CONQUERING EXTREME TURBIDITY

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ABSTRACT

The Kerepehi Water Treatment Plant is subject to extreme turbidity (1700 NTU +) caused by King Tides in the Hauraki Gulf and low river flows. This paper looks at the technology selected to deal with this extreme turbidity as well as methods for reducing the impact, and recounts the first two King Tide events to hit the plant after commissioning.

This paper will look at the technology selection process, the options considered and will build upon last year's paper "King Tides – A Royal Problem" by Nicola Brown, Harrison Grierson(2012). It will examine how the existing plant and originally proposed upgrade was unsuitable for the raw water conditions. It will also provide an in-depth and detailed assessment of two different technologies and explain how a saving of over $3 million dollars was achieved on the initial estimates.

The paper will focus on the close collaboration between Hauraki District Council and the design engineers at Harrison Grierson and how investment and the beginning of the project led to savings being achieved in the final designed delivered to the client.

The project has produced a plant that has exceeded the expectations of the designers and Hauraki District Council. During the one-in-70-year drought over the summer 2012/13, water supply did not restrict milk production as it may have done many summers past.

KEYWORDS

Water Treatment, Membranes, Clarifiers, Turbidity Removal

1 INTRODUCTION

The Kerepehi Water Treatment Plant was originally constructed in the 1960s to supply water the Hauraki Plains Scheme and is key infrastructure in the region, supporting the significant local dairy farming. The plant originally consisted of coagulation followed by two blanket clarifiers and two sand filters. In the late 1990s one of the blanket clarifiers was converted into an absorber clarifier. This clarifier worked well when the turbidity was below 20 NTU. However, at higher turbidities, the absorber clarifier ended up in perpetual backwash leading to heavily restricted water production and intensive operator input to keep the plant running.

The raw water source – the Waihou River – not only suffers from freshes in the way rivers normally do after heavy rainfall but also from the King Tide effect. The causes and effects of King Tides at the Waihou Pump Station are clearly described in Nicola Smalberger's (nee Brown) 2012 paper, "King Tides – A Royal Problem" and are not repeated here other than to reiterate that the river turbidity can exceed 2000 NTU. The confounding factor of these events is that they occur during dry periods when demand is at its highest.

The main focus of "King Tides – A Royal Problem" was the avoidance of extreme turbidity events reaching the plant. This was achieved by stopping pumping at the peak of the tide, when the turbidity was worst, and pumping at a higher rate as the tide dropped. This reduced the treatment requirement for incoming turbidity to about 700 NTU.

2 THE DESIGN PROCESS

2.1 INITIAL COST ESTIMATES

The upgrade initially proposed was to build an additional absorber clarifier and more sand filters. Hauraki District Council (HDC) had been advised that the capital cost of this upgrade would be approximately $13-15 million. This solution would have allowed a plant capacity increase bud did not solve the problem of the poor performance of the absorber clarifiers in high turbidity conditions.

2.2 OPTIONEERING

Harrison Grierson had a brief discussion with HDC regarding the utilization of the Actiflo process by Veolia to treat the high and extreme turbidity experienced in the Waihou River. Anestimate was produced of around $13 million utilizing this process. At this stage Harrison Grierson were engaged to design a 12.5 Mld upgrade of the plant (from the nominal 6.25 Mld) based upon the Actiflo process. The objectives of the upgrade for Hauraki District Council were:

- To provide a reliable and robust plant capable of continuously producing 12.5 Mld of treated water;
- To make the plant more resistant to high turbidity events; and
- To comply with the Drinking Water Standards of New Zealand 2005 (revised 2008) and in particular to increase the WTP's disinfection rating to 5 log for protozoa.

An intense period of optioneering around the layout, hydraulic profile and various configurations was then started. These investigations included:

- Re-pumping from the Actiflo plant to the existing filters
- Placing the Actiflo on top of the existing clarifiers
- Re-using the existing clarifiers and retrofitting with Actiflo
- Retaining the existing plant and installing a smaller parallel Actiflo plant (6.25 Mld) and a new filter
- Installing a completely new Actiflo plant and sand filter system

In all, 10 different options were evaluated, combining and comparing re-use of existing plant with new process units. A high level costing was undertaken for each option and a multi-criteria analysis was carried out to select the preferred option. The top three options were then further analysed to produce the preferred option going forward. About this time, Harrison Grierson put forward an alternative option of converting the existing clarifier shells to tube settlers (to increase throughput) and installing a membrane filtration plant. Two further options were then considered, converting the clarifiers and installing a 12.5 Mld membrane plant or leaving the existing treatment plant and integrating a new 6.25 Mld treatment plant.

As part of the preliminary design phase, a visit was arranged to Oropi Road WTP (36 Mld Siemens Pressure Membrane System) in Tauranga for the operators and engineers of HDC. This visit let them get a feel for the technology and quiz the operators about the performance of the plant. However, some of the operators remained unconvinced at this point.

