PRINCIPLES AND APPROACHES FOR DRINKING WATER TREATMENT PLANT PERFORMANCE ASSESSMENT AND OPTIMISATION

Technical Report to the
Water Research Commission

by

Marlene van der Merwe-Botha[1], Tony Ceronio[2], Leanne Coetzee[2] and Julie Borland[2]

[1]Water Group Holdings (Pty) Ltd
[2]CSVwater Consulting Engineers (Pty) Ltd

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Water Research Commission
Private Bag X03
Gezina, 0031
orders@wrc.org.za or download from www.wrc.org.za

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This report forms part of a series of two reports:

- Principles and approaches for drinking water treatment plant performance assessment and optimisation **(This report)**
- Guidance on drinking water treatment process audits and plant optimisation **(WRC Report No. TT 755/18)**

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EXECUTIVE SUMMARY

The benefits of process optimisation are well recognised in the cost-effective operation of a water treatment plant and deferment of capital cost. Several methodologies have been developed internationally to guide the assessment process. In South Africa, for compliance with the Blue Drop criteria, water services institutions are required to compile a plant-specific process audit on an annual basis which also informs the risk management plan. The objective of the process audit is to ensure that the current treatment plant remains adequate to sustain compliance of the final product with regulatory requirements. The process audit is considered a subset of the optimisation assessment as optimisation and cost savings are not specifically addressed, with the exception of water losses and energy efficiency. Due to the disparity in interpretation of the scope of work and content of a process audit, the WRC commissioned a study to develop a Guidance Document setting out a best practice methodology for audits and optimisation to assist water services institutions. The scope of a process audit is defined by the Department of Water and Sanitation to comply with the Blue Drop criteria. An analysis of 74 process audit reports prepared for the last Blue Drop audit cycle highlighted the significant differences in the range and depth of the process audits undertaken by the different municipalities.

As part of the WRC study, local and international best practice models, guidelines and case studies were reviewed to establish the benefits of the different methodologies and the lessons were learnt from their implementation. Key findings are reported in this document. Based on this review, relevant aspects were incorporated into the guidance document for application in the South African water sector include:

- The American Water Works Association Capable Plant model will be adopted which states that the components of operations, maintenance, design and administration must work together in order to produce high quality drinking water on a continuous basis.
- A comprehensive performance evaluation must comprise a number of steps to identify the performance limiting factors.
- A list of questions must be provided to prompt the assessment team regarding the pertinent information to be gathered. The list however should not be exhaustive and should allow the assessment team to add additional questions based on their experience and the site-specific situation.
- Appropriate benchmarks must be included to provide guidance to the assessment team and the water services institution in evaluating performance. The limited availability of benchmarks applicable to the level of a water treatment plant is noted, particularly for operations and administration components.
- Provide guidance on the qualifications and experience of professionals who should be engaged in plant audits and optimisation studies as well as the frequency at which the studies should be undertaken.

A South African Guidance Document for Process Audits and Optimisation Studies was subsequently prepared and delivered to the WRC in draft form. The draft was approved and this allowed the team to workshop the draft document at a number of round table workshops with interested parties. The stakeholders were in agreement with the approach taken and delivered valuable inputs which were included in the final version of the document which has been submitted. The project raised a number of questions which could not be finalised as part of this project. These questions are addressed in the closing chapter of this document as suggestions for future work.

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- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
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- Technical Sustainable Management (TSM), as national adaptation by Holding Company for Water and Wastewater (HCWW), supported by GIZ-Egypt (Fayex Badr)
- Stockholm International Water Institute (SIWI) (Anton Earle, Nick Tandi).

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CHAPTER 1: **BACKGROUND**

1.1 INTRODUCTION

The treatment and distribution of drinking water is a challenging task that includes many diverse aspects (Van Duuren, 1997; Marx et al., 2002; Schutte, 2006). It is widely recognised that the optimisation of treatment facilities holds various opportunities for reduced capital cost, improved water quality and reduced cost of energy, chemicals, sludge disposal and other operational requirements. The concept of process or performance optimisation has evolved worldwide from individual studies to an operational philosophy and process of continuous improvement (Angereni, 2009; Environment Canada, 2010; Department of Water and Sanitation, 2014; Water Research Australia, 2015; AWWA, 2015). An important element of process audits and optimisation assessments is that the utility evaluate its strengths and weaknesses and to take small incremental steps towards improvement. Water use legislation and regulatory initiatives, such as the South African Blue Drop Certification programme, the German TSM programme and the European EPA Remedial Action Programme, promote this approach. Utilities are required to conduct process assessments of their drinking water treatment plants (EPA, 1998; AWWA, 2001; 2015) and to audit the progress and results achieved (Sembcorp, 2015; Badr, 2016). Globally, process assessments and optimisation studies are considered Best Practice (AWWA, 2001; Eikenbrokk, 2009) which provides valuable input to risk assessments (Boyd et al., 2015).

The concept and principles of a process audit are well established. It provides guidance to the plant manager and operator where process optimisation and technical improvements are required and which performance limiting factors need to be addressed. However, the scope and content of a process audit is open to interpretation by the individual tasked with performing the audit, often leading to confusion and dispute.
Internationally, there are a number of programmes, partnerships, documents and guidelines available which address these investigations. These reports generally indicate that a process audit should result in the identification of performance limiting factors within the water treatment plant which then enables the utility to plan for training, additional maintenance, refurbishments, upgrades or detailed studies, as required. If performed and implemented correctly, a process audit will facilitate cost effective and efficient operation of a water treatment plant with the objective of prolonging optimal functionality. Plant expansions and upgrades are considered as the last option.

In South Africa, the Department of Water and Sanitation (DWS) requires that each drinking water treatment facility be subject to a process audit annually by a technically competent person. The objective of a Process Audit is to ensure that the current treatment plant remains adequate to sustain compliance of the final product to regulatory requirements. The 10-year planning framework of the DWS focuses on the link between the Process Audit and the Water Safety Plan in consistently meeting the SANS 241 water quality standards. Performance limiting factors and optimisation opportunities are identified through the process audit which informs the Water Safety Plan where mitigation measures to address risks are prioritised for implementation.

1.2 AIMS AND OBJECTIVES

The WRC commissioned a study to investigate the current legislative and best practice requirements that inform a Drinking Water Treatment Plant Process Audit and Optimisation Study. The WRC study aims to:

- provide best practice and process methodology for auditing drinking water treatment works in South Africa; and to
- align audit methodology and practice with the Blue Drop regulatory approach.

The output of this study is a practical Guidance Document on undertaking process audits and plant optimisation studies that comply with the regulatory requirements. The Guidance Document is intended to be used by designers, managers, operators and decision makers to inform decisions regarding the operation and optimisation of a water treatment works, in compliance with global best practice and South African regulatory requirements.

1.3 CASE STUDY SELECTION

The development of guidelines is based extensively on a study of local and international best practices. Consequently, careful selection of relevant case studies is one of the critical elements of this study. The 2014 Blue Drop Report provides a list of the top Blue Drop Performers and references the various municipal utilities that are responsible or involved in these water supply systems. A selection of top performing utilities was approached to provide information to the research team on the current status of process audits in the South African municipal sector. The selected municipalities/utilities also provided technical input during the development of the guidance document as during roundtable discussions. The aim of this continuous involvement was to ensure maximum uptake of the document as a support tool and standardisation tool in the water sector. The selected municipalities and utilities achieved a score greater than 95% during the last Blue Drop audit (Blue Drop Report, 2014) and included:

- Ilembe District Municipality, in association with Umgeni Water and Sembcorp Siza Water;
- Mbombela Local Municipality, in association with Sembcorp-Silulumanzi;
- City of Tshwane Metropolitan Municipality, in association with Rand Water;
- Overstrand Local Municipality;
- City of Cape Town Metropolitan Municipality

In addition, randomly selected Process Audit reports from more than 10 municipalities were studied to provide further information to the research team of the current status and typical content of a process audit report. The following international organisations participated and offered case studies for this project:

- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ);
- German Association for Water, Wastewater and Waste (DWA): Department Training and International Cooperation (Roland Knitschy);
- Technical Sustainable Management (TSM), as national adaptation by Holding Company for Water and Wastewater (HCWW), supported by GIZ-Egypt (Fayex Badr);
- Stockholm International Water Institute (SIWI) (Anton Earle, Nick Tandi).

1.4 STUDY APPROACH AND METHODOLOGY

The following methodology and deliverables were planned as part of the execution of this study:

1.4.1 Inception Report

The Inception Report outlines the project scope, objectives, methodology, deliverables and timelines. This report serves as a guideline to the research team and the WRC Reference Group to ensure that the scope and structure of the project fulfils the requirements of the WRC and that all aspects of the project are addressed adequately.

1.4.2 Principles and Approaches to audit and Optimise Drinking Water Treatment Systems

A review study was done to investigate and consolidate current knowledge and best practice application both locally and internationally regarding the auditing and optimisation of drinking water treatment works. Several international and local technical reference documents, as well as local legislation, regulation and standards were reviewed in order to support this comprehensive review. The report compiled following the review study aims to provide an overview of process audit and optimisation methodologies applied internationally, with case study experiences and lessons learned from implementation at drinking water treatment works.

1.4.3 Technical guidance for Performance audit and Optimisation of a Drinking Water Treatment Plants

The Technical Guidance document was developed based on the findings of the principles and Approaches Study. The comprehensive report was circulated to the identified stakeholders for input prior to finalisation. The stakeholders included various interested parties who added their specific input after studying the report at round table workshops. The project team incorporated the feedback in the Comprehensive Report which was named the Guidance Document on completion.

1.4.4 Round Table Workshops and Final Report

Four regional round table workshops were held in order to present and workshop the draft Guidance Document. The input received at the workshop was be incorporated into the final Document. The workshops were held in Tshwane, eThekwini and Cape Town. The latter venue hosted two workshops of which one was dedicated to the WISA Process Controllers Division while the other, as with the first two workshops, enjoyed broad representation from the sector.

1.5 DEFINITION OF CONCEPTS AND SCOPE

Process optimisation is not new to the water treatment sector and various formal and informal studies, with an optimisation goal, have been performed over the years on many plants. The studies have been undertaken by different parties for various reasons and as a result the nomenclature and scope associated with plant or process audits, performance assessments and optimisation studies have become confused. The following three concepts are of immediate importance in the South African context:

- <u>A plant improvement</u> and <u>optimisation study</u> or <u>plant optimisation</u> study looks at optimising the overall efficiency of a plant with respect to the production of water and compliance to water quality goals. This is generally undertaken as a self-improvement effort.

- A process audit or plant audit is driven by regulatory requirement to pro-actively manage water quality by ensuring that the treatment plant is capable of sustainable delivery of SANS241 compliant water.
- Feasibility and Preliminary Design studies are standard services expected of a registered engineer as set out in the “Guideline for Services and Processes for Estimation fees for persons registered in terms of the Engineering Professions Act (Act No.46 of 2000)” published in Government Gazette No. 39480 on 4 December 2015 or later date. A study undertaken in line with the Government Gazette generally precedes the development and establishment of capital works and the services and deliverables are fully prescribed in the Gazette. The feasibility study and preliminary design study generally follows from the findings of a plant improvement and optimisation study or a process audit where the need for capital works is identified.

The focus of the proposed Guidance Document is the first two bullets as listed above. Some deliverables from the third bullet are often, and possibly mistakenly, included in the deliverables of the first two. It should be noted that it is not the intention of this report as well as the Guidance document to elaborate on the Feasibility and Preliminary Design studies. Although the scope and requirements of each study are closely related, a significant amount of confusion arises from the use of various terms used to describe each of these studies. This is particularly noticeable when reviewing available literature. Where possible, however this review has kept to the terminology used in the source documents for purposes of reference. One purpose of this review is to contextualise the various studies and to provide clarity on the deliverables of each in order to assist with appropriate application. While reading this document, it is advisable to attach the question “what this particular study is meant to achieve” when trying to understand the specific terminology used.

CHAPTER 2: **WATER QUALITY AND TREATMENT IN SOUTH AFRICA**

2.1 INTRODUCTION

The provision of drinking water includes water quality management in catchments, operation and control of water treatment plants, distribution of treated water, community participation, project management and various other aspects which make it a challenging task (Schutte, 2006). The term 'water quality' describes the physical, chemical and microbiological characteristics of water. Chemical water quality includes alkalinity, hardness, chemical stability, and chlorine species. Physical water quality properties include turbidity, pH, electrical conductivity, colour, taste and odour. Microbiological quality includes a number of indictor organisms, such as faecal coliforms, total coliforms, heterotrophic bacteria and coliphages, as well as *E. coli* and the protozoan species *Giardia* and *Cryptosporidium* which have been included as a regulatory requirement since 2011. These properties collectively determine the overall water quality and the fitness of the water for a specific use. Water quality is only meaningful when evaluated in relation to the use of the water. Water that is fit for domestic use (drinking water) must comply with the requirements specified in SANS 241 of 2015, or the latest published edition (Department of Water Affairs, 2002).

Multiple treatment processes are required to achieve SANS 241 standards (Van Duuren, 1997). These processes are designed to remove turbidity and microorganisms, as well as to inactivate Giardia and Cryptosporidium cysts or other pathogens. Each process unit through the plant represents a barrier to viable microorganisms and pollutants. The combined treatment process therefore presents a multi-barrier process which minimises the likelihood of microorganisms and pollutants passing through the entire treatment system. Each treatment process must be capable of providing this barrier at all times to ensure minimum or low risk to the consumer (Boyd et al., 2015). The selection of appropriate and effective treatment processes and proper design and combinations of the individual process units are essential for the successful performance of a treatment plant. As it is not the scope of this study to discuss the various process units, only a summary is provided in Table 2-1 below:

Table 2-1: Unit processes for water treatment (Schutte, 2009 and Van Duuren, 1997)

Unit process	Description and application
Trash rack	Provide at the intake for removal of floating debris.
Coarse screen	Mechanically cleaned screens provided at the intake gate or in the sump well ahead of pumps. Remove small solids.
Micro-strainer	Removes algae and plankton from the raw water.
Aeration	Strips and oxidises taste- and odour-causing volatile organics and gases and oxidises iron and manganese. Aeration systems include gravity aerator, spray aerator, diffuser and mechanical aerator.
Mixing	Provides uniform and rapid distribution of chemical and gases into the water.
Pre-oxidation	Application of oxidising agents such as chlorine, potassium permanganate and ozone in raw water and in other treatment units to limit microbiological growth and to oxidise taste, odour and colour causing compounds as well as iron and manganese compounds.
Coagulation	Coagulation is the addition and rapid mixing of coagulant with the water to destabilise colloidal particles and form small flocs.
Flocculation	Flocculation causes aggregation of destabilised colloidal particles to form rapid-settling flocs.
Sedimentation	Gravity separation of suspended solids or floc produced in treatment processes. It is used after coagulation and flocculation and chemical precipitation.

Unit process	Description and application
Flotation	The intentional formation of micro-bubbles in a water body with the intent of removing low density particles and colloids from the water body as a result of attachment of the particles to the air bubbles or the entrapment of the air bubbles in floc that has previously aggregated the particles or colloids.
Sand filtration	Removal of flocculated and particulate matter by filtration through granular media (normally filter sand). Multi-media may also be used (sand and anthracite, or sand and activated carbon, or a third layer may also be incorporated).
Slow sand filtration	Removal of colloidal matter, micro-organisms and colour by means of slow rate filtration through a sand bed on which a layer of colloidal matter and micro-organisms is allowed to form.
Chemical precipitation	Addition of chemicals in the water precipitates dissolved solids with low solubility into insoluble form. Removal of hardness, iron and manganese and heavy metals is achieved by chemical precipitation.
Recarbonation	Addition of carbon dioxide to reduce pH of water after addition of lime for coagulation or softening.
Activated carbon adsorption	Removes dissolved organic substances such as taste and odour causing compounds and chlorinated compounds. It also removes many metals. It is used as powdered activated carbon (PAC) at the intake or as a granular activated carbon (GAC) bed after filtration.
Disinfection	Destroys disease-causing organisms in water. Disinfection is achieved mainly by chlorine, but ultraviolet radiation and other oxidising chemicals such as ozone and chlorine dioxide are also used.
Chloramination	Ammonia converts free chlorine residual to chloramines. In this form, chlorine is less reactive, lasts longer and has a smaller tendency to combine with organic compounds, thus limiting taste and odour and THM formation.
Fluoridation	Addition of sodium fluoride, sodium silicofluoride or hydrofluosilicic acid to produce water that has optimum fluoride level for prevention of dental caries.
Desalination	Involves removal of dissolved salts from the water supply. Desalination may be achieved by membrane processes, ion exchange and distillation.
Reverse osmosis (RO)	High-quality water permeates very dense membrane under pressure while dissolved solids and some organics are prevented from permeating the membrane. RO is also used for nitrate and arsenic removal.
Nanofiltration (NF)	Less dense membranes (than RO) are used for removal of divalent ions (softening), micro-organisms and organics from water under pressure.
Ultrafiltration (UF)	Removal of colloidal material and some micro-organisms from water by membranes under pressure.
Microfiltration (MF)	Removal of all particulate matter and some colloidal matter.
Ion exchange (IX)	The cations and anions in water are selectively removed when water is percolated through beds containing cation and anion exchange resins. The beds are regenerated when the exchange capacity of the beds is exhausted. Selective resins are available fir hardness, nitrate and ammonia removal.
Electro-dialysis (ED/EDR)	An electrical potential is used to remove cations and anions through ion-selective membranes to produce desalinated water and brine.
Distillation	Used mostly for desalination of seawater.

