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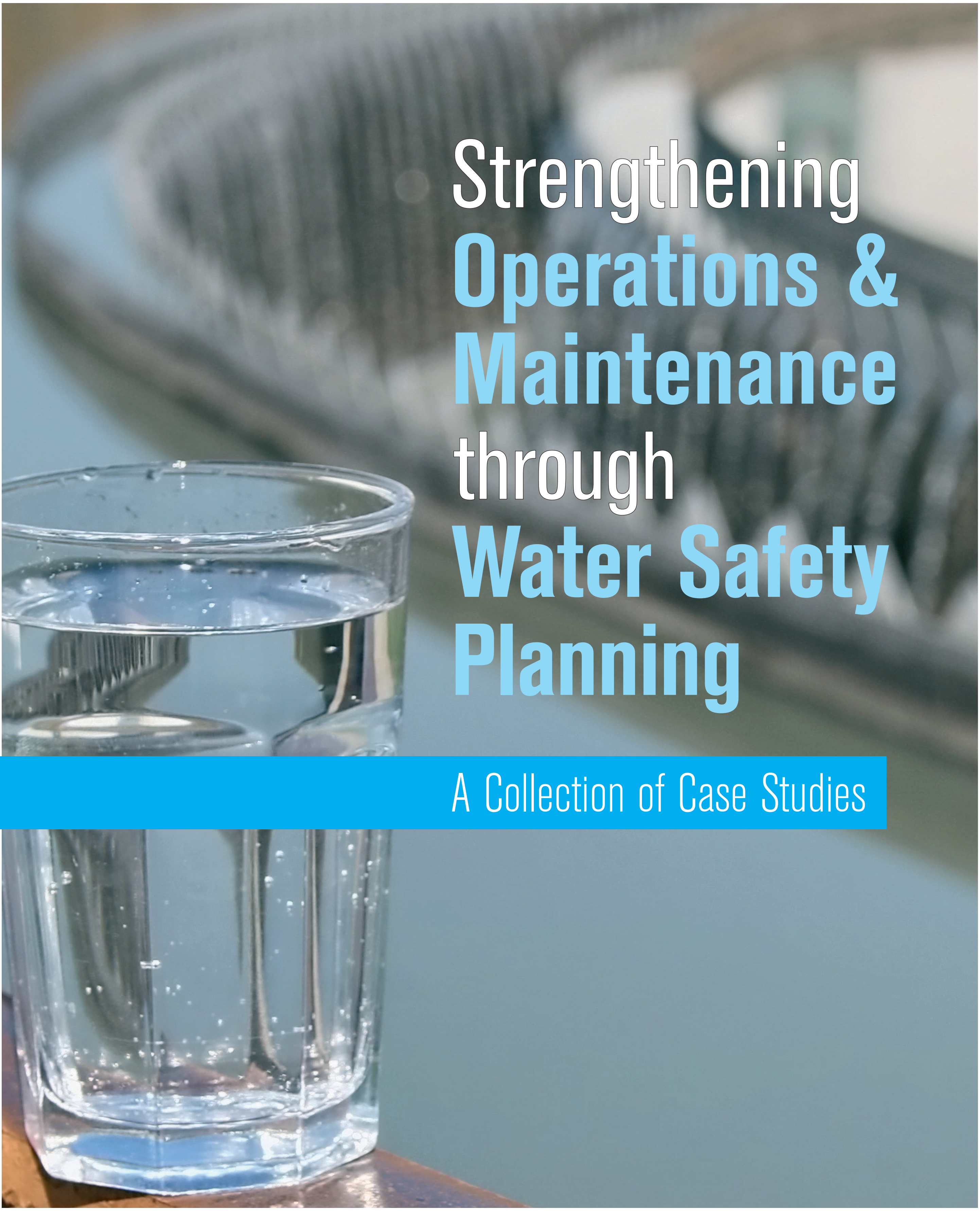

Strengthening Operations & Maintenance through Water Safety Planning

A Collection of Case Studies

World Health Organization

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Strengthening **Operations & Maintenance** through **Water Safety Planning**

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International Water Association 2018

The International Water Association (IWA) is a global knowledge hub for water professionals and anyone concerned about the future of water. It has a seventy-year heritage connecting water professionals worldwide to find solutions to the world's water challenges as part of a broader sustainability agenda. As a non-profit organisation with members in more than 130 countries, the IWA connects scientists to practitioners and communities so that pioneering research delivers sustainable solutions. It further fosters technological innovation and drives best practice through international frameworks and standards.