After the production of the preliminary designs, the process technology package was put out for tender – Actiflo to Veolia and the membranes to Siemens, Pall and GE. Of the membrane suppliers, Siemens were the least expensive although the pricing was very tight. Whole plant costs were then compared between the membranes and the Actiflo plant.

As Hauraki District Council was interested in whole life cost and not just initial capital cost, a 20 year Net Present Value (NPV) was carried out on both the Actiflo and the membrane offers. The two figures for the 20 year NPV were so close it was inconsequential (<0.3%). The operating costs for the membrane also included the costs for a service agreement with Siemens. It was understood by all parties that both technologies would provide the treatment quality required and therefore the selection was based on the falling cost of membranes (albeit the rate of fall has slowed over the past few years) and that this was not accounted for in the NPV costs. Additionally, the membrane option had the lower capital cost of the two options.

The initial concept designs and options studies were started in April 2010 and the technology supplier selected in February 2011. This optioneering process took a significant amount of time and effort by all parties involved and was comprehensive in examining all the possibilities, even the less likely ideas. The preliminary cost estimates for the plants showed a capital saving of between $1.5 and $5 million. Given the initial savings identified by the preliminary design report cost estimate, the time and effort spent up front was already showing a significant value.

2.3 DETAILED DESIGN

Once the above decision was made and the membrane supplier appointed, the detailed design commenced.

There were two major design issues to be overcome:

1. The ground conditions in the Kerepehi area are very poor with the ground water level being about half a metre below ground level in the winter; and

2. The structural integrity of the existing buildings and clarifiers was unknown. The existing buildings had to achieve 67% of the New Building Standard (NBS) as they are regarded as critical infrastructure by HDC.

2.3.1 HIGH GROUND WATER

Given that the ground water was so high, the major problem was how to backwash the membranes without putting a deep waste tank in the ground. The solution was to design a shallow tank below the floor of the membrane building (not more than 1.5 metres deep) that had the capacity for the backwash water and the clarifier sludge. This avoided excavating into the groundwater table but the structural engineering required to achieve the loadings in the building was challenging and involved the construction of significant floor beams in the tank. There were two tanks built underground:1) the CIP neutralization tank, and 2) the backwash and clarifier sludge tank. The second tank was divided so that the backwash water could be separated from the sludge tank , should wash water recycling be considered in the future.

2.3.2 STRUCTURAL INTEGRITY OF THE EXISTING BUILDINGS

Hauraki District Council had good records of the original buildings and a detailed structural analysis of the buildings showed that compliance with 67% of the NBS was already achieved. This meant that no additional strengthening was required.

The clarifier information was lacking and therefore core samples were taken from the part of the clarifiers not currently in use. These cores showed the concrete and reinforcing-bar to be adequate and in good condition with no additional strengthening required.

2.3.3 OTHER DESIGN ISSUES

In terms of design, there were no other major issues to overcome, although the proposed layout did require the demolition of two small reservoirs on site. The key points of the design were:

- Integration between the balance of plant design and the membrane plant;
- Foundations for new structures (flocculation tanks) and settling of new structures;
- Structural integrity of the raw water storage tank;
- Maintaining the plant flow during construction and commissioning, particularly when re-using equipment for a new purpose (transfer pumps);
- Gravity flow during normal operation with pumped assistance during King Tides;
- Re-use of existing plant and structures (filters became membrane feed tanks);
- And no chlorine contact time available on site.

3 FINAL PLANT DESIGN

The following schematic shows the overall plant process selected to meet the project objectives.

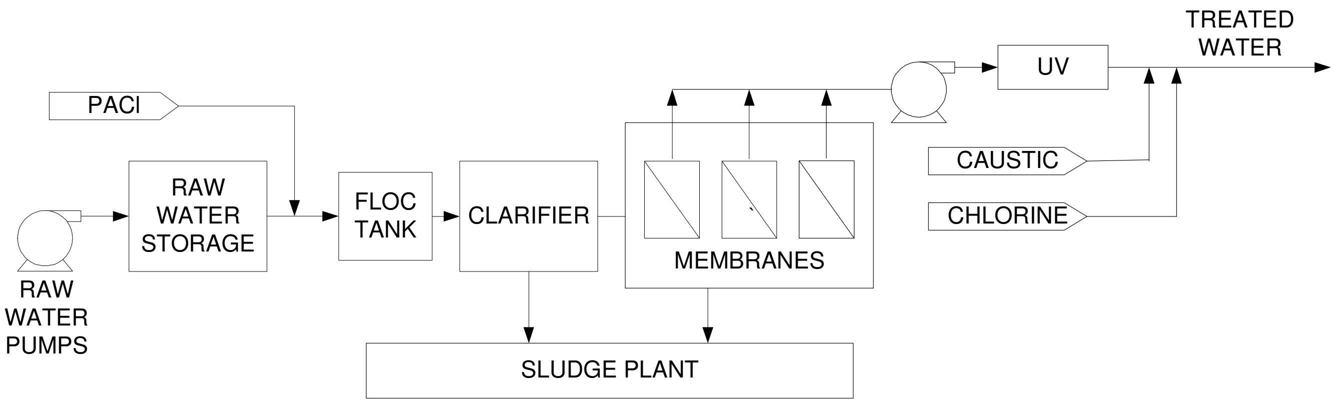


Figure 1 – Kerepehi Plant Schematic

The inlet to the plant and the control of the raw water storage have been addressed in Nicky Smalberger's (nee Brown) paper, "King Tides – A Royal Problem" and are not repeated here.

