THE FUTURE OF WELL HEAD PROTECTION IN CHRISTCHURCH

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ABSTRACT

Wells are our gateway to underground drinking-water reserves which serve many communities around New Zealand. Contamination of the Havelock North supply in August 2016 not only highlighted the importance of source protection and good management, but also the need for good quality infrastructure and in particular the protection of well heads. The Havelock North Drinking Water Inquiry Stage 2 report recommended new installations of below ground well heads be prohibited, abolishing the secure bore water status, and mandating universal treatment. Exemptions from treatment are likely to require evidence of high quality infrastructure being in place and demonstration of sound risk management practices.

The water supply for Christchurch is groundwater taken from 139 wells across the city, pumped directly into the reticulation via 53 pump stations. Late in 2017, Christchurch City Council (CCC) requested experts undertake routine well head inspections of 25 well heads to confirm that the well heads remained secure, and would not allow contaminants to enter the water supply. Previous inspections had found that the wells were secure, however these inspections found none of those well heads were adequately protected which resulted in the Drinking Water Assessor revoking the provisionally secure groundwater status on 22 December 2017. The difference is because of stricter interpretation of the DWSNZ applied by the experts following the Inquiry. As a result, CCC made a decision to temporarily chlorinate the water supply while the well heads are remediated to the required standard.

Whilst new above ground well head installations in Christchurch are of a very high quality and represent best practice in New Zealand, many of the older below ground well heads were installed prior to the DWSNZ requirements for well head protection.

CCC are now proactively planning a remediation programme for the well heads to bring them into line with current standards so that secure groundwater status can be regained and temporary treatment can cease. Beca supported CCC to evaluate two main options for well head remedial works:

- Remediation of the existing below ground well heads
- Raising all below ground well heads above ground

CCC were faced with the difficult decision of which option to select: remediating to meet the current standard, or spending more to meet what might become the future standard. Raising all well heads above ground and replacing shallow aquifer wells appears to provide the best chance of seeking an exemption from mandatory treatment should this be imposed by the government, alongside other reticulation management measures. This option was selected as the preferred solution.

Cost estimates for the two remediation options were required to adequately compare the options. Due to the number of below-ground drinking water well heads owned by CCC, it was not practical to prepare and cost individual designs for each bore in the timeframe available. Instead, costs for the common remediation activities were estimated and applied to each well as required.

This paper shows real-world examples of well heads and discusses the practical realities of remediating well heads to meet the requirements that are likely to emerge from the Havelock North Drinking Water Inquiry.

KEYWORDS

Well head, well, bore, drinking, water supply, standard, Christchurch, groundwater

PRESENTER PROFILE

Mike Thorley is an Associate - Hydrogeology at Beca and has been involved in groundwater supplies and hydrogeological studies for over 14 years. Mike has lead reviews of well heads for a number of water suppliers across New Zealand and works within a multi-disciplinary team at Beca on water supply infrastructure projects.

1 INTRODUCTION

The water supply for Christchurch is sourced from groundwater and taken from 139 wells across the city, and pumped into the reticulation via 53 pump stations.

To avoid treatment under the current Drinking-water Standards New Zealand 2005 (revised 2008), three bore water security criteria need to be met:

1. The bore water must not be directly affected by surface or climatic influences (i.e. the water is at least a year old by which time any pathogens will have died)

2. The well head must provide satisfactory protection to prevent contamination of the water supply

3. *E. coli* must be absent in the bore water.

To demonstrate compliance with Criterion 2, Christchurch City Council (CCC) commissions external experts to assess the security of approximately 20% of its wells each year. The well head inspections of 25 well heads undertaken in late 2017 found none of those well heads met Criterion 2. Previous inspections had found that the wells were secure, however these inspections found none of those well heads were adequately protected which resulted in the Drinking Water Assessor revoking the provisionally secure groundwater status on 22 December 2017. The difference is because of more rigorous application of the DWSNZ applied by different experts and following the Inquiry. As a result, CCC made a decision to temporarily chlorinate the water supply while the well heads were remediated to the required standard.

