National validation guidelines for water recycling: Comprehensive Bayesian recycled water validation

Country: Australia

City/region where project is based: Multiple Australian urban centres

Population (of area where the project is based): Approximately 20 million

Key organisations /stakeholders involved in the project: Australian Water Recycling Centre of Excellence's NatVal Project Stakeholders see:
https://researchdata.ands.org.au/australian-water-recycling-centre-excellence/267239
http://www.waterra.com.au/project-details/44

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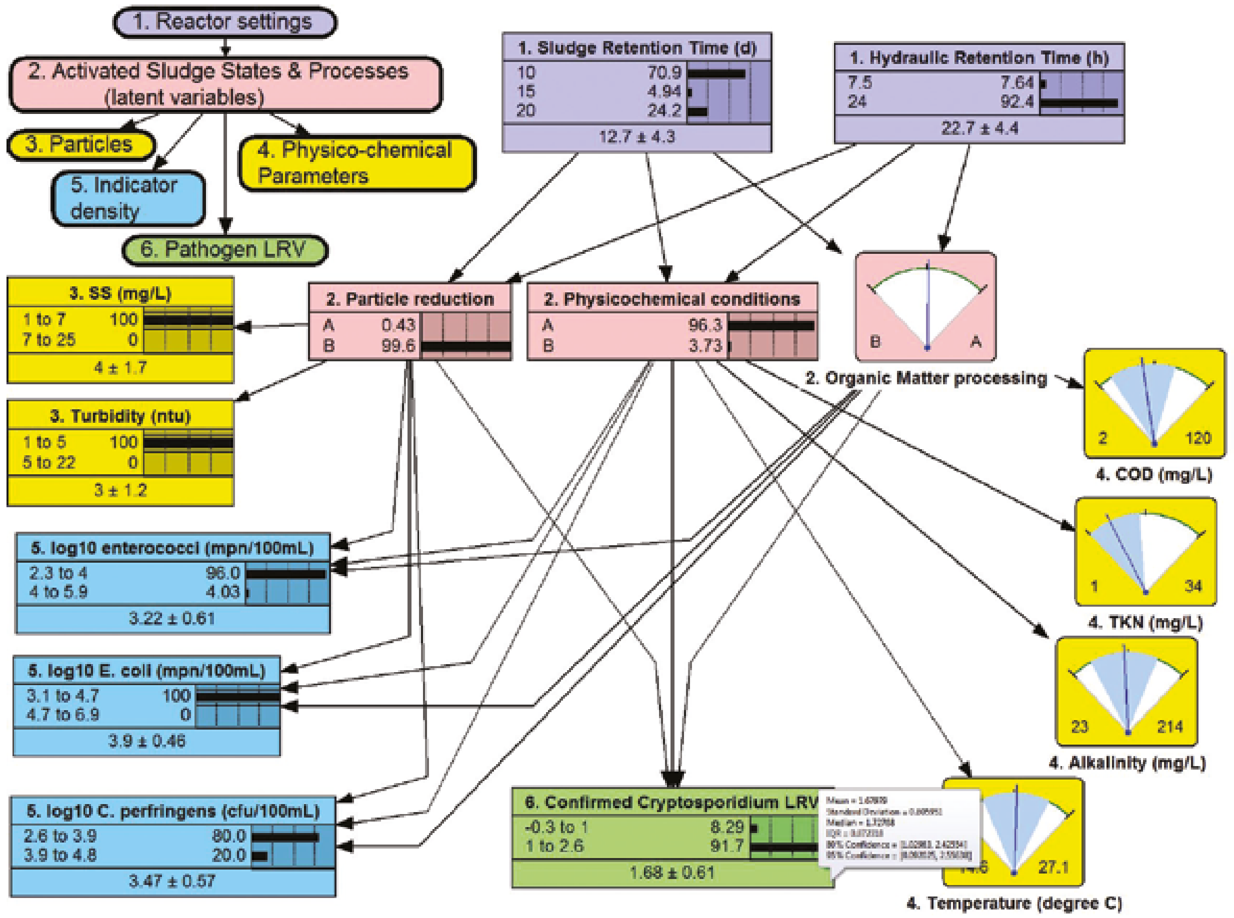

