VISUALISING WATER QUALITY: A GRAPHICAL INDEX FOR DRINKING WATER SYSTEM PERFORMANCE

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ABSTRACT

Communicating water system performance to a non-expert audience is a complex task. The *Water System Performance Index* visualises performance of Coliban Water's 19 drinking water systems by combining information about the performance of Critical Control Points, the results of laboratory testing, regulatory compliance and customer feedback. The purpose of this index is to communicate water system performance to Coliban Water’s Board and senior management. Multiple water systems are visualised using a spatially-oriented traffic-light bubble chart which provides an intuitive overview of drinking water system performance across the business’ service region. This paper discusses the theoretical and practical considerations in developing, implementing and using this index.

INTRODUCTION

Communicating water system performance to a non-expert audience is a complex task. Whereas water usage is defined by a single volumetric parameter, water quality is a function of multiple incommensurable measures. Managing water chemistry involves a delicate balance between often competing objectives. The multivariate nature and complexity of the water quality construct complicates the reporting of drinking water system performance to a non-expert audience. One popular method to achieve this is through a performance index which summarises the state of a water system within a single indicator.

Summarising performance of complex systems through an index has been common practice in business management for decades (Fisher, 1922). Overall business performance is often communicated using a *Balanced Scorecard*, which integrates financial and non-financial measures in a cause-and-effect relationship (Kaplan & Norton, 1996). The performance of share markets is communicated using numerical indices such as the *All Ordinaries* or *Dow Jones* indices. Indices are also used to report performance in public policy, with the *Human Development Index* (UN Development Programme) or the *Environmental Performance Index* (Yale University) as examples. The purpose of any of these indices is to combine related, but otherwise incommensurable, information into a single ordinal number to facilitate an understanding of the system.

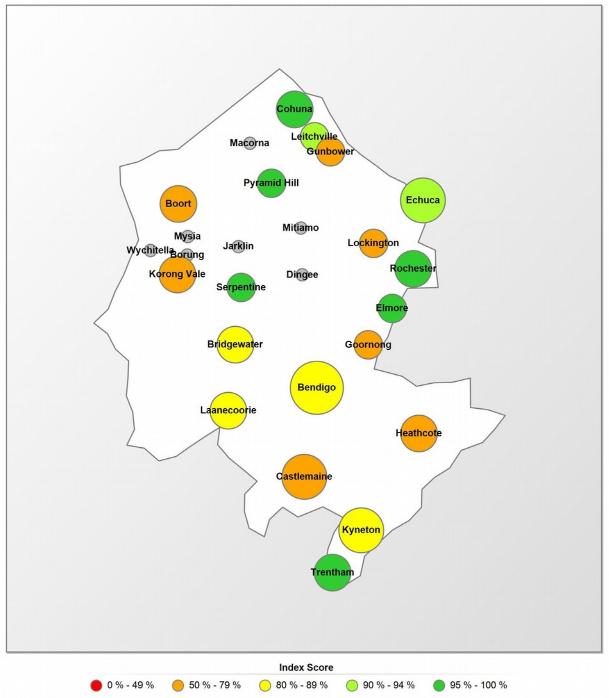


Figure 1: Water System Performance Index.

Indices are also common in water management, and a large variety of drinking water quality-related indices are in use (Abbasi & Abbasi, 2012). These indices focus on the biological and chemical properties of water, but are limited in scope, as they exclude other salient aspects of the catchment-to-consumer supply chain.

This paper introduces an indexing methodology for drinking water quality system performance using information from across the supply chain, building on previous work in water quality indices and scale development theory from the social sciences.

This methodology visualises the performance of multiple systems within a service region (Figure 1) using information from across the drinking water supply chain. The report combines information about Critical Control Point (CCP) performance, laboratory test results, regulatory compliance and customer feedback.

The reporting mechanism also allows operational staff to 'drill down' and query the individual measurements, events and observations on which the index is based.