Contamination of the Havelock North drinking water supply in August 2016 not only highlighted the importance of source protection and good management, but also the quality of infrastructure and in particular the protection of well heads. The Havelock North Drinking Water Inquiry Stage 2 report recommended new installations of below ground well heads be prohibited, abolishing the secure bore water status, and mandating universal treatment. Exemptions from treatment, if accepted by the government, are likely to require evidence of high quality infrastructure being in place and demonstration of sound risk management practices.

This paper summarises the current state of CCC’s well heads and the work being progressed to remediate these wells, not only to the required standard but to meet best practice in anticipation of future changes to the drinking water standards.

2 EXISTING BELOW GROUND WELL HEADS

2.1 INSPECTION APPROACH

All of CCC’s well heads were inspected in March 2018 so that an initial list of remedial work required could be identified. These inspections were carried out by several teams, each with one person from Beca and one person from either Citycare Water (Citycare) or CCC.

The following information was recorded during the inspections:

- Well head measurements and existing means for preventing ponding (i.e. concrete apron or 100mm step above ground level)
- Potential sources of contamination that were visible during the site inspection (e.g. vandalism, diesel or chemical spills, potential flooding from the Heathcote River)
- Any potential points of water entry into the well head or leaks from the pipework within the well head
- The sealing of cable glands, well head wall penetration and the casing
- The condition of pipework and the visible casing
- Presence or absence of air vents, backflow prevention, sump pumps and sample taps
- The feasibility of raising the well head above ground, including access for a drill rig
- Photos of the well head and surrounds.

Canterbury Maps and the Listed Land Use Register (LLUR) were reviewed for each well to identify nearby contamination sources like septic tanks, wastewater mains, landfills and Hazardous Activities and Industries List (HAIL) sites. The risk from these potential sources of contamination can then be addressed in a Water Safety Plan (WSP) and/or through additional measures to protect the well head.

The large number of wells has been a data management challenge. This was overcome by developing a data management system specifically designed to allow information and photos to be digitally recorded onsite and to ensure that the data could easily be processed back at the office. This made use of a proprietary software called Fulcrum.

New survey information was collected at the sites so that flooding and inundation hazards could be identified. It is noted that well heads would normally be assessed against 100 year annual recurrence interval (ARI) flood levels but these were not available at some locations. In some instances, 50 year and 200 year ARI flood levels were used instead.

Annular grout seals around the well casing cannot be inspected although as built information and specifications for grouting sealing the well casing were reviewed. Generally, most wells drilled before 2011 do not have annular grout seals, whilst those drilled from 2011 include a double cased design with a cement-bentonite mix placed in between the two casings. Grouting requirements have been clarified with the Drinking Water Assessor such that the current NZ guidance is for a minimum depth of 3 m annular seal. However, we note that the Inquiry’s Stage 2 report references the Australian Drilling Standards, which require a grout seal to a minimum of 5 m depth.

2.2 INSPECTION FINDINGS

2.2.1 GENERAL OBSERVATIONS

Generally, the condition of the well heads did not meet the current requirements of the drinking water standards. There were a number of well chambers that had water in them and some where the water level completely submerged the well head (see Figure 1). In some cases, this water was due to leakage from the well head, but in other cases the water entered the well head through the lid, unsealed well head penetrations, drainage pipes, and cracks in the well head. In a few cases there was only a gravel floor to the well head (i.e. no concrete floor had been installed).

Figure 1: Example of a well head chamber filled with water

2.2.2 SUMP PUMPS

A relatively small number of well heads had sump pumps to clear water from the well head, but most wells did not have sump pumps. Some sump pumps were not functioning correctly either due to a fault or not being installed correctly. It is important to keep the below ground well head dry as in certain circumstances, and depending on whether there is artesian pressure or not, water in the well head may travel into the water supply through the cable glands, flanges or down the casing.

