Journal of Water & Health

IWA PUBLISHING

Journal of Water and Health Vol 21 No 8, 1098 doi: 10.2166/wh.2023.125

Supporting the implementation of drinking water management systems in New South Wales, Australia

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ABSTRACT

Since 2010, New South Wales (NSW) Health has assisted local water utilities to develop and implement risk-based drinking water management systems based on the Australian Drinking Water Guidelines Framework for Management of Drinking Water Quality. This support has benefited regional communities, and especially smaller utilities, by helping to identify and control risks. NSW Health's support projects have resulted in statistically significant improvements across many elements of drinking water management system implementation. Through this program of support, NSW Health has identified possible infrastructure and operational needs and assessed implementation of drinking water management systems. In parallel, NSW Health has worked to assess the risk from *Cryptosporidium* in drinking water supplies and to develop a formal audit program. Findings from the NSW Health support program informed the development of two NSW Government programs and the commitment of more than $1 billion to help local water utilities address public health and other critical needs. The introduction of risk-based drinking water management systems has driven incremental improvement in drinking water quality management across the state of NSW.

Key words: drinking water management system, drinking water quality, drinking water safety, implementation, regional New South Wales, risk assessment

HIGHLIGHTS

- NSW Health supports regional water utilities implement risk-based drinking water management systems.
- Standardised questionnaires are used to demonstrate statistically significant improvements in implementation.
- Outputs coded into a database and assigned risk ratings to prioritise further support.
- Priorities for support inform investment in infrastructure.
- Incremental improvements seen in water quality management.

GRAPHICAL ABSTRACT

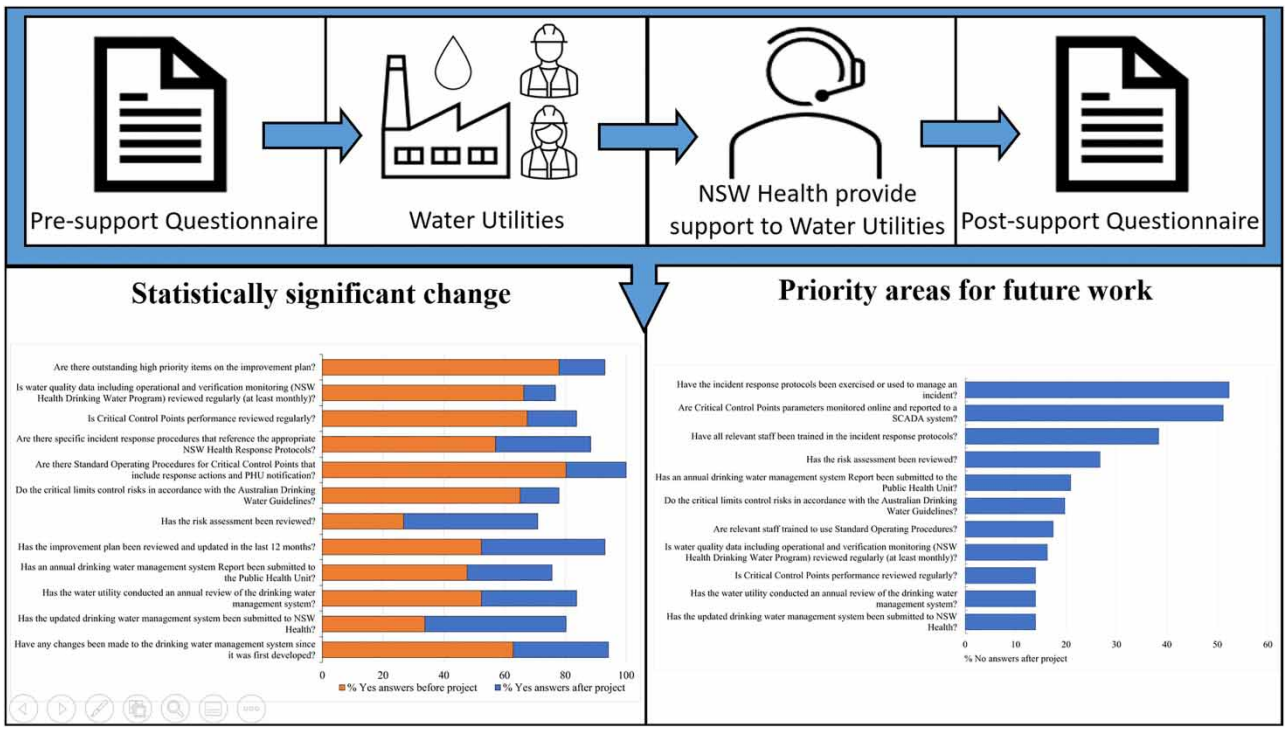

TABLE OF ACRONYMS

Acronym	Definition
CCP	critical control point
DALY	disability-adjusted life year
DPE	Department of Planning and Environment
E. coli	*Escherichia coli*
NSW	New South Wales
NTU	nephelometric turbidity unit
SCADA	supervisory control and data acquisition
SOP	standard operating procedure

INTRODUCTION

New South Wales (NSW), Australia covers an area of 801,137 km^2 and has a population of 8,153,000 (Geoscience Australia 2023; NSW Government 2023). In regional areas of NSW, outside the major cities of Greater Sydney and Newcastle, drinking water is provided by 83 public water utilities, mostly local government councils, serving about 1.8 million people and operating around 270 supply systems. The utilities range in size from those serving large cities with tens of thousands of residents, down to those serving small towns in sparsely populated areas serving very few residents. Around 75% of regional water supplies serve less than 5,000 people and around 45% serve less than 1,000 people. There is a clear declining gradient of population density across NSW from east to west. There is an inverse trend in the area covered by local councils; those in the west are very large, but still with very small populations. Water utilities in Australia are expected to fully fund capital and operating expenses through customer water charges (Productivity Commission 2021). Some utilities, particularly those in remote locations and with small populations, face challenges managing their water supplies. Some of these utilities have difficulty with recruiting and retaining qualified and skilled operators and funding appropriate infrastructure. The World Health Organization (WHO) recommends implementing a water safety plan to help manage drinking water risks in small communities (WHO 2012).