Case Study: Smart tools for water quality data management and interpretation: Bayesian frameworks for recycled treatment process validation

Wastewater is increasingly recycled in Australia and globally for both direct and indirect potable use. To ensure its safety, it is essential to validate the technologies used to treat the water (i.e. assess reliability) over many months during process validation and plant commissioning. Due to the extreme risks arising if a system fails, ongoing monitoring is required to ensure a system shuts down in the unlikely event of hazardous contamination. As monitoring technology has advanced, constraints on data interpretation have been highlighted (e.g. the unclear relationship between online surrogates[1] such as turbidity or pH and risk benchmarks), resulting in increased institutional interest in improving interpretation of real-time water quality data.

This awareness reflects the need to relate all measurements to formal risk assessment metrics (e.g. treatment process Decimal or Log_{10} Reduction Values (LRVs) credits, targets and benchmarks), which are increasingly used by regulators. To support the use of these metrics, a consortium of Australian water researchers and managers developed NatVal, a 'national framework for validating water-recycling technology' (1) to improve confidence in treatment methods and the use of real-time water quality monitoring.

As part of the NatVal framework, our group was charged with identifying a process validation 'Framework' consistent with ISO 31000/31010 Risk Management principles and operational tools. To this end we investigated methods for quantitatively and conceptually relating measurements from surrogates, to monitoring indices (e.g. coliform counts) and then to contaminants of primary concern e.g. *Cryptosporidium*, whose LRV and µDALY risk metrics can be estimated experimentally in smaller trials.

To relate monitoring data to risk metrics in an operational setting, we chose Bayesian Belief Nets (BBNs), a type of artificial intelligence which capture human 'cause and effect' reasoning algebraically to facilitate 'reasoning under uncertainty', were trialled. BBNs are 'directed acyclic graphs' which visually look like flow charts. Unlike the latter though, nodes (e.g. a normal distribution function) and links (causal node inter relationships) are defined mathematically. BBNs proved remarkably adaptable and ideally suited to 'Smart' treatment performance analysis.

1. Online surrogates is the term used to describe water parameters (e.g. turbidity) when they are used as substitutes for direct pathogen monitoring

For example BBNs can 'learn' from databases and probabilistically relate online measurements (especially turbidity, sludge retention time and nitrate) to *Cryptosporidium* LRVs (see reference 2), and indicator (e.g. enterococci) behaviour to pathogen reductions and risk (Figure at left). Combined with another AI approach (neural network Perceptrons) BBNs can integrate disinfectant concentration, contact time, turbidity and pH measurements to estimate disinfection LRVs in real time (see reference 3). By using Bayesian inference we were also able to put uncertainty estimates on risk estimated using surrogate measurements.

While Smart monitoring collects enormous amounts of treatment process data (i.e. big data) and supports real-time equipment management, one issue faced is that current data outputs are often incompletely interpretted. In particular, they provide a lot of data but do not transform this into useful information. Through our research we have shown that BBNs, Bayesian inference and statistical analysis can address this gap operationally, auditably and in real time. It also provides a framework for risk inference suited to regulators and water utilities.

Based on our subsequent trials the greatest challenge to widely rolling out this Smart technology for water utilities and regulators appears not to be a programming constraints, but getting water managers to view their activities from a Bayesian perspective and understand Bayes reasoning and how it provides powerful prioritization mechanisms.

References

1. Australian Water Recycling Centre of Excellence. 2014. A national framework for validating water-recycling technology: Validating multiple-barrier water recycling systems. Streetmap 9.
2. G. Carvajal, D. J. Roser, S. A. Sisson, A. Keegan, S. J. Khan, Water Research 85, 304 (2015).
3. G. Carvajal, D. J. Roser, S. A. Sisson, A. Keegan, S. J. Khan, Water Research 109, 144 (2017).