PROTECTING EDEN PARK FROM FLOODING DURING THE RUGBY WORLD CUP 2011

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ABSTRACT

Eden Park has historically suffered from flooding during major storm events. Flooding occurs as groundwater levels in the underlying basalt aquifer rise in response to infiltration in the upstream catchment. Stormwater drainage in Eden Park itself is constrained by both high groundwater levels and an undersized stormwater network.

A solution to protect Eden Park from flooding in the event of rainfall had to be found. Auckland Council and Beca Carter Hollings & Ferner Limited (Beca) carried out a feasibility study which recommended that a novel groundwater abstraction scheme be taken forward. This was the lowest cost option that could be implemented in the time available. The aim of the project was to draw down groundwater levels to enable surface water to infiltrate into the aquifer, even during large storm events when flooding would normally occur.

This paper reports on the development, commissioning and operational phases of the project. Although designed to operate independently and abstract water to pre-determined levels, many factors could require operator intervention. The paper reviews the actions that were taken, issues that occurred in practice and how these were addressed. It also summarises the overall performance of the scheme during the Rugby World Cup 2011 and the level of protection provided.

KEYWORDS

Eden Park, stormwater, flood risk, groundwater, operation

1 INTRODUCTION

Eden Park and parts of the surrounding Meola catchment have a history of flooding due to a reliance on soakage systems for the disposal of stormwater. During periods of high rainfall, the groundwater level in the underlying shallow basalt aquifer rises to ground level, preventing soakage and contributing to surface flooding.

The Eden Park Redevelopment Board approached Auckland City Council with a request to upgrade the stormwater network in April 2009. This provided a period of 2 years to commence and deliver a project where the scope, cost and programme were undefined. More importantly there was no budget for this project nor was it known whether an appropriate technical solution was feasible.

Auckland City Council aimed to improve the level of flood protection at Eden Park for the Rugby World Cup in 201. They also had the added objective that this investment should provide additional flood alleviation in the wider Meola catchment, or at least be consistent with a longer term solution for the area. A feasibility study was therefore initiated using a multi-skilled team. A steering committee with key stakeholders was also established for input into the feasibility study and to agree to the recommended option.

This feasibility study investigated three key options to increase the level of flood protection at Eden Park. This included two large diameter stormwater sewers and the groundwater abstraction scheme. The feasibility study recommended that the groundwater abstraction scheme be taken forward on the grounds that it could be implemented in advance of the Rugby World Cup and was the lowest cost option. This assessment is reported by Sharma and Ockleston (2010).

2 THE AQUIFER STORAGE SYSTEM

2.1 THE CONCEPT

The concept for the aquifer storage system is presented as Figure 1. This indicates how pumping from the three production wells is used to draw the groundwater table down towards levels that would normally be experienced during the summer. This drawdown leaves an unsaturated zone within the basalt aquifer. Rainfall falling on the Eden Park site or within the upstream catchment will infiltrate to the aquifer and fill this unsaturated zone, raising the water table. The scheme enhances the natural capacity of the aquifer to accept infiltration and will reduce the risk of flooding at Eden Park. Without the scheme in place there would be reduced capacity in the aquifer and flooding could occur either as a result of the groundwater level reaching the surface, or surface water being unable to infiltrate as a result of high groundwater levels.

In addition to the production wells, the other key infrastructure is Auckland Council's existing 750mm diameter stormwater pipe. This pipe runs through Eden Park and discharges downstream to the Alberton Avenue culvert, which forms part of the Meola stream. Discharge pipelines from each of the production wells connect to the 750mm diameter stormwater sewer.

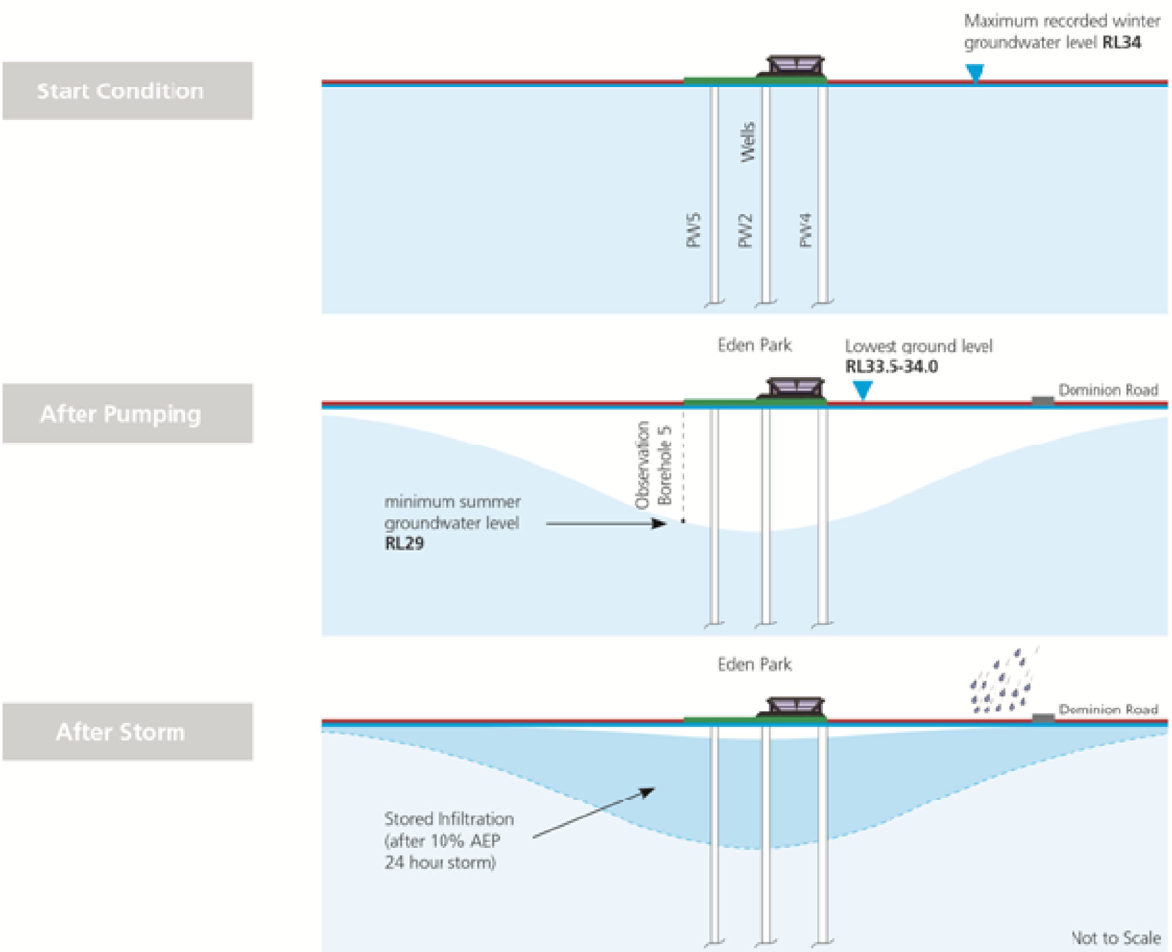


Figure 1: Schematic representation of the aquifer storage system

2.2 KEY DESIGN REQUIREMENTS

The key design requirements for the scheme are summarised in Table 1.