2.2 WATER SERVICES REGULATION FRAMEWORK

The Constitution of South Africa assigns the responsibility for provision of water services to Local Government whilst oversight and performance monitoring duties are allocated to Provincial and National Government. The Department of Water and Sanitation (DWS) is responsible for the regulation and monitoring of water services as stated in Section 62 of the Water Services Act (No. 108 of 1997). In the South African regulatory domain, four approaches to regulation are recognised. These include:

- Compliances Monitoring (Norms and Standards)
- Punitive Regulation (Enforcement)
- Risk-based Targeted Regulation
- Incentive-based Regulation (Blue Drop Certification)

None of these regulatory approaches takes preference over the others due to prominence or importance but are used where appropriate to facilitate improvement.

2.2.1 Drinking Water Quality: Norms and Standards

As the Regulator of water services, the DWS may prescribe and require the utility to implement processes that intend to advance and achieve the objectives of providing safe drinking water quality to water users. SANS 241 sets the standard for drinking water quality in South Africa and is legally enforced by the DWS. The last update of SANS 241 was published in March 2015. SANS 241-1 is applicable to all water services institutions and sets numerical limits for specific determinands to provide the minimum assurance necessary that the drinking water presents an acceptable health risk for lifetime consumption. SANS 241-2 assists with the interpretation and application of the standard. SANS 241 adopts a risk-based approach and prescribes a compulsory list of the most critical determinands to be monitored and mandates the identification and inclusion of additional determinands through a risk-based process. The SANS 241 standard is used by the Regulator as one of the benchmarks for Water Safety Planning, for Process Audits and is the determining factor in awarding Blue Drop status to a water services institute.

The Draft Amendment Regulations relating to the compulsory national standards for provision of drinking water (Reg 5, Aug 2016) states as follows:

> *Clause "5.(1) A water services institution must ensure that comprehensive and preventative drinking water quality management is practiced according to the requirements of SANS 241, which includes the development and implementation of a water safety plan for all relevant drinking water supply systems."*

Given the importance of SANS 241 in drinking water quality regulation, it is of paramount importance that all stakeholders in the South African drinking water industry understand the standard and apply it correctly in their area of responsibility.

2.2.2 Incentive-Based Regulation: Blue Drop Certification

Incentive-based Regulation was introduced on 11 September 2008 by the Minister of Water Affairs. The initiative was implemented though two programmes: The Blue Drop Certification Programme for Drinking Water Quality Management Regulation and the Green Drop Certification Programme for Wastewater Services Management Regulation. The incentive-based regulatory programme was developed locally for the unique South African challenges experienced in drinking water quality and wastewater management services. The Blue Drop Certification Programme promotes the proactive management and regulation of drinking water quality management through the introduction of excellence requirements based on legislated norms and standards, as well as international best practice. A water supply system is awarded Blue Drop Certification according to the performance for that specific system assessed against a stringent set of requirements. Blue Drop Certification is not awarded to a water services institution as a whole but rather on the basis of individual water supply systems under its control.

Definition of Incentive-based regulation:
The conscious use of rewards as well as penalties to encourage performance excellence and continuous improvement,

The objectives of Blue Drop Certification include:

- Introduce incentive-based regulation of drinking water quality management;
- Promote transparency and subsequent accountability;
- Provide reliable and consistent information to the public;
- Facilitate closer relationships between Water Services Authorities and Water Services Providers (where applicable);
- Introducing an element of excellence instead of conventional regulation.

Participation in Blue Drop audits is compulsory and all WSAs are required to participate and submit a Portfolio of Evidence for each Blue Drop criterion. The various criteria are divided into six key performance areas (KPAs) that cover all aspects of water treatment and supply service (Table 2-2). Although all KPAs have individual importance and purpose, weighted scores are applied to each KPA which contribute towards the total Blue Drop Score. A score above 95% ensures that the supply system receives Blue Drop Certification and the accolades that accompany such an achievement.

Table 2-2: Blue Drop Key Performance Areas (Blue Drop Handbook 2014)

#	Key Performance Area	Weighted score	Key Performance Indicator	Weighted Score
1	Water Safety Planning	35%	Water Safety Planning Process	10%
			Risk Assessment	35%
			Monitoring Programme	30%
			Credibility of DWQ Data	15%
			Incident Management	10%
2	Process Management & Control	8%	Works Classification Compliance	15%
			Process Control Registration Compliance	50%
			Water Treatment Works' Logbook	35%
3	Drinking Water Quality Verification	30%	Microbiological DWQ Compliance	50%
			Chemical DWQ Compliance	45%
			Operational Compliance	5%
4		10%	Management Commitment	30%
			Publication of Performance	25%

#	Key Performance Area	Weighted score	Key Performance Indicator	Weighted Score
	Management, Accountability & Local Regulation		Service Level- or Performance Agreement	15%
			Submission of DWQ Data	30%
5	Asset Management	14%	Annual Process Audit	20%
			Asset Register	15%
			Availability & Competence of Maintenance Team	15%
			Operations & Maintenance Manual	15%
			Operations & Maintenance Budget and Expenditure	20%
			Design Capacity vs. Operational Capacity	15%
6	Water Use Efficiency & Water Loss Management	3%	Water Balance	30%
			WDM Strategy, Business Plan and Implementation	30%
			Compliance and Performance	40%

2.2.3 Water Safety Planning

The Regulator places emphasis on Water Safety Planning (BD weighted score of 35%) as this process introduces an integrated risk-based approach to drinking water quality management of a specific supply system, from supply to point of use, through an inclusive stakeholder process. The safety planning process provides a systematic and transparent approach for the consistent provision of safe water with a clear focus on public health. The Regulator has included the requirement for Water Safety Planning into the update of the regulation, *Draft Amendment Regulations relating to Compulsory National Standards for the Provision of Water Services and Quality of Water under Section 9(1) of the Water Services Act (Act no 108 of 1997)* (Draft Reg. 5, August 2016), where the following definition is provided:

Water Safety Plan "means a systematic process that aims to consistently ensure acceptable drinking water quality that does not exceed the numerical limits in SANS 241-1 by implementing an integrated water quality management plan, which includes a risk assessment and risk management approach from catchment to point of delivery."

The draft regulation stipulates that a Water Safety Plan shall contain the following:

a) a description of the processes used to develop the risk assessment;
b) a confirmation letter by the water services institution addressed to the Minister indicating that there is no significant health risk in supplying the water to consumers;
c) provide full details of every property, organism, substance or chemical that has been identified as contributing to risk;
d) specify the mitigation measures that the water services institution has implemented as at the date of the report and also implementing with associated timeframes; and
e) details of mitigation measures that have been implemented and monitoring data which verify those mitigation measures, shall be submitted under the risk based monitoring programme on the Ministerial regulatory system.

Furthermore, where the Minister receives a water safety plan which states that there is, or has been, a significant risk of supplying drinking water that would not pose risk to human health, the Minisiter will require the water services institution

a) to maintain specified mitigation measures for a period of time as considered appropriate to mitigate risks;
b) to review specified mitigation measures by a date considered appropriate to mitigate the risk;
c) not to supply water for drinking purposes from specified water supply systems unless conditions specified by the Minister are met; and
d) to give the Minister information required to monitor progress towards mitigation of that risk.

Finally, an Incident Management Protocol must be developed by the water services institution that details the management of incidents that may affect drinking water supply, including quality.

The Water Safety Planning Process is well documented and the following useful guidelines can be consulted:

- Water Safety Plan Manual: Step-by-Step Risk Management for Drinking-Water Suppliers, World Health Organization, Geneva (WHO, 2009);
- Jack, U. & De Souza, P. 2013: Guidelines on using the Refined and Translated Web-enabled Water Safety Planning Tool (2013 version), WRC Report No. TT 581/13.

The Water Safety Plan 'sets the scene' for the rest of the Blue Drop audit as it essentially considers and contains all KPAs of the Blue Drop within one document. The Blue Drop process audit and the Water Safety Planning process are reassessed by the Regulator before each audit cycle to ensure that the most pertinent questions are asked to drive continuous improvement.

2.2.4 Annual Process Audit

One of the key inputs to the Water Safety Planning Process is the Annual Process Audit, included in KPA 5 of the Blue Drop, as it identifies engineering, and process issues which must be included in the Risk Assessment Process (Coetzee et al., 2011). The requirements for the process audit are however generally left open to interpretation by the assessor and the water services institutions. The purpose of a Process Audit is to assist a water services institution to evaluate whether the current treatment plant remains adequate to sustain compliance of the final product with regulatory requirements.

The DWS requires that each drinking water treatment facility be subject to a process audit by a technically competent person. Draft Regulation 5 (August 2016) requires the following:

> <u>Section 10:</u> *"A WSA must ensure that water treatment processes are adequately managed to ensure the production of safe drinking water for the protection of public health, including:*
>
> *a) A process audit of the water works every year;*
>
> *b) Inspection and process audit of the drinking water supply system by a registered professional person every 5 years..."*
>
> *Where:*
>
> <u>Registered professional person:</u> *"A person with the relevant experience on water services works and registered with ECSA or SACNASP".*

The Regulator regards the Process Audit as a means to evaluate if a plant is capable of achieving specific targets and provides the following guiding principles in the Blue Drop Handbook (2014):

- The performance assessment must evaluate the plant efficiency by comparison of historic raw- and final water qualities. This should include evaluation of plant flows and performance of each unit process in order to assess whether the plant is performing as expected and if it remains capable of meeting the required treated water quality standards;
- A detailed assessment of raw water quality trends in order to assess whether the treatment process will remain sufficient to deal with raw water quality changes as they occur;
- A detailed assessment of current and future demand patterns on the plant in order to assess the demand pressures on the plant with a view on capacity development planning;
- A unit process evaluation which focuses on size, structural and mechanical integrity of each unit process including pipes/pipelines. The integrity checks may be augmented in part by the condition assessment done on the plant as part of the on-going maintenance effort;
- A design assessment of each unit process such as pump efficiency, sufficiency of back-up capacity, storage of chemicals, backwash efficiency, etc., and
- Operational assessment to focus on monitoring efficiency and operators' competence and knowledge.

In this way the water services institution is able to plan for any training, refurbishments and upgrades if required. DWS expects a typical index of a process audit to include the following:

- Raw water quality analysis – problem parameters and trends;
- Final water quality trends – compliance and trends;
- Evaluation of the plant's ability to meet current and future water quality requirements;
- Demand analyses – historical and projected;
- Evaluation of the plant's ability to meet future demands;
- Performance analysis of unit processes;
- Evaluation of plant and equipment condition;
- Assessment of operational competence; and
- Recommendations on process, capacity, infrastructure care and operational optimisation.

Minimum Requirements for Process Audit according to Blue Drop guidelines:

- A Process Audit is required to be undertaken annually.
- The Process Audit report must include findings and prioritised recommendations; and
- The WSI must provide evidence of implementation of recommendations.

CHAPTER 3: PROCESS OPTIMISATION ASSESSMENT AND PROCESS AUDITS

3.1 INTRODUCTION

Two performance evaluation methodologies are used to manage and meet drinking water quality objectives, namely quality audits and assessment. A quality audit examines the compliance of a quality system against a set of standards and their suitability to achieve stated objectives, while an assessment measures organisational performance against a selected excellence model (Karapetrovic & Willborn, 2001). Literature on the subject of process optimisation and audits are abundant and are widely accepted as best practice models (AWWA, 2001; Angreni, 2009). Different models and approaches, with supporting case studies, have been consulted as part of this WRC study. The South African water sector has extensive knowledge and experience which can be provided as input to the development of a practical Guidance Document for Process Audits and Optimisation in South Africa.

This WRC study focuses on both 'process audits' and 'plant optimisation', aimed at maximising plant performance. The optimisation study is viewed as an advanced form of the process audit that aims to operate at a point of highest efficiency which will be measureable in terms of improved cost per production unit while maintaining and improving water quality standards. The Process Audit aims to ensure that the current treatment plant remains adequate to sustain compliance of the final product with regulatory requirements.

A number of criteria define a typical Process Audit:

- It does not describe cost-savings or present alternatives for designing new facilities for expansion purposes;
- It assists a water services institution to better understand and quantify the existing plant performance in order to identify and prioritise the limitations to improved performance, and to construct an action plan to implement and monitor the impact of the changes;
- It is a systematic process for examining the root cause of performance problems at existing plants;
- The goal is to optimise existing facilities without major capital improvements;

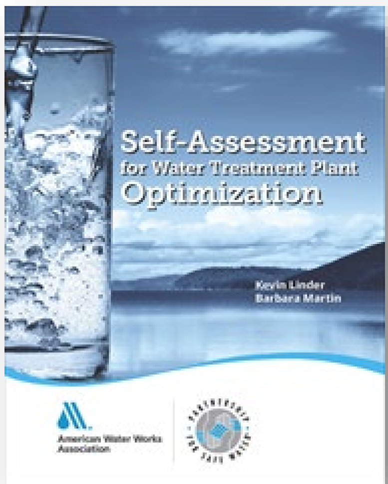
In the literature, the terms optimisation, assessments and audits are often used inter-changeably. These studies however should not be confused with the studies prescribed by the Engineering Council of South Africa. Feasibility studies and preliminary design assessments refer to new or existing built environment elements which include refurbishment activities and integration of new works with existing works (ECSA, 2013). These studies are aimed at establishing infrastructure and not the optimisation of existing processes and will generally follow where optimisation was not sufficient to achieve desired goals. Most literature describes the assessment and optimisation of specific process units within the treatment train, such as optimisation of coagulation and flocculation (Ewerts et al., 2013; Franceshi et al., 2002; Zularizam et al., 2009; Gregor et al., 1997; Huseyin et al., 2005), sedimentation or clarifiers (Banff et al., undated), filtration (Simon Bresse et al., James, 2005; Ewerts et al., 2013;) and disinfection (Nikolauou et al., 2005; Chaiket et al., 2002; Van der Walt et al., 2009). The use of simulators, dynamic programming, decision support systems and models are also the subject of various publications (Buhisi & Abu Naser, 2009, Worm et al., 2009, Karamouz et al., 1999: Li Chen et al., 2007; Rietveld et al., 2009; Brouwer & De Bois, 2008; Macropoulos et al., 2008).

3.2 GUIDELINES FOR CONDUCTING PROCESS OPTIMISATION ASSESSMENTS – GLOBAL REVIEW

Various concepts, principles, approaches, tools and software exist with the sole purpose of assessing and optimising a WTP. Internationally, most models describe best practices for optimisation of the treatment plant aimed not only at regulatory compliance but also cost effective and efficient operations. The following sections evaluate the literature that describes international best practices for process optimisation assessments that can be used to inform the development of the South African Guidance Document.

3.2.1 Partnership for Safe Water

The Composite Correction Programme (CCP) and Partnership for Safe Water is a voluntary programme which encourages subscribers to assess and optimise their plants through a self-directed and own-pace programme. The CCP was developed by the US Environmental Protection Agency and Process Application Incorporated. It includes a guide to evaluate water treatment plant performance against criteria in four major clusters: design, operation, maintenance and administration. The CCP comprises a two-part process consisting of an evaluation phase (Comprehensive Performance Evaluation – CPE), which serves as the basis for a follow-up corrective and optimisation phase (Comprehensive Technical Assistance – CTA). The CCP is a comprehensive, systematic approach for assessing the root cause of performance limiting problems at existing water treatment plants. These performances limiting factors are based on the AWWA 'Capable Plant Model' which states that all factors must work together in order to produce high quality drinking water on a continuous basis (AWWA, 2001; AWWA, 2015). The Capable Plant Model was developed to demonstrate the relationship between administration, design, maintenance and operation in the production of high quality treated water on a continuous basis (Figure 3-1). Initially, the CCP model focused only on operation, maintenance and design aspects. Case studies however found that it was difficult to assess management aspects at the utility so the administrative component was included.



