GUIDANCE ON DRINKING WATER TREATMENT PROCESS AUDITS AND PLANT OPTIMISATION

AD Ceronio, LJ Krouwkamp, J Borland, LZ Coetzee and M van der Merwe-Botha

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GUIDANCE ON DRINKING WATER TREATMENT PROCESS AUDITS AND PLANT OPTIMISATION

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

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. An extended literature review (Van der Merwe-Botha et al., 2016) 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?"

A process audit therefore aims to produce a compliant plant while an optimisation study aims to produce a smart plant.

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. 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.

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.

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CONTENTS

EXECUTIVE SUMMARY .... **iii**

ACKNOWLEDGEMENTS .... **v**

CONTENTS .... **vii**

LIST OF FIGURES .... **xi**

LIST OF TABLES .... **xii**

ACRONYMS & ABBREVIATIONS .... **xiv**

LIST OF VARIABLES .... **xv**

NOTE .... **xvii**

CHAPTER 1: BACKGROUND **1**

1.1 DRINKING WATER QUALITY REGULATION 1
1.1.1 SANS 241 1
1.1.2 Regulation 2834 and Draft Regulation 813 1
1.1.3 Water Use Authorisation 1
1.1.4 Compulsory National Standards 1
1.1.5 The National Blue Drop Programme 1
1.2 PERFORMANCE ASSESSMENTS AND PROCESS AUDITS 2
1.3 REGULATION VS OPTIMISATION 2
1.3.1 Step 0 – Process control and monitoring 3
1.3.2 Step 1 – The Process Audit 3
1.3.3 Step 2 – Optimisation Study 4
1.4 DEVELOPING THE GUIDELINE 4
1.4.1 Literature Survey 4
1.4.2 Case Studies 5
1.4.3 Outcome of the Study 5

CHAPTER 2: GUIDELINE FRAMEWORK **6**

2.1 PURPOSE OF THE GUIDELINE 6
2.2 WHY OPTIMISE? 6
2.3 GUIDELINE FRAMEWORK 7
2.3.1 The capable plant model 7
2.3.2 Components of the guideline 8
2.3.2.1 Step 1 – Performance Assessment (Chapter 3): 9
2.3.2.2 Step 2 – Major Unit Process Capacity Assessment (Chapter 4) 9
2.3.2.3 Step 3 – Major Unit Performance Assessment (Chapter 5) 9
2.3.2.4 Step 4 – Operational Assessment (Chapter 6) 9
2.3.2.5 Step 5 – Administrative Assessment (Chapter 7) 9
2.3.2.6 Step 7 – Implementation Phase (Chapter 8) 9
2.4 GENERAL GUIDANCE IN CONDUCTING ASSESSMENTS 10
2.4.1 Which steps to include? 10
2.4.2 Team Work 10

2.4.3 Data Requirements 10
2.4.4 Hard Hats, Safety Boots, Torches and Test Tubes 11
2.4.5 Questions to Ask 11
2.4.6 Benchmarks 11
2.4.7 Treatment Technologies 12
2.5 WHO SHOULD USE THESE GUIDELINES? 12
2.6 WHO SHOULD PERFORM PROCESS AUDITS AND PLANT OPTIMISATION STUDIES? 13
2.7 HOW OFTEN MUST A PROCESS AUDIT AND PLANT OPTIMISATION STUDY BE UNDERTAKEN?... 13

CHAPTER 3: PERFORMANCE ASSESSMENT OF THE TREATMENT PLANT 14

3.1 INTRODUCTION 14
3.2 PERFORMANCE ASSESSMENT OF THE COMPLETE TREATMENT PLANT 14
3.3 CURRENT PLANT CONFIGURATION 14
3.4 SOURCE WATER AND FINAL WATER QUALITY 15
3.5 PROCESS CONFIGURATION 16
3.6 HYDRAULIC LOAD AND FLOW BALANCE 17
3.7 BENCHMARKS 18
3.8 PERFORMANCE ASSESSMENT SUMMARY 18

CHAPTER 4: MAJOR UNIT CAPACITY ASSESSMENT 19

4.1 INTRODUCTION 19
4.2 DETERMINING PEAK INSTANTANEOUS OPERATING FLOW 20
4.3 RATING INDIVIDUAL UNIT PROCESSES 21
4.3.1 Raw water supply 21
4.3.2 Flocculation 22
4.3.3 Sedimentation 22
4.3.4 Dissolved Air Flotation 23
4.3.5 Sand Filtration 24
4.3.6 Granular Activated Carbon Filters 24
4.3.7 Disinfection 25
4.3.8 Ion Exchange 27
4.3.9 Membrane Filtration 27
4.3.10 Lifting Pump Station 28
4.4 SUMMARY 28

CHAPTER 5: MAJOR UNIT PERFORMANCE ASSESSMENT 29

5.1 INTRODUCTION 29
5.2 WATER QUALITY PERFORMANCE ASSESSMENT 29
5.3 DESIGN ASSESSMENT 30
5.3.1 Pump Stations and Conveyance 30
5.3.2 Chemical Dosing and Dosing Equipment 31
5.3.3 Flocculation 32
5.3.4 Sedimentation 33
5.3.5 Dissolved Air Flotation 34
5.3.6 Slow Sand Filtration 37
5.3.7 Rapid Gravity Sand Filtration 37
5.3.8 Granular Activated Carbon 39
5.3.9 Disinfection 41
5.3.10 Ion Exchange 42

5.3.11 Membrane Filtration 43
5.3.12 Conveyance on site 44
5.3.13 Pump Stations 44
5.3.14 Residuals Handling 45
5.3.15 Energy Consumption 46
5.4 SUMMARY 47

CHAPTER 6: OPERATIONAL ASSESSMENT 48

6.1 INTRODUCTION 48
6.2 OPERATIONAL PROCEDURES 48
6.3 PROCESS PERFORMANCE GOALS AND CONTROL TESTING 49
6.4 PROCESS CONTROLLER UNDERSTANDING AND APPLICATION OF CONTROL CONCEPTS 50
6.5 COMMUNICATION 50
6.6 SUMMARY 51

CHAPTER 7: ADMINISTRATIVE ASSESSMENT 52

7.1 INTRODUCTION 52
7.2 ADMINISTRATIVE POLICIES 52
7.3 STAFF MANAGEMENT 53
7.3.1 Regulatory Compliance 53
7.3.2 Staffing Levels and Staffing Distribution 53
7.3.3 Staff Retention 54
7.3.4 Staff Training 54
7.3.5 Staff Safety 55
7.3.6 Staff Performance Management 55
7.3.7 Summary of the HR Function 55
7.4 ASSET MANAGEMENT 55
7.4.1 Maintenance 55
7.4.2 Asset Renewal 56
7.4.3 Asset Maintenance Plan 57
7.5 FUNDING 58
7.6 PROCUREMENT 59
7.7 CUSTOMER SERVICES 59
7.7.1 Customer satisfaction 59
7.7.2 Unplanned disruption 59
7.7.3 Per Capita Consumption 59
7.8 SUMMARY 60

CHAPTER 8: PRIORITISATION OF COMPREHENSIVE LIST OF FACTORS LIMITING PERFORMANCE 61

8.1 INTRODUCTION 61
8.2 PROCESS AUDIT ACTION PLAN 61
8.2.1 How to Score Risks 62
8.2.2 Risk Rating and Prioritisation 63
8.2.3 Developing Mitigation Measures 64
8.2.4 Implementing Mitigation Measures 64
8.3 OPTIMISATION STUDY ACTION PLAN 64
8.3.1 Identification of Performance Limiting Factors 65
8.3.2 Prioritisation of Performance Limiting Factors 65
8.3.3 Developing Action Plans 65

8.3.4 Implementing Action Plans 66
8.4 SUMMARY 66

CHAPTER 9: DOCUMENTING PROCESS AUDITS AND OPTIMISATION STUDIES 67

9.1 INTRODUCTION 67

BIBLIOGRAPHY 81

LIST OF FIGURES

Figure 1-1: The relationship between Process control, Process Audits, the Water Safety Planning Process and Plant Optimisation Studies 3

Figure 2-1: Capable Plant Model (Linder & Martin, 2015) 7

Figure 2-2: Steps for completion of the assessment (Linder & Martin, 2015) 8

Figure 4-1: Example of Performance Potential Graph of Major Process Units (Ceronio et al., 2010) 20

LIST OF TABLES

Table 3-1: Benchmarks for the High-Level Assessment of Plant Performance 18

Table 4-1: Benchmarks values for piped flow.. 21

Table 4-2: Flocculation Process Typical Hydraulic Retention Times (Minnesota Water Works Operations Manual, 2009)* (Edzwald & Haarhoff, 2012)** 22

Table 4-3:Sedimentation Process Typical Upflow Velocities (Van Duuren, 1997), (Baruth, 2005) 23

Table 4-4: DAF Process Typical Hydraulic Loadings (Van Duuren, 1997) 23

Table 4-5: Filtration Process Typical Loading Rates 24

Table 4-6: Granular Activated Carbon Process Typical Empty Bed Contact Time (Edzwald, 2011).............. 25

Table 4-7: Disinfection Process Typical Contact Time (Edzwald, 2011) (Van der Walt et al., 2009) 26

Table 4-8: Ion Exchange Process Typical Empty Bed Contact Time (Edzwald, 2011) 27

Table 4-9: Typical Membrane Flux Values (Baruth, 2005)... 28

Table 5-1: Example of typical unit process performance goals (South African National Standard, 2015) 30

Table 5-2: Typical Values for Flocculation Velocity Gradient (Van Duuren, 1997) 32

Table 5-3: Typical Design Criteria for Sedimentation Process (Van Duuren, 1997)....................................... 33

Table 5-4: Typical Design Criteria for DAF Process (Van Duuren, 1997).. 36

Table 5-5: Typical Design Criteria for Slow Sand Filtration Process * (Van Duuren, 1997),** (Edzwald, 2011),*** (Cleasby & Logsdon, 1999), **** (Crittenden et al., 2005).. 37

Table 5-6: Typical Design Criteria for Rapid Gravity Filtration Process (Van Duuren, 1997) (Ceronio & Haarhoff, 1994)* 38

Table 5-7: EBCT vs Specific throughput (Crittenden et al., 2005) 40

Table 5-8: Contact Time Values for Inactivation of Viruses (Van Der Walt et al., 2009), (Edzwald, 2011) 41

Table 5-9: Contact Time Values for Inactivation of Giardia cysts (Van Der Walt et al., 2009)........................ 41

Table 5-10: Typical Values for Ion Exchange performance (Edzwald, 2011) 42

Table 5-11: Applicable Size Ranges for the Membrane Processes (Baruth, 2005)....................................... 43

Table 5-12: Other Typical Performance Indicators for Reverse Osmosis (American Water Works Association, 2007) 43

Table 5-13: Energy consumption range for the South African water supply chain for conventional treatment plants (Mander & Van Niekerk, 2014)... 47

Table 7-1: Percentage of staffing levels (American Water Works Association, 2016)................................... 54

Table 7-2: Guideline Maintenance Budget (Department of Water Affairs and Forestry, 2004) 56

Table 7-3: AWWA Maintenance Benchmarks (American Water Works Association, 2016)........................... 56

Table 7-4: Lifecycle discount rates for assets (Boshoff et al., n.d.)... 56

Table 7-5: Replacement and renewal expenditure as a percentage of total plant value (American Water Works Association, 2016).. 57

Table 7-6: South African Bulk Water Tariffs, Production Cost and Cost Breakdowns (Thompson, 2017) 58

Table 7-7: Per Capita Water Consumption (Department of Water and Sanitation, 2016) (SALGA, WRC, IMESA, MBI, 2015) 60

Table 8-1: Risk Rating Scoring for the Water Safety Plan (WSP) 62

Table 8-2: A typical WSP risk rating table* 62

Table 8-3: Responses required based on risk rating (Department of Water and Sanitation, 2013) 63

Table 9-1: Requirements for Process Audit Reports vs. Optimisation Study Reports 68

ACRONYMS & ABBREVIATIONS

AADD	Annual Average Daily Demand
AWWA	American Water Works Association
BD	Blue Drop
CAD	Computer assisted drawing
CCP	Composite Correction Programme
CoGTA	Cooperative Governance and Traditional Affairs
DAF	Dissolved air flotation
DEA	Department of Environmental Affairs
DOC	Dissolved oxygen carbon
DST	Department of Science and Technology
DWA	German Association for Water, Wastewater and Waste
DWS	Department of Water and Sanitation
EBCT	Empty bed contact time
EPA	Environmental Protection Agency
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HCWW	Holding Company for Water and Wastewater
MBI	Municipal Benchmarking Initiative
MF	Microfiltration
NF	Nanofiltration
NTU	Nephelometric Turbidity Units
O&M	Operations and maintenance
PFD	Process flow diagram
RO	Reverse osmosis
SAICE	South Africa Institute for Civil Engineers
SALGA	South Africa Local Government Association
SANS	South African National Standard
SDI	Silt Density Index
SIWI	Stockholm International Water Institute
SOP	Standard operating procedure
TSM	Technical Sustainable Management
UC	Uniform co-efficient
UF	Ultrafiltration
USEPA	US Environmental Protection Agency
WHO	World Health Organisation
WISA	Water Institute of Southern Africa
WRC	Water Research Commission
WSI	Water services institution
WSP	Water safety plan
WWTW	Wastewater Treatment Works

LIST OF VARIABLES

A_{CS}	Horizontal Cross-Sectional Area of floatation zone in the direction from inlet to outlet [m^2]
A_{DAF}	Surface area of DAF floatation zone [m^2]
A_f	Area of individual filter [m^2]
A_{FZ}	Average surface area of floatation zone [m^2]
A_m	Surface area of membrane [m^2]
A_{RZ}	Average surface area of reaction zone [m^2]
A_s	Surface area of the tank [m^2]
$EBCT_{GAC}$	Empty bed contact time [min]
$EBCT_{IX}$	Empty bed contact time for Ion Exchange [min]
G	Mean velocity gradient [s^{-1}]
g	Gravity constant [9.81 m/s^2]
h	Head loss [m]
hr	Hour/s
J	Flux [$l/hr/m^2$]
L_w	Total Length of weir [m]. This is the total length of all the weirs in the tank.
LR_{DAF}	Loading rate DAF
LR_f	Loading rate on Filter [m/hr]
Q_{BH}	High rate flow [m^3/hr]
Q_{BL}	Low rate flow [m^3/hr].
Q_{DAF}	Total flow (inflow and recycle) to individual DAF unit [m^3/hr]
Q_F	IX Feed flow rate [m^3/minute]
Q_f	Flow rate on individual filter [m^3/hr]
Q_{floc}	Flow into the flocculation unit [m^3/min]
Q_{GAC}	Flow into individual GAC filter [m^3/minute]
Q_P	Filtrate flow rate through membrane [l/hr]
Q_{PT}	Total plant flow [m^3/hr]
Q_R	Recycle flow rate [m^3/hr]
Q_T	Total plant flow flowing through the chlorine channel [m^3/minute]
Q_t	Total flow into the tank [m^3/hr]
r	Recycle ratio [%]
S_A	Applied Solids [kg/d]
S_L	Solids Loading Rate [$kg/m^2.d$]
SFR	Service Flow Rate [$m^3/min.m^3$]
t_f	Flocculation retention time [s]
$t_{contact}$	Contact time [min]
t_f	Retention time [s]
t_{floc}	Retention time in Flocculation unit [min]
t_{RZ}	Residence time in the Reaction Zone [s]
μg/l	Micrograms per litre
V_c	Volume of the chlorine contact channel [m^3]
V_{floc}	Volume of the flocculation unit [m^3]
V_{media}	Volume of media [m^3]
V_{O3}	Volume of the Ozone contact channel [m^3]
V_R	Volume of Resin bed [m^3]
V_{RZ}	Volume of reaction zone [m^3]

V_{UV}	Volume of the UV reactor [m^3]
V_w	Weir overflow rate [m^3/hr.m]
ν_{BH}	High Backwash Rate [m/hr]
ν_{BL}	Low Backwash Rate [m/hr]
ν_{CS}	Cross flow velocity [m/hr]
ν_{FZ}	Upflow velocity in Floatation Zone [m/hr]
ν_{RZ}	Upflow velocity in Reaction Zone [m/hr]
ν_u	Upflow velocity [m/hr]
υ	Kinematic Viscosity (at operating temperature) [m^2/s]

NOTE

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.

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CHAPTER 1: BACKGROUND

1.1 DRINKING WATER QUALITY REGULATION

Water treatment is a highly regulated activity. Legislation defines specific water quality performance goals that must be continuously achieved by a treatment plant. Key legislation and regulation are listed below and must be incorporated into the optimisation and audit exercise.

1.1.1 SANS 241

SANS 241 (SANS, 2015) sets the standard for drinking water quality and is legally enforced by the Regulator, DWS. It sets the numerical value for specific determinands that ensures an acceptable health risk for lifetime consumption. The Standard adopts a risk-based approach and prescribes a compulsory list of the most critical determinands to be monitored as well as the frequency of monitoring. SANS 241 is used by the Regulator as a benchmark for Water Safety Planning and Process Audits and is the determining factor in awarding Blue Drop status to a water services institution.

1.1.2 Regulation 2834 and Draft Regulation 813

The required number and classification of process controllers and maintenance personnel is based on the classification of the treatment plant as outlined in Regulation 2834 (Department of Water Affairs, 1986) of the Water Services Act (Act No. 108 of 1997) (South African Goverment, 1997). Regulation 2834 will be replaced in the future by the proposed Regulation 813 to which all Water Services Institutions will be required to comply (Department of Water Affairs, 2013). It must be noted that both Regulations state the minimum requirement for staffing and that compliance to the Act does not imply an optimised plant.

1.1.3 Water Use Authorisation

In terms of Section 21 of the National Water Act, Act No. 36 of 1998 (South African Goverment, 1998), all water services institutions who are using water for water supply services must register their water use with DWS. This covers the use of surface and ground water. The authorisation sets out the quantity of water that can be abstracted and any associated conditions including the management of any waste streams.

1.1.4 Compulsory National Standards

In terms of Regulation 5 of the Regulations Relating to Compulsory National Standards and Measures to Conserve Water (Regulation 509 under the Water Services Act, Act No. 108 of 1997), Water Services Institutions must sample, monitor and compare water quality performance in line with SANS 241. Compliance to SANS 241 is required (Department of Water Affairs and Forestry, 2001).

1.1.5 The National Blue Drop Programme

The National Blue Drop Programme is an incentive based regulatory programme which drives and rewards best practice initiatives and performance in the potable water sector. Although the programme is based on regulation it does strive for performance beyond mere compliance. The programme has a dynamic nature and the Department of Water and Sanitation updates the requirements for Blue Drop Certification on an ongoing basis. These requirements are communicated on an ongoing basis via the Blue Drop web page (http://www.dwa.gov.za/dir_ws/DWQR/), road shows and other sector engagement routes. A process audit is a key deliverable under this programme and the related requirements are constantly under review. Ongoing monitoring of the website and other DWS communiqués are therefore necessary to ensure the process audits remain responsive to the requirements of the Department.

1.2 PERFORMANCE ASSESSMENTS AND PROCESS AUDITS

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. Draft Regulation 5 (Department of Water and Sanitation, 2016) makes provision for this. In addition, during the launch of the Blue Drop 10 Year Strategy at the 2014 WISA Conference, DWS confirmed the role of the process audit in the risk management process and emphasised that the process audit will not be acknowledged unless the findings are included in the Water Safety Plan. The objective of a **Process Audit is to ensure that the current treatment plant remains adequate to sustain compliance** of the final product with regulatory requirements. Although an annual process audit is a requirement for Blue Drop certification, the real benefit of a process audit is that the audit provides an on-going review on whether the plant will remain able to cope with the changing environment in which it is expected to perform and continue to meet the increasingly stringent performance defined by the DWS and imposed by degrading catchments and raw water sources. The required scope and content of a process audit has however been open to interpretation by the individual tasked with performing the audit which leads to confusion and disputes about the output. Although the Blue Drop Handbook has attempted to provide some guidance, this remains limited. An unpublished investigation into the status quo of process audits within the municipal sector found that the range and depth of assessment vary substantially (Van der Merwe-Botha et al., 2016). It is apparent that guidance is required on the content and quality of the process audit. Although the regulatory requirement is a strong motivator for the implementation of a process audit programme, the value of a properly performed Process Review lies beyond compliance.

In an advanced form, a process audit **can also be viewed as a tool that allows a plant to operate at a point of highest efficiency** which will be measurable in terms of improved cost per production unit while maintaining and improving water quality standards. In this advanced form the effort is referred to as an Optimisation Study. The optimisation process, when viewed from the perspective of whether the plant can perform more economically while addressing all risk elements, or whether the plant is producing to its true safe capacity, should be of interest to all Water Service Institutions and managers at a time when financial constraints define the daily discourse. It is important to understand that plant optimisation does not have capital works as an end goal. The focus is on achieving better performance with the current infrastructure while delaying plant augmentation. Plant operations do not occur in isolation. There are a number of factors that impact on the ability of the plant to perform as required. This chapter briefly discusses these factors in order to provide an overview of the various topics that need to be addressed in an assessment of plant performance.

1.3 REGULATION VS OPTIMISATION

Regulation generally states the performance targets that must be achieved. Once this is achieved, the “compliant” status is normally maintained by repeating previous effort. The South African regulatory framework and some international guidelines for potable water quality deviates from this by mandating an on-going assessment of the status quo and the implementation of preventative measures to ensure that water quality failures do not occur. The end goal of regulation remains, as with optimisation, the safety and health of consumers. The approach prescribed in the South African regulatory framework and SANS 241 is risk based. A process audit is critical in supporting this approach as it is used to determine which aspects of the catchment, plant design, operation, maintenance and management of the plant and associated infrastructure, may result in water quality failure, and what must be done to mitigate this. It is 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 goals.

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 this risk to final water quality?"
- A process optimiser asks: 'What can we do better than yesterday?"

A process audit therefore aims to produce a compliant plant while an optimisation study aims to produce a smart plant (Figure 1-1). It helps to consider the two efforts in a step-wise application and in context of other critical plant and process performance management activities as is described in the figure below. The basic philosophy is that compliance must be prioritised (Step 1) over optimisation of the plant (Step 2). The sequence is important as optimisation rarely precedes compliance. Both steps are however underscored and supported by good process control (Step 0).

