water e-journal
Online Journal of the Australian Water Association
ISSN 2206-1991
Volume 3 No 3 2018
https://doi.org/10.21139/wej.2018.028

A NEW APPROACH TO ASSESSING WATER QUALITY RISK

A visual tool combining best practice operations and health based targets

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ABSTRACT

The risk of microbial contamination is something all water utilities must face, and it is critical that measures are in place to quantify and mitigate this risk. Traditionally however these measures haven't necessarily involved a holistic view from catchments to tap with respect to, infrastructure adequacy, operational and managerial practice or on a business wide level. In response, TasWater has developed a robust model which allows for the assessment and management of water quality risk in all systems. A visual water quality risk assessment tool was developed that combines the Manual for the Application of Heath-Based Treatment Targets (HBT) (WSAA) and the operational practices outlined in the Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk (WRA) (GPG). Assessments took weighted scores from the GPG to provide a percent compliance with industry standard operational practices, and also compared the treatment adequacy of each treatment barrier against catchment LRV requirements of the HBT. The results of these assessments have been plotted onto a single chart to allow for visualisation and prioritisation of water quality risk reduction activities across all 51 of TasWater's potable drinking water systems. This has allowed for the development of efficient programs of operational improvements and capital upgrades to reduce risk to consumers.

KEYWORDS

Risk reduction, prioritisation, visibility, improvement, drinking water quality, Health Based Targets (HBT), Log Removal Value (LRV), pathogen, water treatment, treatment optimisation.

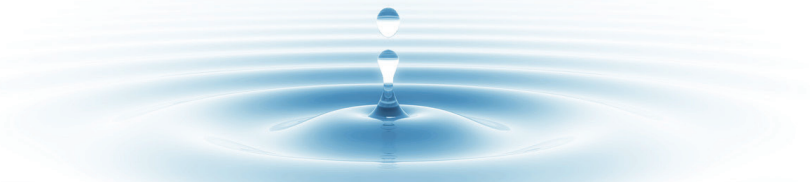
INTRODUCTION

TasWater is Tasmania's sole water and sewage utility, currently operating 51 (prior to August 18) potable drinking water systems state wide. As a legacy of operating as three separate utilities prior to 2013 with different operational standards, these systems vary considerably in complexity, and have inconsistent application of their quality targets and management practices.

Furthermore with a revenue base of approximately 200,000 connections, TasWater faces unique budgetary and cultural challenges compared to its interstate peers. Consequently the business required a robust model to prioritise and focus water quality improvement projects.

Water quality risk management has traditionally been based on a retrospective review of sampling results (lag indicators). Simply monitoring *E.coli* in the distribution network cannot prevent a water quality event from occurring, and only allows a water utility to respond reactively to events that have already occurred.

The current management framework outlined in the Australian Drinking Water Guidelines (ADWG) advocates a proactive methodology to water



quality risk management. In principle this involves understanding the water quality risks profile, establishing multiple barriers, and monitoring their performance in real time (lead indicators).

The two principle factors driving an elevated risk profile in TasWater's water treatment plants currently are:

- An insufficient level of treatment barriers to mitigated catchment risk
- Poor operation or performance of our current treatment barriers.

Understanding and quantifying these risks are critical to effective prioritisation.

To drive a cultural step change and a shift in drinking water quality focus, TasWater has developed a visual approach to assessing its water quality risk profile. This was achieved through an amalgamation of two pieces of industry recognised methodology.

1. The "Manual for the Application of Health-Based Treatment Targets" (HBT), Water Services Association of Australia, (2015)
2. The "Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk" (GPG), Water Research Australia, (*Mosse & Murray*, 2015).

METHOD

Prior to this study TasWater typically based strategic water quality improvement projects on compliance sampling and historic performance. The objective was to deliver a methodology capable of comparing and prioritising water quality risk across all potable drinking water systems. The primary driver of this program came from a need to reduce water quality risk, improve regulatory performance and find productivity savings. In addition it was designed to provide a framework capable of tracking improvement and optimisation gains, and thus demonstrate prudent return on investment.

To deliver the program a multidisciplinary team was established consisting of engineers, senior operators and scientists. The study involved comprehensive system assessments against the requirements of the HBT manual and the operational objectives outlined in the GPG. This provided a holistic view of water quality risk highlighting deficiencies in both operational practices as well as the adequacy of existing treatment barriers. By adopting these methods, systems, regardless of catchment, process complexity or size could be compared on a like-for-like basis.