The National *Australian Drinking Water Guidelines* (NHMRC 2011) provide guidance on safe drinking water and take a similar approach to the WHO *Guidelines for Drinking-Water Quality* (WHO 2022). The Framework for Management of Drinking Water Quality (NHMRC 2011) and its 12 elements entered the *Australian Drinking Water Guidelines* in 2004. This preventive risk management approach to drinking water management was a radical departure from the previous 1996 edition of the *Australian Drinking Water Guidelines*, and a world leading application of a holistic approach to preventive risk management in drinking water.

NSW Health is responsible for the state's public health regulation of drinking water quality. NSW Health recommended adoption of the Framework for Management of Drinking Water Quality as a model of best practice, following its publication in 2004. However, the uptake of implementing the Framework varied considerably across regional NSW (Byleveld *et al.* 2008). Therefore, the NSW Public Health Act (NSW Government 2010) was amended to require all suppliers of drinking water to develop and adhere to a quality assurance program addressing the Framework elements relevant to that supplier. This new requirement was a major change, especially for some smaller utilities. NSW Health gave utilities a long transition period to establish their systems (Byleveld *et al.* 2016) and did not commence the new legislative requirement until 2014. NSW Health has worked closely with utilities and industry to promote awareness of the requirements and share information.

The NSW Health approach to quality assurance programs is similar to WHO water safety plans (WHO 2009, 2012, 2023). The risk-based framework is globally supported as an effective means of assuring the delivery of clean, safe drinking water. It is described in the WHO *Guidelines for Drinking-Water Quality* (WHO 2009, 2022, 2023). Preparing and implementing a water safety plan (or drinking water management system) has been demonstrated in previous studies (Gunnarsdottir *et al.* 2012; Baum *et al.* 2015) to provide a positive impact on water quality and public health. Water safety plans or quality assurance programs are named 'drinking water management systems' for public water utilities in NSW to emphasise the importance of implementing a system of continuous improvement rather than simply preparing a plan.

NSW Health works closely with the co-regulator, the NSW Department of Planning and Environment – Water (DPE Water) to help utilities to manage water quality risks in regional NSW. DPE Water oversees and supports local water utilities in their delivery of water supply and sewerage services and operation of treatment infrastructure. In 2013, NSW Health and the former NSW Department of Primary Industries – Office of Water (now DPE Water) jointly published the *NSW Guidelines for Drinking Water Management Systems* to support water utilities to develop and implement their drinking water management system (NSW Health 2013). The state-wide NSW Health network of public health units and the Water Unit work with DPE Water to provide guidance to local water utilities to manage identified risks in their water supplies. The utilities' drinking water management systems are crucial in this process by identifying protective actions to prevent providing inadequately treated water to the public.

NSW Health has assessed risks in regional NSW from *Cryptosporidium*. In some locations, a higher standard of treatment may be required for effective control of this protozoa than for other pathogens. Assessment of *Cryptosporidium* risk informs the prioritisation of water treatment upgrade projects and health-based targets implementation (Petterson *et al.* 2021). Microbial health-based targets were incorporated into the *Australian Drinking Water Guidelines* in 2022. NSW Health and DPE Water have developed an implementation plan for the incorporation of health-based targets in regional NSW, informed by the *Cryptosporidium* risk assessment (NSW Health 2023). It has been acknowledged that implementing health-based targets into drinking water management systems will take time, particularly for small water suppliers (NHMRC 2011).

At the heart of a management system is monitoring of critical control points (CCPs). A CCP is an activity, procedure or process that is critical to control a water quality hazard. CCPs exist throughout the multi-barrier drinking water treatment process, such as from source water supply, catchment characteristics, water treatment processes, distribution systems, down to user interface (WHO 2023). However, the main focus in NSW are CCPs such as filtration (where present), disinfection and maintaining reservoir integrity. Most water utilities in regional NSW do not have control over their catchment making it difficult to manage catchments as CCPs for water quality. Drinking water management systems include barriers from catchment to tap that are managed as operational control points. Suitable water treatment infrastructure and a well-trained workforce are essential to complying with CCPs and managing risks, as is the commitment to drinking water quality management at all levels of governance. To assist local water utilities, NSW Health has published guidance on CCPs for drinking water management systems (NSW Health 2018).

The implementation of water safety plans has faced challenges around the world (Perrier *et al.* 2014; Baum *et al.* 2015; Gagnon & Castleden 2015; Lane *et al.* 2018). In 2023, Nguyen and colleagues surveyed 23 provincial water utilities in

Vietnam serving populations from 141,000 people to over 8 million people and found the greatest barriers to developing and implementation was cost, training, and the need for better guidance material. Developing guidance documents, offering training, and providing network opportunities between water suppliers and responsible authorities were recommended actions to help establish an enabling environment for implementing water safety plans (WHO EURO *et al.* 2014).

In 2011, Alberta, Canada became the first jurisdiction in North America to require all drinking water suppliers to develop drinking water safety plans, as such, but Ontario adopted a mandatory regulated Drinking Water Quality Management Standard in 2007 (Ontario Ministry of the Environment 2007) as a recommendation of the Walkerton Inquiry (O'Connor 2002). This standard is similar to the Framework for the Management of Drinking Water Quality (NHMRC 2011) first adopted in the *Australian Drinking Water Guidelines* in 2004.

Perrier and colleagues (2014) collected data via qualitative interviews with operators from 15 small communities (fewer than 500 residents – fewer than 10,000 residents) in Alberta. The main obstacle to implementation was found to be lack of communication between water operators, councillors, and community members. Operators hold numerous responsibilities (for example, landscape maintenance, infrastructure repairs, snow removal) and face challenges where councillors and decision makers do not know what water operations entails. However, where there was a good relationship with decision makers, operators felt comfortable sharing their concerns around their water systems. The drinking water safety plan could serve to facilitate addressing concerns within a water supply system, in a clear manner with risks prioritised for effective and timely decision making (Perrier *et al.* 2014). In the same province, Reid and colleagues (2013) identified issues of capacity constraints, geographical remoteness and lack of resources as significant barriers to successful adoption.

Despite these barriers, multiple sources report that developing and implementing a plan is superior to the traditional regulatory approach of meeting standards for certain water quality parameters (Reid *et al.* 2013; Lane *et al.* 2018).