2.2.3 SURFACE DRAINAGE PATHWAYS

Some below ground well heads were positioned in a surface drainage pathway meaning that runoff from a road, footpath or driveway would enter the well head chamber if the lid was not sealed (see Figure 2). Another area of concern is the level of the well head relative to flood level. Below ground well heads located in flood prone areas have a risk of becoming inundated through any unsealed pathways. This surface water is likely to contain contaminants that have been collected as it passes over land. The surface water may also contain raw sewage e.g. near the Heathcote River where sewage overflows may occur during significant wet weather events. Three below ground well heads located near or on the banks of the Heathcote River were of particular concern and are highly likely to have been, or showed recent evidence of being, inundated by river water (see Figure 3).

Figure 2: Example of a well head with surface water drainage paths into it

Figure 3: Example of a well head on the banks of the Heathcote River

2.2.4 AIR VENTS

Air vents were rarely installed on the wells. They are important for any pumped bore and those artesian bores where the surface pump suction head drops below the well head. When water is pumped from a well, the water level inside the well drops causing a vacuum or a void which needs to be replaced by air. If there is no air vent then there is no pathway for air to enter the well, and suction within the well develops. This may result in potentially contaminated water being drawn in from the ground and/or from surface through gaps in the well casing or the well head. Air vents must also be set above the 100 year flood level so that flood water cannot enter the well via the air vent.

Figure 4 shows an example of how an air vent can be installed outside the well head. In left hand photo, the air vent is installed in a bollard together with the sample tap. The other photo, the air vent is positioned on top of the well head. Two way air valves can also be used where flowing artesian conditions occur at the well head. It is important to add mesh to the vent pipes including the valves to prevent access by vermin etc.

Figure 4: Examples of an air vent outside of a well head

2.2.5 SAMPLE TAPS

Some wells had sample taps installed within the below ground well heads while others had sample taps situated in cabinets outside the well heads. Locating sample taps outside the well heads is preferable as it is important to avoid draining of the sample tap into the well head (see Figure 5). We note that the sample taps should not form a direct connection to the main line and should have an air gap device to prevent material being potentially drawn through into the reticulation.

Figure 5: Example of a sample tap outside of the well head

2.2.6 ACCESS

Consistent with good practice, below ground well head lids usually required a key to open a padlock and many included a lid alarm. However, there were exceptions particularly with some of the older wells. Generally, 5 m exclusion fences were not installed around the well heads as those are only required in rural areas where livestock are present. This was confirmed as being acceptable by the Drinking Water Assessor.

2.2.7 IMMEDIATE PUBLIC HEALTH RISK

A number of wells were identified to pose an immediate public health risk and this was communicated to CCC staff without delay following the inspection work. CCC staff immediately isolated those wells that it could and took risk management measures for those wells which were essential in providing sufficient water to the city. It is vital that issues which pose a public health risk are promptly highlighted so that the issue can be addressed and rectified.

3 WELL HEAD REMEDIATION OPTIONS

3.1 REMEDIATION OPTIONS

CCC's longer term objective (by a unanimous vote of Council) is to not treat the city's groundwater. If the Inquiry's Stage 2 report recommendations are accepted by the Government, it is likely that achieving an exemption would be an onerous task and will require evidence of high quality of infrastructure being in place and that sound risk management practices are able to be demonstrated. It is possible that the Government will decide not to adopt these recommendations and Council could avoid treating drinking water by meeting the current secure bore water requirements – this is the basis of Scenario 1 as outlined below.

However, bringing below ground well heads above ground (and above the flood level) is recommended for all wells regardless of the recommendations that the Government adopts. The Inquiry found that this is best practice for well head protection, but does acknowledge that there are many existing below ground well heads. However, bringing all CCC below ground well heads above ground would be costly. Therefore, two scenarios for remedial work were considered:

- Scenario 1 - Remedial work to meet current drinking water standards
  - Below ground well heads are an acceptable solution under the current drinking water standards but they must be sealed to prevent the ingress of surface water and contaminants
  - Designs for Scenario 1 include remedial work to the existing below ground well heads (where possible)
- Scenario 2 - Remedial work to meet best practice and likely drinking water standards changes
  - Above ground well heads are best practice and are likely to assist in the application for a treatment exemption if the Inquiry's recommendations are adopted
  - Designs for Scenario 2 including filling in below ground well heads and raising them above ground (where possible)

