UV DISINFECTION OF GROUNDWATER WITHOUT FILTRATION

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ABSTRACT

UV disinfection has been used without filtration to treat Blenheim's water supply. The water source could not be shown to be secure and required 3 log Cryptosporidium removal or inactivation to meet the Drinking Water Standards for New Zealand 2005 (revised 2008) (DWSNZ) protozoal compliance. UV disinfection was able to achieve this.

Filtration was not required because the groundwater is of good quality with UV transmissivity (UVT) greater than 96%/cm and turbidity less than 0.2 NTU except at pump start-up when the turbidity is elevated. Each bore includes a flush to waste system so that only water of sufficient quality for effective treatment is directed to the UV reactors. This ensures proper disinfection and compliance with the DWSNZ.

The UV reactors will also provide bacterial compliance with the DWSNZ once issues over validation are resolved to the satisfaction of the Ministry of Health.

UV disinfection was lower cost than other treatment technologies available for protozoal compliance. The success of UV disinfection relied upon good quality groundwater and a method for diverting and disposing of poor quality water at bore pump start-up.

KEYWORDS

UV, groundwater, water treatment, Drinking Water Standards for New Zealand, Blenheim

1 INTRODUCTION

It had generally been thought that Blenheim's groundwater was safe to use without treatment for bacteria or protozoa, a view supported by regular E.coli monitoring, however in 2008 E.coli was detected in a group of three bores supplying the town's water. Low level contamination continued for weeks although the boil water notice was able to be lifted by shutting down the affected bores and operating on the remaining six.

The quality of Blenheim's bore water had been under active consideration since 1998 along with treatment technologies that could be used for protozoal and bacterial compliance in the event that the groundwater could not be shown to be secure. Over that period UV disinfection came to the fore and gained acceptance for the treatment of protozoa.

In preparation for treatment upgrading, additional adjoining land was purchased at the two main pH correction water treatment plants, Middle Renwick Road Water Treatment Plant (MRRWTP) where the contamination had occurred and Central Water Treatment Plant (CWTP). Resource consents were obtained for MRRWTP. Treatment for protozoa and bacteria brought about major changes to the pumping and storage of water in the system. Bore water had been pumped directly into the reticulation with the only treatment being lime and caustic soda dosed online to raise the pH. Now the raw water would be treated and stored at the water treatment plants before being pumped into the reticulation.

2 BLENHEIM WATER SUPPLY BEFORE UV DISINFECTION

2.1 EARLY DEVELOPMENT OF WATER SUPPLY

The first reticulated water supply in Blenheim drew water from the Taylor River. That source was augmented with groundwater in 1946. More bores were drilled in the 1960's and soon Blenheim was supplied entirely with groundwater. The water is of good quality but is highly aggressive with a Langalier Saturation Index (LSI) of -2.6 and low hardness of 45g/m³ $CaCO_3$.

Bores were fitted with submersible pumps which delivered untreated water direct to the reticulation in one pressure zone. The town developed to the south on higher ground towards the Wither Hills and away from the bore supply. In 1971 a booster pump station and reservoir were constructed. The reservoir was situated on the Wither Hills to provide higher pressure for the town's expansion to the south. The reticulation was now in two zones, the northern zone that the bore pumps pumped directly into and had no storage, and the southern zone which had a reservoir and booster pumps.

2.2 INTRODUCTION OF PH CORRECTION

In the late 1990's pH correction was introduced at three sites to reduce the aggressiveness of the water, thereby reducing rates of corrosion in asbestos cement (AC) pipes as well as metal pipes and fittings. AC pipes account for about 30% of the reticulation mains. Copper was widely used in household plumbing and hot water cylinders, and for service connections. The design included two water treatment plants (WTP's) using caustic soda and the third and largest capacity using lime in the form of limewater from a saturator. The two caustic soda WTP's operated primarily in summer to meet peak demand while the lime plant operated all year round. Lime plants are more expensive to build than caustic soda plants but lime is lower cost than caustic soda. Caustic soda plants are much more easily started and stopped than lime plants which makes them more suited to meeting peaks in demand.

Table 1 pH Correction Water Treatment Plants

Water Treatment Plant	Alkali	Usage	Bores	Capacity
Middle Renwick Road (MRRWTP)	Na OH	Summer	3	180 L/s
Andrew Street	Na OH	Summer	1	75 L/s
Central (CWTP)	$Ca (OH)_2$	All Year	5	330 L/s

Bore water continued to be pumped directly into the reticulation with caustic soda and limewater dosed directly into the mains.

2.3 GROUND WATER SECURITY

The bores supplying Blenheim are in the semi-confined zone of the Wairau Aquifer. To the east towards the coast the aquifer is confined, to the west it is unconfined. The depths of the nine water supply bores are similar, with the top of the screens in the range of 18 to 21 metres below ground.