This plant had some key differences in philosophy from the pre-upgrade plant.

3.1 GRAVITY FLOW

The first major change was that the hydraulics of the plant from the raw water storage tank. Under normal conditions, with the raw water storage tank at high level, it was possible to gravity flow from the raw water tank to the plant. However, if the raw water tank level reduced due to a King Tide event, then pumping was still required. This required a carefully designed system that could automatically change from gravity flow to pumped flow, whilst not causing cavitation on the pumps due to a low pumping head and the re-use of the existing pumps. The reduction in pumping costs produces a saving for Haruaki District Council over the original philosophy. The photograph below shows the arrangement of three duty pumps and a bypass gravity system.

Photograph 1 – Raw Water Booster Pumps and Gravity Flow Valve

3.2 FLASH MIXING AND FLOCCULATION

The second difference was the flash mixing of coagulant and the separate flocculation tanks. The pre-upgrade design relied on the use of polymer to enhance flocculation for the existing blanket clarifier and was required as a principle of operation for the absorber clarifier. Given that tube settlers have no integral flocculation zone, separate flocculation is required.

Jar testing of the raw water indicated that the use of polymer had little or no effect on the size and settle-ability of the floc. Therefore by moving to tube settlers, there was the initial disadvantage of the additional flocculation towers but the advantage of potentially removing polymer from the dosing stream completely. As shown in the schematic above, the plant was designed without polymer but with the ability to add it at a later date if required. At the time of writing (August 2013), polymer has still not been used in the upgraded plant.

Photograph 2 – Flocculation Tank Mixers

3.3 RE-USE OF EXISTING STRUCTURES

The main items to be re-used were the existing building for chemical storage and dosing, the existing clarifiers (converted to tube settlers), the existing filters being used as the membrane feed tanks and the existing clear water tank becoming the clarifier to waste tank. The majority of the existing structures were used with only minor modifications. In most cases, this consisted of adding an outlet pipe and valving. In the case of the clarifiers, significant internal modifications were made; however, the existing shells were largely untouched.