The outcome from the assessment phase was the development of the Galaxy Chart (Figure 1) which is capable of delivering critical information at all levels of the business.

Phase 1: Assessment

In order to collect the necessary data set, a rapid assessment phase was conducted of all treatment plants across the state from February 2017 to June 2017.

The rapid assessment phase primarily focussed on the water treatment stage of the water system. Catchment reviews had previously been undertaken and the findings adopted for this study. Additionally, due to the scale and complexity of some reticulation systems, and the time constraints on each assessment, the distribution side of the systems was not studied in as much detail as the treatment stage.

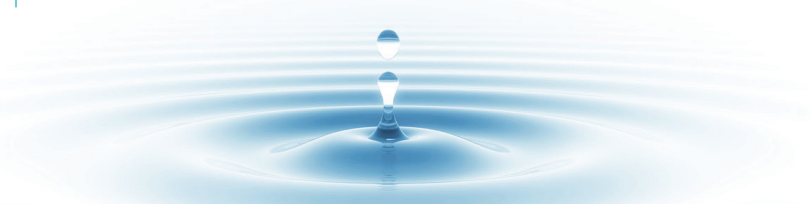
Health Based Targets Assessment – Treatment Adequacy

The HBT manual was adopted as a method to assess the performance, effectiveness and suitability of a water treatment process against the catchment water quality objectives. The manual outlines the treatment and performance requirements, and provides a framework to assess a drinking water system.

As a prerequisite the HBT manual requires that a catchment assessment and risk classification be conducted for every system. TasWater had already completed this step and this informed the basis of the assessment process. As anticipated for surface water supplies, the majority of TasWater's systems fell within the HBT type 3 or 4 classification thus requiring significant, multi barrier treatment to fully mitigate the pathogen risk.

By now comparing the catchment classifications and assessment findings, the outcomes could demonstrate the log surplus or deficit of a system. To do this several other factors needed to be considered including:

- Catchment pathogen LRV removal requirement (from the HBT);
- At least 12 months of SCADA and operational data;
- Operator observations;
- Compliance sampling; and
- Any control measures onsite that could prevent contamination due to ineffective unit processes (i.e. filter to waste post backwash or during breakthrough periods).



The culmination of this information is presented as an example in Table 1. The most unfavourable LRV balance (Protozoa -2.5 in the example) formed the x-axis data point of the chart which loosely represents the impact of the risk.

Where treatment barriers were found to narrowly miss the HBT targets a secondary set of guidelines (stretch targets) adapted from Xagoraraki, et al (2004) were used to assign partial LRV credits. This would later prove critical in differentiating systems requiring optimisation as opposed to systems missing critical treatment barriers, and would be fundamental in visualising CAPEX or OPEX improvement strategies.

Item	Detail				LRV Balance	Comments
Water Quality Objectives (LRV reduction Required)	Bacteria = **5**; Protozoa = **3.5**; Virus = **4**					Type 3 catchment classification
Theoretical maximum LRV credits from current plant barriers		**Coag/Floc/Filtration**	**Cl**	**Total**		Total LRV achievable assuming optimum plant operations and compliance with HBT manual.
	Bacteria	2	4	6	**1**	
	Protozoa	3	0	3	**-0.5**	
	Virus	2	4	6	**2**	
Actual LRV being achieved from plant		**Coag/Floc/Filtration**	**Cl**	**Total**		Filter compliance not achieving HBT performance targets. Combined filter turbidity 95% < 0.8NTU max 0.95NTU. Partial LRV credits applied.
	Bacteria	1	4	5	**0**	
	Protozoa	1	0	1	**-2.5**	
	Virus	1	4	5	**1**	

Table 1: Example LRV assessment

The Good Practice Guide – Operational Practices

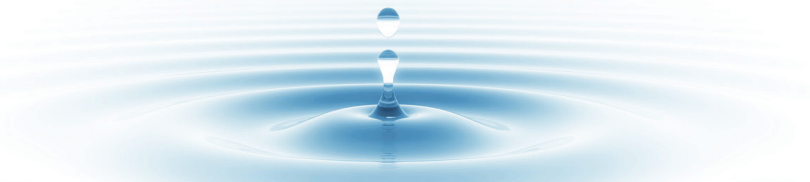
The GPG assessment was chosen for the study as it represented an accepted benchmark for management and operational industry best practices. The requirements outlined in the guide were adapted into a simple pass/fail questionnaire, with score weighting attributed to the identified criticality. In the manual, these are represented by a red-amber-green colour coding system reflecting most critical to least critical. The applied weightings are outlined in Table 2. The assessment questionnaire consisted of 146 questions divided across 13 aspects of treatment. These categories, including the weighted criticality and maximum possible score, are given in Table 3.

