1	0.01%
Total	**8,882**	**617,020**	**81,681**	**8,880**	**727,889**	**328**	-29,514	-4.17%

Notes:

1. *Imbalance in outflow from K1W4 (more out than in). No issues detected in model so may be caused by the way the head in the retention wetland is estimated and used to calculate the flow through the culvert.*

Appendix C: Sediment Transport Equations

Bed Load Transport - Van Rijn (1984, 1993)

$$q_b = \alpha_b \rho_s U h \left(\frac{d_{50}}{h}\right)^{1.2} \left(M_{e,m}\right)^{\eta}$$

$$M_{e,m} = \frac{(U - U_{cr,m})}{[\left(\frac{\rho_s}{\rho_w} - 1\right) g d_{50}]^{0.5}}$$

$$U_{cr,m} = 0.19 d_{50}^{0.1} \log\left(\frac{12h}{6d_{50}}\right) \qquad 0.0001m < d_{50} < 0.0005m$$

$$U_{cr,m} = 8.5 d_{50}^{0.6} \log\left(\frac{12h}{6d_{50}}\right) \qquad 0.0005m < d_{50} < 0.002m$$

- q_b bed-load transport (kg/s/m)
- α_b coefficient 0.005
- η coefficient 2.4
- ρ_s sediment density (kg/m^3)
- ρ_w water density (kg/m^3)
- U depth averaged velocity (m/s)
- h water depth (m)
- d_{50} median particle size (m)
- $M_{e,m}$ mobility parameter for initiation of motion (-)
- $U_{cr,m}$ critical depth-averaged velocity for initiation of motion (m/s)

Suspended Load Transport - Van Rijn (1984)

$$q_s = \alpha_s \rho_s U d_{50} M_{e,s}^{2.4} D_*{}^{-0.6}$$

$$D_* = \left[\frac{(s-1)g}{\nu^2}\right]^{1/3} d_{50}$$

$$M_{e,s} = \frac{(U - U_{cr,s})}{[\left(\frac{\rho_s}{\rho_w} - 1\right) g d_{50}]^{0.5}}$$

$$U_{cr,s} = 2.8\left[\frac{h}{d_{50}}\right]^{0.1}\left[\left(\frac{\rho_s}{\rho_w} - 1\right) g d_{50}\right]^{0.5} \qquad 0.0001m < d_{50} < 0.002m$$

- Q_s sediment-load transport (kg/s/m)
- α_s coefficient 0.012 (-)
- ρ_s sediment density (-) (kg/m^3)
- ρ_w water density (kg/m^3)
- U depth averaged velocity (m/s)
- h water depth (m)
- d_{50} median particle size (m)
- $M_{e,s}$ mobility parameter for initiation of suspension (-)
- $U_{cr,s}$ critical depth-averaged velocity for initiation of suspension (m/s),
- D_* dimensionless particle size (-)