Element of design	Criteria	Comment
Design storm	24 hour, 1 in 10 year ARI storm	Selected as it is Auckland Council's level of service for non-habitable floors.
Receiving stormwater pipe capacity	Maximum pipe capacity modelled as 310 l/s	Availability of the stormwater pipe was assessed as being greater than 95% over a 2 week period.
Target abstraction rate	Peak abstraction should be at least 200 l/s to control groundwater levels.	Redundancy required in case of mechanical failure.
Pump sizing	Range of flows between 40l/s and 120 l/s.	
Discharge pipeline and chambers	Pipework designed for a maximum flowrate of 120 l/s.	
Control system	Automatic control required based on groundwater level and flow in the stormwater pipe.	Interlock also required to prevent operation when the stadium floodlights are in operation.

Table 1: Summary of key design requirements

2.3 PROGRAMME REQUIREMENTS

Meeting the requirements of the programme was fundamental in the selection of the proposed scheme and drove many of the design decisions. The key programme requirement was that the scheme should be operational in time for the Rugby World Cup in September 2011.

Beca's original feasibility study was completed in December 2009. This was followed by a 'pre-design' report in March 2010, although at this time construction of some of the elements of the scheme was progressing. The overall construction constraints relating to the construction of a new stand at Eden Park meant that elements of the scheme were constructed in advance of proving the yield and reliability of the production wells.

The approach to the design and construction was therefore driven by programme. This meant that Auckland Council worked closely with the Eden Park Trust and their contractors to implement the scheme within the timescales available. This changed the approach to how the project was designed and built, with elements of work being built to meet the construction programme for other parts of the Eden Park redevelopment.

2.4 CONSTRUCTION

Construction of the whole scheme was carried out in two phases. The first phase consisted of investigation boreholes and one production well to assess the feasibility of the scheme, the second phase production wells, observation boreholes and the other infrastructure to implement the proposed solution.

2.4.1 CONSTRUCTION DURING THE FEASIBILITY PHASE

Four investigation boreholes were drilled during the feasibility phase of the project in 2009. In-situ hydraulic conductivity tests were carried out in these boreholes to obtain an indication of the aquifer properties and to optimise the final design of the proposed production well and pump size.

One of the investigation boreholes was then over-drilled to a diameter of 400mm to enable full pump testing to be carried out and was later named PW4. It was completed with 350mm diameter casing and screen. The three remaining boreholes were completed as observation boreholes with 50mm piezometer tubes.

2.4.2 CONSTRUCTION DURING THE IMPLEMENTATION PHASE

The feasibility phase of the project indicated that the capacity of the production wells at Eden Park should be approximately 200 l/s. As part of the implementation phase of the project additional production wells were drilled to provide this increased abstraction across Eden Park.

Initially a further three production wells (named as PW1, PW2 and PW3) were drilled. Together with the existing production well PW4, these provide locations to abstract groundwater at each corner of Eden Park. The four production wells were expected to provide the capacity to abstract at least 200 l/s, together with some redundancy.

Testing of these three new production wells was carried out which showed that PW1 and PW3, on the north side of Eden Park, were much less effective than expected. It also became clear that the basalt, rather than being a uniform thickness under the site, became much thinner to the north to the extent that it was only a few metres thick. This limited the ability of production wells located on the north side of Eden Park to abstract groundwater in sufficient quantities to contribute to the project. The results of tests carried out to assess the capacity of PW2 (to the south of Eden Park) showed a similar performance to PW4.

In response to this a number of options were considered to provide sufficient capacity. Whilst PW2 and PW4 together provide the required 200 l/s capacity, there was no redundancy. A number of options were considered, including ‘development’ of PW1 and PW3 to attempt to improve the yield, or to construct a further production well at another location within Eden Park. A decision was taken to abandon PW1 and PW3 and in July 2010 a fifth production well, PW5, was drilled close to the western boundary of Eden Park. All production wells were completed with 350mm diameter casing and screens.

Additional observation boreholes were also drilled. Observation borehole BH5 was drilled to the south west of Eden Park on Reimers Avenue. At a later date observation boreholes BH7 and BH8 were also drilled to provide additional monitoring locations.

Figure 2 shows an overview of Eden Park and some of the key infrastructure. This includes the three active production wells, observation boreholes, the location of control cabinets and Auckland Council’s stormwater drain.

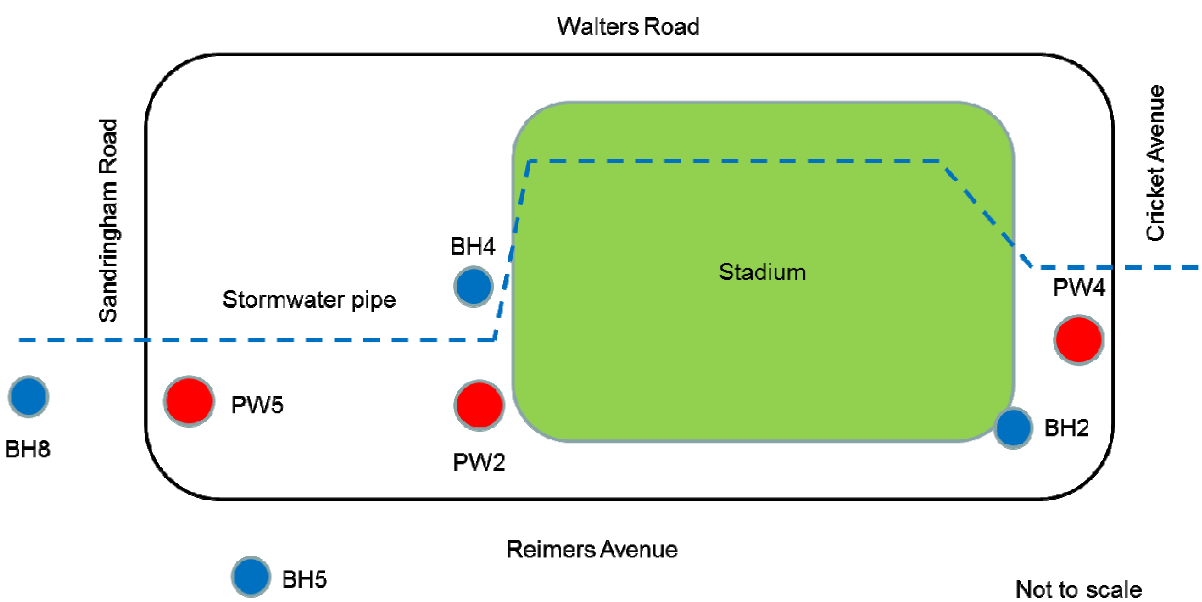


Figure 2: Schematic layout of key infrastructure at Eden Park

3 GEOLOGY AND HYDROGEOLOGY

3.1 THE GEOLOGICAL AND HYDROGEOLOGICAL CONTEXT

Eden Park is underlain by volcanic rock, mainly basalt flows, with minor inter-bedded ash and airfall deposits. Fractures within the lava flows vary from very widely spaced to very closely spaced and scoria occurs between some individual flows. The different flows are recognised also by their different appearance and the presence of reddish ('baked') silt/clay and soft silty clay infilling the upper parts of the flows. In some boreholes, ash layers, generally less than 1 m thick, are recorded between the flows.