Only the categories applicable to the individual system were assessed and thus a final score against the maximum available score was established and used to give a percent compliance. This figure represents the Galaxy Chart y-axis data point.

This score roughly outlined the likelihood of deterioration of water quality. The benefit of adopting this methodology is that factors critical to ensuring water quality are given more impact and improvements focussing on these will have a larger impact on the operation and risk of the system.

Criticality	Weighting (points)
Required (red)	5
Supporting (amber)	3
Desirable (green)	1

Table 2: Weighting attributed to table entries in the GPG



Category	No. of Required	No. of Supporting	No. of Desirable	Total Possible Score
Raw water extraction and storage	1	4	1	18
Supernatant return	2	2	0	16
Coagulation	5	6	1	44
Flocculation	0	5	1	16
Clarification/DAF	2	5	0	25
Media filtration	15	8	1	100
UV disinfection	4	0	0	20
Membrane filtration	10	3	2	61
Chlorine-based primary disinfection	3	3	0	24
Distribution system	7	4	4	51
Water quality information management	7	2	0	41
General water treatment plant operations	4	13	5	64
Equipment and instrumentation	11	4	1	68

Table 3: GPG questionnaire categories and total possible score

Phase 2: Building the Galaxy Chart

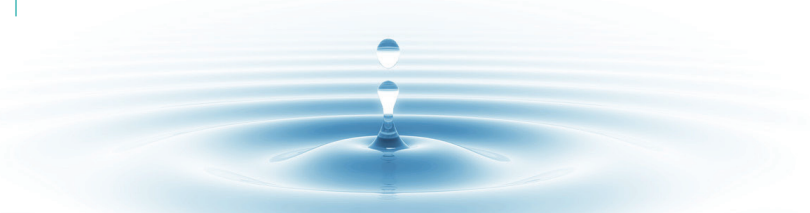
The Galaxy Chart is simply a scatter plot where:

- The y-axis represents the percentage score from the assessment method developed from the GPG;
- The x-axis represents the most unfavourable LRV balance from the catchment requirements and treatment performance HBT assessments;
- The shaded regions represent regions of risk. The boundaries along the x-axis were adopted from the Water Safety Continuum risk regions (as outlined in the HBT manual, -1.25 log and -2.25 log), and the boundaries along the y-axis were defined from internal benchmarking using the GPG scores (50% and 75%); and
- The size of each system point indicates the relative number of connections in a given system. The scale is logarithmic so larger systems do not obscure the graph.

The benefit of adopting this simplistic view is that it can convey an extensive range of information to a broad range of personnel. Executives and management can view the chart from a holistic point of view and gauge the status and requirements of their assets. Regional managers and operators can look at their individual systems and understand their systems strengths and shortfalls to help focus operational effort. Engineers, scientists and technical staff can use the chart to gain either a general or focused perspective of systems, aiding in the development of state-wide and individual system improvements and plans.

RESULTS

The assessment of the GPG and HBT culminated in an extensive data set outlining water quality risk. This results is visualised in Figure 1.



