STORMWATER MANAGEMENT FOR REGENERATION OF THE THREE KINGS QUARRY

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ABSTRACT

Fletcher Residential Ltd (Fletcher) own the former Three Kings quarry in central Auckland and are turning the quarry into a large scale residential development – a place of 1200 homes. The development is directed by a comprehensive masterplan which includes recognising the quarrying heritage, the former pit filled by about 70%, cultural recognition, sports fields and a range of different housing typologies.

The Three Kings quarry sits within a unique environment. The geology is complex, with a 1km diameter surrounding tuff ring (with a breach to the north), a series of scoria cones and basalt in dykes and lakes. Much of the geology is disturbed, interbedded and overlain by subsequent eruptions. The quarry sits at the top of the Meola Catchment with little separated stormwater infrastructure and only an overloaded combined sewer nearby. The planned development retains part of the former quarry pit, which means the development floor sits 15 to 17m below adjacent land with no way of providing piped gravity drainage or overland flow paths. And finally, groundwater pumping is to cease and the groundwater levels will return to the pre-pumping levels of RL 56.5m (about 21-23m below Mt Eden Rd).

Fletcher therefore faced the unique challenge of how to develop the land comprehensively, drain the development via soakage into the scoria and fractured basalt with groundwater close to the surface and manage long term flood risk. In short, groundwater provides a lower bound constraint: floor levels and freeboard provide an upper bound constraint, and the stormwater must be carefully directed to soakage in between these levels.

As well as the global upper and lower bound level constraints, development of the stormwater management concept had to deal with a range of design questions. The upper and lower bounds meant that the solution involved storage (above and below ground) and the soakage of stormwater at multiple sites. Design challenges included; managing flood risk, confirming aquifer responses to rainfall, assessing local groundwater mounding, how to keep sediment out of the soakage during construction and long term, the factor of safety to be adopted in soakage systems, identifying the variation in rock permeability, sports fields drainage and operation and the porosity of rock to be used in underground storage facilities. These constraints however provide a unique opportunity for the adoption of soakage at a large scale and provide an excellent example of implementing water sensitive design.

The stormwater management concept has been through a Plan Change process and has recently been updated as a result of an Environment Court mediation agreement and the Unitary Plan Three Kings precinct provisions.

This paper sets out the development of the overall stormwater management approach and how the challenges were addressed.

A companion paper to this paper by Messrs Strayton, Namjou and Matheson of PDP presented to this conference describes the hydrogeological assessments, groundwater effects and soakage investigations and construction in more detail.

1 INTRODUCTION

1.1 PROPOSED DEVELOPMENT

Fletcher has owned and operated the 15.2 ha Winstone Three Kings Quarry (the Quarry) on Mt Eden Road since 1922. The Quarry has provided aggregate for many civil engineering projects over the years and is particularly well known as a source of scoria for drainage aggregate and lightweight backfill. By 2012, the Quarry had been dewatered and excavated some 30m below the original groundwater level and was at the end of its economic life. Fletcher now intends to develop the quarry into a residential precinct including apartments, townhouses, and open space including sports fields, walkways and cycleways. The development is expected to provide 900 to 1500 dwellings and house between 3,500 and 4,275 people.

To optimise and integrate the development area with adjoining land, a land swap is to occur with Auckland Council for parts of the adjoining land to the south which were previously operated as a quarry by the former Mt Roskill Borough Council. Auckland Council will receive land with two new sports fields and open space areas in exchange.

Master plan layouts have been worked on for a number of years with the most recent layout being Master Plan option 22B. This layout provides a comprehensive development plan for both the former Quarry land owned by Fletcher and the area of adjoining land to the south. The Masterplan includes a "Riu" (or gently graded floor) with terrace and town housing, the two new sports fields and a belt of green space and swale on the eastern side. The perimeter of the development is bounded by split level "cascading" apartment buildings which traverse the former quarry faces so that internal walls are some eight to ten stories and exterior walls are four to five storeys, with internal parking "sleeved" against the quarry walls.

Stormwater from the development is to be discharged via soakage into the scoria and fractured basalt within the Three Kings volcanic crater.

1.2 RMA PROCESSES

Fletcher has consent to fill the quarry through a consent process concluded in 2011 with an Environment Court decision. With respect to enabling future development, two RMA processes were progressed in parallel - to allow for uncertainty of how long the Unitary Plan process might take. A Plan Change application (PC372) to the existing Auckland Council District Plan: Isthmus Section was promoted to change the existing quarry zone to residential. Alongside this, the same provisions were promulgated as a specific Three Kings Precinct in the Unitary Plan process. These processes both envisioned the sports fields at RL 59m and the Riu generally at RL 61m to 64m.

The PC372 provisions were recommended for granting following the Council Hearing in 2015, but were appealed to the Environment Court. The Environment Court hearing was completed in 2016 with a key outcome of the interim decision being that the sports field was raised to RL 62m and the Riu was set at RL 64m to 66m to resolve urban design issues. Further mediation then occurred between the parties. Meanwhile, the Precinct provisions in Unitary Plan were issued and also appealed on a "point of law" by the same appellants. Mediation with the appellants reached an agreement in mid-2017, which incorporated the higher development levels from the Environment Court process.

Finally, Auckland Council has notified a Plan Change in February 2018 to the Unitary Plan (PC11) so that the Three Kings Precinct provisions in the Unitary Plan are consistent with the outcomes of the mediated agreement.

1.3 STAGING

During the RMA processes, filling of the quarry was occurring. As the filling progressed alongside the formulation of the soakage discharge for future development, it became clear that soakage zones would need to be constructed at the same time as future filling stages and before the RMA Plan Change or Unitary Plan processes were complete.

An Engineering Plan Approval (EPA) application (required for new public infrastructure assets) for the first soakage zone was therefore made in late 2016. As this application was in advance of the RMA processes, it was "at risk" and the works needed to be flexible enough to facilitate potential changes and future development layouts.

Figure 1: Three Kings Masterplan Layout 22B

2 CONCEPT

2.1 CONSTRAINTS

2.1.1 TOPOGRAPHY

The Quarry has been extensively excavated for basalt and scoria since the early 1900s and began the process of filling in 2012. The deepest parts of the excavation were taken to about RL 34m, approximately 46m below the surrounding public roads. The walls of the quarry are typically cut at 60 to 70 degrees and consist of a complex mix of volcanic materials, primarily scoria with basalt intrusions.

Surface topography drains to the low point within the quarry footprint from both internal and external areas. These external areas comprise part of the Big King Reserve to the west, the north-east corner of the plan change area (which is currently used as the entrance to the quarry and for commercial buildings), and during extreme events, part of the residential development around Smallfield Avenue and the playing field to the west of the Quarry.

Filling of the Quarry footprint has progressed by the end of 2017 so that the southern half has been filled to about RL 60m.

