Journal of Water & Health

IWA PUBLISHING

Journal of Water and Health Vol 21 No 12, 1761 doi: 10.2166/wh.2023.100

Development of a tool to support operationalising water safety plans: experiences from a national water utility in Ghana

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ABSTRACT

Since their incorporation into the 2004 version of the World Health Organization's (WHO's) Guidelines for Drinking Water Quality (GDWQ), Water Safety Plans (WSPs) continue to be the pre-eminent process for the delivery of safe drinking water to consumers. WSPs achieve this by prioritising proactive, rather than reactive, management of risks to drinking water quality. Since the use of WSPs was incorporated into the GDWQ, a range of supporting resources have been produced to assist water suppliers in preparing WSPs. Producing a robust WSP is an important first step in the management of risk, but in many cases, the implementation of WSPs presents significant challenges, particularly in relation to the implementation of Module 5 (implementing improvements) and Module 6 (monitoring of control measures). To address barriers to WSP implementation, the Ghana Water Company Limited (GWCL), in a peer-to-peer partnership with two Australian water utilities, developed a pilot WSP implementation strategy for one of the company's drinking water supply systems. One of the outputs of the collaboration was the development of a framework for operationalising water safety planning, which incorporates basic guidance for embedding the WSP within routine operations, in order to ensure the safe management of drinking water.

Key words: Ghana, implementation, operational framework, water safety plans

HIGHLIGHTS

- Demonstration of the benefits of peer-to-peer support to improve operational practice.
- Development of an adaptable and scalable operational framework to assist WSP implementation.
- Organisational adoption of the operational framework, which facilitates both improved water treatment practice and the monitoring of the effectiveness of control measures.
- Operational framework could be used as a checklist when conducting internal and external WSP audits.

INTRODUCTION

Since their incorporation into the 2004 version of the World Health Organization's (WHO's) Guidelines for Drinking Water Quality (GDWQ) (WHO 2004), Water Safety Plans (WSPs) continue to be the pre-eminent process for the delivery of safe drinking water to consumers. Water safety planning achieves this by prioritising proactive, rather than reactive, management of risks to drinking water quality (WHO 2005, 2023).

In 2017, WHO and the International Water Association (IWA) released a comprehensive review on the national adoption of WSPs (WHO & IWA 2017), which found that WSPs had been developed and implemented in 93 countries worldwide.

As detailed in the GDWQ (WHO 2022a), there are 11 steps involved in developing a WSP. These 11 steps are described as modules in WHO's 2009 WSP Manual and are summarised in Figure 1.

In Figure 1, Module 6 is highlighted, as the primary aim of this project was to create an operational framework to support improved implementation of this module within suppliers that have had difficulties in achieving effective implementation.

The field component and write-up of this project were undertaken in late 2019 and early 2020, prior to the release of a second edition of the WSP Manual (WHO 2023). The second edition of the Manual, while still based on 11 modules, has revised titles for each of the modules. This paper uses the module titles that were current at the time of the project.