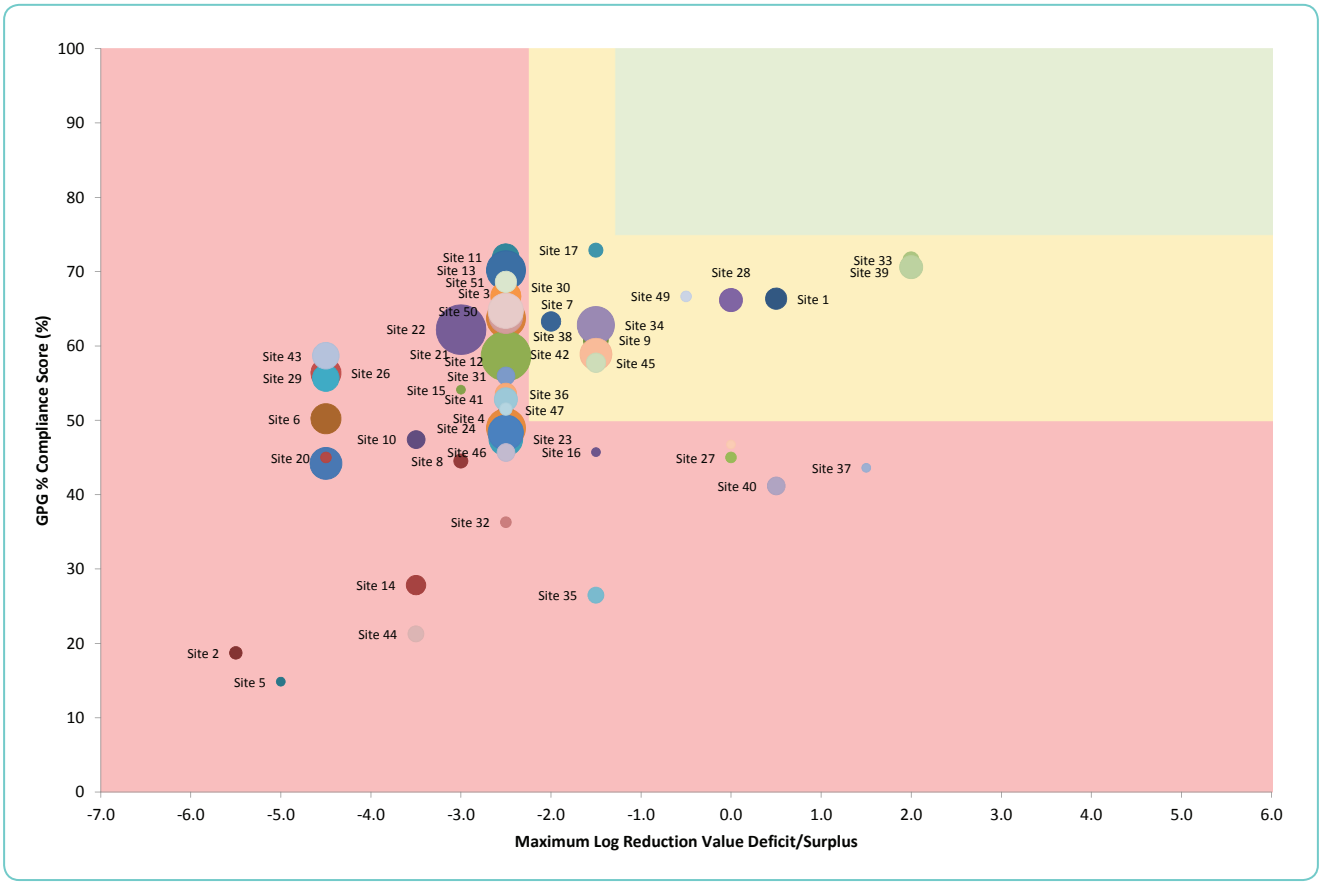


Figure 1: The Galaxy Chart. A visual representation of water quality risk in Tasmania's drinking water systems

In this example, a clear deficiency is evident in two-thirds of the systems (those in the red region). Whilst some may see this as a critical failing, it is worth considering that this risk assessment essential adopts a new set of guidelines and standards. Whereas previously water treatment compliance was based on compliance sampling (i.e. *E.coli* testing), this method takes a more proactive, cautions approach, redefining the needs of treatment.

For example, conventional treatment for decades dominated the process in Tasmania. Coagulation, flocculation, DAF/clarification, filtration and chlorination were the norm. However under the HBT guidelines, this previous standard is insufficient and future efforts to fully mitigate catchment microbial requirements may require additional barriers (e.g. ultraviolet disinfection).

Figure 1 also illustrates this new standard. Sites 33 and 39 are two recently upgraded sites which surpass the new HBT requirements.

DISCUSSION

The Galaxy Chart has been widely adopted by the business and is now beginning to help inform the strategic direction of TasWater's long-term capital plan. More importantly the chart can be used to prioritise improvement projects, plot returns from improvement projects, highlight CAPEX and OPEX requirements, and present individual system improvement plans to move to a tolerable region of risk.