A report for Council in 1998 considered the Drinking Water Standards for New Zealand 1995 in respect to microbiological contaminants, groundwater security and treatment options. Treatment technologies were presented which could ensure compliance if the water could not be shown to be secure. Recommendations were made to monitor water quality.

The Drinking Water Standards for New Zealand 2000 provided specific requirements for demonstrating security of groundwater. Three criteria had to be met as briefly summarized below:

i) No E.coli in a 12 month period of testing.

ii) A secure bore head

iii) Groundwater not directly affected by surface or climatic influences as shown by either one or both of;

- Less than 0.005% of the water has been in the aquifer for less than one year
- Variations in groundwater quality not to exceed a co-efficient of variation of more than the following when measured at least monthly for one year or two monthly for two years or three monthly for three years;
  - 3% in conductivity
  - 4% in chloride
  - 2.5% in nitrate (standardized variance)

Secure groundwater would mean no requirement for protozoa treatment which would save considerable expenditure.

From 2002 conductivity, chloride and nitrate were tested monthly on raw water samples from Middle Renwick Road Water Treatment Plant (MRRWTP) and Central Water Treatment Plant (CWTP) when the plants were operating. These determinands were soon shown to have considerable variability which suggested surface water influences and non-compliance with the second part of the third criterion for groundwater security.

Age dating of the groundwater was carried out to estimate the fraction of water that has been in the aquifer for less than one year. If this fraction was less than 0.005% and the first two criteria were satisfied, the water would be considered secure under the Drinking Water Standards for New Zealand 2000. Testing in 2001 using isotopes of chlorofluorocarbon (CFC) found the bore water at MRRWTP was 'modern' and the young fraction could not be determined due to an excess of CFC-12. A bore supplying CWTP had water that was 12 years or more old and a young fraction of 0.075% which meant it did not meet the maximum limit of 0.005%.

2.4 WATER QUALITY AT BORE PUMP START-UP

In 2002 groundwater was tested at bore pump start-up to investigate observations made when first starting pumps after winter shutdown. Turbidity and iron were elevated for several minutes when starting a pump after a long shutdown. Figure 1 shows the results for turbidity testing at pump start-up after a shutdown of several days.

Bore pumps were flushed to waste manually when they had been shut off for long periods. Future treatment processes if required would need to take account of this issue because turbidity would rise for a short period after pump start-up after only a short duration shutdown. Elevated iron and turbidity was not unexpected given that the water is of low alkalinity and low pH and the bore casings are steel.

2.5 PROVISION FOR FURTHER TREATMENT

With the release of the Drinking Water Standards for New Zealand 2000 and from an initial review of the data on groundwater security, it appeared likely that Blenheim's groundwater supply was not secure and if that was later confirmed to be the case, treatment for protozoa and bacteria would be needed to comply with the Standards. Several treatment technologies had been identified as being suitable for the Blenheim water supply but UV was not among them for protozoa treatment because it was not approved at the time. UV was included in two options but was limited to bacteria treatment in conjunction with an accepted process for treatment of protozoa, for example cartridge filtration and UV disinfection.

The pH correction water treatment plants had insufficient land for expansion to accommodate any of the treatment processes that would meet microbiological compliance. UV disinfection would not fit within the existing WTP sites either, due to the need for reservoir storage and reticulation pumping. Council approved the purchase of properties adjoining MRRWTP and CWTP so that expansion of facilities to include protozoa and bacteria treatment would be possible in the future. In 2002 resource consents were obtained for the expansion of MRRWTP. The consents were based on a black box approach and the greatest effects of a range of processes, which did not include UV disinfection for protozoa treatment. UV disinfection was rapidly gaining credibility for inactivating protozoa and held the promise of lower cost treatment than that which was currently approved, provided it could perform without prior filtration.

The Drinking Water Standards for New Zealand 2000 were replaced in 2005 and UV disinfection was now an acceptable treatment process for priority 1 determinants, protozoa and bacteria, with up to 3 log Cryptosporidium inactivation credits available. The 2005 Standard introduced a process of log credits for Cryptosporidium compliance. Cryptosporidium was chosen as the reference organism for protozoa removal or inactivation. The source waters are classified with the number of log credits required. The sum of the log credits of the treatment processes must equal or exceed the source water log credit requirement for the treatment plant to comply for protozoa. Criteria for bore security in the 2005 Standard were similar to the criteria in the 2000 Standard.

Earlier investigations into water quality and in particular elevated turbidity at bore pump start-up, proved invaluable when later considering the suitability of UV disinfection for Blenheim.

2.6 HYDRAULIC MODELLING

Hydraulic modelling had been carried out on the whole network for planning upgrades in capacity for future growth and to provide for the changes to introduce UV disinfection. High peak summer water usage was reaching the system's capacity.