Figure 2: Three Kings Quarry Image from 2014

2.1.2 CATCHMENT DRAINAGE

The development is situated at the top of the Meola surface water catchment in central Auckland. The catchment generally runs to the north-west through Mt Eden and Sandringham towards the Meola reef in the Waitemata Harbour.

The main piped drainage system for the Meola catchment consists of combined sewers for stormwater and wastewater with many pipes overloaded during heavy rain. In the areas around the development, a combined sewer system services Mt Eden Rd and then passes south of the site, running westwards to Haverstock Road on the southern branch of the Meola Creek. Here, a major constructed overflow throttles storm flows and they overflow to the Meola Creek.

Water quality concerns from combined sewer overflows are a significant issue within the Meola catchment. In the longer term a new wastewater tunnel, the Central Interceptor tunnel, is proposed by Watercare Services Ltd to provide additional downstream trunk sewer capacity, but this will not necessarily improve the capacity of the upstream connecting sewers.

Within the crater to the east, a separated stormwater system drains a residential area through a tunnel running toward Royal Oak. In extreme rainfall events the tunnel capacity is exceeded and flooding covers lower lying areas. Flows from the Three Kings shopping centre carpark to the south are piped directly to the land previously operated as a quarry by the Mt Roskill Borough Council where it drains informally by soakage.

2.1.3 THE BUCKET

The Quarry sits approximately in the centre of the Three Kings volcanic crater. The crater is a hole within the older surrounding Waitemata and Tauranga Group rocks, which at the surface is approximately 1000m in diameter and takes the approximate form of an inverted cone or bucket. This crater was filled with volcanic material - primarily scoria and basaltic lava - during the eruptive phases of the Three Kings volcano.

During the initial explosive eruptive phases of the Three Kings volcano the pre-existing Waitemata and Tauranga Group rocks were shattered and blown out of the crater to be deposited as tuff in a raised ring around the edge of the crater. The height of this ring varies around the crater and in the north, around Landscape Road to the west of Mt Eden Road, where there is a low point. A series of scoria eruptions followed, interspersed with lava flows. Basalt lava, which ponded within the crater, eventually spilled over the low point in the tuff ring and flowed to the north-west (near Landscape Rd). From there it joined with basalt flows from One Tree Hill, Mt Eden and Mt Albert volcanoes to infill the Meola Valley and form the Meola Reef in the Waitemata Harbour.

2.1.4 GROUNDWATER

Around the quarry, due to the high permeability of the volcanic materials and the low permeability of the surrounding tuff and Waitemata and Tauranga Group rocks, rainfall over the crater soaks into the ground to recharge the groundwater within the crater

Prior to the advent of quarry dewatering in 1999, groundwater levels within the crater were at approximately RL 56.5m (which is 22m higher than the maximum dewatered level of RL34), and groundwater outflows occurred (within the high permeability lava flows) by spilling over the underground low point in the tuff ring (at approximately RL 48m) in the vicinity of Landscape Road. This groundwater would then have migrated through the basalt flows infilling the former Meola Valley and eventually discharged to the Waitemata Harbour close to the Meola Reef.

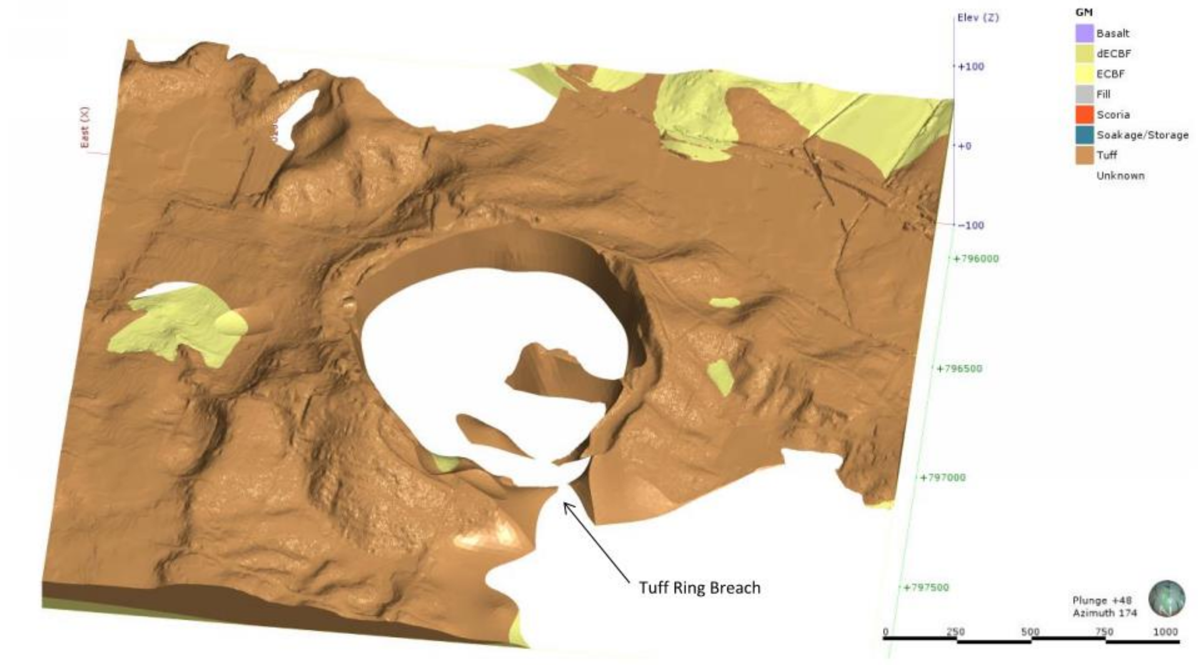

FIGURE 3C: "BUCKET" OR TUFF RING LIP ABOVE R.L. 49.0 M

Y:\AJ400_AJ499\AJ456 Three Kings Quarry\AJ456307 - Three Kings Southern Soakage Design\007_Work\Reporting\SWMP\Appendix\A\FIGURE3C

Figure 3: Three Kings Tuff Ring

The crater can be thought of like a bucket collecting water - with a notch on the north-western side which allows water to overflow underground into the Meola catchment. The groundwater level in the crater is determined as a balance between the incoming soakage and outgoing aquifer outflow to the Meola groundwater system. The groundwater level varies seasonally and in response to rainfall. The completed ground level on the site will be above the natural groundwater levels (without the need for any on-going pumping).

2.2 WHY SOAKAGE?

Stormwater from the development will be disposed of by soakage to the volcanic rock within the tuff ring crater. The fractured basalt and scoria (which make up most of the existing quarry walls and floor) provide ample capacity to discharge surface water to ground via soakage. Discharging stormwater to soakage avoids potential effects on existing flooding areas off-site and does not cause a deterioration in the performance of the under capacity combined sewer surrounding the site.