Further outcomes of the tool include:

- Microbiological risk comparison irrespective of system complexity, size, or source water type;
- Strategic prioritisation and focus of CAPEX and OPEX budgets;
- A defendable framework based on industry recognised methodologies;
- Planning and prioritisation for improvement projects and programs;

› Tracking optimisation gains and demonstrating return on investment; and

› A visual training aid for driving cultural change through understanding of the treatment water quality targets and performance goals.

System Prioritisation

One advantage of this assessment is that the data gathered is objective, and can be easily used to assist in outlining a prioritisation. Simply, a multi criteria analysis (MCA) was undertaken to do this for TasWater's systems. System prioritisation is based on three criteria:

1. The severity of the LRV deficit – the lower the score, the more points are attainable (i.e. the higher the priority);
2. The severity of the system performance – the lower the score, the more points are attainable (i.e. the higher the priority); and
3. The potential for LRV improvement – if a system can be optimised from say -5.5LRV to -3LRV without the need for additional barriers (UV), then the larger the potential improvement, the more points are attainable (i.e. the higher the priority).

Figure 2 illustrates the prioritised results. The most critical sites are the highest ranked (on the right hand side of the graph). A sensitivity analysis of the MCA in this example was also undertaken by conducting several trials, changing the impact of each criteria. In turn, the min/max range (cyan bars) and average range (grey dashed line) of each system is shown.

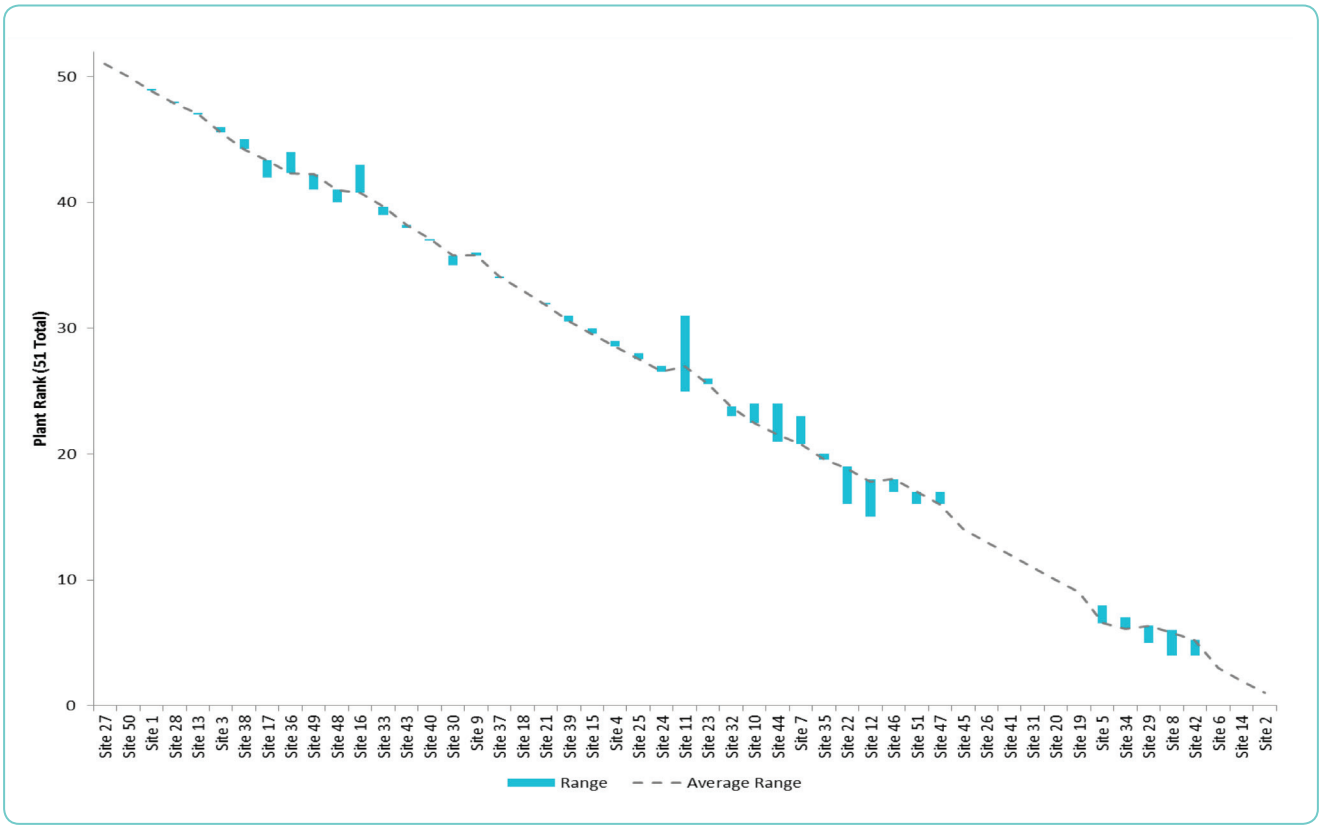


Figure 2: System prioritisation based on assessment data.