The International Water Association (IWA) is a nongovernmental organisation (NGO) in Official Relations with WHO. WHO's network of NGOs in Official Relations contributes to promote the policies, strategies and programmes derived from the decisions of the Organisation's governing bodies. IWA's role as an NGO in Official Relations with WHO focuses on supporting countries to implement intersectoral policies and interventions for protecting health from immediate and longer term environmental threats. A long history of cooperation exits, built on previous joint activities between WHO and IWA's predecessors, the International Water Supply Association and the International Water Quality Association. A key area of cooperation is drinking-water safety.

IWA's *Bonn Charter for Safe Drinking Water* promotes the application of water safety plans (WSPs) as expressed in the WHO *Guidelines for Drinking-water Quality*. (Revisions to the WHO Guidelines will be taken as revisions to the Bonn Charter in as much as the Bonn Charter refers to the Guidelines.) IWA promotes WSPs with WHO through collaboration agreements, and through its membership of water utilities, research institutes, industry, and individual professionals. IWA is a registered charity in England (Company registered in England No. 3597005 Registered Charity (England) No. 1076690).

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Introduction

Strong operations and maintenance (O&M) programmes underpin the effectiveness and sustainability of any drinking-water supply system. Failure to adequately address O&M can bring serious consequences, including operational and/or infrastructural failures, contamination events and economic losses. Despite the critical role of O&M in the provision of safe and adequate drinking-water supplies, basic O&M functions are often under-resourced – marked by undertrained staff and/or inadequate funding. In a recent global survey, half of the 75 responding countries indicated that tariffs were insufficient[1] to recover O&M costs (UN-Water & WHO, 2017).

Increased attention to and investment in O&M are needed to ensure that water safety and service delivery targets are consistently met and that public health is protected. With the ambition to achieve universal and equitable access to safe drinking-water by 2030, as articulated in the Sustainable Development Goals, the role of effective O&M is critical to sustain improvements made in the Millennium Development Goal era and ensure progress in the longer term.

[1] Defined as less than 80% of O&M costs

Water safety plans (WSPs) contribute to improved O&M by supporting the systematic assessment, prioritization and management of risks from catchment to consumer, including those related to inadequate O&M. Introduced in 2004 in the third edition of the *Guidelines for drinking-water quality* (WHO, 2004) and the *Bonn charter for safe drinking water* (IWA, 2004), the WSP approach is considered the most effective means of consistently ensuring the safety of a drinking-water supply. WSPs have been implemented in at least 93 countries, with 69 countries reporting to have policies or regulations in place or under development that promote or require WSPs (WHO & IWA, 2017).

The *Water safety plan manual* (WHO & IWA, 2009) describes the core elements of a WSP, many of which highlight the critical role of effective O&M. (See text box for an overview of the linkage between WSPs and O&M.) WSPs are therefore a valuable tool to strengthen O&M programmes. Indeed, WSP implementation has resulted in a wide range of O&M improvements across systems of various types, sizes and resource levels globally.

This document presents seven case studies[2] from six countries around the world that highlight O&M benefits resulting from WSP implementation. Figure 1 summarizes the wide range of benefits realised, which include catchments, treatment plants and distribution systems. These case studies contribute to a growing body of information on the outcomes of water safety planning and may be useful in building support for WSPs among water sector senior managers, operational staff and other stakeholders. In addition, the experiences offer insights into the particular WSP focus areas that are most likely to yield O&M benefits.

Defining O&M

Operations refers to the day-to-day "running" of a water supply system under normal or emergency conditions.

Maintenance involves (a) scheduled or planned activities under normal operating conditions to maintain operational systems, equipment and assets essential to supplying safe water to consumers (including the catchment, raw water storage, abstraction, treatment, distribution and customer interface); and (b) unscheduled activities during unforeseen or emergency situations to bring the water supply system back to normal operating conditions. Most maintenance activities require engagement of operational personnel.