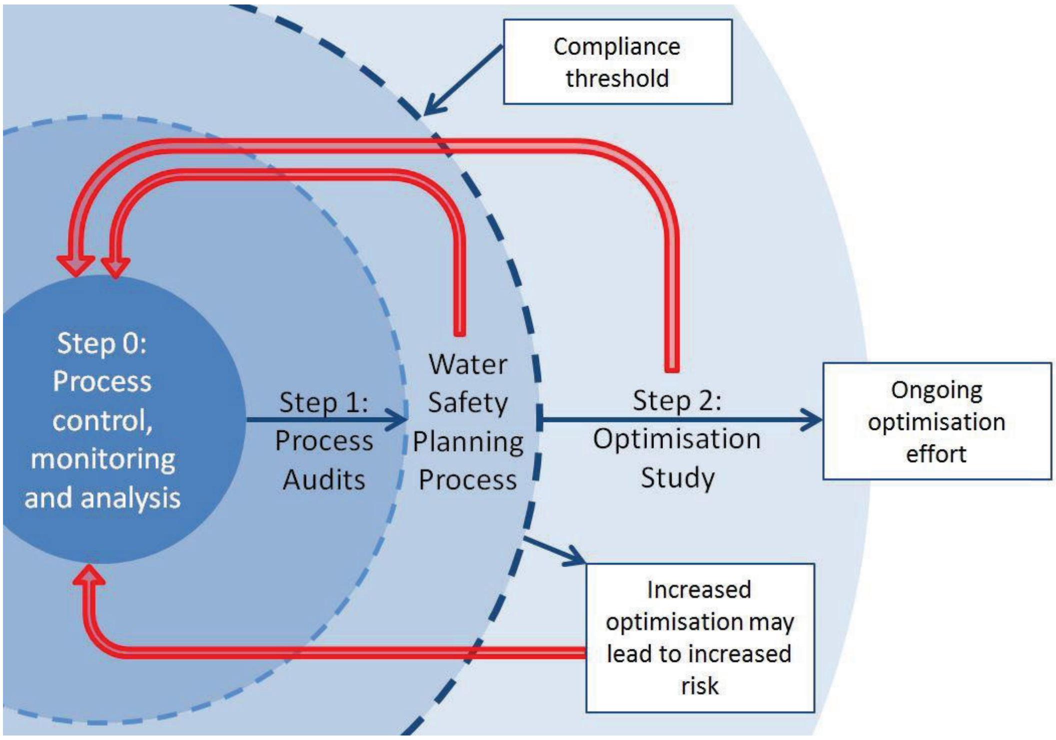

Figure 1-1: The relationship between Process control, Process Audits, the Water Safety Planning Process and Plant Optimisation Studies

1.3.1 Step 0 – Process control and monitoring

Normal process control activities will be ongoing at the plant under consideration. Process control activities are considered as the basis for what is to follow and it is therefore referred to in this Guideline as "Step 0". Step 0 is critical as it generates information and records which are required for the Audit and Optimisation efforts that follow and also generates the data which is used the determine the effect of the interventions proposed by both the process audit and the optimisation study

1.3.2 Step 1 – The Process Audit

The Process Audit (Step 1) is designed to identify issues that are leading to water quality risk or which may result in the plant not producing compliant water. These issues (or hazards) are addressed via the Water Safety Planning process and the interventions (mitigating measures) will impact, amongst others, on the way the plant is operated (Step 0). Regulatory compliance may be achieved once the Water Safety Plan has been implemented. This document does not focus on the compilation of the Water Safety Plan. It should however be noted that the

Process Audit is dependent on the Water Safety Planning process to ensure its findings and recommendations are incorporated, weighted and prioritised along with the recommendations of other studies which address water quality related hazards.

1.3.3 Step 2 – Optimisation Study

Plant optimisation (Step 2) may follow once regulatory compliance has been achieved. A process audit has regulatory compliance as a non-negotiable endpoint while process optimisation is a discretionary further step. Both efforts, however, follow the same process of investigation and response but they do it with different endpoints in mind. The two processes can however not be considered as completely separate processes as optimisation efforts will introduce new compliance risks or may, at the very least, impact on existing compliance risks. A careful balance must therefore be established between going about water treatment in a more cost-effective manner and maintaining compliance levels. In a mature system these targets will be managed in parallel and will inform ongoing process control activities. The methods used and approach to the process audit and plant optimisation exercises however overlap substantially and both have been addressed in this Guideline. The difference lies in the perspective of the reporter. The questions above must be answered clearly in either the process audit report or the process optimisation report. Due to the dual purpose of this Guideline, the user will be called either a process auditor or process assessor. The person could also be playing both roles at once. Use of either name is not necessarily meant to exclude the other. For the purposes of this Guideline therefore the neutral term "process investigator" will be used.

1.4 DEVELOPING THE GUIDELINE

A separate study was undertaken at the start of the compilation of this Guideline in order to understand the current national and international landscape that touches on the process optimisation and process audit field (refer to Technical report). This was essentially a literature study which has limited benefit to the objective of this Guideline and it is consequently not included. However, through the review of relevant literature, case studies and international best practices, the move toward plant optimisation effort was noted and underscores the approach adopted in these Guidelines. A summary of the review process is described below.

1.4.1 Literature Survey

A review was undertaken on various documents available in the public domain that provide guidance on performing process audits. Internationally, there are a number of programmes, partnerships, documents and guidelines which address process assessments. These include:

- US Environmental Protection Agency: Composite Correction Programme (CCP) (Environmental Protection Agency, 1998);
- Partnership for Safe Water. A co-operative effort between EPA, American Water Works Association, Association of Metropolitan Water Agencies, National Association of Water Companies, and Association of State Drinking Water Administrators;
- Water Research Australia: Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk (Water Research Australia, 2015);
- European Union: TRUST – Transition to the Urban Water Services of Tomorrow (Eikenbrokk et al., 2015);
- Canada: Optimisation Guidance Manual for Sewage Works (2010);
- New Zealand Ministry of Health: Optimisation of small drinking water treatment systems: Resources for the drinking-water Assistance Programme (Ministry of Health New Zealand, 2007); and
- GIZ and Arab Countries Water Utilities Association: Technical Sustainable Management (TSM_{Egypt}) Water Supply and Wastewater Management Programme (Abotalec et al., 2014);

The case studies revealed 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.

1.4.2 Case Studies

A selection of the top performing water services institutions during the 2014 Blue Drop audit were approached to provide local case studies to evaluate the current status of process assessments in the South African municipal sector. The selected municipalities and utilities achieved > 95% Blue Drop Scores and include:

- 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; and
- City of Cape Town Metropolitan Municipality.

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); and
- Stockholm International Water Institute (SIWI) (Anton Earle, Nick Tandi).

The reports were reviewed and assessed against the following three questions:

- Does the report provide guidance on the optimisation of the plant?
- Does the report guide plant management in meeting regulatory requirements?
- Does the report identify hazards which will impact on the ability of the plant to meet regulatory requirements?

In addition, 74 Process Assessment/Audit reports drafted by 13 authors were also studied. Where novel approaches were noted, these were incorporated into these Guidelines.

1.4.3 Outcome of the Study

The Capable Plant model is also already familiar to the South African water sector as DWS have promoted this approach in the Blue Drop Handbook (Department of Water and Sanitation, 2013). 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 have 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.

CHAPTER 2: GUIDELINE FRAMEWORK

2.1 PURPOSE OF THE GUIDELINE

This development of this Guideline is therefore based on the principle that process audit and plant optimisation are inextricable linked and it is further based on the assumption that plant optimisation is the primary goal for undertaking this process exercise and that legal compliance and risk management will be achieved as a consequence en-route to optimisation. This Guideline is based on a study of local and international best practice and the aim of the Guideline is to provide a tool to ensure a uniform and standardised approach to undertaking, Plant Optimisation Studies and Process Audits within the South African water sector. The Guideline addresses the treatment facility from the point of water abstraction to the first point of bulk distribution and makes reference to the latest version of the drinking water standard, SANS 241 where relevant. The Guidelines do not offer optimisation solutions. It 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.

2.2 WHY OPTIMISE?

The fundamental philosophy of the Blue Drop Certification 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. This must happen while consumers continue to have access to a safe and reliable water supply. This can only be achieved if plants and plant operations target best practice principles, this is optimisation. Optimisation is part of the DWS regulatory framework which states that strengths and weakness of the facility should be identified and that incremental steps be implemented to make improvements. It acknowledges that process assessments are linked to risk-based planning (water safety plan) and provide a critical combination to improve performance of a facility on a systematic, consistent and prioritised basis (Department of Water and Sanitation, 2014). The following are important characteristics of optimisation in the context of this Guideline:

- Optimisation does not target plant expansion or augmentation (capital works) as a final outcome.
- Optimisation happens incrementally through the continued improvement of operation, maintenance, administration and finally installation.
- Optimisation needs to be measured against performance benchmarks with a view of continually improving on the results achieved. An important aspect of optimisation is therefore self-assessment.
- Optimisation builds on previous successes.

The optimisation exercise is never complete and full optimisation is never achieved. It is an on-going process. 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. It is critical to note that performance optimisation is not a mission to find fault. The purpose of the systematic self-assessment process is to identify issues that are negatively impacting on plant performance and to then develop solutions (Linder & Martin, 2015).

2.3 GUIDELINE FRAMEWORK

2.3.1 The capable plant model

The Capable Plant Model presents the most concise approach to this discussion. The model has been adopted by the American Water Works Association as an approach to plant assessments (Linder & Martin, 2015). The capable plant model confirms that a plant will only perform as required if all aspects of plant design, operation, maintenance and management are effectively implemented as is illustrated in Figure 2-1 below. The model dictates that a plant will only produce water of high quality if the plant is capable to do so *and* it is operated correctly. A plant will also only be capable to perform as required if:

- It is designed correctly for the intended purpose,
- It is properly maintained in order to perform according to the original design intent, and finally,
- The administration of the plant allocates the necessary resources to perform as the design intended.

A failure of any of these elements will result in non-compliance and will hinder attempts at optimising plant performance. It is therefore necessary that the four main elements of the capable plant model are focus points in a process audit or an optimisation study.

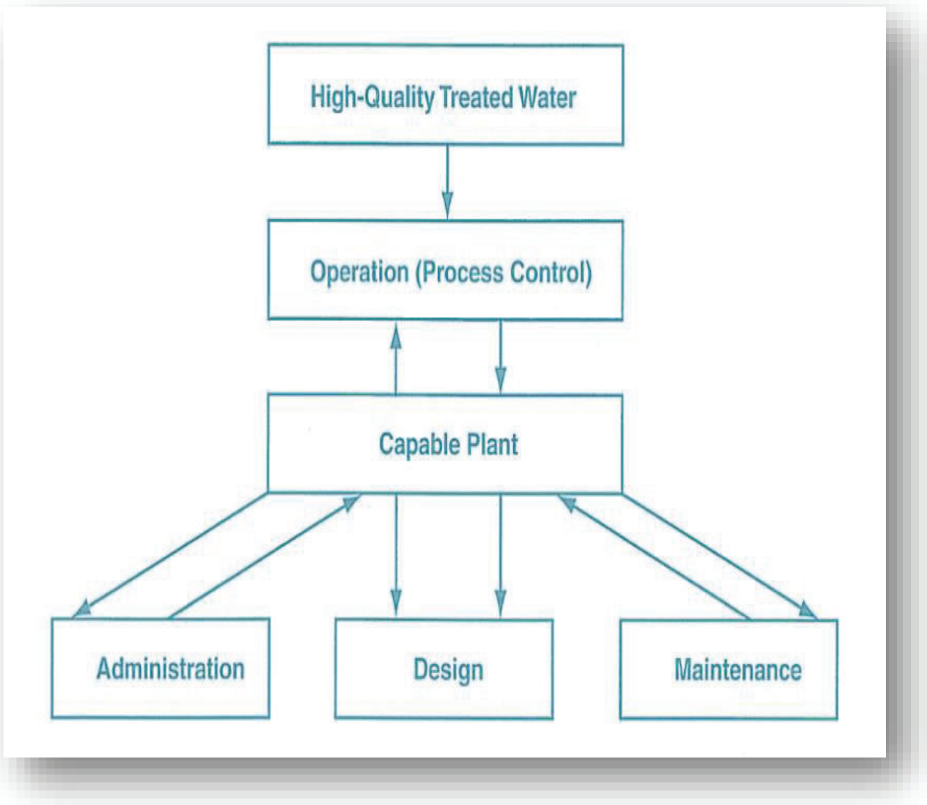

Figure 2-1: Capable Plant Model (Linder & Martin, 2015)

2.3.2 Components of the guideline

These Guidelines are structured to provide a systematic approach to either a process optimisation or a process audit. The process investigator is guided through each component with regard to the information to be compiled and assessed. In accordance with the Capable Plant Model, the plant is assessed in terms of the design, operation, maintenance and administration. The assessment comprises two distinct phases namely a Performance Evaluation Phase and an Improvement Phase. Although it will be necessary to periodically review the plant using all the assessment steps included in this Guideline, an experienced process investigator may be able to motivate for the exclusion of some steps when undertaking regular assessments. Performance assessments initially apply a global overview of plant performance before detailed aspects of the plant are considered. Each step (Figure 2-2) in this process is presented in separate chapters in this guideline, as indicated in the sections that follow.

Step 1 - Perform a complete performance assessment
Determine current plant performance levels vs. optimised/regulatory goals

Step 2 - Perform a complete capacity assessment
Determine if major unit process sizes are limiting performance

Step 3 - Do a unit process performance assessment
Identify any other aspects of unit process design which limits performance

Step 4 - Perform an assessment of operations
Determine if operational practices are limiting performance

Step 5 - Perform an assessment of administration
Determine if administrative practices are limiting performance

Step 6 - Compile a comprehensive list of performance limiting factors
Determine activities to address factors that will improve performance

Step 7 - Implement activities that will improve performance

Step 8 - Assess performance improvements (Step 1)

Figure 2-2: Steps for completion of the assessment (Linder & Martin, 2015)

2.3.2.1 Step 1 – Performance Assessment (Chapter 3):

The focus of this chapter is an assessment of total plant performance against regulatory and optimisation goals. The process investigator is required to develop a detailed understanding of the plant and ***high-level plant performance*** by looking at the hydraulic and process performance of the plant. The process investigator will be required to compile a process flow diagram, consult drawings, collect and consult raw and treated water quality results and flow records of the plant. By the end of this chapter, the process investigator will understand the high-level performance of the plant and know if there is any potential performance limiting issues. The findings will guide the use of subsequent chapters.

2.3.2.2 Step 2 – Major Unit Process Capacity Assessment (Chapter 4)

After assessment of the total plant, the process investigator will focus on ***individual process unit capacity***. The aim is to determine if the physical size of each individual process unit is adequate to meet the desired performance. If the process investigator found in step 1 that the plant is not performing to standard or expectation, this step is used to identify which process units are limiting performance. It will also provide insight into possible causes for inadequate performance. This chapter will also allow the process investigator to develop a Performance Potential Graph which will compare the demand on the plant with the potential performance of each process unit. The graph demonstrates clearly where plant performance and delivery are constrained.

2.3.2.3 Step 3 – Major Unit Performance Assessment (Chapter 5)

After completing steps 1 and 2, the process investigator will have a good understanding of global plant performance and treatment capacities of individual process units. Step 3 focuses on the ***detail design aspects of the process units.*** This may also require the process investigator to consult with specialists with respect to specific areas of concern.

2.3.2.4 Step 4 – Operational Assessment (Chapter 6)

Any treatment plant requires effective operation and monitoring to ensure production of the highest quality water. This step is an ***assessment of the operations*** of the treatment plant. It assesses the ability of process controllers and systems to collect and interpret data and to effect changes to the process based on their findings. It is essential that the process controllers have an excellent understanding of their plant and how to monitor performance and adjust the processes to meet any changing situation that they may encounter.

2.3.2.5 Step 5 – Administrative Assessment (Chapter 7)

Plant administration has a significant impact on the treatment plant and its operations. This chapter focuses on policies implemented by the water services institution, involvement of all parties both vertically and horizontally within the organisation, competence (further training and staffing) and funding. This is a particularly challenging part of the assessment which should be adjusted to meet the specific needs of the organisation. The chapter will provide guidance on a basic first order assessment.

2.3.2.6 Step 7 – Implementation Phase (Chapter 8)

Chapter 8 addresses the compilation of a comprehensive list of performance limiting issues identified from the performance assessments and their prioritisation. The process of developing action plans is set out that defines the issues, the required responses, the implementation mechanism and how progress is to be measured. This is a critical part of both the process audit and the optimisation process as it will determine and measure the overall success of any intervention.

2.4 GENERAL GUIDANCE IN CONDUCTING ASSESSMENTS

2.4.1 Which steps to include?

Although it will be necessary to periodically review the performance of the plant using all the assessments addressed in this Guideline, an experienced process investigator may be able to motivate for the exclusion of certain elements during some assessment cycles. As examples:

- The “Major Unit Process Capacity Assessment” may for example be excluded from subsequent rounds once it has been thoroughly assessed in the first audit as the findings will rarely change unless there have been substantial modifications to the plant or the raw water quality or treatment objectives have changed.
- Where the status quo has remained since the previous assessment, it would be acceptable to reference those findings.
- It may also be more appropriate to specifically focus on individual processes units during optimisation studies.
- During upgrading/construction stage, implementation stage should be based on findings of previous studies or audits. After commissioning stage, these process units should be assessed to design criteria.

2.4.2 Team Work

It is essential to approach plant optimisation and process audits as a team. Plant optimisation is not the responsibility of a single person. The development and implementation of an optimisation action plan needs to be driven from the highest levels of management and all levels must contribute to its development. Successful implementation will require co-operation by all role-players. Similarly, a process auditor, in the case of a process audit, is tasked to identify risks in the day-to-day operation of a treatment facility. Should the necessary input and support from all levels of the organisation not be provided, and information or input remains outstanding or unresolved, the auditor is compelled to mark the unresolved matters as hazards. This results in issues being captured in the risk register that should not necessarily be there. Consequently, the organisation may be distracted from dealing with the “real” issues.

2.4.3 Data Requirements

The assessment is based on plant design and performance data, as well as information regarding the structure and policies of the organisation. Access to appropriate good quality data is therefore mandatory to the successful completion of the assessment. The collection and compilation of the data and intelligence required for execution of a process audit and optimisation study commences and is primarily housed in “Step 0” as discussed in Chapter 1. The following will typically be required for an initial process audit or a plant optimisation assessment:

1. As-built plans for the plant and associated infrastructure.
2. Catchment related records and documents detailing the status of the resource and quality and quantity of raw water (minimum 12 months but preferably 3 to 5 years).
3. Raw and final water flow meter readings (minimum 12 months but preferably 3 to 5 years).
4. Demand projections for a 5-year horizon.
5. Final water quality records (minimum 12 months but preferably 3 to 5 years).
6. Current internal performance targets and optimisation goals.
7. Flow meter readings for internal recycle streams (minimum 12 months but preferably 3 to 5 years)
8. Water quality records for processes units (minimum 12 months but preferably 3 to 5 years)
9. Equipment failure and maintenance records (minimum 12 months but preferably 3 to 5 years)
10. Plant organogram with process controller registration information.
11. Plant classification certificates.
12. Management structures.
13. Previous process audits, other performance related studies and feasibility studies.

14. Operations manuals.
15. Process Controller's logbooks and periodic process control reports.
16. Plant financial records including budget allocation and budget expenditure.
17. Regulatory correspondence including Directives or Pre-directives.

The list will be augmented during the assessment as specific needs arise. For example, information requirements will generally increase as specific optimisation goals or specific performance challenges are identified and addressed. A minimum of 12 months of monitoring data must be reviewed as this will cover at least one seasonal variation. A longer record of information will however better define extreme conditions and will also allow for more accurate trend analysis.

2.4.4 Hard Hats, Safety Boots, Torches and Test Tubes

Optimisation studies and process audits cannot be completed as desktop exercises. A detailed inspection of the plant is essential to gather information about the physical plant, operational practises, collect data and engage with process controllers and maintenance staff. This process may be repeated a number of times and may require emptying and inspection of process reactors in extreme cases. **It should be expected that additional samples will be taken** for water quality analyses that do not form part of the plant's normal monitoring regime.

2.4.5 Questions to Ask

Both the Optimisation Study and Process Audit approaches are based on asking questions. The questions are open ended and should be formulated to probe current practise and operations activities in order to identify risks and opportunity for improvement. Employees and process controllers specifically, may respond with model answers to the investigator and may not speak freely for fear of presenting a poor impression of the organisation or placing someone's job in jeopardy. Gaining the trust of the interviewees is important so that they are able to raise issues freely without fear of reprisal and with the full understanding that this is a constructive process that the organisation is embarking on. This Guideline lists a number of questions, clearly framed in text boxes from Chapter 3 onward, that can be asked to commence the discussion and to guide thought processes and discussions with regard to process optimisation and process focused risk assessments.

Notes:

- **The investigator could use these questions initially but must be prepared to expand discussion points based on the responses received during the interview in order to establish the real issues of concern.**
- ***It would be incorrect to use the list of questions as a tick list as this will have little benefit to the organisation. A simple "yes" or "no" response to the questions will also not be sufficient as the intent is that opportunities are actively sought for further risk mitigation or performance improvement through the discussion around these questions.***
- **The most critical question to ask during the interview and site inspection will be: "*please show me what you are talking about?*" As this leads to a proper understanding of the underlying issues.**

2.4.6 Benchmarks

All assessment results have to be tested against a set of expectations or benchmarks. Typical benchmarks include the regulatory requirements against which the plant must perform which will change from time to time. Additional benchmarks will be developed through the optimisation process. The optimisation benchmarks will be self-imposed and the target will move continuously, mostly towards a more challenging goal. This Guideline document states some benchmarks which have been compiled from local literature, where available, as initial targets to compare performance against. The list of benchmarks is however not exhaustive and also not definitive. Benchmarks should be interpreted based on the experience and professional discretion of the investigator. This does not mean that the investigator is allowed to deviate from generally accepted norms but rather that the investigator must adequately motivate for deviations when needed. The process optimiser has a large degree of freedom in defining internal benchmarks. The intent however is to re-assess and adjust the benchmarks to continuously improve on performance and meet and exceed best practice while maintaining an acceptable compliance record.

2.4.7 Treatment Technologies

The Guideline includes many treatment technologies and treatment scenarios that may be encountered in South Africa. It is however not exhaustive. While the document considers the range of raw water sources, from boreholes to major impoundments and even the ocean, and includes treatment options from slow sand filtration to reverse osmosis, it will be necessary for process investigators to extend the spirit of this Guideline to situations not specifically covered. Process investigators can do this by recognising the commonality between options that are covered in the Guideline with site specific treatment processes being assessed by the investigator that have not been included. As an example, the Guideline requires the process investigator to identify "activities taking place within the catchment that may be a source of contaminants". This statement is unambiguous for conventional surface water treatment plants but requires the process investigator to extend the interpretation where the source water is from boreholes or even a direct reuse situation. Irrespective of the source of water, the question remains whether human activities or natural processes can impact on the quality of the raw water. The Guideline does not attempt to cover each specific situation but assumes that an experienced process investigator is capable of appropriately extending the requirement to the specific plant.