THEORETICAL FRAMEWORK

Measurement is a fundamental activity of all scientific and technical endeavours, and is essentially an attempt to make sense of the world. Not every phenomenon that is knowable to us can, however, be measured. Water quality is such a phenomenon, as it is not an object or a physical property that can be directly observed. Instead, water quality should be interpreted as a construct of the mind that can only be indirectly known using a range of measurements. Water quality is not simply the sum of all measurements of contaminants, but a function of the fitness for purpose of a given volume of water in the context in which the water is used. Water quality has, as such, an intrinsic social dimension.

Business performance in general and water system performance specifically are also latent constructs that cannot be measured directly. Determining the level of performance of any system is context-specific and dependent on the objectives of the process being measured.

Scale development theory, commonly used in the social sciences, provides a practical framework to assist in creating a performance index for water quality. The performance of a system is a so called formative latent construct. This means that performance cannot be directly perceived, but can only be indirectly determined as a combination of the parameters of which it is considered to consist (Coltman, et al., 2008). The inherent subjective component associated with latent constructs can be managed by using analytical techniques to assess the reliability and validity of the performance measure.

Water Quality Indices

The first water quality index was developed fifty years ago by Robert Horton (1965), who selected the ten most commonly measured water-quality variables and combined them in a weighted linear sum aggregation function. Since Horton, a large variety of approaches to water quality indices have been published (Abbasi & Abbasi, 2012).

Water quality indices are either based on physico-chemical characteristics or bioassessment. Most indices have been developed to assess pollution of natural water systems, with some indices used to assess drinking water. All previously published indices have are based on the chemical and biological composition of the water, and use a range of decision rules to transform measurements into an index score. These indices are usually based on an assessment of the water quality in the distribution network. None of the previously published indices incorporate other salient aspects from the water supply chain, such as barrier performance, customer feedback or regulatory compliance. Another aspect commonly missing in water quality indices are assessments of reliability and validity.

METHODOLOGY

Coliban Water's *Water System Performance Index* extends traditional water quality indices by providing a whole-of-system view of performance. The design of the index is based on water quality expertise and borrows from scale development theory from the social sciences (DeVellis, 2011).

Combining methodologies from the physical and social sciences provides an innovative view on the problem of indexation that enables the presentation of a more holistic view of system performance than is possible using traditional water quality indices. It could be argued that all water quality measurement is in essence a social measure because the objective of water quality monitoring is to assess the water's fitness for human use. All water quality science thus has an inherent social dimension.

The design of the index followed a four step approach, as suggested by Abassi and Abassi (2012), plus reliability testing methods commonly used in scale development:

- Factor selection
- Assignment of weights
- Transformation of parameters
- Aggregation of factors
- Reliability testing

Factor selection

To develop the performance index a choice had to be made as to which factors would form part of the index. A water sample can have hundreds of constituents, including, but not limited to, metals, organics, suspended solids, taste, odour and so on.

To provide an overall view of system performance a catchment-to-consumer approach was chosen. This enables the communication of a causal relationship of water quality from the catchment to consumers, in accordance with the *Balance Scorecard* model, using the following factors:

- Catchment protection
- Barrier effectiveness
- Network protection
- Regulatory compliance
- Customer perception

These factors consist of a mixture of numerical measurements (SCADA and laboratory data), qualitative observations (customer complaints) and events (regulatory notifications) for each of the nineteen water systems. The network protection factor consists of eight sub-factors. The barrier effectiveness, regulatory compliance and customer perception factors are single factors.

Assignment of weights

The reduction of multiple parameters of differing data types into single factor scores and an overall index score involves subjective judgements regarding the relative importance of individual factors. For example: How much weight should be given to objective laboratory results, compared to the subjective views of customers? Is exceeding maximum turbidity levels more important than a lack of chlorine residual?

To control for this inherent subjectivity, a panel of 36 water quality experts from Australia, New Zealand, Europe and the US were asked to provide their views on the relative importance of each of the chosen factors and sub-factors. Each of the five factors was rated on a scale of 1 to 100. The collective responses are visualised in Figure 2.

