THE UNITED REPUBLIC OF TANZANIA

MINISTRY OF WATER | GOVERNMENT CITY
MAJI STREET | P. O. BOX 456
DODOMA

MKUKI NA NYOTA
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ISBN 978-9987-08-435-7
9 789987 084357

DCOM Manual

Volume IV

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF WATER

| DESIGN |
| CONSTRUCTION SUPERVISION |
| OPERATION & MAINTENANCE |
(DCOM) MANUAL

VOLUME IV
OPERATION AND MAINTENANCE OF WATER SUPPLY AND SANITATION PROJECTS

MAY 2020

4TH EDITION

THE UNITED REPUBLIC OF TANZANIA

MINISTRY OF WATER

DESIGN, CONSTRUCTION SUPERVISION, OPERATION AND MAINTENANCE (DCOM) MANUAL FOURTH EDITION

VOLUME IV

OPERATION AND MAINTENANCE OF WATER SUPPLY AND SANITATION PROJECTS

**Edited by Ninatubu Lema,
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PROJECT PREPARATION, COORDINATION AND DELIVERY UNIT (PCDU)

Published for
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Published by:
Mkuki na Nyota Publishers Ltd

Publication Title:
Design, Construction Supervision, Operation and Maintenance (DCOM) Manual Fourth Edition
Volume III: Operation and Maintenance of Water Supply and Sanitation Projects

ISBN 978-9987-084-35-7

PREFACE

The Government of the United Republic of Tanzania, through the Ministry of Water, oversees the implementation of the Water Supply and Sanitation projects in the country. The Ministry of Water has published several editions of the relevant Design Manuals. The First Edition was the Water Supply and Wastewater Disposal Manual of 1985/86. The Second Edition was titled "Design Manual for Water Supply and Wastewater Disposal of 1997". The Third Edition was titled "Design Manual for Water Supply and Wastewater Disposal of 2009". These manuals guided the Ministry and the general public in the planning and design of water supply and sanitation projects in the country.

As it is now well over ten years since the Third Edition of the Design manual was adopted, and since many scientific and technological changes have taken place, including the conclusion of MDGs and adoption of the SDGs in 2015 as well as useful lessons learnt out of implementation of the WSDP I and WSDP II (which is still on-going), it has become necessary to revise the 2009 design manual. Notably, the 3rd Edition Design Manual has, among other things, limited coverage on the impact of climate change, application software and sanitation management issues.

The Ministry is now at various stages of instituting policy and legal reforms that are deemed necessary for futuristic improvement in the design, construction supervision, operation and maintenance of water supply and sanitation projects in Tanzania. Therefore, the 4th Edition of the Design, Construction Supervision, Operation and Maintenance (DCOM) Manual will make invaluable contribution in this regard. It is important to recall that the Government has established the Rural Water Supply and Sanitation Agency (RUWASA), which is responsible for the supervision, execution and management of rural water supply and sanitation projects. RUWASA is expected to improve the existing responsibility and accountability in the management of water and sanitation services in rural areas. The 4th Edition DCOM Manual will support the sector development and implementation institutions (including RUWASA, Water Supply and Sanitation Authorities, development partners, and civil society organisations), and will provide valuable information relating to implementation of water supply and sanitation projects in their various stages, from pre-feasibility and feasibility studies, to planning, designing, construction supervision and operation and maintenance.

It is expected that the 4th Edition of the DCOM Manual will position the Ministry well to systematically and comprehensively implement the design, construction supervision, operation and maintenance of water supply and sanitation projects in order to ensure the sustainability of water supply and sanitation projects in the country. This is also expected to contribute in realising the water sector's contribution towards achieving the Tanzania Development Vision 2025, as well as the various national and international commitments and milestones in the water sector as also specified in the Agenda 2063 in the "Africa that we want" and the Sustainable Development Goals (SDGs) on water and sanitation (SDG No. 6).

The preparation of this Water Supply and Sanitation Projects DCOM Manual required contributions in form of both human and financial resources. The Ministry of Water, therefore, takes this opportunity to thank the members of the Special Committee for Reviewing and Updating the 3^{rd} Edition of the Design Manual for Water Supply and Wastewater Disposal of 2009, specifically for their efforts in preparation of this comprehensive 4^{th} Edition of the DCOM Manual. Thanks are also due to the World Bank for financing the major part of the activities, and to all others who contributed in the preparation of this new DCOM Manual.

In the future, the Ministry plans to periodically review and update the DCOM Manual in order to keep in pace and address emerging changes in policy and societal needs, emerging technologies, and sustainability concerns in the implementation of water supply and sanitation projects in the country.

Prof. Makame Mbarawa (MP)
Minister
Ministry of Water
May, 2020

ACKNOWLEDGEMENTS

Changes of policy and technology have necessitated the preparation of this new edition of the DCOM Manual for the design, construction supervision, operation and maintenance of water supply and sanitation projects in Tanzania. The 4th Edition of the DCOM Manual is expected to guide engineers and technicians in their design work, construction supervision as well as in operation and maintenance of relevant projects. The manual is to be adopted for all water supply and sanitation projects in the country.