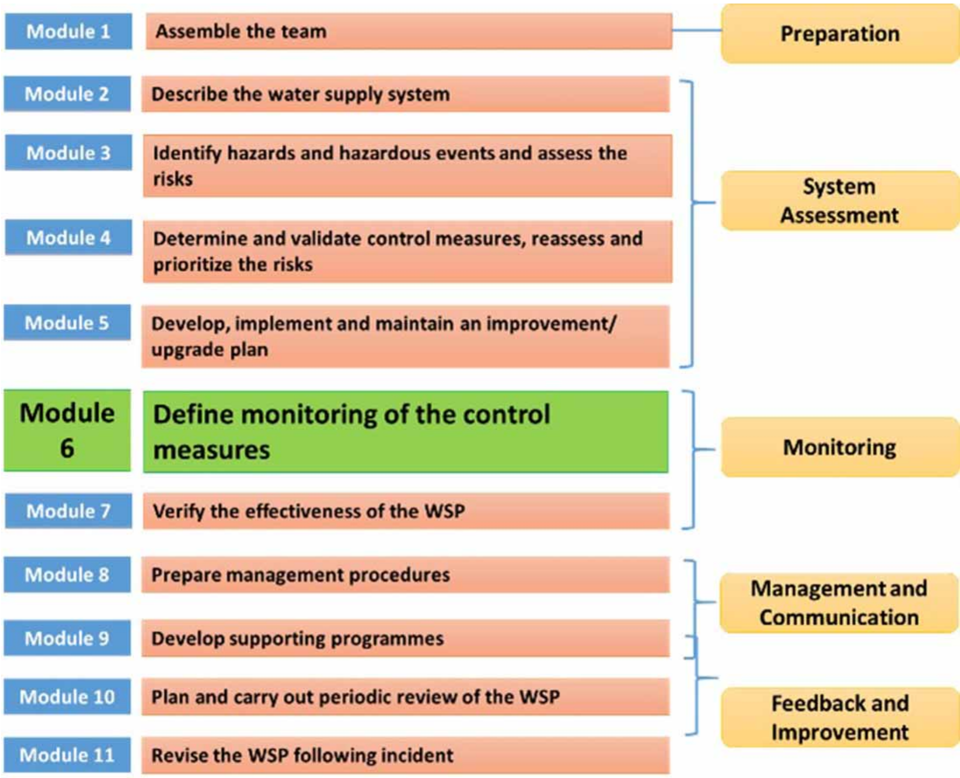


Figure 1 | Eleven modules of WSPs (adapted from Bartram *et al.* (2009).

Despite the widespread adoption of WSPs, and the production of a range of supporting resources to assist water suppliers in preparing and implementing WSPs (WHO 2016, 2019; Setty & Ferrero 2021), a number of barriers to successful WSP implementation continue to exist (Ferrero *et al.* 2019). Kumpel *et al.* (2018) looked at the effectiveness of WSP implementation across 99 water supply utilities in 12 countries in the Asia-Pacific region. This study identified the benefits that arose from the adoption of WSPs, but it also identified a number of challenges to their effective implementation, including financial constraints and insufficient capacity.

Comprehensive reviews of WSP implementation, and associated barriers have also been undertaken in Germany (Schmiege *et al.* 2020) and Vietnam (Nguyen *et al.* 2023). Consistent with Kumpel *et al.* (2018), a number of barriers to local WSP implementation were found. In the case of Germany, amongst other issues, developing a national WSP strategy, securing financial instruments, and undertaking activities to support the continual implementation of WSPs appeared to be scarce (Schmiege *et al.* 2020), while, in Vietnam, key barriers to WSP implementation were a lack of WSP guidance suitable for the local context and insufficient funds for WSP implementation (Nguyen *et al.* 2023).

While the barriers and challenges identified in the quoted articles are not the focus of this paper, what they highlight is that, despite the clear benefits that WSPs bring to the ongoing provision of safe drinking water, the universal adoption, and effective and sustained implementation of, water safety planning remains elusive.

Developing and documenting the WSP is an important first step in the management of risk, but a WSP's role as an operations and management tool needs to be emphasised (WHO 2019). The emphasis on developing and documenting the WSP can result in a tendency for WSPs to focus primarily on risk assessment and improvement planning, rather than also giving due attention to the ongoing operations, management, monitoring and review aspects of water safety planning. It is the latter elements of a WSP that underpin its effectiveness and sustainability, by making clear that water safety planning is not a one-off event intended only to identify and address current problems, but instead, that effective WSPs rely on a long-term commitment to improved system management. Having due regard for this aspect of WSPs facilitates their integration into routine operations.

For the purposes of this paper, the operationalisation of a WSP, or, alternately, operationalising a WSP, refers to the integration of the WSP into routine operations, whether this be within the catchment area of the water supply system, or across any associated water treatment facilities or distribution network.

In practical terms, operationalising a WSP requires its implementation in the field, particularly in relation to the implementation of Module 5 (implementing improvements) and Module 6 (monitoring of control measures). These operational aspects are critically important to achieving and sustaining the benefits of water safety planning.

Ghana Water Company Limited (GWCL), which is the major water supplier to urban areas in Ghana, was an early adopter of WSPs. Since 2004, GWCL has been working in collaboration with the country's Public Utilities Regulatory Commission (PURC) on the development of WSPs for various water supply systems. In 2018, PURC included WSPs as a key performance indicator (KPI) for GWCL. Consequently, management identified the need for the development of a framework that would facilitate and promote the standardisation of WSP implementation across the 96 water supply systems managed by GWCL.

GWCL has developed WSPs for a number of water supply systems, however, sustainable implementation of these WSPs has remained elusive. The key challenges to the adoption of WSPs were identified as a lack of an operational policy and guidance document, and inadequate capacity to develop the framework.

This paper describes the approach that was undertaken to address this implementation gap through the development of an operationalisation framework that would help support sustainable WSP implementation across the water supply systems operated by GWCL.

METHODS

In early 2018, GWCL approached WHO and IWA, seeking support to undertake a project to strengthen the adoption and implementation of WSPs across GWCL's water supply systems. With support provided by United Nations International Children's Emergency Fund (UNICEF), WHO engaged WSP experts from two water utilities, Yarra Valley Water and Coliban Water, which are based in the Australian state of Victoria, to deliver the project.

An important aspect of the project was that it was structured on a peer-to-peer model, where operational experience on the day-to-day management of water treatment plants (WTPs) within a WSP could be shared and discussed.