The total thickness of the basalt flows in the immediate vicinity of Eden Park varies between 25 m and 35 m. The basalt is underlain by a paleo-valley in sediments of the Tauranga Group and sedimentary rocks of the Waitemata Groups. These soils and rocks also outcrop to the south and north of Eden Park. Cross sections showing the lateral extent and depth of the basalt are provided in Appendix A.

The basalt aquifer is unconfined. The data analysed shows that groundwater within the aquifer flows from the east (where the groundwater levels are typically 2.5 m to 3.5 m below ground surface) to the west (where groundwater levels are 10 m to 11 m below ground surface, but the ground surface is higher, i.e. the groundwater gradient is greater than the terrain slope) within the basalt. The aquifer thins rapidly to the north and south and has a maximum thickness close to Eden Park.

Since both the base of the aquifer and the groundwater level dip to the west, the aquifer must be considered as a "sloping" aquifer in fractured rock. Hydraulic conductivity values have previously been reported in the range 10^{-3} m/s to 10^{-4} m/s, corresponding with the most fractured sections of the basalt flows.

Groundwater levels in monitored boreholes indicate a seasonal variation of 3 m to 3.5 m; lowest levels being recorded in February and March and highest levels generally in July and August. One exception to this is the period from January 2008 to January 2009 in which groundwater levels at the two long term observation boreholes indicate a variation of close to 5 m (the lowest level being lower than typical).

3.2 PUMPING TESTS

A total of five production wells were constructed. Of these, PW1 and PW3 were not tested as during development the yield was found to be low. PW5 was tested as part of the combined pumping test.

The pumping test of PW4 was carried out as part of the feasibility study and included a stepped rate pumping test followed by a constant rate pumping test. The stepped rate test was carried out on 8th September 2009. After completing the stepped rate test, the water levels in the production well and the observation bores were allowed to recover before the constant rate aquifer test commenced at 14:54 on 9 September 2009. The well was pumped at a rate of 117 l/s and was terminated after 14 days of pumping. Recovery monitoring commenced on test termination at 15:00 on 23rd September 2009.

The pumping test of PW2 comprised a stepped rate pumping test followed by a constant rate pumping test. The stepped rate pumping test was carried out on 5th December 2010. After completing the stepped rate test, the water levels in the production well and the observation bores were allowed to recover before the constant rate pumping test commenced at 11:44 on 6th December 2010. The well was pumped at a rate of 110 l/s for a period of 6 days. Recovery monitoring commenced at 16:20 on 12th December 2010.

In order to confirm the proposed operation of the system during winter conditions a combined pumping test was carried out from 27th June to 21st July 2011. The combined pumping test comprised simultaneous pumping of PW2, PW4 and PW5 at a total rate of approximately 165 l/s. There were some outages in pumping during the test period as a result of rainfall and operator error. This combined pumping test proved the overall yield of the scheme and identified how it should be operated during the operational phase.

3.3 GROUNDWATER MODELLING

Three dimensional groundwater flow modelling was used to evaluate the aquifer budget (water flowing into and out of the model) and assess the aquifer response to the design rainfall event. The groundwater model was developed using the USGS model code MODFLOW (Harbaugh et al, 2000), and the Schlumberger pre- and post-processor Visual Modflow Pro 2010.

A model area of 4 km by 3 km was selected. The model extends from approximately 130 m above sea level to 5 m below sea level, and comprises 2 layers. The upper layer represents flow in the basalt aquifer, and the lower layer the contact boundary with the underlying Tauranga Group and Waitemata Group aquitard. In the immediate vicinity of Eden Park the grid resolution is 5 m x 5 m, gradually widening to 20 m x 20 m at the outer bounds of the model.

Following calibration of the model the pumping regimes being considered were simulated to check their viability and provide an assessment of the likely effects on the local groundwater regime.

3.3.1 MODEL CALIBRATION

For steady state model calibration, an average annual rainfall of 1300 mm/year (calculated from ARC records over the period 1999 to 2010) was used. Water levels in observation boreholes have been taken from ARC monitoring bores and Eden Park observation boreholes in the model area. For the steady state model a good calibration to the data was achieved with a normalised RMS of 2.9%.

For the transient model, a recharge and water level time series for the period from January 2010 to December 2010 (1 year) was used. This model simulates actual rainfall variation (average weekly) over the pumping period. Limited water level data are available for Eden Park for the entire period modelled, however a good calibration to the water level time series during pumping testing in October 2010 and December 2010 was achieved. The sensitivity of the calibration was checked by simulating the constant rate pumping tests and comparing the calculated water levels in observation bores with the observed water levels recorded during the actual pumping tests.

The final hydrogeological parameters used to calibrate the model are given in Table 2.

Hydrogeological Horizon	Numerical Horizon		Hydrogeological Parameters			
			K_h [m/day]	K_v [m/day]	S_s	S_y
Fractured basalt	1	Unconfined Aquifer	6×10^{-5} - 8×10^{-3}	6×10^{-5} - 8×10^{-3}	-	0.06
Tauranga Group and Waitemata Group sediments	2	Aquitard	1×10^{-8}	1×10^{-9}	1×10^{-5}	-

Table 2: Key hydrogeological properties

3.3.2 MINIMUM SUMMER LEVELS

Dewatering of the basalt aquifer has the potential to cause adverse effects if not properly controlled. These effects could include derogation of other licensed abstractors or ground settlement of properties and infrastructure located on or in compressible materials beyond the margins of the basalt. In order to minimise the potential for these adverse effects, the scheme will be operated such that minimum summer water levels are maintained at the boundary of Eden Park.

Lowest recorded levels at the ARC monitoring stations (Bellevue and Leslie) are from April 2005, based on a 20 year record. No monitoring data are available at Eden Park for this time. Observed levels from 2010 and 2011 at boreholes developed within Eden Park were compared with levels at Bellevue and Leslie to assess the hydraulic gradient between these sites. These observed values are presented as Figure 3.

For this assessment, a summer minimum water level of 29.0 m at the western boundary of Eden Park and 30.0m at the eastern boundary is assumed. These are monitored at observation borehole BH 2 (western boundary) and observation boreholes BH5 and BH8 (eastern boundary). This approach is expected to minimise any potential adverse effects of the scheme. It is proposed that this will be reviewed by a programme of environmental monitoring and updated as better information becomes available.