Whilst Figure 2 illustrates some variation amongst systems, overall the consensus shows minimal disagreement between trials indicating that the MCA is not overly-sensitive and confidence in the adopted prioritisation is high. By comparing it to Figure 1, those systems which are critically prioritised, are the same systems in the bottom left of the Galaxy Chart. This provides further confidence that the most in-need systems are prioritised.

OPEX vs CAPEX: Project Planning

The chart provides a valuable tool to understanding the capital and operational investment required to reduce the current risk. This is made possible by leveraging off the two assessments that create the chart.

In general to improve the GPG score (y-axis uplift) some OPEX and minor CAPEX is required. Improving or implementing operational procedures such as daily monitoring and trending, online monitoring, alarming and procedures (i.e. jar testing) will add more passes to the GPG assessment, thereby increasing compliance and shifting the percentage up.

Major CAPEX investments, such as major process upgrades or additional process units will typically shift the points to the right (x-axis uplift) as additional LRV credits are gained. It is however also possible to achieve minor improvements on this axis via OPEX by optimising existing treatment processes (for example improving filtered water turbidity by refurbishing a filter with new media). A combination of both will move the points closer to the top right (lowest risk) region of the graph. This is illustrated in Figure 3.

With a strong understanding of the CAPEX and OPEX requirements of each system, it was then possible to group systems according to common strategies or work plans to reduce risk. This gives an indication of the nature of work needed and systems to address upfront as a priority. The groupings that emerged are described below and illustrated in Figure 4.