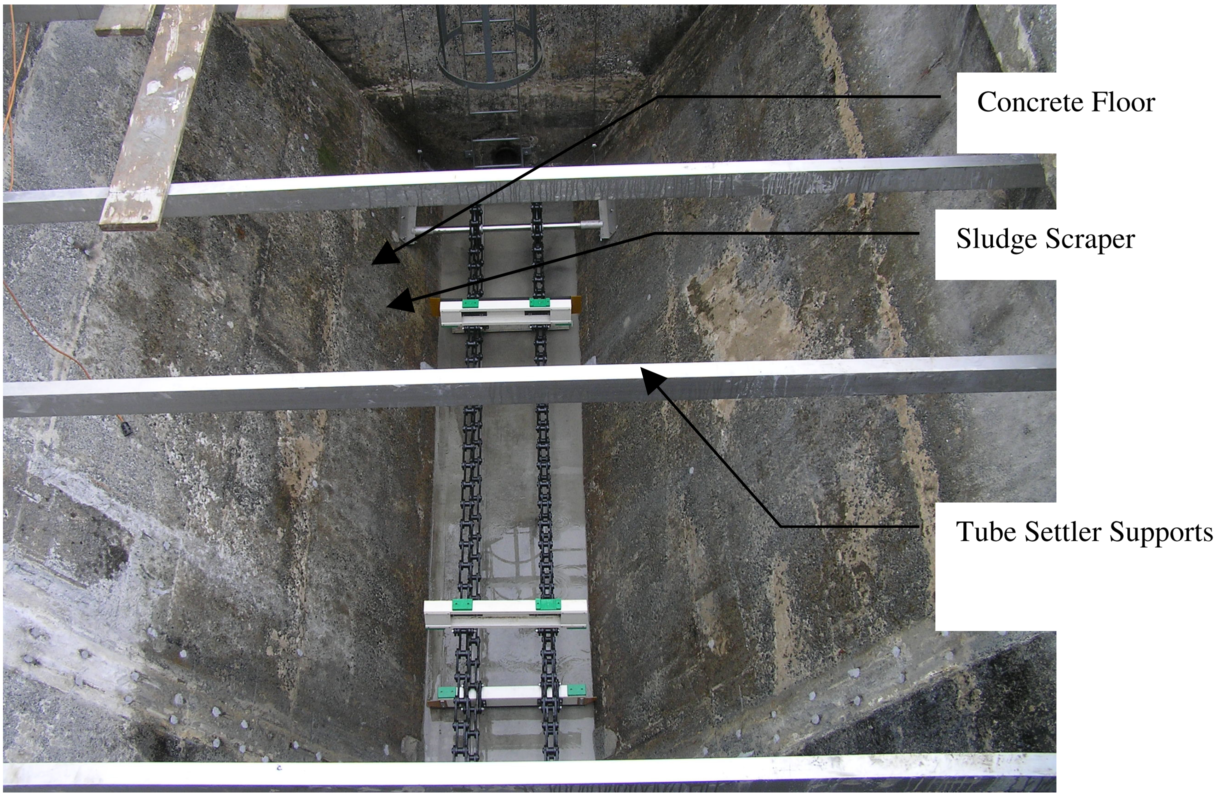
3.3.1 CLARIFIERS

The existing clarifiers had originally been two blanket type clarifiers approximately 11 metres long by 5.5 metres wide. In the early 1990s, one of the clarifiers had been converted into an absorber clarifier by halving the length of the clarifier – with a cast in-situ concrete wall – and installing the necessary mechanical equipment.

Whilst the original blanket clarifier performed well within its design limits, the absorber clarifier did not perform well with turbidities over 20 NTU without constant manual intervention. Both clarifiers were converted in this upgrade to horizontal flow tube settlers.

Photograph 3 – Original Clarifiers

To ensure the plant could continue to treat water during the upgrade, the blanket clarifier was decommissioned and upgraded first, leaving the absorber clarifier to take the full plant flow. The upgrade involved removing all the internals and pouring a concrete base in the bottom of the 'V' of the clarifier (see photo below). A sludge scraper was then installed to scrape the sludge to the inlet end of the clarifier.



Photograph 4 - Clarifier Concrete Floor and Sludge Scraper

Once the first clarifier had been completed and commissioned, the absorber clarifier could be decommissioned and upgraded.

3.3.2 FILTERS

The existing sand filters served as a water tank with a top water level sufficient to drive the clarified water through the pre-screens and into the membrane cells. The only modifications to the filters were removing the old media and installing a new clarified water outlet to the membrane pre-screens. The photo below shows the new outlets and the pre-screens as installed.

Photograph 5 – Membrane Pre-screens

3.4 NEW PLANT AND STRUCTURES

A new building was constructed to house the new membrane plant and the new UV disinfection system. As discussed above, the membrane plant and building was to be built over the sludge/backwash and CIP neutralization tanks. Each of these tanks were about 70 m^3 with a maximum depth of about 1.5 metres. The photo below shows the construction of these tanks. The depth of the tanks is clearly indicated by the men standing inside them.

The new building housed not only the membrane plant (including the CIP chemicals and the UV disinfection) but also the electrical room, control room, locker and shower facilities for the operators, and a meeting room.

The membrane plant is a Memcor submerged membrane plant consisting of three cells, each with 144 membrane modules, and has a capacity of 12.5 Mld output. The feed for the membranes was clarified water from the converted filter tanks via the pre-screens to the membrane cells. The hydraulic head available to drive the water through the screens to the membrane cells was approximately 4.8 metres. This achieved two goals: 1) to refill the membrane cells quickly after backwash; and 2) to provide sufficient head to drive through the pre-screens. This available head was a result of re-using the existing clarifiers and filters to feed the membrane plant installed at grade.

Photograph 6 – Construction of the Sludge/Backwash and CIP Tanks

Photograph 7 – Membrane Cells

3.5 FINAL PLANT COST

The final plant cost inclusive of all internal HDC and external costs was approximately $10.2 million dollars. This cost was within 2% of the preliminary design cost estimate and approximately $3-5million less than the initial concept costs. Again, it highlights the significant savings that can be achieved through thorough concept analysis, which far outweigh the time spent in the optioneering phase.

4 PLANT PERFORMANCE IN EXTREME TURBIDITY

Two of the key requirements of the plant was to produce 12.5 Mld and provide resistance to high turbidity events. Clearly the primary method of achieving this goal is to avoid, as much as possible, those high turbidity events. As described in "King Tides – A Royal Problem", the high turbidity events correspond to periods of low rainfall, high demand, low river levels and a King Tide in the Firth of Thames. The plant was initially commissioned in December 2012 at the start of the drought and continued to run throughout this period.

4.1 EXTREME TURBIDITY EVENT JANUARY 2013

In January 2013, the first King Tide event occurred with turbidity in the river exceeded 1000 NTU. As designed, the raw water pumps on the Waihou River shut down at 500 NTU (the setpoint at the time) and remained off for approximately four hours. Over that time the plant was fed from the raw water tank and the tank level dropped. When the turbidity dropped back under 500 NTU, the raw water pumps restarted at a high rate to replace the water used from the raw water tank in eight hours. The tank was filled as expected. Throughout the entire event, the plant maintained an output of 12.5 Mld. The changeover from gravity to pumped flow at the plant was seamless and the clarified water turbidity never exceeded 1 NTU.