The development's design uses the former quarry form with the Riu set at RL 64m to 66m, some 15m below Mt Eden Rd. This form allows intensification of the site with a series of apartment buildings around the perimeter. Filling the quarry to the surrounding ground level was discounted by Fletcher early in the development's design due to the benefits of intensification, the availability of fill and the time required for filling. While a higher development would have allowed off site overland flow paths to be considered, the effects of flooding on downstream areas would still need to be managed and attenuation provided so as to not exacerbate existing flooding. Furthermore, due to the lack of capacity in both the combined sewer and separated stormwater system to the east, soakage would still need to be used as the primary drainage system.

Soakage is considered to be an effective and desirable means of stormwater discharge as it utilises a readily available existing resource, avoids changes to the natural water cycle, avoids the need for pumping and minimises reticulated drainage both within and external to the Precinct.

2.3 UNIQUENESS

Stormwater disposal by soakage is common across the central Auckland isthmus in basalt areas with approximately 40% of the developed area within the Meola catchment serviced by soakage. Similar approaches are used in the Motions, Epsom, Greenlane, Penrose, Onehunga and parts of the Oakley catchments. There are many areas across these catchments where the local topography forms a potential ponding area with soakage providing the primary drainage.

Soakage devices are often private drainage systems with each house or development having a separate system - typically consisting of a 100mm pneumatically drilled bore and an overlying manhole. Soakage trenches are also used, for example a 1 x 3 x 2m deep trench backfilled with a high porosity aggregate. Soakholes are usually constructed so that the bore(s) have a discharge rate sufficient for the peak design flow, while trenches are routed so that a balance between soakage wall area and storage volume caters for the design flow rate. In soakage areas road catchpits are also typically connected to individual soakholes. To date, large scale public soakage devices are rare and are typically only constructed to relieve existing flooding problems.

The use of soakage for the Three Kings development is, therefore, unique in terms of the scale of soakage provided for the site and the scale of development for one project and for the fact that modern development standards require careful integration of development with flood freeboard and overland flow paths for extreme rainfall events.

The proximity of the groundwater table reduces the amount of available soakage and flood storage, but conversely the topography of the quarry and its exposed rock has advantages with very large rock faces able to be developed for soakage without excavation.

The proposed Three Kings system is sometimes compared to the Stonefields subdivision in Mt Wellington. A key difference is however that the water from the Stonefields drainage system collects in a pond that is continuously pumped to the adjacent Waiatarua wetland which in turn discharges to the Orakei Basin. The Three Kings system is however a passive soakage system with no reliance on pumping.

3 OVERALL DESIGN APPROACH

3.1 THE SANDWICH

Due to the elevation of the Three Kings development land below the surrounding topography, stormwater management planning has had to account for the effects of both surface water flows and groundwater levels. Stormwater runoff within the Three Kings development will be managed through a combination of soakage, reticulated networks, stormwater treatment and overland flow.

Surface water which does not infiltrate into pervious areas and is not directly discharged to soakage on individual super-lots will be conveyed to storage and soakage areas around the perimeter of the former quarry wall. Soakage will be into rock both above and below the long-term groundwater level, and will travel laterally into unsaturated voids above the groundwater table. Constructed temporary water storage (both above and below ground) - will be provided in case the rate of incoming stormwater runoff is greater than the soakage rate at a given area. Once water has entered the crater aquifer (the "bucket"), the groundwater level rises and outflow occurs through the notch in the "bucket" to the north. The soakage rate and amount of temporary water storage available then determine the surface water flood levels within the riu and therefore set minimum building floor levels.

The two key design constraints for water storage are therefore a sandwich between the groundwater and building floor levels. The lower limit for the 10 and 100-year ARI flood storages are the respective design groundwater levels. The upper limit for storing the 10-year ARI rainfall event is the surface of the field (less a freeboard allowance) and the upper limit for the 100-year ARI rainfall event plus freeboard sets the minimum habitable floor levels.

3.2 GROUNDWATER

Following the cessation of the groundwater abstraction within the volcanic crater, the groundwater level within the crater will recover to its pre-dewatering level (RL 56.5 m). This will result in a resumption of the groundwater flow reaching the Greater Western Springs Aquifer through the tuff ring breach to the north. The invert of the tuff ring breach is approximately 8m below the pre-dewatering groundwater level of RL 56.5m. Therefore, the groundwater level in the crater would need to be kept at approximately RL 49m (or lower) to result in no groundwater outflow from the crater.

A simplified three-dimensional (3D) numerical groundwater model was constructed to estimate the rise in the natural groundwater level (above RL 56.5m) in the crater as a result of the 10- and 100-year rainfall events. The natural groundwater level of RL 56.5m was used to represent the case of no long-term groundwater pumping conditions.

The modelling was undertaken to set maximum groundwater table design levels for the development to define the freeboard within the unsaturated zone between the base of the underground storage facility and the normal water table level. That is, the distance required to host the (short term) groundwater level rise associated with the design storm. The groundwater level reduces vertical soakage – that is water from soakage zones will preferentially travel horizontally into unsaturated zones.

Mounding of groundwater occurs where the local rock characteristics of the aquifer prevent the water entering the aquifer without an increase in hydraulic head. As a phreatic surface establishes horizontally, head will build up and this will start to drive a proportion of water vertically into saturated rock as well. In effect, a cone of elevated groundwater forms around each soakage zone. Where these cones overlap the effect is cumulative.

The modelling results (excluding mounding) showed that a 10-year rainfall event causes approximately a 0.9m rise in the groundwater level in the centre of the crater and a 100-year rainfall event causes approximately a 1.2m rise in the groundwater level in the centre of the crater. After the 100-year rainfall event the groundwater level then gradually dissipates (within 1.5 months) to RL 56.5m. A total rise in the groundwater level was made allowing for an additional 0.3m for future soakage development in surrounding areas (which could increase groundwater levels) and normal seasonal maximums in groundwater levels (which could be present at the start of a rainfall event). This gives a maximum water table design level of RL 58.5m for the 100-year rainfall event (which is a total groundwater rise of 2m above the natural ground level). The water table design level for the 10-year rainfall event is RL 58.0m (which is 1.5m above the natural groundwater level).

3.3 FLOOD RISK

Surface water modelling has been used to; generate catchment flows, model soakage discharges, determine conveyance capacity through the eastern swale and assess/size the proposed flood storage areas. Modelling was carried out in accordance with Auckland Council's TP 108 "Stormwater Runoff Modelling Guidelines for the Auckland Region" (TP108) (and the associated recommended HEC HMS modelling software). The effects of future climate change on rainfall were included. The model was set up so that upstream soakage zones overflowed to the downstream system. The performance of the upstream soakage zones was also restricted so that it could represent reduced levels of performance (resulting in higher downstream flows and potential storage).