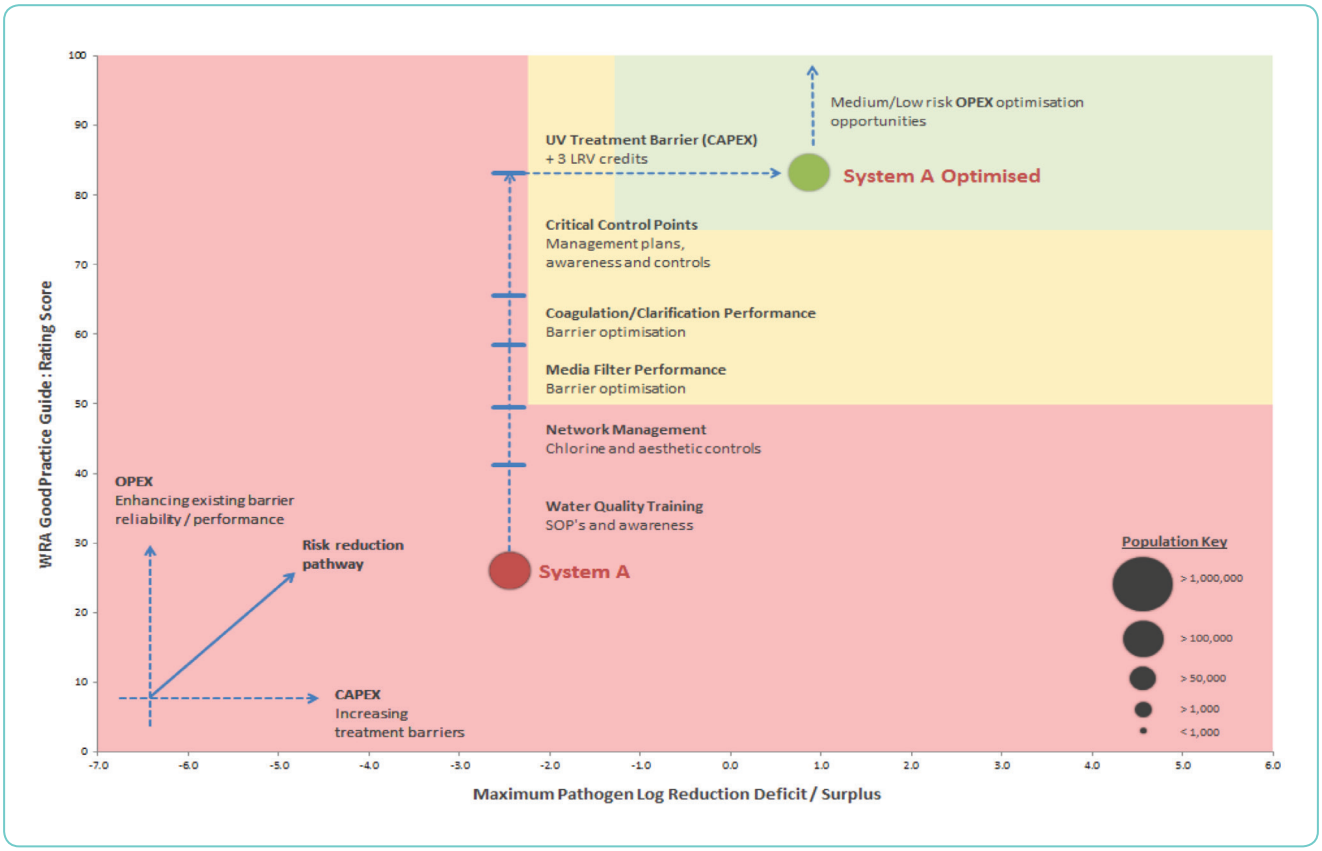


Figure 3: Impact of OPEX vs CAPEX improvements

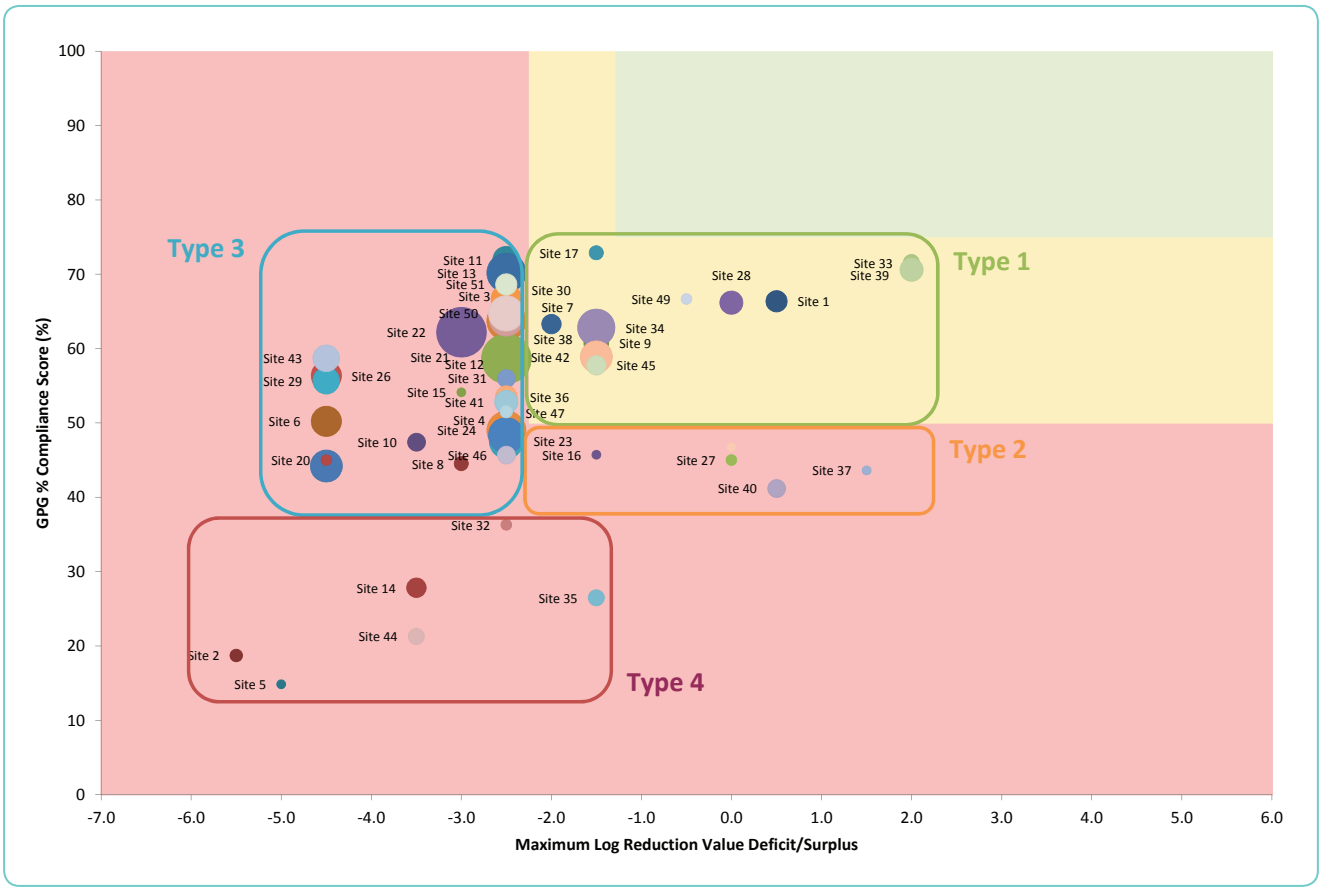


Figure 4: System grouping on the Galaxy Chart

- **Type 1** systems are characterised as not requiring any immediate work. They currently reside in a tolerable risk region. A future program will review the risk profiles of these systems.
- **Type 2** systems are characterised as systems with barriers not currently meeting acceptable standards (HBT manual). Therefore they only received partial or no LRV credits. These systems typically require process optimisation and minor operational improvement in regard to the GPG.
- **Type 3** systems are characterised as having insufficient barriers to mitigate the catchment classification LRV assignment and/or requiring only minor GPG improvement. The barriers installed at these plants are operating as required. A program of UV installation has been prioritised for some systems in this classification.
- **Type 4** systems are TasWater's most at risk systems. The risk profile of these systems cannot be adequately reduced without both significant operational intervention and major CAPEX upgrades.

Individual System Improvement Project Pathways

Due to the fact that the GPG assessment is conveniently divided into individual treatment process steps, it is possible to determine and even model the improvement outcomes (y-axis) from implementing different projects or strategies. This was achieved by simply reviewing the current GPG pass/fail score of a system and implementing a new theoretical score, based on the successful completion of a proposed project.

This process also applies to improvement projects targeting LRV improvements (x-axis) by simply reassessing the theoretical LRV score post project completion.

Through an understanding of individual systems improvement needs and armed with a model to predict the improvement outcomes it was therefore possible to plot a CAPEX and OPEX pathway to sufficiently mitigate the risk. This is illustrated in Figure 3.

On an individual scale, a high level CAPEX / OPEX estimation could now be assigned to each system's improvement pathway.

State-Wide Programs