4.2 EXTREME TURBIDITY EVENT FEBRUARY 2013

The second high turbidity event occurred from Monday 11th February to Wednesday 13th February 2013. The predicted tide height in the Firth of Thames was 3.5 metres and the Hauraki District was in the grip of the worst drought for 70 years. Very high turbidities were expected in the Waihou River. As shown in the photograph below, the high tide occurred as predicted and almost submerged the intake structure.

Photograph 8 – Waihou Intake February 2013

4.2.1 FEBRUARY 11TH 2013

The idea of the trial was to challenge the plant with high turbidity. The turbidity rose as expected with the peak turbidity in the river at about 11:00am being about 1200 NTU. The raw water pumps switched off at approximately 10:00 am when the river water turbidity exceeded 700 NTU. The raw water being fed from the raw water tank peaked at about 170 NTU but the trend was severely flattened out as expected by the buffering effect of the raw water tank.

The raw water pumps were restarted at approximately 11:45 am. The level in the raw water tank dropped to a minimum level of 78% from the starting point of 91%. Figure 2 below shows the turbidities into the plant and from the clarifier. What is interesting is that the clarified water turbidity does not vary over this time.

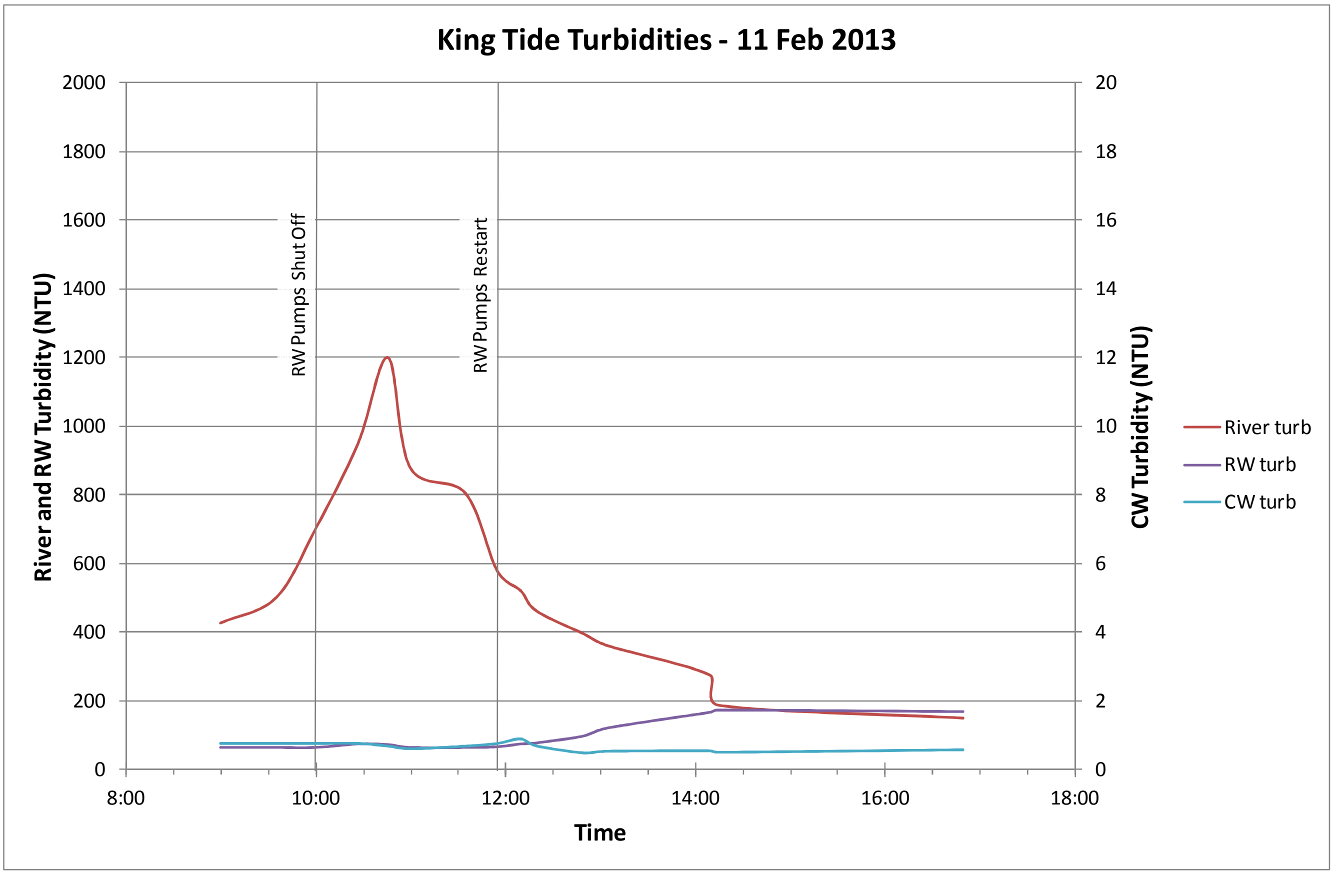


Figure 2 – King Tide Event 11th February 2013

4.2.2 FEBRUARY 12TH 2013

High tide in Auckland was predicted to occur at 09:47am on Tuesday 12th February. Peak turbidity was reached at approximately 11:30 am at the Waihou intake. Given that the previous day, the maximum turbidity recorded into the plant was approximately 170 NTU, the decision was taken to bypass the raw water tank and pump water direct from the river into the plant inlet. Due to the need to be able to desludge the raw water tank, this facility had been programmed into the software. However, the intention had been to use this facility at times when the river was clean and allow the plant to treat river water. It did provide the function that allowed us to put extreme turbidity directly into the plant without filling the Raw Water Storage Tank with high turbidity water.