Modelling and process design required the following upgrading;

1) A service reservoir on the Wither Hills for the northern reticulation zone (the Low reservoir) to;
   - Provide storage for future peak diurnal demand
   - Maintain pressure if the reticulation pumps shutdown for any reason
   - Provide emergency storage.
2) Increased bore capacity for future growth. This would come from existing and new bores supplying CWTP.
3) Storage reservoirs at CWTP and MRRWTP to;
   - Avoid immediate disruption to the supply when a UV reactor shuts down on fault
   - Ensure low pressures and minimal surge effects on UV reactors
   - Improve control of pH correction
   - Provide storage for future peak diurnal demand
   - Enable separation of the treatment process, from pumping treated water into the reticulation

The modelling included reticulation pumps at both CWTP and MRRWTP. Andrew Street WTP with its single bore would be decommissioned for economic reasons and other issues including lack of land.

Figure 2 shows Blenheim reticulation including the location of the bores, treatment plants and reservoirs.

3 INTRODUCTION OF UV TREATMENT

3.1 DECISION TO TREAT AND PROCESS SELECTION

In late January 2008, routine monitoring detected E.coli in water sampled from the MRRWTP bores. The contamination was at low levels but persisted. Council decided to treat the water for bacteria and protozoa. The Drinking Water Standards for New Zealand 2005 did not require protozoa monitoring due to the low E.coli in the raw water (<10/100mL) and assigned a 3 log credit requirement of the treatment process. This could be achieved at lowest cost with UV disinfection and was the process taken to design given the high UV transmissivity (UVT) and low turbidity water.

The bores supplying CWTP did not have the immediate concern of E.coli being present but like MRRWTP the groundwater supplying CWTP could not be shown to be secure. There is 1.6km between the bores supplying the two water treatment plants. The decision was made to also treat CWTP bores with UV disinfection.

Because of the fact that Blenheim's water supply had not been chlorinated, there was a strong desire for the UV process to also provide bacterial compliance without the need for ongoing E. coli monitoring.

3.2 MRRWTP – DESIGN

Figure 3 is a schematic of the Blenheim water supply following upgrade and shows the nine supply bores and two treatment plants.

30 lamp UV reactors in duty/standby arrangement were chosen for MRRWTP. Each reactor is rated 7.5kW and can treat well in excess of the 180 L/s capacity of the plant. The reactors were validated in terms of the DVGW standard.

The UV disinfection, storage and pumping plant that was designed for this site had environmental effects that were no greater than what had been earlier consented and a certificate of compliance was issued. During earlier discussion with neighbours to the site as part of the consenting process, noise and visual appearance had been the main issues of concern. The reticulation pumps had been identified as the highest risk of noise. Submersible bore pumps produce little noise and would not be an issue. It was decided to build the reticulation pump station in-ground and reutilize the existing bore pumps. Installing the three bore pumps below ground in vertical pipes that simulated bores created a risk, albeit low, of shallow groundwater contaminating the treated water. To protect against this risk, a robust construction system was designed. Large diameter steel lined bores were drilled and the ends plugged with concrete. Polyethylene (PE) pipes were fabricated, fully welded and water tested, before being lowered into the bores, and then the annulus between the steel and PE was filled with concrete.

Gathering reliable water quality data, specifically turbidity and UVT over a long period was a challenge. The accuracy of the data was critical for UV reactor selection. The design provided for the reduced water quality at bore pump start-up with a flush to waste system controlled by a turbidimeter. This would ensure the UV reactors only received feed water of quality suitable for effective UV treatment. At times of high rainfall the stormwater system at the site could not cope with the flush to waste flows so a holding tank consisting of concrete culverts was installed for storage to limit the discharge.

A 1000m³ concrete reservoir was constructed first at the rear of the site while the detailed design of the treatment process was completed. The same contractor building the reservoir later won the tender for the WTP upgrade. UV equipment and bore pumps were supplied under separate contracts.

The existing building housing the caustic soda dosing plant was extended to house the UV reactors and the new variable speed drives for the bore pumps. The electrical soft starters used for the original bore pumps were retained to start the same three pumps which were reused as reticulation pumps, pumping treated water into the reticulation.

In April 2009 the MRRWTP was back in service with UV disinfection.

3.3 PLANNING OF THE REMAINING UPGRADES

There were several key requirements to enable the rest of the upgrades to be completed without affecting customers. Every effort would be made to avoid water restrictions given those that had already been imposed while MRRWTP was upgraded.