Both Yarra Valley Water and Coliban Water have close to 17 years of experience with the development and implementation of WSPs, as Victoria was one of the first jurisdictions in the world to include a formal legal requirement for WSPs in its drinking water legislation (*Safe Drinking Water Act 2003*, Victorian Government, Australia). Victoria's Safe Drinking Water Act, which commenced on 1 July 2004, required all Victorian water suppliers to develop and implement WSPs by 1 July 2005. The risk management framework that underpins the requirements of the Act is detailed in the Australian Drinking Water Guidelines (ADWG) (NHMRC 2011). The risk framework detailed in the ADWG largely mirrors the content of WSPs contained in the GDWQ.

The primary output for the project was the development of a framework that would allow GWCL to operationalise its WSPs. The approach focussed on developing such a framework for a trial site, which could then be scaled-up to all WTPs under GWCL's operation.

The trial site for the project was GWCL's Kwanyako WTP. The Kwanyako WTP, which is located approximately 60 kilometres from Accra, the capital of Ghana (Figure 2), services the townships of Kwanyako, Agona Swedru, Agona Nyarkrom, Mensakrom, Bawjiasi, and Budumburam.

Kwanyako WTP was chosen as the trial site because a draft WSP had been developed for the WTP and associated water supply system, but finalisation and implementation had stalled. This site was also considered to be representative of other systems operated by GWCL.

In October 2019, two WSP experts from Coliban Water spent 4 days in Ghana working first-hand with operational staff at the Kwanyako WTP, in order to fully understand the operation of the water supply system and associated challenges.

In the company of operational staff, and using their site knowledge and expertise, the water treatment process was tracked from the point where raw water was extracted from the Ayensu River to when the fully treated water was sent to the townships of Kwanyako, Agona Swedru, Agona Nyarkrom, Mensakrom, Bawjiasi, and Budumburam.

The Kwanyako WTP is what is generally described as a conventional WTP, in that it consists of a clarification step, followed by dual media filtration and then chlorination. At the time of the visit, there was limited automation at the plant, with processes such as the backwashing of the dual media filters being undertaken manually.

In addition to the site visit, meetings were held with both senior water quality staff and management at GWCL, to gain an understanding of how the principles and practices of WSPs had thus far been embedded into the organisation, and to seek to identify additional opportunities to enhance current practices.