2.5 WHO SHOULD USE THESE GUIDELINES?

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. They are based on recognised international best practices, as well as South African regulatory requirements. It is expected that the process assessor/auditor has an excellent understanding and experience of water treatment processes, operation and maintenance requirements, management functions and has knowledge of the regulatory framework. For this reason, the document is written in a concise style with little limited focus on the basics of water treatment, plant hydraulics and plant operation. The intent is to provide a framework within which professionals can apply their established expertise. The document does however reference a number of other WRC reports which can be used to augment the knowledge base of the process investigator. Stakeholders who will benefit from the Guidelines include:

- Professionals who need to perform process audits and plant optimisation studies.
- Water Treatment Plant Process Controllers and Management who need to comply with regulatory requirements and who need to promote best practice management of a facility through plant assessment and optimisation. These Guidelines provide information on the preparation and inputs required by the various disciplines within the organisation in anticipation of the Audit or Optimisation Study. It can also be used as a tool to provide in-house training of treatment plant process controllers in terms of day-to-day responsibilities and tasks.
- Regulators (DWS and DEA) who assess compliance with the regulatory framework will be able to reference the Guidelines that provide a standardised approach to implementing process audits.
- National Treasury and Finance Institutions which need to promote the deferment or reduction of capital expenditure through plant and process optimisation.
- Professional organisations to promote the Guidelines as a tool for implementation by specialists within the water sector and to build capacity of registered professional persons as required by Draft Regulation 5.
- Educators who can use the Guidelines as training material to build capacity.

2.6 WHO SHOULD PERFORM PROCESS AUDITS AND PLANT OPTIMISATION STUDIES?

Ideally the professional responsible for leading the process audit will:

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

A survey of various Water Services Institutions undertaken as part of the preparation of this Guideline show that some require that a process auditor must be an Engineer while others are satisfied if the auditor 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. An additional requirement is that the Process auditor must be independent of the day-to-day operation and management of the plant under consideration as this provides for additional perspective. This implies that the audit may be performed by an organisation's own specialists but only of that specialist is truly independent of the day-to-day operation or management of the facility being assessed.

<u>Note</u>: It is an absolute requirement that the inspector must be unsympathetic toward internal matters pertaining to the particular plant being inspected for a process audit as his/her focus must at all times be on water quality risk.

A team making up the above requirement is not generally accepted as the integration of the above skill sets cannot be "simulated" by the integration of separate skill sets from various individuals. The team lead does however need a support team consisting of at least the process controllers from the facility and also senior management representatives from the Water Services Institution. A process audit provides an ideal opportunity to expose aspirant Professional Process Controllers to the various issues that need to be attended to in the management of operational risk as well as the opportunities that exist for plant optimisation. Plant optimisation studies can be performed by teams constituted in a similar manner. Ongoing initiatives may however be led by smaller and focussed teams lead by Professional Process Controllers.

2.7 HOW OFTEN MUST A PROCESS AUDIT AND PLANT OPTIMISATION STUDY BE UNDERTAKEN?

Regulation requires that water safety plans be updated on at least an annual basis. Process Audits provide critical inputs to the water safety plan and should remain up to date. A survey of various Water Services Institutions undertaken as part of the preparation of this Guideline suggests best practice is an annual process audit as many internal and external process influencers can change significantly in this period. There are elements of an audit that remain fairly static and these can be reviewed less frequently. This is addressed in more detail under Chapter 10. A typical approach may entail:

- A full process audit in Year 1, and
- A process audit review in Year 2 and 3 which updates all the water quality and flow related data analysis and interpretation elements of the guideline, all on-site inspections related to plant and equipment condition and finally the administrative assessment.

Similarly, an annual or bi-annual reassessment of the plant to identify additional opportunities for optimisation is advisable. The response to previously identified optimisation opportunities will be ongoing in terms of timeframes identified by per optimisation opportunity.

CHAPTER 3: PERFORMANCE ASSESSMENT OF THE TREATMENT PLANT

STEP 1 – PERFORM A PERFORMANCE ASSESSMENT OF THE COMPLETE PROCESS
Determine current plant performance levels against optimised / regulatory goals.

3.1 INTRODUCTION

The focus of this chapter is the assessment of the plant's overall performance against optimisation or regulatory goals. The process investigator is required to develop a detailed understanding of the plant and **high-level plant performance** by looking at the hydraulic and process performance. The process investigator will be required to draw up a process flow diagram, consult drawings, collect and consult raw and treated water quality results and flow records. By the end of Step 1, the process investigator will understand the high-level performance of the plant and know if there is any potential performance limiting issues. These findings will guide the use of subsequent steps. In completing this step of the process, it helps to consider the plant as a "black box" and to focus attention almost exclusively on what comes into the box and what is produced from it. This step is mandatory for all process audits and process optimisation assessments.

3.2 PERFORMANCE ASSESSMENT OF THE COMPLETE TREATMENT PLANT

The first task is to assess the performance of the treatment plant in achieving water quality regulatory compliance as set out in SANS 241, or more stringent internal targets where these are available. A treatment plant should be capable of treating a variable raw water source and continuously produce consistent, high quality final water. The performance assessment will include both on-site and off-site activities. The key outputs from this section will be:

- Confirmation of the plant configuration.
- An understanding of the water balance in the plant.
- An understanding of the profile of raw water quality.
- An understanding of the adequacy of the current process configuration.
- An understanding of the sufficiency of the response of the plant to the raw water profile.

3.3 CURRENT PLANT CONFIGURATION

Treatment plants comprise a sequence of processes units that are designed to produce water of the required quality. The process design of the plant is dependent on:

- Source water quality.
- Seasonal and variations in raw water quality.
- Required treated water quality.

The current treatment process configuration must be described in a Process Flow Diagram (PFD) as part of the study if an adequate version is not yet available. The level of detail should be sufficient to describe the process and the different process units installed. This step is facilitated by input from as-built drawings, where they are available, as well as from process controllers that have extensive knowledge of the operation of the plant. The PFD can be a hand drawn sketch done on site as the investigator moves through the plant which can be further developed into a computer graphic or CAD drawing.

A summary description of the existing plant should be provided including the location, source of raw water and population served by the treatment facility. The original design specifications should be provided and any upgrades to the plant that were required due to changes in water demand or source water quality noted. Additionally, the sizing of the various unit processes must be confirmed while on site.

IMPORTANT QUESTIONS TO ASK: CURRENT PLANT CONFIGURATION

1. Are all the raw water sources identified and documented?
2. Are all the reactors, as well as recycle and bypass streams, identified and documented?
3. Any additional questions that the data may suggest or the investigator may have.

3.4 SOURCE WATER AND FINAL WATER QUALITY

Results of raw and final water monitoring should be gathered. Where recycle streams are introduced to the inlet works, this should also be analysed separately as well as the combined inlet stream after mixing. In the case of a mixed raw water source, the term "mixed stream" should be used in the assessment. At least 12 months data should be available to evaluate seasonal and temporal changes in the source water. Data for longer periods is however preferable to create a better understanding of the source water characteristics and trends. A minimum of three to five years' data is therefore more ideal. Data should include physical, chemical and microbiological determinands as specified in SANS 241 as well as any additional parameters that are specifically measured due to an already identified hazard in the system. A source water assessment must be completed that characterises the resource and identifies point and non-point contributors that have the potential to impact on the quality of the water. Mitigating actions that have been implemented to eliminate point source contributions should be identified. Raw and final water data must be tabulated in a spread sheet and compared to the SANS 241 permissible levels, as well as in-house standards in order to identify problematic determinands present in the raw water and non-compliant determinands in the final water. This will establish whether the current treatment facility can consistently achieve the required final water quality.

IMPORTANT QUESTIONS TO ASK: SOURCE WATER AND FINAL WATER QUALITY

1. Is the laboratory that undertakes compliance monitoring SANAS accredited or does it take part in a proficiency testing programme?
2. Is the laboratory's performance in proficiency testing programme available and does it comply with the limits?
3. Is the process of sampling compliant with SANS 5667 and are the samplers regularly trained?
4. Is the position of sampling points relevant and representative?
5. Have risk determinands in the raw water been identified that exceed SANS 241 or in-house compliance levels (this must be done in line with the requirements of SANS 241)?
6. Does the risk-based monitoring programme comply with the requirements of SANS 241 with regard to the risk determinands monitored and frequency of monitoring?
7. Are the plants meeting SANS 241 water quality targets for final water? Identify non-compliant determinands.
8. Is the plant meeting in-house water quality targets for final water? Identify non-compliant determinands.
9. Has the plant achieved quality compliance even during seasonal variations in raw water quality?
10. Are there any activities taking place within the catchment that may be a source of contaminants? What mitigation actions are implemented to minimise the impact of predicted and unpredicted contamination on the treatment facility?
11. Have any incidents occurred in the catchment that have impacted on raw water quality? Is there a protocol in place to respond to incidents?
12. Have customer complaints been considered in the analysis of potential water quality-based concerns and has this been included in the SANS 241 monitoring programme?

13. What impact do any recycle streams have on the quality of water introduced to the treatment facility?
14. Does the monitoring programme allow for the timeous recognition of changes in raw water quality?
15. Is there an impact on the final water quality when the flow to the plant is reduced or increased?
16. Can the raw water source be selected to ensure the best available raw water quality is entering the plant?
17. Are the necessary precautions in place to ensure unwanted contaminants, objects and animals aren't allowed to enter the plant with the raw water?
18. Any additional questions that the data may suggest or the investigator may have

3.5 PROCESS CONFIGURATION

The process configuration should be assessed to determine whether the existing plant is appropriate for the treatment of the raw water received and whether the desired final water quality is consistently achieved. Typically:

- If raw water turbidity exceeds 5 NTU for extended periods of time, clarification should be included.
- If chlorophyll levels exceed 25 µg/l for extended periods of time, DAF should be included.
- Elevated iron and manganese levels require the inclusion of a pre-oxidation step.
- Elevated DOC levels may require the inclusion of enhanced coagulation, advanced oxidation or activated carbon.
- Low alkalinity waters must include a stabilisation process giving particular consideration to coagulation conditions.
- Coloured waters or waters with high levels of humic and fulvic acids, present a further level of complication on the water type bulleted above (Swartz et al., 2004).
- Taste/odour problems can be addressed by an activated carbon process or a strong oxidant.
- Fluoride and nitrate removal require an ion exchange process.

Other challenging situations may be identified which the investigator will need to respond to. For example:

- Is it appropriate to apply pre-oxidation to raw water if it contains high algal loads?
- When is enhanced coagulation appropriate for DOC removal?
- When is powdered activated carbon sufficient and when must granular activated carbon be considered?
- If the plant experiences abnormal raw water conditions for limited periods can the plant continue to produce high quality water?
- For how long can the existing plant continue to produce water of high quality when variations in raw water are periodically experienced?

The analysis of the installed process will be guided by the process expertise and experience of the investigator. A critical and often overlooked aspect of process design is the impact of recycle streams on the overall process requirement. Additionally, it will be necessary to consider the potential impacts of catchment activities on the plant which may not yet have manifested itself in the raw water quality data.

IMPORTANT QUESTIONS TO ASK: PROCESS CONFIGURATION

1. Have risk determinands been identified as present or potentially present in the raw water source that impact on the treatment configuration?
2. Have the correct process units been installed to address risk determinands?
3. Does the final water quality consistently comply with requirements or are elevated concentrations of risk parameters measured?
4. Has any provision been made to upgrade the plant to address risk determinands in the raw water?
5. Any additional questions that the data may suggest or the investigator may have.

3.6 HYDRAULIC LOAD AND FLOW BALANCE

The hydraulic balance of the plant can be assessed by compiling the data from raw and final flow meter readings. The information can be presented graphically to show trends over at least one year. The known design capacity of the plant should also be included on the trend graph to establish whether the plant is operating at maximum capacity or under capacity and to highlight any inefficiency. The assessment must include historical data to identify any past performance issues and must also consider a five-year demand projection to determine whether the plant will have sufficient spare capacity for the foreseeable future. A five-year horizon generally allows sufficient time for the necessary expansion plans to be properly developed and implemented. Larger plants may need a longer time horizon. A flow balance must be drawn up to fully understand the hydraulic load on the plant as a whole as well as on individual process units. This will also allow for the hydraulic efficiency of the plant to be evaluated. All water and process streams should be monitored including raw water abstraction, internal recycles, residual discharge water and final product water.

IMPORTANT QUESTIONS TO ASK: HYDRAULIC LOAD AND FLOW BALANCE	
1.	Are flow meters installed at the inlet and outlet of the plant?
2.	Are the flow meters calibrated at least once per year or are mechanisms in place to verify flows?
3.	Is the volume of water abstracted compliant with water use authorisation?
4.	Where groundwater is the water source, has a yield study been undertaken?
5.	Are there any potential threats to a sustainable source of water to meet water demand?
6.	What is the current and projected water demand and is sufficient treatment capacity available?
7.	Are abstraction licences in place and do abstraction rates comply with the stated limits? In the case of boreholes and small rural systems the question may be rephrased to address sustainability limits such as confirmed draw-off rates.
8.	Are the flows of recycle streams and residual discharge streams measured?
9.	Do inflows and outflow meter readings balance?
10.	What are the water losses at the plant as a percentage of water production?
11.	What is the annual and peak production? For how many days of the year does the plant operate at full capacity and is this sustainable?
12.	Any additional questions that the data may suggest or the investigator may have.

3.7 BENCHMARKS

The table below contains typical benchmarks relevant to this chapter which are based on local experience. Note that water losses are function of plant size as well and small plants will experience higher losses.

Table 3-1: Benchmarks for the High-Level Assessment of Plant Performance

Processes	Parameter	Typical Values
Percentage capacity utilisation	Maximum AADD plant utilisation rates	80-90% of capacity based on AADD based on the spare capacity required to recover reservoir levels after periods of production interruption.
	Peak Daily Demand utilisation rates	90-100% of capacity at peak daily demand
	Capacity horizon	>5 years horizon when demand growth exceeds plant capacity
Hydraulic efficiencies for conventional plants	On site water balance accuracy	95%-105% (all inflows vs. all outflows)
	Overall plant efficiency for conventional plants < 10 Ml/d	4-8% water losses (raw meter vs. final meter). Could be as high as 12% on small plants
	Overall plant efficiency for conventional plants > 10 Ml/d	3-5% water losses (raw meter vs. final meter)
	Waste streams from DAF	1-2%
	Waste streams from Clarifiers	1-4%
	Waste streams from rapid gravity sand filters	1-2%
	Waste streams from membrane filtration systems	As per supplier's performance targets
Water quality compliance	Various	Refer SANS 241 for minimum compliance values and compliance percentages.

3.8 PERFORMANCE ASSESSMENT SUMMARY

At the conclusion of the performance assessment, an **overview of the total plant** has been compiled and final water quality compliance verified. More specifically, the following information is available:

- Description of the plant configuration and process units.
- Confirmation of the accuracy and reliability of water quality and flow metering data.
- The average and peak hydraulic loading of the plant compared to the design loading.
- Water balance across the plant and water losses.
- Percentage compliance of final water quality based on SANS 241, as well as in-house water quality targets.
- Risk determinands in raw water source and the performance of the plant in reducing these risks.
- Identification of determinands that are not effectively removed during the treatment process.
- Trends in raw water quality and impact on treatment performance.
- Trends in water supply and demand which impact on treatment performance.

CHAPTER 4: MAJOR UNIT CAPACITY ASSESSMENT

STEP 2 – PERFORM A HYDRAULIC CAPACITY ASSESSMENT FOR THE COMPLETE PROCESS
Determine if major unit process sizes are limiting performance.

4.1 INTRODUCTION

An evaluation of the major process units should be undertaken to determine whether process units have sufficient hydraulic capacity to handle the maximum expected load on the plant while still meeting performance goals. This evaluation serves two purposes:

1. If the outcome of the performance assessment step 1 (Chapter 3) is that the plant is not meeting regulatory requirements with regard to water quality, the hydraulic loading on each major unit can be used to identify units that are operating beyond design capacity. This will inform upgrade requirements.
2. If however the design capacity is adequate while the performance is not, other limiting factors (e.g. related to management, operational, or maintenance) may be impacting on performance and a different set of opportunities will be highlighted for optimisation. These factors are discussed in later chapters.

A performance potential graph assists in presenting the result of the investigation in such a way that bottlenecks and spare capacity are easily identified. The graph provides a visual presentation of the capacity of each process unit compared against the flow. An example is presented in Figure 4-1 below. The graph focuses on the process units that are most likely to experience challenges of water quality performance. An easy comparison of hydraulic load vs. treatment capacity is possible if data is presented in the form of the graph. Development of the graph is based on a high-level capacity assessment of the individual process units which essentially focuses only on the physical size of reactor. Detail design elements and associated complications are only considered in the next step (Step 3). This has the advantage of first focusing attention on the "big" issue followed by a focus on the "detail" issues. This chapter presents a number of analytical tools for the high-level determination of capacity for various process units. Once known, this must be compared with the peak instantaneous flow received at the plant in recent years. As capital expansion projects take on average 2 to 5 years to implement, the individual process unit capacities should also be compared against the estimated increase in demand. The required plant expansions need to be finalised to ensure increased water demand can be met without compromising water quality. By following the approach proposed in this chapter, an accurate plant hydraulic capacity (rated capacity) can be determined, which is a critical regulatory requirement. Any variation from generally accepted average loading rates must however be motivated in the hydraulic capacity rating report.

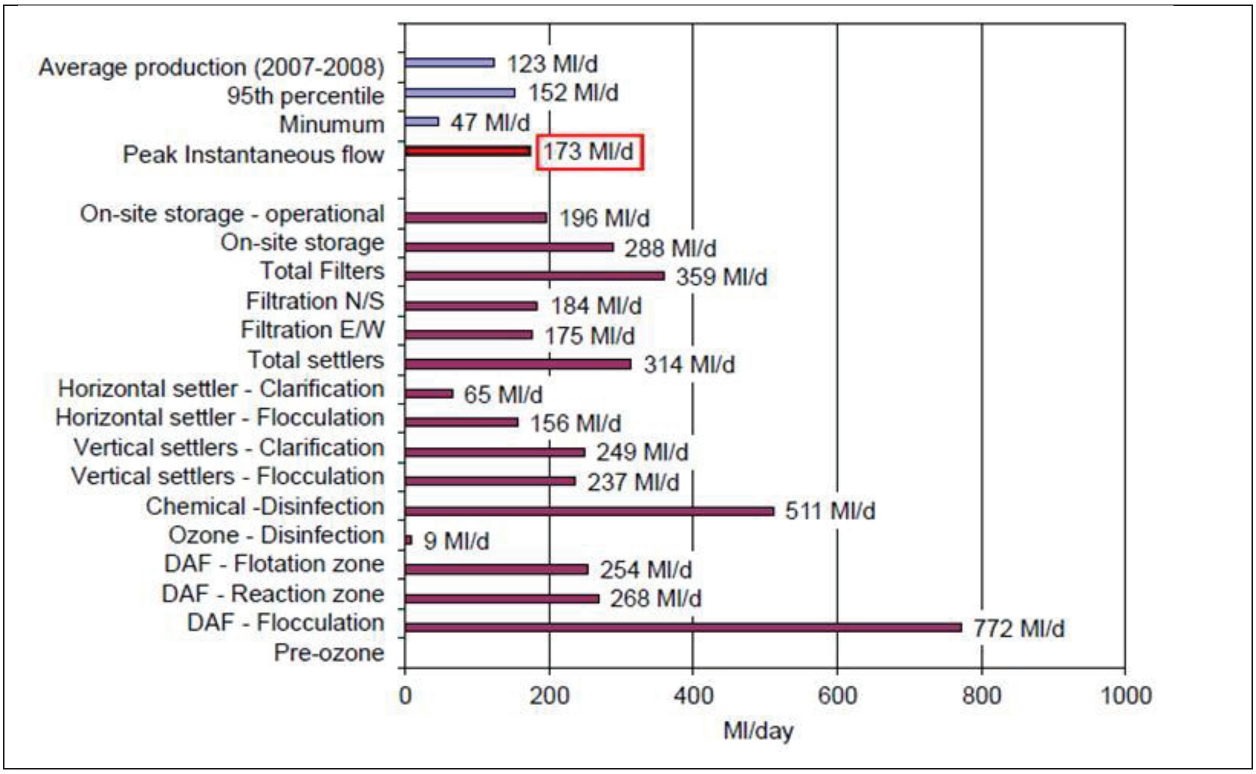

Figure 4-1: Example of Performance Potential Graph of Major Process Units (Ceronio et al., 2010)

4.2 DETERMINING PEAK INSTANTANEOUS OPERATING FLOW

Peak instantaneous operating flow rate is identified through a review of the operating records over a period of at least 12 months. It is the peak flow rate which the plant or process unit receives during normal operating conditions. For example, where a pump delivers the daily flow to a process unit over a twelve-hour period, the peak flow will be double the average daily flow. A plant may also operate at higher flow rates to catch up on lost production so this will be the peak flow rate. It is critical that this rate is used in the assessment as treatment facilities have to sustainably produce high quality water even at peak flows. It is also advisable that forecast peaks flows be considered if the demand on the plant is expected to grow over the next 5 years. The peak flows for the various process units must be tabulated once determined.

IMPORTANT QUESTIONS TO ASK: DETERMINING PEAK INSTANTANEOUS OPERATING FLOW

1. Is a flow meter installed to measure raw water flow? Is the meter calibrated annually?
2. Is reliable flow data available to determine the peak instantaneous flow to the plant or within the plant at process units?
3. How does current operational peaks compare with expected demand growth? Use both in the assessment.
4. Can the peak flow on a process unit be reduced, or delivered over a longer period of time in order to reduce the size of a process unit?
5. Any additional questions that the data may suggest or the investigator may have.

4.3 RATING INDIVIDUAL UNIT PROCESSES

The key activity in developing a performance potential graph is the selection of an appropriate loading rate for each process unit. The guidelines provided below can be used to assist in this or alternative rates if substantiated by the process investigator. Lower hydraulic retention times can be applied where plant data demonstrates that the expected performance can be achieved at higher hydraulic loading rates. Loading rates are generally based on the physical dimensions of each process unit and the number of units installed. It is therefore necessary to have the relevant dimensions when this assessment is done. As-built information must be obtained if possible.
The major unit capacity assessment should also be based on the peak operating flow which includes recycle flows, where applicable. The plant flow diagram (PFD) and confirmed recycle rates from Step 1 will be needed to confirm the correct flow rates. The remainder of this section provides guidance on calculating the capacities, or rating, of major process units.

