REDUNDANCY AND DIVERSITY – WHEN IS ENOUGH ENOUGH?

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ABSTRACT

The redundancy and diversity which is built into Water Treatment Plant (WTP) design varies considerably between provincial and large urban water suppliers. The main drivers are:

- The acceptable level of risk associated with maintaining adequate water supply to the community,
- Meeting the quality required by the Drinking Water Standards of New Zealand and
- Cost

Failure of a critical element of a water treatment plant may compromise either water quality or the provision of an uninterrupted supply. Smaller communities may accept a higher level of risk due to a limit in available funding. Arguably, the consequence of any hazard increases when serving a large population, and decreases for smaller populations thereby changing the level of risk associated with that hazard. Therefore, depending on the way in which consequences are assessed, the risks for a small supplier are lower than for a large supplier.

Large water providers may opt for sophisticated, automated systems with redundancy and diversity which ensure that the water supplied meets quality standards and meets the demand at all times.

A small supplier may opt for a simpler, proven process which has less potential for failure. The system may have significantly less diversity and / or redundancy and the control system may automatically shut down on equipment failure / non-compliance. Although all mechanical and electrical equipment has a risk of failure, the more complex equipment requires much more rigorous testing, both by the manufacturer and during on site commissioning thereby increasing cost. When including redundancy in a design, consideration must be given to a number of factors including equipment failures, how the process will continue to operate while equipment is being maintained, and cost.

In the past, most WTPs used the conventional three stage treatment process comprising coagulation, sedimentation, and filtration. However, there are now a variety of proven technologies which has diversified the equipment available for water suppliers to use. Water suppliers must now consider the diverse treatment options available as well as equipment redundancy and the ever important costs of these when designing a new or upgrading an existing process.

This paper discusses the benefits of building redundancy and diversity into a process in the context of achieving the requirements of the current Drinking Water Standards of New Zealand, including a discussion of how the risks may vary depending on the size and type of population supplied. The design of a medium sized water treatment process which compares conventional three stage treatment and membrane treatment is presented in this paper as a case study.

KEYWORDS

Redundancy, Diversity, Risk, Design, Quality

1 INTRODUCTION

Redundancy and diversity is discussed in this paper in the context of use of processing equipment that enables water to be treated to a quality that is acceptable for human consumption. Equipment redundancy is defined as provision of a set of equipment where there is more than one item that can complete the required duty. For example, a set of two pumps, each of which can provide the maximum design plant flowrate. Equipment diversity is defined as provision of two or more items of equipment that can achieve a specific outcome. For example, both UV disinfection and chlorine disinfection over a required time period will achieve bacterial disinfection.

Globally, potable water standards are set according to the results of research into treatment for removal or inactivation of cryptosporidium, bacteria, and chemical contaminants. The Drinking Water Standards for New Zealand which are aligned with World Health Standards and US Environmental Protection Agency. The requirement for suppliers providing water to populations greater than 500 to have a Public Health Risk Management Plant (PHRMP) was part of the Health (Drinking Water) Amendment Act 2007. The development of the PHRMP is an important part of providing quality potable water. It includes risk assessment of the process from the raw water source through treatment to reticulation operated by that supplier and enables suppliers to objectively analyse the water supply in terms of risks and highlight areas that may require improvement. It is the improvements identified in the PHRMP that require thorough planning and design to ensure that they mitigate the identified risk to a level that is acceptable for the particular water supply.

Maintaining potable water quality is an important objective for a water supplier. However, potable water system improvements must also meet other objectives that a water supplier may have, such as uninterrupted water supply to meet demand, and alignment with the capital works budget available. This is where water suppliers must consider the level of equipment redundancy and diversity in their treatment process, and decide when enough is enough.

2 RISK ASSESSMENT

The PHRMP document includes the results of a risk assessment process which allows water suppliers to identify barriers to contamination of potable water. AS/NZS ISO 31000:2009 Risk management – Principles and guidelines provides information on risk assessment process and is depicted in the diagram below.