The 4th Edition of the DCOM Manual has been developed using the following approaches:

- Review of the 3rd Edition, including benchmarking with design manuals from other countries,
- Website reviews and review of other manuals prepared by consultants who have had working experience in Tanzania,
- Review of Literature data collection and design methods review,
- Data collection from stakeholders, namely: Primary stakeholders-MoW technical and management staff; Private companies that deal with implementation of water supply and sanitation projects; Beneficiaries of water supply and sanitation projects,
- Collection and digitization of existing standard drawings after conversion into metric units as felt necessary,
- Review of the 4th Edition drafts by various stakeholders including MoW staff and other stakeholders outside the MoW,
- Revision of the 4th Edition by incorporating comments and views from all the stakeholders,
- Preparation and submission of the 4th Edition of the DCOM Manual.

The review and updating of the 3rd Edition of the DCOM Manual is considered to be a continuous process involving regular updating to incorporate changes in policy and societal needs, emerging issues, technologies or methods. The MoW welcomes comments on this new edition of the DCOM Manual from users in order to facilitate further improvement of future editions.

The new features in the 4th Edition of the DCOM Manual include mainstreaming of climate change impacts and use of various types of software in the design of water supply and sanitation projects. These features have facilitated the faster and more accurate analysis of pertinent data. The DCOM manual has also encouraged the use of Supervisory Control and Data Acquisition Systems (SCADA) for large urban and generally national projects where local capacity building can be guaranteed by the providers. It should be borne in mind that relevant software allows a wide variety of scenarios to be considered. However, it should also be noted that, despite the critical role of software/models in guiding decision-making, its limits should be realised so as to avoid its becoming a substitute for critical practical evaluation.

I wish to thank the different stakeholders for their active participation and support in contributing towards the various inputs during the course of preparation of this DCOM Manual. They include those from within and outside the Ministry of Water as well as Development Partners, NGOs, Consultants, Suppliers and Contractors as well as other Ministries. The review team of engineers and technicians from MoW, RUWASA, WSSA who worked with the Special Committee for three days in March 2020 are hereby gratefully acknowledged

Finally, I take this opportunity to thank the members of the Special Committee on Reviewing and Updating the 3rd Design Manual of 2009 under the Chairmanship of Eng. Prof. Tolly S. A. Mbwette for diligently undertaking this assignment.

Prof. Kitila Mkumbo
Permanent Secretary
Ministry of Water
May, 2020

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Dodoma May, 2020

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LIST OF ABBREVIATIONS

AGM	Annual General Meeting
ATAWAS	Association of Tanzania Water Suppliers
CBWSO	Community Based Water Supply Organisations
CCTV	Closed Circuit Television
COWSOs	Community Owned Water Supply Organizations
CMIP5	Coupled Model Inter-comparison Project Phase 5
DAWASA	Dar es Salaam Water Supply and Sanitation Authority
DBO	Design, Build and Operate
DEWAT	Decentralized Wastewater Treatment Systems
DCOM	Design, Construction Supervision, Operation and Maintenance
EAP	Emergency Action Plan
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMA	Environmental Management Act
ENSO	El Nino-Southern Oscillation
ERB	Engineers Registration Board
EWURA	Energy and Water Utilities Regulating Authority
FYDP	Five Year Development Plan
GCMs	Global Climate Models
GHGs	Greenhouse gases
IHP	International Hydrological Programme
ITCZ	Inter-tropical Convergence Zone
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
MKUKUTA	Mkakati wa Kukuza Uchumi Tanzania
MoEST	Ministry of Education, Science and Technology
MoHCDGEC	Ministry of Health, Community Development, Gender, Elderly and Children
MoW	Ministry of Water

NAWAPO	National Water Policy
NEMC	National Environmental Management Council
NMAIST	Nelson Mandela African Institute of Science and Technology
NRW	Non Revenue Water
NSGRP	National Strategy for Growth and Reduction of Poverty
NWSDS	National Water Sector Development Strategy
O&M	Operation and Maintenance
PPPs	Public-Private Partnerships
PORALG	President's Office Regional Administration and Local Government
RCPs	Representative Concentration Pathways
RFP	Request for Proposal
RUWASA	Rural Water Supply and Sanitation Agency
SADC	Southern Africa Development Community
SDGs	Sustainable Development Goals
SST	Sea Surface Temperature
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCC	United Nations Framework Convention on Climate Change
UWSSA	Urban Water Supply and Sanitation Authority
UDSM	University of Dar es Salaam
URT	United Republic of Tanzania
TAWASANET	Tanzania Water Supply and Sanitation Network
TDV	Tanzania Development Vision
TS	Total Solids
WMO	World Meteorological Organization
WP	Water point
WSDP	Water Sector Development Programme

PART A: ESSENTIALS OF OPERATION AND MAINTENANCE

Chapter 1 INTRODUCTION

The preparation of this DCOM manual was preceded by an overview of five important global considerations of Water Supply and Sanitation prior to reviewing the water and sanitation sector in Tanzania. This was followed by an explanation of the rationale for the preparation of the 4th edition. The introductory chapter is concluded by presenting the organization of the manual as well as the purpose and content of this volume of the DCOM manual.