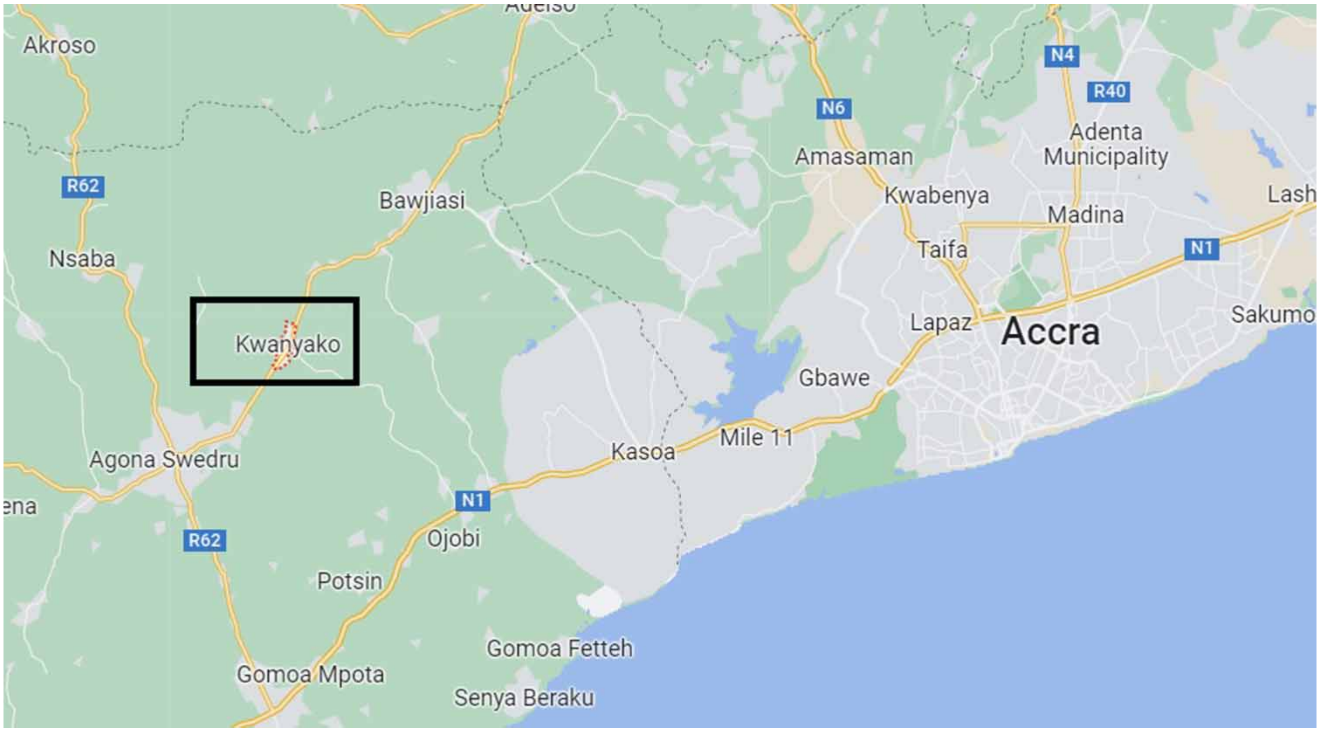


Figure 2 | Location of Kwanyako, Ghana (image sourced from Google Maps).

The field visit was conducted on a single day, and the catchment area and the townships that are supplied by the Kwanyako WTP were not visited. A detailed report on opportunities for operational improvement in Kwanyako WTP was prepared, along with the creation of a more generic operational framework that could be adapted and applied to other WTPs operated by GWCL. The catchment and distribution aspects reflect current good practice, but only the operational, treatment aspects draw from the direct observations at the Kwanyako WTP.

RESULTS

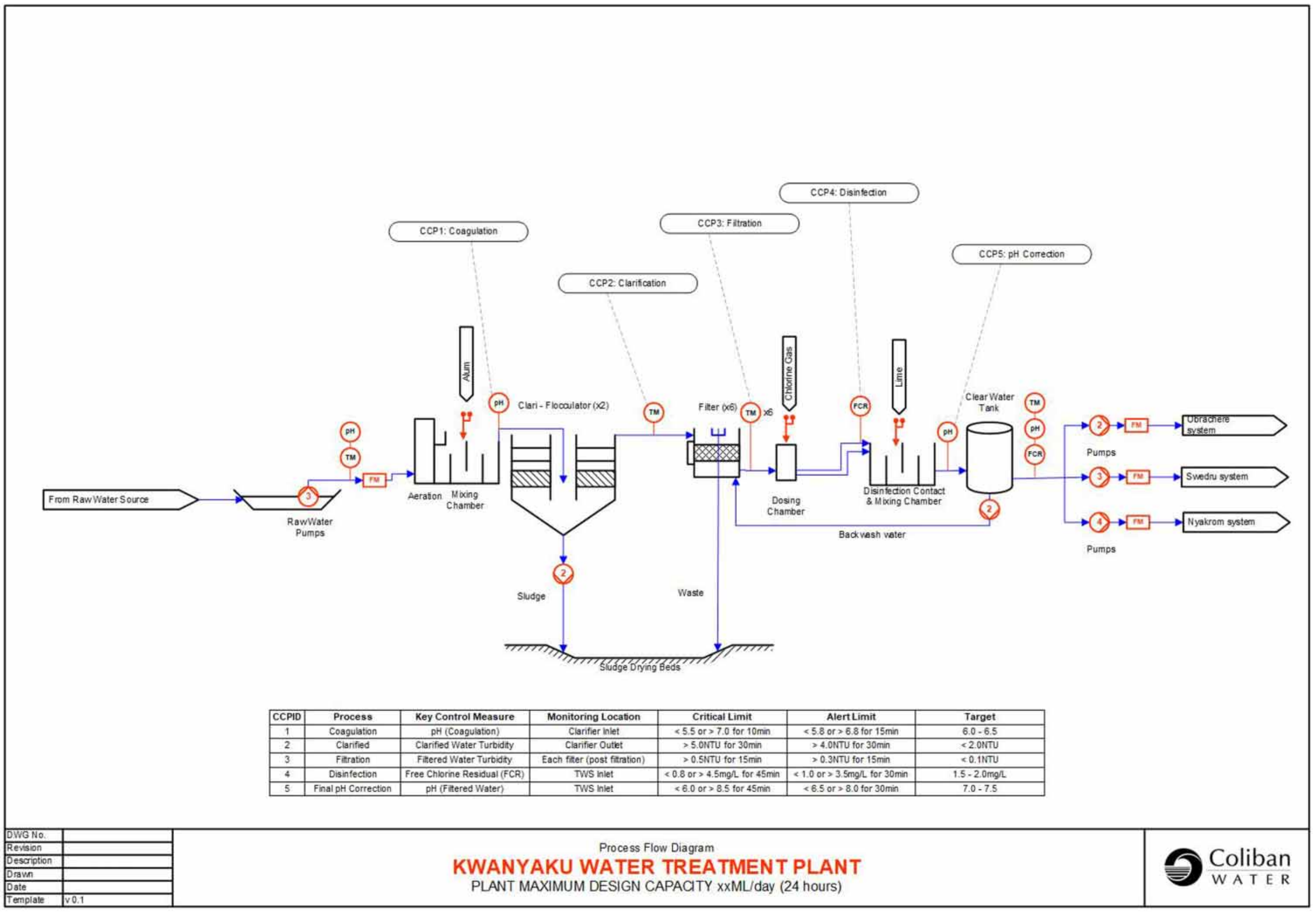
The first output from the in-country work was a detailed report on operational improvements that could be made at the Kwanyako WTP to improve plant performance. One important aspect of the report was the identification of likely critical control points (CCPs) across the WTP, and the specification of alert and critical limits for each CCP, in line with Hazard Analysis Critical Control Point (HACCP) principles.