The relationship between WSPs and O&M

O&M are central to successful implementation of WSPs. Identifying O&M-related hazards, determining and validating associated control measures, monitoring those control measures, preparing standard operating procedures (SOPs) for O&M activities and ensuring sufficient training for O&M staff are essential components of a WSP. The full benefits of a WSP cannot be realised without these key O&M processes.

WSPs drive O&M improvements. The risk assessment process that underpins WSPs is a mechanism to identify any gaps in a water supply system's O&M practices and the control measures required to manage risk to water quality and service delivery. This gap analysis becomes the platform to drive O&M process improvements.

[2] The case studies in this document were prepared in 2016.

O&M benefits highlighted in the case studies include the following:

- increased **operator awareness and training**
- enhanced **treatment plant performance**
- reduced **treatment chemical consumption**
- operational **cost savings**
- less **treatment plant down time**
- fewer **critical limit exceedances** for chlorination, filtration and fluoridation
- fewer **disinfection plant failures**
- **incident management costs** avoided
- better **microbiological quality** of treated water
- reduced **non-revenue water**
- reduced **raw water losses** and improved **raw water quality**
- optimized **water quality monitoring** equipment and practices
- better control of **hazardous events** from catchment to consumer

Figure 1: O&M benefits

Case Study 1 – AUSTRALIA

Fewer disinfection plant failures and associated incident management costs avoided

Yarra Valley Water is the largest retail water company in Melbourne, Australia. Owned by the State Government of Victoria, it provides water, sewerage and recycled water services to over 2 million people in the northern and eastern suburbs of Melbourne. Yarra Valley Water and two other retail water companies receive their treated water supply from the wholesaler, Melbourne Water. Melbourne Water is responsible for catchment management, storage and treatment of the water supply before it enters Yarra Valley Water's water supply pipe network. Approximately 80% of the water supplied by Melbourne Water is sourced from a fully protected catchment for which disinfection is the only treatment required to produce safe water that meets stringent regulatory requirements. The remaining 20% of the water supplied by Melbourne Water is treated using conventional treatment.

Yarra Valley Water and Melbourne Water were pioneers in applying risk assessment and risk management concepts to water supply. The wholesale and retail water companies introduced the Hazard Analysis and Critical Control Point (HACCP) framework in 1999 and maintained accreditation to the international standard of HACCP 9000. The HACCP Plan has since been integrated into the broader Drinking Water Risk Management Plan (equivalent to a WSP), which is a regulatory requirement introduced in 2003 with the enactment of the Victorian Safe Drinking Water Act.

The supply of undisinfected water by the wholesaler caused by a disinfection plant failure was identified as one of the significant risks, or critical control points (CCPs), in both the wholesaler's and in the retailer's WSPs. Significant operational improvements were therefore made, including continuous monitoring of key indicators of water treatment (for example chlorine, turbidity, filter head loss, fluoride); continuous review of CCP performance, including treatment plant failures; operator training; internal, external and regulatory audits; and well-established programmes of water treatment plant maintenance. As a result, a significant reduction in critical limit breaches has been achieved since 1999, including fewer disinfection plant failures (Figure 2). As disinfection plant failure triggers a declaration of an incident, operational expenditure on the order of 10 000-50 000 Australian dollars per incident has been avoided. Typical examples of costs avoided include mobilization of an incident management team, field work such as water mains cleaning (flushing, air scouring, swabbing), spot chlorination of water storages, use of bottled water, use of water tankers as an alternative water supply, additional water quality sampling and laboratory testing, and customer and media communications.