Baum and colleagues (2015) stated that water safety plans can help address gaps in the United States regulation through the identification of system specific risks, thereby reducing factors leading to waterborne disease. They concluded that the plans enhance a sense of ownership and lead to an improved understanding of the greatest risks to each water supply, allowing prioritisation of risk management measures. In 2012, Gunnarsdottir and colleagues concluded that it was essential to have adequate staff training and participation in the process, as well as simple and well-structured guidelines, and good cooperation with health authorities. Through effective implementation, water safety plans have led to improvements in water quality, regulatory compliance, communication, asset management, and public health outcomes (Gunnarsdottir *et al.* 2012). Reid and colleagues (2013) stated that training workshops were critical to successful implementation. They stressed the importance of ongoing support and communication, and regular reviews and updates to the plan they described as a 'living document'.

In Australia, there is limited literature assessing the efficacy and impact of implementation of water safety plans. This paper aims to assess the impact of NSW Health support to water utilities with implementing drinking water management systems, as well as in identifying challenges and areas of improvement in the NSW context.

METHODS

Drinking water management system support projects

Since 2010, NSW Health has supported water utilities to develop and implement their drinking water management systems (Byleveld *et al.* 2016). Drinking water management system implementation projects have provided water utilities in regional NSW with skilled water quality and engineering specialist assistance to review water quality risks and water treatment performance, optimise water treatment, develop standard operating and incident response procedures, conduct annual reviews of drinking water management systems, and pilot guidelines for auditing of drinking water management systems. Each project is scoped to address specific needs and is not a holistic program of support. Through the projects, other needs may be identified, and water utilities may request additional support from NSW Health.

To date, over 90 water utilities have been supported with over 250 projects. Currently, there are 83 local water utilities in NSW following the amalgamation of some local councils. Public health units and DPE Water identify water utilities that could benefit from having this support to implement their drinking water management system. The priority for NSW Health assistance is targeted at the least resourced water utilities with the greatest vulnerability and/or financial need, and those serving the largest Aboriginal populations, who experience inequality in health outcomes (AIHW 2018).

Standardised questionnaire and reports

NSW Health contractors work with water utilities to complete a standardised pre- and post-project questionnaire (Supplementary Material S1) to assess progress on drinking water management system implementation. The questionnaire contains 21 questions with a 'yes', 'no', and 'not applicable' answers, and two open-ended questions that allow water utilities to share insights on implementation barriers. Identified barriers or challenges are addressed throughout the projects where possible.

The NSW Health contractors summarise the results from the pre- and post-questionnaires in a project completion report. This report assesses the project's impact and identifies any ongoing support needs. Any unaddressed barriers or challenges are noted in the reports and will be considered by NSW Health as priority areas for future support projects.

Each local water utility is also asked to prepare an annual review report for its local public health unit on the implementation of their drinking water management systems. Annual review reports provide detail on CCP performance and improvement plan progress.

Categorisation and analysis of drinking water management system achievements and needs

To better understand, assess, and prioritise issues water utilities face with implementing drinking water management systems, a coding system was developed to capture and categorise the achievements and needs identified through support projects and annual review reports. Coding is used extensively in qualitative research to identify themes in within a data set (Gibbs 2007). Extensive data has been collected from more than 250 support projects, and a process of compacting diverse data into a structure was needed. Coding allowed for the identification and analysis of common themes and patterns arising from projects, such as the need for online monitoring or supervisory control and data acquisition (SCADA) upgrade.

The coded data was then entered into a Microsoft Access database to be kept organised and retrievable, and to allow for subsequent quantitative analysis, for example, most common needs identified for all utilities in the program.

The recommendations from drinking water management system implementation support projects, outcomes of standardised pre- and post-project survey, risk assessments and improvement plan items identified in annual review reports are recorded and coded into the database. The data is collected as a 'need', an 'achievement', or a 'need-met'. A 'need' becomes a 'need-met' when the contractor or the public health unit has verified that the 'need' has been met.

The codes are based on the 12 elements of the Framework for Management of Drinking Water Quality in the *Australian Drinking Water Guidelines* (NHMRC 2011). Seventy codes (Supplementary Material S2) were developed and grouped into six main categories: risk assessment, barriers, operation and maintenance, capacity resources and culture, fluoride, and work health and safety. This step helps identify overarching themes that emerged from the individual codes. Each code was risk assessed by the Water Unit in a workshop and assigned a risk level from low, medium, high to very high based on the public health risk potentially associated with the issue, using the risk matrix in the *Australian Drinking Water Guidelines* (NHMRC 2011).

Support projects have focused on improving the adequacy of drinking water management systems and their implementation by helping utilities improve operations, develop and provide training on standard operating procedures (SOPs) and incident management plans, improve operational monitoring, conduct annual management system reviews, and follow-up improvement plan actions. Projects have identified barriers and challenges to implementation that are out of the scope of the NSW Health support projects such as infrastructure upgrades and online monitoring needs.

Statistical analysis

The impact of NSW Health's support projects on the implementation of specific areas of drinking water management systems for water utilities was statistically analysed using McNemar's test in R Studio (version 2022-06-23 Build 492). From the 62 water utilities that participated, 86 projects (Supplementary Material S3) were completed and analysed for this paper.

The McNemar's test compared the 86 paired nominal results from the first 21 questions pre- and post-project surveys. The surveys yielded 'Yes', 'No', 'Not applicable', or blank answers. Question 22 was excluded from the statistical analysis because the question could not be answered with 'Yes', 'No', or 'Not applicable'.

The responses to each question from the pre- and post-project surveys were paired to form the categories of 'Before: Yes, After: Yes' 'Before: Yes, After: No', 'Before: No, After: Yes', and 'Before: No, After: No'. Blank responses were excluded from the analysis. The frequency of each category was collated for each question across the 86 projects in Microsoft Excel. The null

hypothesis is that the support projects had no impact on water utilities implementing specific areas of their drinking water management system.

The frequencies were then entered in R Studio to create a 2×2 contingency table for each question. The results were analysed for its *p*-value using the Exact McNemar analysis in R Studio.

The results with a *p*-value ≤ 0.05 are considered statistically significant and reject the null hypothesis. In other words, the support project had a statistically significant impact on water utilities implementing specific areas of their drinking water management system. The *p*-value data are provided in Supplementary Material S4.