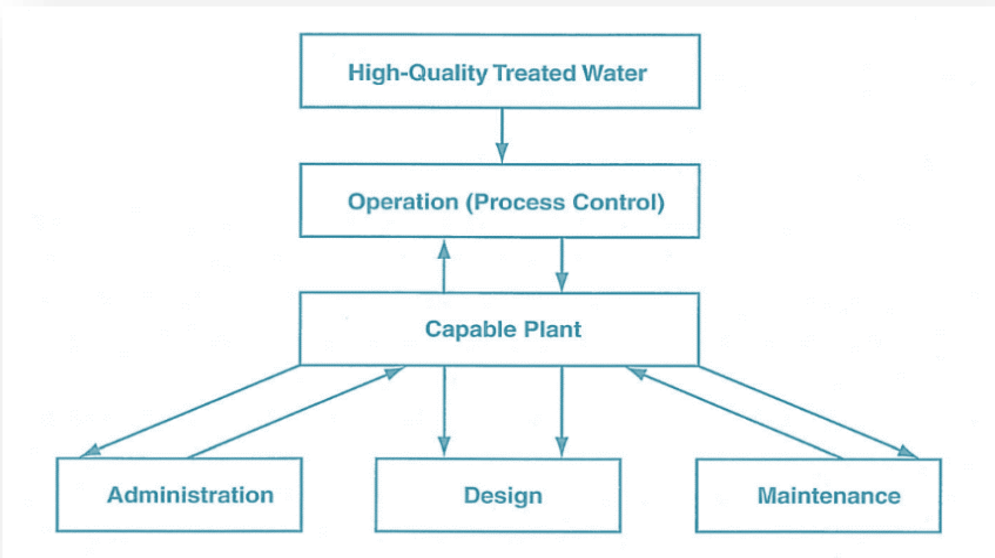


Figure 3-1: Capable Plant Model (AWWA, 2001; 2015)

Administration issues are however dealt with in lesser depth compared to the other components. From an evaluation of more than 200 plants, it was revealed that the main problem area related overwhelmingly to the operations component of the model. Plant operations personnel found it difficult to monitor incoming water quality changes and apply operational controls to maintain consistently high quality finished water with variable raw water (AWWA, 2015). The AWWA report "Self-assessment for Water Treatment Plant Optimization" (2015) is an updated version of the 2001 report and uses the same assessment concepts and principles as the first guide but has incorporated modern day technologies. These technologies include high-rate clarification, membrane filtration, precipitative softening, bio-filtration and the use of online instrumentation and SCADA systems (Angreni, 2009; AWWA, 2015). The Partnership for Safe Water develop and provide guidelines, software and tools to their (world-wide) subscribers to participate in the various phases of the programme: Phase I (signing up and commitment), Phase II (submit baseline data), Phase III (self-assessment) and Phase IV which represents fully optimised performance plants. Phase IV plants are reviewed, analysed and approved by Partnership representatives, peer reviewers and optimisation experts (AWWA, 2015). Scoring is based on criteria in the following categories: Performance, Administrative, Operational, Design, and Overall parameters. President and Director Awards recognise achievement in improvement and excellence. The programme recommends a series of steps when embarking on a self-assessment programme (AWWA, 2015) (Figure 3-2).

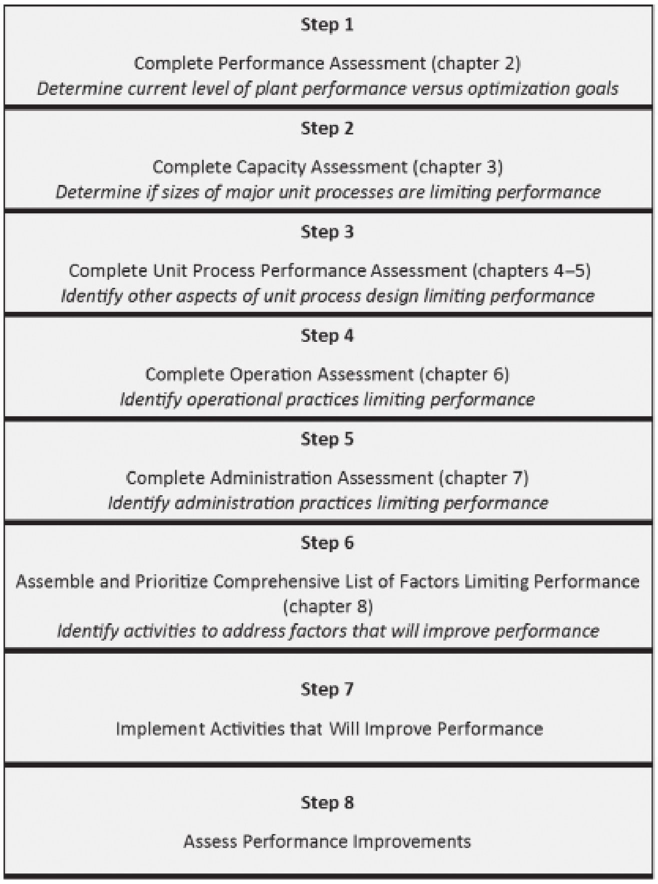


Figure 3-2: Consecutive steps proposed in the CCP process (AWWA, 2015)

Step 1: Performance Assessment

This step determines if the current levels of performance are meeting the performance goals and if performance needs to be improved. Questions are asked to assist in identifying the potential causes for not complying with performance goals. If performance is assessed to be optimum, there may not be a need to continue with the remaining sections of the assessment. However, if desired, the utility can still complete the self-assessment to "polish" plant operation and administration, even though changes will probably not result in measurable improvement in performance. Before making the decision 'not to proceed', personnel need to ensure that the reason for optimum performance is not simply a stable, high-quality water source that masks the lack of treatment skills which may lead to complacency. It is suggested that the utility adopt a self-assessment process as a part of a continuous quality improvement programme (e.g. by completing a self-assessment every three years).

Step 2: Capacity Assessment

A capacity assessment is done based on the physical size of the major unit processes of the plant (i.e. the concrete basins) to determine if they are adequate to meet the desired performance goal. This evaluation allows the utility to determine if the physical sizes of the major unit processes (concrete basins) are performance limiting factors. Compilation of a Potential Graph or Performance Potential Graph graphically presents the treatment capacities of each unit, treatment component and conveyance structures in order to determine which are limiting the capacity of the treatment plant. If the sizes of the major unit processes are adequate, the plant should be able to continuously perform at an optimum level and other factors of design, operation, or administration are likely to be the cause of non-optimum performance. Although the objective of an optimisation assessment is to improve performance through operational improvements while minimising major capital expenditures, plants that identify a design or capacity deficit may find that more significant modifications to plant may be required to ultimately improve plant performance.

Step 3: Unit Process Performance Assessment (Design)
This step assesses the performance-limiting factors that are associated with the design of the unit processes of the plant. The data gathered from plant drawings, specifications, and the completed evaluation of major unit processes, including the Potential Graph, provide the basic information needed to assess design-related performance-limiting factors. This step focuses on aspects of physical aspects other than basin size, such as process flexibility and the capability of chemical feed facilities. The assessment is divided into: pre-treatment/source water, pre-oxidation, coagulation/rapid mixing, flocculation, sedimentation, softening, high-rate clarification, filtration, disinfection and recycle streams. Membrane filtration is discussed under a separate heading.

Note: Utilities only assess the process units which are applicable to their plants.

Step 4: Operation Assessment
This step determines if there are operational practices that may be limiting performance. The operations topics assess the process control programme and the ability of operations staff to interpret raw water quality changes and their ability to respond with appropriate control, such as changing coagulant dose, to achieve the performance goals. Topics covered in this step are most often identified as areas needing improvement. Aspects to be addressed under this part of the assessment include: process control testing, operator application of concepts, communications, online instrumentation / SCADA.

Step 5: Administration
This step determines if the administration of the utility provides the support required to achieve optimum plant performance. Administrative aspects include: administrative policies, acceptance of optimisation goals, stakeholder involvement, documentation and demonstration of addressing complacency, training, staffing and funding.

Note: Topics in this step have proven to be the most difficult to assess objectively.

Step 6: Assemble and Prioritise Performance Limiting Factors
In this step, the list of performance limiting factors are assembled and prioritised and corrective activities that will lead to optimum performance are identified. In addition, tools that can be used to correct the identified performance limiting factors are listed. It is important to prioritise the performance limiting factors in order to apply the resources of the utility to the highest-ranking activities first and then lower ranking activities as time and resources allow. Typically, performance limitations often have to be addressed simultaneously because an interdependent combination of factors often contributes to non-optimum plant performance (Renner et al., 2010, Partnership for Safe Water, 2011).

Step 7: Implement Activities that will Improve Performance
This step implements the activities which were identified in Step 6.

Step 8: Assess Performance Improvements
This step determines if the changes made during step 7 actually resulted in optimum performance. This is done by using the performance assessment process (Step 1) to quantify results and compare performance with the earlier assessment. If the performance goals have not been achieved, activities that were implemented are reassessed and implementation plans developed to further improve performance. If performance limitations are severe, the optimisation process could take several years of concentrated effort to complete.

Other positive impacts of the self-assessment, which may not be evident from performance data especially if the plant is already producing very low-turbidity water, could include increased reliability and improved operator dedication to the production of high-quality water and/or improved efficiency.

The use of Assessment Checks

An important element of each step is the assessment of the performance limiting factors and their status within the optimised plant. The following two examples are extracted from AWWA (2015) to demonstrate the typical checks that will be performed for disinfection and recycle streams during a process assessment (Table 3-1 and 3-2).

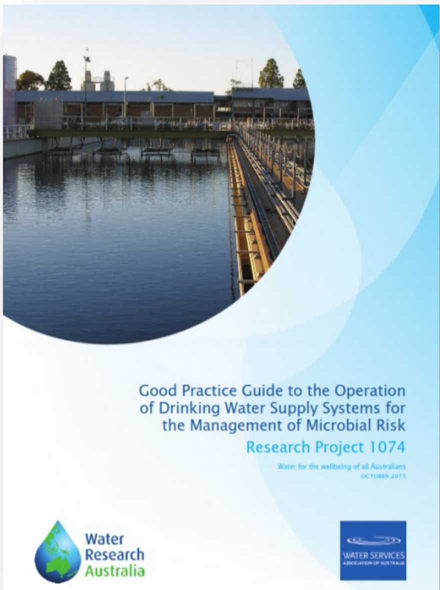
Table 3-1: Disinfection factors assessments (AWWA, 2015)

Self-Assessment Category	Questions for Gauging Optimization Status	Optimization Status		
		Optimized & Documented	Partially Optimized	Not Optimized
Disinfection	Is *CT* continuously achieved, based on approved monitoring and reporting methods?			
	Is disinfectant concentration continuously monitored to meet *CT* requirements and monitored in all applications for which the concentration is critical to maintaining optimized plant operation?			
	Is the disinfectant concentration applied at the plant determined in conjunction with distribution system staff such that it can aid in maintaining an adequate residual concentration in the distribution system?			
	For plants applying chloramines prior to the water entering the distribution system, has a plant-specific ratio of chlorine to ammonia been determined?			
	Has the plant staff identified and tracked any seasonal patterns in water quality or treatment efficiency that may impact the disinfection process and a means to recognize these changes so that treatment can be modified when they occur?			
	Have alarms been established to alert operators to changes in disinfection or *CT* status, and have procedures been created that guide operations through the process of addressing such alarms?			
	Do plant disinfection procedures balance the need to maintain adequate disinfection and meet *CT* requirements at all times, while minimizing DBP formation to ensure compliance (if applicable)?			
	Is redundancy available in equipment used for disinfection?			
	If disinfected water must be dechlorinated or the oxidant residual quenched for any purpose, including discharge of the water, does the plant have the means to monitor the dechlorination process?			
	Does the domestic water system supplying the treatment plant meet all local regulatory requirements for *CT*/disinfection?			

Table 3-2: Recycle factors assessment (AWWA, 2015)

Self-Assessment Category	Questions for Gauging Optimization Status	Optimization Status		
		Optimized & Documented	Partially Optimized	Not Optimized
Recycle	Has a comprehensive characterization of the plant's recycle streams been performed to understand the most appropriate treatment approach to introduce the recycle stream back into the production stream?			
	Are sampling points available to allow characterization of the recycle stream alone, independent of other flows that may be blended with the recycle flow?			
	Have a contingency plan and procedures been developed to implement in the event of a recycle process failure?			
	Has plant staff assessed the adequacy of recycle stream treatment processes to determine if they are properly designed and if operation of these processes is optimized?			
	Have any relevant additional parameters, such as water quality constituents, for handling recycle streams been assessed by plant staff, and are they monitored on a continuous or frequent basis?			
	Are flowmeters capable of monitoring the flow rate of recycle streams?			
	Are any key pieces of equipment out of service that impact the performance of the plant's recycle system, and have the root causes of the equipment issues been identified?			

3.2.2 Water Research Australia: Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk (2015)



The "Framework for Management of Drinking Water Quality that underpins the Australian Drinking Water Guidelines" (2015) follows a risk-based approach to the production of microbially safe drinking water from catchment-to-consumer. This process is based on the identification of risks to the supply of high quality drinking water to consumers and their control. A reduction in risk is achieved by implementing a multiple barrier approach, where a number of different barriers to prevent or treat contamination are implemented. The majority of risks are managed through the use of various water treatment processes, which are multi-barrier units in their own right. A guide was developed to provide concise advice on good practice preventative measures for the management of drinking water treatment processes and the distribution of treated water to the consumer. This is achieved by providing targets, both numerical and observational, for the various activities along the treatment and supply system. The guide assumes that a risk assessment has been done and therefore focuses on the optimisation, management and control of the existing treatment and supply system. The Guide is presented in a tabular format for simplicity. The table includes sections that relate to the key control points in typical systems. The table is colour coded to present ‘Required Measures’, ‘Support Measures’ and ‘Desirable Measures’. By providing Frequency, Measure of Assessment and a Required Result, the intent is that the results will be incorporated in the reporting framework of the utility. The value of referencing this Guideline is that it outlines the process units and the typical measures that need to be assessed to identify optimisation opportunities. The Guideline does not prescribe the method of assessment but provides information on the areas that need to be included. The Guideline identifies the following clusters:

– General WTP Operation	– Chorine-based Primary Disinfection
– Raw Water Extraction and Storage Systems	– UV disinfection
– Raw Water Flow Management	– Membrane Filtration
– Residuals Management	– Equipment and Instrumentation
– Coagulation	– Distribution System
– Flocculation	– Water Quality Information
– Clarification	– Management
– Media Filtration	

Each cluster contains the following information:

- Measure
- Rationale
- Frequency and Measure of Assessment
- Required result (after optimisation)

Table 3-3: Snapshot of tabular information presented in the Guideline (WRA, 2015)

Chlorine-Based Primary Disinfection			
Introduction Chlorine-based disinfection (free chlorine or chloramine) is an effective barrier for bacteria and most viruses; however at the concentrations typically used in a conventional WTP, it is not an effective barrier for protozoan pathogens.			
Measure	**Rationale**	**Frequency and Measure of Assessment**	**Required Result**
CHLORINATION AND CHLORAMINATION			
Primary disinfection is based on achieving a minimum target of T_{10} contact time for the ambient temperature and pH at all times. Calculation of *Ct* takes into consideration the contact tank baffling factor (see Appendix 1).	Control of pathogens using chlorine-based disinfectants is determined by a *Ct* value, not free chlorine residual. The necessary T_{10} to control pathogens is dependent on temperature and the free chlorine residual corrected for pH. The use of a baffling factor is satisfactory; however more reliable data can be obtained using tracer studies or computational flow dynamics.	***Monthly*** No. observations with *Ct* ≥ target x 100 Total observations No. observations with *Ct* > critical x 100 Total observations	>95% 100%
There is a system in place to ensure that no undisinfected water leaves the water treatment plant.	Distribution of water that has not been disinfected for the target *Ct* should never occur. Online monitoring and PLC interlock with the treated water pump(s) is essential to ensure this.	***Monthly*** No. observations with *Ct* < critical x 100 Total observations	0%
Short circuiting is minimised in the contact tank and in treated water storages.	Short circuiting compromises achievement of *Ct* and also increases residual decay.	***One off*** Assessment that short circuiting is not occurring.	Records confirm checks.

3.2.3 European Union: TRUST – Transition to the Urban Water Services of Tomorrow (2015)

The objective of the European Union project TRUST (Transition to the Urban Water Services of Tomorrow) is to deliver co-produced knowledge support, enabling communities to achieve a sustainable, and a low-carbon water future without compromising service quality. TRUST delivers this knowledge through research driven innovations in governance, modelling concepts, technologies, decision support tools, and novel approaches to integrated water, energy and infrastructure asset management. TRUST demonstrates and legitimises these innovations by the implementation of the most promising interventions in the urban water systems of nine different participating city regions (TRUST, 2015). The EU TRUST programme developed a framework for water plant optimisation, namely "Safe and sustainable water supply: Status of operation performance" (Figure 3-3). This framework and the associated diagnostic tools were applied and tested at plants in the United Kingdom, the Netherlands and Norway.