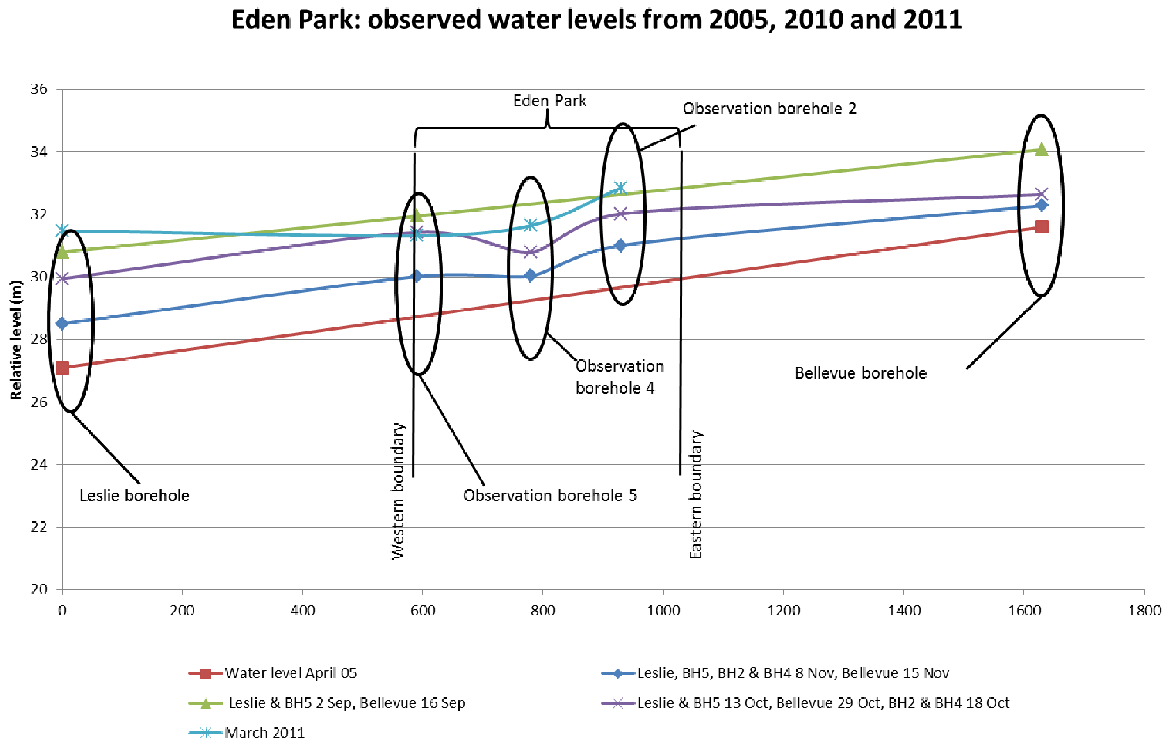


Figure 3: Assessment of minimum summer levels

4 SCENARIO ANALYSIS

The calibrated groundwater model was used to simulate the effects of pumping on drawdown and rainfall/recharge on recovery in observation boreholes. Initial groundwater conditions in model runs were simulated to reflect the maximum winter water level recorded in ARC long term monitoring boreholes at Bellevue Road and Leslie Avenue. This is a conservative starting position for groundwater levels, as it has the greatest potential for flooding.

Iteration runs of the model were undertaken to obtain the optimal pumping rates required to achieve consent compliance target levels (29m in both BH5 and BH8, 30m in BH2). Once optimal rates were achieved, the effects of a 1 in 10 year storm were modelled for some baseline conditions and other scenarios.

4.1 BASELINE CONDITIONS

Two key baseline conditions were considered, with and without the dewatering scheme in place.

4.1.1 NO SCHEME

Baseline conditions with no pumping and high winter groundwater levels show that groundwater levels are approximately 1m below ground at Eden Park. The scenario of a 1 in 10 year 24 hour storm applied to this baseline is shown as a hydrograph in Figure 4. This shows that groundwater levels at Eden Park are above ground level following a 1 in 10 year 24 hour intensity rainfall event and would likely cause local surface flooding. It should be noted that the model does not account for surface water drainage and so the extent of standing surface water at Eden Park will be less than presented by the model. It is clear that the groundwater would be close to the surface, preventing the discharge of stormwater by soakage and leading to overland flow from low points.

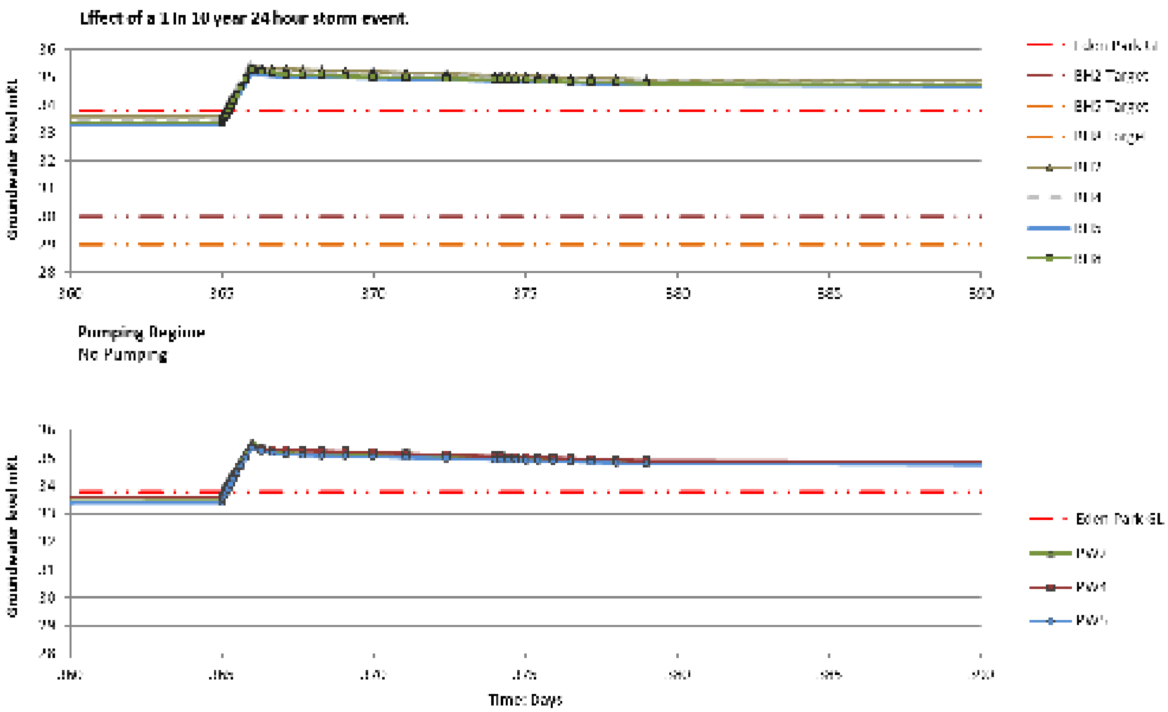


Figure 4: Hydrograph showing groundwater levels at Eden Park following a 1 in 10 year storm with no scheme in place

4.1.2 OPERATION OF THE SCHEME

Operation of the pumping scheme is restricted by the consent requirement to maintain minimum summer groundwater level at the boundary of Eden Park. The model was used to find the optimal pumping regime to maintain groundwater levels at these levels. Pumping was modelled for a total period of 14 days as follows:

- Pumping at 230 l/s from 3 production wells for 7 days to reach target levels; and
- Pumping at 130 l/s from 3 production wells for a further 7 days to maintain groundwater levels at the target levels.