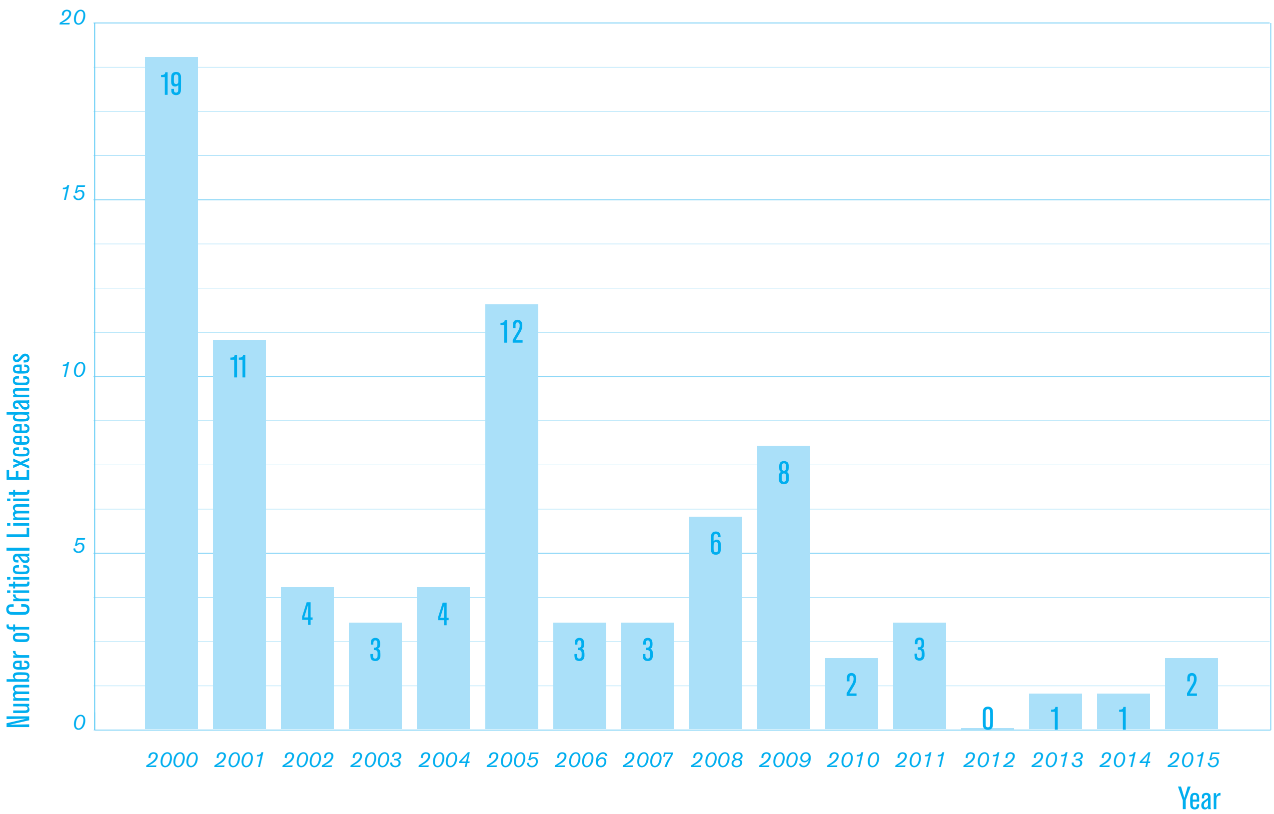


Figure 2: Reduction in critical limit exceedances at water treatment plants

Case Study 2 – BHUTAN[3]

Improved operator capacity, more effective treatment and better microbial water quality

The water supply system in Wangdue, Bhutan, serves approximately 6 000 water users through 330 metered pipe connections. Prior to delivery, the stream source undergoes sedimentation followed by pressure filtration and chlorination.

Before the WSP, the water supply system struggled with several infrastructural, operational and capacity issues. Challenges included insufficient treatment works, lack of water quality monitoring equipment, undertrained system operators, limited staff numbers and many competing responsibilities on staff time.

WSP implementation in Wangdue catalysed water supplier action to implement low-cost solutions to address risks, such as repairing fencing around the treatment plant. It also helped to leverage donor support for larger capital works, including installation of additional filters and an improved chlorination system. The WSP also led to considerable improvements in operator training and system operations. It prioritised the procurement of water quality testing equipment and training on developing and implementing an ongoing operational monitoring programme using the new equipment. The comprehensive training programme also covered chlorination principles and practices, as well as practical guidance on developing SOPs for key operational activities such as chlorine batching and dosing, as well as water quality sampling and testing. Treatment plant operators now have the equipment and training to effectively chlorinate and to conduct regular turbidity, pH and chlorine residual tests across the water supply system.