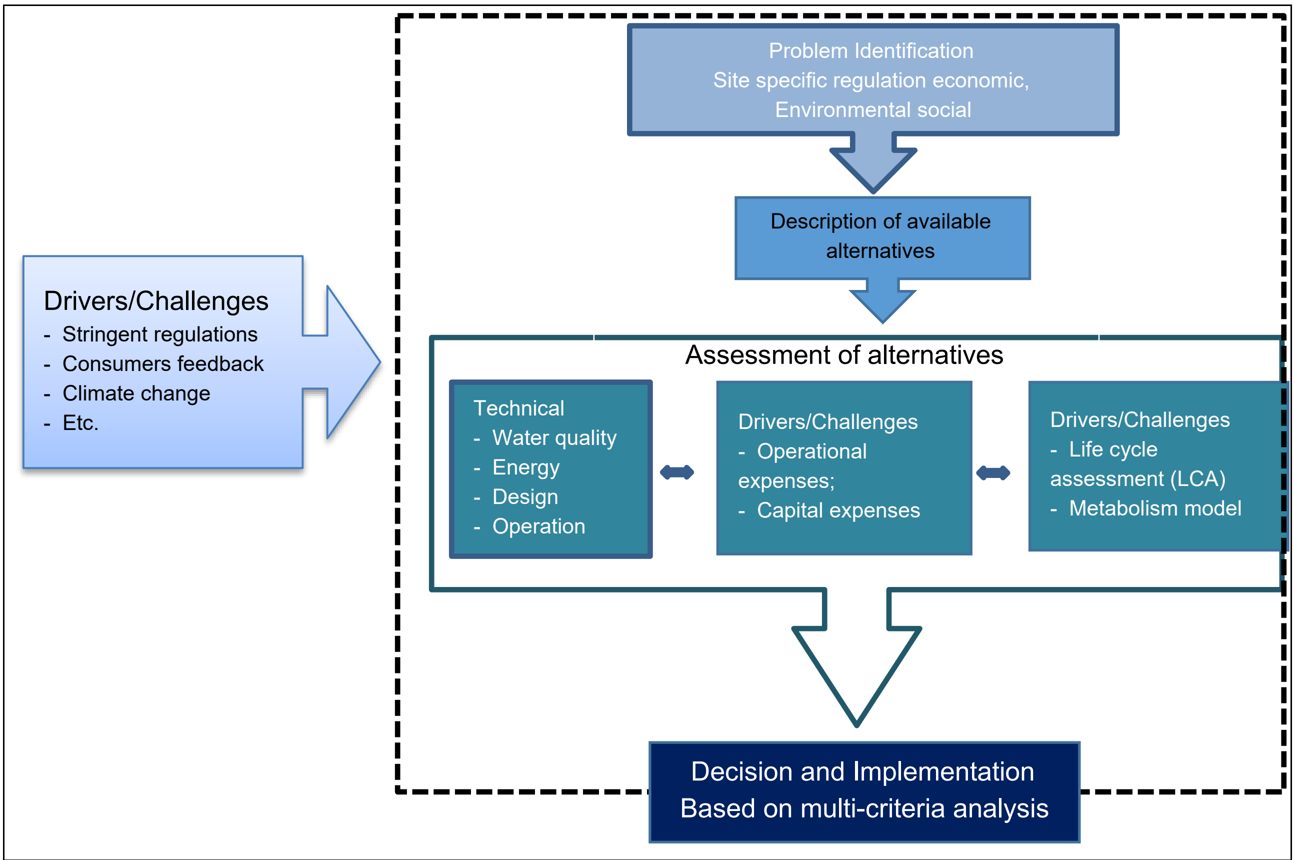


Figure 3-3: Framework for sustainable optimisation of water treatment systems

The Framework comprises four main elements:

Step 1: Technical Evaluation and Optimisation
This part includes technical measures that would help to maximise:

i. compliance with the water quality standards and regulation,
ii. treatment and disinfection barrier efficiency,
iii. stability and safety, and
iv. cost-efficiency and minimise use of resources such as chemicals and energy.

The suggested optimisation procedures include:

- Mapping operational performance status including an initial performance evaluation and comparison with model predictions;
- Utilising diagnostic tools, e.g. for water quality characterisation, that also help with identification of variations in performance;
- Utilising curative tools that include experiments and trials without compromising the quality of the water produced;
- Using decision support systems to highlight aspects, e.g. economic and environmental issues, that are not covered by the diagnostic and curative tools;
- Identifying performance optimisation potentials and possible benefits, and
- Implementing selected operational conditions based on an overall assessment of potential advantages and disadvantages for both treatment and distribution systems.

Step 2: Environmental Impact Assessment
The Framework proposes the use of Life Cycle Assessment (LCA) (Figure 3-4) to assess the environmental impact, as defined by ISO-14004. The main goal of the LCA analysis is to determine the environmental impacts attributable to the WTP during different operational options considered to optimise operations.

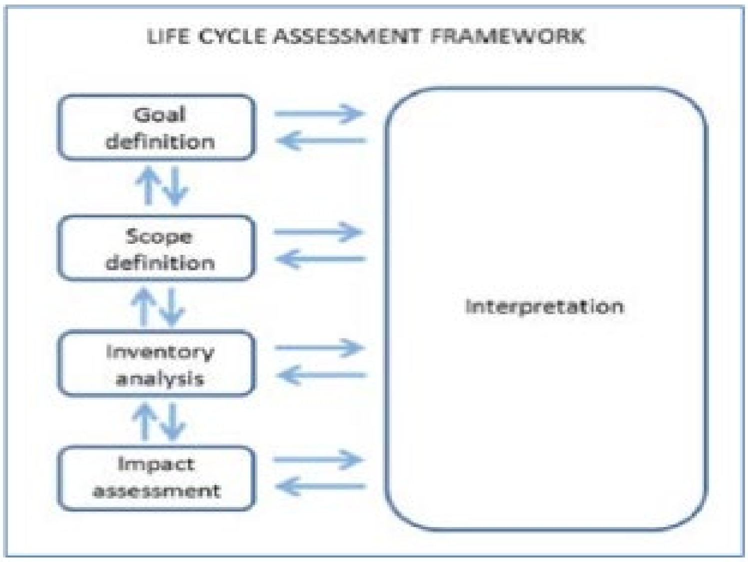


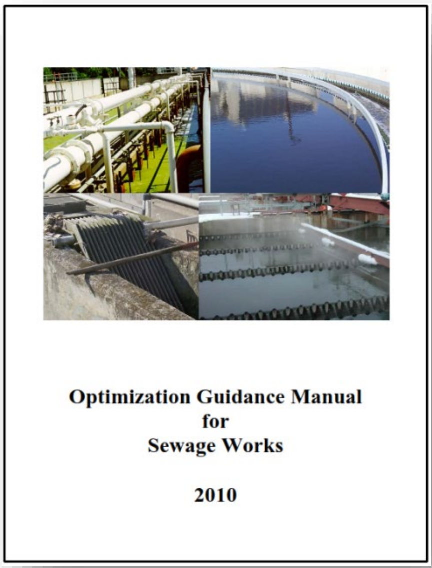
Figure 3-4: Life Cycle Assessment framework according to the ILCD Handbook (2010)

Step 3: Economic Evaluation
Depending on the optimisation option under consideration, economic criteria can be assessed using various methods such as capital/operational expense (CAPEX/OPEX), Life Cycle Cost (LCC), Cost-Benefit Analysis (CBA), etc. Where no additional equipment needs to be installed at an existing plant, it is sufficient to only evaluate operating costs (OPEX). Operation and maintenance expenses incurred in water treatment are collected and systematised.

Step 4: Multi-Criteria Assessment

In order to identify the appropriate option, a multi-criteria assessment is used to integrate the outcomes of the technical, environmental and economic evaluations. Several methods exist in the literature which could be applied (Pawlowski, 2008; Quental et al., 2011; Venkatesh et al., 2015). All these tools require that criteria are weighted against each other. The weighting may be carried out using a questionnaire addressed to relevant professionals. Case studies which used this Framework for optimisation are discussed under "Case Studies" in the next section.

3.2.4 Canada: Optimisation Guidance Manual for Sewage Works (2010)



The "Optimisation Guidance Manual for Sewage Works" (2010) was prepared by consultants under the guidance of a Technical Steering Committee and reviewed by the Ontario Ministry of the Environment. The guideline was developed for wastewater treatment plants but is equally applicable to drinking water treatment systems, noting that different technologies will apply. The Ontario guideline was developed by adopting the CCP approach and demonstrating its applicability in Ontario. The CCP has been amended to be specific to the Ontario situation version for use in water and wastewater treatment plants. The Guideline regards optimisation as an iterative process which includes four major steps:

- **Step 1***:* Define the objectives of the optimisation programme;
- **Step 2:** Evaluate specific components of the works to establish the baseline conditions and identify the processes or factors that limit the capacity or the performance of the existing works;
- **Step 3***:* Develop and implement a study programme aimed at mitigating the capacity or performance limiting factors; and
- **Step 4***:* Conduct follow-up monitoring after upgrades or process changes have been implemented to assess and document the results.

The study objectives depend on the optimisation objectives, which could typically include (adapted for WTP):

- Improving water quality to ensure public health;
- Increasing the capacity of the works to service growth in the community;
- Upgrading the performance of the WTP to meet more stringent regulatory requirements;
- Improving the reliability, flexibility and robustness of the works;
- Reducing the operating cost associated with energy, chemical and labour;
- Reducing solids production and sludge management cost.

The baseline condition of a plant is established by a desktop analysis of the design of the plant and historic data over a period of time which is usually 3-5 years. A site visit is conducted with all relevant staff to:

- Familiarise the optimisation team with the design of the plant, its layout, and to identify the locations of sampling and monitoring stations;
- Obtain input from plant operations staff regarding equipment, hydraulic or process limitations based on operating experience
- Discuss standard operating procedures for major unit processes.

The design of the plant is compared to standard design practices and guidelines, such as MOU Design Guidelines for Sewage Works (MOU, 2008), Ten State Standards (2004), Wastewater Engineering (Metcalf and Eddy, 2003), and Design of Municipal Wastewater Treatment Plants (WEF/ASCE, 1998). The guide prescribes the development of a process chart that identifies the capacity and capability of each unit process or the processes under investigation. This establishes which unit process(es) limit the capacity or performance of the plant and would benefit from the optimisation activities. Field investigations can be undertaken to confirm the findings of the desktop analysis and to identify the optimisation details. The design or operational improvements are implemented and follow-up monitoring is undertaken to confirm the benefits.

The following recommendations were made regarding the application of this guide:

- Value Engineering is seen to benefit the optimisation process at the planning stage or during project execution by serving as a forum for peer review of the work plan, results and recommendations;
- Tools, such as Stress Tests, can be effective to verify what a unit process can achieve and the required performance level stated in the design guideline;
- Optimisation may remove the requirement for expensive capital investment;
- Optimisation must involve active participation of the plant operating authority, including the operational staff;
- Some aspects of the process assessment and optimisation are best undertaken by experienced process engineering professionals or scientists;
- It is prudent to include the Regulator as part of the project;
- The development and empowerment of operational staff is the focus of the CPA phase in the CCP, and is highly recommended;
- Certification to ISO 9001 and 14000 is highly recommended to show the commitment of the organisation to quality assurance and compliance to standards;
- A Process Audit procedure was developed by Environment Canada as a tool for evaluating plant performance and capacity and energy use using online instrumentation and microcomputer technology. The 'Guidance Manual for Sewage Treatment Plant Process Audits' (MOEE et al., 1996) provides the processes involved in such an audit;
- Numerical models can be used as tools to support the assessment of plant performance and capacity, as well as a means of predicting the impact of design or process changes on performance and capacity.

3.2.5 New Zealand Ministry of Health: Optimisation of small drinking water treatment systems: Resources for the drinking-water Assistance Programme (2007).

The New Zealand Ministry of Health promotes the process of risk management planning of public health risks to control the hazards to a water supply system. This process is viewed as an important part of plant optimisation and a guideline has been developed within the context of Water Safety Planning (formerly known as Public Health Risk Management Plan). This guideline provides a framework and index for the assessment of WTPs for the supply of safe drinking-water to small water supplies serving fewer than 5000 people. The intent of optimisation is to achieve the most effective and efficient use of a water treatment plant, which includes maximising the performance of each piece of equipment and unit process that is part of the supply and treatment facility, with the objective of producing the highest quality final water possible. The Guideline promotes a logical and consistent approach of assessment which includes the outline in Table 3-4 below:

Table 3-4: Framework of the New Zealand Guideline

Optimisation Measures	○ Develop a Process Flow Diagram of the plant; list the objectives and relevant detail of each process unit (e.g. quality, flow, pressure, level, etc.) ○ Visual inspection of the plant ○ Study plant operating records (incl. water quality, production /demand figures, operational changes, power consumption, maintenance frequency) ○ Evaluate the information and confirm gaps via additional measurements, develop trend graphs ○ Identify process limiting factors and its associated risks ○ Effect plant adjustments (optimisation) ○ Identify critical points where optimisation need to be prioritised ○ Address skills and support structures ○ Risk management – develop the Water Safety Plan with contingency measures
Maintenance and Performance Checks	○ List of good practices
Improving the Source	○ Minimisation ○ River intake (including operating targets, water quality records, inspection, maintenance, recording) ○ Infiltration galleries ○ Bores ○ Springs
Improving Pre-Treatment	○ Roughing filters ○ Raw water storage
Improving Filtration	○ Cartridge filters ○ Media filters
Improving Disinfection	○ Chlorination ○ Ultra-violet
Improving Treated Water Storage	
Places to Get Information	

3.2.6 Technical Sustainable Management (TSM$_{Egypt}$) Water Supply and Wastewater Management Programme

The Technical Safety Management (TSM) is a system originally developed by the DWA and DVGW (German Water/Gas Associations) to support German Utility companies in meeting their regulatory obligations. The Technical Sustainable Management programme was developed jointly by GIZ and the Holding Company for Water and Wastewater (HCWW) within the Egyptian-German Water Supply and Wastewater Management Programme (TSM$_{Egypt}$). The aim of the programme is the improvement of the operation and maintenance of water and wastewater facilities focusing on the following Plant focus areas:

- Occupational Health and Safety
- Human resources management
- QA/QC
- Operation
- Maintenance.

The initial approach taken under the strategic direction of the TSM_{Egypt} Working Group was:

- Assessment of all relevant codes, regulations, water quality objectives, etc.;
- Compilation of guidelines for each plant focus area (above) with a specific question and corresponding response to address the aspect under assessment;
- Compilation of questionnaires, forms, rules and templates to support the process;
- Compilation of audit questionnaires with actions listed for i) the plant and ii) the auditor;
- Pilot five plants with direct DWA/DVGW audits;
- Awards of five certificates of compliance.

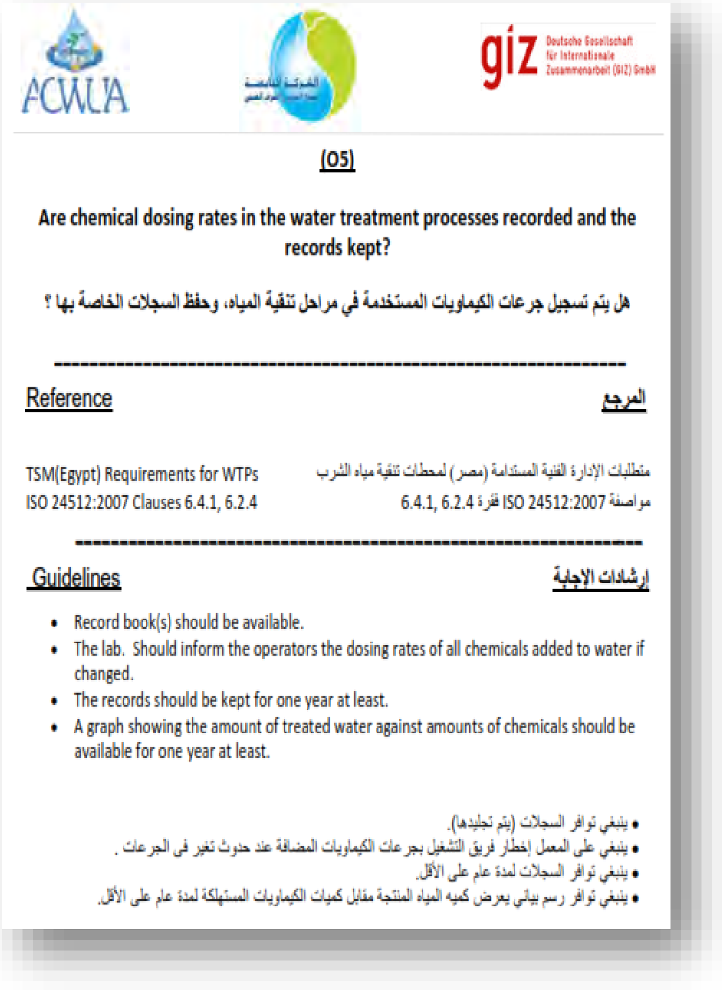
The audit process comprises the following steps:

- TSM_{Egypt} provides a questions catalogue which acts as a guide to the plant manager to support compliance with their Codes and Standards and Quality Management Systems based on procedures and processes;
- Audits are carried out by independent inspectors to verify compliance;
- The entire process is monitored and approved by external auditors (DWA);
- Certificates are issued once inspectors are satisfied that standards have been met using an auditable process (valid for 3 years).