In some cases, remediation of the existing below ground well is not feasible. This can be due the extent of the work required or because further investment in the well is not worthwhile and it should be replaced. Other factors which can affect the decision to remediate a below ground well head include:

- Access into the chamber for remedial works is not possible
- The local contamination risks are considered too great
- The well is not worth further investment e.g. due to flood vulnerability, age, and/or is in a shallow aquifer
- Grout sealing requires demolition of the chamber
- A below ground chamber with above ground pipework where it makes more sense to remove the chamber

- The chamber is particularly deep and remediating it may not be feasible and it needs to be raised above ground (chambers more than 3 m deep will likely fall into this category).

Raising well heads above ground can also be constrained by several factors including:

- Bringing the below ground well head above ground would obstruct a thoroughfare
- There is insufficient access for a large drilling rig
- The increased head may mean that an artesian well may have reduced flow or cease flowing altogether (net positive suction head issues), this can be overcome by pumping.

3.2 WELL CASING SEALING

Two methods for retrofitting grout seals were identified and are shown schematically in Figure 6. The first method involves injection of a bentonite/concrete fluid around the casing to the desired depth. The second method involves over-drilling the casing with a larger casing and then backfilling the annulus with the bentonite/concrete fluid while the outer casing is withdrawn. The advantages and disadvantages of each option are compared in Table 1. The injection method has been assumed for all wells where the below ground well head is to be maintained while the over-drilling method is assumed for chambers that are to be brought above ground.