After maintaining a constant water level the 1 in 10 year 24 hour intensity rainfall event was applied to the model immediately following cessation of pumping. The hydrograph (Figure 5) shows that the potential for flooding is significantly reduced as a result of pumping, with water levels around 1.5m below ground level in observation borehole BH4 (at Eden Park) at the end of the rainfall event. The hydrograph also shows that operational pumping rates are primarily restricted by drawdown to compliance levels in observation borehole BH2 and observation borehole BH8 after more than 7 days pumping at peak rates. This would be expected as these are the closest boreholes to Eden Park.

These results infer that pumping enables groundwater levels to be maintained below ground level with a small freeboard.

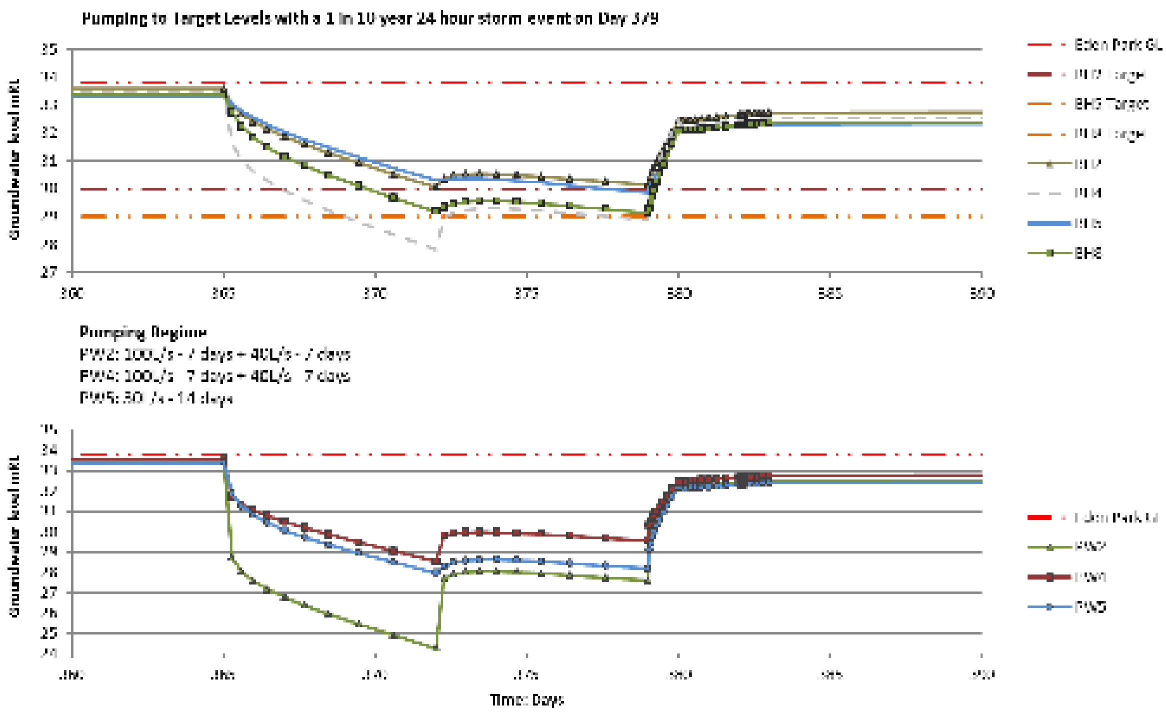


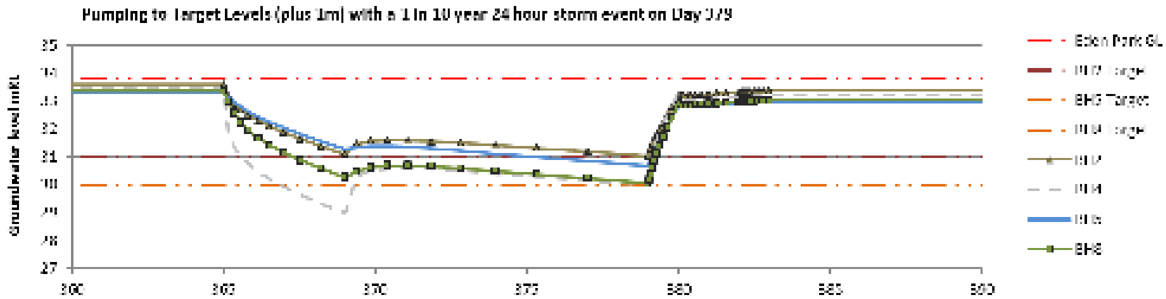
Figure 5: Hydrograph showing groundwater levels at Eden Park following a 1 in 10 year storm with the scheme in place

4.2 ALTERNATIVE SCENARIOS

A number of alternative scenarios were also investigated to assist with the operation of the scheme. The scheme may be operated differently as a result of outage, operator error or the requirement to stop pumping during a Rugby World Cup match. These scenarios provide information about the level of protection provided and some further information about different modes of operation, summarised below.

4.2.1 DRAWDOWN TO 1 METRE ABOVE TARGET LEVELS

A number of conditions such as operator error or adverse weather may lead to less drawdown being achieved than required. A scenario has been investigated where levels are 1 metre above the target levels, i.e. only 30m in observation boreholes BH5 and BH8 and 31m in observation borehole BH2. The results of this analysis are presented in Figure 6. This shows that even with this reduced level of protection, the model indicates that groundwater levels following a 1 in 10 year 24 hour storm would still be below ground level. There is less freeboard than the baseline scenario which may lead to some localised flooding, but widespread flooding should be avoided.