IMPORTANT QUESTIONS TO ASK: RATING OF UNIT PROCESSES

1. Is the original design information available?
2. Is as-built information available?
3. Are accurate dimensions of the process unit available?
4. Any additional questions that the data may suggest or the investigator may have.

4.3.1 Raw water supply

Intakes to water treatment plants must supply an adequate quantity of water. The operating capacity of the inlet works should be monitored by calibrated flow meters, pressure gauges and by consulting available design data and supplier information. The pump curve obtained from the pump supplier must be compared with the pipe system curve in order to determine a duty point. The age and maintenance condition of both the pump and the pipeline should be taken into account when comparing actual flow rates with a pump curve. The capacities of the various components of the intake system will be site specific and must be determined through an engineering analysis of the hydraulic system. Benchmark values cannot be provided. In performing the analysis, the investigator, or the qualified engineering service provider, must comment on the acceptability of the result. For example, whether the flow velocity in the pipeline is below an acceptable limit.

IMPORTANT QUESTIONS TO ASK: RAW WATER SUPPLY

1. Are raw water and recycle water flow meters calibrated in line with regulatory expectations?
2. What is the capacity of the abstraction structure?
3. Are the capacities of the abstraction structures, raw water pumps, and raw water supply lines matched?
4. Is the inlet works sufficiently sized to receive the peak raw water supply flow as well as all recycle flows which enter the plant at this point?
5 Are flow velocities below acceptable limits and has this been considered in the rating calculation? Will high flow velocities expose the pipe to high levels of risk (water hammer, etc.)? This is particularly important if the pipe is old or has a low-pressure rating.
6. Any additional questions that the data may suggest or the investigator may have.

Table 4-1: Benchmarks values for piped flow

Piped Flow	Parameter	Typical Values (m/s)
Pumped line	Pipe flow velocity	1.5-2.5
Gravity main		1.0-2.0

4.3.2 Flocculation

Good flocculation requires sufficient time to allow aggregation of particles. For design purposes both mixing intensity and duration of mixing are considered (G x t) but this may be simplified by looking only at sizing or retention time at this point of the assessment. The rating of the flocculation process is therefore based on the hydraulic retention time required to allow floc to form at the lowest water temperature. The formula to calculate hydraulic retention time is:

$$t_{floc} = \frac{Q_{floc}}{V_{floc}}$$

Where:

- t_{floc} = Retention time [min]
- Q_{floc} = Flow into the flocculation unit [m^3/min]
- V_{floc} = Volume of the flocculation unit [m^3]

The following hydraulic retention times are typically applied:

Table 4-2: Flocculation Process Typical Hydraulic Retention Times (Minnesota Water Works Operations Manual, 2009)* (Edzwald & Haarhoff, 2012)**

Treatment Process	Parameter	Typical Values (minutes)
Conventional Treatment	Hydraulic Retention Time	15-30*
Direct filtration		10-20*
DAF		6-10**

**Modified from source to reflect SA practice*

IMPORTANT QUESTIONS TO ASK: FLOCCULATION	
1.	Is there adequate retention time in the flocculation system to meet current water demand? If not, can it be motivated?
2.	Any additional questions that the data may suggest or the investigator may have.

4.3.3 Sedimentation

Sedimentation is required to reduce the particle load on following processes and is generally used for high turbidity waters. Capacity is rated by consideration of the upflow velocity. The formula to calculate upflow velocity is:

$$v_u = \frac{Q_t}{A_s}$$

Where:

- v_u = Upflow velocity [m/hr]
- Q_t = Total flow into the tank [m^3/hr]
- A_s = Surface area of the tank [m^2]

The following upflow velocities are typically applied:

Table 4-3: Sedimentation Process Typical Upflow Velocities (Van Duuren, 1997), (Baruth, 2005)

Sedimentation Processes	Parameter	Typical Values (m/hr)
Rectangular tanks	Upflow Velocity	0.5-1.5 m/hr
Vertical flow tanks		1-3 m/hr
Conventional sedimentation with lamella plates/tubes		3-6 m/hr
High Rate Clarification		5-15 m/hr
Super high rate ballasted clarification[1]		40-60 m/hr

IMPORTANT QUESTIONS TO ASK: SEDIMENTATION	
1.	Is the upflow velocity within the typical ranges? If not, can it be motivated?
2.	Any additional questions that the data may suggest or the investigator may have.
3.	Are special monitoring measures in place to warn against the higher risk levels of process failure in clarifiers which make use of increased upflow rates?

4.3.4 Dissolved Air Flotation

Dissolved air flotation is typically selected as a preliminary treatment process for waters that contain constituents that are not readily settleable such as algae, ash, and colour, or for low turbidity waters. Particles are flocculated and removed by floating them out of the basin with a saturated air stream. Effluent quality is mainly determined by the hydraulic loading, i.e. water downflow and particle upflow. The formula to calculate hydraulic loading is:

$$LR_{DAF} = \frac{Q_{DAF}}{A_{DAF}}$$

Where:

- LR_{DAF} = Loading rate [m/hr]
- Q_{DAF} = Total flow (inflow and recycle) to individual DAF unit [m^3/hr]
- A_{DAF} = Surface area of DAF floatation zone [m^2]

The following hydraulic loading is typically applied:

Table 4-4: DAF Process Typical Hydraulic Loadings (Van Duuren, 1997)

DAF Processes	Parameter	Typical Values (m/hr)
Rectangular Tanks	Hydraulic loading in floatation zone	5-15

IMPORTANT QUESTIONS TO ASK: DISSOLVED AIR FLOTATION	
1.	Is the hydraulic loading within the typical values? If not, can it be motivated?
2.	Any additional questions that the data may suggest or the investigator may have.

[1] Associated with metal hydroxide flocs with specific gravity higher than 1, that is dosed with a ballasting agent such as clay. Only applicable in water with low turbidity. This system also requires a recovery stage for the ballasting agent.

4.3.5 Sand Filtration

Filtration is one of the most important processes for the removal of microbial contaminants. A high level of consistent performance is therefore essential. The hydraulic loading rates are dependent upon the type of filter as well as the media. Higher filtration rates are possible when a coarse media is used but this will also require a much deeper bed. High rates cannot be allowed through a coarse media filter if the bed depth is insufficient. Capacity of the sand filters should be based on the assumption that one filter is being backwashed or cleaned and that the remaining filters receive the additional load evenly (Van Duuren, 1997). The formula to calculate loading rate is:

$$LR_f = \frac{Q_f}{A_f}$$

Where:

- LR_f = Loading rate on Filter [m/hr]
- Q_f = Flow rate on individual filter (assuming one filter out of operation for maintenance) [m^3/hr]
- A_f = Media area of individual filter [m^2]

The following loading rates are typically applied:

Table 4-5: Filtration Process Typical Loading Rates

Sand Filtration Processes	Parameter	Typical Values (m/hr)
Slow sand filter with effective grain sizes (d_{10}) between 0.3 and 0.5 mm and minimum bed depth 0.5-1.0 m	Loading rate	0.1-0.4
Rapid Gravity with effective grain sizes (d_{10}) between 0.6 and 0.9 mm and minimum bed depth 0.75 m.	Loading rate	4-7
Rapid Gravity Filter with effective grain sizes (d_{10}) between 0.8 and 1.0 mm and minimum bed depth 0.9 m-	Loading rate	6-10
Pressure Filter with effective grain sizes (d_{10}) between 0.6 and 0.9 mm and minimum bed depth 0.6 m.	Loading rate	8-12

IMPORTANT QUESTIONS TO ASK: Sand Filtration

1. Has the media grading classification been checked?
2. Is the loading rate within the typical values? If not, can it be motivated?
3. Any additional questions that the data may suggest or the investigator may have.

4.3.6 Granular Activated Carbon Filters

Granular activated carbon systems are installed where organic compounds cannot be removed through conventional treatment. The design of the system is based upon the filtration rate and contact time called empty bed contact time (EBCT) to achieve the desired adsorption. The optimal EBCT is dependent on the contaminant to be removed and the dynamics of the removal process and should be confirmed as part of on-going plant operations. The required EBCT must therefore be confirmed with the plant chemist who will determine the current EBCT requirements based on the raw water profile, carbon utilised and treatment goals.

The formula to calculate the EBCT is:

$$EBCT_{GAC} = \frac{V_{media}}{Q_{GAC}}$$

Where:

- $EBCT_{GAC}$ = Empty bed contact time [min]
- V_{media} = Volume of media [m^3]
- Q_{GAC} = Flow into individual GAC filter [m^3/minute]

The following empty bed contact time is typically applied:

Table 4-6: Granular Activated Carbon Process Typical Empty Bed Contact Time (Edzwald, 2011)

GAC Processes	Parameter	Typical Values
Granular	Empty bed contact time	10-15 minutes This must be confirmed through on-going testing of carbon and monitoring of contaminants

IMPORTANT QUESTIONS TO ASK: GRANULAR ACTIVATED CARBON FILTERS	
1.	Are the performance goals of the GAC process known and have they been verified within the last year?
2.	Is the EBCT within the typical values or within the values determined for the specific contaminant? If not, can it be motivated?
3.	Any additional questions that the data may suggest or the investigator may have.

4.3.7 Disinfection

Final disinfection is the most important stage of water treatment and is designed to reduce the pathogenic organisms present. The efficiency of disinfection is determined by the oxidative property of the disinfectant and the contact time in the water. Widely used disinfectants include chlorine gas, sodium hypochlorite and chloramines and the more advanced technologies of ozone and UV radiation. Required capacity is based on the water temperature, pH, the disinfectant used and the extent of inactivation of the indicator micro-organism. Giardia inactivation requirements are more difficult to achieve when compared to inactivation of viruses and bacteria. For design purposes either the concentration or dose of the disinfectant as well as the duration of exposure to the disinfectant must be considered (this is the CT concept) but this may be simplified at this point of the assessment by only looking at sizing or retention time. The formula to calculate the contact time for chlorine or other chemical disinfectant is:

$$t_{contact} = \frac{Q_T}{V_c}$$

Where:

- $t_{contact}$ = Contact time [min]
- Q_T = Total plant flow flowing through the chlorine channel [m^3/minute]
- V_c = Volume of the chlorine contact channel [m^3]

The formula to calculate the contact time for UV is:

$$t_{contact} = \frac{Q_T}{V_{UV}}$$

Where:

- $t_{contact}$ = Contact time in the UV reactor [min]
- Q_T = Total flow through the reactor [m^3/min]
- V_{UV} = Volume of the UV reactor [m^3]

Contact times for UV is normally within seconds. The contact time should be compared to the supplier irradiation specifications for disinfection. The table below indicates the typical irradiation, or UV dose applied. The formula to calculate the contact time for Ozone is:

$$t_{contact} = \frac{Q_T}{V_{O3}}$$

Where:

- $t_{contact}$ = Contact time in the UV reactor [min]
- Q_T = Total flow through the reactor [m^3/min]
- V_{O3} = Volume of the Ozone contact channel [m^3]

The contact time should be compared to the dose applied to the system. Typical CT values are listed in the table below.

Table 4-7: Disinfection Process Typical Contact Time (Edzwald, 2011) (Van Der Walt et al., 2009)

Process	**Parameter**	**Typical Values**
Chlorine:	Contact Time	
Bacteria		60 minutes with a residual chlorine concentration of at least 0.5 mg/l at the end of the contact period.
Viruses		
Giardia		
Cryptosporidium		Limited impact
UV radiation (4.0 log inactivation) *	UV Dose	
E.coli, Legionella, Salmonella, Sheela, V. cholerae		5-10 mJ/cm^2
Hepatitis, Polio virus, Rotavirus, Cryptosporidium, Giardia		20-40 mJ/cm^2
Adenovirus		200 mJ/cm^2
Ozone (3.0 log removal)	CT value	
Viruses		0.5 mg.min/l at >20°C 0.8 mg.min/l at between 10-20°C 1.4 mg.min/l at between 1-10°C
Giardia		0.7 mg.min/l at >20°C 1.4 mg.min/l at between 10-20°C 2.9 mg.min/l at between 1-10°C
Cryptosporidium		14 mg.min/l at >20°C 22 mg.min/l at between 10-20°C 72 mg.min/l at between 1-10°C

IMPORTANT QUESTIONS TO ASK: DISINFECTION	
1.	Are the performance goals of the disinfection process consistently achieved?
2.	Is the contact time within the typical values? If not, can it be motivated?
3.	Any additional questions that the data may suggest or the investigator may have.

4.3.8 Ion Exchange

The major application of ion exchange is for softening of water by removal of calcium and magnesium and other polyvalent cations. The design of the reactor is based on the empty bed contact time (EBCT) which determines the resin volume. The formula to calculate the EBCT is:

$$EBCT_{IX} = \frac{V_R}{Q_F}$$

Where:

- $EBCT_{IX}$ = Empty bed contact time for Ion Exchange [min]
- V_R = Volume of Resin bed [m^3]
- Q_F = Feed flow rate [m^3/min]

Table 4-8: Ion Exchange Process Typical Empty Bed Contact Time (Edzwald, 2011)

Ion Exchange Processes	Parameter	Typical Values (minutes)
Resin	Empty bed contact time	1.5-7.5 This must be confirmed through on-going testing of resin and monitoring of contaminants

IMPORTANT QUESTIONS TO ASK: ION EXCHANGE	
1.	Are the performance goals of the ion exchange process consistently achieved?
2.	Is the empty bed contact time within the typical values? If not, can it be motivated?
3.	Any additional questions that the data may suggest or the investigator may have.

4.3.9 Membrane Filtration

Membrane processes with the greatest application to drinking water treatment are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Capacity of membrane systems are based on the flux which is the flowrate of filtrate per unit of area of membrane. The downtime for backwashing and cleaning of the membrane units must be taken into account to ensure that available capacity can meet water demand. The formula to calculate the flux is:

$$J = \frac{Q_P}{A_m}$$

Where:

- J = Flux [l/hr/m^2]
- Q_P = Filtrate flow rate through membrane [l/hr]
- A_m = Surface area of membrane [m^2]

The following values for flux are typically applied:

Table 4-9: Typical Membrane Flux Values (Baruth, 2005)

Membrane classification	Parameter	Typical Values (l/hr/m^2)
Microfiltration	Flux	34-170
Ultrafiltration		
Nanofiltration		22-30 (groundwater) 14-20 (surface water)
Reverse Osmosis		

IMPORTANT QUESTIONS TO ASK: MEMBRANE FILTRATION

1. Are performance goals knowns from the supplier's source documents?
2. Are the performance goals of the membrane process consistently achieved?
3. Is the membrane flux within the typical values? If not, can it be motivated?
4. Is there mixing or blending with fresh water sources in the product water?
5. Any additional questions that the data may suggest or the investigator may have.

4.3.10 Lifting Pump Station

A lifting station pumps the final water to reservoirs and the reticulation system. Flow should be monitored by flow meters, pressure gauges and by consulting available design data and supplier information. The pump curve should be investigated and compared to the system curve. This will indicate whether the pumps will operate at the required duty. Age and maintenance should be taken into account when comparing actual flow rates with a pump curve. There should be sufficient capacity to satisfy the demand.

IMPORTANT QUESTIONS TO ASK: PUMP STATIONS

1. Is the pump station adequately sized to supply the required quantity of water to meet current water demand?
2. Any additional questions that the data may suggest or the investigator may have.

4.4 SUMMARY

At the conclusion of the major unit process evaluation, the installed capacity **of each key process unit** has been rated and compared with the peak hydraulic loading. This is achieved by drawing up a Potential Graph, similar graph to the Figure 4-1. More specifically the following information is now available:

1. The capability of each process unit to receive peak instantaneous operating flows.
2. The key process units that are limiting optimised performance.
3. Process units that could be optimised by consideration of other performance limiting factors.
4. Process units whose capacity is categorised as inadequate and may need to be upgraded.

CHAPTER 5: MAJOR UNIT PERFORMANCE ASSESSMENT

STEP 3 – DO A UNIT PROCESS PERFORMANCE ASSESSMENT
Identify any aspects (other than unit size) of unit process design which limits performance

5.1 INTRODUCTION

The evaluation of major unit process in Step 2 has identified whether process units are adequately rated for the peak hydraulic loadings received by the treatment plant. Process units may however be appropriately sized but still fail to meet performance goals. This may be due to issues with the detail design of individual process units or because of the condition of the equipment. This next step in the process optimisation study or the process audit therefore focuses on:

- Detail design elements, and
- The condition of installed equipment.

The critical issues to consider in this evaluation are:

- Water quality performance goals for each process unit,
- Appropriate design of each unit process,
- Energy usage profiles, and
- Equipment condition.

5.2 WATER QUALITY PERFORMANCE ASSESSMENT

A detailed assessment of relevant water quality data at each individual process unit (under varying operational conditions and loads) provides the first indicator of whether the unit is performing to expectation or whether a more detailed evaluation is required. Performance goals should be set for individual units against which performance can be evaluated. These goals should be used by process controllers to guide operational activities and to promote corrective actions. Examples of performance goals are listed in Table 5-1 below. Data should be recorded and trends reviewed. An assessment of performance against goals provides information on the status of the plant operations and progress made towards their achievement. The ultimate goal is that final water quality should consistently comply with the standards set out in the latest SANS 241. This evaluation results in a detailed understanding of the challenges of a plant and also provides guidance on which elements of a process unit need further investigation.

Table 5-1: Example of typical unit process performance goals (South African National Standard, 2015)

Unit Process Performance Goals Table		
Objective: To establish process control targets for each major sampling location/unit process to ensure optimised plant performance		
Sampling Location/Unit Process	**Tests**	**Target Value**
Raw Water	NTU pH Alkalinity Iron Manganese Dissolved oxygen	< 15.0 NTU 7-9 80-120 mg/l CaCO3 < 0.3 mg/l < 0.05 mg/l > 4.0 mg/l
Rapid mix	pH	< 7.5
Clarified / Settled water	Turbidity pH Alkalinity	< 2 NTU < 7.6 80-100 mg/l $CaCO_3$
Filter effluent (sand or membrane)	Turbidity	< 0.30 NTU 95^{th} percentile
Final Water	SANS 241	SANS241

IMPORTANT QUESTIONS TO ASK: WATER QUALITY PERFORMANCE ASSESSMENT	
1.	Have performance goals been set for each treatment process unit for turbidity and other risk parameters?
2.	Is an appropriate monitoring programme of turbidity of raw, settled and filtered water implemented?
3.	Is an appropriate monitoring programme of risk parameters implemented?
4.	Have any performance goals been exceeded over the past 12 months?
5.	Has there been a risk to public health over the past 12 months due to high turbidity and microbial contamination in the final water?
6.	Do turbidity values fluctuate after sedimentation and filtration with variations in raw water quality?
7.	Any additional questions that the data may suggest or the investigator may have.

5.3 DESIGN ASSESSMENT

In the previous section, capacity related performance limiting factors have been identified through the development of a performance potential graph. Although a unit may be adequately sized, the performance fails to meet its potential. This section focuses on the evaluation of design issues other than hydraulic capacity, such as process flexibility and capability of chemical dosing facilities that may impact on the capability and performance of the major process units. Key assessment criteria for the various process units are set out below.

5.3.1 Pump Stations and Conveyance

Water abstraction systems need to supply a reliable and an adequate quantity of raw water at the required quality to the treatment plant. Abstraction points must be correctly designed to ensure reliable draw-off and minimise any impacts on the operation of the treatment plant. Key factors to be taken into account include the topography, the quantity of water to be abstracted and environmental conditions that cause variations in water quality.

IMPORTANT QUESTIONS TO ASK: PUMP STATIONS AND CONVEYANCE	
1.	Are all possible raw water sources identified and documented?
2.	Is a hydraulic flow diagram available that identifies all flows to the plant, including recycles and bypass streams?
3.	Does the location of the intake provide the highest quality water possible?
4.	Can water be abstracted at various depths, if required?
5.	Does the intake ensure reliable supply despite fluctuations in the water level?
6.	Is the abstraction point protected from surges and flooding?
7.	Does the design of the intake point minimise the impact of silt and solid deposits?
8.	Are screens installed to protect pumps from large floatable objects? Can they be easily cleaned to prevent flow restriction?
9.	Are the pumps accessible and can they be easily removed for maintenance purposes?
10.	Are standby pumps installed?
11.	Is the abstraction point upstream of potential local sources of pollution?
12.	Does the capacity of the abstraction system meet the maximum water demand during the projected lifetime?
13	Any additional questions that the data may suggest or the investigator may have.

5.3.2 Chemical Dosing and Dosing Equipment

There are different distinct forms of chemical addition systems. They are generally gaseous (chlorine, ozone, carbon dioxide), liquid (chlorine dioxide, potassium permanganate, flocculent, soda ash, etc.) and powder (lime, powdered activated carbon, bentonite, etc.). Chemical addition is dependent on the source water quality or process requirements, such as the removal of metals or creating flocs that can be removed by a specific process. The type of equipment for chemical addition also varies ranging from simple dosing systems with limited input and control, to intricate systems with multiple components, numerous controls, inputs and outputs. The plant investigator should use their experience and knowledge of these units to assess the requirements in more detail.

IMPORTANT QUESTIONS TO ASK: CHEMICAL DOSING AND DOSING EQUIPMENT	
1.	Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2.	Are the possible raw water contaminants identified and correct chemical usage employed to address their removal or treatment?
3.	Are there sufficient and effective dosing equipment installed?
4.	Is there sufficient standby capacity?
5.	Is the control of the dosing system operator friendly and effective to allow for turndown or optimisation of dosage as water quality and requirements change?
6.	Does the system have sufficient turndown capacity?
7.	Is the storage capacity sufficient taking into account maximum usage, procurement and availability of chemicals?
8.	Can the metered dosage rate be confirmed by other mechanisms?
9.	Are all necessary residual flows measured?
10.	Is a maintenance plan in place to ensure continuous operation of the system?
11.	Has an OHS inspection being done to ensure that all safety aspects are identified and addressed?
12.	Any additional questions that the data may suggest or the investigator may have.

5.3.3 Flocculation

Flocculation is preceded by coagulation and is a mechanical process of mixing to promote the formation of macroflocs by collision of particles and microflocs. Three basic types of flocculators are found:

- Completely stirred reactors,
- Baffled channels, and
- Spiral flocculators.