Cryptosporidium risk assessment

In parallel, NSW Health worked with a microbial risk assessment specialist to develop quantitative microbial risk assessment model to assess the *Cryptosporidium* risk to water supplies in regional NSW (Petterson *et al.* 2021). Assessments were based on a combination of 30 case studies (including site visits) and a standardised survey of all local water utilities that focused on catchment risks and treatment processes. The model calculated the annual disability-adjusted life year (DALY) value per person for each system (with and without treatment), which was then used to rank all local water utility drinking water supplies in the state according to their *Cryptosporidium* risk. Assigning a ranking based on the individual adverse health outcome risk value was chosen to provide equitable ranking, independent of the population supplied. The approach of assessing risk using DALYs is consistent with the most recent update to the *Australian Drinking Water Guidelines* (NHMRC 2011).

RESULTS AND DISCUSSION

Better understanding of risks and improved management of CCPs

The introduction of drinking water management systems has resulted in acknowledgement of risks, closer attention to CCPs and, in many towns, incremental improvements in drinking water quality management.

A study of 66 water utility supplies in the Hunter New England region of NSW found that the introduction of drinking water management systems contributed to the increase in sampling compliance (from 64% in 2001 to 100% in 2015) and reduced *Escherichia coli* detections (from 5.0% in 2001 to 0.1% of samples in 2015) (Jaravani *et al.* 2020). This inverse relationship was likely associated with increased awareness, informed vigilance, and early recognition and response to adverse signals such as exceedances of CCP limits (for example, turbidity and chlorine) (Jaravani *et al.* 2020).

Across NSW, there have been some sustained improvements. Through the rigorous process of identifying CCPs, water utilities have improved data collection and their capacity to assess system performance (for example, close monitoring of filtration system performance via turbidity measurement). Before the introduction of drinking water management systems, some smaller water utilities recorded operational data on notebooks or printed forms. Many have now moved to electronic recording, allowing easy trend analysis.

While developing their management systems, many utilities expressed uncertainty about the turbidity reduction ability of their filters. More attention to operation and more regular monitoring has given utilities increased confidence in their equipment. It has also enabled them to optimise their filter operations, allowing them to more consistently meet the *Australian Drinking Water Guideline* individual filter turbidity values, targeting < 0.2 NTU and applying a critical limit of 0.5 NTU. Close monitoring of CCPs has also allowed water utilities and local public health units identify near-misses or incidents that may present a risk to public health, allowing for prompt action such as shutting down the treatment plant while performance is optimised, or issuing a 'boil water alert'. NSW Health has observed an increase in the number of 'boil water alerts' that are issued based on preventive reasons, including critical limit exceedances, rather than relying on end-point monitoring such as the detection of *E. coli* since the introduction of drinking water management systems in 2014 (Figure 1 and Supplementary Material S5).

In the years before 2014, a preventive trigger for a boil water alert usually meant that a utility could not adequately treat flood water. Since 2014, there has been an increasing proportion of alerts that are related to utilities recognising that they had exceeded the critical limit of a CCP. At least eight alerts in early 2020 were issued because of the effects of bushfires. The subsequent large numbers in 2020–2022 were the results of three very wet years, with numerous floods across wide areas of NSW. Not all boil water alerts could be classified as having an *E. coli* or preventive trigger, such as alerts issued when a main break emptied a supply network. These have been excluded from Figure 1 but represent only 4% of all boil water alerts in this period.

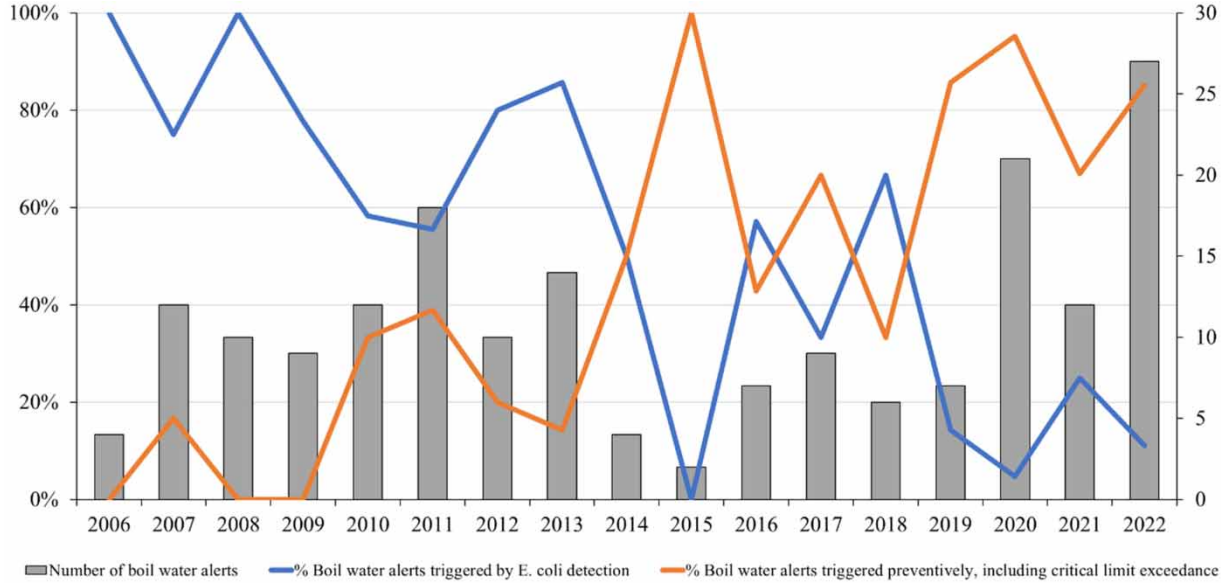

Figure 1 | Reasons for issuing boil water alerts 2006 to 2023.

Examples of NSW Health implementation support projects that lead to improvements

In 2019, a regional water utility was identified for a NSW Health support project following a near-miss incident of elevated turbidity in the clear water tank after backwash, which could impact the safety of the water supplied. The project scope included a review of the drinking water management system, which had last been formally updated in 2014, a review of the risk assessment and CCPs, development of operating procedures, and debrief of the incident. Prior to the project, it was identified that the CCPs sometimes had multiple limits for the same parameter while other limits were not in line with *Australian Drinking Water Guidelines* (NHMRC 2011).