Improvements to operations and infrastructure directly related to WSP implementation have significantly affected the quality of drinking-water delivered to consumers in Wangdue. A review of water quality data from 2012 and 2013 revealed that none of the samples in the two years complied with Bhutan's faecal coliform target of 0 colony-forming units (CFU) per 100 mL, i.e. 0% compliance (Table 1). Since WSP implementation began in earnest in May 2014, water quality has improved markedly. Forty-one per cent of all samples collected in 2014 (after May) complied with the target for faecal coliforms, and 66% of samples collected in 2015 (through July[4]) complied. It is anticipated that further water quality improvements will be achieved as the water supplier continues to implement the WSP, including securing financial support for additional infrastructure improvement needs (WHO & IWA, 2017).

Table 1: Changes in faecal coliform compliance following WSP implementation

Year	Number of samples	% of samples complying with 0 CFU/100mL limit for faecal coliforms
2012	36	0
2013	58	0
2014 *(after May)*	37	41
2015 *(through July)*	67	66

[3] This case study is an augmented version of a similar case study presented in the *Global status report on water safety plans* (WHO & IWA 2017).

[4] Only data through July 2015 were available for this analysis.

Case Study 3 – INDIA

Reduced raw and treated water losses, less treatment plant plant down time and better water quality

A public–private partnership between Orange City Water Private Limited as the private operator and Nagpur Municipal Corporation as the owner and regulator is responsible for drinking-water supply to 2.5 million people in the city of Nagpur, India.

Five water treatment plants supply the daily demand of 660 mega litres. Three treatment plants use conventional tube settlers, rapid sand filters and chlorine disinfection. The treatment process at the other two plants consists of intake wells and a pre-settler (one plant only), a cascade aerator, multi-flow lamella settlers, rapid sand filters and chlorine gas disinfection.

Several improvements to operations, infrastructure and water quality have been realised since the implementation of a WSP in 2011. Raw water supply to the water treatment plants from the dilapidated, 48-kilometre open canal was prone to frequent contamination, water pilferage for agricultural use, seepage, leakage and evaporation. Implementing the WSP resulted in the replacement of the open canal with a 2300 mm diameter closed pipeline. Raw water losses have been reduced by about 30% and, as a result, downtime related to raw water supply to the water treatment plants has been reduced by 7-10 days in one year. Inlet turbidity decreased from 25 to 5 nephelometric turbidity units (NTU), improving treatment plant operational performance.

Through the WSP, Orange City Water has also developed an in-house technique for cleaning elevated service reservoirs; cleaning 56 such reservoirs increased reservoir capacity by 1-2% owing to removal of accumulated sludge.

Approximately 496 kilometres of water mains have been replaced, significantly reducing physical water losses from 22% to 4%. Daily water supply hours have been boosted from 2-4 hours (pre-WSP) to 4-24 hours (post-WSP) in 7 out of 10 water supply zones where the repair and rehabilitation work is in progress or completed. Water quality compliance in terms of thermotolerant coliforms and residual chlorine at 100 randomly selected locations at the consumer end every day increased from 79% in 2011 to 96% in 2016. Improved communication between stakeholders also contributed to O&M improvements.

Implementation of these improvements was prioritized using the improvement plan in the WSP, focusing on eliminating or reducing significant risks, as shown in Figure 3. Improvements are consistently monitored to measure the effectiveness of the WSP.