While mentioned in both the first and second editions of the WSP Manual, the application of HACCP principles within a WSP is not explored in detail. In summary, HACCP was developed to assist the food industry in ensuring that potentially unsafe foods are quickly identified during the manufacturing process, and it has subsequently been adopted by water suppliers as a way of managing the performance of treatment processes (APHA 1972; AIFST 1989; Havelaar 1994; Deere & Davison 1998).

A hazard analysis (HA) is undertaken, which is the first element of the risk assessment undertaken as part of a WSP. The outputs of the HA are used to identify those points that are critical to the production of safe drinking water, specifically at those points in the process where operational control can be exerted over the process, known as CCPs.

At each CCP, alert and critical limits are put in place. If an alert limit is breached, it alerts operational staff that a water treatment process is tending towards failure. If a critical limit is breached, then the water treatment process has failed and there is a higher probability that unsafe drinking water is being produced.

These recommendations were presented in the same format that Coliban Water uses for its management of CCPs at its WTPs (Figure 3).



CCPID	Process	Key Control Measure	Monitoring Location	Critical Limit	Alert Limit	Target
1	Coagulation	pH (Coagulation)	Clarifier Inlet	< 5.5 or > 7.0 for 10min	< 5.8 or > 6.8 for 15min	6.0 - 6.5
2	Clarified	Clarified Water Turbidity	Clarifier Outlet	> 5.0NTU for 30min	> 4.0NTU for 30min	< 2.0NTU
3	Filtration	Filtered Water Turbidity	Each filter (post filtration)	> 0.5NTU for 15min	> 0.3NTU for 15min	< 0.1NTU
4	Disinfection	Free Chlorine Residual (FCR)	TWS Inlet	< 0.8 or > 4.5mg/L for 45min	< 1.0 or > 3.5mg/L for 30min	1.5 - 2.0mg/L
5	Final pH Correction	pH (Filtered Water)	TWS Inlet	< 6.0 or > 8.5 for 45min	< 6.5 or > 8.0 for 30min	7.0 - 7.5

Figure 3 | Suggested CCP plan for the Kwanyako WTP.

In a tabular format, the recommended CCPs and their associated alert and critical limits, along with target values for each process, are presented in Table 1. Also included in Table 1 is the rationale for classifying these particular points in the treatment process as CCPs.

Following extensive engagement with operational staff, the critical and alert limits were tailored to reflect the local circumstances (for example, the limited availability of process automation at the WTP at the time of the site visit). In modifying some of the limits, it was important that while some of the values were less stringent than what might be applied at WTPs in Australia if the proposed limits were consistently met, there was still a high probability that the water being produced by the Kwanyako WTP would be safe to use as drinking water.

The report was based around a continuous improvement model, where the WTP would be optimised based on the capability and limitations of the available treatment processes, with many of the recommended improvements being either no-cost, or low-cost, changes to current operation, but, as funds became available to invest in any necessary capital upgrades, the alert and critical limits could be reviewed and tightened, as appropriate.

The information and recommendations in the report could also be fed back into the draft WSP for the Kwanyako water supply system, in order to further develop Modules 5 and 6 of the WSP so that they were reflective of current operational practice at the Kwanyako WTP.

The second, and more substantial, part of the project was the development of an operational framework document that could be applied across all of GWCL's water supply system, as the basis of Modules 5 and 6 of any WSP.