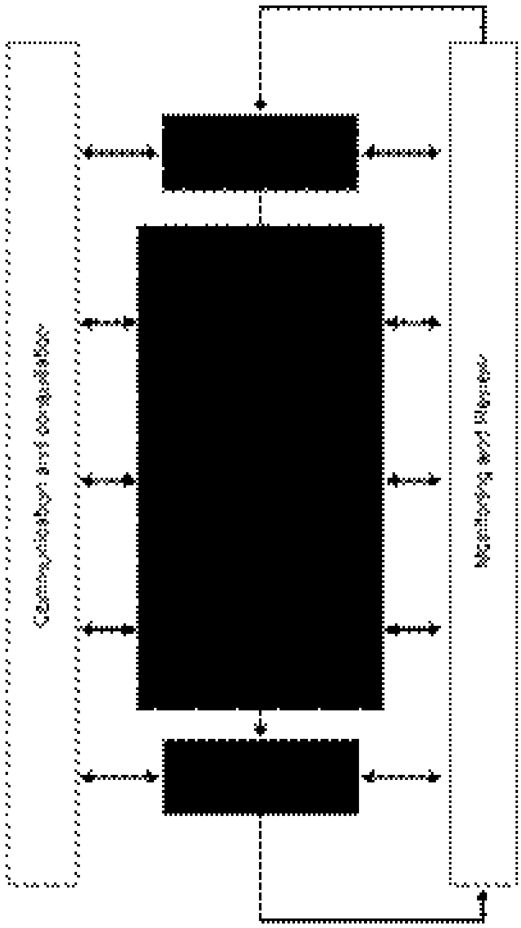

Figure 1: Risk Management Process

In the PHRMP risk assessment process, the context is maintaining water quality to ensure the health of the public that receive the water and is therefore a limited tool in developing the water treatment plant and reticulation system. Water quality is just one of the contexts that needs to be considered by a water supplier when planning and designing a treatment plant upgrade. Outside of the PHRMP requirements, a water supplier may also wish to assess their process in other contexts, for example:

- Maintaining water supply to meet demand
- Minimising operational complexity
- Improvements designed to meet the available budgets

Risk assessments must focus on the context as this will affect identified risk level. Changing the context will affect the results of some parts of the risk assessment. For example, assessment of a process which consists of a shallow bore being supplied directly to reticulation may score low risk in terms of meeting demand but high risk on water quality as there are no barriers for contaminants between source and supply to the public. The supplier must then decide whether the risk needs to be reduced and this can be done with the budgets they have available.

3 TREATMENT FOR WATER QUALITY

Large municipal water suppliers and small rural water suppliers must each meet the same standards for water quality – the Drinking Water Standards for New Zealand 2005 (revised 2008) (referred to as DWSNZ) as these provide the framework for best practice levels of treatment of potable water. Although the DWSNZ have slightly different requirements depending on the population supplied; these requirements are largely associated with monitoring. The requirements for providing barriers to contaminants depend on the water source and not the population supplied.

Water from secure bores requires minimal treatment and therefore minimal capital expenditure for process equipment. However, surface water abstracted from a catchment which is surrounded by farmland will require maximum barriers to contaminants. This results in high capital expenditure required for processing equipment and is required regardless of the water supplier's size. A small water supplier is likely to have much less capital available for installation of new equipment and for the operation and maintenance required for that equipment on an ongoing basis, than a large water supplier.

In practice, the cost of a water treatment plant cannot be scaled proportionally to the population served. This is because the pricing of equipment, pumps, valves, pipework, buildings and other elements required to make-up a water treatment plant includes an economy of scale. In addition, small water treatment plants are often located in rural areas. The cost of equipment delivery and construction tend to be higher due to travel distances. In order to reduce costs but ensure water quality, a small water supplier may compromise equipment redundancy.

4 WATER SUPPLY

4.1 DEMAND AND EQUIPMENT REDUNDANCY

Water suppliers may assign a high priority to consistently maintaining water supply volumes to meet demand. If budget is available, a water supplier may choose to have complete redundancy throughout the water treatment process. This will ensure that if one item of equipment fails, there will always be a backup available.

Small water suppliers with small budgets may need to make tough decisions on level of redundancy as this will always affect capital cost. For example; a UV disinfection unit may be installed as part of the water treatment process. In order to provide some redundancy, two UV units could be installed each sized for 50% of maximum required water treatment plant flowrate and operated as duty/assist. The risk is then that in the event of a failure of one unit, the water treatment plant is then limited to 50% of maximum plant flow (i.e. the flow that can be treated through one UV unit).

A larger water supplier may consider that this risk to maintaining water supply volume is not acceptable and could choose to install either three 50% UV units operated as duty/assist/standby or two 100% units operated as duty/standby. Thus if one unit fails, maximum production can still be maintained.