Floc particle size depends on the downstream process units. For example, large settleable flocs are required for settlement in sedimentation tanks but pinpoint flocs are required in direct filtration plants. Key design considerations include mixing energy, hydraulic retention time, temperature and solids concentration. Good flocculation is achieved in a suspension subjected to uniform turbulence and optimum shear rate. The magnitude of shear should decrease smoothly as floc size increases to prevent floc breakdown (Van Duuren, 1997). Calculation of the velocity gradient (G) as the measure of the intensity of mixing is an important design parameter. The formula to calculate the velocity gradient is:

$$G = \left[\frac{g \times h}{\upsilon \times t_f}\right]^{1/2}$$

Where:

- G = Mean velocity gradient [s^{-1}]
- g = Gravity constant [9.81 m/s^2]
- h = Head loss in the channel system [m] (calculated by assessor)
- υ = Kinematic Viscosity (at operating temperature) [m^2/s]
- t_f = retention time [s]

Typical design values for the flocculation process are:

Table 5-2: Typical Values for Flocculation Velocity Gradient (Van Duuren, 1997)

Processes	Parameter	Typical Values
Flocculation	Velocity gradient	30-60 s^{-1}
DAF		50-120 s^{-1}
Flash Mixing		600-1000 s^{-1}

IMPORTANT QUESTIONS TO ASK: FLOCCULATION

1. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Do basin inlet conditions allow for accurate flow division between duplicate units before flocculation?
3. Are there an adequate number of stages (minimum of three recommended) to create plug flow conditions with desired energy gradients and to form the desired floc size?
4. Is there adequate flocculation taking place to form the desired floc particles?
5. Is the baffling adequate to optimise performance or could additional baffling improve flocculation?
6. Is there a protocol to optimise floc particle size? Are jar tests being done on a regular basis to support the protocol?
7. Is the quality of water from each basin monitored for compliance against performance goals?
8. Do basin outlet conditions avoid floc breakup or premature settlement?
9. Any additional questions that the data may suggest or the investigator may have.

5.3.4 Sedimentation

Settlement of the aggregated particles formed during the flocculation process is achieved through sedimentation. The process is dependent on the conditions and properties of the settling basin. Sedimentation tanks are rectangular, square or circular. Tank shape and internal configuration are important aspects for optimised operation. All tanks have four operational zones, i.e. inlet, sedimentation, outlet and sludge, which determine the hydraulic efficiency. The inlet is often baffled to improve flow distribution across the settling area. Proper inlet design is important to prevent deterioration of the floc structure and achieve good settling efficiencies. The velocity of the water is reduced as it enters the sedimentation zone, which allows the flocs to settle. Particle settling velocity and the velocity of water rising (overflow rate) are the parameters that impact on the efficiency of solids removal. The outlet zone has a large surface area to minimise flow velocity and prevent lifting of the settled floc. Sludge must be regularly pumped from the tank. This needs to be carefully controlled to prevent the sludge becoming too thick to pump if left too long but at a frequency that prevents discharge of thin sludge is thin that increases water losses. The larger tanks are impacted by external factors of temperature, density currents and wind effects. The key formulae used to assess the operation of the sedimentation process are listed below noting that loading rates have already been discussed in the previous chapter:

(a) **Weir overflow rate**: In order to ensure that there is no carry-over of particles, the weir overflow rate should be low enough to ensure that the upflow velocity is not exceeded.

$$V_w = \frac{Q_t}{L_w}$$

Where:

- V_w = Weir overflow rate [m³/hr.m]
- Q_t = Flow into tank [m³/hr]
- L_w = Total Length of weir [m]. This is the total length of all the weirs in the tank.

(b) **Solids loading rate**:

$$S_L = \frac{S_A}{A_s}$$

Where:

- S_L = Solids Loading Rate [kg/m².d]
- S_A = Applied Solids [kg/d]
- A_s = Surface Area of tank [m²]

Typical design values for the sedimentation process are:

Table 5-3: Typical Design Criteria for Sedimentation Process (Van Duuren, 1997)

Sedimentation Processes	Parameter	Typical Values
Sedimentation	Inlet velocity Weir overflow rate Solids loading Desludging water loss	<1 m/s < 10 m^3/hr.m 1-3 kg/m^2.d < 3%
High Rate Clarifier	Inlet velocity Weir overflow rate Solids loading Desludging water loss	5 m/s < 10 m^3/hr.m 5 kg/m^2.d < 2%

IMPORTANT QUESTIONS TO ASK: SEDIMENTATION

1. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Do inlet conditions disturb the settling conditions in the basin?
3. Is there short circuiting in the tank?
4. Is floc breakdown observed at the inlet?
5. Is there accurate flow division between duplicate units?
6. Are overflow weirs level?
7. Is there excessive turbulence at the outlet?
8. Is the tank prone to disturbance from weather conditions or biological growth?
9. Is sludge regularly removed?
10. Does the capacity of the sludge management facility impact on sludge removal rates?
11. Is the quality of water from each clarifier monitored for compliance against performance goals?
12. Are performance goals consistently achieved?
13. Any additional questions that the data may suggest or the investigator may have.

5.3.5 Dissolved Air Flotation

Dissolved air flotation comprises the following components:

- Reaction zone, where particles, water and bubbles come together. Reaction efficiency is based on the length of time for mixing and mixing intensity, which is approximated by the flow velocity through the unit based in the area of the reaction zone.
- Bubble production system which includes water abstraction, air saturation and recycling back of supersaturated water into the reaction zone. Recycle rates are based on the air requirements. Typical air pressures range from 400-600 kPa.
- Flotation zone where phase separation takes place. Important parameters include the cross-flow velocity between reaction and flotation zone, hydraulic loading, and side depth of flotation tank. The outlet zone should prevent recirculation of water in the flotation tank. Rectangular tanks may need multiple draw-off points.
- Float layer removal.

The key formulae to assess the operation of the sedimentation process are:

(a) Recycle ratio:

$$r = \left[\frac{Air\ requirements}{Theoretical\ Solubility\ \times Saturator\ Pressure\ \times Assumed\ efficiency}\right] \times 100$$

Where:

r = Recycle ratio [%]

- Air Requirements = Water solubility [mg/l] based on site conditions
- Theoretical Solubility = Solubility in saturator corrected for temperature [$mg/l.kPa^{-1}$]
- Saturator Pressure = Selected pressure of the saturator [kPa]
- Assumed efficiency = The assumed efficiency of the system [%] (generally around 75%)

(c) Recycle flow rate

$$Q_R = Q_{PT} \times r$$

Where:

- Q_R = Recycle flow rate [m^3/hr]
- Q_{PT} = Total plant flow [m^3/hr]
- r = Recycle Ratio [%]

(d) Reaction zone residence time

$$t_{RZ} = \frac{Q_{DAF} + Q_R}{V_{RZ}}$$

Where:

- t_{RZ} = Residence time in the Reaction Zone [s]
- Q_{DAF} = Flow into individual DAF unit [m^3/s]
- Q_R = Recycle flow [m^3/s]
- V_{RZ} = Volume of reaction zone [m^3] (Note that some reaction zones have inclined walls. This volume should be taken into account)

(e) Reaction zone upflow velocity:

$$v_{RZ} = \frac{Q_{DAF} + Q_R}{A_{RZ}}$$

Where:

- v_{RZ} = Upflow velocity in Reaction Zone [m/hr]
- Q_{DAF} = Flow into individual DAF unit [m^3/hr]
- Q_R = Recycle flow [m^3/hr]
- A_{RZ} = Average surface area of reaction zone [m^2]

(f) Floatation zone cross flow velocity:

$$v_{CS} = \frac{Q_{DAF} + Q_R}{A_{CS}}$$

Where:

- v_{CS} = Cross flow velocity [m/hr]
- Q_{DAF} = Flow into individual DAF unit [m^3/hr]
- Q_R = Recycle flow [m^3/hr]
- A_{CS} = Horizontal cross sectional area of floatation zone in the direction from inlet to outlet [m^2]

(g) Flotation zone hydraulic loading:

$$v_{FZ} = \frac{Q_{DAF} + Q_R}{A_{FZ}}$$

Where:

- v_{FZ} = Upflow velocity in floatation zone [m/hr]
- Q_{DAF} = Flow into individual DAF unit [m^3/hr]

- Q_R = Recycle flow [m^3/hr]
- A_{FZ} = Average surface area of floatation zone [m^2]

The following are typical values for the DAF process:

Table 5-4: Typical Design Criteria for DAF Process (Van Duuren, 1997)

Component	Typical Values	
	Minimum	Maximum
Reaction zone hydraulic loading	40 m/hr	100 m/hr
Recycle System		
Air requirement	6.0 mg/l	8.0 mg/l
Recycle ratio	6%	10%
Saturation pressure	400 kPa	600 kPa
Packed Saturators		
Hydraulic loading	50 m/hr	80 m/hr
Packing depth	0.8 m	1.2 m
Water depth	15%	25%
Unpacked saturator (no internal recycle)		
Water depth	40%	60%
Injection nozzle velocity	20 m/s	
Flotation zone		
Cross flow velocity	20 m/hr	100 m/hr
Hydraulic loading	5 m/hr	11 m/hr
Side depth	1.5 m	3 m

IMPORTANT QUESTIONS TO ASK: DISSOLVED AIR FLOTATION

1. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Is floc breakdown observed at the inlet?
3. Is there good distribution of saturated water in the reaction zone?
4. Is there excessive turbulence at the outlet?
5. Is there accurate flow division between duplicate units?
6. Is sludge regularly removed?
7. Does the capacity of the sludge management facility impact on sludge removal rates?
8. Are the recycle pumps functioning properly? Are standby pumps installed?
9 Is the unit operating at the correct pressure?
10. Is the quality of water from each unit monitored for compliance against performance goals?
11. Any additional questions that the data may suggest or the investigator may have.

5.3.6 Slow Sand Filtration

Slow sand filtration is usually employed without the pre-treatment step of coagulation. Opportunities for slow sand filtration are limited due to the restricted source water qualities that are suitable for this process. Ideal water qualities are < 5 NTU turbidity, < 5 mg/m^3 chlorophyll a, < 0.3 g/m^3 iron, < 0.05 g/m^3 manganese, and < 25 g/m^3 Pt colour. Key parameters impacting on performance include the hydraulic loading (already discussed in the previous chapter) and filter media. Typical values for the design of slow sand filters are:

Table 5-5: Typical Design Criteria for Slow Sand Filtration Process * (Van Duuren, 1997), (Edzwald, 2011),*** (Cleasby & Logsdon, 1999), **** (Crittenden et al., 2005)**

Parameter	Typical Values	
	Minimum	Maximum
Hydraulic loading rate*	0.1 m/hr	0.4 m/hr
Media effective size (d_{10})*	0.25 mm	0.4 mm
Media Uniformity co-efficient (UC)	<2 in local references* and <3 internationally**	
Depth of gravel support **	0.4 m	0.6 m
Depth of filter sand **	0.8 m	1.2 m
Headloss allowed****	0.9 m	1.5 m
Water depth over media ****	0.9 m	1.5 m
Maximum run length****	1 month	6 months

IMPORTANT QUESTIONS TO ASK: SLOW SAND FILTRATION

1. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Do inlet conditions allow for accurate flow division between duplicate units?
3. Have under drains or support media been damaged?
4. Is the treatment process applicable for the raw water quality received at the plant?
5. Is the quality of water from each filter monitored for compliance against performance goals?
6. Any additional questions that the data may suggest or the investigator may have.

5.3.7 Rapid Gravity Sand Filtration

Rapid gravity sand filters usually receive pre-treated water where the solid concentration has been reduced. Filtration efficiency is largely dependent on proper chemical treatment. Most filters in South Africa use downflow filtration. Normally a minimum of three but preferably four filters are installed to minimise variation in filtration rates when one filter is backwashed. Key design parameters include the hydraulic loading, media size, clogging head loss and backwash rate and air scour. The loading rate calculation was discussed in the previous chapter.

(a) Clogging head calculation:

Clogging head loss is calculated by measuring the difference between the top water level and the outlet weir level (metres) and subtracting the head loss through the media, underdrain system and pipework (approximately 0.7 metres on average but highly variable).

(b) Low backwash rate:

$$v_{BL} = \frac{Q_{BL}}{A_F}$$

(c) High backwash rate:

$$v_{BH} = \frac{Q_{BH}}{A_f}$$

Where:

- v_{BL} = Low Backwash Rate [m/hr]
- v_{BH} = High Backwash Rate [m/hr]
- Q_{BL} = Low rate flow [m^3/hr]. Information obtained from designer, supplier or pump curve.
- Q_{BH} = High rate flow [m^3/hr]. Information obtained from designer, supplier or pump curve.
- A_f = Individual filter area [m^2]

(d) Air scour

Air scour is difficult to determine and information should be obtained from the designer or equipment supplier.

(e) Additional tests

Additional testing can be done to determine the following performance indicators (Haarhoff, n.d.):

- Backwash rates
- Bed expansion
- Backwash water quality profiles
- Filter media cleanliness tests
- Filter media grading analysis
- Filter ripening and breakthrough curves

The following are typical values for the Rapid Gravity Filtration process:

Table 5-6: Typical Design Criteria for Rapid Gravity Filtration Process (Van Duuren, 1997) (Ceronio & Haarhoff, 1994)*

Parameter	Typical Values	
	Minimum	Maximum
Hydraulic loading rate	5 m/hr	10 m/hr
Clogging head	1.5 m	2.0 m
Media effective size (d_{10})	0.7 mm	0.9 mm
Media Uniformity co-efficient (UC) *	1.20	1.40
Depth of filter sand	0.8 m	1.0 m
Water depth	0.3m	2m
Filter run lengths	24 hr	48 hr
Consecutive air and water backwash		
Air rate	18 m/hr	36 m/hr
Water rate	12 m/hr	30 m/hr
Simultaneous air and water backwash		
Air rate (scour cycle)	50 m/hr	60 m/hr
Water rate (scour cycle)	2 m/hr	8 m/hr
Water rate (rinse cycle)	20 m/hr	40 m/hr

IMPORTANT QUESTIONS TO ASK: RAPID GRAVITY SAND FILTRATION

1. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Do inlet conditions allow for accurate flow division between duplicate units?
3. Have under drains or support media been damaged?
4. Is the treatment process applicable for the raw water quality received at the plant?
5. Are the backwash facilities adequate to maintain a clean filter bed?
6. Are filter rate control valves functioning properly to ensure uniform filtration rates?
7. Is the quality of water from each filter monitored for compliance against performance goals?
8. Are there any sign of cracks, mud balls or an unusually uneven surface in the media bed?
9. How does the media bed respond to the different backwash sequences? Are there any abnormal flows at certain points or dead spots observed?
10. Are individual units monitored for treatment performance?
11. Is the filter media clean after washing?
12. What is the quality of the filtrate immediately after backwash and how is this managed?
13. Is the filter media bed grading correct and is the media bed depth to specification?
14. Any additional questions that the data may suggest or the investigator may have.

5.3.8 Granular Activated Carbon

Most natural waters contain small amounts of dissolved organic matter. Although most of the dissolved organic matter is harmless some pose a risk to human health. GAC can be used to remove these compounds through adsorption onto the surface of the activated carbon. This process requires the application of adequate driving force to move the molecule from the water onto the surface of the carbon. The affinity of the molecules for water and carbon will affect the performance of the GAC. This must be confirmed through ongoing testing of carbon adsorption and monitoring removal of contaminants. EBCT has already been calculated in the previous step. Specific throughput can be used to determine the minimum and maximum EBCT for each plant based on the time for breakthrough of contaminants:

$$ST_{GAC} = \frac{t_{bt}}{EBCT_{GAC}\rho_{GAC}}$$

Where:

$\rho_{GAC} = \frac{M_{GAC}}{V_{GAC}}$

And

- ST_{GAC} = Specific throughput of GAC [m^3 feed water/kg GAC media]
- t_{bt} = Time to breakthrough [min]
- ρ_{GAC} = GAC filter bed density [kg/m^3]
- M_{GAC} = Mass of media [kg]
- V_{GAC} = Absorber available volume [m^3]

Figure 5-7 below presents the relationship between EBCT and specific throughput.

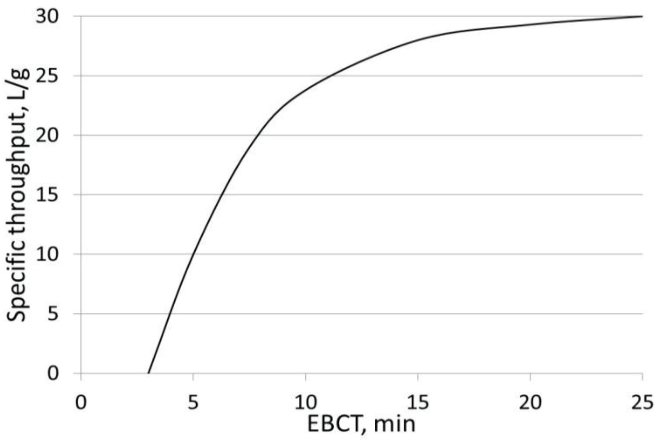

Table 5-7: EBCT vs Specific throughput (Crittenden et al., 2005)

<u>IMPORTANT QUESTIONS TO ASK: GAC</u>

1. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Do inlet conditions allow for accurate flow division between duplicate units?
3. Has underdrains been damaged or has support media placement been disturbed?
4. Is the treatment process applicable for the raw water quality received at the plant?
5. Are the backwash facilities adequate? Are the facilities dedicated to the GAC process or are they shared with the sand filters?
6. Are there formal procedures to remove and reactivate the carbon?
7. Is the available EBCT appropriate for the specific contaminants?
8. Has the maximum and minimum specific throughput been verified?
9. Are the original design specifications known for the GAC (source material, size grading, iodine number, density and hardness) and does the current GAC media comply?
10. Are operational monitoring of contaminants and their removal being done and is this compared with the performance targets of the GAC filter?
11. Are individual units monitored for treatment performance?
12. Is the filter media clean after washing?
13. What is the quality of the filtrate immediately after backwash and how is this managed?
14. Is the filter media bed grading correct and is the media bed depth to specification?
15. Any additional questions that the data may suggest or the investigator may have.

5.3.9 Disinfection

Disinfectants and their dosage rates must be selected to ensure that the chemical demand of water is met and the desired residual is maintained throughout the distribution system up to the point of use. Although capacity and contact time of disinfectant is important, other issues are important to optimise performance. Disinfection efficiency can be assessed by reviewing the CT value, which is based on the residual disinfectant concentration in mg/l (C), the effective disinfectant contact time in minutes (T), as well as the reaction temperature and pH. CT requirements expressed as mg/l.min have been calculated for the log removal of different target organisms. CT values for inactivation of viruses and Giardia cysts for different disinfectants are reported by the EPA (copied below). Chlorine and chloramines are not effective as a disinfectant for removal of *Cryptosporidium*. Although *E.coli* and heterotrophic micro-organisms are used as indicators of effective disinfection, these organisms do not have the highest resistance to disinfectants and are inactivated at lower CT values.

Table 5-8: Contact Time Values for Inactivation of Viruses (Van Der Walt et al., 2009), (Edzwald, 2011)

Disinfectant	Inactivation		
	2-log	3-log	4-log
Chlorine (mg/l.min)[2]	3	5	6
Chloramine (mg/l.min)[3]	643	1,067	1,491
Chlorine dioxide (mg/l.min)[4]	4.2	12.8	25.1
Ozone (mg/l.min)	0.5	0.8	1
UV (mW.s/cm2)[5]	21	36	40

Table 5-9: Contact Time Values for Inactivation of Giardia cysts (Van Der Walt et al., 2009)

Disinfectant	Inactivation					
	0.5-log	1-log	1.5 log	2-log	2.5-log	3-log
Chlorine (mg/l.min)	17	35	52	69	87	104
Chloramine (mg/l.min)	310	615	930	1,230	1,540	1,850
Chlorine dioxide (mg/l.min)	4	7.7	12	15	19	23
Ozone (mg/l.min)	0.23	0.48	0.72	0.95	12	1.43

IMPORTANT QUESTIONS TO ASK: DISINFECTION

1. Are performance goals consistently achieved?
2. Is the contact tank baffling adequate to optimise performance or could additional baffling improve disinfection?
3. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
4. Are disinfectant concentrations regularly monitored to maintain optimised operating conditions?
5. Are there any determinands in the water at the inlet to the disinfection process that impact on efficiency?
6. Is adequate disinfectant residual maintained in the distribution system?
7. Is the microbiological quality of final water and at point of use regularly monitored for regulatory compliance?
8. Is the treatment plant subject to seasonal changes that many impact on the efficacy of the disinfection process?
9. Is disinfection efficiency impacted by inadequate mixing or by short circuiting?
10. Has a plant specific ratio of chlorine to ammonia been determined for optimisation of chloramine?

[2] Values based on temperature 10°C, pH 6-9 and free chlorine residual of 0.2-0.5 mg/l
[3] Values based on temperature 10°C and pH of 8
[4] Values based on temperature 10°C and pH 6-9
[5] (Edzwald, 2011)

IMPORTANT QUESTIONS TO ASK: DISINFECTION
11. Is monitoring equipment available on-site that is regularly calibrated and maintained in operating condition?
12. Is a maintenance plan in place to ensure continuous operation of the system?
13. Has an OHS inspection being done to ensure that all safety aspects are identified and addressed?
14. Any additional questions that the data may suggest or the investigator may have.

5.3.10 Ion Exchange

Ion exchange process units are generally classified as a strong acid, strong base, weak acid or weak base exchanger. The appropriate resin should be verified for the specific water quality of water to be treated and the contaminant to be removed. This must be confirmed through ongoing testing of performance in removal of contaminants. Operation of the ion exchange unit is assessed according to the service flow rate (SFR) or exhaustion rate which is the reciprocal of EBCT.

$$SFR = \frac{Q_F}{V_R}$$

Where

- SFR = Service flow rate [$m^3/min \cdot m^3$]
- Q_F = IX Feed flow rate [m^3/min],
- V_R = Resin bed volume including voids, [m^3]

The following are typical values for the ion exchange process:

Table 5-10: Typical Values for Ion Exchange performance (Edzwald, 2011)

Parameter	Typical Values	
	Minimum	Maximum
Service flow rate	0.15 $m^3/min \cdot m^3$	0.70 $m^3/min \cdot m^3$
Bed depth (varies substantially)	0.7m	3.7m

IMPORTANT QUESTIONS TO ASK: ION EXCHANGE
1. Are performance goals consistently achieved?
2. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2. Is Ion Exchange necessary within the plant configuration based on water quality analyses?
3. Has the correct resin been selected for the specific contaminant?
4. Are there formal procedures in place to regenerate the resin?
5. Are the reject streams properly managed?
6. Are individual units monitored for treatment performance?
7. Is the storage capacity for new resin sufficient taking into account maximum usage, procurement and availability of chemicals?
8. Is there sufficient standby capacity?
9. Any additional questions that the data may suggest or the investigator may have.

5.3.11 Membrane Filtration

Membranes provide a barrier to the flow of suspended, colloidal or dissolved species. MF and UF membrane technologies are alternatives to conventional treatment removing turbidity, pathogens and particulates from raw water. Nanofiltration is used to soften raw water and remove disinfection by-products. Reverse osmosis typically removes dissolved substances.