The main elements of the upgrades still to be completed were;

1) Construction of a 10,000 m³ service reservoir (the Low reservoir) on the Wither Hills for the northern supply zone serving about 75% of the town's population
2) Drilling new bores and redeveloping existing bores supplying CWTP
3) Constructing a new 3000m³ treated water storage reservoir at the CWTP site
4) Upgrading the CWTP to include UV disinfection, new bore pumps and new reticulation pump station

In winter MRRWTP could supply the whole town so that CWTP could be shut down but this would require the Low reservoir to be in service for security of supply and operational reasons, in particular for the operation of the booster pumps feeding the southern pressure zone.

New bores at CWTP would need to be drilled and existing bores redeveloped in winter when MRRWTP could take over the supply. Keeping some CWTP bores in operation was not an option because;

1) Development of bores would cause an increase in turbidity at other nearby bores
2) The trunk main from the bores to the CWTP reservoir was required for bore pump tests
3) Better bore pump test results would be obtained if there was no abstraction from nearby bores

The CWTP treated water reservoir was needed prior to the drilling contract commencing to allow for full flow testing of the CWTP bores. A combined test pump of four bores needed to be carried out at high flow rate that would be in excess of the existing stormwater reticulation capacity. The new reservoir was being designed with a high capacity overflow direct to the Taylor River to protect the reservoir from overfilling in the event of a failure of the controls or communications to the bore pumps. The inlet to the reservoir would have a magnetic flow meter which would be used to confirm bore pump test flow rates.

The project was planned and executed to achieve these requirements. The drilling contractor reinstalled the original bore pumps after completing work on the bores so that the full supply could be reinstated for the following summer. The next winter the main treatment plant contractor would remove the bore pumps and replace with new low head pumps.

3.4 CWTP – DESIGN

CWTP UV upgrade was similar in concept to MRRWTP. The significant components of the CWTP upgrade were as follows;

1) New low head bore pumps sized for 405 L/s combined flow with capability to expand beyond that
2) Double suction reticulation pumps in a new pump house installed below reservoir floor level to ensure positive prime
3) One local and five remote bores supplying the raw water to the treatment plant
4) Ethernet over dedicated fibre optic cable between bores and CWTP and the ‘base station’ at Council’s offices, with radio backup
5) Back up generator
6) Surge vessels
7) Earthquake activated valve on the reservoir outlet to the reticulation pumps

Figure 3 is a schematic of the Blenheim water supply and figure 4 is a process schematic for CWTP.

Separate supply contracts were used for the following equipment: UV reactors, bore pumps, reticulation pumps and generator set.

Changes to the lime plant were minimal. Limewater dosing was relocated to just downstream of the UV reactors.

As at MRRWTP, two 30 lamp UV reactors were installed in duty and standby configuration. Any fault which could affect disinfection shuts down the bore pumps and changes over the duty reactor. High turbidity at the UV inlet stops the water treatment process. Low UVT limits the number of bore pumps available to keep flow within the UV reactor’s rated flow. If UVT falls below 80%/cm the treatment process shuts down. The reactors were validated in terms of the USEPA “Ultraviolet Disinfection Guidance Manual” (UVDGM) standard.

It is important to note that the wording in DWSNZ in relation to using UV to achieve bacterial compliance needs to be clearer if the UV reactor is validated under the UVDGM. Clause 4.3.5 of DWSNZ states: “If the protozoal compliance requirements are met with UV light using a dose equivalent to 40 mJ/cm^2, bacterial compliance is automatically achieved, ….”. By “dose equivalent to” it means a “reduction equivalent dose” (RED) when using Bacillus subtilis or MS2 phage as the test organism”.

Bore pumps operate at low heads. Water level in the bores is no more than 7 metres below ground when the pump is running, so static heads are no more than 14 metres. If bore pumps are operated at fixed speed the flow range would vary considerably depending on the drawdown, the water level in the treatment plant reservoir and the number of pumps running. To ensure bore water drawdown is not excessive and to control flows to the UV reactor, the bore pumps operate on variable speed drive and are controlled to achieve set point flow. This also enables flush to waste to be controlled to the same flow. If the bore is flushed to waste at a lower flow than the operating flow to the treatment plant, then elevated turbidity can be expected when the bore water flow is increased on changeover to the UV reactor.

3.5 CWTP BORE PUMP CONTROL

The bore pumps are controlled to maintain individual set point flow from each bore. Bore pumps are started on a time to empty function. If the treatment plant reservoir water level is falling the control checks the time it will take at the current rate of decline to reach the empty level and if that is less than the time to empty set point, the control will start the next bore pump in sequence. The time to fill function works in a similar fashion to stop pumps. This control allows reservoir capacity to be used while maintaining some reserve and can help to reduce the number of pump starts and stops which is beneficial for the pumps and the treatment process.

3.6 RETICULATION PUMP CONTROL

The reticulation pumps at CWTP are operated on variable speed drives. There are three duty and one standby pump. The pumps operate on discrete speed steps depending on the water level in the Low reservoir situated 5km from the reticulation pump station. Time to empty and time to fill functions are used to increase and decrease the speed step in a similar way that the bore pumps are started and stopped. If more than one CWTP reticulation pump is running then the pumps are controlled on the same speed step.