The Riu is high in the west and generally grades toward the overland flow path along the eastern side ending at the lowest level on the sports field flood storage. The amount of storage and level of the sports field required careful design to provide; maximum above ground flood storage, drainage of the sports field surface and suitable height above the short term ground water design level (to allow sub-surface drainage).

Floor levels adjacent to the sports field were set based on either:

- keeping building floor levels above the 100-year ARI flood level with required freeboard;
- keeping road low points above 100-year ARI flood levels and minimum crossfall and height requirements for roading and landscaping; or
- setting the outlets from local drainage pipes from the apartment blocks above the 10 year ARI flood level, hydraulically following this back through treatment and collection devices and allowing for required cover over the pipes.

During the Plan Change process a range of flood freeboard requirements were considered from the Unitary Plan, Auckland Regional Plan: Air, Land, Water, Auckland Council Code of Practice for Land Development and Subdivision and the Building Code. These typically required 500mm freeboard above the 100 year ARI flood level and secondary overland flow paths. However, given that there was no physical above ground overland flow path away from the development, a flood risk approach was adopted. This entailed considering various levels of service and risk scenarios as follows:

1. Maintaining the regular operation of the sports fields by requiring no ponding during the 10 year rainfall event;
2. An impaired drainage system scenario. Conservative assumptions were made about the operation of the soakage system so that its capacity was reduced, runoff volumes increased and resulting flood levels calculated. This was taken as the base case operating condition;
3. Consideration of overland flow paths down roadways and running south along the eastern swale/channel;
4. A hypothetical case of no soakage occurring at all and the flood level resulting from storing the entire rainfall, not runoff, volume for the 100 year event;
5. Two sequential 100 year events with the soakage system operating at its impaired rate;
6. Consideration of the Probable Maximum Flood effects - with soakage and external drainage systems operating and with no drainage systems operating.

Minimum building floor levels were determined using the standard of 0.5m freeboard in the 100 year event except where scenario 4 (with no freeboard) identified a higher level. The resulting requirements were included in the proposed PC372 text so that habitable floor levels must be above the 100-year flood level on the sports fields (catchment B) with at least 0.75m freeboard and 0.5m adjacent to the eastern channel flood levels. Habitable floors must also have freeboard above the water level in adjacent overland major flow paths along the roads.

Scenarios 5 and 6 were undertaken as further assessments to understand the so called "Noah's Ark" type rainfall effects on building floor levels. The scenario 5 assessment (two sequential 100 year events) assumed that some soakage in the upper parts of the catchments and around the sports fields was operating. The resulting flood level allowing for soakage and groundwater level changes over 1 day, was RL 61 approximately. The proposed minimum building floor level of the development at this point in time was RL61.5m – meaning this floor level provided protection in the unlikely case of two sequential 100 year events. Note however that this level was not formally promulgated as a minimum floor level through the Plan Change process as it was considered that scenario 4 already provided sufficient conservatism above the normal standards for setting freeboard.

During the Environment Court process, further assessment of the flood risk was also carried out by assessing scenario 6 (the Probable Maximum Flood). The 24 hour rainfall for this event was assessed (using Thompson and Tomlinson 1995) as 759mm in 24 hours – being more than three times the 100 year plus climate change event. Using the same catchments as the 100 year event and assuming some soakage and storage was available gave an approximate flood level of RL 61.7m, while containing the rainfall volume for the full rainfall event gave a flood level of RL 62.25m.

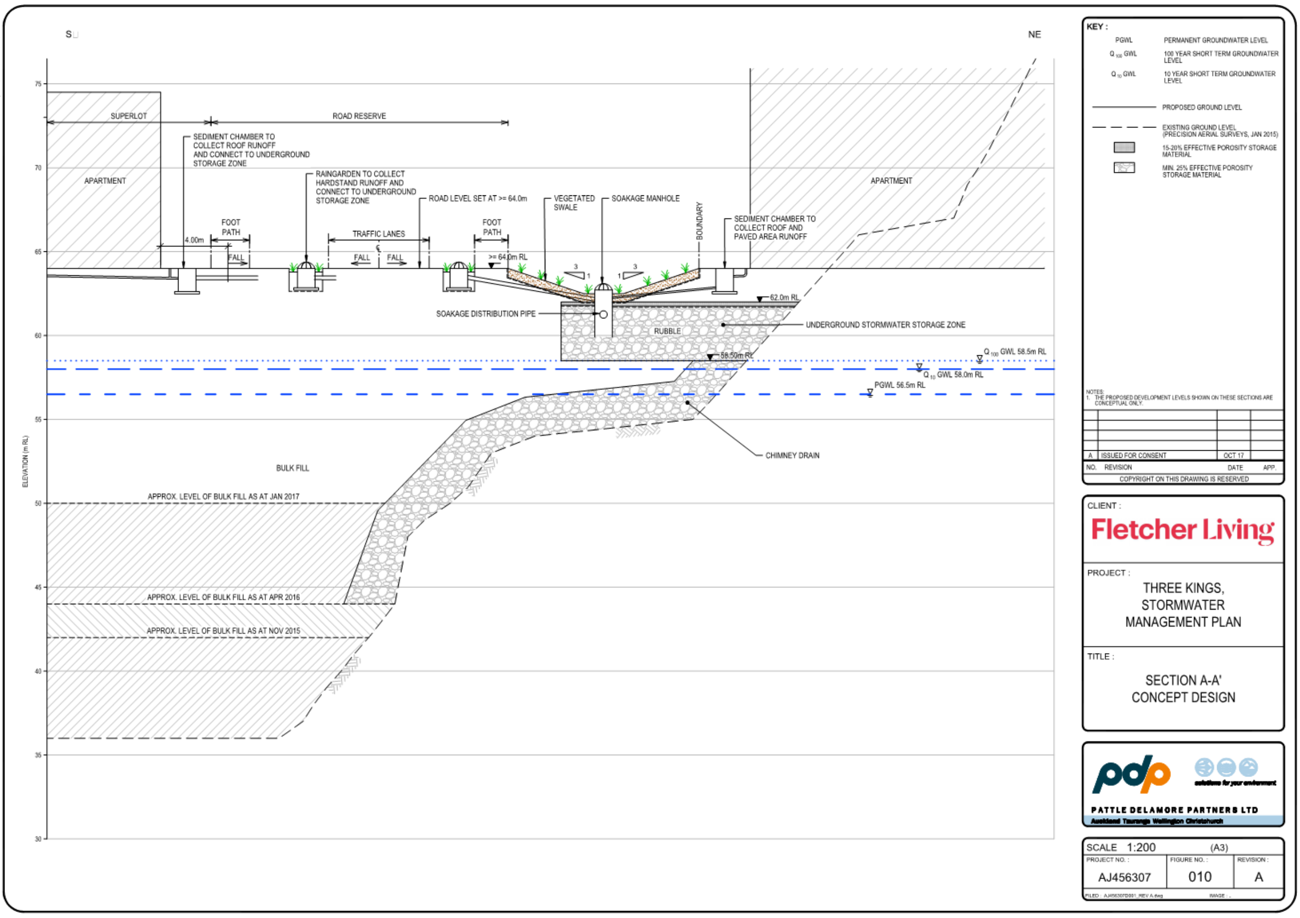

Figure 4: Soakage Concept through Eastern soakage zone

Further assessment of the surrounding catchments identified that it was possible that out of catchment above ground storage would be filled up in the PMP, meaning additional water could flow towards the development. Assuming that some soakage was occurring, this gave a PMP flood level in the development of RL 62.75m (with the sports fields at RL 59m). In all cases considered, the PMP caused some flooding of the floor levels. However, given the magnitude of the rainfall event against the adopted design events, the author did not recommend increasing the required freeboard to accommodate the PMP.