Table 5-11: Applicable Size Ranges for the Membrane Processes (Baruth, 2005)

Process	Typical Operating Pressure (kPa)	Typical Particle Size (microns)	Typical Molecular weight cut-off (Dalton)
Microfiltration	<100-500	0.0775-5.5	100,000-500,000
Ultrafiltration	70-700	0.00325-0.325	1,000-50,000
Nanofiltration	310-1,000	0.00-0.0325	200-500
Reverse Osmosis	1,000-10,000	0.0001-0.0055	100

Table 5-12: Other Typical Performance Indicators for Reverse Osmosis (American Water Works Association, 2007)

Process	Potable Water	Ground Water	Surface Water	Sea Water
Feed SDI	< 3	< 3	< 5	< 5
Feed Turbidity	< 0.3	< 0.3	< 0.3	< 0.3

Key parameters to be considered for the design and operation of membrane systems are membrane flux, water quality, temperature compensation, cross connection control and system reliability. Maintenance and monitoring of the integrity of the membrane, as well as proper cleaning and backwashing are key to optimisation of membrane operations. The integrity of the membrane is monitored by either direct or indirect monitoring. Indirect integrity monitoring, which includes turbidity and conductivity measurements, can be conducted continuously during filtration. Careful review of the data provides an early indication of potential problems. Direct integrity testing, including pressure decay rate, is implemented at regular intervals for MF and UF membranes. Control limits should be set for both direct and indirect integrity testing. Reference should be made to the supplier information.

IMPORTANT QUESTIONS TO ASK: MEMBRANE FILTRATION

1. Are the membranes' specific design guidelines known from supplier documentation?
2. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
3. Do inlet conditions allow for accurate flow division between duplicate units?
4. Have alert levels been set for indirect integrity testing and actions defined?
5. Are individual units monitored for treatment performance?
6. Is indirect integrity data reviewed and analysed by process controllers?
7. Does the direct integrity testing programme monitor efficiency of reduction of microbial contamination and pressure decay?
8. Is the integrity of membranes tested following repairs to the unit?
9. Are current SOPs implemented that describe routine maintenance and corrective actions to be taken?
10. Do process controllers have the correct monitoring equipment and tools to properly operate and maintain the unit?
11. Is debris that may damage the membranes effectively screened at the inlet to the unit?
12. Is the inlet water turbidity monitored to ensure that the water quality is optimal for the treatment performance of the membranes?
13. Are clean-in-place procedures modified to address variations in inlet water quality?

IMPORTANT QUESTIONS TO ASK: MEMBRANE FILTRATION	
14.	Are appropriately sized pressure sensors installed on each membrane unit to monitor changes?
15.	Do the trans-membrane pressures and other performance indicators correspond with supplier specifications?
16.	Are the brine streams monitored? What is the disposal/reuse of this stream?
17.	Are any energy recovery options employed at the plant? If not, can the additions be made?
18.	Are there enough stock holding, especially on long lead items?
19.	Any additional questions that the data may suggest or the investigator may have.

5.3.12 Conveyance on site

The capacity of pumped and gravity-based conveyance systems has been addressed under Step 2 of the assessment. The condition and integrity of pipes and canals substantially impact on the ability of the systems to deliver the required flows and need to be monitored.

IMPORTANT QUESTIONS TO ASK: CONVEYANCE ON SITE	
1.	Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2.	Have corrosion and scaling of the pipeline been controlled?
3.	Are the channels and pipes adequately sized for the maximum expected flow conditions?
4.	Is the equipment kept clean when not in use (e.g. emergency equipment) in order not to compromise water quality when brought into operation?
5.	Is there sufficient bypass capacity if required?
6.	Any additional questions that the data may suggest or the investigator may have.

5.3.13 Pump Stations

Pump stations are key components of a water treatment facility and must be carefully managed and assessed.

IMPORTANT QUESTIONS TO ASK: PUMP STATIONS	
1.	Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and actions implemented to correct the problem?
2.	Does the installed capacity exceed with the flow requirements as covered in the previous chapter?
3.	Is there sufficient standby capacity?
4.	Are all control functions operational?
5.	Have any on-site pump capacity tests been done on large pump stations?
6.	Are the pump curves for all pumps available?
7.	Do all flow meter installations comply with the installation requirements of the suppliers?
8.	Is the water hammer phenomena adequately addressed?
9.	Any additional questions that the data may suggest or the investigator may have.

5.3.14 Residuals Handling

The water treatment process removes suspended solids during sedimentation and filtration. Suspended solids can include clay and fine particulate matter, organic and inorganic precipitates, algae, bacteria and viruses which are present in the raw water (Van Duuren, 1997). Coagulation and flocculation add chemicals to the process which in turn also ends up in the sludge produced. RO and Ion exchange produce brine streams and reject streams containing chemicals and high concentration of substances removed from raw water. These residuals need to be handled and disposed of in a safe and economical manner. There are different methods of handling and disposing of these residual products. Inorganic wastes are normally concentrated and dewatered before disposal but organic wastes must be stabilized prior to disposal (Schutte, 2006). It is important to know the characteristics of the residuals as they vary according to their chemical nature. There are three aspects that need to be considered:

- Settleability and settling rate: This could cause problems with thickening and could require chemicals to enhance thickening.
- Suspended solids concentration: This should be as high as possible to minimize water loss but low enough not to cause pumping and handling problems
- Chemical and Bacterial quality of residuals: Raw water could contain high amounts of algae which will in turn result in large amounts of organic material in residuals. Anaerobic conditions may adversely impact the sludge characteristics.

Treatment processes for residuals include:

- Lagoons,
- Drying beds,
- Gravity thickening,
- Dissolved air flotation;
- Centrifuge;
- Vacuum filtration and belt filters, and
- Filter presses

The large variation in sludge thickening and dewatering technologies used make directly relates to a large variation in design and operational requirement. The detail of which will not be discussed here. Each of these processes has their advantages and limitations. A plant should employ the most economical and safe technology available to it for residuals handling depending on the land the site has available, capital cost vs. operational cost, and reliability. The assessment of the specific infrastructure installed at the plant must follow the expected requirements of the particular installation. The supplier of the equipment must provide the performance requirements where proprietary technology is used. Ultimately the residuals need to be disposed of in a sustainable manner. Disposal back to the source will normally not be permitted in South Africa (Schutte, 2006). Residuals can be disposed to a wastewater treatment works if it can accommodate the load and conveyance is possible. Dewatered sludge can be sent to an approved landfill site. Ideally beneficiation of the sludge must be considered. It would be the goal to reduce the residuals and supernatant water as far as possible within the capability of the plant and resources. Reuse of the supernatant water is a further goal but this must be considered it terms the economic and water quality implications of such activities. The absence of legislation specifically governing the management of water treatment residues is one of the biggest challenges faced by the water sector nationally and consequently the disposal of solid waste is currently regulated by a group of general standards/criteria that may not be appropriate for water treatment residue disposal (Mokonyama et al., 2016). A report was therefore prepared under guidance of the Water Research Commission titled "Guidelines and Good Practices for Water Treatment Residues Handling, Disposal and Reuse in South Africa (Mokonyama et al., 2016) which can be used as a reference point for the assessment of current residuals handling practices.

The current disposal options for treatment residues are as follows (Mokonyama et al., 2016):

- Land application to agricultural land, forests and for land reclamation;
- On-site disposal on dedicated land or in lagoons;
- Off-site disposal on landfill including:
  - Co-disposal with municipal solid waste;
  - Use as daily landfill cover;
  - Mono-disposal of treatment residues; and
  - Co-disposal with wastewater sludge.
- Discharge of treatment residues to a wastewater treatment works via sewer line
- Treatment residue reuse – although treatment residues do not have the inherent fertilizer value of wastewater sludge, the following reuse alternatives can be considered:
  - Recovery of coagulants; and
  - Use in making bricks and Portland cement (high solids).
- The direct discharge to source stream is not encouraged since it is not an environmentally responsible management option.

In all cases some form of regulatory approval is needed (Mokonyama et al., 2016). These may include:

- Waste Management Licences or
- Discharge Permits.

IMPORTANT QUESTIONS TO ASK: RESIDUALS HANDLING

1. Does the plant have proper/relevant residuals handling infrastructure, processes and procedures?
2. Do the current handling, disposal, and reuse practices conform to the recommendations of guideline documents (Mokonyama et al., 2016)?
3. Are there key pieces of equipment that are out of service and impact on performance? Has the reason for their disrepair been identified and have actions been implemented to correct the problem?
4. Are all chemical dosing systems, if required for the system, installed and operational?
5. Are all delivery pumps, recovery pumps and related monitoring and control equipment installed and operational?
6. Has residual production been quantified and are the key drivers for residual production known?
7. Is there sufficient storage capacity?
8. Are the process controllers optimizing residual reduction?
9. Are the residuals disposed of in a safe, economical and environmentally acceptable manner?
10. Are the regulatory requirements for residual disposal known for the particular site and are the requirements met?
11. Any additional questions that the data may suggest or the investigator may have.

5.3.15 Energy Consumption

Energy consumption is a focus area for optimisation studies at water treatment plants. Energy costs significantly contribute to the cost of water production and delivery. Pumping activities comprise the largest cost item. Ageing equipment will reduce energy efficiency. In addition, with the use of more advanced treatment technologies, the energy component is increasing. SALGA estimates that water and wastewater can account for about 35% of a typical energy cost of an organisation (Mander & Van Niekerk, 2014). Typical ranges for energy consumption for conventional drinking water production are reported to be as per the table below. The energy consumption rates for membrane processes, particularly reverse osmosis plants, are substantially higher. Information from a recent South African Cities Network Study indicates that a treatment works can reduce energy consumption by 5% through installation of energy efficient motors and by a further 15% through installing variable speed drives. (Mander & Van Niekerk, 2014)

Data compiled through the AWWA benchmarking programme, established the range of energy consumption for water operations to range from 294-783 kWh/Ml with a median value of 485 kWh/Ml (American Water Works Association, 2016). Information on current energy consumption at a specific treatment plant is a pre-requisite to understanding the potential for energy efficiency initiatives.

Table 5-13: Energy consumption range for the South African water supply chain for conventional treatment plants (Mander & Van Niekerk, 2014)

Process	Minimum (kWh/Ml)	Maximum (kWh/Ml)
Abstraction	0	100
Distribution	0	350
Treatment	150	650
Reticulation	0	350

IMPORTANT QUESTIONS TO ASK: ENERGY CONSUMPTION

1. Is energy consumption at the treatment plant level recorded?
2. Is the energy cost to produce 1 Ml of water known?
3 Has an energy audit been undertaken on each process unit to identify which components consume energy?
4. Have opportunities to reduce energy consumption been identified?
5. Have any energy targets been set?
6. Has an energy efficiency strategy been developed?
7. Is management aware of the actual energy consumption of the plant?

5.4 SUMMARY

At the conclusion of the major unit performance assessment, the installed process units have been assessed to establish whether the design or condition of the equipment is adequate to consistently meet the performance goals. More specifically the following information is available:

- The performance of each process units against the set targets which is evaluated for trends and compliance.
- The key process units that are limiting optimised performance due to design issues or condition of the equipment.
- Process units that could be optimised by consideration of other performance limiting factors.
- Process units whose design or condition is categorised as inadequate and may need to be refurbished or upgraded.

CHAPTER 6: OPERATIONAL ASSESSMENT

STEP 4 – PERFORM AN ASSESSMENT OF OPERATIONS
Determine if operational practices are limiting performance

6.1 INTRODUCTION

Regulatory compliance and the ability to optimise operations and treatment performance are dependent on proper operations. Although the outcome of the performance evaluation and design assessment may have verified the capability of all process units, performance limiting factors may be identified within operations. This chapter presents a number of operational aspects that significantly impact on the performance of the water treatment plant, the ability to optimise operations and achievement of the ultimate goal of high quality water. Operational factors include the approach taken to the optimisation and control of the various process units. Key factors include the operational procedures and performance goal setting, process control sampling and testing, understanding and application of control concepts and communication protocols. There are strong links between the assessment of operational systems of a plant and the assessment of administrative related issues, which are considered in the next chapter.

6.2 OPERATIONAL PROCEDURES

Implementation of the correct operational procedures that are relevant to the installed infrastructure and which are understood by all process controllers is key to optimised performance. The development and implementation of standard operating procedures (SOPs) provide process controllers with the information to perform a job properly and consistently, minimising individual interpretation and miscommunication. Standard operating procedures should be available for each process unit. The SOPs must be informed by the O&M manual, which is the reference document for the treatment plant. The operational procedures should describe instructions for operation and control tasks, the performance goals, the control philosophy, testing regime and emergency procedures. All process controllers should be trained on an ongoing basis on the implementation of the standard operating procedures.

IMPORTANT QUESTIONS TO ASK: OPERATIONAL PROCEDURES

1. Is an O&M manual available at the plant that is relevant to the current plant configuration? Do process controllers have unrestricted access?
2. Are process controllers aware of the contents of the O&M manual?
3. Are relevant SOPs readily available and visible at each process unit? For example, are the instructions on filter backwashing visible from the control panel where the relevant equipment is operated?
4. Have SOPs been developed and implemented for each process unit?
5. Are SOPs regularly reviewed to test relevance?
6. Do process controllers have a formal feedback loop in place to report on SOPs which do not work, cannot be executed as stated, or are no longer relevant?
7. Are process controllers provided with on-site training on the implementation of the SOPs?

IMPORTANT QUESTIONS TO ASK: OPERATIONAL PROCEDURES

8. Do the SOPs provide direction on process operation and tasks, control systems, monitoring requirements, and emergency procedures?
9. Is progress towards improved SOP compliance being monitored?
10. Any additional questions that the data may suggest or the investigator may have.

6.3 PROCESS PERFORMANCE GOALS AND CONTROL TESTING

In order for a plant to meet the goal of producing high quality water consistently, each process unit must operate properly. This can only be monitored if the quality of raw water and performance of each process unit is routinely measured, recorded and interpreted against set targets. Based on this information, the correct process controls and adjustments must be implemented to ensure high quality water is produced. Achievement of performance goals and the need for adjustment should be monitored through the development and implementation of a water quality monitoring programme. The monitoring plan must be drawn up in line with the requirements of SANS 241 and in line with other relevant guideline such as those published by Swartz et al. (2015) who proposed monitoring systems which make provision for early detection of deteriorating incoming raw water quality, rapid changes in the raw water quality, maintenance of treatment barriers in the plant through setting of operational alert levels for the various unit treatment processes in the plant, and compliance of the final water quality with adopted local and international norms and standards.

Effective monitoring is dependent upon the availability of reliable equipment which is maintained, verified and calibrated and correctly operated to ensure accuracy of data. Correct sampling procedures and management of samples before analysis is also critical. Where samples are analysed by an off-site laboratory, protocols should be implemented to ensure that samples are properly managed and that data is communicated timeously to process controllers. The frequency of monitoring is dependent on the impact of the variable on process performance and the variability in the level of determinand. SANS 241 sets out minimum frequencies for some operational parameters. Online monitoring is of benefit for critical processes such as individual filter turbidity values. Increased frequencies may be required where seasonal variations in raw water quality are experienced. The performance control testing strategy should be formally documented and be reviewed and revised as required. All data must be correctly recorded and maintained and be available for review by process controllers and management. Compilation of trend charts assist in interpretation of data and identify the need for adjustments to be made to process controls. Progress towards achieving performance goals for each process unit should be monitored by assessing the number of non-compliant samples as a percentage of the total number of samples analysed. Compliance to the internal water quality performance goals can be calculated as follows:

$$Performance\ goal\ compliance\ (\%) = \frac{Number\ of\ samples\ in\ full\ compliance}{Total\ Number\ of\ samples\ analysed}$$

IMPORTANT QUESTIONS TO ASK: PERFORMANCE GOALS AND CONTROL TESTING

1. Have performance goals been set for each process unit?
2. Have procedures been developed that link analytical results with actions? Is implementation monitored on an ongoing basis?
3. Is a monitoring programme available that meets regulatory compliance and process optimisation goals?
4. Does the monitoring and reporting strategy meet the requirements of national guidelines (Swartz et al., 2015)?
5. Is sampling and sample preservation carried out according to the SANS 5667 series of documents on the sampling and handling of water samples before reaching the laboratory?
6. Are process controllers trained on sampling techniques and are they subjected to ongoing formal or informal re-certification?

IMPORTANT QUESTIONS TO ASK: PERFORMANCE GOALS AND CONTROL TESTING	
7.	Does the laboratory ensure its results are credible by maintaining SANAS accreditation or participating in an inter-laboratory comparison or benchmarking programme?
8.	Is online equipment calibrated according to supplier recommendations?
9.	Are the results generated by online monitoring equipment verified against manual sampling and analysis on at least a daily basis?
10.	Are process controllers and support staff trained in the use of analytical equipment and the reading of on-line monitoring? Is there an ongoing formal or informal re-certification process in place?
11.	Is data recorded correctly and maintained in a format that is available to all process controllers and management?
12.	Are trend graphs developed for quick review and correlation with daily operation?
13.	Is compliance to the performance goals calculated on an ongoing basis and are negative trends or non-compliant performances investigated and corrected timeously?
14.	Any additional questions that the data may suggest or the investigator may have.

6.4 PROCESS CONTROLLER UNDERSTANDING AND APPLICATION OF CONTROL CONCEPTS

Process controllers must be able to interpret water quality data and be confident to make the necessary changes to process unit operation to ensure performance goals are met. Process controllers must be vigilant of possible changes in raw water quality and the impact that this may have on plant performance. Refresher training should be implemented regularly to ensure that the knowledge and skills of the process controllers remain appropriate.

IMPORTANT QUESTIONS TO ASK: PROCESS CONTROLLER'S UNDERSTANDING AND APPLICATION OF CONTROL CONCEPTS	
1.	Is there a documented fault-finding strategy in place? Does this include the necessary triggers for escalation?
2.	Are all process controllers able to investigate potential causes for poor performance and to implement the corrective actions according to an appropriate fault-finding strategy?
3.	Are process controllers able to proactively implement corrective actions or do they rely on supervisory staff to tell them what to do?
4.	Do process controllers have the knowledge, skills and ability to investigate alternative procedures?
5.	Are process controllers able to demonstrate that they can conduct a coagulant control test?
6.	Can process controllers undertake the necessary calculations to make adjustments to chemical dosing rates?
7.	Is a formal incident management protocol implemented? Have process controllers and support staff been trained on the implementation of the IMP?
8.	Any additional questions that the data may suggest or the investigator may have.

6.5 COMMUNICATION

Effective dissemination of information throughout the organisation is essential. Communication channels may be horizontal or vertical between management and process controllers. Communication may be formal such as written documents, reports and meetings or informal such as that used in daily operations. Verification of comprehension and a proper interpretation of the information will ensure a uniform understanding of instructions and actions.

IMPORTANT QUESTIONS TO ASK: COMMUNICATION

1. Has a formal communication protocol been developed and implemented?
2. Is disseminated information easily accessible to process controllers and other support staff?
3. Are regular planned meetings with formal agendas held across all responsibility levels?
4. Is there a mechanism to ensure that information is exchanged between shifts?
5. Do process controllers and supervisors meet regularly?
6. Are process controllers made aware of maintenance activities?
7. Is operating information recorded and available to all staff?
8. How is comprehension of information by all staff verified by management and supervisors?
9. Any additional questions that the data may suggest or the investigator may have.

6.6 SUMMARY

At the conclusion of the operational assessment, performance limiting factors related to operations have been identified. More specifically the following information is available:

- The understanding by process controllers of the standard operating procedures and whether they are able to implement the required process changes.
- The effectiveness of the monitoring programme and the ability of process controllers and support staff to interpret analytical data.
- Communication channels available within the organisation to ensure exchange of information and instruction vertically and horizontally.
- Mechanisms implemented to ensure that data and information is accessible and comprehended by all process controllers and support staff to ensure correct interpretation.

CHAPTER 7: ADMINISTRATIVE ASSESSMENT

STEP 5 – PERFORM AN ASSESSMENT OF ADMINISTRATION
Determine if administrative practices are limiting performance

7.1 INTRODUCTION

It is the responsibility of the Water Service Institution to meet all the legal requirements that apply to the supply of drinking water. The process controller is responsible for the day-to-day operation and technical activities of the plant. It is therefore important that both parties work together to ensure that high quality water is supplied. Administrative practises can significantly impact on the ability to optimise operations and performance. Demonstrated commitment to excellence at all levels, including upper management, within the organisation is essential. Administrators must be aware of the risk to human health should the plant not be capable of producing high quality water, as well as the need for all process units to operate properly and consistently. Lowering treatment costs should not be done at the expense of water quality. This chapter highlights the core administrative functions within an organisation that can be performance limiting factors. Implementation of good management principles will create an enabling environment that facilitates sound operations. The focus areas that are considered include the administrative polices of the organisation, human resources, funding, asset management, procurement and customer services. The impact of administrative performance limiting factors is more difficult to define than assessing issues such as hydraulic capacity and design limitations. Guidance has been provided on best practice management tools that promote a strong organisation, as well as performance indicators that could be applied to monitor progress towards optimisation.

Currently, limited performance indicators have been developed within the South African 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. However, as the benefits of benchmarking are recognised by water services institutions, it is expected that more specific and focused performance indicators that are relevant to water treatment will be developed and implemented in South Africa.

7.2 ADMINISTRATIVE POLICIES

It is the role of the administrator to develop the environment within which excellence in water quality provision is promoted. The supply of high quality water should be identified as the highest priority and be documented in the overall goal of the organisation. This should be communicated throughout all levels within the organisation.
Best practice operations should include strategic plans, long-term financial plans, risk management plans, performance measurement systems, asset management programme, customer services programme and continuous improvement programme.

IMPORTANT QUESTIONS TO ASK: ADMINISTRATIVE POLICIES

1. Is there a commitment to excellence and best practices implemented within the organisation?
2. Does the mission statement of the organisation prioritise the supply of high quality water? Is this communicated to all levels within the organisation?
3. Does the strategic planning process include financial planning, future facility planning, capital replacement plans, and water quality master plans?
4. Have external and internal factors been identified that will impact on the performance of the organisation?
5. Has a longer-term financial plan been developed that considers projected income and capex and opex expenditure?
6. Has a performance measurement system been developed and implemented that focuses on quality, efficiency and effectiveness?
7. Are water quality objectives prioritised before quantity issues are addressed?
8. Do administrators have an awareness of the current and future regulatory framework to inform the development of long-term plans to ensure compliance?
9. Any additional questions that the data may suggest or the investigator may have.