Many comprehensive and high-quality guides have been produced to assist water utilities of varying sizes and circumstances in developing WSPs (WHO 2005, 2023). A potential limitation has been that these guides have generally not gone into great detail on how the water should be treated, and what operational controls should be put in place to manage the

Table 1 | Recommended CCPs for Kwanyako WTP

	Critical control point identification number (CCPID)				
	1	2	3	4	5
Process	Coagulation	Clarifier	Filtration	Disinfection	Final pH correction
Key Control Measure	pH (Coagulation)	Clarified Water Turbidity	Filtered Water Turbidity	Free Chlorine Residual (FCR)	pH (Filtered Water)
Monitoring Location	Clarifier Inlet	Clarifier Outlet	Each Filter (post filtration)	TWS Inlet	TWS Inlet
Rationale	The pH at the time of coagulation has a significant bearing on the effectiveness of the coagulation process	In order to minimise the overloading of any downstream filters, the turbidity of the clarified water needs to be as low as possible	Post-filter turbidity is an indicator or surrogate for pathogen removal through the filtration process	Free chlorine residual is important to ensure that an adequate Ct value has been achieved in order to inactivate a range of waterborne viruses and bacteria	As for CCPID 1, the pH at the time of chlorination is an important determinant as to the effectiveness of the chlorination process
Critical Limit	<5.5 or >7.0 for 10 min	>5.0 NTU for 30 min	>0.5 NTU for 15 min	<0.8 or >4.5 mg/L for 45 min	<6.0 or >8.5 for 45 min
Alert Limit	<5.8 or >6.8 for 15 min	>4.0 NTU for 30 min	>0.3 NTU for 15 min	<1.0 or >3.5 mg/L for 30 min	<6.5 or >8.0 for 30 min
Target	6.0–6.5	<2.0 NTU	<0.1 NTU	1.5–2.0 mg/L	7.0–7.5

Note: TWS, treated water storage.

treatment processes are being used. In many respects this makes sense, as WSPs guides and manuals are not designed to be treatment handbooks; they are primarily designed to assist water utilities in identifying and assessing risks to drinking water quality, and then put in place controls to manage the risk.

A more relevant guide is the second edition of Water Research Australia's *Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk* (2020). This comprehensive guide is designed largely as a resource for high-income countries, with mature WSPs, rather than those countries that may still be implementing a WSP.

The operational framework that was produced as an output of the project provides an overview of the *minimum* requirements for the preparation and implementation of the operational aspects of a WSP across a water supply system in countries where water safety planning is still very much the development phase, as is the case for many systems operated by GWCL. The framework document is not intended to replace any applicable local regulatory requirements with respect to WSPs, or the development of a more detailed WSP, but, rather, it is intended to provide '*checklist-style*' guidance on important aspects of WSP implementation in a user-friendly and accessible format.

The framework document is divided into three distinct sections in line with GWCL's mandate: Catchment (Table 2), Treatment (Table 3), and Distribution (Table 4), and provides information on the minimum requirements for each part of the catchment-to-consumer WSP framework. It also includes a list of good practice general requirements (Table 5).

With respect to Table 4, it is important to note that, while the WSP is structured around the management of risk from the catchment to the consumer, which implies the WSP will address risks beyond the point of delivery to the consumer (i.e. beyond the water meter), like many water suppliers, GWCL's responsibilities stop at the customer meter, so aspects beyond this were not included in the document.

DISCUSSION

One of the ongoing challenges with the implementation of WSPs is how to apply them to existing water supply systems, particularly where the water supply system includes an existing WTP. This is because either the operational controls that have been established for the WTP may not have been set with contemporary public health or treatment limits in mind, or the available treatment processes are not reflective of current source water risks. This issue can be exacerbated by a widely-held assumption that the WSP needs to be implemented in addition to the current operational controls and processes.

Table 2 | Catchment aspects of the GWCL operational framework

Minimum catchment requirements	Undertaken (Y/N)
As part of the preparation of the WSP, a survey is undertaken of the catchment area for the water supply system (Module 2*), with the aim being to identify potential sources of hazards for the production of safe drinking water (Module 3)	
Undertake a risk assessment to determine the priority catchment-level risks to the water supply (Modules 3 and 4)	
Identify short, medium and long-term catchment improvement activities that are needed to remove or minimise the identified risks, in consultation with relevant stakeholders (Module 5), and develop and implement a management plan endorsed by the senior management (Modules 6–8)	
At the offtake point(s) to the water treatment facility, routine monitoring is undertaken in order to understand changes in raw water quality and potential impacts on the downstream water treatment process (Module 6). Preferably this monitoring is undertaken continuously, using online meters, but if that is not possible, then regular grab samples should be collected to capture baseline data for both normal flow regimes and events, such as heavy rainfall and drought	
The collected raw water quality data is reviewed regularly, and triggers or targets have been developed that would alert operational staff when the raw water quality deteriorates to a point where it should either not be drawn into the water treatment facility, or, if it has to be used, that it either compromises the ability of the facility to adequately treat the water, or would necessitate a major change to the treatment process (e.g. increased coagulant dosing; more frequent backwashing of filters) (Module 6)	

The above table indicates the ***minimum requirements*** that need to be undertaken for the **catchment** elements of a WSP. It is important that these requirements are integrated into the WSP.
*Module reference refers to WSP module as described in WHO (2023).