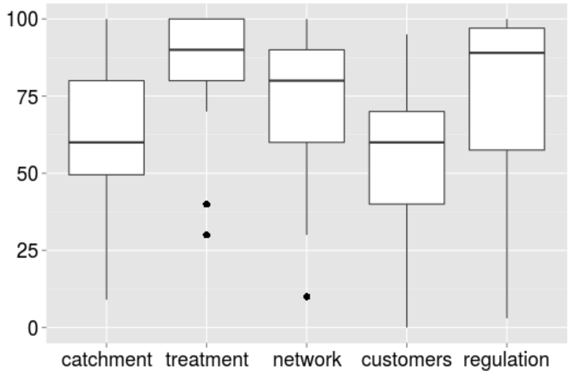


Figure 2: Perceived importance of factors.

The panel's median assessment was used to assign the optimal scores for each of the factors and sub-factors, as shown in Table 1. It was decided not to include the catchment factor as no methodology is currently available to measure performance as Coliban Water has little to no influence over the status of the catchments. The optimum factor scores were rounded to the nearest 50 to ensure sufficient numerical distance between factors. The regulation factor was rounded downward to ensure the total added to 1000.

A maximum performance index score of 1000 was chosen to allow for a sufficiently large number of points to be assigned to each of the (sub)factor scores. This method was used to account for the psychological principle known as the distance effect: the closer the distance between two numbers, the greater the difficulty a subject has in discriminating between them. Therefore, if the individual (sub)factor scores in the model are too close to each other, they will not be perceived as different (Moyer & Landauer, 1967).

The optimum factor scores were adjusted for individual systems to allow for differences in treatment methodology and data availability. The barrier effectiveness factor was omitted for systems where CCP alarm data is currently not retrievable through Coliban Water's Data Warehouse. For systems without chlorine dosing or alum coagulation the optimum score for the network protection factor was downwardly adjusted. Also the optimum score for non-potable systems was downwardly adjusted to 360 points to reflect the limited scope in supply requirements. Each water supply system is as such assigned an optimum index score based on the system configuration and the available data.

Table 1: Water system performance index factors.

Factor	**Median Score**	**Optimum factor score**	
		Calculated	Rounded
Catchment	60	-	-
Barriers	90	282	300
Network	80	251	250
Customers	60	188	200
Regulation	89	279	250
TOTAL	**348**	**1000**	**1000**

Transformation of parameters

To enable comparison of the different types of data used to construct the index, each factor and sub-factor is converted to a non-dimensional score. The scores are derived by using a combination of linear functions and segmented linear functions in a decremental system, with the optimal scores derived from the expert survey (Table 1). Perfect performance is defined as the absence of problems with any of the factors and sub-factors.

Barrier Effectiveness

The factor for barrier effectiveness is based on alert and critical alarms at the Critical Control Points for each of the treatment barriers. This approach was chosen as a proxy for treatment plant performance. The central assumption is that a perfectly operating barrier is characterised by a low level of variability and thus a low number of alert and critical alarms. This approach, rather than direct analysis of process variables was chosen for practical considerations regarding data availability.

The transformation rule for the barrier effectiveness factor is based on historic data and was chosen so that a factor score of zero is expected to have a frequency of 1% (once every eight years):

$$F_t = 300 - (5\,alert) - (15\,critical)$$

This factor provides an indication of control over the process. The score is not a reflection of the quality of the water leaving the plant. The disadvantage of using this metric is that the alarm count in the SCADA historian currently cannot distinguish between actual alarms, and false or test alarms.

Network Protection

The network protection factor consists of a range of salient parameters that form part of Coliban Water's laboratory testing monitoring program. The chosen parameters are based on a previous index used by Coliban Water.

Each parameter is assigned a weighting, which was derived from the expert opinion survey. Figure 3 shows the raw scores as provided by the survey respondents. These responses were converted to sub-factor scores by normalising the median values to the optimal score of the network protection factor listed in Table 2.