7.3 STAFF MANAGEMENT

7.3.1 Regulatory Compliance

The DWS requirements in respect to staffing of potable water treatment plant are mandatory and must be adhered to. In cases where this is not possible, the express authorisation for this must be obtained from the Department. This requirement is however a minimum requirement and the remainder of this section will consider additional human resources related requirements.

7.3.2 Staffing Levels and Staffing Distribution

Maintaining staffing levels compliant with regulatory requirements (Regulation 2834 and Draft Regulation 813) is non-negotiable. Compliance with this requirement is assumed as a baseline in this section. Shift patterns should take into account staffing requirements to ensure continuous operation and maintenance. To meet the objective of sustainable provision of safe water, adequate staffing levels must be maintained to undertake all tasks. The measure of efficiency can be monitored by the ratio of water produced per employee.

$$Ml\ per\ employee\ (for\ plants\ over\ 10\ Ml/d) = \frac{Average\ daily\ production}{Number\ of\ full\ time\ site\ based\ employees}$$

AWWA benchmarking values indicate water production per employee (across all disciplines) to range between 0.5-1.0 Ml/employee with a median of 0.7Ml/employee (American Water Works Association, 2016). Care should however be employed in using this figure as a benchmark as it does not respond to the minimum staffing levels required by DWS. The regulatory requirement will supersede this benchmark. The above guideline may not be appropriate in the South African context and a local guideline must be developed. Its development may be based on the following indicators (the indicators may also be used as an interim indicator of staff shortages):

- For process control staff – overtime hours spent to complete the basic operational function, and
- For maintenance staff – overtime hours as well as aging on preventative and reactive maintenance works orders.

The organisational structure must include various disciplines and skills mix to meet the range of tasks that are required. This includes the appropriate balance between managers, technical and administration/support staff. Process investigators can evaluate the existing organogram and assess whether key functions are appropriately addressed. Although this should be evaluated within the specific operating environment, guidance can be taken from the results of the AWWA benchmarking programme that evaluated the percentage of staffing levels within a water utility (American Water Works Association, 2016).

Table 7-1: Percentage of staffing levels (American Water Works Association, 2016)

Function	Range Staffing Levels (%)	Median Staffing Levels (%)
Operations and maintenance	43-59	49
Engineering	2.4-12	7.3
Customer Services	10-29	16
Human resources	0-2.4	1.1
Admin/legal	0.3-4.9	2.4
Finance	2.6-6.0	3.9
Support services	1.4-21.1	9.2

National Treasury has defined that renumeration should be between 25% to 40% of total operating expendiure (National Treasury, 2014).

7.3.3 Staff Retention

Staff retention policies are important to maintain institutional memory and experience within the organisation and facilitate regulatory compliance. Monitoring of staff turnover within a defined timeframe will establish whether this issue needs specific intervention.

$$Employee\ turnover\ (\%) = \frac{Number\ of\ employee\ departures}{Total\ Number\ of\ employees}$$

AWWA (2016) benchmarking values indicate staff turnover to range between 5.8-9.6% with a median of 6.8% (American Water Works Association, 2016).

7.3.4 Staff Training

The development and implementation of a training programme is a critical component of plant optimisation. All employees should receive regular training on health and safety, regulatory issues, operational procedures and emergency response. Levels of training can be monitored by assessing the number of training hours provided per employee per year.

$$Training\ (hrs\ per\ employee) = \frac{Total\ number\ of\ training\ hours\ completed\ by\ all\ employees\ in\ one\ year}{Total\ Number\ of\ hours\ worked\ by\ all\ employees\ in\ one\ year}$$

AWWA (2016) benchmarking values indicate training hours range from 13.3 to 28.1 hours per employee per year with a median of 19.9 hours (American Water Works Association, 2016). This can be further refined by considering for example only training provided on emergency response readiness, which would include training on incident management as set out in the IMP.

7.3.5 Staff Safety

Safety of the site staff and process controllers is paramount to the operation of the treatment plant. The site should be well secured to prevent uncontrolled access which may result in physical harm to staff, as well as theft and vandalism. Process controllers will only be able to work efficiently if appropriate facilities are available including an office, laboratory area, and kitchen and ablution facilities. Availability of personal protective equipment and safety equipment and training on their use is essential to enable proper operations.

7.3.6 Staff Performance Management

Staff performance can be a significant challenge at some plants and initiatives to monitor staff performance must be considered as critical in the overall review of the human resources function.

7.3.7 Summary of the HR Function

The following questions can be used to lead a discussion on the issues raised in this section.

IMPORTANT QUESTIONS TO ASK: HUMAN RESOURCES	
1.	Does the organisational structure support the objective of achieving sustainable water quality goals?
2	Do the number and classification of process controllers comply with the relevant Regulations?
3.	Is staff participation in professional organisations supported?
4.	Are there procedures in place to ensure that employees receive appropriate training?
5.	Is the plant routinely operated in the absence of staff?
6.	Is staff performance managed?
7.	Are job descriptions available for all staff and are they aware of their duties and responsibilities?
8.	Does staff have access to an office, laboratory, kitchen and ablutions facilities?
9.	Does staff have access to appropriate personal protective equipment and safety equipment? Do they receive regular training on its use?
10.	Are safety railings provided where necessary?
11.	Is the site secure to prevent uncontrolled access?
12.	Have there been any incidents of vandalism, theft or attacks on process controllers?
13.	Have emergency showers, eye wash and bunded area been provided at chemical dosing stations?
14	Do process controllers have the authority to make the required operations, maintenance and administrative decisions?
15.	Are regular meetings held where issues related to operations and water quality are discussed?
16.	Do administrators have first-hand knowledge of the plant through site visits or discussions with staff?
17.	Do process controllers have support of management to make the necessary process adjustments?
18.	Any additional questions that the data may suggest or the investigator may have.

7.4 ASSET MANAGEMENT

7.4.1 Maintenance

Implementation of asset management practises ensures the most cost effective delivery of drinking water. Maintenance of equipment will reduce breakdowns, extend life and defer capex and ensure consistent plant performance. Routine or planned maintenance minimises unforeseen disruptions and “down-time”. An asset management system will assist in scheduling preventative maintenance and prioritising replacement needs and budget requirements. The responsibility for the management of assets within a public service water utility, including their maintenance, is allocated to the accounting office in terms of the Public Finance Management Act (South African Goverment, 2016) and the Municipal Finance Management Act (South African Goverment, 2003). Reactive maintenance when equipment fails is characterised by the inability to plan and budget for the work and a poor use of resources. The goal should be to reduce emergency maintenance by undertaking preventative maintenance and optimise operations costs. There are a number of guidelines available with regard to allocation of maintenance expenditure. In the Budget Speech 22 February 2017, Minister Gordhan stated that National Treasury and provincial treasuries have agreed on adherence of 8% of the value of the asset should be spent on maintenance. In a separate and older benchmark by DWS, a lower requirement is indicated (Department of Water Affairs and Forestry, 2004). This is summarised in the table below.

Table 7-2: Guideline Maintenance Budget (Department of Water Affairs and Forestry, 2004)

Asset	Reference cost (Current replacement value)	Maintenance budget percentage
Pipelines	Pipeline cost	0.5% per annum
Civil structures	Civil cost	0.25% per annum
Mechanical equipment	Mechanical installation cost	4% per annum
Electrical equipment	Electrical installation cost	4% per annum

AWWA performance indicators to benchmark maintenance performance consider time for both planned and reactive activities are indicated in the table below:

Table 7-3: AWWA Maintenance Benchmarks (American Water Works Association, 2016)

Description	Formula	Benchmark	
		Range	Median
Planned maintenance ratio	$\frac{\text{Total time for planned maintenance}}{\text{Time for planned + reactive maintenance}}$	29-67%	44%
Reactive maintenance to production (hr/Ml)	$\frac{\text{Total time for reactive maintenance}}{\text{Average daily production x 365}}$	0.16-0.53	0.24
Planned maintenance to production (hr/Ml)	$\frac{\text{Total time for planned maintenance}}{\text{Average daily production x 365}}$	0.05-0.74	0.35

7.4.2 Asset Renewal

Adequate budget must be allocated for asset renewal. Depreciation guidelines provide a good indicator of replacement cycles as life cycle depreciation costs of assets should be calculated on actual consumption of the current replacement value (brown field not greenfield) (Childs, 2017) and not be based on historic costs. The following guidelines on life cycle costs are published locally:

Table 7-4: Lifecycle discount rates for assets (Boshoff et al., n.d.)

Item	Benchmark	
	CoGTA	DWS
Design life	20 years	-
Concrete structures	5%/year	30 years / 3.3% p.a.
Steel structures and steel pipelines	8%/year	30 years / 3.3% p.a.
Electric motors and switchgear	10%/year	15 years / 6.7% p.a.6.7%
Mechanical equipment	8%/year	15 years / 6.7% p.a.
Electronic equipment	15%/year	-

National Treasury has set out a number of financial ratios and norms to benchmark performance (National Treasury, 2014) . Asset management is monitored according to the following ratio:

$$\frac{Total\ capital\ expenditure}{Total\ expenditure\ (total\ operating\ and\ capital\ expendture}\ x\ 100$$

The norm range is between 10% and 20% with the upper value being proposed as the benchmark for water in the SALGA MBI annual report (SALGA, WRC, IMESA, MBI, 2015). AWWA benchmarks were compiled for system renewal and replacement expenditure as a percentage of the total renewal and replacement needs which were estimated through an asset management programme.

Table 7-5: Replacement and renewal expenditure as a percentage of total plant value (American Water Works Association, 2016)

Infrastructure	Benchmark	
	Range	Median
Water supply	0.3-2.5%	1.2%
Water Treatment	0.5-1.6%	1.0%
Water pump stations	0.6-2.8%	1.5%

7.4.3 Asset Maintenance Plan

A detailed maintenance manual should be available that sets out regular maintenance requirements for all process units. Equipment critical to operation should be identified. Key spare parts should be readily available to allow repairs to be undertaken immediately. Adequately skilled maintenance personnel must be available in accordance with regulatory requirements (Reg.2834, Draft Reg.813). The personnel should be equipped with appropriate tools.

IMPORTANT QUESTIONS TO ASK: ASSET MANAGEMENT

1. Has an asset register been developed for the plant that lists all equipment and infrastructure?
2. Does the register include the information regarding location, description, condition, life expectancy, value and replacement value of the asset?
3. Has the asset register been used to develop a preventative maintenance schedule and to project capex requirements?
4. Are funding requirements captured in the Opex and Capex budgets?
5. Do the number and competency of maintenance personnel comply with the relevant Regulations?
6. Where external service providers are appointed, has competency to meet maintenance requirements been verified?
7. Is a detailed maintenance manual available? Are all process units included?
8. Is a preventative maintenance plan available and implemented? Are all tasks defined?
9. Are maintenance service records maintained?
10. Has critical equipment been identified? Are key spare parts available on-site or can be easily accessed in an emergency?
11. Any additional questions that the data may suggest or the investigator may have.

7.5 FUNDING

Capital and operating costs should be included in the budget. The budget should include recurrent costs to deliver water and projected capital expenditure to meet strategic planning projections. Operating expenses include items such as salaries, supplies, treatment chemicals, consumables, laboratory fees, minor repairs and regular maintenance. Regular maintenance costs should be informed by an asset management register. Operational and maintenance costs should be separately captured for each treatment facility to facilitate monitoring of trends in expenditure and treatment performance and to benchmark against values for similar facilities. Actual expenditure should be assessed against budget allocations. The Blue Drop programme benchmarks maintenance expenditure as more than 5% of the operational expenditure. The actual cost for producing water (R/Ml) should be regularly monitored to identify opportunities for further optimisation initiatives, as well as for monitoring the impact of initiatives already implemented. This value will also inform the budgeting process and assist the organisation to implement an actual cost reflective tariff. The table below will assist in evaluating the results of the analysis of operating expenses.

Table 7-6: South African Bulk Water Tariffs, Production Cost and Cost Breakdowns (Thompson, 2017)

Production Cost	Low value	Middle range	High value
Production cost per kl (2017 base year)	R 3,89	R 4.28 - R 4,48	R 5,63
Bulk tariffs (2017 base year)	R 5,14	R 6,23 - R 7,14	R 8,79
Cost breakdown			
Chemicals	3,1%	3,5% - 3,8%	4,6%
Staff Costs	18,8%	22,2% - 26,2%	30,9%
Raw Water	7,7%	8,6% - 9,4%	13,8%
Maintenance	3,4%	9,7% - 11,2%	12,9%
Energy	5,8%	8,3% - 8,8%	20,1%
Depreciation	6,9%	7,9% - 9,2%	14,0%
Other (including distribution cost, other operating expenses, finance expenses and impairment of trade receivables)	12,1%	26,0% - 34,6%	40,3%

IMPORTANT QUESTIONS TO ASK: Funding

1. Do budget allocations meet operational and maintenance demands?
2. Does the actual expenditure on operations and maintenance meet the budget allocation?
3. Does O&M expenditure exceed budget allocations?
4. Are budgets developed on the basis of true O&M costs or is a percentage increase allocated each year?
5. Are O&M budgets ring-fenced?
6. Has capex been allocated to meet current and future water demands and quality requirements?
7. Are there backlogs of refurbishment and maintenance work?
8. Are water tariffs informed by actual O&M expenditure and future needs?
9. Any additional questions that the data may suggest or the investigator may have.
10. Are water tariffs informed by actual O&M expenditure and future needs?

7.6 PROCUREMENT

The role of supply chain management as a key department within an organisation should be assessed to establish whether any practises are performance limiting factors. The public utility procurement process is regulated by the Municipal Finance Management Act and associated regulations. Procurement procedures are prescribed which must be taken into account within the operating environment of a water treatment works.

<u>IMPORTANT QUESTIONS TO ASK: PROCUREMENT</u>

1. Do financial officials participate in the planning and management processes of water production?
2. Are formal procedures in place at the WTP to guarantee continuity of supply of chemicals?
3. Has provision been made for emergency maintenance requirements for identified key equipment?
4. Is there any agreement regarding timeframes to respond to maintenance requirements?
5. Are chemical supplies stored at the treatment plant sufficient to supply more than 30 days' consumption?
6. Is chemical consumption monitored at the treatment plant to ensure timeous order and supply?
7. Any additional questions that the data may suggest or the investigator may have.

7.7 CUSTOMER SERVICES

Customer management initiatives are important factors in meeting expectations of service delivery. Appropriate communication channels enable monitoring of the reliability and quality of the service. Funding of the organisation is dependent on the satisfaction of customers and their willingness to pay for the service. The mission of the organisation to provide high quality water should flow down from senior management and through to the customer. Customers should be aware of the quality of water that they are receiving and receive response where issues of concern are raised.

7.7.1 Customer satisfaction

Customer satisfaction that is relevant to the water treatment process can be monitored by the number of complaints received about water quality as well as the number of planned and unplanned disruptions to water production. Water quality complaints can be related to the population served in the community.

$$WQ\ Customer\ complaints\ = \frac{Number\ of\ complaints}{Population\ served}$$

7.7.2 Unplanned disruption

Planned or unplanned disruptions can be categorised according to operations or maintenance factors, as well as the time taken to resolve, such as < 4hours, 4-12 hours or > 12 hours.

7.7.3 Per Capita Consumption

Monitoring of consumption per capita enables the organisation to identify trends in water demands and opportunities to implement water conservation initiatives.

$$Consumption\ (Ml\ per\ capita\ per\ day)\ = \frac{Total\ average\ daily\ production}{Population\ served}$$

Domestic consumption can be calculated to refine gathering of baseline information.

$$Domestic\ consumption\ (Ml\ per\ capita\ per\ day) = \frac{Total\ residential\ sales\ per\ annum}{Population\ served}$$

The table below includes the average per capita consumption of water as calculated through the No Drop programme and the SALGA MBI, as well as the target consumption value. The international value as per the No Drop benchmark programme is included for comparison.

Table 7-7: Per Capita Water Consumption (Department of Water and Sanitation, 2016) (SALGA, WRC, IMESA, MBI, 2015)

Description	Benchmark	
	Current Average	Best Practice
DWS National Weighted Consumption per capita (l/person/day)	252	< 150
SALGA MIB Study of 66% WSA consumption per capita (l/person/day)	199	175
International Consumption per capita (l/person/day)	180	-

IMPORTANT QUESTIONS TO ASK: CUSTOMER SERVICES	
1.	Is there a formal communication strategy for communicating water quality and supply information to consumers?
2.	Is the water quality and supply information presented in various media and accessible to consumers?
3.	Any additional questions that the data may suggest or the investigator may have.

7.8 SUMMARY

At the conclusion of the administrative assessment, performance limiting factors related to the administration practises of the organisation have been identified. More specifically the following information is available:

- The adequacy of the policies and systems of the organisation to facilitate the delivery of sustainable high quality water that meets both the current and future demands.
- The compliance of the staffing complement with regulatory requirements and the effectiveness of the skills set to meet all responsibilities.
- The approach to the management of assets and whether plant breakdowns are mitigated.
- The adequacy of the mechanism to develop and implement operating and capital budgets.

CHAPTER 8: PRIORITISATION OF COMPREHENSIVE LIST OF FACTORS LIMITING PERFORMANCE

STEP 6 – COMPILE A COMPREHENSIVE LIST OF PERFORMANCE LIMITING FACTORS Determine activities to address factors that will improve performance

8.1 INTRODUCTION

Once the self-assessment process has been completed, the performance limiting factors need to be prioritised to provide a roadmap towards optimisation. The findings and recommendations from an optimisation study can be prioritised based on the priorities of the Water Service Institution and process controller of the plant and their internal requirements. However, the prioritisation process of performance limiting factors identified during a process audit is prescribed by Regulation. The discussion on prioritisation of the findings of the process optimisation study and the process audit are therefore presented below in separate sections.

8.2 Process Audit Action Plan

The performance limiting factors identified through audit should be incorporated into a Water Safety Plan (WSP) in order to ensure that all the hazards are equally evaluated and prioritised accordingly (Coetzee et al., 2011).
Although this Guideline does not focus on the Water Safety Plan, the concept of the planning process includes prioritisation of the risks as high, medium and low level and includes their mitigation. Within the Blue Drop Certification Programme, the Water Safety Plan sets out the water services strategy of an organisation. The key question that is posed during the development of a Water Safety Plan is:

> *"What can potentially go wrong at the plant that will detrimentally impact on its ability to achieve the performance goals, and are the current mitigation measures sufficient to manage the risks at acceptable levels?"*

Key inputs into the WSP are the findings of the process audit, as well as other information on plant performance and associated hazards. Current and additional mitigation measures are identified for each hazard. The effectiveness of mitigation is monitored through the improvement in the condition and performance of the plant and reduction in the level of risk. The impacts are assessed during the next process audit and the findings incorporated into the updated WSP. This cyclical approach to risk management allows for a process of continuous improvement. It is important to note that the process is never complete and continues indefinitely. More importantly, process auditing is an ongoing process and although the Blue Drop certification programme requires audit reports to be issued annually or bi-annually, the fundamentals can be implemented every day.
The DWS has and will continue to increase its focus on the use of risk abatement to influence business decisions, determine priorities and (re)allocate resources, in order to achieve regulatory compliance and best practice (Department of Water and Sanitation, 2014). Risk-based planning allows an organisation to identify and prioritise the critical risk areas within its drinking water treatment process and to take corrective measures to rectify or abate them.

8.2.1 How to Score Risks

The hazards identified through the assessment process (Steps 1-5) are analysed to determine the level of risk it presents to the production of safe drinking water. Two criteria are applied, namely the frequency of the occurrence and the severity of the consequence. Numerical values are allocated to each criterion. The table below gives an example of a scoring system that can be used for the Frequency of Occurrence (expressed as Probability / Likelihood) and the severity (expressed as Impact / Consequence). The risk score is calculated by multiplying the probability score with the impact score.

Table 8-1: Risk Rating Scoring for the Water Safety Plan (WSP)

Risk Rating Scoring*					
Probability/ Likelihood			**Impact/ Consequence**		
Category	**Definition**	**Score**	**Category**	**Definition**	**Score**
Almost certain	Once per day	5	Catastrophic	Public health concern	25
Likely	Once per week	4	Major	Regulatory impact	20
Moderately likely	Once per month	3	Moderate	Aesthetic impact	15
Unlikely	Once per year	2	Minor	Compliance impact	10
Rare	Once every 5 years	1	Insignificant	No impact / not detectable	5

**Adapted from the 2013 Blue Drop and No Drop Handbook (Department of Water and Sanitation, 2013)*

As an example:

- The chlorine supplier is unreliable and usually delivers chlorine once per month: *Probability Score = 3*.
- The impact of supplying water that is not disinfected is catastrophic as people could become gravely ill or die. *Impact score = 25*.

By multiplying the probability score with impact score, a risk rating is calculated as is indicated in the table. The risk rating for the example above will be 3 x 25 = 75 which his falls into the "high risk" category.

Table 8-2: A typical WSP risk rating table*

PROBABILITY/ LIKELIHOOD	**IMPACT/ CONSEQUENCE**				
	5	**10**	**15**	**20**	**25**
1	5	10	15	20	25
2	10	20	30	40	50
3	15	30	45	60	75
4	20	40	60	80	100
5	25	50	75	100	125

Legend:	
	Low Risk
	Medium Risk
	High Risk

*Adapted from the 2013 Blue Drop and No Drop Handbook (Department of Water and Sanitation, 2013)

It is often necessary to be more flexible in interpreting the Risk Rating Score. For example, the delivery of chlorine is late every second month. However, the rating for every month should still be used as the next rating bracket (once per year) would under-rate the risk. Although it is preferable to use standardised ratings tables, such as that proposed by the WHO (World Health Organisation, 2009), it is sometimes necessary for a WSI to modify the table in order to meet their specific requirements. These adjustments however must be motivated as DWS will review the risk matrix methodology during the Blue Drop audit. The ratings and risk level grading in the table above can be motivated in the as follows:

The risk rating definition for high risk is based on the following principles:

- If an event occurs once a month or more (score ≥ 3), and
- The consequence has a regulatory or health impact (score ≥ 20),
- Then the event must be considered a high risk. Consequently, a score ≥ 60 must be a high risk.

The risk rating definition for low is based on the following principles:

- If an event occurs for any duration of time (score ≤ 5), and
- The consequence does not have a public image impact (compliance or aesthetic) (score = 5),
- Then the event must be considered a low risk. Consequently, a score of ≤ 25 must be a low risk.

The medium risk rating then lies between 25 and 60 as it caters for all risks that have a public image impact but which are not yet of health or regulatory concern. This is summarised in the table below.

Table 8-3: Responses required based on risk rating (Department of Water and Sanitation, 2013)

Score		**Risk Profile**
0-25	LOW	No immediate action required. Keep under review and introduce simple and inexpensive controls.
26-59	MEDIUM	Evaluate underlying factors and set timescale for putting extra control measures in place.
60-125	HIGH	Immediate substantive action is required to bring the situation under control and then introduce additional control measures.