3.4 RE ASSESSMENT WITH RAISED DEVELOPMENT LEVELS

Following the Environment Court hearing, an agreement on the appeal was achieved which changed the development levels so that the Riu is to be set at RL 64 to 66m. Raising the development levels made the soakage design easier to achieve in that there was a greater height available for mounding to occur.

The results of soakage zone investigations and final soakage zone layouts were re-assessed in the groundwater model to give 3.1 to 3.4m groundwater level rises (including mounding) at the soakage zones for the 10 year rainfall event and about a 1m rise in the crater aquifer groundwater level. The groundwater model was also used to calculate the required volumes of water to be stored to cater for the 100 year rainfall event and two sequential 100 year rainfall events. These were then used to assess storage requirements and the resulting flood levels.

The flood levels for the table below show the recalculated flood levels for the higher development levels. These range between R.L. 63.40 m to R.L. 64.95 m depending on the scenario. The flood level with soakage operating caused by the 100-year ARI rainfall event is R.L. 63.40 m. The more conservative 100-year scenario where no soakage is operating results in a flood level of R.L. 64.60 m. If soakage into the surrounding rock was not quick enough, there may still be water in the storage zones during a second extreme rainfall event. The flood level resulting from two sequential 100-year ARI rainfall events is R.L. 64.39 m. The most conservative scenario, where all of the rainfall is converted to runoff with no soakage operating results in a flood level of R.L. 64.95 m.

The Three Kings Precinct provisions have subsequently become easier to achieve, given the increase in the proposed ground levels in the Riu from RL 61/64 up to RL64/66m. The resulting development grading and proposed buildings will meet all of the original and the updated flood freeboard requirements.

Table 1: Flood Levels

Rainfall Event ARI	Runoff Vol. to 3K Precinct (m^3)	Vol. Stored and Discharged in Storage & Soakage Zones (m^3)	Vol. to be Stored Above Ground (m^3)	Flood Level (R.L. m)
10-year with soakage operating	23,411	23,411	0	NA
100-year with soakage operating	48,064	27,764[1]	20,300[1]	63.40
2 x 100-year with soakage operating	105,813	49,313[1]	56,500[1]	64.39
100-year runoff with no soakage operating	76,925	12,035	64,890	64.60
100-year rainfall volume with no soakage operating	94,508		82,472	64.95

Notes:

1. *Volumes taken from groundwater model results which provide a conservatively high flood level.*

3.5 DESIGN SUMMARY

3.5.1 OVERVIEW

Stormwater runoff will therefore be managed through a combination of: soakage, stormwater treatment, reticulated networks, overland flow, flood storage and further soakage. The overall flood management concept was discussed above and are shown in Figures 4 and 5.

The piped drainage system will be designed for the 10-year event and will discharge to various soakage areas around the perimeter of the development.

The drainage system operates as follows:

1. Stormwater from individual buildings and roads is treated and discharged to soakage in the upper parts of the development. Pipes are provided from super-lots to soakage zones.
2. Excess runoff from the northern development is collected in an eastern swale and discharges to underground flood storage and soakage in the north east corner of the site, or it can travel south to further soakage areas or the sports fields.
3. Runoff from the eastern apartment buildings goes to the 175m soakage zone below the eastern swale.
4. The eastern swale ends at soakage areas to the south–east of the sports field.
5. The sports field will collect rain falling directly on it and is graded so that any surface water drains toward the south eastern or south western soakage zones.

6. Soakage has been designed to allow for short term rises in groundwater levels and sized to allow water to drain both vertically into the aquifer and horizontally into unsaturated zones.
7. A balancing stormwater pipe connects all soakage zones so that flows can equalise and make the best use of the available soakage.

All contaminant-generating surfaces from the development such as roads and roofs will discharge to a water quality treatment train prior to soakage. At source, contaminant management is provided by avoiding the use of unpainted metal roofing products. Following construction, the residential development and low traffic volumes on the internal roads will not generate large volumes of sediment. Treatment devices will comprise sediment chambers, rain-gardens and tree-pits – each close to the source of the stormwater.

In terms of long-term ownership, it is envisaged that the soakage system and stormwater pipe system in public roads and reserves will be vested with Auckland Council. The first of the soakage zones, below the eastern channel has been granted Engineering Plan Approval and is in the process of being constructed, refer Strayton et al.

Sedimentation and clogging of soakage pits from untreated stormwater can be a significant issue. During construction a high degree of erosion and sediment control will be required and final soakage systems will be need to be well protected during the construction programme to minimise the risk of construction-related sediment blockage. A monitoring and testing programme will be undertaken to verify the construction of the soakage zones.

A comprehensive operations and maintenance plan and programme is also envisaged to ensure long-term effective operation.

3.5.2 SOAKAGE

A comprehensive series of investigations have identified a range of basalt and scoria formations in the crater and have been used to confirm the infiltration and soakage system parameters and develop the soakage system design.

The areal extent of soakage zones required against the in-situ quarry walls has been determined from on-site mapping to maximise exposure to the preferred geological deposits with the highest permeability. Extensive soakage testing and geological characterisation has been undertaken to assess the permeability of the different geological deposits throughout the quarry. In summary, soakage capacity is available at a number of locations within the development, primarily where a connection to loose scoria, a basalt scoria interface, or fractured basalt is available. Soakage is best in coarse un-welded scoria lapilli located in the north-east corner of the quarry and near the existing dewatering well in the south. The best soakage on the eastern side is expected to be in the un-welded coarse scoria deposit approximately midway along the eastern wall.

Soakage is feasible into both saturated and unsaturated material. Following the cessation of groundwater pumping, the permanent groundwater level will return to approximately R.L. 56.5 m. Soakage into the unsaturated material provides both storage (within the rock voids) and a drainage path allowing water to spread out on top of the aquifer surface (which is governed by the material porosity and permeability). Soakage into the saturated material is governed by the available drainage rate, which in turn is governed by the head available (between the stored water level and the groundwater level) and the permeability of the aquifer over that area.