Pumping Regime
PW2: 100L/s - 4 days + 30L/s - 10 days
PW4: 100L/s - 4 days + 30L/s - 10 days
PW5: 30L/s - 14 days

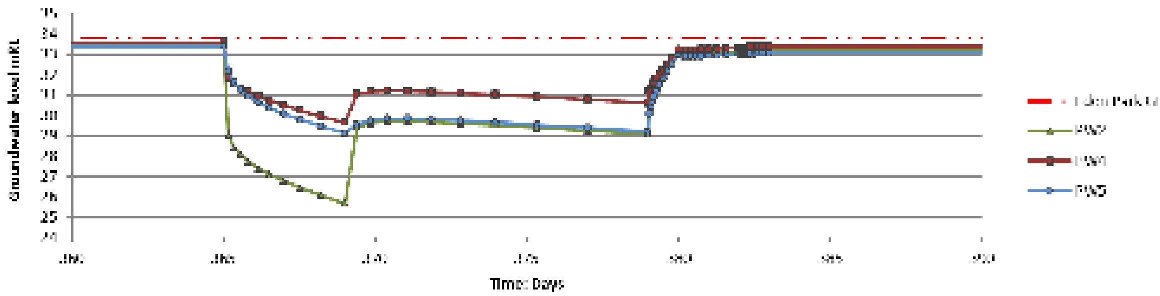
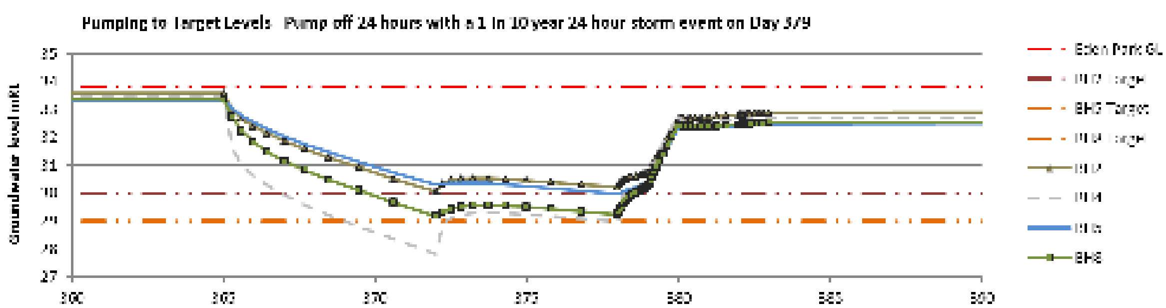


Figure 6: Hydrograph showing groundwater levels at Eden Park following a 1 in 10 year storm with drawdown to 1 metre above target levels

4.2.2 OUTAGE OF 24 HOURS PRIOR TO A RAINFALL EVENT

The scenario of a longer outage period with no pumping prior to a rainfall event was also examined. The results, presented as Figure 7, show that groundwater levels reach approximately 1m below ground level. This suggests that widespread flooding should be avoided but there may be local issues, and there is a lower standard of protection than when pumping can be quickly restarted.



Pumping Regime
PW2: 100L/s - 7 days + 40L/s - 6 days
PW4: 100L/s - 7 days + 40L/s - 6 days
PW5: 30L/s - 13 days

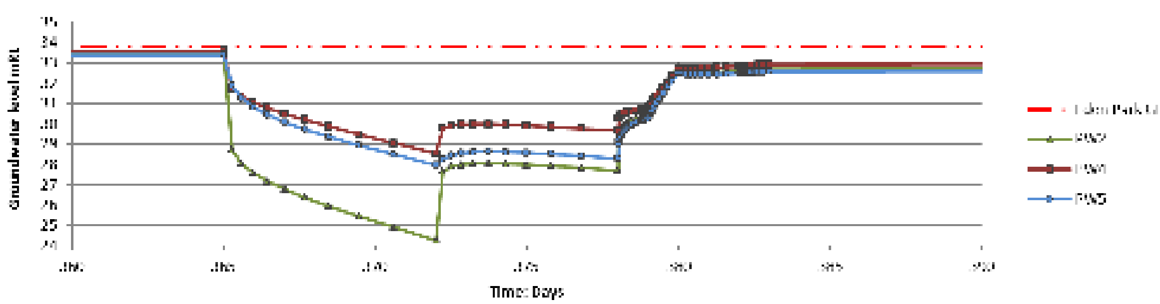


Figure 7: Hydrograph showing groundwater levels at Eden Park following a 1 in 10 year storm and an outage of 24 hours

4.2.3 TWO CONSECUTIVE RAINFALL EVENTS

This scenario is outside of the design condition as it considers consecutive 1 in 10 year 24 hour storms occurring 48 hours apart. This combined event has a much lower probability of occurring than a single 1 in 10 year 24 hour storm. This scenario, presented as Figure 8, shows that groundwater levels within and close to Eden Park are just below ground level. Stormwater flooding would be expected during the second rainfall event as soakage devices would be below the water table.

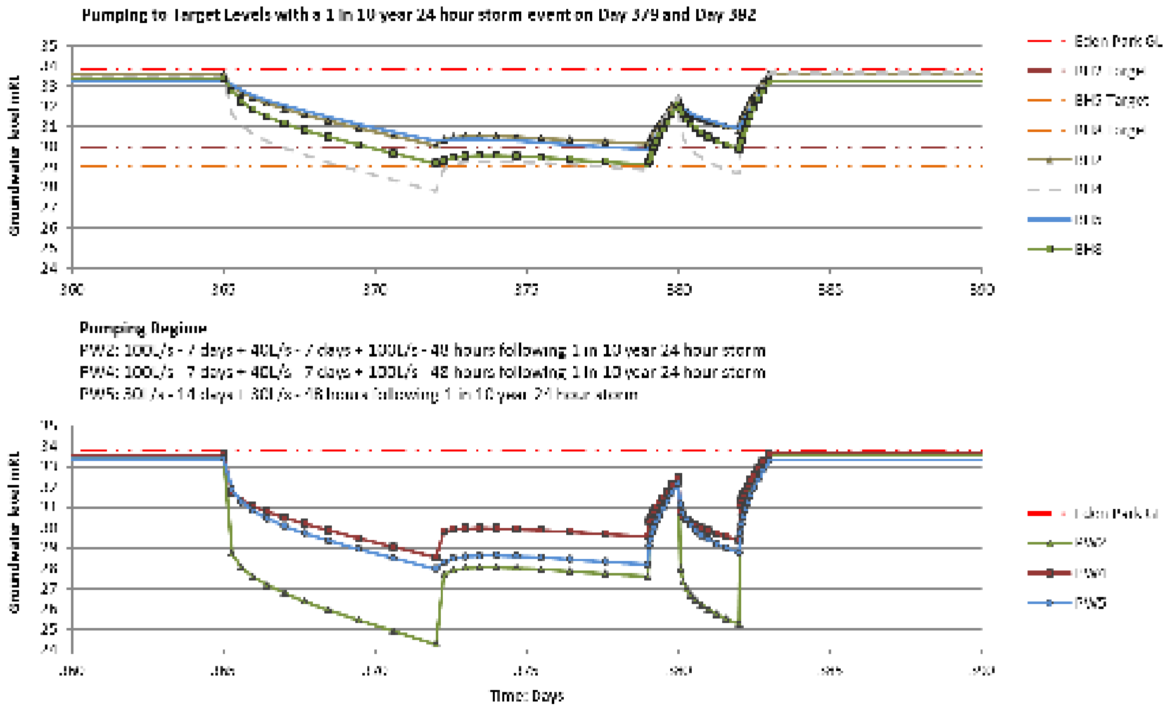


Figure 8: Hydrograph showing groundwater levels at Eden Park following two consecutive storms

4.3 IMPLICATIONS FOR OPERATION

The scenario analysis provides some key information for operation of the scheme. Two clear results stand out, firstly to ensure that groundwater levels are drawn down as close to the target as possible, and secondly that following an outage or rainfall event abstraction should be immediately restarted, even if only for a matter of a few hours.