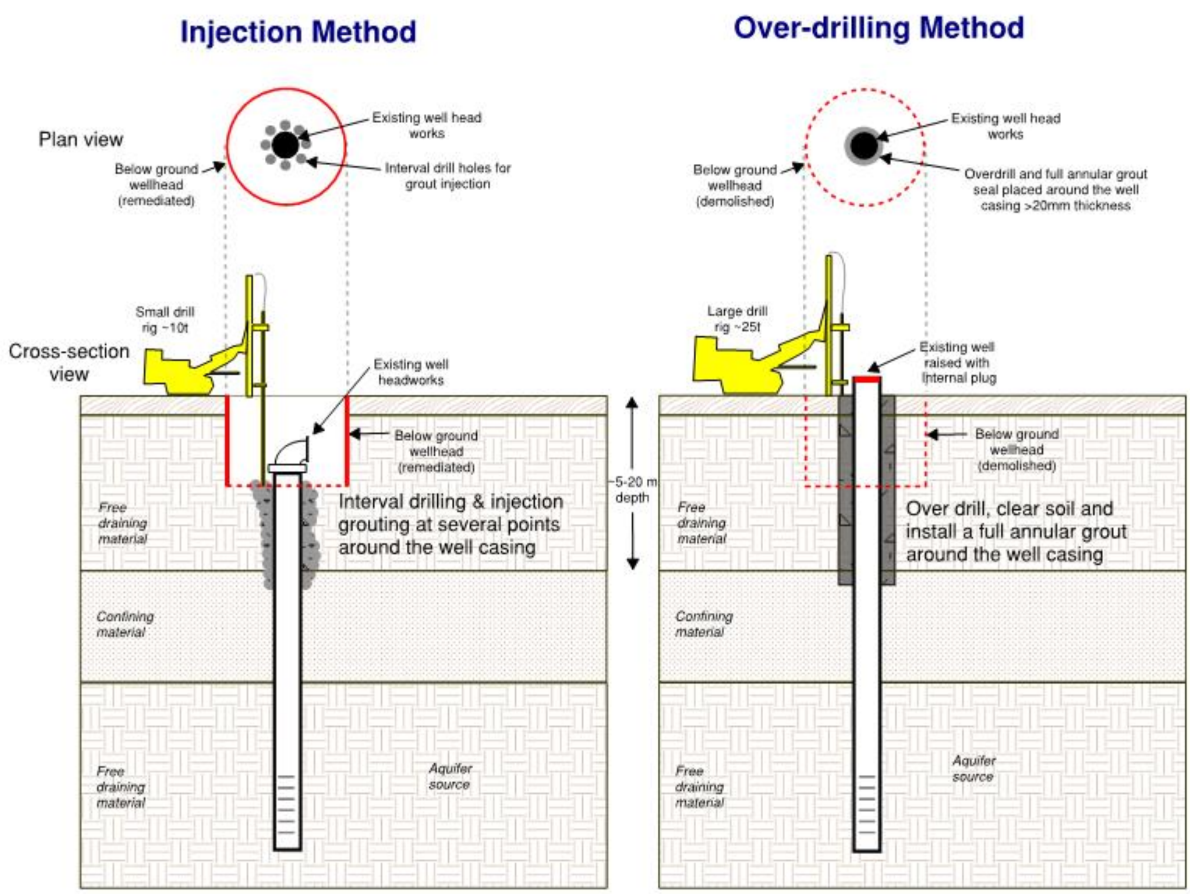

Figure 6: Schematic of options to retrofit annular grout seals to the well casing

Table 1: Comparison of the Advantages and Disadvantages of each Grout Sealing Method

Grouting Sealing Method	**Advantages**	**Disadvantages**
Injection Method	▪ Chamber can be maintained, only the floor will need to be replaced. ▪ Likely to take a few days and in some cases the well can be left in service. ▪ Smaller sized drill rig required. ▪ Meets the current drinking water standards.	▪ Does not provide a full annular grout seal and so cannot provide full protection around the casing. Testing can be done to check effectiveness of the seal i.e. monographic downhole geophysical testing. ▪ Low risk of damage to the well casing.
Over-drilling Method	▪ Considered a full annular grout seal and provides full protection around the casing. ▪ The below ground well head would be brought above ground which is a preferred solution in terms of well head protection. ▪ Meets the current drinking water standards and represents best practice.	▪ The headworks piping must be removed and the below ground well head either demolished or filled in to allow access for the 25 tonne drilling rig. In this situation it is not worth retaining the well head below ground. ▪ Likely to take a couple of weeks and the well cannot be left in service during the works. ▪ Low risk of damage to the well casing.

3.3 REMEDIATION COSTS

Cost estimates for the two remediation options were required to adequately compare the options. Due to the number of below-ground drinking water well heads owned by CCC, it was not practical to prepare and cost individual designs for each bore in the timeframe available. Instead, costs for the common remediation activities were estimated and applied to each well as required. There are also 19 wells supplying water from the uppermost Aquifer 1 which may need to be replaced due to possible bore water security risks. These Aquifer 1 wells may not meet Criterion 1.

The capital cost estimates for each scenario were as follows:

- Scenario 1 (remediate below ground well heads) - average cost to remediate each well was estimated to be **$122,000**
- Scenario 2 (raise well heads above ground) - cost to convert a typical below ground well into an above ground installation, with full annular grout seal, was estimated to be **$250,000**

It is important to note that these cost estimates are based on concept level design, and are considered to be at an accuracy of ± 30%. The preferred well head designs have been further developed since these estimates were prepared. There has been further discussion around hydraulic requirements and the need for additional pumping in some cases. This also may affect the capacity of the existing power and control infrastructure. These changes, among others, are likely to modify the overall cost of the remediation programme.

4 REMEDIATION SOLUTION

4.1 PREFFERRED OPTION

By and large CCC have opted to remediate the well heads, by raising them above ground, and retrofit grout seals to the casings by over-drilling to a minimum of 5 m depth as this places CCC in the best position to gain an exemption from mandatory treatment. This is Scenario 2. Where wells are nearing the end of their design life, or are in a shallow vulnerable aquifer, replacement wells are planned. A programme of works is now underway to remediate existing below ground well heads, and progressively remove chlorination.

Further work is being done to determine the best solution at the more challenging sites. This includes groundwater modelling to demonstrate compliance with Criterion 1 (the groundwater is not subject to surface or climatic influences), assessments of nearby contaminated sites and more detailed investigations of wells that may suffer from net positive suction head (NPSH) issues. UV treatment is planned at Christchurch's largest pump station (Main Pumps), as this takes water from the shallowest aquifer and there is no deeper aquifer at this location.