Some of the storage zones will be connected to lower level, high permeability blankets known as "chimney drains" which extend down the quarry wall. Chimney drains will be connected via high permeability material to the base of the storage zones. The large area connection that chimney drains provide against the quarry wall will allow for good soakage into the saturated zone. Construction of the eastern chimney drain has already been approved through an EPA process and is currently near completion of construction.

Figure 5 shows the overall stormwater management approach and the location of the soakage zones.

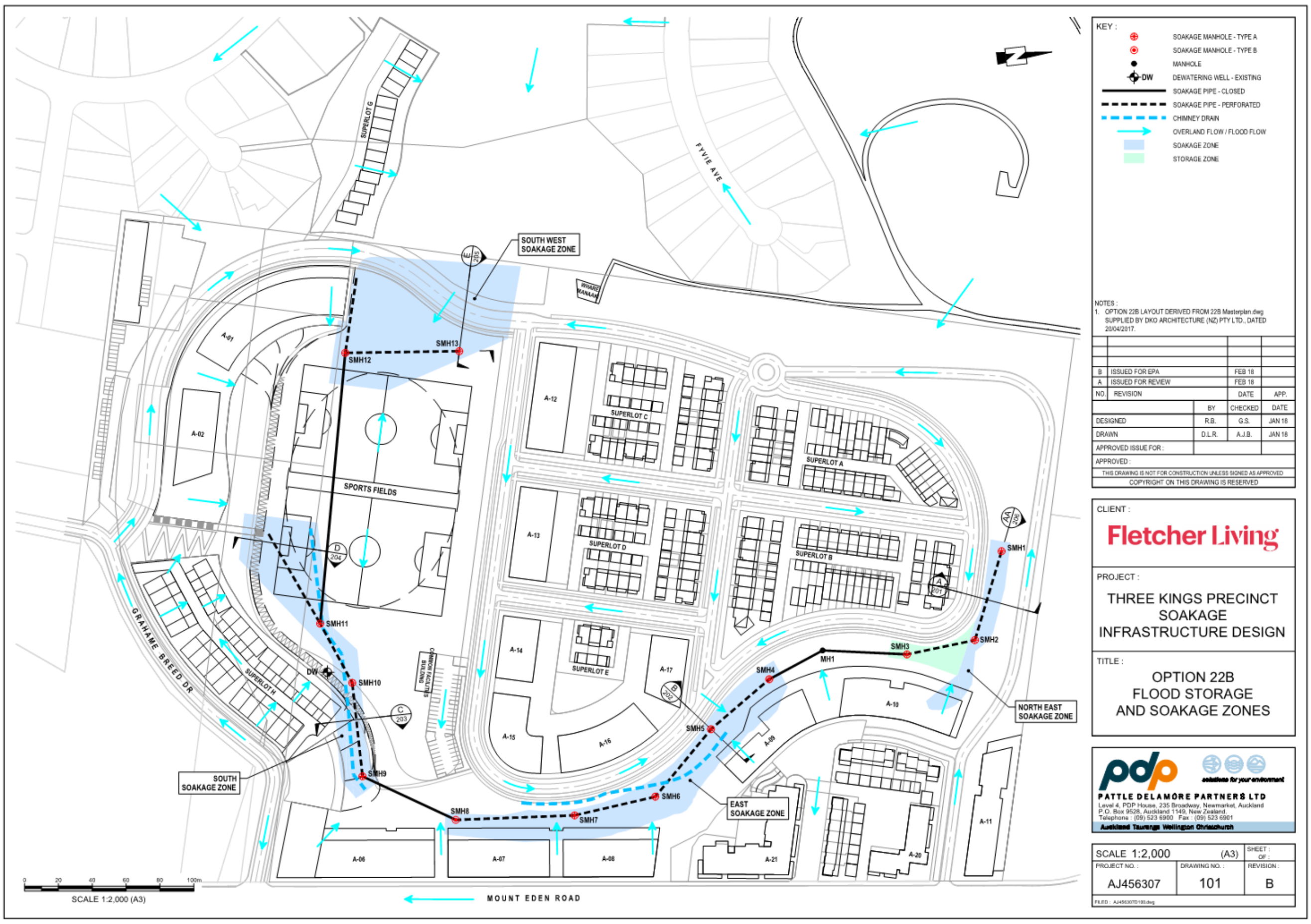

Figure 5: Flood Storage and Soakage Zones, Scheme 22B

The locations of the soakage zones and chimney drains are:

- A zone between R.L. 58.5 m and 62.0 m in the north-eastern corner of the quarry;
- A zone between R.L. 58.5 m and 62.0 m against the eastern quarry wall with a chimney drain between R.L. 45.0 m and 62.0 m;
- A zone between R.L. 58.5 m and 61.0 m under the proposed eastern sports field with a chimney drain between R.L. 54.0 m and 58.5 m;
- A zone between R.L. 56.0 m and 61.0 m under the southeast perimeter of the quarry and within the former Mt Roskill Borough Council quarry area.
- A zone between R.L. 40.0 m and 61.0 m located in the southwest area of the Precinct.

3.6 KEY INTERFACES AND ASSUMPTIONS

There are a number of key interfaces and assumptions that have been considered as a part of the detailed soakage design;

1. Soakage zone design has been in advance of the main civil design to coordinate with the quarry fill programme. Interfaces between the earthworks, civil, sports fields, architectural and landscaping designs will require confirmation and consequently integration with assumptions made in the soakage design phase.
2. The interfaces between soakage zones and building foundations are to be confirmed. It is also assumed storage is acceptable under roads and landscaping if required and foundations can be designed in the future. In particular some parts of the soakage zone public assets are under apartment buildings to allow access to the existing scoria wall faces. Confirmation of future apartment foundations is required.
3. Soakage rates for soakage zone wall areas were estimated from field investigations, including borehole testing, soakage pits, geological mapping of different hydrogeological units, double ring infiltrometer testing. Statistical analysis identified confidence intervals for average permeabilities and the lower bound values were used to estimate overall soakage for larger areas of scoria and rock. Further monitoring and testing of in situ soakage has been carried out during construction of the soakage zones to confirm the required soakage rates are available.
4. A factor of safety of three has been applied to design soakage rates to along for long term deterioration of soakage. This is based on a review of factor of safety used for soakage facilities in New Zealand. The FOS are empirical factors that allow for sedimentation and blockage. Given these are empirical a range of specific risks such as flood level and sedimentation have also been considered. A conservative approach has been adopted to physically test individual locations such that the cumulative soakage rates tested equals the required flow rate including the factor of safety. In addition the overall soakage in the zone is expected to be significantly higher due to soakage from the non-tested parts of the soakage zone.
5. Testing has been carried out under unsaturated conditions. In the long term, significant parts of the soakage will be saturated. Assumptions have been made to account for this but further monitoring and testing will be carried out on the behavior of groundwater levels in higher level strata to verify the expected aquifer response and soakage zone performance as long term water levels recover to the pre-pumping state.
6. The porosity of the storage aggregate is assumed to be 35%. Testing of different aggregates has been carried out to confirm this and has given porosity of 40% to 50% in soakage zone transition layer aggregates and large diameter (200 to 500 mm) rubble.