In terms of operation, it is expected that pumps should be operated for a minimum of 14 days prior to the Rugby World Cup tournament, very possibly more, on the following basis:

- Maximum pumping rate (230 l/s) until the target groundwater levels are reached (approximately 7 days);
- Reduction in pumping rates to approximately 120 – 150 l/s to maintain target levels; and
- Ongoing monitoring to vary pumping rates in response to rainfall or other factors.

5 OPERATION

5.1 APPROACH AND KEY ISSUES

The scheme was operated by Auckland Council's incumbent network maintenance contractor 'Utility Services' through a contract which included commissioning of the system and operational maintenance through the Rugby World Cup period. General operations required daily monitoring of key boreholes around Eden Park to verify the minimum groundwater level was not exceeded, ensuring the electrical systems were performing without faults and keeping the groundwater level as low as possible to provide maximum storage in the aquifer. As the main driver of the system was to provide 10 year ARI flood protection to Eden Park, a careful balance was required to ensure all the above criteria were met. This was addressed through the provision of a weekly report of key information, which enabled any key decisions about operation of the scheme to be made.

Beca managed the construction and commissioning of the scheme and were further engaged to provide feedback on the operational phase to make sure the system was performing as intended. Other interested stakeholders included the Eden Park Trust who own the land the pumps were constructed on (and who will be responsible for ongoing operation of the system post Rugby World Cup) and Auckland Tourism, Events and Economic Development who were interested in the scheme as the Council Controlled Organisation responsible for making the Rugby World Cup a success.

During the commissioning and operational phase a number of issues arose which were unforeseen. The most significant of these was related to a requirement of the agreement between Auckland Council and Eden Park Trust to guarantee the pumps were not drawing power when Eden Park's floodlights were in use during matches. To achieve this, an interlock was installed to deactivate the pumps when Eden Park entered "event mode", which was based on the assumption Eden Park would only enter event mode for a short period on game days. However, during the lead up to the opening match, Eden Park activated event mode on a regular basis, resulting in the pumps being deactivated for significant periods of time and preventing the required drawdown of groundwater. The solution was to install a manual bypass to the interlock system on days when matches were not being played. However, a strict operational procedure was required to ensure the bypass was removed when the floodlights were in use. Other issues which arose included minor electrical faults and the inability to take readings from BH8 due to it being located in a parking bay.

Overall the operation of the system in the lead up to, and during, the Rugby World Cup worked well. The operator, Auckland Council and Beca worked together to operate the scheme and address issues as they arose.

5.2 RESULTS DURING OPERATION

During the operation of the scheme prior to and during the Rugby World Cup monitoring of pumping, groundwater levels and discharge took place. These data enabled a comparison of the actual field data to be made against the model results.

Prior to the start of the Rugby World Cup there was a long dry period, when the pumps were operated and the groundwater level drawn down to minimum levels. Thereafter groundwater levels fluctuated in response to a combination of rainfall and pump downtime due to the stadium being in 'event mode'.

Three graphs are presented; Figure 9 shows groundwater levels, Figure 10 shows pumping rates and Figure 11 the flow recorded in the stormwater drain. The periods when the pumps are switched on and off is clearly visible, as the groundwater level quickly recharges when pumping stops. Interestingly, the pumping rate during operation trends from approximately 180 l/s to less than 150 l/s as the target groundwater levels approach. This agrees with the output from the modelling, which suggested a 'maintenance' level of pumping of 120 to 150 l/s.