4.2 FUNCTIONAL DESIGN BRIEF

Given the large programme of work which lies ahead, a Functional Design Brief was developed which sets out the objectives and key design strategies of the programme. The document captures the best practice already used by CCC across the water supply wells. The document is a living brief and will be updated periodically as the programme develops and current covers the following:

- Hydraulics
- Flood level
- Annual seal
- Backflow prevention
- Scour line
- Plinth
- Connections
- Provision for future treatment
- Well head enclosures
- Utilities
- Landscaping
- Seismic resilience
- Durability
- Structural loadings
- Consenting
- Approval and sign-off

- Sequencing

4.3 STANDARDISED DESIGN APPROACH

The standard CCC above ground well head design was adapted to include the retro-fitting of an annular seal, filling of the chamber, and the installation of an above ground head works. Figure 6 shows an example of one of the standard design drawings developed as part of the well head remediation programme.

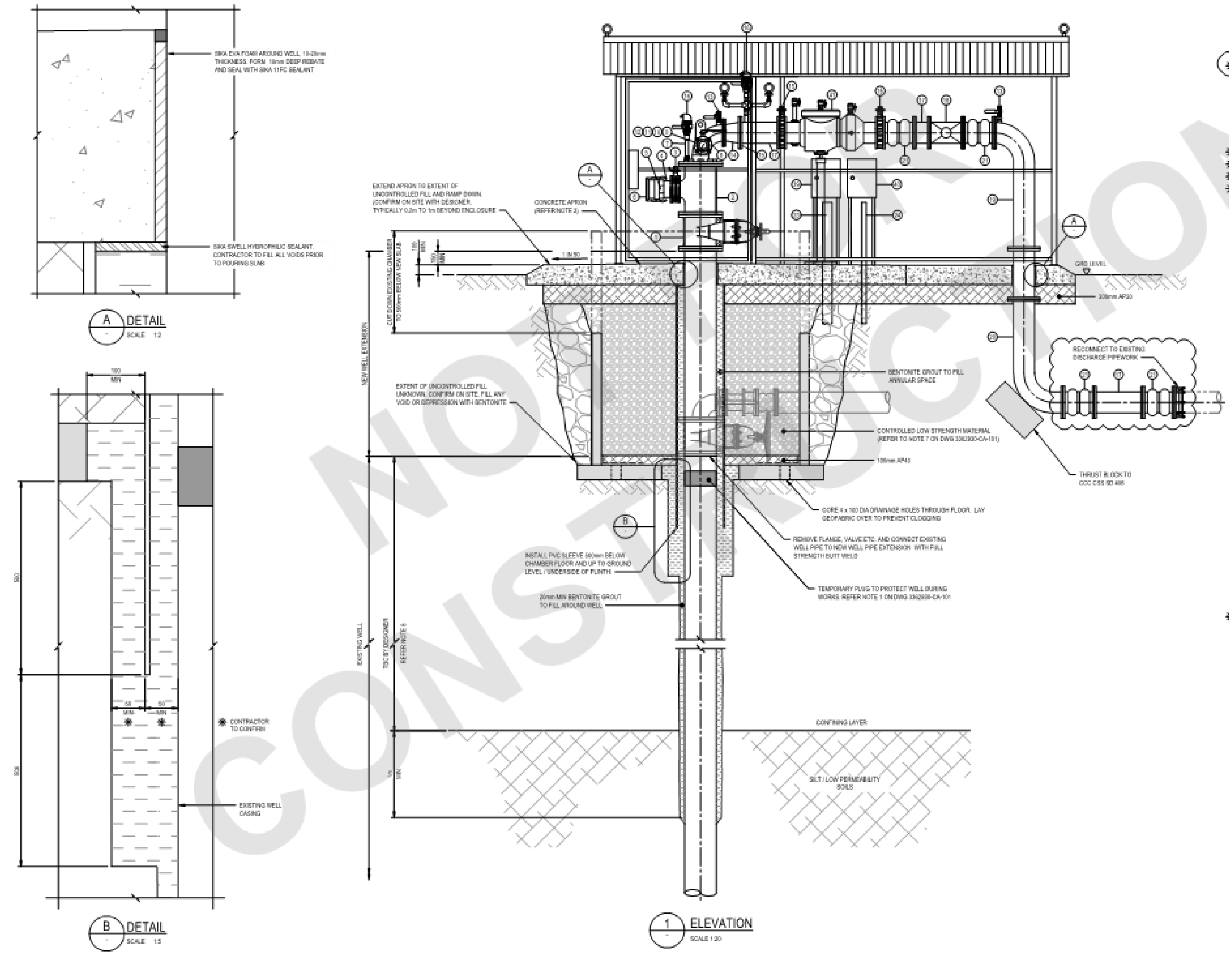

Figure 7: Standard drawing for raising a well head above ground

Raising and remediating the below ground well heads involves the follow key steps:

1. Removing the existing well head works, adding a length of well casing to reach above ground and installing a temporary plug to hold back the artesian flow.
2. The chamber base is then cut back such that a drilling contractor can install a stabilised bentonite mix to at least 5 m and key into a confining shallow layer. This exceeds the current drinking water standards guidance requirements of 3 m and meets aspect of the Australian Drilling Standards. The grouting approach seals the potential pathway for contaminants to enter around the well casing.

3. Once the annular seal is near the chamber floor level a PVC sleeve is placed around the well casing to create a form work within with the stabilized bentonite seal is placed. Considerations of seismic resilience show a preference for a flexible stabilised bentonite mix, rather than a rigid cement grout.
4. The chamber floor is prepared by cutting drainage holes and cover and placing geofabric and a thin layer of drainage aggregate over the floor. The chamber walls are cut down to avoid pressure points on the underside of the plinth.
5. A low density low strength flowable fill is then added to the chamber for ease of filling, to avoid confined space entry, and to provide a light weight alternative to compacted granular material and minimise seismic risk.