A number of these points and how they were addressed are discussed in more detail in the companion paper to this paper (refer Strayton et al).

4 OTHER DESIGN ISSUES

4.1 CULTURAL ISSUES

Cultural and landscaping themes are key components of the development. In relation to stormwater they include; recognition of the Maunga and natural geological forms, recognition of the pathway and cycle of water, using water within the development and the integration of stormwater management requirements and native vegetation.

A key reference to the geological past is the recognition for the "Belt of Riukiuta", the chain of volcanoes that erupted 28,500 years ago to create the original formations now known as Three Kings. Originally, numerous scoria cones existed on-site, with five significant peaks. In terms of stormwater, the concept includes a swale channel along the eastern perimeter of the development – which is itself a representation of the Belt. The swale is both a feature of the stormwater management system and a landscape feature which wraps the Riu’s eastern perimeter in a pathway for water and native planting.

4.2 WATER SENSITIVE DESIGN

Maintaining the natural pathway of water is also a key concept of Water Sensitive Design – an approach to stormwater management that seeks to minimise changes to the natural hydrological cycle. The Three Kings geology made the site an ideal location to adopt water sensitive design at a development wide scale. It is an opportunity that does not often occur.

The fractured basalt and scoria provide capacity to discharge surface water to ground via soakage. This is an effective and desirable means of stormwater discharge as it utilises a readily available existing resource, avoids changes to the natural water cycle, avoids the need for pumping and minimises reticulated drainage both within and external to the development area. The distribution of soakage points within superlots around the perimeter of the development mean the rain water is retained near its natural point of contact with the ground and also minimises the potential for concentration of flows and the potential for groundwater mounding.

The management approach also incorporates source control of roof contaminants by choice of roofing materials. Many of the proposed stormwater treatment devices (such as rain-gardens, tree-pits and swales) are also water sensitive methods which allow infiltration and will be integrated into public spaces to offer other benefits such as habitat creation and public amenity values.

4.3 SEDIMENT MANAGEMENT

4.3.1 CONSTRUCTION

Sedimentation and clogging of soakage pits can be a significant issue where there are high sediment loads. Over time discharges containing sediment can fill interstitial cracks and reduce the capacity of soakage bores and soakpits. This is particularly an issue where sediment loads are high such as from industrial sites, heavily trafficked roads and eroding landscaping areas.

During construction a high degree of erosion and sediment control will be provided and final connections to the proposed public soakage systems will be constructed late in the construction programme to minimise the risk of construction related sediment blockage.

An Erosion and Sediment Control Plan (ESCP) has been prepared to detail the erosion and sediment control measures required during the bulk filling process and works set out in the rehabilitation consent. The ESCP plan has been based largely on Auckland Council’s (2016) GD005. Key methods for protection of the long term soakage zones include; protecting storage and soakage zones adjacent to clayey fill with ‘dirty water’ diversion bunds, retaining sediment laden runoff on the earthworks areas, and directing runoff from earthworks areas to a sediment retention pond or a ‘sacrificial sump’ prior to discharge via construction phase soakpits.

4.3.2 LONG TERM

The Three Kings development will not generate high volumes of sediment once the construction phase is complete. A series of treatment processes (through sediment chambers, raingardens and inlet protection at soakage zones) will be provided to reduce the sediment load that is generated.

Whilst sediment accumulation will be greatly reduced using treatment, over time, void spaces and interstitial cracks within the storage and soakage zones may be filled. This could result in reduced soakage capacity and performance of the stormwater system.

Auckland Council TP10, Table 4-4 provides a contaminant loading for Total Suspended Solids (TSS) for Residential (high) developments between 97 and 547 kg/ha/yr. Based on a catchment area of 39.4 ha, TSS concentration of 547 kg/ha/yr and a sediment density of 1,500 kg/m^3 an annual pre-treated TSS volume of 14.4 m^3/year is expected from the Precinct.

To account for the stormwater treatment provided by sediment chambers and raingardens, a more detailed analysis of sediment accumulation was completed. The analysis calculated sediment accumulation based on a daily rainfall record from 1949 – 2007 (Auckland, Owairaka Gauge) and a 75% TSS removal efficiency of the water quality volume (WQV) for hardstand areas. Stormwater in excess of the WQV is assumed to have no treatment. No treatment is assumed for external catchments. Based on the detailed simulation it is predicted that the sediment accumulation is 5.4 m^3/year. Over 100 years this equates to a TSS accumulation volume of 538 m^3. There is sufficient redundancy within the underground stormwater storage to account for this sediment accumulation. The assessment is highly conservative as it assumes no TSS treatment for external catchments, much of the external areas will be directed to offsite soakage or drainage and assumes a higher pre-treatment TSS concentration compared to the TP10 loading information.

Finally, monitoring wells will be installed within underground storage areas and soakage zones to allow soakage rates to be monitored, identify any reductions in soakage capacity and trigger maintenance if required.

4.4 STORMWATER QUALITY TREATMENT DEVICE CHOICE

A wetland was considered as an alternative to the eastern swale and was supported by iwi (during Fletchers' consultation with them) and it provides a range of amenity, ecological and landscape benefits. From a stormwater quality point of view a wetland offers good levels of stormwater treatment for a range of contaminants including sediment, metals and dissolved contaminants. The wetland design also allowed flood storage to occur via a series of stepped cells which can "head up" and attenuate flows during flood conditions.

Through the PC372 process various issues were raised by Council and assessed as a result of the wetland being proposed to become a public asset. These included:

1. The layout of the wetland and its flow paths was narrow compared to its length;
2. The lining and maintenance of a water supply to the wetland to provide through flow to prevent issues such as stagnation;
3. Nutrients in stormwater discharges or water pumped from the underlying aquifer had the potential to adversely affect the wetland's water quality and allow algal growth;
4. The ongoing operational costs associated with management of algal and maintenance of through flow.

The PC372 Council Officer's report recommended that a wetland swale be used instead of the eastern wetland, mainly because of expected lower maintenance requirements.

We assessed that either a swale or wetland could be provided for treatment along the eastern perimeter of the development, but because it was proposed to be a public stormwater asset an alternative approach using raingardens and a swale was selected.