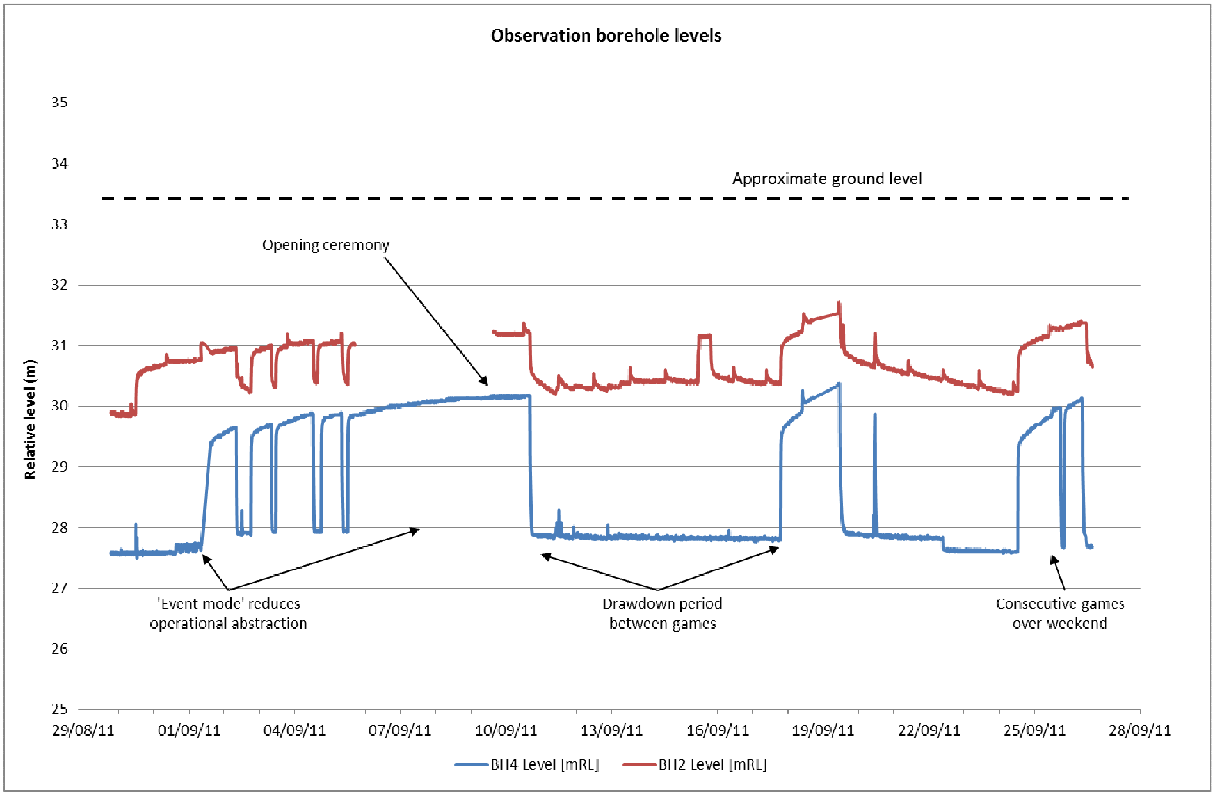


Figure 9: Record of groundwater levels at observation boreholes

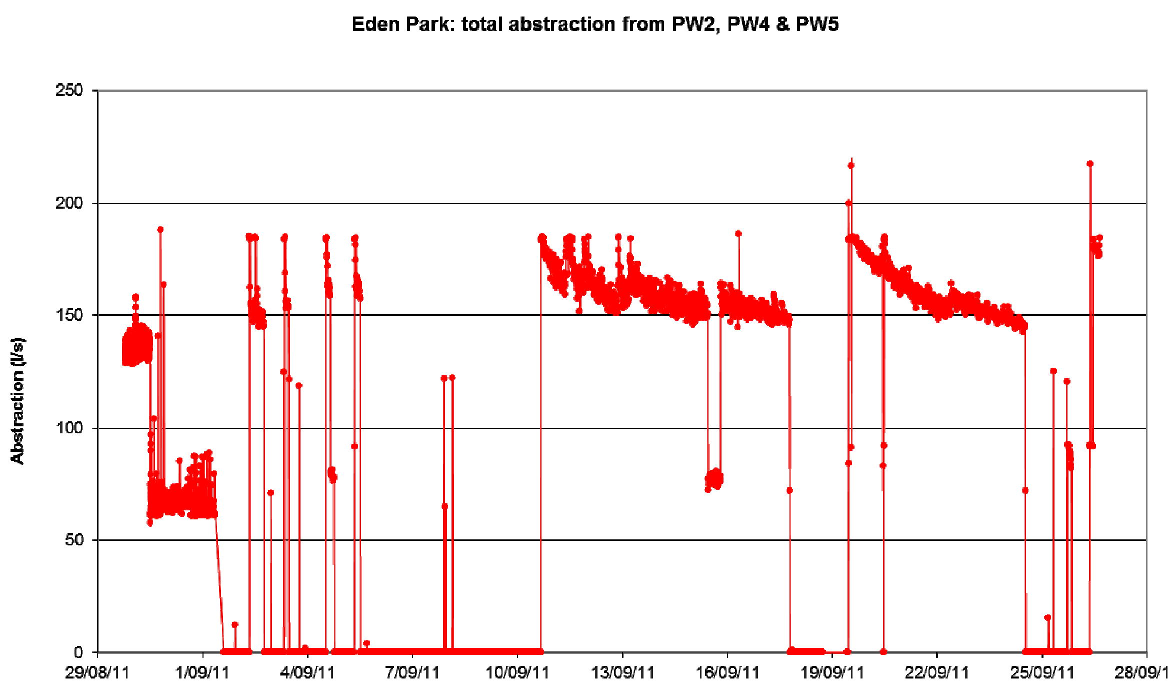


Figure 10: Record of pumping rates

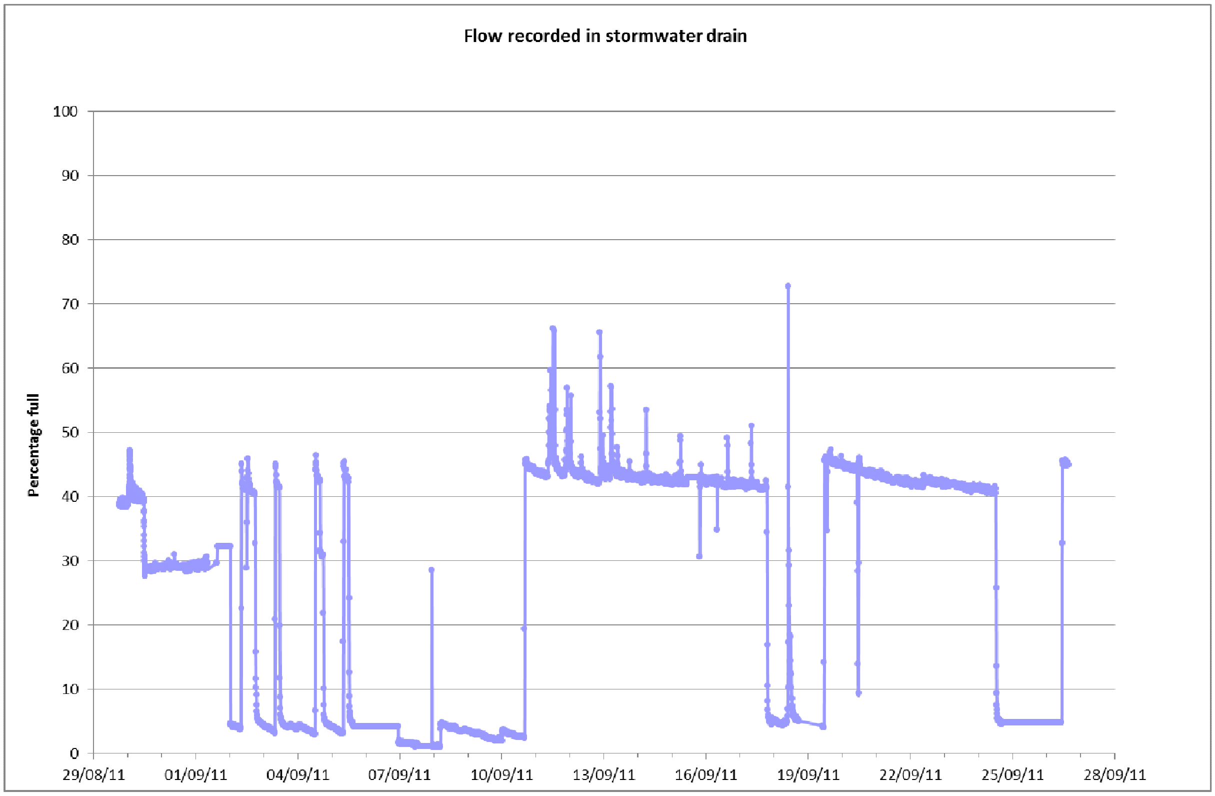


Figure 11: Record of flow recorded in the stormwater drain

6 CONCLUSIONS

This paper summarises the scheme that was proposed and implemented to protect Eden Park from flooding during the Rugby World Cup. Due to the nature of the flood risk and the short term nature of the Rugby World Cup, an operational scheme was developed. This approach enabled a cost effective scheme to be developed over a short time period.

By its nature the scheme was operationally based; groundwater levels were managed to provide storage well in advance of any storm event occurring. This approach was managed by Auckland Council and its maintenance contractor. Over the period of the Rugby World Cup, groundwater levels were drawn down to a target level and maintained. This provides an area of storage within the aquifer, which could be used to accept stormwater infiltration in the event of a large storm.

Operation of the scheme was effective, with groundwater levels drawn down close to the target in between matches. The abstraction rates required to maintain groundwater levels at the target were close to those that were modelled. The operation of the scheme was therefore effective in providing protection to Eden Park from the risk of stormwater flooding.

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