The project reviewed and updated the drinking water management system and risk assessment. CCPs were updated to align with *Australian Drinking Water Guidelines* (NHMRC 2011) and NSW Health guidance, eight operational procedures were reviewed, four new procedures and an incident response plan were developed, an incident debrief conducted and staff awareness of CCPs improved through workshops. The improvement plan was updated, actions prioritised, and filter refurbishment fast tracked as a result.

The project completed with outstanding improvement plan actions identified including implementing automatic plant shutdown on critical limit exceptions and refurbishment of the remaining filters. The project identified barriers including aging infrastructure and lack of funding for water treatment plant upgrades and ongoing maintenance, and difficulties retaining a water and sewer engineer.

In 2020, a regional NSW water utility was identified for a NSW Health support project to review their drinking water management system. The water utility had built a new treatment plant with improved controls including online monitoring and SCADA, but the drinking water management system and risk assessment were not current, and the new plant required establishment of CCPs. Therefore, the drinking water management system did not identify the risks in the system and controls in place.

The scope of the project included a review and update of the drinking water management system, risk assessment and identification and documentation of CCPs for the new treatment plant. Operating procedures were documented for seven key processes and a drinking water quality incident response protocol was developed. The project developed editable procedures and drinking water management system documentation to be adopted and used by the utility to ensure they could develop further procedures, maintain and review their drinking water management system to manage risks and maintain currency.

The project completed with outstanding improvement plan actions identified including the need to formally communicate Council's commitment to the management of water quality and to implement a process for senior executive to review the

effectiveness of the drinking water management system. Staff would need to be made aware and trained on these updated documents. The project identified key barriers to implementation including a small customer base with a decline in population, which made recovery of costs challenging, lack of funding for required infrastructure projects including reservoir roof repair and replacement of mains, difficulties recruiting and retaining an adequate number of skilled staff due to remoteness of the utility and salary offered, high turn-over of staff impacting knowledge transfer between old and new staff and difficultly maintaining appropriate technical supervision and support. The remoteness of the utility was also identified as a barrier, with the distance between supply systems impacting ability to manage water supplies, limiting access to services (for example, communications networks to enable remote monitoring and control of CCPs by telemetry, and qualified tradespeople to assist in routine maintenance or responding to critical equipment failures).

Standardised project and annual review reporting has focused support, improved management system implementation, and identified ongoing priorities

Analysis of the standardised pre- and post-project surveys has highlighted the benefits that the support had on implementing key areas of drinking water management systems.

The results show that NSW Health support projects led to a statistically significant impact (p-value ≤ 0.05) on 12 out 21 key areas of drinking water management system implementation. The key areas are defined from the 21 questions in the pre- and post-project surveys. Out of the 12 key areas shown to have a statistically significant impact, 11 key areas improved as indicated by the increased percentage of 'Yes' responses after the support project (Figure 2). The greatest reported benefits from support projects are related to improved review activities, including review and update of improvement plans, annual review and update of the management system, regular review of CCP performance, risk assessment review, and submission of the updated drinking water management system to NSW Health (Figure 2).

The 12th key area with a statistically significant result refers to the outstanding high priority items on the improvement plan after the support project. There was an increase in 'Yes' responses after the support project (Figure 2), which indicates that more water utilities were able to find areas of improvement through the NSW Health support projects. This highlights the need for ongoing support from NSW Health to assist water utilities in identifying and addressing improvement actions so that their drinking water management system remains robust and proactive in managing water quality risks.

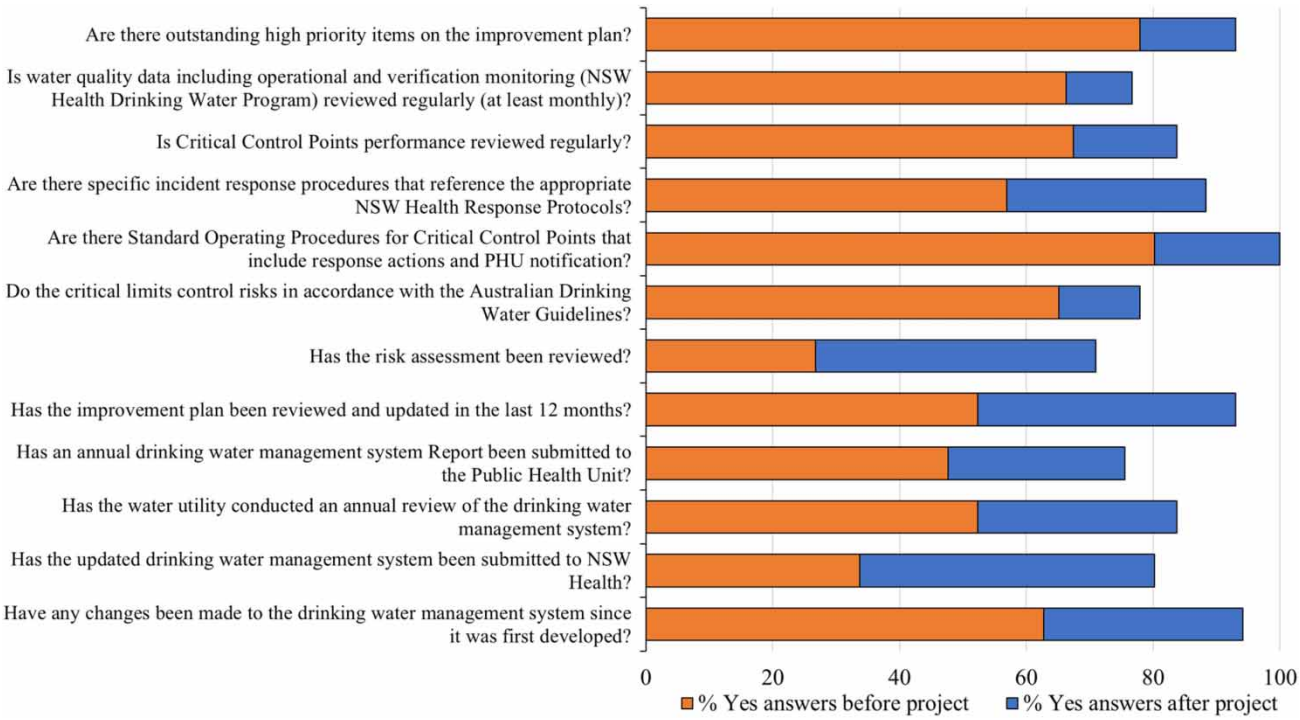

Figure 2 | Impact of drinking water management system implementation support projects (all $p \leq 0.05$).