One of the objectives of this project was to demonstrate to the operational staff at the Kwanyko WTP that much of their current day-to-day operational practice at the WTP was consistent with the content and intent of the draft WSP so that the implementation of the WSP did not mean that all current practices had to be replaced, but equally that the content of the draft WSP would not just be added on top of current practice at the WTP.

What needs to occur is that current operational practice across a water supply system needs to be viewed through a WSP lens, so that good operational practices are retained and form the basis of Modules 5 and 6 of the WSP, outdated practices are updated, inappropriate practices are removed or cease, and gaps identified, where new operational procedures need to be developed and implemented.

The second objective of the project was to develop an operational framework that, when implemented, would form the basis of good operational practice at all of GWCL's WTPs. The elements within the operational framework document were developed with those countries that are still in the WSP development stage in mind, and represent a set of elements that, if fully implemented, can assist water suppliers in achieving the safe management of drinking water supplies.

The elements included in the operational framework are a distillation of information contained within more comprehensive operational guidance documents (e.g. as produced Water Research Australia (2020)), or more recent WHO documents (such as, *A field guide to improving small drinking water supplies: water safety planning for rural communities* (2022b)). The elements are also not intended to replace more comprehensive assessments and tools that would support the implementation of Modules 5 and 6 of the WSP, but they are intended as scalable starting points.

The value of doing a site tour, and discussing water quality and treatment issues and challenges with operational staff, should not be underestimated, as this provides important insights into current operational practice.

Having input from operational staff is an important aspect of WSP development, as it helps ensure that the operational aspects of the WSP are achievable and reflect the current capabilities and limitations of treatment processes. The adoption of water safety planning is less likely to occur if operational staff feel removed from the process.

After the conclusion of the project, GWCL began the process of turning the operational framework into an endorsed company policy. The endorsed policy document was launched in October 2022, and it can be downloaded from the WHO/IWA Water Safety Portal (https://wsportal.org/find-wsp-resources).

Since the launch, GWCL has undertaken further training on WSPs, with the long-term view of using the operational policy to support the development and implementation of WSPs across all its water supply systems.

Some of the improvements in water safety planning that have been achieved are:

Table 3 | Treatment aspects of GWCL operational framework

Minimum Treatment Requirements	Undertaken (Y/N)
At each water supply system, a process has been undertaken to compare the hazards that were identified during the catchment survey with the available treatment processes to determine whether the sufficient treatment to guarantee consistent production of safe drinking water (i.e. the effectiveness of any existing barriers (control measures) that are in place to manage the associated risks (Module 4))	
If the above process finds that there is insufficient available treatment, and improvement plan needs to be prepared for consideration by senior management	
For each water treatment process at a water treatment facility, a standard operating procedure (SOP) has been development, which helps ensure that all operational staff have a common understanding and methodology for operating each treatment process	
Develop water treatment targets for each water treatment process	
Appropriate critical control points (CCPs) have been identified within each water treatment facility	
For each identified CCP, alert and critical limits have been developed and implemented	
For each identified CCP, the alert and critical limits is regularly monitored, ideally with online meters, but if that is not possible, then with regular grab samples	
For each identified CCP, a response plan has been developed for any breach of either an alert or critical limit, and this response plan details the actions to be taken in the event that either an alert or critical limit is breached	
All meters that are used to monitor the performance of CCPs, whether online or in an onsite laboratory, are maintained, regularly calibrated and regularly serviced, in order to ensure that all monitoring results are as accurate as possible	
There is a process in place to notify staff in the event that the chlorination of the final treated water stops. The importance of continuous primary disinfection with chlorine needs to be recognised	
All staff are adequately trained and competency-assessed in the aspects of water treatment that they are responsible for, as well as drinking water quality risk management	
While each WTP will be different, and local circumstances will vary greatly, below are some targets that should met, as much of as is possible, to ensure adequate treatment has occurred: **Turbidity of water after clarification:** ***Ideally <1 NTU, no greater than 5 NTU*** **Turbidity of water after media filtration:** ***Ideally <0.3 NTU, acceptable <0.5 NTU, but no greater than 1 NTU*** **Chlorination:** ***the minimum Ct value disinfection should be 15 mg/L.min, which equates to maintaining a free chlorine concentration of 0.5 mg/L for 30 min.*** **Chlorination:** ***The turbidity of the water at time of chlorination must be <1 NTU*** Based on recommendations in Water Research Australia (2020)) ***Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk Second Edition*** https://www.waterra.com.au/project/update-the-good-practice-guide-to-the-operation-of-drinking-water-supply-systems-for-the-management-of-microbial-risk-gpg (which are based on other recognised international good practice (e.g. USEPA)	
There is a management system in place to ensure that all chemical additives (e.g. chlorine, coagulants) are of suitable quality for use in drinking water, and consumables for water quality testing are stored appropriately (with basic good stock management practices in place), handled safely, ordered in a timely fashion, with appropriate supply chain contingency in place.	