Risks should be proactively mitigated to prevent a failure occurring or to reduce the impact. It is nearly impossible to reduce the impact of a failure.

8.2.2 Risk Rating and Prioritisation

A spreadsheet can be used to list, calculate and prioritise risks. Corrective measures or mitigation measures are identified for each risk. Some control measures may exist and theses need to be evaluated as part of this process. There are several approaches to the spreadsheet but a simple application will be as follows:

- Column 1: List the hazards identified from the process audit.
- Column 2: List the existing mitigation measures to address the specific hazard. If none are in place, leave this column empty.
- Column 3: Provide an impact/consequence rating from the Risk Rating Scoring table that would apply if all mitigation measures fail.
- Column 4: Analyse plant performance records, maintenance records, incidence reports and all other available records to determine how often an incident occurs. Select a score for the probability or likelihood of the hazard occurring. If data is not available, an estimate must be made but this must be accompanied with a performance indicator that will be tracked going forward (refer Column 11).
- Column 5: Multiply column 3 and column 4 to calculate the risk rating that can be categorised. DWS calls this the residual risk, which is the risk that remains after current mitigation measures have been considered but is exclusive of any new mitigation measures.
- Column 6: Indicate if the risk rating in column 5 is low, medium or high.

- Column 7: If the risk is low it means that the mitigation measures listed in column 2 are adequate and must remain in place. If however the risk is medium or high, it means that the hazard has not been mitigated properly and that additional or other measures (mitigations) must be implemented. Column 7 should therefore contain a statement indicating "Current control measures are adequate – continue" or "Current control measures are not adequate – review".

The hazards can be sorted from a high to a low risk rating.

8.2.3 Developing Mitigation Measures

The DWS requires that additional or new mitigation measures are implemented for all risks which are categorised as "medium" or "high". An action plan should be developed as described for the optimisation study prioritisation process. The action plan can be incorporated into the risk rating matrix as follows:

- Column 8: If the rating is "medium" or "high", indicate what must be done in addition to the current control measures.
- Column 9: Indicate who is responsible to do this. A name of the specific person must be provided as DWS does not accept a position or title in this column.
- Column 10: Indicate by when the control measure must be in place.
- Column 11: The efficacy of the new control measures must be monitored in order to determine if the desired impact has been achieved. A performance indicator that will be monitored must be provided.
- Column 12: Indicate which IMP (Incident Management Protocol) action and alert level responds to this particular hazard. Develop an appropriate IMP action if one does not exist.

8.2.4 Implementing Mitigation Measures

The DWS has indicated that it will monitor the implementation of mitigation measures (Department of Water and Sanitation, 2014). One critical component of the implementation process is to monitor whether the mitigation measure has the desired effect of reducing the frequency or impact of a hazard. Performance indicators include water quality results, equipment or other failure rates, and incident frequencies. The indicator must be objectively tracked for progress and performance. Performance indicators should be considered in progress meetings, planning meetings and in the next round of process audits and further corrective measures must be implemented if the desired outcome is not achieved.

8.3 OPTIMISATION STUDY ACTION PLAN

The assessment process has gathered information about the performance of the system and identified any factors that may be limiting the optimisation of the process. Performance limiting factors may be issues regarding the capacity, design, operations or administration. Each factor needs to be evaluated and prioritised in terms of the impact on plant performance and the urgency of implementing corrective actions. It is recommended that the evaluation and prioritisation process is undertaken by a multi-disciplinary team that are all committed to the goal of process optimisation. The output of the prioritisation process is an action plan that sets out the pathway to achieve optimisation. Actions can be categorised as short-term that can be implemented immediately and longer-term actions that will require additional time and resources to achieve. Progress of implementation must be monitored and when needed adjustments made to the action plan to ensure the successful completion of identified activities. The optimisation process is a continuous activity. Re-assessment of performance and development of new optimisation activities that are relevant to the changing situation should be an ongoing activity. The steps to be followed in developing the action plan are described below:

8.3.1 Identification of Performance Limiting Factors

Through the guidance provided in this Guideline, the investigation team has been directed on how to review the management and operation of the plant in order to identify potential areas for improvement. Cognisance should also be given to limiting factors that may be interrelated in order to identify the correct action to address poor performance.

8.3.2 Prioritisation of Performance Limiting Factors

Performance limiting factors can be prioritised in order of the impact on plant optimisation and the urgency for implementation by allocating a numerical rating. Factors should be categorised according to performance, unit process, operation and administration. This process should be undertaken in two steps:

1. Impact on optimised performance can be rated from 1 to 5 according to the following impacts (Linder & Martin, 2015):

Rating	Description
5	Major impact on long-term optimisation goals, sustained
4	Major impact on short-term optimisation goals
3	Important impact on optimisation
2	Minor impact but sustained
1	Minor short-term impact

2. Once prioritised in order of impact, performance limiting factors should then be rated in terms of their urgency where 1 is the least urgent and 5 is the most urgent.

The performance limiting factors should be divided into two lists – one for short-term implementation and the other for longer-term actions. This will ensure that actions that can more easily be implemented continue to be addressed while planning and resourcing take place for the more complex interventions. The prioritisation can be handled with the same rigidity as that used in the development of a Water Safety Plan but this is not needed in all cases as optimisation is a discretionary exercise and is not subject to the same rigorous audit requirements as that of the Water Safety Plan. A structured approach to, and documentation of, the optimisation effort will however allow for more controlled review of progress and resource allocation.

8.3.3 Developing Action Plans

An action plan should be developed that incorporates the following information:

- Definition of the issue,
- Required actions,
- Responsible person and department to implement the action,
- Target completion date,
- Parameters to measure success, and
- Budgetary requirements.

8.3.4 Implementing Action Plans

Progress with implementation should be regularly monitored and actions critically re-assessed to ensure that the desired outcome is achieved.

8.4 SUMMARY

At the conclusion of the prioritisation step, all performance limiting factors have been listed and categorised according to the impact on performance and the following will follow from this:

- A list of interventions and optimisation opportunities,
- Allocation of responsibilities, budgets and timelines for the implementation of the interventions,
- Measurement indicators will be in place and tracked, and
- A framework will be set for the regular tracking of performance against the required outcomes for reporting and intervention purposes.

CHAPTER 9: DOCUMENTING PROCESS AUDITS AND OPTIMISATION STUDIES

9.1 INTRODUCTION

Optimisation studies and process audits are formalised with the preparation of a report. These reports provide a record of the status quo of the plant, as well as progress made against the action plans that were implemented following the previous study and audit. The reports are not however static documents. Monitoring of the implementation of mitigation measures and optimisation activities requires a more dynamic form of record keeping that allows for review and updates. Maintenance of action plans in electronic format allows for regular recording of progress and for inclusion of additional risks and mitigation measures that may be identified during daily operations. The format of the electronic system is not defined and can be prepared to address the specific needs of the WSI. Consideration should however be given to utilising the same spreadsheet developed for rating and prioritising the risks (section 8.2.2). Each hazard occupies one line in this matrix which can be expanded by adding columns to record regular (daily, weekly or monthly) progress reports and data. This will facilitate an analysis of progress and identify where activities should be reviewed.

The content and format of the written 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. The table below provides guidance on what should be included in a Process Audit and what could be included in an Optimisation Study report. It also emphasises the important support role of process control in the implementation of findings from the process audits (via the Water Safety Plan) and also the optimisation study. TABLE 9-1illustrates the significant overlap if consideration is not given to the discretionary nature of Optimisation Studies. In consideration of the table it again remains critical to be mindful of the fact that the fundamental difference between the two exercised does not lie in the subject matter investigated but rather the mind-set with which is it investigated and the end goals required in each case. The distinction is repeated here below in order to again refresh on this point:

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

Table 9-1: Requirements for Process Audit Reports vs. Optimisation Study Reports

Process Audit and Optimisation Study Approach	Criteria with paragraph reference	Step 0: Daily Process Assessment *Process Controllers' Responsibility*	Step 1: Process Audit (Minimum considerations subject to Regulation) *Independent Audit Process*	Step 2: Optimisation Study (Suggested considerations but no limit implied) *Internal or External Specialist Study*
Step 1: Performance assessment Determine the current level of plant performance versus regulatory or optimisation goals	Definition of plant configuration	• Ensure implementation and compliance with previous Process Audit and Optimisation Study outcomes.	• Develop a Process Flow Diagram	• As per the Process Audit + As built drawings + Design detail and philosophy. + Process Upgrade information
	Raw water quality assessment	• Prepare catchment risk studies to facilitate interpretation during the Process Audit and Optimisation studies. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Compare the raw water quality to the SANS 241 limit to determine the risks present in the raw water. • Compare the raw water quality to the non-SANS 241 limits for known contaminants to determine the risks present in the raw water. • Review current list of identified risks against the water quality data and augment as needed.	• As per the Process Audit + Catchment analysis and identification of potential problematic determinands. + Determination of pollution loads within the catchment + Additional sampling protocols based on findings
	Final water quality trend analysis and comparison with current and future water quality requirements	• Maintain documentation on an ongoing basis to track performance and to facilitate the Process Audits and Optimisation studies. • Ensure that samples have been drawn and analysed in line with the full SANS241 in order to ensure that all spatial and temporal risks are monitored. • Identify all water quality risks associated with this criterion, take corrective action and adapt the sampling programme as per SANS241. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Compare the final water quality to SANS 241 limits to determine compliance and identify risk determinands. • Compare the final water quality to WHO limits for known non-SANS risk determinands. • Review current list of identified risks against the water quality data and augment as needed.	• As per the Process Audit + Final water – comparison of values with internal limits more stringent than SANS241. + Final water – comparison of values with guidelines and limits as listed in international guideline documents and standards for emerging determinands.
	Suitability of the process	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis and prepare relevant documentation to track progress and document findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Is the installed process suitable for treating the raw water quality entering the plant? • Identify all water quality related risks associated with the above.	• As per the Process Audit + Are there other treatment processes that can achieve the same or better results at reduced cost?

Process Audit and Optimisation Study Approach	Criteria with paragraph reference	Step 0: Daily Process Assessment *Process Controllers' Responsibility*	Step 1: Process Audit (Minimum considerations subject to Regulation) *Independent Audit Process*	Step 2: Optimisation Study (Suggested considerations but no limit implied) *Internal or External Specialist Study*
	Demand analysis (historic)	• Maintain a graphical presentation of flow statistical data on an ongoing basis to facilitate the Process Audit and Optimisation studies. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Graphic depiction of historic flows compared to design capacity • Identify all water quality related risks associated with the above.	• As per the Process Audit
	Demand projection (future)	• Update demand projections and prepare relevant documentation to facilitate the Process Audit and Optimisation studies. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Determine if the current plant is able to reach the future demand required • Identify all water quality related risks associated with the above.	• As per the Process Audit
	Plant efficiencies (hydraulic)	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Prepare a water balance for the plant and record the flows required to monitor the balance. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Comparison of the demand on the plant to the design capacity. • Identify all water quality related risks associated with the above.	• As per the Process Audit + Calculation of losses in the WTP. + Benchmarking of losses to accepted norms and investigation of the losses to improve plant efficiency where required.

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Step 2: Major Process Unit Capacity Assessment Determine if sizes of major unit processes are limiting performance	Determine peak instantaneous operating flow	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Record dates of peak and low flows and also reasons for the flow variations. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Review of operational data over a minimum of a12 month period to determine the peak instantaneous operating flow.	• As per the Process Audit + Investigate the possibility of reducing or attenuating peak plant flows to improve performance and extend service life, e.g. additional reservoir.
	Rate the capacity of individual unit processes	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to document progress and findings. • Compile plant capacity and technical data on the treatment units if there is none with support of a specialist Professional Engineer. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Evaluate individual units in terms of hydraulic capacity and accepted benchmarks (e.g. loading rate). This may not be required during follow-up audits if this has been done in the last 3 years.	• As per the Process Audit + Determine, by running on-site evaluations, what the maximum loading rates of the treatment reactors are in order to inform future process audits.
	Develop a performance potential graph and identify hydraulic performance restrictions	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Develop a Performance Potential Graph to identify the restrictive units. This may not be required during follow-up audits if this has been done in the last 3 years. • Compare the updated peak instantaneous operating flow against the latest Performance Potential Graph. • Identify all water quality related risks associated with the above.	• As per the Process Audit + Identify any other optimisation opportunities

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Step 3: Unit Process Performance Assessment Identify other aspects of unit process design limiting performance	Process unit water quality performance assessment	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Maintain water quality data records on unit processes to track performance and to document progress and findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Compare process unit performance in terms water quality produced to benchmark or industry (or in-house) target values.	• As per the Process Audit + Review and modify industry norm process unit performance targets to suit the particular plant being considered by developing in-house targets based on site specific data analysis and on-site field test work. + Update and review internal performance limit setting for each process unit on an ongoing basis (minimum 5 year intervals).
	Evaluation of detail unit process unit design and condition	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Ensure all relevant design and manufacture documentation is safe while remaining accessible. Ideally documents should be available in electronic form. Duplicates should be kept off-site if hard copies are preferred on site. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Visual Inspection of each unit process. • Identify detail design issues which may affect performance or increase water quality risk. • Identify maintenance or equipment condition issues which may affect performance or increase water quality risk.	• As per the Process Audit + Develop internal specifications for equipment installations regarding 1) uptime 2) level of standby and 3) internal equipment specifications and compare these internal requirements with the installed equipment and their performance, availability and reliability. + Develop an asset management strategy which considers performance, availability and reliability on an ongoing basis and includes the same into the maintenance activity.

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	Energy efficiency	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Record energy consumption. • Consult Professional Electrical Engineering support during implementation if needed but always in association with Process Engineering support. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Log energy consumption and analyse usage • Determine assurance levels of power supply • Determine the availability and condition of the standby energy supply or emergency generator	• As per the Process Audit + Energy efficiency and energy savings initiatives + Alternative energy usage
	Identify risk mitigation or optimisation opportunities	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Identify all water quality related risks associated with the above.	• As per the Process Audit + Identify any other optimisation opportunities + Have ongoing site based sessions will all process controllers to determine optimisation opportunities.

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Step 4: Operational Assessment **Identify operation practices limiting performance**	Operational Procedures	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Compile new and site-specific O & M if not available. • Compile site-specific SOPs if not available. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Review Operations Manual and Standard Operational Procedures for sufficiency for all process units and operational activities in terms availability, relevance and clarity. • Review training and upskilling activities focussing on plant specific O&M manuals and SOPs. • Review records indicating implementation of and compliance with the plant specific O&M manuals and SOPs. • Identify all water quality related risks associated with the above.	• As per the Process Audit + Perform regular internal reviews of the O&M and SOP to ensure relevance and sufficiency.
	Process performance goals and routine sampling and testing schedule	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. • Implement the routine sampling and testing schedule and ensure results are documented. Track progress and performance and document findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Review the sampling schedule for operational and compliance monitoring to ensure that it meets SANS 241 requirements. • Review the internal performance targets to determine if this is appropriate for each unit process and compare this to the internal monitoring programme. • Review sampling, sample preservation, analysis techniques, and analytical equipment and reagent maintenance to ensure that these are sufficient to allow for accurate compliance monitoring. • Review the plant performance record systems to ensure that these accurately and sufficiently capture plant performance history. This should include at least flow records, water quality records, chemical stock reports, incident records, logbooks, etc. • Identify all water quality related risks associated with the above.	• As per the Process Audit + Perform regular internal reviews of the performance goals, monitoring strategy, and record system to ensure relevance and sufficiency.

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	Process controller competence	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Hold process controller meetings regularly to discuss SOP's, O&M related issues, etc. • Ensure a training programme is in place for continuous development of skills and knowledge development. Record activities and outcomes. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Compare process control staffing with regulatory compliance requirements. • Review process control staff knowledge of the O&M manual, SOPs and other site related guidance documents, reports, responses to adverse water quality results, etc. • Review record keeping and data analysis by process control staff. • Review records on IMP implementation. • Determine the water quality related risks associated with the above.	• As per the Process Audit + Perform on-going on-the-job evaluations of process controller competence. + Consider the sufficiency and appropriateness of current development programmes for process control staff. + Review progress of process control staff against their unique development plans.
	Communication	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Ensure all records are inspected, signed off and actioned as needed. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Review if plant operations records are available and accessible to all staff. • Review operational report development and dissemination. • Review IMP implementation and Incident Record maintenance. • Determine the water quality related risks associated with the above.	• Assess the extent to which top management remain informed on current water quality performance. • Assess the sufficiency of communication strategies with other management spheres including HR, procurement, asset management, etc.
Step 5: Administration Assessment **Identify administration practices limiting performance**	Administrative policies	• Review actions from previous Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.		• Determine the priority levels allocated to water quality in the mission statement of the organisation. • Has a recent gap analysis focussing on water quality been done by the organisation and has the findings been used to prioritise funding, staffing and organisational development?

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	Staff management	• Review actions from previous Process Audit and Optimisation studies on an ongoing basis (include technical maintenance staff). Prepare relevant records to track performance and to document progress and findings. Records must include but will not be limited to compliance to staffing regulations, training, hours worked and performance management. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Determine if a sufficient number of qualified staff are available as per regulatory requirement.	• As per the Process Audit + Review current staffing in terms of acceptability of staffing qualification, role, and position against best practice targets. + Review current staffing stability in terms of staff retention. + Review staff training sufficiency against quantum and quality of training per employee. + Review staff safety in terms of injury rates or other backed statistics. + Review staff performance management strategies for all levels of the organisation.
	Asset management strategies	• Review actions from previous Process Audit and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. Records must include but will not be limited to work performed against job cards, budgets utilised, ratio of preventative to reactive maintenance and downtime per component. • Compile a DWS compliant asset register and asset management strategy if there is none. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Review the sufficiency of the current asset register against both DWS and Treasury requirements. • Review maintenance budget spend against target values. • Review planned maintenance to reactive maintenance in terms of spend and time taken. • Determine the water quality related risks associated with the above.	• As per the Process Audit + Review financial planning for asset renewal against lifecycle discount rates for various asset classes. + Review asset repair and maintenance implementation against planned and unplanned job cards + Compare equipment up-time with repair works order status to ensure the aim remains to return equipment to service and not to simply close job cards.

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	Funding of operations and maintenance efforts	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Liaise with the Director: Finance to support this task particularly if data is not available. • Maintain records on procurement activities including turn-around time. • Draw up a zero-base operations and maintenance budget based for the specific plant and compare against the current budget. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Compare the operating cost against the potential total net sales value of the treated water (exclude water losses, free basic water and other non-income generating "uses").	• As per the Process Audit + Review the current Operation and Maintenance budget against a zero base budget. + Review the budget process to ensure adequate financial planning. + Review the financial structures of the organisation to ensure that funding for water services are ring-fenced.
	Procurement policies and support of Operations	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Liaise with the Director: Finance to support this task particularly if data is not available. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Confirm procurement policies are in place for continuous chemical supply. • Consider stock levels of chemicals on treatment sites and confirm that stock levels do not drop below minimum order levels • Confirm that 30 days of chemicals can be stored on site. • Confirm emergency repair policies are in place and are accessible to operations and maintenance office.	• As per the Process Audit + Review administrative timelines on placement of orders. + Review supplier response in terms of agreed timelines. + Review levels of co-operation between the procurement office and operations (both ways). + Review training efforts aimed at ensuring operations and maintenance offices follow the required procurement routes. + Review the response of the procurement office to the needs of the operations and maintenance office.

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	Customer Services	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track consumer complaints and to document progress and findings. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Review the Customer Complaints register to determine the rate of complaints received and compare with historic trends.	• As per the Process Audit + Review the supply disruption record and compare with historic trends. + Review per capita consumption levels and compare with resource availability and treatment capacity. + Undertake a Customer Satisfaction Survey and analyse the results.
Step 6: Assemble and prioritise a comprehensive list of factors limiting performance. Identify activities to address factors that will improve performance	Identify performance limiting factors	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Action and monitor implementation. Solicit support from relevant persons and departments if needed. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Summarise the list of performance limiting factors and forward for inclusion in the Water Safety Planning Process.	• Summarise opportunities for improved operations and plant performance.
	Prioritise performance limiting factors	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Action and monitor implementation. Solicit support from relevant persons and departments if needed. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Prioritise list of performance limiting factors to assist with inclusion into the Water Safety Planning Process.	• Prioritise opportunities based on potential impact of the initiative.

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	Develop action plans	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Action and monitor implementation. Solicit support from relevant persons and departments if needed and provide input to the Water Safety Planning process. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Produce a list of recommendations for inclusion into the Water Safety Planning Process.	• Develop action plans around selected initiatives.
	Allocate responsibilities and timelines	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Action and monitor implementation. Solicit support from relevant persons and departments if needed. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Allocate responsibilities as part of the Water Safety Planning Process.	• Identify a responsible individual to run the investigation or develop the action plan further.
	Define performance indicators	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Action and monitor implementation. Solicit support from relevant persons and departments if needed. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Include in the Water Safety Planning Process in order to measure effect of the intervention.	• Identify performance indicators to assess the effect of the intervention.

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	Develop corresponding Incident Management Plant and Mitigation Measures	• Review actions from previous Process Audits and Water Safety Plan and prepare the relevant documentation in a consultative manner. • Conduct incident drills. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Include in the Water Safety Planning Process and development of the Incident Management Protocol	
	Allocate funding	• Review actions from previous Process Audits and Optimisation studies and monitor implementation. • Solicit support of Director: Finance • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Include in the Water Safety Planning Process. • To be signed off by the head of the organisation.	• Allocate the budget and required time frames.
Step 7: Implement activities that will improve performance	Implement initiatives	• Review actions from previous Process Audits and Optimisation studies and prepare evidence. Ensure the process is inclusive and well represented. • Identify all water quality risks associated with this criterion and take corrective action. • Identify service delivery risk associated with this criterion and take corrective action in terms of short-, medium- and long term planning.	• Water Safety Plan Implementation	• Implement the optimisation strategy
	Monitor performance indicators and progress toward goals	• Review actions from previous Process Audits and Optimisation studies on an ongoing basis. Prepare relevant records to track performance and to document progress and findings. • Ensure constant capacity training of staff.	• Water Safety Plan implementation monitoring and follow-up process audits	• Track the selected performance indicators

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Step 8: Assess performance improvements	Measure results, make adjustments, re-evaluate and continue the optimisation sequence	• Review records related to implementation of actions from previous Process Audits and Optimisation studies on a continuous basis. • Progress records will provide feedback into an analysis to refine the initiative. • Ensure constant capacity training of staff.	• Water Safety Plan Implementation monitoring and follow-up process audits.	• The optimisation exercise will provide detailed reports which can be fed back into an analysis process to refine the initiative.

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