The programme aims to progressively certify more plants with each year of implementation. The impact of the programme is envisioned as follows:

- Plants are operated in accordance with national codes and standards;
- Raises management standards;
- Improves the working environment for staff;
- Demonstrate improved motivation of staff to meet national codes and standards;
- Encourage in-depth discussion on regulation and best practices;
- Establish qualified working group capable to replicate TSM_{Egypt} in the next phases.

The Guideline, with the various questions and guiding points under each of the five Plant focus areas, has been made available to the WRC. The content will be used to inform the development of the WRC Guidance Document. An example of the typical detail presented in the TSM_{Egypt} guideline is presented in Figure 5-5 below:



(05)

Are chemical dosing rates in the water treatment processes recorded and the records kept?

هل يتم تسجيل جرعات الكيماويات المستخدمة في مراحل تنقية المياه، وحفظ السجلات الخاصة بها ؟

<u>Reference</u> | <u>المرجع</u>

TSM(Egypt) Requirements for WTPs
ISO 24512:2007 Clauses 6.4.1, 6.2.4

متطلبات الإدارة الفنية المستدامة (مصر) لمحطات تنقية مياه الشرب
مواصفة ISO 24512:2007 فقرة 6.4.1, 6.2.4

<u>Guidelines</u> | <u>إرشادات الإجابة</u>

- Record book(s) should be available.
- The lab. Should inform the operators the dosing rates of all chemicals added to water if changed.
- The records should be kept for one year at least.
- A graph showing the amount of treated water against amounts of chemicals should be available for one year at least.

- ينبغي توافر السجلات (يتم تجليدها).
- ينبغي على المعمل إخطار فريق التشغيل بجرعات الكيماويات المضافة عند حدوث تغير في الجرعات .
- ينبغي توافر السجلات لمدة عام على الأقل.
- ينبغي توافر رسم بياني يعرض كميه المياه المنتجة مقابل كميات الكيماويات المستهلكة لمدة عام على الأقل.

Figure 3-5: Extract from the TSM Guidelines to inform operational improvement and compliance

3.3 OPTIMISATION OF WATER TREATMENT – INTERNATIONAL CASE STUDIES

3.3.1 Norway: TECHNAEU Case Study: Optimisation of water treatment: enhanced coagulation and ozonation-biofiltration

This study identifies the following main reasons why process optimisation assessments are an appropriate method for improvement within a reasonable time-scale:

- Most WTPs are already built and will be in operation for decades;
- Operation performance assessments, optimisation efforts with respect to safety and sustainability, and identification of best operation practices are not adequately performed or implemented;
- Diagnostic and operational tools are widely used but not well understood and improved knowledge is imperative;
- Sub-optimum operation of plants is widespread and responsible for 30-50% of waterborne disease outbreaks;
- Full-scale optimisation efforts revealed unexploited operation optimisation potential and benefits;
- Alternative ways of benchmarking are required where the current operational performance is compared to the optimum performance/best operation practice identified. This also allows for internal benchmarking to be established.

An operation optimisation procedure was implemented according to the TECHNEAU enhanced coagulation optimisation roadmap (Eikebrokk & Juhna, 2010). This roadmap consists of the following:

- Mapping of operational performance status;
- Application of diagnostic tools for water quality and NOM characterisation;
- Optimisation trials using curative tools, including planning and performance of full scale trials; with systematic variation of coagulant dose and pH;
- Identification of optimisation potentials and possible benefits;
- Implementation of selected operation conditions.

Five full scale plants located in Riga and Bergen were assessed and optimised. The performance of the WTPs were evaluated mainly with respect to water quality, safety and sustainability, which included final water quality, bio-stability, corrosion control, coagulation chemical and waste (sludge) produced. The optimisation included the enhanced coagulation and ozonation-biofiltration processes. The results from the optimisation study indicated various areas for improvement, mainly in savings of chemicals, where over-dosing was identified during the assessment, and reduced sludge production as result of reduced dosing. Application of the optimisation procedures and diagnostic tools assisted in understanding treatment performance and operational requirements and provided new design recommendations specific to the technology in use. The tools used provided valuable links between raw water characteristics and treatment, as well as between treatment and distribution.

3.3.2 EU-TRUST Case Studies

The test sites for the TRUST's Optimisation Framework were the Netherlands, United Kingdom and Norway. The framework was implemented fully in Norway and the Netherlands, while Scotland only evaluated the technical aspects (Figure 3-6). The Norway case study is presented in detail in the overview. The findings of the case studies at the Brandan, Tullich, Amlaid, Waternet and Weespekarspel WTPs are reported in Eikenbrokk et al., 2015. The Stangaasen WTP is located in Oppegard, Oslo Region, Norway. Raw water is pumped from a lake at a depth of 36 metres to the WTP. Coagulant (granulated aluminium sulphate) is added before the flow is split in two parallel lines consisting of flotation and settling, followed by typical media filtration (Figure 3-7). A UV disinfection system is installed to provide robust treatment and to provide primary disinfection. Sodium hypochlorite and sodium hydroxide are then added to provide a residual disinfectant (only for the time spent in the header tank, there is no residual chlorine in the distribution system) and corrosion control respectively.

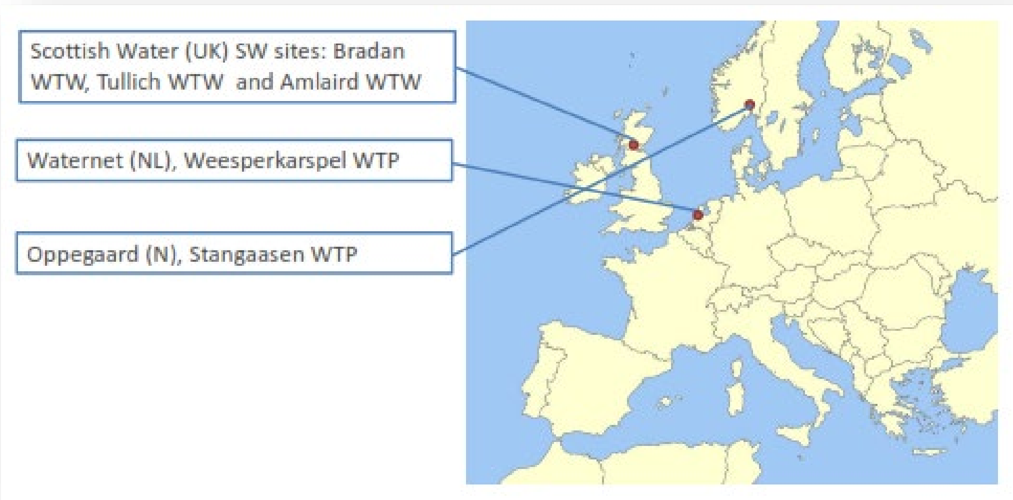


Figure 3-6: TRUST Selected Test Sites

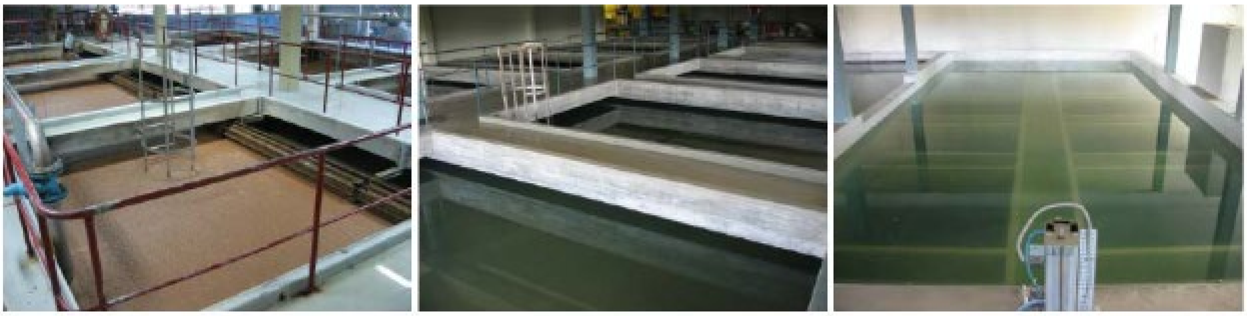


Figure 3-7: Images from the flotation step (left), sedimentation and filtration (right)

The following steps were followed as outlined by the Optimisation Framework:

- Mapping of current operational performance;
- Mapping of the resources (energy, chemicals, water);
- Advanced raw and treated water quality analysis;
- Full-scale optimisation trials in line with the TECHNEAU enhance coagulation optimisation procedures (Eikebrokk, 2009);
- Triple bottom line assessment of economic, environmental and social aspects considered in decision-making (Venkatesh et al., 2015).

The case study presented detailed results, graphs and analysis from each element of the Optimisation Framework (Eikebrokk et al., 2015). The following summarises the main findings (2011-2014):

- Operations performance status mapping, as well as comprehensive full-scale optimisation trials were performed, including water quality surveys and general and specialised analyses, such as NOM fractionation, BDOC analysis, use of chemical and energy, etc.;
- The performance assessments and optimisation studies at the Stangasen WTP revealed that the main challenge was to meet the barrier targets, especially for TOC and turbidity. *Giardia* and *Cryptosporidum* targets were also difficult to meet with conventional chlorination;
- The challenges in meeting barrier indicator requirements for TOC indicated that a transition to iron-based coagulation should be considered. Iron-based coagulation generally removes NOM in a more effective way than Aluminium-based coagulation (often around a 10% improvement) although at a lower pH of 4-5. UV was installed as an additional step to meet the *Giardia* and *Cryptosporidium* barrier targets;
- LCA studies showed that the coagulant aluminium sulphate contributes the most to the overall environmental impact. Alternative coagulants may be used to reduce environmental impacts. Different types of coagulants have been assessed with the LCA tool, including liquid aluminium sulphate, $FeCl_3$ and iron chloride sulphate $FeClSO_4$, all being produced with green energy in Norway;
- The sustainable assessment identified that iron chloride sulphate is the best option to improve the sustainability of the WTP.

3.3.3 Canadian Case Studies and Costing

The Canadian Guidelines are an adaptation of the CCP model to suit the Ontario specific requirements. The following results were obtained at treatment plants where the guideline has been implemented for the optimisation of treatment facilities:

- Field studies and process modelling were used successfully at the Mid-Halton Water Pollution Control Plant in the Region of Halton to substantiate a successful application for plant re-rating (Hribljan, 2005);

- Optimisation of the chemical phosphorus removal process at the Collington plant showed that the more stringent requirements could be met without the need to construct tertiary filters, saving $6.0m (CH2M Hill, 1991);
- Optimisation resulted in the Little River Plant in the City of Windor achieving nitrification despite it not being a design objective. This was done through physical upgrades and SRT control, saving $4.6m expansion cost (Environment Canada, 2003);
- The Region of Halton has adopted the CCP as its preferred optimisation tool which resulted in a substantial improvement in the plant's phosphate removal performance as well as nitrification, without capital expenditure (Wheeler & Hegg, 1999);
- Durham's Newcastle Plant had a history of settleability problems that required frequent reseeding of the reactors. An optimisation programme demonstrated the control of filamentous organisms by process changes which improved settling (Hansler et al., 2006);
- The Region of Halton reduced chemical use for phosphorus removal at the Burlington Skyway plant by 30% due to optimisation, with savings of $30,000 (Eastwood & Murphy, 1991);
- Optimisation and automation of aeration equipment at the Tillsonburg plant resulted in power savings of 15% followed by 16-26% further savings with implementation of on-off aeration energy (Phagoo et al., 1996).

The cost of process assessment and optimisation studies was documented for the various case studies. The following summary provides some guidance regarding costing:

- Significant detail and a Terms of Reference for a process assessment and optimisation study are required to confirm cost.
- As guidance, the cost of a process assessment according to the CCP could be $20,000 (for CPE only) to $50,000 (for full CCP) (2010 prices). This equates to approximately R200,000 to R500,000 (as South African Rand).
- The cost of implementation of an optimisation study depends on a number of factors ranging from the scope of the work, size of the facility, level of field work and analysis required, etc. (Canada, 2010).
- Stress testing and process audit activities to re-rate a small to medium size plant, including multi-season testing of the process, range from $80,000 to $120,000. A large facility process assessment can cost up to $500,000 (R5,000,000).

3.3.4 Ireland: Case Studies from EPA Office of Environmental Enforcement: Drinking Water Audit Report

Two case studies were identified regarding the use of Drinking Water Audits at plants which are listed on the EPAs Remedial Action List (RAL) for exceeding certain levels of contaminants. The audits were carried out to assess the progress made to improve the operational performance at the WTPs in order to reduce the risks identified.

3.3.4.1 South Leithrim Regional Water Supply Scheme, Carrick-on-Shannon

Intervention was required at the Carrick on Shannon WTP in the South Leithrim Regional Water Supply Scheme, due to THMs levels that exceeded the standard specified in the Drinking Water Regulations.
The Carrick-On-Shannon WTP was audited (May 2016) in terms of the following audit categories: Source, Coagulation, Flocculation and Clarification, Filtration, Disinfection, Exceedance of the Parametric Values, Hygiene and Housekeeping, Management and Control. The findings reflected that good progress was being made by Irish Water and Leitrim County Council's Implementation Group to improve the operational performance of the WTP in order to reduce the risk of THM formation. Process optimisation included:

- Caustic soda dosing for alkalinity correction;
- Installation of automatic chemical dosing;
- Provision of run-to-waste facilities on the filters; and

- Implementation of Irish Water's Alarm and Critical Control Criteria.

The Auditor recommended that the WTP be removed from the RAL in September 2016, subject to verification. Specific recommendations were made for further improvement.

3.3.4.2 Midleton WTP

Midleton WTP experienced elevated aluminium levels which exceeded the value required in Regulations. The Midleton WTP was audited (March 2015) after undergoing systems and process upgrade work in response to aluminium exceedance and notification by Irish Water to meet the aluminium parametric value specified in the Regulations. The audit report included the following audit categories: Source Protection, Monitoring and Sampling Programme for Raw Water, Coagulation, Flocculation and Clarification, Filtration, Sludge management, Chlorination and Disinfection, Fluoridation, Treated Water Storage, Exceedance of the Parametric Values, Chemical Storage and Bunds, Hygiene and Housekeeping, Management and Control. The Auditor noted that work related process optimisation in coagulation, flocculation, clarification and filtration had made progress. In addition, the automatic shut-off based alarm set points for ammonia, chlorine and turbidity formed a critical control element during changing raw water conditions. The Auditor noted commendable improvement on minor works and made specific recommendations for further improvement.

3.3.5 Case Studies from The Technical Sustainable Management (Tsm_{egypt}): Water Supply and Wastewater Management Programme

The TSM is a self-control instrument of the DVGW and the German Association for Water, Wastewater and Waste (DWA) for the quality management of water and wastewater companies in terms of technical quality and organisation issues, such as operation and maintenance. Successful implementation of the programme in Egypt ensures that legal and technical requirements are met. Although this programme is not specifically designed to focus on process optimisation, it addresses these aspects through the assessment of operational, maintenance, administration and management functionality in line with the codes and standards applicable in Egypt. The Audit process allows for the independent verification and certification of WTPs if they are found to be compliant with the audit criteria. The programme has been in development and implementation since 2009, to meet the requirements of the Egyptian Water sector. A summary of the results are as follows (Badr, 2016; Abotaleb et al., 2015):

- Development and implementation of an Implementation Guide to clarify processes and procedures;
- 6 out of 19 affiliated companies (out of a total of 25) have been reached;
- Substantial economic impact through decreased production costs of 5-20%;
- Increase lifetime of the assets of the facilities due to improvements in maintenance;
- Changing the culture of the operator to promote professionalism;
- Training of new inspectors for plant audits;
- Compliance with ISO 17020.