The redundancy selected for each part of the water treatment plant process will be dependent on the criticality, cost, and reliability of that item of equipment. For example, a coagulant dosing pump is normally relatively inexpensive but if it fails, has a significant impact on the water treatment process. Therefore, even a small water supplier may choose to have duty/standby pumps installed for this service.

4.2 OPERATIONAL COMPLEXITY

There is diverse range of technologies available in the market today which presents a challenge to water supplier when selecting the appropriate equipment for their water treatment plant. When designing a new process for water treatment, the water supplier must consider a number of factors which affect the equipment selection. Factors may include:

- Operator's skill level and knowledge of the equipment
- Local maintenance support available for the equipment
- Required routine operational and maintenance tasks
- Track record of the equipment supplier and the particular model of equipment
- Specifying equipment that is already owned and operated by the water supplier at other facilities

The equipment selection must be based on an analysis of the benefits it provides against the risks. Capital and operating costs are usually a significant contributing factor in this analysis, as well as the operator's familiarity with the equipment. This is specifically important where a water supplier may have one or two operators that operate a number of small facilities. It can be much easier and less risky for that operator to work with a standard set of equipment at each facility.

5 WATER TREATMENT CASE STUDY

This case study is for a medium sized water treatment plant. The plant was designed to produce up to a maximum of 12.5MLD of treated water. The raw water is abstracted from a river which is in a farm area and it has been identified that five protozoa log credits are required to ensure public health.

In this case study, the raw water source is particularly susceptible to high turbidity events. Therefore, the treatment process must be capable of treating water with very high levels of turbidity. The existing process train was not able to achieve the log credits required given the highly turbid raw water available. In some cases, a water supplier may have the luxury of considering an alternative water source and this may prove to be the simplest and least expensive option. However, development of a new water source can be expensive and in some cases impossible.

Two process options which achieve at least 5 protozoa log credits were assessed:

1. Flocculation, clarification, gravity sand filtration, and UV disinfection (up to 7 credits total)

   This option includes a flash mixer, three stage flocculation, two clarifiers, three sand filters, two 50% UV units and chlorine disinfection.

2. Flocculation, clarification, membrane filtration and UV disinfection (7 credits total)

   This option includes a flash mixer, three stage flocculation, two clarifiers, three sand membrane cells, two 50% UV units and chlorine disinfection.

Photograph 1: Submerged Membrane Cells

Photograph 2: Conventional 3 Stage Water Treatment

In both options, the capacity of the main process equipment was designed to exactly match the maximum required treated water flowrate. This was done to minimize capital costs for this water supplier. However, if one item of equipment fails, the water production rate will have to be reduced. With this limit to redundancy it is necessary to ensure that a proven process with low risk of failure is selected.

The options were assessed based on cost, advantages and disadvantages. The results of this analysis are provided in table 1.

Table 1: Process Option Comparison Summary

	Option 1	Option 2
Capital Cost[2]	$11.6	$10.0
Annualised O&M Cost[2]	$6.6	$7.3
Net Present Value (20 yrs)[1,2]	$18.2	$17.3
Advantages	• Lower operating and maintenance cost • Quality water will be produced at full plant capacity (12.5MLD) when turbidities are high • The WTP will achieve 6 protozoa log credits (5 log required) • Proven technology • Operators familiar with the process equipment	• Lower capital cost • Quality water will be produced at full plant capacity (12.5MLD) when turbidities are high • The WTP will achieve 7 protozoa log credits (5 log required) • Proven technology
Disadvantages	• Higher capital cost • Higher 20year NPV	• Higher operating and maintenance cost • Higher operator input required (e.g. pinning membranes) • Operators unfamiliar with the process equipment
Notes: 1. The above NPV figures are based on a 20 years period with 2% annual inflation rate and 8% annual discount rate. 2. The figures are all stated in millions of dollars.		

The costs presented in table 1, are based on the specific raw water source, site location, ground conditions, constraints from surrounding buildings, available land, and operational requirements. Therefore, the costs will vary from site to site.

Although each option comes with a cost, advantages and disadvantages, there is very little difference between the options. Both options consist of proven technologies that are recognised in the DWSNZ. The decision will ultimately be based on the water supplier's preference as neither process is clearly superior.