The decision to by-pass the raw water tank was taken only when it became apparent that the raw water in the storage tank was not likely to exceed the readings of the previous day. In preparation for this bypass, a sample of river water was taken and a jar test performed to select the optimum coagulant level. The Raw Water Storage Tank (RWST) bypass valves were then opened and river water turbidity fed into the plant. The raw water entering the plant peaked at around 925 NTU for a short period. Figure 3 below shows the turbidity results for the day. Again, the clarified water turbidity was not affected.

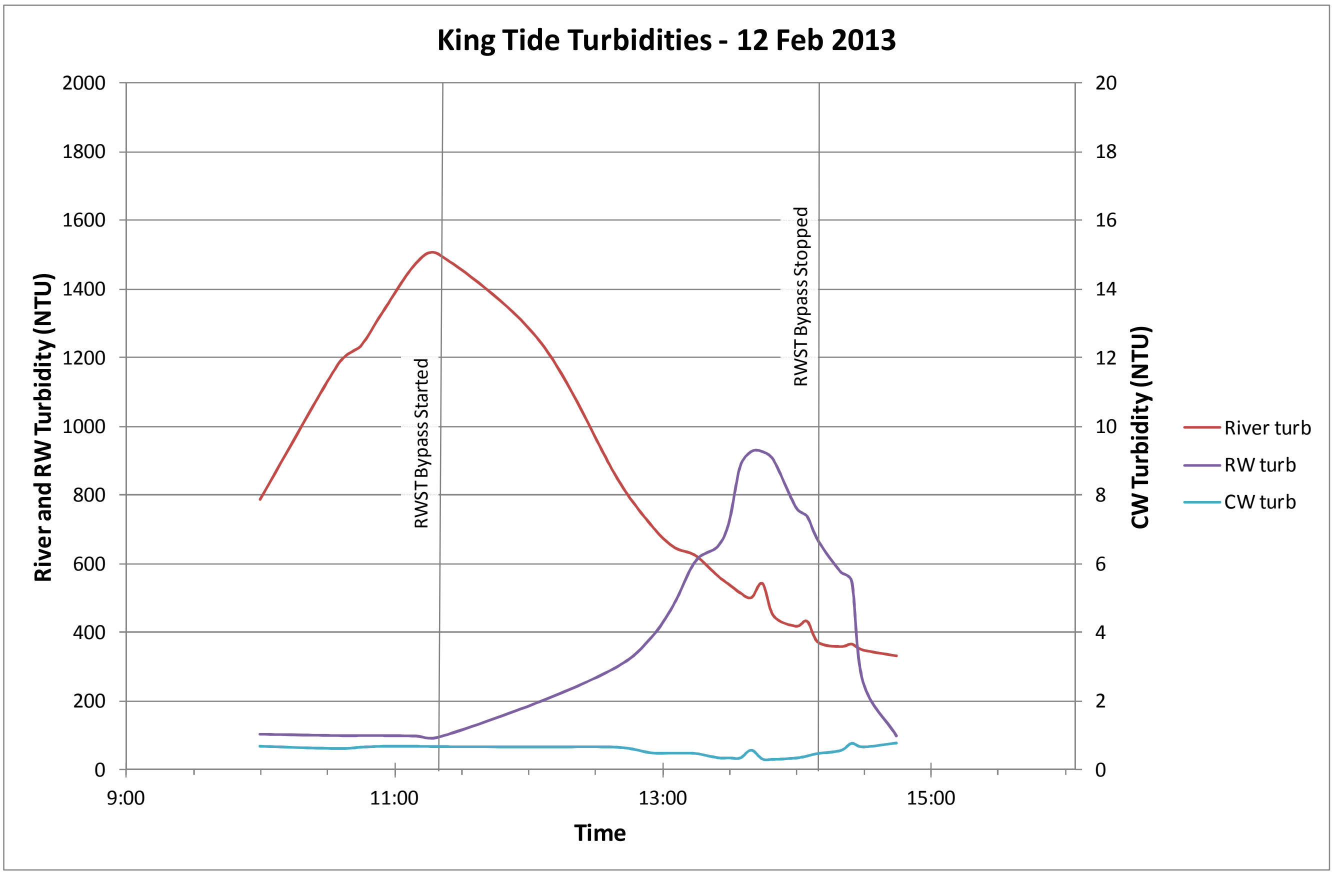


Figure 3 – King Tide Event 12th February 2013

After the success of this trial it was agreed that the Raw Water Storage Tank would be by-passed for the full period of the tidal effect the next day.