3.3.6 Summary from case studies

The literature study and cases studies give rise to findings that many regulatory and support programmes exist which guide Water Service Institutions and process controllers along the path towards compliance but not all have a self-improvement or optimisation focus. As examples, and possibly stated over simplistically:

- The Water Research Australia document can be described as a risk focused operations guide.
- The European Union Trust approach is better suited to the development of new infrastructure and specifically focuses on the consideration of a number of sustainability issues.
- The GIZ system has a strong regulatory compliance slant.

- The New Zealand Ministry of Health programme focuses on defining best practice design and maintenance for small plants. It does however touch on a number of critical optimisation questions although limited in scope.

The US Environmental Protection Agency: Composite Correction Programme (CCP) (Environmental Protection Agency, 1998) and the Partnership for Safe Water however have a strong self-improvement focus which makes these strong baseline models around which the South African Guideline Document can be developed.

3.4 PROCESS AUDITS AND PLANT OPTIMISATION STUDIES IN SOUTH AFRICA

3.4.1 Process audits

The basic fundamentals and requirements of Process Audits are well known in South-Africa as it has formed part of the DWS' Blue Drop Certification Programme since its inception. In the Blue Drop Certification Programme, the Process Audit is a key input to the mandated risk management strategy or "Water Safety Plan" (WSP), which is intended to form the basis of the water services strategy of the water services institution. Key questions posed during a Blue Drop process audit will be:

- Is the facility able to produce sufficient volumes of good quality water at present and will it be able to continue to do so in the foreseeable future?
- What can potentially go wrong at the plant that will detrimentally impact on the ability of the plant to achieve the water quality goals, and are the current mitigation measures in place sufficient to manage the risks at acceptable levels?

The role of the process audit in the risk management cycle is shown in Figure 3-8 below and its position illustrates the risk focus of the Blue Drop process audit.

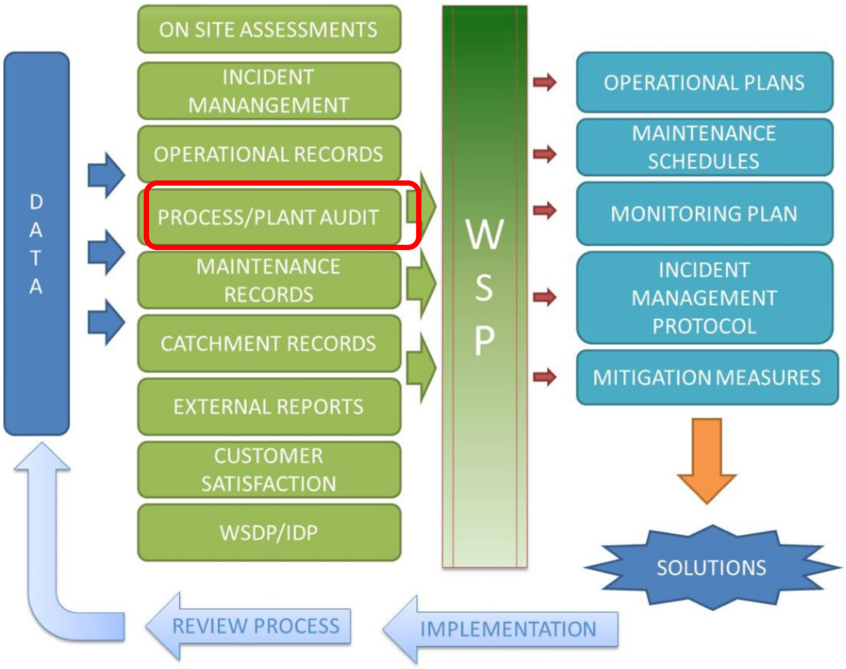


Figure 3-8: Position of the Process Audit in the Risk Management Cycle[1]

[1] Adapted from Coetzee L.Z., Ceronio, A.D., Laher, A.H. (2011) Water Safety Plans – a Case Study from the City of Tshwane Second Municipal Water Conference, Cape Town.

The requirements of the DWS for a Process Audit Report are set out in its 10 Year Blue Drop Strategy[2] which was launched at the WISA Conference held in Mbombela from the 25th-29th May 2014. Although listed earlier in this chapter, a repeat of requirements is warranted. DWS requires that an annual Process Audit Report on the technical inspection and assessment of a treatment facility be presented on demand and that there is evidence of implementation of the recommendations of the report. According to DWS, the report must cover the following:

- Analysis of raw water quality and trends with particular focus on problem parameters,
- Analysis of final water quality performance as well as trends,
- An evaluation of the plant's ability to meet current and future water quality requirements,
- Demand analyses of based on historic and projected data with a specific focus on the ability of the plant to meet the future supply needs,
- Plant efficiencies with a focus on reduced in-plant water losses,
- Performance analyses of the plant's unit processes,
- An evaluation of the condition of the equipment installed at the plant,
- An evaluation of energy efficiency at the plant
- An evaluation of the operational competence at the plant and in conclusion
- Recommendations on the process, capacity, infrastructure care and operational optimisation of the plant.

The critical role of the process audit in the risk management process is emphasised in the refusal of the DWS to acknowledge the process audit should:

- the findings not be included in the Water Safety Plan (WSP),
- the assessment not be conducted independently of the plant owner and operator at least every second year.[3]

A critical point to note is that cost saving and process optimisation (other than water losses and power consumption) is not a requirement of the DWS Process Audit. The need for reducing water losses and improving energy efficiency is driven by the understanding that water and power availability are critical risks in the supply of potable water. The study of literature, as reported in earlier sections of this Chapter, has shown that the Process Audit as a regulatory requirement, is not mirrored internationally. The international norm has been to focus on self-regulation and a drive to improve plant optimisation on an ongoing basis. This approach has found application in South Africa outside of the regulatory Blue Drop Certification programme. The first known application of a formalised optimisation study based on international guidelines was undertaken by Midvaal Water in 2008[4]. Midvaal Water undertook a Process Optimisation and Improvement Study in order to develop a strategic plan for operational and capital interventions at their plant located near Stilfontein in the North-West Province. The study was not limited in any respect and the project scope definition was deliberately broad and was stated as: "a detailed assessment of the plant to determine how the plant and plant operation could be optimised". The capable plant model was identified by the project team as a workable model through a literature study that preceded the execution of the project. Work was undertaken based on an earlier version of the AWWA capable plant approach model guideline[5] of which the principles remain the

[2] Launch of the BD 10-year Strategy at the 2014 WISA Conference on 25-29 May 2014 in Mbombela, Mpumalanga

[3] Launch of the BD 10-year Strategy at the 2014 WISA Conference on 25-29 May 2014 in Mbombela, Mpumalanga

[4] Personal communication – Marina Kruger, Midvaal Water, August 2016.

[5] Lauer B (Editor) (2001) Self-Assessment for Water Treatment Plant Optimisation (International Edition). American Water Works Association, Denver, CO.

same as those contained in the 2015 version. The capable plant model and the optimisation study approach were later recommended as a guideline for consideration for the requirement of the Blue Drop process audit[6,7]. Table 3-5 below lists the requirements of the capable plant model approach to plant optimisation and those of the Blue Drop certification programme. The points of shared focus are clear and it is easy to consider the Blue Drop Audit as a subset of the Plant Optimisation study. Although there are several commonalities, the main difference is that the Blue Drop Process Audit has a risk motivation focus while the Plant Optimisation focuses essentially on improved operation.

Table 3-5: Comparison of the AWWA Plant Optimisation approach and the requirements of a Blue Drop Process Audit

AWWA Process Optimisation Approach	Criteria	Capable Plant Model	Blue Drop Requirements (10-Year Plan)
Performance assessment Determine the current level of plant performance versus optimisation goals	Raw water quality assessment	☑	☑
	Process unit water quality	☑	-
	Final water quality trends	☑	☑
	Current water quality requirements	☑	☑
Capacity Assessment Determine if sizes of major unit processes are limiting performance	Demand analysis (historic)	☑	☑
	Demand analysis (future)	-	☑
	Energy efficiency	-	☑
	Plant efficiencies (hydraulic)	☑	☑
Unit Process Performance Assessment Identify other aspects of unit process design limiting performance	Performance analysis of unit process	☑	☑
	Evaluation of plant and equipment condition	☑	☑
	Emergency / Failure plan	☑	-
Operational Assessment Identify operation practices limiting performance	Routine sampling and testing schedule	☑	-
	Unit process control	☑	-
	Maintenance and calibration schedule	☑	-
	Status of equipment	☑	☑
	Communication	☑	-
	Documented procedures and record keeping	☑	-
Administration Assessment Identify administration practices limiting performance	Administrative policies	☑	-
	Acceptance of optimisation goals	☑	-
	Partnerships	☑	-
	Action plans	☑	-
	Training	☑	-
	Staffing	☑	☑
Assemble and prioritise a comprehensive list of factors limiting performance.	Identify performance limiting factors	☑	☑
	Prioritise performance limiting factors	☑	☑

6 Carrim A, Ceronio A, Kruger M (2010) A Guide to Plant Evaluation and Optimisation. Presented at the Water Institute of Southern Africa's Biennial Conference and Exhibition, 18-22 April 2010, Durban ICC, South Africa

7 Laher A, Ceronio A (2011) A Guide to Process Audits. Presented at the 3rd Municipal Water Quality Conference, 28-30 June 2011, Cape Town ICC, South Africa.

AWWA Process Optimisation Approach	Criteria	Capable Plant Model	Blue Drop Requirements (10-Year Plan)
Identify activities to address factors that will improve performance			
Implement activities that will improve performance	Activities to improve performance	☑	-
	Funding	☑	-
Assess performance improvements	Measure results, make adjustments, re-evaluate and continue the optimisation sequence	☑	-

3.4.2 Plant Optimisation and Process Auditing Principles in South Africa

Given that process audits specifically, and by implication plant optimisation principles, have a history in South Africa, it is necessary to investigate the extent to which current process audit reports meet the requirements listed in the previous section. A large number of reports have been prepared in compliance with the requirements of the Blue Drop programme and have been made available for consideration as part of this study. A total of 74 reports, prepared by 13 separate authors or service providers, were reviewed. An analysis was done of how many of the criteria of the AWWA Process Optimisation and BD Process Audit are met by the reports. The results are summarised in Figure 3-9 below.

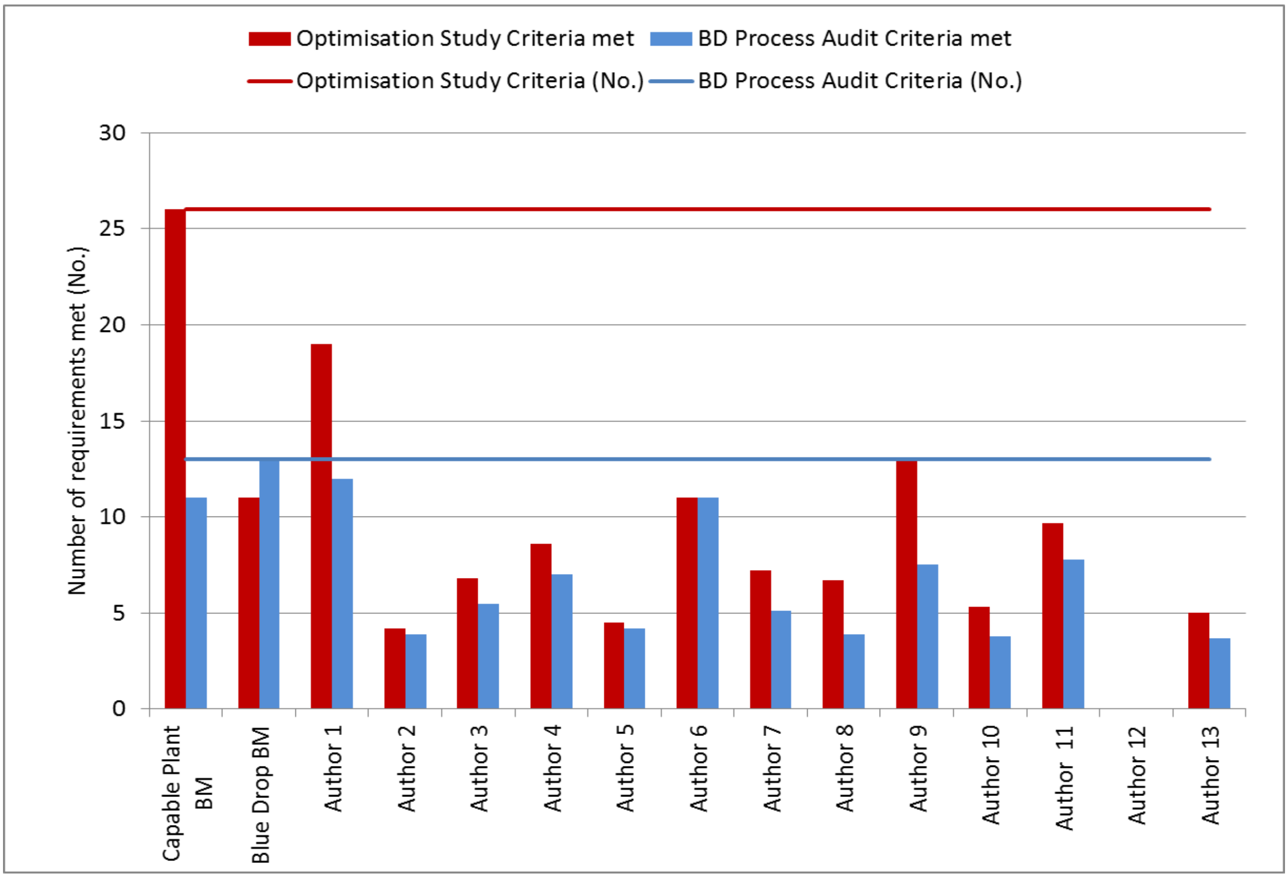


Figure 3-9: Comparison of current South African Process Audits with established requirements

The results are reported as a score for each author as the number of reports available per author differed substantially and also that the reports generated by each author were fairly generic in terms of scope and presentation although they were prepared to address the needs of specific plants. Based on the information presented in Table 3-5, the AWWA Capable Plant benchmark (BM) consists of 26 criteria while the Blue Drop benchmark (BM) has 13 criteria. It should however be noted that the AWWA Capable Plant Model does not cover two of the requirements of the Blue Drop list while the Blue Drop list only covers 11 of the 26 AWWA criteria. Consequently, each report was evaluated in terms of the number of criteria it addressed in terms of the AWWA requirements, as well as the number of criteria met for the Blue Drop list. Since all of the reports were prepared as "process audits" for Blue Drop purposes, it is to be expected that the reports will not perform well when measured against the requirements for the AWWA Capable Plant approach. Furthermore, the risk focus associated with the BD benchmark and the optimisation focus associated with the AWWA model, were not strictly considered during this analysis. The result of this analysis is therefore a quasi-quantitative indication of the achievement in meeting both the AWWA and Blue Drop requirements. As an example of interpretation of the graph, Author 1's report meets 19 of the 26 AWWA optimisation study requirements and 12 of the 13 BD process audit requirements. The results of the analysis indicate that the reports submitted as BD Audit reports meet on average 5.8 of 13 BD criteria and 7.8 of 26 AWWA criteria. It is clear that the reports generated in South Africa generally fall short in terms of the required scope for either the BD Process Audit or AWWA optimisation studies.

Figure 3-10 and 3-11 present the results of an assessment of where the reports fall short of the two benchmarks. In both these analyses the question asked was whether the report addressed the topic as required by the AWWA capable plant approach as well as the BD Audit requirements. Generally, a full mark was allocated if the requirement is addressed in some detail while a fraction of a score was allocated if the topic is superficially addressed. Results are then presented in terms of the percentage of authors who have addressed the specific requirements. The combined set of requirements for the AWWA capable plant approach as well as the BD Audit is listed along the x-axis in Figures 3-10 and 3-11 while the BD requirements are annotated with a dot above the relevant requirements. It is clear from the graphs that the South African reports are responding to the requirements of the Blue Drop certification programme but only limited compliance with the AWWA Optimisation study guidelines. However, the average Blue Drop report only addresses an average of 45% of the requirements of the Blue Drop requirements. It is important to note that the Blue Drop requirements of the 10-Year Blue Drop Certification Strategy have been used in this assessment and that many of the reports evaluated are based on previous, and somewhat reduced, Blue Drop requirements. The difference in requirements is however not sufficient to change the findings of the assessment. The range and depth of the audit against the various Blue Drop requirements varies substantially in the reports studied. This results in the "usefulness" of the report being compromised in some cases as the requirements are dealt with in a cursory manner without substantive analysis and inspection of the available data. The findings and recommendations are consequently not substantiated or insufficient in all cases.