6 DISINFECTION CASE STUDY

Disinfection is important at the end of a water treatment process and also within the reticulation system. It is also a requirement of the DWSNZ to ensure that bacterial compliance criteria are met and disinfection is one method of achieving this. There are a variety of equipment installations around New Zealand which each have a different level of redundancy built into the design. A water supplier that places a high risk on meeting demand may require a high level of redundancy in the disinfection equipment. Two alternative designs using chlorine disinfection are detailed below:

1. Two complete sets of chlorination equipment, each includes - duty/standby water booster pumps, injector, and chlorinator. If chlorination fails when one set is operating, the control system is setup to automatically start the other set. As an additional backup, a gravity water system is connected to the injector in case all booster pumps fail.
2. One set of chlorination equipment consisting of duty/standby booster pump set, injector and chlorinator. If chlorination fails, the control system is setup to automatically shutdown the plant.

Option 1 provides redundancy with the two sets of identical equipment systems, but it also provides some diversity with the alternative booster water available. This system has a much lower risk of complete failure than option 2. As long as at least one of the systems is operational, water demand and bacterial disinfection will be achieved.

Option 2 can be reasonably robust if equipment is purchased from reputable suppliers and regularly maintained. However, the risk of failure is much higher than for option 1 as the only redundancy is the one set of duty/standby booster pumps. If equipment fails, the plant will be shutdown and demand may not be maintained until the equipment is fixed. If the demand is such that the operator is forced to run the treatment plant without disinfection, water quality will not be maintained. In either scenario, there is a risk for the water supplier.

Obviously, option 1 will be more expensive than option 2 and a water supplier must decide what level of risk is appropriate for their system, and what level of redundancy and diversity can be achieved with their set budget.

7 REDUNDANCY AND DIVERSITY

The ultimate redundancy and diversity in a water supply includes two or more completely separate water treatment plants which take water from different sources, using different treatment processes, and either can be shutdown while the other can still supply the required demand. This is an ideal situation as many of the biggest risks to the water supply are minimized in this scenario. Risks such as raw water source contamination and treatment process failure are reduced as there is a completely separate raw water treatment process that can still supply water into the reticulation network. Many of New Zealand's larger cities have a water supply that is set-up in this way, but it is not usually realistic for smaller communities. This is because although smaller water suppliers could setup their systems in this way, economies of scale normally prevail and one large water treatment facility is designed and installed rather than a number of smaller independent facilities.

Smaller water suppliers must assess their raw water source, treatment process and reticulation to decide where the most significant risks are. Improvements can then be made systematically to the highest risk items as funding is available. Careful equipment selection is required to ensure value for money. Redundancy and diversity can only be built into the system where this can be specifically justified by a high risk item or available funding.

7.1 FUTURE PROOFING

Designing upgrades to treatment plants involves careful planning for future requirements. A new or upgraded facility can be designed such that it is possible to retrofit easily in future is adequate consideration is given to whether future improvement in redundancy and diversity, or an increase in plant capacity is planned. For example, increasing the size of the membrane building and including a tie-in point so that additional cells can easily be added at a later date. Although this will increase the cost of the building slightly, it will significantly reduce upgrade costs in future.

8 CONCLUSIONS

Water suppliers must make their own informed decisions on processing equipment redundancy and diversity and when enough is enough. The level of redundancy considered appropriate for one water supplier, may not be appropriate for another. The decision is best made after a risk assessment with a well-defined context. This risk assessment will produce a list of risks rated low to high and usually the highest risk items receive the highest priority within the improvement programme. Water suppliers must ensure that they not only maintain water quality, but also maintain demand, ensure good operability, and meet the set budget.

Available budget must be considered when planning and designing improvements, as no work can be implemented without the appropriate funding. Once the available budget is confirmed, a decision can be made about the processing equipment redundancy and diversity to be built into the improvement. There are always a number of options that can be considered when developing the design of the improvement item. Each option must be considered with specific benefits and risks that are relevant to the water supplier.

Appropriate planning is also necessary for future improvements of a treatment plant. Future equipment installations may be necessary due to increasing demand or tighter quality requirements. Allowing space on the site and including carefully planned tie-in points make future improvements and retrofits easier and more cost effective.

REFERENCES

Drinking Water Standards for New Zealand 2005 (Revised 2008)

AS/NZS ISO 31000:2009 Risk Management – Principles and guidelines