4.5 TESTING THE GROUNDWATER RESPONSE

Continuous monitoring of the groundwater level to rainfall events has provided additional information for calibrating the groundwater model of the aquifer response post development. Water level monitoring has been carried out at two boreholes either side of the quarry over the winter of 2016 with the particular aim of recording some large rainfall events and measuring the timing and magnitude of the aquifer response. The record was used to verify the porosity of the overall crater's volcanic rocks as about 8.5%.

Once filling is completed, the dewatering pump will be turned off and the groundwater will be allowed to recover. To date the soakage testing has been carried out under unsaturated conditions and results have had to be adjusted for the rock being saturated. Short term responses in ground water levels in the crater are recommended to be monitored as soon as pumping ceases so that the performance of rock material between RL 35 and 56m are assessed under saturated conditions. This means it is preferable that pumping ceases sooner rather than later so that any variations in groundwater level response are identified and assessed prior to construction of the upper storage and soakage zones and the designs adapted if required.

4.6 OPERATIONAL ISSUES FOR A PUBLIC STORMWATER ASSET

4.6.1 SEDIMENT MANAGEMENT

The design and construction of the proposed stormwater system are critical in ensuring that the short and long term performance of the system is maintained and these methods are described above. In addition, the AUP requires that the development includes an effective monitoring and maintenance programme which addresses sediment loads, maintaining treatment required for the protection of long term soakage capacity and the monitoring and maintenance required to maintain soakage capacity. Sediment treatment methods are discussed above, but suffice to say this is a key ongoing issue to be monitored.

Maintenance and monitoring should focus on preventing sediment entering and accumulating within the storage and soakage zones. Excess sediment accumulation may reduce both the void space and soakage capacity. Should monitoring identify significantly reduced soakage capacity, rehabilitation of the zones may be required.

Sediment accumulation in sediment chambers and raingardens is to be observed at the commencement of development to provide a baseline for monitoring over time and identify the required frequency of clean-outs. Sediment accumulation can also be re-assessed on an occasional basis to determine if there are any trends in sediment generation.

Observation wells within each underground storage zone will be installed and equipped with transducers to monitor water levels and the performance of the soakage zones, especially during rainfall events. This will monitor the water level build up and drainage times against different events to provide a baseline of system performance. The data gathered from this network will allow the efficiency of the system to be established and tracked, identify if future assessments are needed and assist in determining if rehabilitation measures are required. Monitoring well locations have not been set at this stage as it is expected that they will generally be in road reserves or parks. Wells can be drilled following placement of storage layers so that the locations are better integrated with later design stages. While sediment loads post-construction are expected to be low, maintaining the soakage capacity of soakage devices in the long term is necessary to ensure the long term viability of the Stormwater Management Plan.

4.6.2 MAINTENANCE AND BLOCKAGE OF INLETS

Sediment chambers should be inspected and maintained regularly to ensure that the depth of stored sediment does not cause sediment to migrate out of the chamber. Maintenance will take the form of vacuuming the sediment from the sediment chambers on a regular basis.

Raingardens should be inspected and maintained regularly to ensure that they are performing as intended. Sediment removal should occur when surface ponding persists, which indicates surface clogging. When sediments are to be removed, vegetation and soil conditions should be restored to the originally constructed condition. Regular inspections must be done to ensure that the desired vegetation remains and is not overtaken by invasive undesirable plants. General maintenance to remove coarse debris and rubbish should routinely be undertaken.

Soakage manholes located within the storage and soakage zones should be inspected regularly and especially after significant storm events such as those events larger than the 5-year ARI rainfall event. Inspection of these manholes could indicate if any sediment is entering the storage and if necessary the manholes should be cleaned.

Sediment chambers, raingardens and soakage manholes have inlets and outlets that may become blocked with debris or sediment accumulation. The number and distribution of inlets throughout the development means that total blockage of all inlets simultaneously would not occur. The potential risk of all inlets being blocked during an extreme rainfall event has been considered and mitigated by conservatively setting floor levels above the 100-year ARI event assuming no soakage is occurring.

4.6.3 REHABILITATION

In the very unlikely event that the soakage and storage zones become ineffective due to accumulation of sediment, the following rehabilitation options have been considered:

1. Extending the southern underground stormwater storage and soakage zone beneath the proposed sports fields;
2. Drilling of sub-horizontal boreholes into rock fracture zones or voids; and
3. Diverting runoff from external catchments away from the Precinct in order to reduce the load on the stormwater system.

These rehabilitation options are likely to be costly and cause disruption to residents. As such, the proposed system has been designed using very conservative assumptions and with a high level of redundancy.

4.6.4 LONG TERM PUMPING

While the whole concept does not require ongoing pumping, the existing quarry dewatering pump is to be transferred to council ownership as a public asset for a final back-up for dewatering the aquifer. This allows the potential drawdown of groundwater levels so that there is further underground storage within unsaturated rock.

5 CONCLUSIONS

The stormwater management plan concludes that:

1. Statistical analysis of the soakage investigation tests has identified good soakage within the quarry. A factor of safety of 3 has then been applied to the soakage rates used in sizing soakage zones to allow for future degradation in soakage;
2. A detailed 3D groundwater model confirms that discharge of stormwater via soakage is feasible;
3. The future runoff volume caused by the 10-year ARI rainfall event can be appropriately managed in underground storage and soakage zones without any above ground flooding;
4. The future predicted flood level caused by the 100-year ARI rainfall event assuming that no soakage is operating within the soakage zones is R.L. 64.60 m;
5. All habitable floor levels are to be above the 100-year ARI flood level assuming that soakage is not operating plus an allowance for freeboard as per the AUP requirements;
6. The flood freeboard available is such that all of the rainfall volume (not the lesser runoff volume) from a 100-year ARI rainfall event without any soakage during the event can be accommodated below all habitable floors;
7. Stormwater quality treatment is provided for all hardstand areas by way of sediment chambers and raingardens. High quality roof water will be achieved through the use of non-exposed metal products such as pre-painted steel;
8. Based on a simulation of sediment accumulation it is predicted that 5.4 m^3/year of sediment may accumulate in the underground stormwater storage zones. Over 100 years this equates to a TSS accumulation of 538 m^3. There is sufficient redundancy within the underground stormwater storage to account for this sediment accumulation;
9. Maintenance and monitoring will focus on preventing sediment entering and accumulating within the storage and soakage zones. In the very unlikely event that the soakage and storage zones become ineffective due to accumulation of sediment, a number of potential rehabilitation options are available;
10. Erosion and sediment control for the rehabilitation will be managed through a combination of measures in order to protect the receiving environment. These measures include staged construction, surface roughening and rapid stabilisation, stabilised entranceway, geotextiles, ‘dirty water’ diversion bund, ‘dirty water’ diversion channel, sediment retention pond and sacrificial sump and dust control.

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