There are 9 out of 21 key areas of the drinking water management system implementation that did not show a statistically significant change, and these are:

- having a nominated person responsible for updating and implementing drinking water management system,
- having SOPs for other operational activities,
- using SOPs,
- documenting, displaying, and using CCP limits to operate the treatment plant,
- online monitoring and reporting of CCP parameters into a SCADA system,
- having relevant staff trained to use SOPs,
- having relevant staff trained in incident response protocols,
- exercising and using incident response protocols to manage an incident, and
- responding to CCP exceedances in accordance with the CCP SOP and reporting to the public health unit.

A high percentage (>70%) of water utilities were already implementing the key areas of having a nominated person, having SOP for other operational activities, using SOPs, and displaying CCP limits at treatment plant prior to the NSW Health support projects (Supplementary Material S3). Therefore, the NSW Health support projects could have minimal impact in improving or supporting drinking water management system areas that are already implemented by the water utility.

The next three areas relating to SCADA and staff training are dependent on the water utilities' resources to implement new infrastructure and access training. It is expected that NSW Health support projects are unlikely to make changes in these areas due to out-of-scope factors such as infrastructure needs and external training requirements, and resource limitations.

The last two areas are event-based actions, whereby the water utilities' response is dependent on the occurrence of an incident or CCP exceedance. It is likely that some water utilities had not experienced any incidences or CCP exceedance during the project for it to cause a statistically significant result. This will require a separate, targeted analysis once there is more data from future projects and a formal audit program.

Although the NSW Health support projects did not cause a statistically significant impact in these areas, assessing these key areas is useful in understanding the needs of water utilities and how support projects can be improved to meet those needs.

Review of the post-project surveys has identified high priority areas to improve implementation of drinking water management systems and the control of health risks. Post-project survey results are used to prioritise ongoing NSW Health support. The areas with the most 'No' responses after the support project, regardless of their *p*-value, are presented in Figure 3.

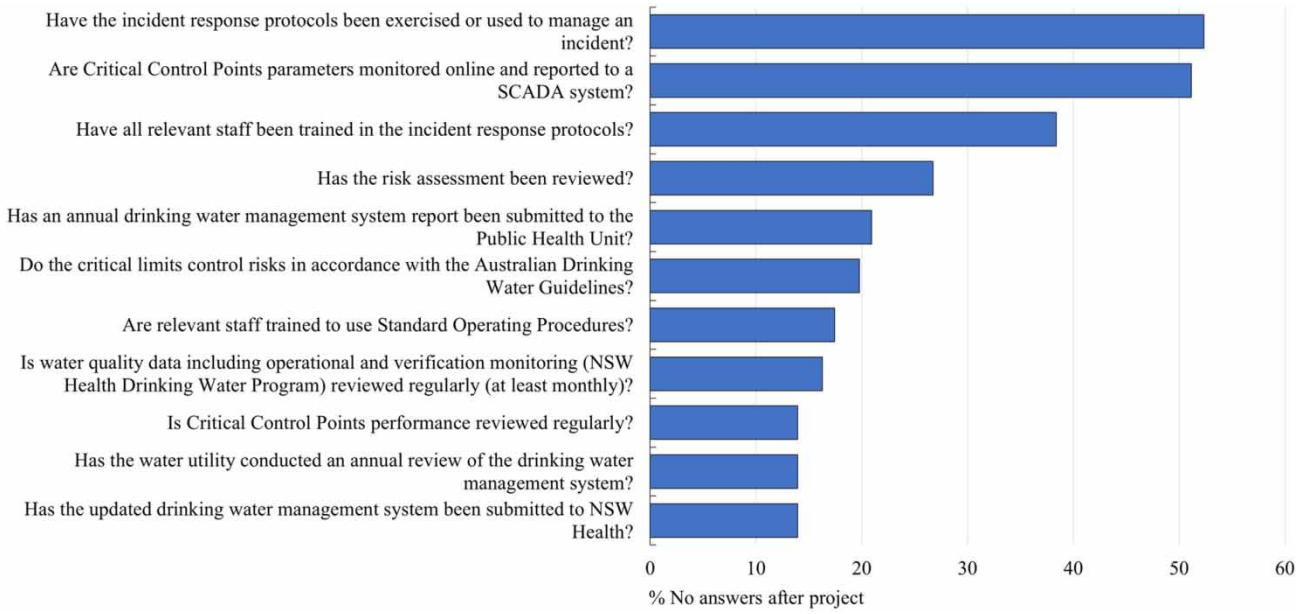

Figure 3 | Priority areas to improve implementation of drinking water management systems.

Areas for future support and focus include improving or establishing online operational monitoring and control systems, risk assessment review, submission of annual review reports to local public health units, and ensuring critical limits control risks in accordance with that *Australian Drinking Water Guidelines* (Figure 3).

Annual review report findings

Similarly, assessment of annual review reports identified common themes and challenges that water utilities face with implementing drinking water management system. The majority of implementation issues identified from the review of annual review reports from 69 water utilities are related to operation matters. The most common areas identified to require improvements were in the development and documentation of operational procedures, incident and emergency response plans, improvement plans, and maintaining reticulation systems. This understanding allows NSW Health to focus future support and guidance on addressing priority areas common to many water utilities.

Supporting upgrades to infrastructure

Implementation of management systems has highlighted a number of potential infrastructure needs and treatment control upgrades. Some water supplies lack infrastructure, such as monitoring and control systems, that are needed to effectively and reliably manage public health risks from *Cryptosporidium*, cyanobacteria (blue-green algae) blooms, and other contamination risks. In these cases, NSW Health's support projects help provide good quality data to inform applications for funding for upgrades.