4.2.3 FEBRUARY 13TH 2013

High tide on the Wednesday was approximately 10:35 am. By the time the jar testing had been completed, the by-pass was not opened until 11:55am. The graph below shows the turbidity traces from the river, the raw water into the plant and the clarified water turbidity.

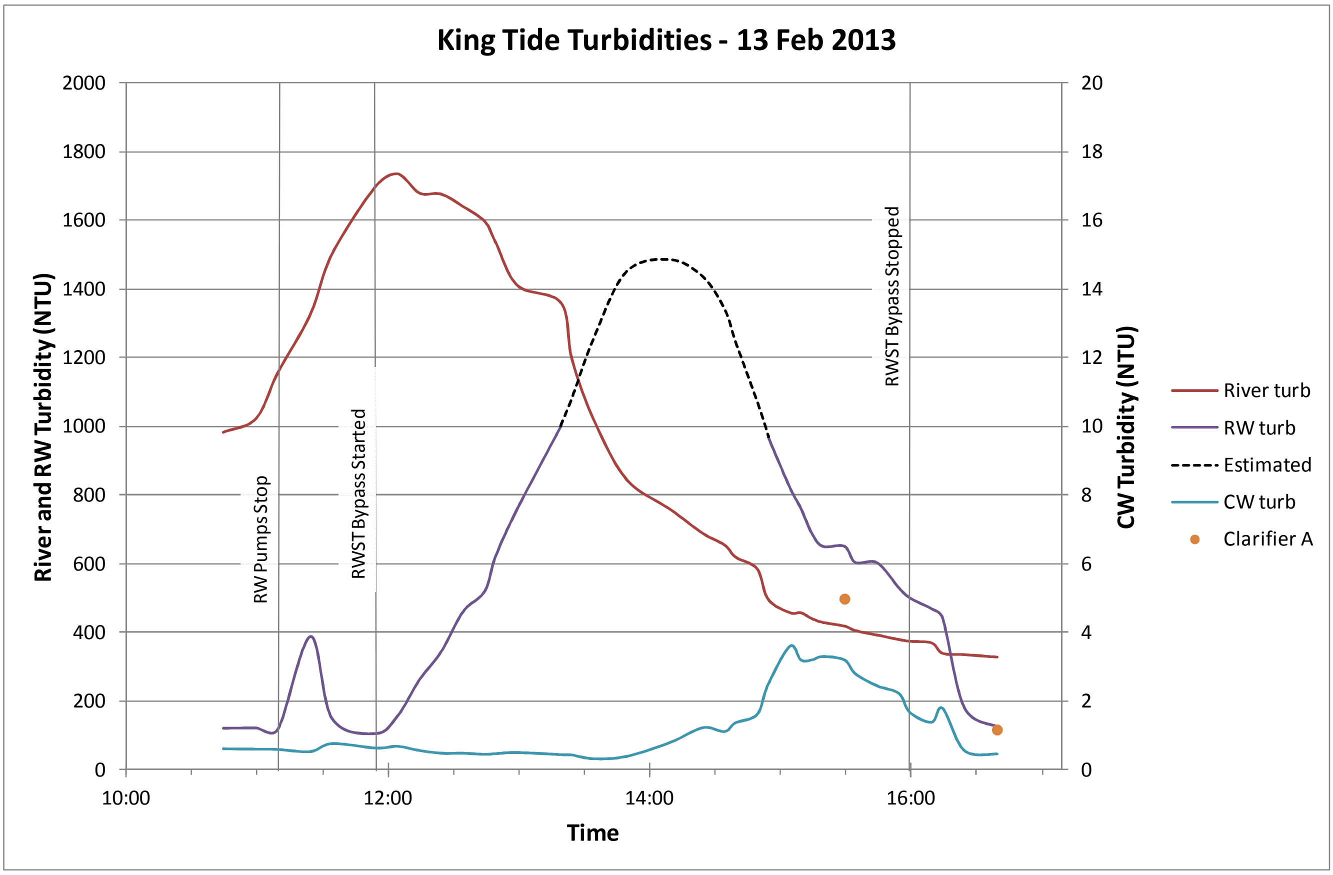


Figure 4 - King Tide Event 13th February 2013

There are a number of interesting areas to address in the graph above. The first is the problem of the raw water turbidity meter at the plant having a range of 0 to 1000 NTU. The dotted line is a best guess at the turbidity that actually came into the plant, estimated at over 1400 NTU. The second issue is the delay between the turbidity reading in the river and the turbidity reading in the plant (in the order of two hours). This can partially be attributed to the transit time in the raw water pipeline which is approximately five kilometres long.