6. A standard CCC well head works is then installed which includes a two-way low pressure air vent with mesh set above flood level, with double bellows and double check valves. Electrical upgrades including level sensors and a flow meter connected to SCADA will also improve the operational understanding of each well.
7. A trafficable structural apron around the well head is laid which is sufficiently wide to cap the underling chamber in order to prevent surface ingress. The connection with the apron and well casing includes a rattle space and flexible sealant to allow for movement in earthquakes.
8. An optional cage is utilised where a pumping station site is not secure and/or where vandalism or environmental factors require it.

5 CONCLUSIONS

CCC has had an exemplar programme of developing best practice water supply wells and well heads in recent years (generally since 2011). However, inspections of well heads in the CCC network showed the older below ground well heads failed to meet the drinking water standards Criterion 2 for bore water security (i.e. that the well head must provide satisfactory protection to prevent contamination of the water supply), particularly in light of more robust interpretation of the standards following the Havelock North contamination event.

The Drinking Water Assessor revoked the provisionally secure status for Christchurch’s water supply which resulted in CCC deciding to temporarily chlorinate the water supply until its well heads were remediated. Options including remediating below ground well heads and raising them above ground were evaluated against time, cost and quality criteria. Raising the well heads above ground was found to be the preferred option and will ultimately place CCC in a better position if the recommendations of the Havelock North Drinking Water Inquiry Stage 2 report are adopted by the Government.

A broad programme of work is now underway across Christchurch to improve the safety and security of the water supply and remove temporary chlorination. This includes raising well heads above ground, replacing older and vulnerable wells with new wells, new pumping stations, network improvements including preferentially using the more protected wells (without chlorination), adding UV treatment in limited instances, and reviewing contamination sources and Water Safety Plans.

Raising the below ground well heads above ground significantly advances the protection of well heads from surface contamination sources, increases the resilience of the well head infrastructure and improves operations and maintenance activities.

ACKNOWLEDGEMENTS

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