The above table indicates the ***minimum requirements*** that need to be undertaken for the **treatment** elements of a WSP. It is important that these requirements are integrated into the WSP.

- The identification of, and discussion on the importance of, adding additional CCPs within WTPs, and how this would improve the effectiveness of the water treatment processes in use.
- Knowledge sharing, and providing access to current literature and reference materials.
- Providing supporting literature and scientific argument that highlighted the need for GWCL to engage the country's National Committee to discuss a review of water quality standards, specifically in relation to the turbidity standards for filtered and final water. The existing Ghana Standard value for final water is 5 NTU, while the recommended international value is <1 NTU. Lowering the value would help minimise potential health risks, by supporting improved filter performance.

Additionally, the operational framework provides one-stop access to all the critical minimum requirements for the catchment, treatment, distribution as well and customer responsibilities.

Table 4 | Distribution aspects of GWCL operational framework

Minimum distribution requirements	Undertaken (Y/N)
A minimum free chlorine residual 0.2 mg/L is maintained across the entire distribution system to the point of delivery.	
A process to identify and eliminate, or manage, points of cross-connection between treated drinking water and untreated water has been developed and implemented	
A process to identify and eliminate points of backflow between untreated water and treated drinking water has been developed and implemented	
A process to identify and eliminate points of backflow between customers' premises and treated drinking water has been developed and implemented	
A process to manage safely manage mains breaks and mains repairs has been developed and implemented, so that breaks and repairs are managed in such a way to minimise the risk of contamination, specifically in relation to the ingress of contaminants, unplanned interruptions and low-pressure events	
A process to manage tools, equipment and materials, including chemicals used by construction, operation and maintenance staff has been developed and implemented, in order to manage risks associated cross contamination and maintain good hygienic practices	
A process to manage contamination risks during design, construction and commissioning of new water supply assets, or system upgrades, in accordance with the relevant standards/guidelines, has been developed and implemented	
All distribution staff are adequately trained and competency-assessed in water distribution system management and drinking water quality risk management	
As appropriate, asset maintenance programmes, such as storage tank inspection and cleaning and water mains cleaning programmes, are developed and implemented, in order to minimise biofilm growth and the accumulation of sediments/particles within distribution systems	

The above table indicates the ***minimum requirements*** that need to be undertaken for the **distribution** elements of a WSP. It is important that these requirements are integrated into the WSP.

Table 5 | General requirements of the GWCL operational framework

General WSP requirements
Catchment surveys are conducted at a routine interval (e.g. every 5 years) in order to identify any changes in the catchment environment, or land use, which may impact on the quality or available quantity of source waters (Module 2)
A process to support customers with water quality related issues in the customer's premises and a process to measure customer satisfaction are developed and implemented
A process to manage customers complaints and queries is developed and implemented
Educational material on the way that the water utility manages drinking water quality from the catchment to the consumer is prepared and made available to customers
The WSP undergoes regular (e.g. yearly) internal review to ensure that it reflects the currently available water treatment infrastructure and current risk management practice. The internal reviews are documented and kept for future reference
The WSP undergoes both regular internal and external audit, as required by the executive of the water utility, or regulatory agencies

The above table contains a number of general requirements that should be implemented to ensure that the WSP stays current, is reviewed regularly, and that the views and concerns of customers are valued and used as part of a continuous improvement culture.

It should also be noted that the operational framework could be used as a checklist when undertaking internal and external WSP audits.

Further work needs to be undertaken to verify the operational framework has resulted in improved implementation of WSPs at other water supply systems, as well as sustained and sustainable changes in operational practice.

In a broader context, the operational framework developed as part of this project can support other countries with the implementation of water safety planning, with a checklist of tangible actions that can be adapted and applied to help improve the safety of drinking water supplies.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the operational and technical support to the project provided by Ms Margaret Macauley, Chief Manager, Water Quality Assurance and Mr Mark Tettey Ayertey, Senior Water Quality Expert, at the Ghana Water Company Limited. The authors would also like to acknowledge the valuable support by Mr Kizito Masinde, currently Global Events and Awards Director at the International Water Association, and Mr Samuel Amoako-Mensah, WASH specialist at UNICEF, who is based in Accra, Ghana, provided to this project.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 28 April 2023; accepted in revised form 30 October 2023. Available online 10 November 2023