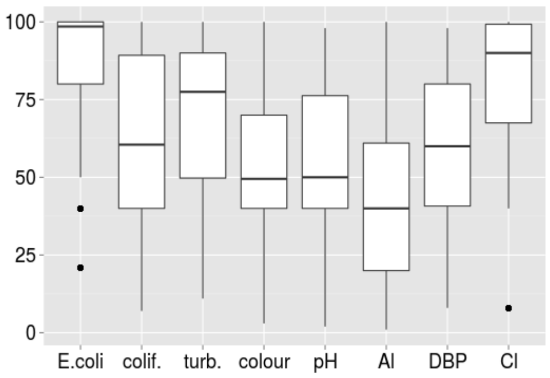


Figure 3: Perceived importance of network sub-factors.

The transformation rules for the network protection sub-factors have been determined using a combination of public health and aesthetic guideline values which were mostly derived from the 2011 *Australian Drinking Water Guidelines* (ADWG).

Table 2: Network protection sub-factors.

Factor	**Median Score**	**Optimum sub-factor score**	
		Calculated	Rounded
E. coli	98	47	45
Coliform	60	29	30
Turbidity	78	37	35
Colour	50	24	25
pH	50	24	25
Aluminium	40	19	20
DBP[1]	60	29	30
Chlorine	90	43	40
TOTAL	**348**	**250**	**250**

The score for *E. coli* assigns 45 points to this factor if no *E. coli* are detected in any sample. Any detection of *E. coli* results in a sub-factor score of zero:

$$f_1 = 45(ecoli = 0)$$

Although the ADWG recognises that coliform bacteria are not a health-related parameter, the presence of coliforms in chlorinated drinking water indicates that some form of contamination has occurred post-chlorination. The critical value for coliforms has therefore been set to zero. This approach is consistent with the US EPA's approach to the presence of coliforms in drinking water:

$$f_2 = 30(coliform = 0)$$

The sub-factor score for turbidity is calculated using a segmented linear function. Any turbidity value in the network that is greater than 5 NTU (ADWG aesthetic guideline) results in a score of 0 points. The middle value of 1 NTU is the ADWG target for effective disinfection and 0.2 NTU is the ADWG target for effective filtration of *Cryptosporidium* and *Giardia*:

$$f_3 = 10(NTU \leq 5) + 10(NTU \leq 1) + 15(NTU < 0.2)$$

The colour sub-factor is also calculated using a segmented linear function with two critical values. Whilst the ADWG contains an aesthetic guideline value of 15 HU for colour, in order to ensure that the production of disinfection by-products is minimised, a target value of 5 HU for colour is used in the index:

$$f_4 = 10(colour \leq 15) + 15(colour \leq 5)$$

The fifth sub-factor involves the pH value of the water. The critical values have been chosen to ensure optimal disinfection. Full points are awarded when all measurements in the system are within defined limits. For chlorinated or UV disinfected systems this is between pH 6.5 and 8.5, for chloraminated systems the ideal range is between pH 7.5 and 9.5:

$$f_{5a} = 25(pH \geq 6.5 \wedge pH \leq 8.5)$$

$$f_{5b} = 25(pH \geq 7.5 \wedge pH \leq 9.5)$$

The critical value for acid soluble aluminium is set at 0.2 mg/L as advised in the ADWG. Full points are assigned to each system for which the maximum measured value is less than the critical value.

$$f_6 = 20(Al \leq 0.2)$$

The sub-factor for disinfection by-products is based on the maximum measured concentration of total trihalomethanes in the system, with a critical value of 0.25 mg/L:

$$f_7 = 20(THM \leq 0.25)$$

Finally, the disinfection sub-factor assigns points to the degree to which the levels of free and total

[1] DBP: Disinfection By-Products.

chlorine within the network fall within defined limits, where *n* is the total number of chlorine test results:

$$f_8 = 40 \frac{(Cl \geq 0.1 \wedge Cl \leq 4)}{n}$$

The network protection factor is determined as the sum of the eight network sub-factors:

$$F_n = \sum_{i=1}^{i=8} f_i$$

Regulatory Compliance

Regulatory compliance has been added to the index to prevent eclipsing, which is occurs when the index does not exceed a critical level despite one or more of the factors exceeding their own critical level (Abbasi & Abbasi, 2012). Eclipsing occurs when insufficient points are assigned to an event that has significant importance.