The programmable logic controller (PLC) monitors the pumps in relation to the preferred operating range (POR). If the pump flow exceeds the POR the next pump in the sequence is started. If the pump is operating at flows less than the POR the last reticulation pump on is stopped. This control includes starting and stopping MRRWTP fixed speed reticulation pumps. The operator has a wide range of pump sequences to choose from. The POR control ensures high efficiencies are maintained.

3.7 OVERALL CWTP CONTROL

The process is automated, apart from a few functions, with the use of PLC’s and operator interface through HMI (human machine interface) and SCADA (Supervisory Control and Data Acquisition). Operations that can be performed remotely by SCADA are limited to those that are considered safe to do without an operator present on site. There are two independent systems for communication between the CWTP bore pumps, the CWTP and the ‘base station’ at Council’s offices. The primary Ethernet over dedicated fibre optic cable is backed up by radio for limited critical control and data for demonstrating compliance with the DWSNZ.

The bore pumps and treatment system through to the treatment plant reservoir is controlled as a unit independent of the reticulation pumps. The control operates bore pumps and treatment to maintain water in the treatment plant reservoir. The reticulation pumps are operated to maintain water level in the Low reservoir which maintains the supply.

3.8 COMMISSIONING CWTP

Commissioning was carried out by Council and its consultants with the assistance of contractors as required. Commissioning followed testing and pre-commissioning by the construction contractor. This was different to the more conventional approach of the construction contractor commissioning and then handing over to the client. Issues with commissioning other plants with significant mechanical and electrical systems, which were led by civil main contractors, had brought about a review of alternatives. Having commissioning outside the construction contract allowed Council to control the process. This is a valuable time for water treatment plant operators to be involved, to see the issues that arise and to gain experience from working along side the consultants.

The specification set out in detail what was required of the construction contractor in terms of testing and pre-commissioning and essentially meant proving all the individual elements of the contract works would operate correctly. It excluded proving overall system functionality and did not require the operation of the PLC logic. The CWTP was designed by consultants engaged by Council. The construction contract was structured so that the contractor tested and pre-commissioned, in the main, to the extent of its responsibilities and what it controlled. Council had separate contracts with the suppliers of; UV equipment, bore pumps, reticulation pumps and generator which set out performance requirements, witnessing the installation and testing of the equipment supplied.

4 SUMMARY

After considering groundwater security and treatment options for protozoa and bacteria for 10 years, a low level E.coli contamination event in early 2008 at a group of three bores supplying Blenheim led to the decision to accelerate the implementation of treatment for protozoa and bacteria. UV disinfection became an accepted treatment process when the Drinking Water Standards for New Zealand 2005 were released. This gave a more economical option for treatment than had previously been available. The two main pH correction plants were retained and extensive works carried out to add UV reactors, treated water storage and reticulation pumps.

UV disinfection can work directly on good quality groundwater without filtration but it is important to establish a reliable record of the relevant water quality parameters including at bore pump start-up.