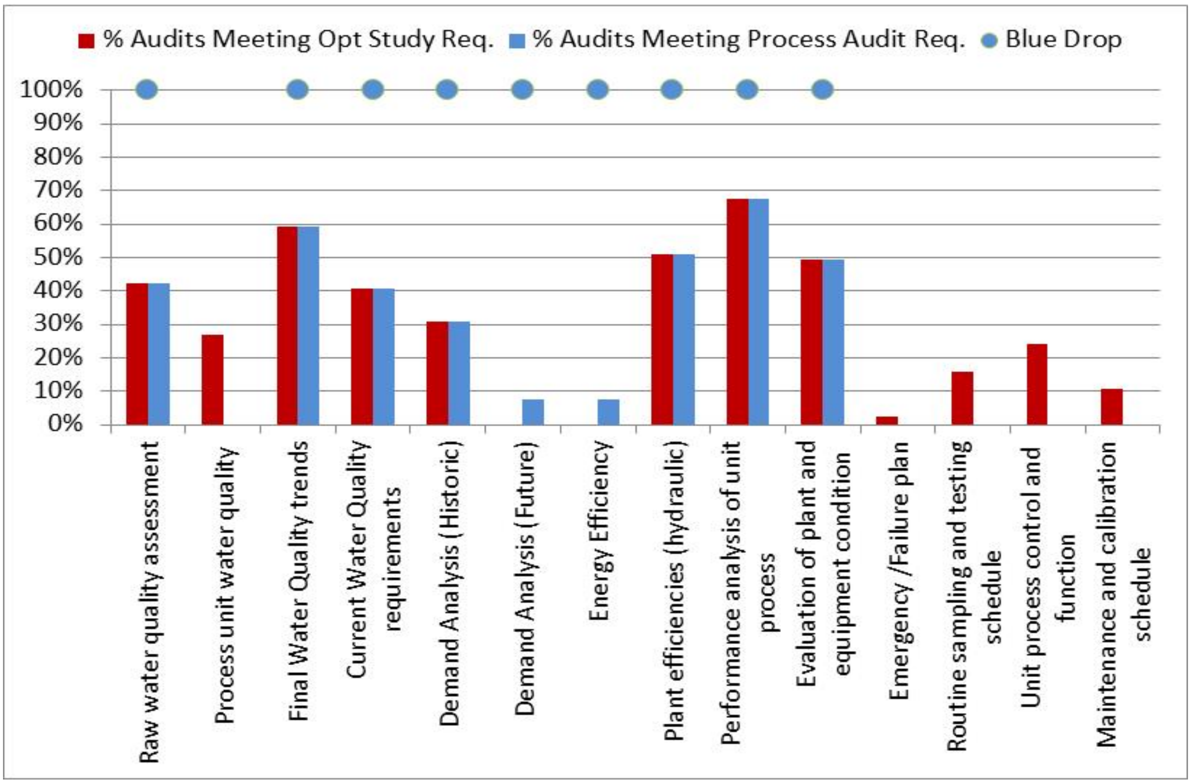


Figure 3-10: Comparison of current reports against current requirements (Graph 1)

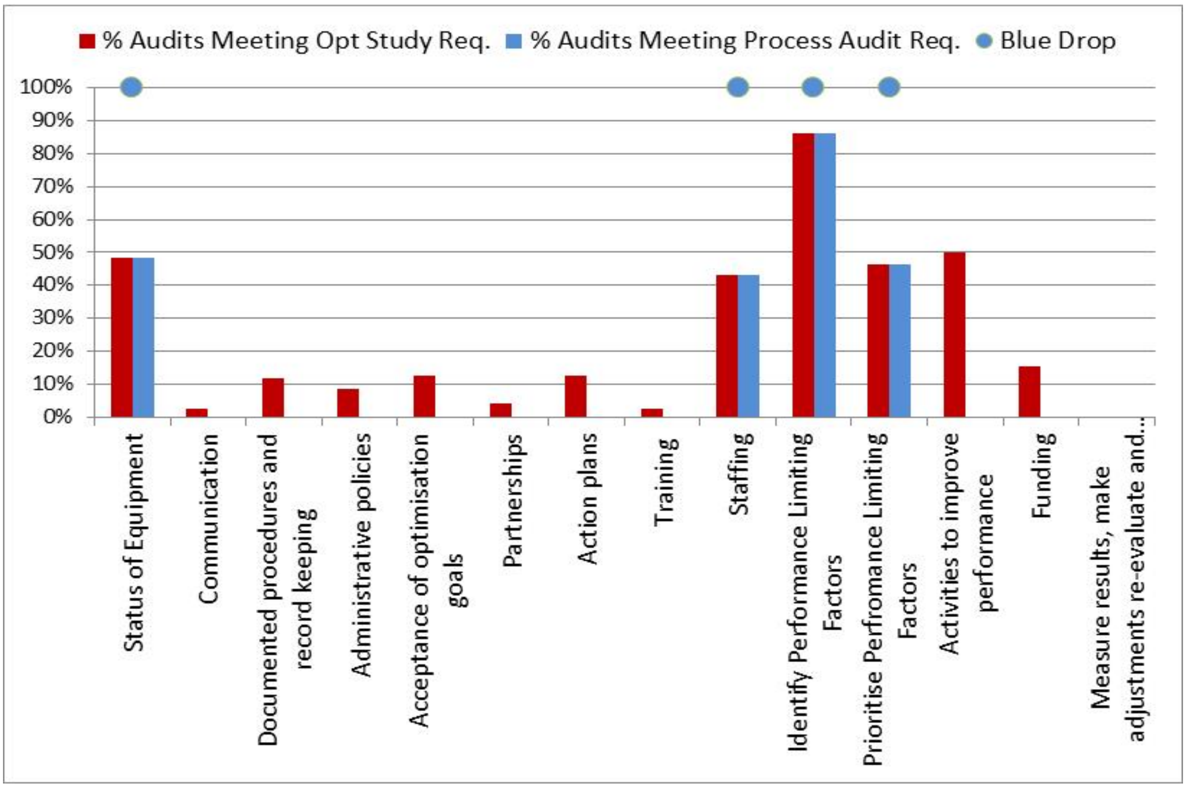


Figure 3-11: Comparison of current reports against current requirements (Graph 2)

3.5 BENCHMARKING

The various models that have been discussed in this Chapter include the application of benchmarks against which performance can be tested. These benchmarks range from regulatory compliance for water quality to internal performance indicators set by the water services institutions to monitor individual process units. Benchmarks can also be used as a tool for water services institutions to evaluate their performance with other institutions or national benchmarks to identify where further improvement of performance can be considered. Literature references acceptable design parameters for various treatment process units that serve as benchmarks. Comparison of operating conditions to either typical sectoral benchmarks or design data enables the WSI to identify performance limiting factors related to the installed facilities and equipment. Most audit and optimisation models include an assessment step that evaluates performance of major unit processes to establish design aspects other than unit size which limit performance. The proposed Guidance Document should include typical process design benchmarks that are applied in South Africa to assist and guide both the assessor and the WSI where site specific information is not available. Some examples of benchmarking initiatives are covered below.

3.5.1 American Water Works Association

The AWWA has been running a benchmarking programme since 2013 that provides benchmarks for both water and wastewater in five areas of operations, namely Organisational Development, Customer Relations, Business Operations, Water Operations, and Wastewater Operations (AWWA, 2016). The benchmarks have been selected for their usefulness in assisting utilities to track and improve operational and managerial efficiency. Data submitted by the AWWA members is aggregated and published annually to enable utility managers to determine how their performance compares to that of the sector and facilitates setting of targets for continual improvement. Where data are available, historical trends from previous AWWA utility benchmarking surveys are also provided.

3.5.2 Status quo of Optimisation Studies and Process Audits in South Africa

A Municipal Benchmarking Initiative was launched in 2011 by the South African Local Government Association (SALGA) in partnership with the Water Research Commission (WRC), the Institution of Municipal Engineering of Southern Africa (IMESA) and eThekwini municipality. Information on municipal performance is uploaded to and tracked through a web-based system called Munibench. The objective is to improve effectiveness in water services delivery through comparative performance benchmarking and peer-to-peer knowledge sharing. Provision of data by the municipality is voluntary. Data is collated from information submitted to other national databases as well as information uploaded to Munibench by participating municipalities. There are six performance areas, namely water conservation and demand management, Human resources and skills development, Service delivery and backlogs, Operations and maintenance, Product quality and financial management. Benchmarks are provided for each performance indicator, as well as results of the aggregated data for each category of municipality. The initiative currently assesses water services performance at a municipal level. Limited data and benchmarks are compiled that will enable the assessment team to monitor and evaluate performance at a treatment plant level, as well as benchmarking appropriate administration and operations performance indicators.

The assessment of process audits, and by extension process optimisation studies, has shown that local activities are driven by the requirements of the Blue Drop Certification programme and consequently tend to have a risk bias. There is fairly wide uptake of the optimisation and audit concepts but the extent to which the various study elements are handled varies substantially. It is clear from this assessment that it is necessary to provide guidance on the requirements and focus of a process audit and optimisation assessment while providing clear delineation between the optimisation study and process audit.

3.6 SUMMARY

An optimised process unit can be defined by its ability to consistently and continuously remove targeted contaminants at the level required to prevent a risk to public health. The review study indicates that various countries and utilities take different approaches to assess and optimise WTPs. The key features from the international set of frameworks and guides are summarised below and will be used to inform and guide the development of a Guideline suitable for the South African water sector:

- Optimisation studies focus on achieving best possible performance at a plant and do not have capital works as an anticipated outcome;
- The setting of performance goals is supported by numerous researchers and case studies (Patania et al*.,* 1995);
- Trend graphs are useful and should include as a minimum raw, settled or clarified and combined filter effluent water turbidities, as well as any other determinands under consideration;
- The use of Performance Potential Graphs is useful in identifying capacity constraints in production (Renner et al., 1991);
- The use of process unit performance goals must be standardised with some allowance of variance based on the experience of the assessment team (example from AWWA, 2015)

Unit Process Performance Goals Table		
Objective: To establish process control targets for each major sampling location/unit process to ensure optimized plant performance		
Sampling location/ unit process	**Tests**	**Target value**
Raw Water	Turbidity pH Alkalinity Iron Manganese Dissolved Oxygen (DO)	<5.0 NTU 7–9 80–120 mg/L $CaCO_3$ <0.3 mg/L <0.05 mg/L >4.0 mg/L
Rapid Mix	pH	<7.5
Settled Water	Turbidity pH Alkalinity	<0.5 NTU <7.6 80–100 mg/L $CaCO_3$
Filter Effluent	Turbidity	<0.10 NTU, 95th percentile
Finished Water	pH Total Chlorine Turbidity Fluoride Free Ammonia Alkalinity	>8.4 >2.2 mg/L <0.1 NTU 0.8 mg/L <0.1 mg/L as N 90–100 mg/L $CaCO_3$

- A list of questions to prompt the assessment team is useful to ensure that the assessment produces answers to the most pertinent questions. This list of questions should ideally align with the various categories to ensure that the assessment stages have achieved their goals. However, the list should not be considered to be exhaustive and the assessment team must be able to add questions that are relevant to the plant;
- If problems are identified during the status review of the performance of the plant, corrective actions should be developed, scheduled and initiated to address the identified deficiency and performance limiting factor;
- The inclusion of 'References' with each Chapter of the Guideline to provide further reading material to the user, will be useful;
- The inclusion of examples or case study extracts to support a particular point in the guideline and to assist the user's understanding.

CHAPTER 4: **DEVELOPING A GUIDANCE DOCUMENT FOR SOUTH AFRICA**

4.1 INTRODUCTION

The framework for South African Guidelines for process audits and optimisation assessments was based on the following:

- The Capable Plant methodology of the Partnerships for Water for plant assessments in line with the AWWA (2015) and the dynamics and regulatory environment of South Africa;
- Consider the treatment process units as described by the WRC Report 265/06 to allow for South African context and conditions. These process units include: coagulation-flocculation, sedimentation and flotation, sand filtration, disinfection, chemical stabilisation, fluoridation, residuals handling and treatment, and advanced processes (incl. DAF and membrane filtration) (Schutte, 2006).
- Include contributions to the disinfection process unit from the WRC Report 406/09 (Van der Walt et al., 2009).
- Include contributions to the Administrative Assessment Step from WRC Report 408/09 (Swartz et al., 2009).
- Consider optimisation aspects and comment relevant to energy efficiency and water losses, as these are two pertinent limiting factors facing the sector;
- Include guiding parameters for plants which are under refurbishment. Best practice dictates that assessments continue during refurbishment and that the same assessment steps be followed for the refurbished plant by consideration of separate information and data set for the new plant. Pilot study data may be used to evaluate performance (AWWA, 2015).
- Make comment about the value of linking (or following through) the assessment and optimisation process of the treatment plant and the distribution system in order to maximise the desired output in achieving high quality finished water (Eikebrokk and Juhna, 2010);
- Provide a flow diagram which assists the user to understand the role of the Process Audit and Optimisation Assessment in context and sequence of the municipal decision-making process – to include the Water Safety Plan, Process Audits, SANS 241, Water Services Development Plan, master plans, Integrated Development Plan and the budgeting and finance plans.
- Provide guidance on the qualifications and experience of professionals who should be engaged in plant audits and optimisation studies.

4.2 NEED FOR BENCHMARKING

As demonstrated in all models reviewed, performance is measured against appropriate benchmarks. This concept must be promoted in the Guidance Document. It is the intention to source and reference local benchmarks, where they are available. Literature addressing process design and associated benchmarks in the South African water sector is widely available and can support the assessor to identify performance limiting issues in this regard. However, operational and administrative information of drinking water treatment at a plant level is generally limited in the availability. This negatively impacts on audit and optimisation process, especially due to the importance of these aspects in creating an enabling environment. Where available, local benchmarks, which will be complemented by international benchmarks compiled by the AWWA, should be included in the Guidance Document. It is anticipated that as the process audit and optimisation methodology described in the Guidance Document is more widely adopted and the outcomes of the assessments are strengthened, additional information will be available to inform national benchmarks. Development and adoption of appropriate benchmarks can be facilitated and promoted by intervention by the WRC.

4.3 STAKEHOLDERS

The following stakeholders may have an interest and could derive benefit from this study:

4.3.1 The Regulator

- The Department of Water and Sanitation develops and enforces regulations pertaining to the requirements of process audits, professionals who conduct technical and compliance audits, as well as the frequency of these audits. The Blue Drop Audit process will benefit by referencing the Guideline with the aim to standardise the content and quality of process audits.
- The Department of Environmental Affairs has a regulatory role to monitor, regulate and manage wastes in accordance with the requirements of the Waste Act and therefore have an interest in the section of the Guideline dealing with sludge and residue management.

4.3.2 Other Role players

- The research and development institutes have a vital role in terms of sourcing, developing, and communicating technologies and performance driven knowledge in the field of water treatment and domestic water quality. Research and knowledge derived from this study would typically inform policy, strategy and further research directives in South Africa.
- National Treasury and finance institutions have possibly one of the most significant roles to play. Effective treatment plant operations hold various benefits and incentives in terms of social and economic aspects, including health, environment, commodities, infrastructure development, etc. The aim of a process audit and optimisation assessment is the reduction or deferment of capital expenditure.
- The Departments of Trade and Industry, and Science and Technology, recognise the role of emerging technology, research, innovation, opportunities and partnerships to advance water treatment in South Africa. Possible partnerships could be established for example with the Partners for Safe Water and introduce SA utilities to this programme.
- Professional organisations, such as SAICE, WISA, ECSA, are important stakeholders in terms of their members who are working as specialists in the water sector and who have a key role in applying the concepts of the guideline and building capacity.
- CoGTA has a role to ensure that local government manage treatment plants in a sustainable and cost-effective manner. Any protests regarding ‘unsafe’ drinking water and public perception can be managed and mitigated using process audits and optimisation assessments to ensure that plants produce safe drinking water.
- SALGA has an active role to play in benchmarking local government and sharing best practice and tools that assist municipalities to improve the performance of water treatment plants through process optimisation.
- The Department of Energy has a stake in ensuring that treatment facilities are well managed and that energy efficiency measures form part of decision making processes. Process optimisation aim to derive energy savings and a reduced carbon footprint as part of process optimisation.
- The Department of Labour has a role in the value chain of water treatment as the hazards associated with the operation of sophisticated equipment and handling of chemicals are recognised. The safety of workers and the public health impact of inadequate management practices are high on the agenda of the Department and its regulation and legislature.
- Training institutions’ roles are to facilitate training on the use of the Guideline, which could include theoretical training and practical demonstrations. Various opportunities for post-graduate studies could become available where plant optimisation studies are undertaken as some optimisations are undertaken over a period of 2-3 years.