The network protection factor does not incorporate every single parameter that could cause a risk to public health. The Victorian *Safe Drinking Water Act 2003* (the Act) requires any suspicion of non-complying drinking water (section 18 of the Act) or contamination of drinking water (section 22 of the Act) to be formally notified to the Department of Health. The regulation factor incorporates these events into the performance index.

The regulation factor is a dichotomous factor which is either 250 or 0, based on whether a notification has been lodged to the Department of Health, as recorded in the Coliban Water's *Issue Manager* system.

$$F_c = 250 - (notifications = 0)$$

This dichotomous function was chosen to ensure that notifications to the regulator are given sufficient importance, which prevents the eclipsing of such events. If a water system has a perfect score on all factors but shows, for example, lead in the system that exceeds safe levels, the index for that system will be only 75% of the maximum value, resulting in a yellow bubble in the visualisation.

Customer Perception

Traditionally, water quality assessments are separated in health and aesthetic targets, with primacy given to health considerations (ADWG, 2011). A customer-focused utility will assess these two aspects on equal footing. Consumer perceptions of the health risk associated with drinking water are heavily influenced by perceptions of aesthetics. Perceptions of drinking water service quality are also influenced by factors outside of water quality parameters, such as the level of hardship experienced by customers and their level of involvement with the service (Prevos, 2015). The subjective views of customers need to be taken into consideration in order to provide a holistic view of system performance. This performance index is based on the principle that health targets are a necessary condition for a high level of service quality, but not a sufficient condition.

The integration of customer perceptions into this index starts with the incorporation of both health and aesthetic targets in the network protection factor, outlined above.

The final factor of the index incorporates the subjective views of customers and is based on the number of water quality complaints. The factor score is derived using a linear function based on the number of complaints per 1000 connections in each month.

Recent research in the US showed that the mean complaint frequency for several systems ranged between 0.2 and 2.6 complaints per 1,000 connections per year (Gallagher & Dietrich, 2014). Based on this study a critical value of 2 complaints per 1000 connections was used.

$$F_c = 200 - \frac{complaints}{connections/1000} 100$$

Although using complaints per 1000 connections normalises the data for system size, in practice smaller systems show a much higher variability in the perception factor score than larger systems. In systems with fewer than 500 connections the factor score is either 200 or 0. Analysis of long term complaint ratio data for Coliban Water shows that there is, however, no significant relationship between system size and complaint ratio. Although smaller systems have more variability in their perception score over the monthly reporting cycles, the long term pattern is similar to larger systems.

Aggregation of factors

The final index for each individual system is expressed as a percentage of the sum of the factor and sub-factor scores over the maximum score for the system under consideration.

$$WSPI = 100 \frac{F_t + F_n + F_c + F_n}{F_{max}}$$

The index can only be expressed for individual systems over the time period of one month. All transformations from measurements, observations and events to factor scores are calibrated to a monthly reporting cycle. Calculating the index score over a different reporting window would require a full review of the methodology.

Reliability and validity

The face validity of the methodology was tested using a panel of experts from Coliban Water. The panel was presented with the draft methodology and was reviewed to assess whether the index would, in their opinion, accurately communicate water system performance. This assessment included simulations of events to assess whether they would be reliably reflected in the report.