The chart also allowed TasWater to appreciate the value of larger state-wide improvement programs, such as Critical Control Point (CCP) methodology or UV implementation. These programs will target a utility wide step change, and it was possible to plot the outcome on the chart. This represents a valuable high level strategical planning tool and adds weight and context at the business case phase.

Finally an unanticipated application was discovered as TasWater seeks to embed a critical control point culture into WTP operations. The plot provided a valuable visual training tool and assisted in the understanding of HBT performance targets.

CONCLUSION

The visual risk assessment tool (Galaxy Chart) was developed to quantify and visualise the risk in all of TasWater's potable water systems. By combining two assessment methodologies adapted from the GPG and HBT manual, the assessment provided a holistic risk review, taking into account various catchments, treatments processes and system complexities.

The results of the assessment have been used to prioritise, group, and scope system improvement works according to the deficiencies identified in each system. By adapting this assessment methodology, TasWater has been able to demonstrate risk exposure along with the activities, process and functions required to safely treat and manage the risk.

ACKNOWLEDGEMENTS

For their work in the delivery of this case study and preparation of the paper: -

- TasWater WSO Team
- Antoine Chassagne (Process Engineer)
- All TasWater operational teams involved in the assessment phases
- Luc Richard (Water Quality Manager)
- Lance Stapleton (DM System Performance & Productivity)

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Stephen has over 12 years experience in the water industry. Holding a chemistry degree, Stephen has had a diverse scientific career with roles in offshore gas, waste management, and analytical services supporting his career in the water sector. Stephen built his water science career in the UK through positions at two major UK utilities, Anglian and Thames water. Stephen was a distribution network scientist overseeing over 2 million connections and this led him to his current position as senior water quality scientist with TasWater. Now specialising in water quality risk management and system optimisation, Stephen has a sound understanding of both the strategic and technical challenges required to drive improvement and change in our industry.

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