NSW Health's analysis of needs has helped inform the NSW Government's Safe and Secure Water Program, which has committed $1 billion to support public health, water security, environmental outcomes, and/or social benefits (NSW DPE 2023a). The Safe and Secure Water Program co-funds water and sewerage infrastructure projects. In line with the State Infrastructure Strategy 2018–2038, NSW Health and DPE Water work with utilities to identify and prioritise infrastructure projects to protect drinking water safety. NSW Health's analysis of needs also helped inform the development of the Town Water Risk Reduction Program, which is a collaboration of the NSW Government, local water utilities, and the wider water sector (NSW DPE 2023b). The Town Water Risk Reduction Program aims to manage risks and priorities in water systems more strategically and effectively and, as a result, reduce risks in regional communities over time. The program is being implemented in partnership with NSW Health. Its aims include addressing skills and training needs, and supporting the optimisation and monitoring of water treatment infrastructure. The outcomes of NSW Health's drinking water management system support projects will guide the prioritisation of local water utilities to be supported under the Town Water Risk Reduction Program.

Insights from implementing drinking water management systems in NSW

The *Australian Drinking Water Guidelines* embody a preventive risk management approach (NHMRC 2011). By supporting and requiring water utilities to develop and implement drinking water management systems that incorporate this preventive risk management approach, NSW Health has seen a shift from a traditionally reactive approach to water quality management. Water utilities in NSW have improved their understanding of their water quality risks and how these risks are managed. The focus on CCP operations has helped to bring this shift into the workplace culture of regional water utilities. This shift requires high levels of commitment to drinking water management systems by water utilities and regulators.

Commitment to managing drinking water quality is the first element in the Framework from the *Australian Drinking Water Guidelines* and is essential at all levels of governance (NHMRC 2011). McLaren and colleagues (2022) discussed the failing of two large drinking water supplies that lead to substantial public health impacts, in Flint, Michigan, USA and in Havelock North, New Zealand. Both incidents showed a lack of commitment from water utility staff and government agencies in proactively responding to a history of issues within the water supplies that had a potential impact on public health. The Inquiry into Havelock North recommended improved regulatory oversight with the introduction of a drinking water regulator and requirements for water safety plans to be living documents, reviewed frequently and to ensure all levels of utility governance have the understanding of drinking water risks, and a focus on CCPs (Government Inquiry into Havelock North Drinking Water 2017). Despite having a water safety plan, Havelock North still experienced a significant water quality incident as the plan was not appropriately regulated or implemented effectively (McLaren *et al.* 2022).

NSW Health has found the application of drinking water management systems in NSW is a journey of incremental improvement that requires continual robust and water utility specific support. Taking a support approach has not only improved implementation of drinking water management systems but also informed the development of a formal auditing

program. The information provided about water utility drinking water management system implementation and readiness for audit allowed the development of an audit program that focuses on continual improvement.

A limitation of drinking water management system implementation support projects is their focus on specific identified risks. They do not evaluate holistic implementation of the Framework. Like Sutherland & Payden (2017), who reflected on the experience of water safety planning in South-East Asia, NSW Health has learned that long-term support to water utilities will be required to ensure drinking water management systems in NSW are fully implemented, sustainable and drive continual improvement in drinking water quality management. The findings, recommendations, and opportunities for improvement identified during formal auditing of drinking water management systems are expected to inform this holistic view and allow for better understanding of drinking water management system implementation and the needs of water utilities across NSW (Sutherland & Payden 2017).

Many local water utilities in regional NSW serve small, and in some cases declining, populations. This places a significant challenge on these utilities to implement their drinking water management systems, but also fund water infrastructure needs and operating costs. (Nguyen and colleagues 2023) identified the importance of government support in Vietnam for smaller water supplies who face financial constraints and challenges with implementing water safety plans. Staff shortages are another key challenge facing almost all water utilities in Australia (Productivity Commission 2021). Low remuneration, remoteness, and high workload are key factors impacting the ability of regional utilities to attract and retain skilled staff. Vacancies are often filled by staff from neighbouring utilities due to low numbers of new industry entrants. This is particularly acute in the more remote parts of NSW, where there may be limited access to tradespeople to assist in routine maintenance or responding to critical equipment failures, or communication networks to remote monitoring and control of CCPs via telemetry, as identified in the 2020 case study presented earlier in the paper. These challenges highlight that ongoing support is needed to assist utilities to manage water quality risks.

CONCLUSION

Since 2010, NSW Health has worked alongside local water utilities to help them develop and implement risk-based drinking water management systems. This partnership approach has assessed water quality risks and informed the development of new infrastructure funding programs, the development of a formal audit program and better government collaboration. NSW Health's support projects have resulted in statistically significant improvements across many elements of drinking water management system implementation. This support has benefited regional communities, and especially smaller utilities, by helping to identify and better control risks. The introduction of risk-based drinking water management systems has driven incremental improvement in drinking water quality management across the state of NSW. Ongoing support is needed due to the financial and resource constraints faced by many regional water utilities.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Australian Institute of Health and Welfare (AIHW). 2018 *Australia's Health 2018: In Brief (Full Publication; 18 June 2019 Edition)*. AIHW. Available from: https://www.aihw.gov.au/getmedia/fe037cf1-0cd0-4663-a8c0-67cd09b1f30c/aihw-aus-222.pdf.aspx?inline=true.

Baum, R., Amjad, U., Luh, J. & Bartram, J. 2015 An examination of the potential added value of water safety plans to the United States national drinking water legislation. *International Journal of Hygiene and Environmental Health* **218** (8), 677–685.

Byleveld, P. M., Cretikos, M. A., Leask, S. D. & Durrheim, D. N. 2008 Ensuring safe drinking water in regional NSW: the role of regulation. *New South Wales Public Health Bulletin* **19** (12), 203–207. https://doi.org/10.1071/NB08031.

Byleveld, P., Leask, S., Jarvis, L., Wall, K., Henderson, W. & Tickell, J. 2016 Safe drinking water in regional NSW, Australia. *Public Health Research and Practice* **26** (2), e2621615.

Gagnon, G. & Castleden, H. 2015 *Drinking Water Safety Plans*. Canadian Network Water. Available from: https://cwn-rce.ca/wp-content/uploads/2015/04/Drinking-Water-Safety-Plan-Report-2015.pdf (accessed 14 June 2023).

Geoscience Australia. 2023 *Area of Australia – States and Territories*. Available from: https://www.ga.gov.au/scientific-topics/national-location-information/dimensions/area-of-australia-states-and-territories.

Gibbs, G. 2007 *Analyzing Qualitative Data*. doi:10.4135/9781849208574.