The internal consistency of the factor and sub-factor weightings was assessed be employing principal component analysis and calculation of the Cron*bach Alpha* value (DeVellis, 2011). Principal component analysis of the expert survey shows that a single component solution explains more than half of the variance in the responses. This indicates that the responses relate to a single latent construct, which ostensibly relates to water system performance. The internal consistency of the index was further tested using Cronbach's Alpha. The survey results yielded an excellent level of reliability (α=0.92). Scales are generally considered to have sufficient reliability when Alpha is more than 0.70. These two statistical tests of the expert survey indicate that the structure of the index has a high level of reliability and internal consistency.

The index has been in use since July 2014 and is continuously reviewed to assess construct validity, which assesses the index's ability to measure water system performance.

Performance to date indicates that the system has a high level of construct validity. For example, a recent trial using direct chlorination in one system resulted in improved performance levels due to the elimination of coliform bacteria and improved chlorine residuals. This shows that the index is capable of reporting both positive and negative events that impact on performance.

IMPLEMENTATION

Deployment

The guiding principles for the deployment of this methodology was that no additional software would have to be purchased and that preparation of the index is fully automated using information available in Coliban Water’s Data Warehouse.

The index was developed in Microsoft's *SQL Server Reporting Services* (SSRS) and consists of twenty hyper-linked reports for each water system. The visualisation consists of a shape-file containing the spatial information regarding system location.

The report is automatically updated at the end of each month and e-mailed to relevant managers. Operational staff can explore data by moving from the visualisation to the previous index values of individual systems, and querying individual factors and sub-factors.

Visualisation

The report provides five levels of information:

1. Service region
2. System level
3. Factor level
4. Measurements, events and observations for water systems
5. Links to other business systems

The calculated index values are visualised using a spatial representation of the Coliban Water service region with individual water systems visualised as a circle (Figure 1). The service area is visualised using only an outline of the boundaries, removing any visual information that does not contribute to communicating system performance. The size of each bubble is equivalent to the logarithm of the number of connections. This method was used to increase the visual impact of larger systems. A logarithmic conversion was used due to the exponential differences in size between systems in the Coliban Water region. The bubble chart is coloured using a red to green diverging colour palette. The assignment of colours is weighted towards the negative, with only the top 10% range shown as green. Non-potable water systems are included in the visualisation, but are displayed in grey.

At the second level an overview of the performance of a specific system is provided (Figure 4). This page shows any trends in performance over the previous twelve months.