Photograph 9 – Clarifier Inlet February 2013

During this event, the turbidity into the plant exceeded the design inlet conditions of 700 NTU for approximately two hours. The clarified water turbidity was mildly affected and rose to approximately 5 NTU on one of the clarifiers. Given that what was being put into the clarifier was roughly the same as the sludge normally discharged, the ability of the clarifiers to remove the sludge was compromised. The design had been for a certain solids loading and the plant was treating roughly double that amount. Solids were building up in the clarifier despite the frequency of desludges and the duration being increased. It was of interest that at the time of the turbidity spike, sludge was seen by the commissioning engineer coming out the tubes at the far end of the clarifier, possibly indicating that the sludge scraper had been over-loaded and unable to remove the amount of sludge produced in the clarifier sufficiently quickly.

4.2.4 MEMBRANE PLANT PERFORMANCE

During the King Tide event in February, the membrane supplier was on site monitoring the performance of the membrane plant. During the whole period, the membrane plant feed did not exceed 5 NTU from the clarifiers. The report produced by Mason's Engineers says, "After reviewing the Memlog trends for the period between the 10th and 13th Feb, we can see little or no effects of this at the membrane plant".

There was certainly no filtered water turbidity spike and no real change in trans-membrane pressure (TMP). The intention was to challenge the membrane plant with this event but the performance of the upstream processes exceeded expectations to the extent that a turbidity breakthrough of the clarifiers was achieved only so far as 5 NTU – not really a challenge for the membranes.

4.3 PERFORMANCE THROUGHOUT THE 2013 DROUGHT

The plant continued to produce 12.5 Mld throughout the 2013 drought and successfully protected the dairy farming in the Hauraki district against the worst of the drought. Just by producing an additional 3.5 Mld, it has been calculated that this enabled an additional $11.5 million in milk production for the region. This number does not make any allowance for the times when the previous plant would have had to shut down due poor water quality.

5 CONCLUSIONS

There are many areas where this project exceeded expectation. However, there are four key lessons to come from this process.

The first major item of note is the amount of time and effort spent in the examination of options. Clearly this time had a major impact on the duration of the project and at times ideas that seemed unlikely to proceed were pursued. However, it is worth noting that Hauraki District Council has a group of consumers who have been involved in the Plains Water Supply for – in some cases – over 50 years and take a healthy interest in the development of the supply. These consumers want to see the best use of resources and maximisation of the existing asset. As such they need to be convinced that all options, no matter how unlikely, have been investigated and discussed. This investigation of all options provided a capital saving to Council of approximately $3-5 million and a preliminary design estimate to within 2% of the final cost. It is therefore hard to argue with the approach adopted by Council and Harrison Grierson.

The second item is how and when to re-use existing structures and processes. There was a great deal of time spent on looking at re-using the existing filters. The problem with the filters was that they needed significant upgrades (filter to waste, improved backwashing, conversion to flow control, etc) to meet the current standards and best practice for sand filtration. So whilst the filters seemed like a valuable asset, the value of the asset was in the filter shells only. These shells were eventually re-used as membrane feed tanks. In another example, the clarifier shells having a length to width ratio of approximately 2:1 were ideally suited to conversion to tube settlers.

In terms of plant performance, the plant was designed to avoid the extreme turbidity events and has been demonstrated to do so effectively, making up the water in the Raw Water Storage Tank when the turbidity drops very effectively. However, the plant was challenged with an extreme turbidity event and treated the water successfully for the duration of the event. From the data, it could be argued that the plant could not sustain the performance if the event had lasted longer. The major issue that the plant had with extreme turbidity was the removal of sludge from the clarifiers. When the water coming in has the turbidity equal to the normal sludge stream, then continuous desludging may be required. The other major problem was the capacity of the sludge scraper being able to remove the sludge from the far end of the clarifier quickly enough. If the turbidity event had been sustained, the design capacity of the sludge scraper would have had to be increased to cope with the higher solids load. Given that the plant was designed to cope with a peak turbidity of 700 NTU over a series of tides, the plant performed well beyond expectations when more than double that turbidity was taken from the river.

The last major and perhaps most important result of the project and the King Tide testing was that the operators are not only happy with the plant but have confidence in its ability to treat all the possible water qualities in the source water. The resistance to membrane technology is gone and HDC are now actively developing membrane technology upgrades for two further plants, Waihi and Paeroa.

The close co-operation of Hauraki District Council and Harrison Grierson during the Kerepehi WTP optionioneering and design was a long process that:

- Delivered a plant that met the project objectives
    - To provide a reliable and robust plant capable of continuously producing 12.5 Mld of treated water;
    - To make the plant more resistant to high turbidity events; and
    - To comply with the Drinking Water Standards of New Zealand 2005 (revised 2008) and in particular to increase the WTP's disinfection rating to 5 log for protozoa
- Reduced the capital cost of the project by 30%

- Provided water throughout the worst drought in 70 years and enabled an additional $11.5 million of milk production.

- And delivered a plant that the Councillors and ratepayers were proud of.

REFERENCES

Brown, N.; Harrison Grierson (2012). *King Tides – A Royal Problem.* Paper presented at Water New Zealand's Annual Conference, Rotorua, 24 – 28 September, 2012.