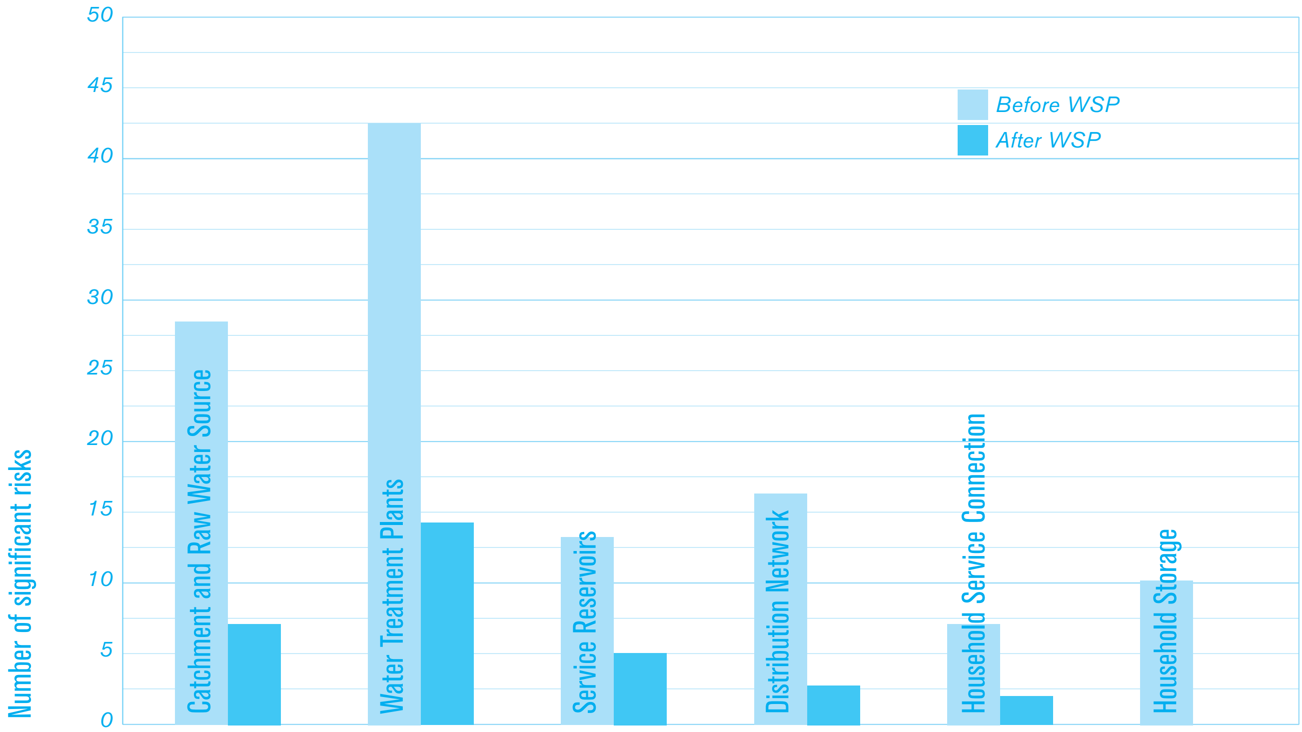


Figure 3: Water quality risk reduction due to O&M improvements

Case Study 4 – MALAYSIA

Fewer fluoride exceedances and lower operating costs through reduced chemical consumption

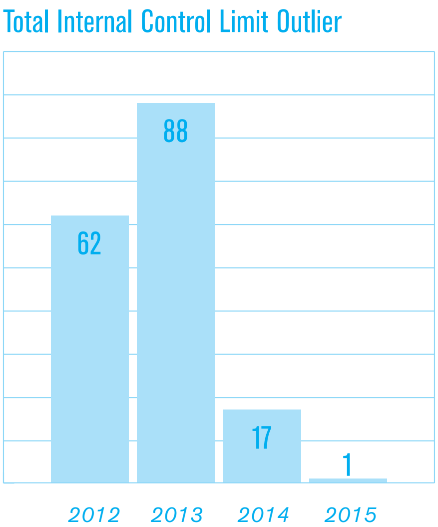
The Sungai Semenyih water treatment plant in Malaysia is operated and maintained by the private consortium ABASS. It supplies safe drinking-water to about 2 million residents in one of the most developed states in Malaysia, which includes Selangor, part of Kuala Lumpur, Cyberjaya, and the Federal Government Administrative Centre of Putrajaya.

The conventional water treatment process consists of coagulation, flocculation, sedimentation, filtration and chemical treatment. The chemicals used in the treatment process are aluminium sulfate, polymer, hydrated lime, chlorine and sodium silicofluoride.

The Ministry of Health in Malaysia requires fluoride levels in drinking-water to be between 0.4 mg/L and 0.6 mg/L in accordance with the National Drinking Water Quality Standard. Before WSP implementation, fluoride concentrations in treated water were higher than the internal control limit, which was set within the range 0.45-0.58 mg/L. The unstable fluoride dosing system led to frequent breakdowns and fluoride exceedances in treated water. Implementation of a WSP, which began in 2011, identified the need to upgrade the fluoridation system to ensure production of safe water. The upgrades to the dosing system, combined with improvements in operational processes (enhanced maintenance and effective communications with operational staff), greatly increased the performance of the fluoride dosing system.