Figure 1: Turbidity in Middle Renwick Road Bore No. 3 after pump start-up

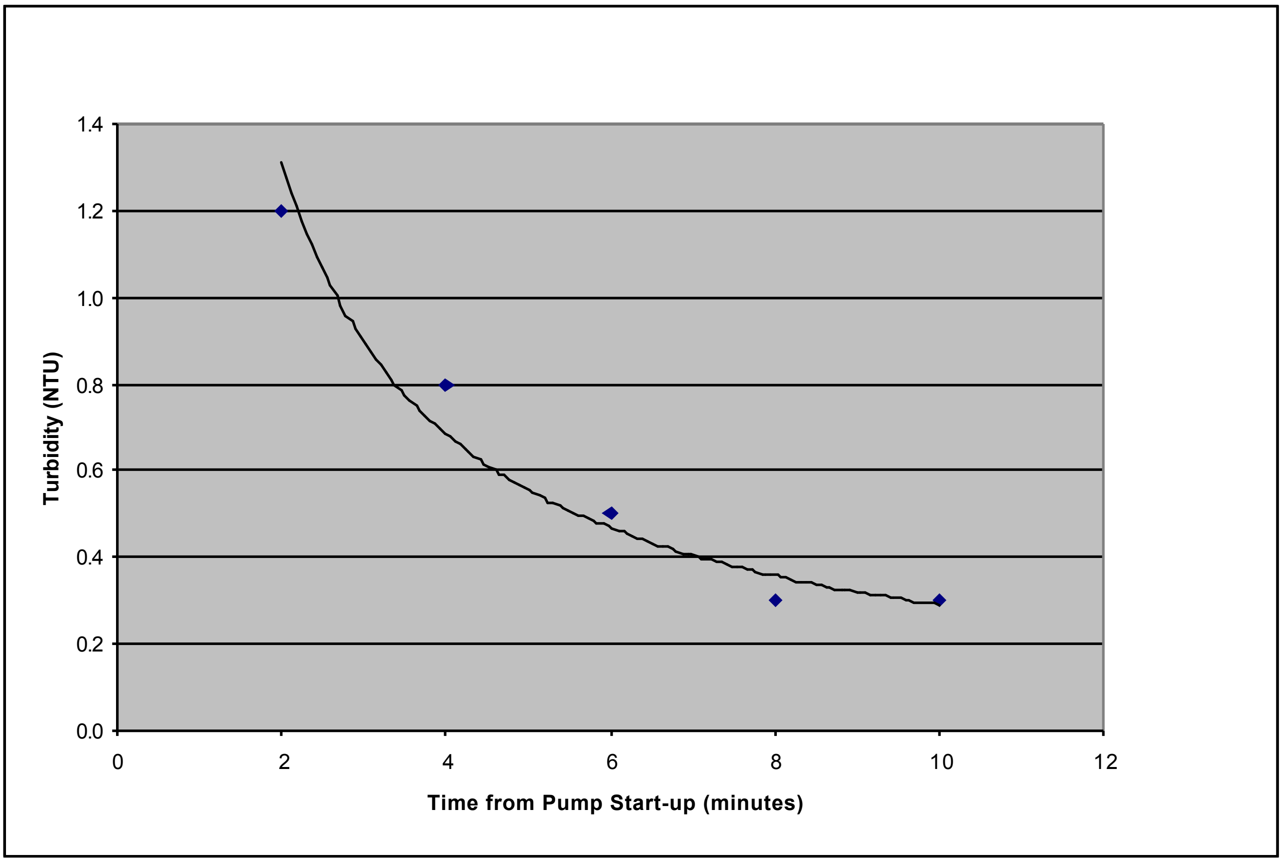
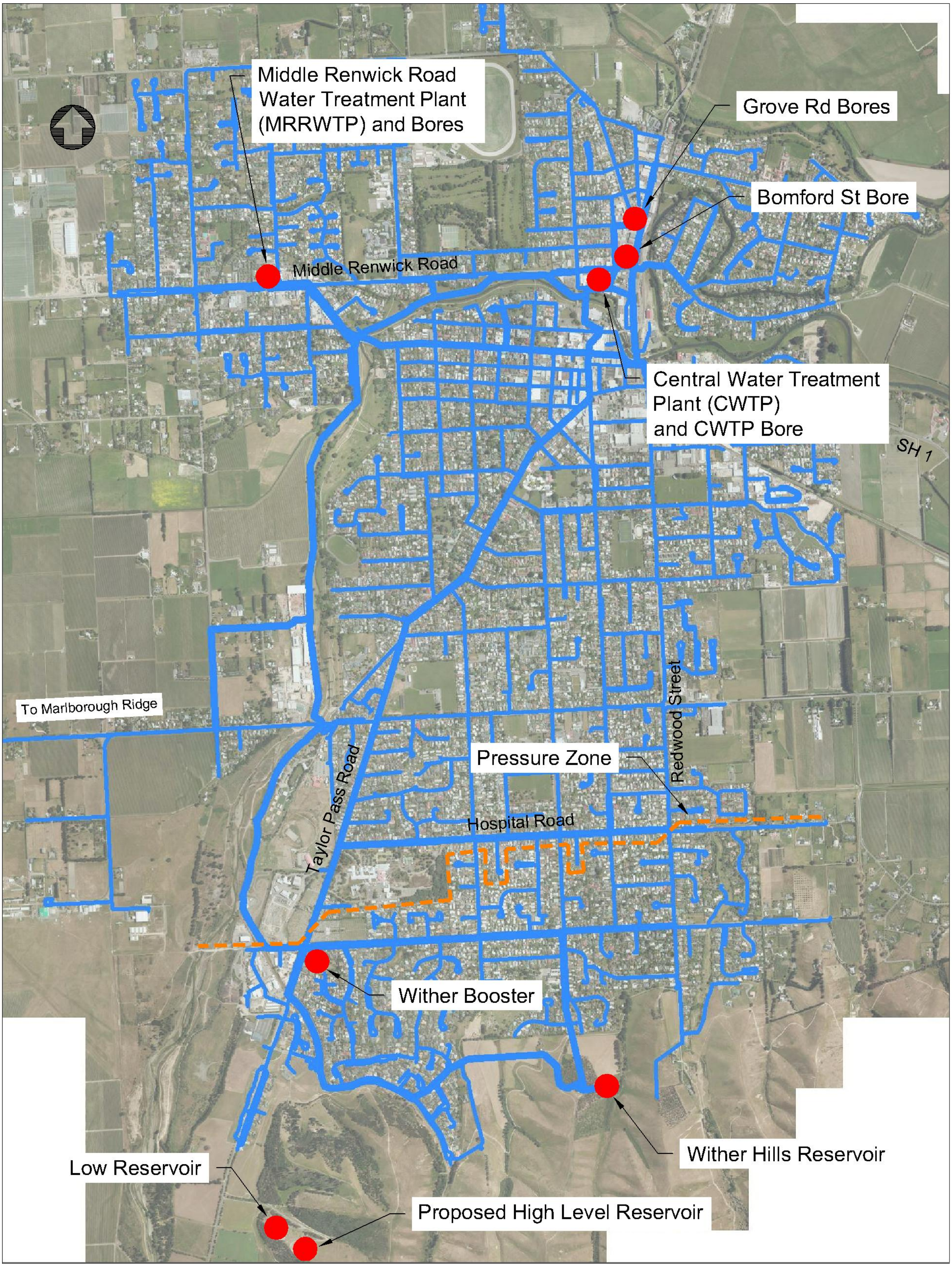