Government Inquiry into Havelock North Drinking Water. 2017 *Report of the Havelock North Drinking Water Inquiry: Stage 2*. Auckland, New Zealand. Available from: dia.govt.nz/diawebsite.nsf/Files/Report-Havelock-North-Water-Inquiry-Stage-2/$file/Report-Havelock-North-Water-Inquiry-Stage-2.pdf.

Gunnarsdottir, M. J., Gardarsson, S. M., Elliott, M., Sigmundsdottir, G. & Bartram, J. 2012 Benefits of water safety plans: microbiology, compliance, and public health. *Environmental Science & Technology* **46** (14), 7782–7789.

Jaravani, F. G., Butler, M., Byleveld, P., Durrheim, D. N., Massey, P. D., Collins, J., Judd, J. A. & Oelgemöller, M. 2020 Drinking water quality in regional Hunter New England, New South Wales, Australia, 2001–2015. *Australasian Journal of Water Resources* **24** (1), 73–83.

Lane, K., Stoddart, A. K. & Gagnon, G. A. 2018 Water safety plans as a tool for drinking water regulatory frameworks in Arctic communities. *Environmental Science and Pollution Research* **25**, 32988–33000.

McLaren, S. J., Sahli, M. W., Selig, S., Masten, S. J. & Page, W. H. 2022 The drinking water crises of Flint and Havelock North: a failure of public health risk management. *Journal of Water and Health* **20** (9), 1314–1328. doi:10.2166/wh.2022.035.

National Health and Medical Research Council (NHMRC). 2011 *National Water Quality Management Strategy, Australian Drinking Water Guidelines Paper 6*. Available from: https://www.nhmrc.gov.au/sites/default/files/documents/reports/aust-drinking-water-guidelines.pdf.

Nguyen, V.-A., Tran Thi Hien, H., Nijhawan, A., Howard, G. & Nghia Ton, T. 2023 Evaluation of water safety plan implementation at provincial water utilities in Vietnam. *Journal of Water and Health* **21** (1), 47–65.

NSW Department of Planning and Environment (NSW DPE). 2023a *Safe and Secure Water Program*. Available from: https://www.industry.nsw.gov.au/water/plans-programs/infrastructure-programs/safe-and-secure-water-program.

NSW Department of Planning and Environment (NSW DPE). 2023b *Town Water Risk Reduction Program*. Available from: https://www.dpie.nsw.gov.au/water/plans-and-programs/town-water-risk-reduction-program.

NSW Government. 2010 Public Health Act No. 127, Sydney, New South Wales Government.

NSW Government. 2023 *Key Facts About NSW*. Available from: https://www.nsw.gov.au/about-nsw/key-facts-about-nsw.

NSW Health. 2013 *NSW Guidelines for Drinking Water Management Systems*. Available from: https://www.health.nsw.gov.au/environment/water/Pages/NSW-guidelines-for-drinking-water-management-systems.aspx.

NSW Health. 2018 *Critical Control Points for Drinking Water Management Systems*. Available from: https://www.health.nsw.gov.au/environment/water/Pages/critical-control-points.aspx.

NSW Health. 2023 *Incorporating Health-Based Targets Into Drinking Water Management Systems and Section 60 Approvals*. Available from: https://www.health.nsw.gov.au/environment/factsheets/Pages/incorporating-hbts-into-dwms-and-s60.aspx.

O'Connor, D. R. 2002 *A Strategy for Safe Drinking Water – Part Two of the Report of the Walkerton Inquiry, Ministry of the Attorney General*. Available from: http://www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton.

Ontario Ministry of the Environment (MOE). 2007 *Implementing Quality Management: A Guide 30 for Ontario's Drinking Water Systems*. Available from: https://www.ontario.ca/page/ontarios-drinking-water-quality-management-standard-pocket-guide.

Perrier, E., Kot, M., Castleden, H. & Gagnon, G. A. 2014 Drinking water safety plans: barriers and bridges for small systems in Alberta, Canada. *Water Policy* **16** (6), 1140–1154.

Petterson, S., Bradford-Hartke, Z., Leask, S., Jarvis, L., Wall, K. & Byleveld, P. 2021 Application of QMRA to prioritise water supplies for *Cryptosporidium* risk in New South Wales, Australia. *Science of The Total Environment* **784**, 147107. https://doi.org/10.1016/j.scitotenv.2021.147107.

Productivity Commission. 2021 *National Water Reform 2020. Findings, recommendations and renewal advice.* Inquiry Report no. 96, Canberra, Australian Government.

Reid, D. C., Abramowski, K., Beier, A., Janzen, A., Lok, D., Mack, H., Radhakrishnan, H., Rahman, M. M., Schroth, R. & Vatcher, R. 2013 Implementation of Alberta's drinking water safety plans. *Water Quality Research Journal* **49** (1), 5–9. doi:10.2166/wqrjc.2013.063.

Sutherland, D. & Payden 2017 Observations and lessons learnt from more than a decade of water safety planning in South-East Asia. *WHO South-East Asia Journal of Public Health* **6** (2), 27–33. Availabel from: https://doi.org/10.4103/2224-3151.213788.

World Health Organization – Europe (WHO EURO), Umwelt Bundesamt (UBA), & International Water Association (IWA) 2014 *European Strategic Workshop on Water Safety Planning*. Available from: http://www.umweltbundesamt.de/sites/default/files/medien/374/dokumente/berlin_wsp_workshop_report_final.pdf (accessed 14 June 2023).

World Health Organization (WHO). 2009 *Water Safety Plan Manual Step-by-Step Risk Management for Drinking-Water Suppliers*. Available from: https://apps.who.int/iris/handle/10665/75141.

World Health Organization (WHO). 2012 *Water Safety Planning for Small Community Water Supplies: Step-by-Step Risk Management Guidance for Drinking-Water Supplies in Small Communities*. World Health Organization, Geneva.

World Health Organization (WHO). 2022 *Guidelines for Drinking-Water Quality, Fourth Edition Incorporating the First and Second Addenda*. Available from: https://www.who.int/publications-detail-redirect/9789240045064.

World Health Organization (WHO). 2023 *Water Safety Plan Manual: Step-by-Step Risk Management for Drinking-Water Suppliers*, 2nd edn. Available from: https://iwa-network.org/wp-content/uploads/2023/02/WHO_WSPManual2ndEd_final.pdf.

First received 15 May 2023; accepted in revised form 10 July 2023. Available online 20 July 2023