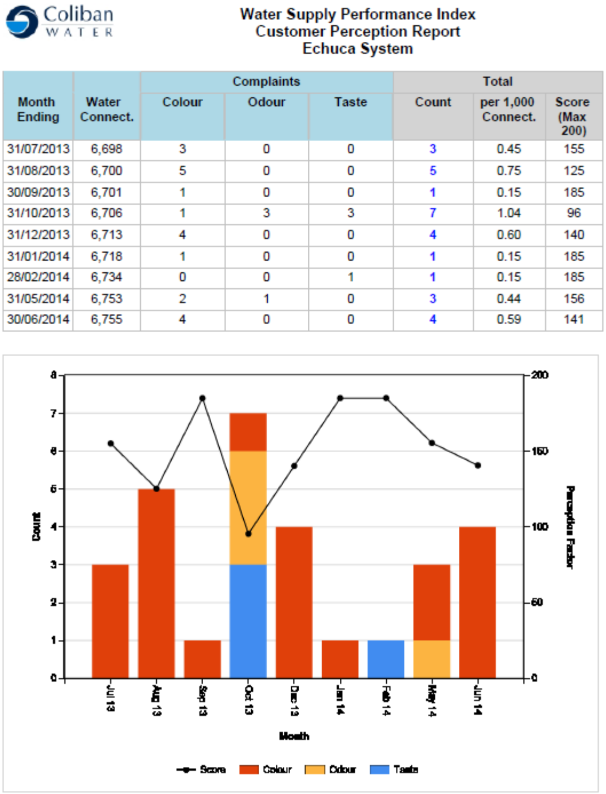
Coliban WATER

Water Quality Performance Index
Echuca System

Month Ending	No. Connect.	Treatment	Networks	Regulation	Customer Perception	Total Score	Raw Score Max	Index Value
31/07/2013	6,698	230	230	250	155	865	1000	87%
31/08/2013	6,700	265	220	250	125	860	1000	86%
30/09/2013	6,701	300	220	250	185	955	1000	96%
31/10/2013	6,706	205	235	250	96	786	1000	79%
30/11/2013	6,710	205	235	250	200	890	1000	89%
31/12/2013	6,713	195	235	250	140	820	1000	82%
31/01/2014	6,718	170	220	250	185	825	1000	83%
28/02/2014	6,734	100	235	250	185	770	1000	77%
31/03/2014	6,740	190	220	250	200	860	1000	86%
30/04/2014	6,744	110	235	250	200	795	1000	80%
31/05/2014	6,753	220	235	250	156	861	1000	86%
30/06/2014	6,755	155	235	250	141	781	1000	78%

Figure 4: Twelve month system overview (level 2).

The third level provides a one year view of the performance of each of the individual factors for a given system, providing operational staff with the relevant measurements, events and observations for each water system (Figure 5).

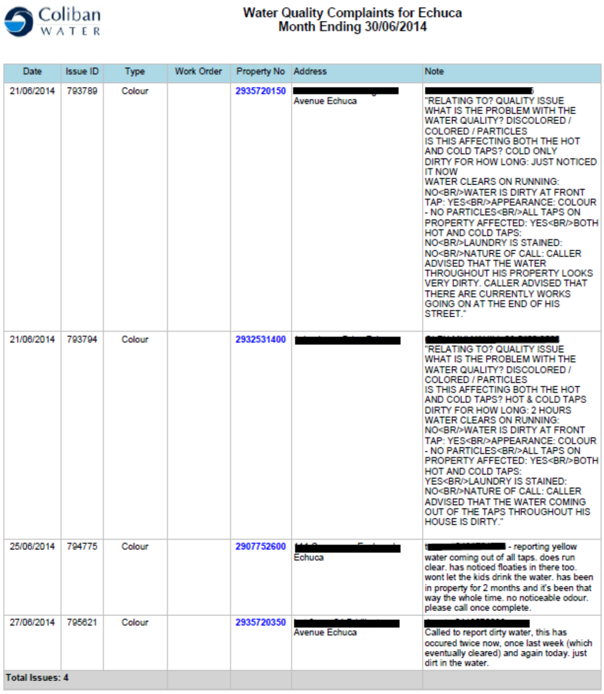


Water Supply Performance Index
Customer Perception Report
Echuca System

Month Ending	Water Connect.	Complaints			Total		
		Colour	Odour	Taste	Count	per 1,000 Connect.	Score (Max 200)
31/07/2013	6,698	3	0	0	3	0.45	155
31/08/2013	6,700	5	0	0	5	0.75	125
30/09/2013	6,701	1	0	0	1	0.15	185
31/10/2013	6,706	1	3	3	7	1.04	96
31/12/2013	6,713	4	0	0	4	0.60	140
31/01/2014	6,718	1	0	0	1	0.15	185
28/02/2014	6,734	0	0	1	1	0.15	185
31/05/2014	6,753	2	1	0	3	0.44	156
30/06/2014	6,755	4	0	0	4	0.59	141

Figure 5: Customer complaints per month (level 3).

At the fourth level of detail, information is provided on the individual parameters (Figure 6), including links to Coliban Water's geographical and asset management information systems (level 5).