4.4 THE GUIDANCE DOCUMENT

4.4.1 The Blue Drop Regulation Programme

The fundamental philosophy of the Blue Drop Regulation Programme is that regulatory performance is not enough. Water treatment and water supply must also remain sustainable in an environment where more has to be done with less on a day-to-day basis. This extends to producing more water from the same infrastructure with lower budgets against a more challenging water quality requirement. These processes must occur while consumers continue to have access to a safe and reliable water supply and this can only be achieved if plants and plant operations target best practice principles, this is optimisation. Typical optimisation targets may include:

- Improved water quality compliance,
- Reduced operations cost as reflected in chemical and energy expenditure,
- Reduced environmental impact as reflected in reduced water loss and sludge production, and
- Improved production rates and income generation as reflected in increased production rates and reduced water losses.

The list can be modified to address any improvement target that may be relevant to the Water Service Institution and process controller. There are therefore two very clear and sometimes opposing targets which must be addressed – compliance and optimisation of resources. The concept of a process audit is familiar to the South African water sector as it was introduced as part of the Blue Drop Programme and Water Services Authorities are required to submit these to the Department of Water and Sanitation on an annual basis. The content and format of the process audit report however remains problematic as this varies broadly in the sector (Van der Merwe-Botha, et al., 2016). This creates problems when presented to the DWS for regulatory purposes as the reports often fall short of the Department's requirements. Clear guidance is therefore required on the requirements of process audits and also optimisation studies which naturally follow from this.

4.4.2 Framework for guideline

An extended literature review concluded that, in terms of clear guidance on focused plant optimisation with a goal of continuous improvement, the approach adopted by the American Water Works Association (AWWA) and USEPA was found to be most appropriate. The Canadian model for Sewage Works is based on the same model. The AWWA developed and implemented the "Capable Plant" model which provides a holistic and integrated approach to optimisation of water treatment facilities. This model has been used as a basis for the development of these South African Guidelines. In short, the model confirms that water quality can only be assured if:

- The plant design is appropriate,
- The plant is properly maintained,
- The plant is properly resourced, and
- The plant is properly operated.

This model carries forward into the discussion on optimisation as each ot the listed bullets present opportunities for optimisation. It is consequently easy to confuse the processes of optimisation and regulation when considering the complexities of water treatment. It then becomes difficult to distinguish between the two end goals as mentioned earlier. The following two simple questions define the line of separation between the two:

- A regulatory process auditor asks: "What can go wrong (identify hazards) and what do we put in place to mitigate these risks to final water quality?"
- A process optimiser asks: 'What can we do better than yesterday?"

4.4.3 Process audits

A process audit therefore aims to produce a compliant plant while an optimisation study aims to produce a smart plant. Schematically the differentiation can be illustrated as follows as per Figure 4-1.

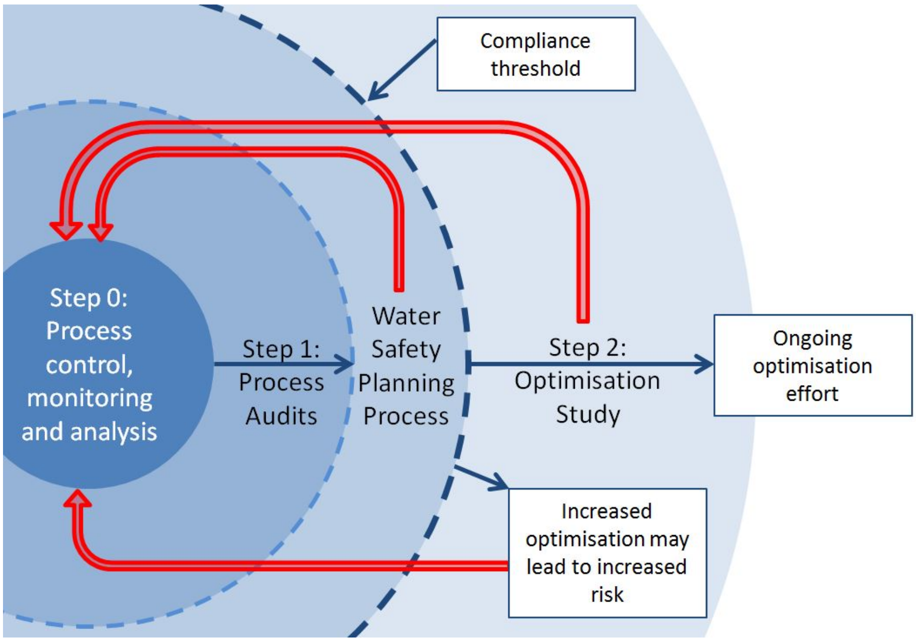


Figure 4-1: The relationship between Process control, Process Audits, the Water Safety Planning Process and Plant Optimisation Studies

It should be clear that regulatory compliance needs to precede cost saving and process optimisation in general. The conventional approach would therefore be to invest in risk evaluation via the process audit route and mitigation of these issues prior to investing in optimisation. These are however not mutually exclusive exercises and in a mature organisation, will exist side-by-side.

4.4.4 Who is this guideline intended for?

These Guidelines are intended to be used by skilled plant designers, senior process controllers and decision makers to inform decisions regarding the operation, maintenance and ongoing improvement of water treatment works. It is expected that the process inspector has an excellent understanding and experience of water treatment processes, operation and maintenance requirements, management functions and has a good knowledge of the regulatory framework. This document was written at a level which assumes an advanced degree of understanding and competence in terms of treatment process design, treatment plant design and the South African regulatory framework.
Ideally the inspector will have:

- an advanced tertiary qualification in a water treatment related field and;
- will have at least 10 years' experience in the field of water treatment and;
- Professional registration with an appropriate regulatory body.

4.4.5 Who should conduct process audits?

A survey of various Water Services Institutions show that some require that a process auditor must be an Engineer while others are satisfied if the inspector is a Scientist or a Professional Process Controller. In many cases Blue Drop or Green Drop Audit training and experience is seen as an advantage. On the basis of the established expertise of the inspector, the Guidelines do not offer specific optimisation solutions as this will limit opportunities and the depth of investigation. The Guideline presents an approach to be followed by self-assessors or process auditors who require a structured methodology to assess the performance of a plant, identify factors that detrimentally impact on the performance of the plant, and how to develop a response to those factors in such a way that plant performance is optimised. The basic approach offered is based on basic quality assurance principles. This includes an assessment of the current status, the identification of risk management and optimisation opportunities, the identification and implementation of solutions and the monitoring and adjustment of approach as results are generated. The basic steps of the approach are as follows:

- Determine current plant performance levels against optimised / regulatory goals;
- Determine if major unit process sizes are limiting performance,
- Identify any aspects (other than unit size) of unit process design which limits performance,
- Determine if operational practises are limiting performance,
- Determine if administrative practises are limiting performance,
- Determine activities to address factors that will improve performance, and
- Implement strategies and monitor performance to assess progress toward the identified goal.

After application of the Guideline document it is anticipated that the inspector will repeat the process on an ongoing basis to refine the risk management and optimisation approach. The system drives the continuous improvement effort at the plant.

CHAPTER 5: **SUMMARY AND CONCLUSIONS**

5.1 SUMMARY

The development of the guideline document for process audits resulted in the identification of a number of shortcomings in the sector which may be addressed via project support from the Water Research Commission. The most pertinent shortcomings are briefly discussed below:

- **Development of an Annexure to the Guidance Document in order to address process audits for Wastewater Treatment Plants** – The principles presented in the Guidance Document were written in the context of the potable water sector. The principles are however generic and can be applied to the wastewater treatment sector as well. This was noted by various attendees during the various round table discussion sessions. The technology specific sections of the Guidance Document however do not sufficiently support the wastewater treatment sector. This can be addressed by preparing an annexure or companion document which will provide the equivalent content which will be required for the wastewater treatment sector.

- **Regulatory and Professional Requirements for Process Inspectors** – This Guidance Document was written at a level which assumes an advanced degree of understanding and competence in terms of treatment process design, treatment plant design and the South African regulatory framework. The approach was supported by the various round table discussions of the draft report where it was clear from discussion that a specialist was required to perform the required assessments. This was because the audit methodology could not be exhaustive in its discussion of all water treatment technology options or all operational conditions. The Guidance Document places significant responsibility on the inspector to draw on his or her extensive experience to analyse situations and recommend actions. This requires that inspector to be qualified and experienced. The various round table discussions could however not adequately conclude what the type and level of qualification and experience should be. This is problematic in that:
    - Limiting access and authority to the “right” to perform of process audits to very highly qualified and experienced individuals or placing a too narrow view on the requirements for a process inspector, serves to limit the pool of “competent” persons available to perform the work and consequently increasing the cost while limiting the general application of the Guideline Document and the rate of process audit delivery.
    - If the required qualification and experience of a process inspector is not adequately defined, the risk is that the market is open to poorly skilled persons who advise on matters that have a direct effect on the health and wellbeing of the general population that will be the direct beneficiaries or victims of the audit findings.

It is therefore necessary that a detailed and structured approach is developed, and possibly a scoring system, which can be used in the definition of competence in order to grade prospective process inspectors and so that water utility owners and consumers are assured that the services rendered, will be done in a safe and responsible manner.

5.2 FUTURE WORK

5.2.1 Guidance for Process Controllers in the Support of Process Audits

Process Controllers play a critical role in the overall performance of a treatment facility and, in most cases, are the first persons to recognise a process risk or optimisation opportunity. They are also significant role-players in the implementation of measures which follow from process audits and optimisation studies. This is illustrated by the central role process controllers play in the schematic provided as Figure 12 of this report.
The Guidance Document prepared under this project however do not cater for most process controllers as it assumes an advanced degree of understanding and competence in terms of treatment process design, treatment plant design and the South African regulatory framework. Very few process controllers have been skilled to this level. In order to "activate" the resources available within the current process controller community, and also the allow process controllers an opportunity to further develop their skillset, it is necessary to develop a companion document to the Guidance Document which supports the Guidance Document at the level of the process controllers. The companion document should focus on the role of the process controller within the continuous improvement and risk management cycle and must include tools and instructions which will capacitate process controllers to fulfil their critical roles.

5.2.2 Development of benchmarks for operational and administrative functions

The Administrative Assessment (Chapter 7) of the Guidance document is probably one of the most critical chapters of the document. The chapter guides the inspection to a determination if the administration of the utility provides the support required to achieve optimum plant performance. Administrative aspects include: administrative policies, acceptance of optimisation goals, stakeholder involvement, documentation and demonstration of addressing complacency, training, staffing and funding. International and local experience has shown that the plant operations often fail due to a lack of administrative and management support and that this is the most difficult performance and compliance influencer to objectively assess and address. Limited South African based performance assessment methodologies and indicators are available to the local water sector to monitor and optimise operational and administrative activities. The South African Local Government Association (SALGA), supported by the Water Research Commission, has initiated a Municipal Benchmarking Initiative which measures operational performance and proposes benchmarks. The information is however reported at a municipal level for total water services and currently relies heavily on data that is already reported to national departments through other processes. The data made available is therefore not sufficient to allow for a detailed assessment at plant level. South Africa is in need of generally accepted benchmark definitions at plant level which will allow for a case by case assessment of the support afforded by administrative and management structures in a utility which will allow the specific plant to achieve optimum performance. The benchmark definitions must also be tested on a number of South African case studies from where initial performance targets can be set for general application in the South African water treatment sector.

5.2.3 A Series of Detailed Performance Assessments Guidelines for Specific Process Reactor

The Guidance Document succeeds in building a framework around which an Optimisation Study can be done and it contains a number of assessment criteria which can be used to assess the performance of the facility and which can be used to evaluate the specific reactor against available benchmarks. Since the document aims to cover the full treatment process and achieved this at a basic level. There is room to develop a series of guideline documents which focus on the detailed assessment of specific reactors such as flocculation channels, flotation units, clarifiers and filters of various types. This will support process controllers and decision makers who have moved beyond initial and high-level assessments. Internationally some guidelines are available such as the Filter Maintenance and Operations Guidance Manual as published by the American Water Works Association Research Foundation in 2002. The document is however expensive, consists of approximately 560 pages of text, and is written with an American perspective and focussed on American technology. There is need to develop a South African alternative to this manual which will find broader local application and will be more easily accessible to typical South African plant supervisors. The intent is that the manual contain detailed illustrated methodologies and test procedures, typical calculation examples. The manual could also contain specific software tools (spreadsheets, etc.) which could assist in the recording and analysis of data.

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APPENDIX

Annotated List of WRC Research Related to Process Audits and Plant Optimisation

Water purification works design
Authors: Van Duuren FA; 1997/01/01; Research Report No.TT 92/97

Quality of domestic water supplies Volume 1: Assessment Guide
1998/01/01; Research Report No.TT 101/98

Quality of domestic water supplies Volume 2: Sampling Guide
Authors: Venter IS; 2003/01/01; Research Report No.TT 117/99

Quality of domestic water supplies: Volume 3: Analysis guide
Authors: Schutte CF; 2003/01/01; Research Report No.TT 129/00

Quality of domestic water supplies Volume 4: Treatment guide
Authors: Schutte CF; 2002/01/01; Research Report No.TT 181/02

Quality of domestic water supplies Volume 5: Management Guide
2002/01/01; Research Report No.TT 162/01

Water Re-Use – Concepts, Application and Strategy for South Africa (D&I)
Authors: Van Wyk N; 2015/09/18; Conference Proceedings

Water related microbial disease guidelines – Volume 3: How big is the problem? Health Impact Assessment
Authors: Bailey I; 2010/08/08; Research Report No.TT 429/10

Aluminium hydro(oxide)-based (AO) adsorbent for defluoridation of drinking water: Optimisation, performance comparison, and field testing
Authors: Mulugeta E; Zewge F; Johnson CA; Chandravanshi BS; 2015/01/28; Water SA Manuscript

SHORT COMMUNICATION: Assessment of the pro-inflammatory activity of water sampled from major water treatment facilities in the greater Pretoria region
Authors: Adebayo SA; Shai LJ; Cholo MC; Anderson R; Du Toit D; 2014/04/03; Water SA Manuscript

Selection and use of home water-treatment systems and devices
Authors: Momba MNB; Mwabi JK; Mamba BB; Brouckaert BM; Swartz CD; Offringa G; Rugimbane RO; 2013/12/11; Research Report No.1884/1/13

Contaminants of Emerging Concern in USA waters: Assessment and Prevention (D&I)
Authors: Van Drunick; 2015/09/16; Conference Proceedings

Direct reclamation of municipal wastewater for drinking purposes Volume 1: Guidance on monitoring, management and communication of water quality
Authors: Swartz CD; Genthe B; Menge JG; Coomans CJ; Offringa G; 2015/10/01; Research Report No.TT 641/15

Aluminium hydro(oxide)-based (AO) adsorbent for defluoridation of drinking water: Optimisation, performance comparison, and field testing

Authors: Mulugeta E; Zewge F; Johnson CA; Chandravanshi BS; 2015/01/28; Water SA Manuscript

Guidelines for the Selection and Use of Appropriate Home Water-Treatment Systems by Rural Households
Authors: Momba MNB; Mwabi JK; Mamba BB; Brouckaert B; Swartz CD; Offringa G; Rugimbane RO; 2013/12/01; Research Report No.TT 580/13

An illustrated guide to basic water purification operations
Authors: Bouwer JL; Haylett; 2006/02/01; Research Report No.TT 247/05

WRC/DWA framework document for the revision of water quality guidelines: Facilitation of workshops for the risk-based water quality guidelines update
Authors: Boyd L; Moodley P; Jooste S; 2015/05/01; Research Report No. KV 333/15

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Authors: Swartz CD; Mwiinga G; Marler M; Meyer V; Hlophe M; Rajagopaul R; Charles K; 2009/09/14; Research Report No.1599/1/09

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Authors: Van der Walt M; Kruger M; Van der Walt C; 2009/07/31; Research Report No.TT 406/09

A monitoring and evaluation manual for municipal water and sanitation management
Authors: Atkinson D; Wellman G; Xaba; 2003/01/07; Research Report No.1287/1/03

The development of a generic water safety plan for small community water supply
Authors: Thompson P; Majam S; 2009/08/25; Research Report No.TT 415/09

Assessment of the occurrence and key causes of drinking-water quality failures within non-metropolitan water supply systems in SA, and guidelines for the practical management thereof
Authors: Mackintosh G; Jack U; 2008/11/01; Research Report No.TT 373/08

Guidelines for the Sustainable Operation and Maintenance of Small Water Treatment Plants
Authors: Swartz CD; Mwiinga G; Marler M; Meyer V; Hlophe M; Rajagopaul R; Charles K; 2009/08/01; Research Report No.TT 408/09

Efficacy of conventional drinking water treatment processes in removing problem-causing phytoplankton and associated organic compounds
Authors: Ewerts H; Swanepoel A; Du Preez HH; 2013/10/16; Water SA Manuscript

Removal of waterborne bacteria from surface water and groundwater by cost-effective household water treatment systems (HWTS): A sustainable solution for improving water quality in rural communities of Africa
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