Figure 2: Blenheim Reticulation



Middle Renwick Road
Water Treatment Plant
(MRRWTP) and Bores
Grove Rd Bores
Bomford St Bore
Middle Renwick Road
Central Water Treatment
Plant (CWTP)
and CWTP Bore
SH 1
To Marlborough Ridge
Redwood Street
Taylor Pass Road
Pressure Zone
Hospital Road
Wither Booster
Wither Hills Reservoir
Low Reservoir
Proposed High Level Reservoir

Figure 3: Blenheim Water Supply Schematic

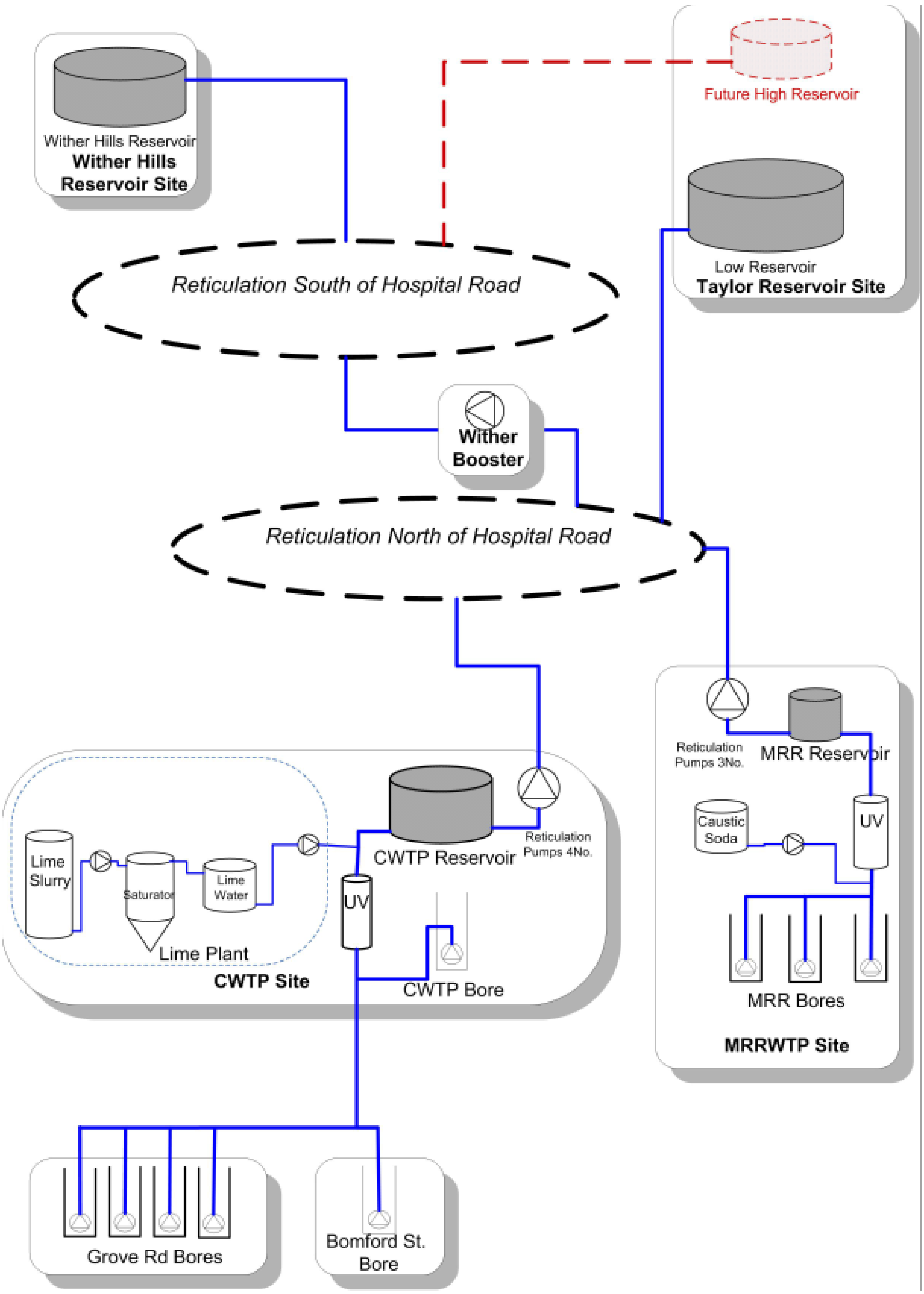
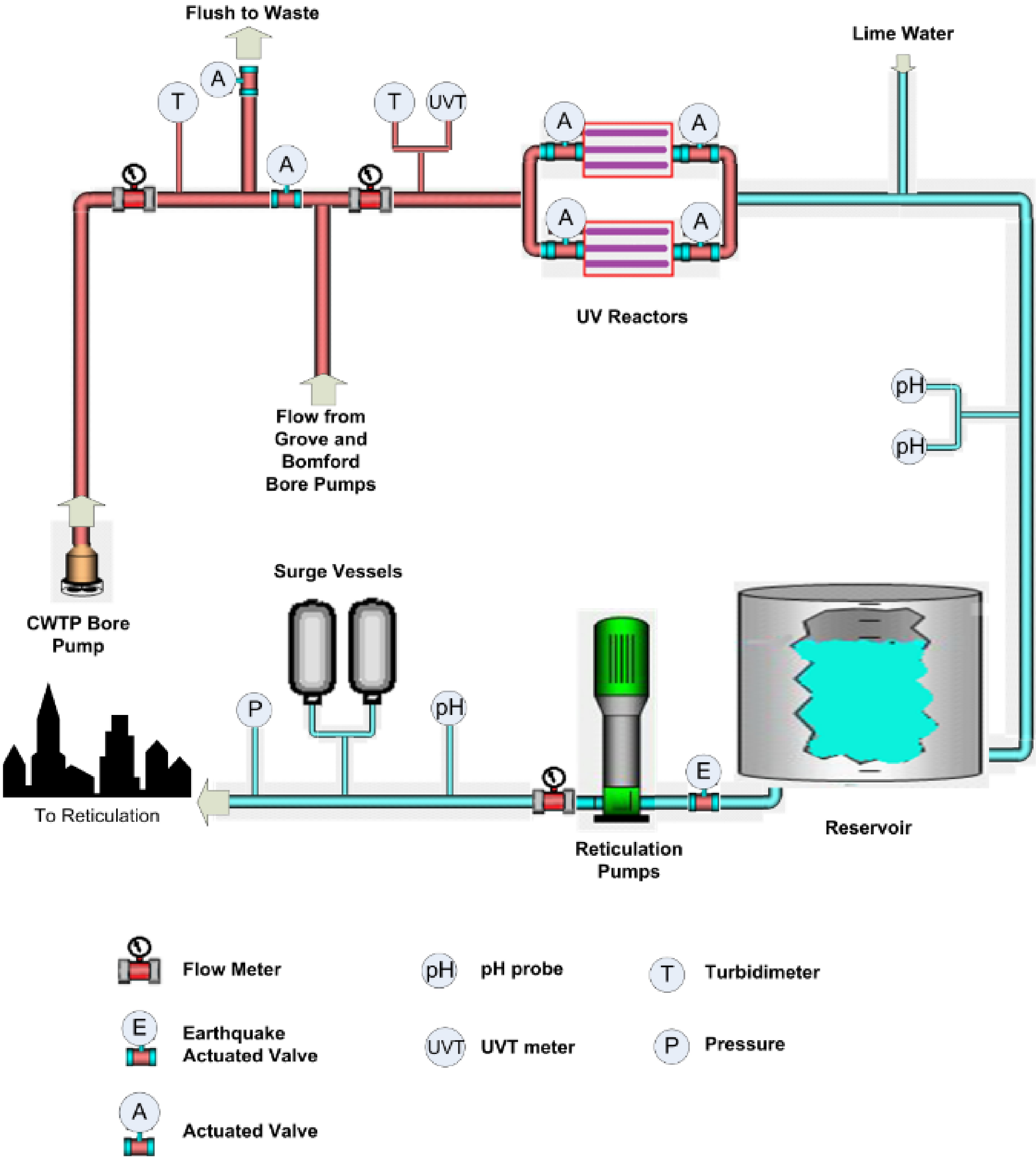


Figure 4: Central Water Treatment Plant Schematic



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