Water Quality Complaints for Echuca
Month Ending 30/06/2014

Date	Issue ID	Type	Work Order	Property No	Address	Note
21/06/2014	793789	Colour		2935720150	[redacted] Avenue Echuca	[redacted] "RELATING TO? QUALITY ISSUE WHAT IS THE PROBLEM WITH THE WATER QUALITY? DISCOLORED / COLORED / PARTICLES IS THIS AFFECTING BOTH THE HOT AND COLD TAPS? COLD ONLY DIRTY FOR HOW LONG: JUST NOTICED IT NOW WATER CLEARS ON RUNNING: NO WATER IS DIRTY AT FRONT TAP: YES APPEARANCE: COLOUR - NO PARTICLES ALL TAPS ON PROPERTY AFFECTED: YES BOTH HOT AND COLD TAPS: NO LAUNDRY IS STAINED: NO NATURE OF CALL: CALLER ADVISED THAT THE WATER THROUGHOUT HIS PROPERTY LOOKS VERY DIRTY. CALLER ADVISED THAT THERE ARE CURRENTLY WORKS GOING ON AT THE END OF HIS STREET."
21/06/2014	793794	Colour		2932531400	[redacted]	[redacted] "RELATING TO? QUALITY ISSUE WHAT IS THE PROBLEM WITH THE WATER QUALITY? DISCOLORED / COLORED / PARTICLES IS THIS AFFECTING BOTH THE HOT AND COLD TAPS? HOT & COLD TAPS DIRTY FOR HOW LONG: 2 HOURS WATER CLEARS ON RUNNING: NO WATER IS DIRTY AT FRONT TAP: YES APPEARANCE: COLOUR - NO PARTICLES ALL TAPS ON PROPERTY AFFECTED: YES BOTH HOT AND COLD TAPS: YES LAUNDRY IS STAINED: NO NATURE OF CALL: CALLER ADVISED THAT THE WATER COMING OUT OF THE TAPS THROUGHOUT HIS HOUSE IS DIRTY."
25/06/2014	794775	Colour		2907752600	[redacted] Echuca	t[redacted] - reporting yellow water coming out of all taps. does run clear. has noticed floaties in there too. wont let the kids drink the water. has been in property for 2 months and it's been that way the whole time. no noticeable odour. please call once complete.
27/06/2014	795621	Colour		2935720350	[redacted] Avenue Echuca	[redacted] Called to report dirty water, this has occured twice now, once last week (which eventually cleared) and again today. just dirt in the water.
Total Issues: 4						

Figure 6: Customer complaints for one system in one month (level 4).

For each system, more than twenty pages of information are available to facilitate exception reporting on systems that are performing below the threshold level of 90% of optimal performance.

Usage

An important aspect of this system is the level of trust that the senior management and the Board of Coliban Water have in its ability to reliably reflect water system performance.

To ensure the system is reproducible and transparent the methodology is codified in Coliban Water's quality management system and can only be changed with approval of the responsible executive. It is envisaged that an annual review of the index is undertaken to continuously improve reliability and validity.

The spatial visualisation of system performance is presented to Coliban Water's Board in the monthly performance report. Each system which has not received a green classification is accompanied with an exception report, describing the reasons for any shortfall in performance.

CONCLUSION

The index provides a reliable and valid overview of drinking water system performance for boards and senior managers of water corporations. The index also assists in developing a greater understanding of the performance of water systems by linking the raw data to the index, and enabling exploration of the data.

Despite limitations in combining data from a wide range of sources, the index provides a holistic and auditable framework within which drinking water system performance can be assessed.

Limitations

The index amalgamates a range of otherwise incommensurable system parameters into a single number. Due to the subjective nature of the weightings and the non-dimensionality of the index and (sub)factor scores, the final results should be viewed as ordinal variables, expressing a ranking and not a metric of performance. The factor and sub-factor scores can thus only be used for comparative reporting, either over time or between systems, and has limited use in detailed analysis.

Further Development

The visualisation of information at system and factor level is envisaged to be improved by providing a scorecard type presentation and remove reliance on tables. At the fourth level of information it is envisaged that information is spatially presented to further remove reliance on tables.

The use of CCP alarm counts for the barrier effectiveness factor is being reconsidered and possibly replaced with indicators of barrier performance using the *Health-Based Treatment Targets* manual developed by the Water Services Association of Australia (WSAA, 2014).

ACKNOWLEDGEMENTS

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