Figure 4 shows the decreasing trend in fluoride outliers and consumption of sodium silicofluoride over the first four years of WSP implementation (2012-2015). As is evident from Figure 4, implementation of the WSP at Sungai Semenyih water treatment plant dramatically reduced the number of fluoride outliers against its internal control limit: from 88 cases in 2013 to just a single case in 2015. In addition, the consumption of sodium silicofluoride was reduced by 20%, resulting in cost savings.

WSP implementation has driven capital improvements and strengthened O&M processes, leading to significantly improved water quality and eventually reduced operational expenditure.



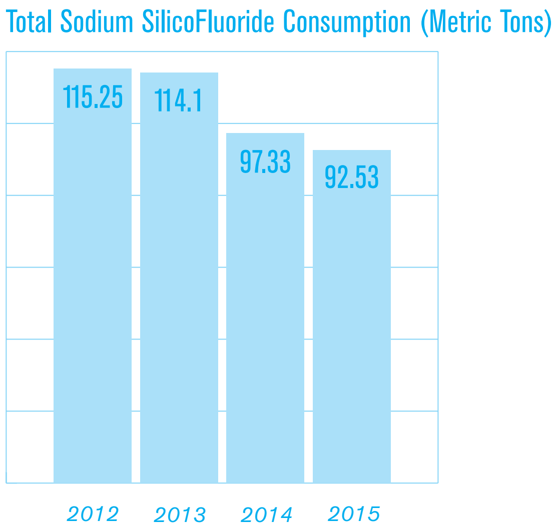


Figure 4: Operational performance improvements and reduction in operational costs due to WSP implementation

Case Study 5 – THE PHILIPPINES (Metropolitan Cebu)

More effective and efficient treatment, better water quality and reduced water losses

The Metropolitan Cebu Water District in Cebu, Philippines, is a government-owned corporation supplying drinking-water to a population of 1.3 million in four cities and four municipalities in the Metro Cebu area. The surface water treatment plant consists of pre-chlorination, sedimentation, sand filtration and chlorination.

As a direct outcome of the WSP process, significant upgrades were made to the treatment processes, including installation of baffling plates for the settling ponds and total rehabilitation of the rapid sand filters and backwashing equipment. These capital improvements contributed to significant improvements in operational performance of the sand filters to meet the turbidity control limits set out in the WSP. The improved filter backwash process ensures control limits for filter head loss are not breached. In addition, improved sand filter performance increased the effectiveness of primary chlorination, and improved backwash time has reduced the operational cost of backwash pumps by 60%.

In addition to water treatment plant upgrades and resulting operational improvements, significant improvements in the distribution system O&M processes were made through the WSP process, including:

- SOP for water main repairs amended to include specific requirements on water quality;
- storage facility constructed to prevent contamination of water pipes and fittings during storage; and
- leak detection programme improved to prevent re-contamination during low pressure events and to reduce non-revenue water.

Measurable improvements at Cebu Water District related to the WSP are summarised in Table 2, including improved water quality, greater filter backwash efficiency and reduced water losses.

Table 2: Quantification of benefits from O&M improvements resulting from WSP implementation

	Pre-WSP Implementation *(before January 2009)*	Post-WSP Implementation *(after December 2015)*
Positive *Escherichia coli* samples per month	291 of 4 954 (6%)	0 of 1 991 (0%)*
Heterotopic plate count results greater than 500 CFU/mL	38 of 1 375 (3%)	0 of 1 580 (0%)
Positive total coliforms samples per month	532 of 4 954 (11%)	85 of 1 991 (4%)*
Sand filter performance: turbidity	Too high to read	1.95 NTU
Sand filter performance: filter backwash cycle	Every 8 hours Average duration = 10 minutes	Once a week Average duration = 3-5 minutes
Non-revenue water	31%	23%

**The reduction in the number of samples tested from 2009 to 2015 is due to adjustments made to accommodate random samples and to decrease the number of samples collected from sample sites permanently listed in the monitoring programme. The revised testing programme satisfies the requirements of the Philippine National Standards for Drinking Water (2007).*

Case Study 6 – THE PHILIPPINES (Manila Water)

Operational efficiencies and significant reductions in annual O&M costs

Manila Water Company, Inc. (Manila Water) serves more than 6 million customers in the East Zone of Metro Manila, Philippines, covering 23 cities and municipalities served through a network of over 5 000 kilometres of water mains in five water supply systems. The vast majority (97%) of the supply is sourced from surface water. Manila Water operates three conventional water treatment plants, one reverse-osmosis plant and one deep well with direct chlorination.

Following WSP implementation in 2009, an alert matrix system for critical water quality parameters was established to facilitate improved monitoring and communication, as well as escalation of unusual or unacceptable changes in water quality or treatment process. Across all treatment processes, critical operational parameters including turbidity, filter head loss, pH and chlorine are monitored. Through the WSP process, monitoring frequencies were better defined and reporting protocols enabled centralized performance monitoring.

Improved operational controls, creation of SOPs, equipment calibration programmes, operator training and reduction of the number of water quality tests (approved by the regulator) since WSP implementation have helped Manila Water reduce annual O&M costs by 32.25 million Philippine pesos (approximately US$ 603 000). See Table 3. These improvements have also helped Manila water to consistently achieve 100% microbiological compliance with the Philippine National Standards for Drinking Water over the seven year period (2010-2016) following WSP implementation.

Table 3: O&M improvements and annual cost savings resulting from WSP implementation

	Pre-WSP	Post-WSP	Reduction	Savings (million Philippine peso)
Number of water quality tests (treatment plants)	34 831	11 054	23 277	5.2
Number of water quality tests (distribution)	42 321	34 202	8 119	1.8
Average dirty water complaints/annum*	150	<10	132 (92%)	-
Chlorinator dosing system improvements	-	-	-	5.7
Chemical dosing optimization through selective operation of accelerators	-	-	-	5.0
Optimization of flocculator operation	-	-	-	1.6
Chemical dosing optimization from enhanced jar test results	-	-	-	8.7
Chemical efficiency	-	-	-	4.25
			TOTAL	**32.25**

**Based on 2012 -2013 data from Rodriguez, Rizal water supply system. Improvements were due to a change in source water from groundwater to surface water and commissioning of the new treatment plant.*

Case Study 7 – PORTUGAL

Improved equipment calibration and maintenance, greater monitoring efficiencies and considerable cost savings

Aguas do Algarve (AdA) is a public water supplier with private management serving a population of approximately 410 000 people (up to 1.5 million people during the peak season) in 16 municipalities in Algarve, southern Portugal. AdA has approximately 160 employees supporting water and wastewater bulk services.

Before WSP implementation, online monitoring equipment was in place to monitor several parameters, including chlorine, pH, turbidity and conductivity. However, the quality of monitoring results was such that operators lacked confidence in readings and relied instead on manual sampling and laboratory testing. Through the WSP process, the WSP team focused on increasing the quality of data generated by the online instrumentation through improved calibration and maintenance, which resulted in greater confidence in readings and reduced reliance on laboratory testing. Also, the WSP risk assessment process revealed that some online instrumentation was unnecessary and could be removed from service. In addition, the frequency of laboratory testing for other parameters (that is, those not monitored with the online equipment) was reduced on the basis of the outcomes of the risk assessment and prioritization.

As a result of WSP implementation, a 56% reduction in the cost of water quality monitoring was achieved through O&M costs avoided for the online instrumentation removed from service as well as reduced frequency of laboratory analysis.

Conclusion: WSPs for stronger O&M

These case studies clearly demonstrate that significant O&M improvements have been achieved as a direct outcome of WSP implementation. The experiences also highlight certain WSP focus areas that will help stakeholders realise the full O&M benefit of water safety planning, including:

- robust and efficient operational monitoring programmes
- treatment plant optimization
- preventive maintenance programmes
- SOPs for key operational activities
- training of operational staff
- risk-based prioritization for capital upgrades
- effective communication between stakeholders

Given the centrality of O&M to the WSP process, water safety planning is a valuable tool to strengthen O&M programmes, which requires greater attention and investment to ensure drinking-water safety and improved service delivery.

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