1.1 GLOBAL CONSIDERATIONS ON WATER SUPPLY AND SANITATION

1.1.1 Sustainable Development Goals (SDGs)

In 2015, world leaders convened at the United Nations Headquarters in New York and adopted the 2030 Agenda for Sustainable Development. Governments responded to the common development challenges then faced and to the changing world around them by uniting behind a truly forward-looking, yet urgent plan to end poverty and create shared prosperity on a healthy and peaceful planet. The central principle of Agenda 2030 is leaving no one behind in achieving the 17 SDGs through 169 targets.

The 2030 Agenda for Sustainable Development adopted at the UN Summit includes SDG 6 on Water and Sanitation and in December 2016, the United Nations General Assembly unanimously adopted the resolution "International Decade for Action-Water for Sustainable Development" (2018–2028) in support of the achievement of SDG 6 on water and sanitation and the related targets (United Nations, 2015). It should also be noted that, water and sanitation are at the heart of the Paris Agreement on climate change 2015 (UNFCC (2015).

Ensuring availability and sustainable management of water and sanitation for all has therefore been, for a long while, an important topic at the United Nations and is now turning this vision into a reality, through national leadership and global partnerships. Water and sanitation are at the core of sustainable development and the range of services they provide, underpin poverty reduction, economic growth and environmental sustainability. The world needs to transform the way it manages water resources and the way it delivers water and sanitation services for billions of people.

The designers and engineers, therefore, have the responsibility to support the Government of Tanzania in achieving the SDG 6, where population growth and rapid urbanisation have intensified demand for water and sanitation services beyond all past thresholds.

1.1.2 Climate Change and Resilience to Climate Change

Climate change is now recognized as one of the defining challenges for the 21st century. More frequent, intense and extreme weather events continue to result in higher incidences of floods and droughts around the planet. The ensuing adverse impacts of climate change on water and sanitation services constitute a serious threat to human health and overall development of nations. Ensuring optimal resilience of water and sanitation services in a globally changing climate context will continue to be crucial for maintaining the momentum of making progress in health and general socio-economic development. Climate variability is already a threat to the sustainability of water supplies and sanitation infrastructure.

Flood occurrences continue to cause shocks for affected populations and to challenge water and sanitation managers. In many places floods are likely to become more frequent with intensification of climate change, thus;

- Floods can have catastrophic consequences for basic water and sanitation infrastructure. Such damages can take years to repair.
- On a smaller scale, drinking-water infrastructure can be flooded and put out of commission for days, weeks or months.
- Where flooding of sanitation facilities occurs, there may not only be a break in services, but the resultant flooding may distribute human excreta and its attendant health risks across entire neighbourhoods and communities.

Droughts occur unpredictably worldwide. In many places they are likely to become more frequent and more widespread with climate change. For example: Falling groundwater tables and reduced surface water flows can lead to wells drying up, extending distances that must be travelled to collect water, and increasing water source pollution. In response, drilling rigs, which would otherwise be used to increase access, may be redeployed to renew or replace out-of-service wells, slowing the actual progress in extending access.

Since climate change is likely to affect water sources and infrastructure in Tanzania, it must therefore be taken into consideration (i.e. ensure enhanced adaptation capacity) in design, operation and maintenance of water and sanitation infrastructure or projects. Globally, climate change studies are coordinated by the United Nations Framework Convention on Climate Change (UNFCCC) and the Inter-Governmental Panel on Climate Change (IPCC). Accordingly, designers should use the latest information, data and model predictions available and include statements on what measures, if any, have been allowed for in order to cope up with (or adapt to) climate change within the time frame of pertinent project design (i.e. design period).

1.1.3 Public Private Partnership in Water Supply and Sanitation Projects in Developing Countries

One of the key challenges faced by water authorities in Developing Countries (DC) is how best to manage service delivery obligations to rural communities. Even in decentralized sectors, water authorities may find it hard to provide services to remote rural communities. It is recognized that water user associations and/or local private operators may be best placed to provide services as they are close to the users. The majority of the agreements are currently in place in the short term (1 to 3 years) management or operation and maintenance contracts for existing systems that involve minimal investment from the private sector. One key issue that arises repeatedly though is how to effectively regulate and monitor performance of activities under these contracts.

Globally, activities undertaken in 2005 suggest that private participation in the water sector is entering a new phase. New private firm involvement is continuously focusing on smaller projects and bulk facilities. Contractual arrangements involving utilities are combining private operations with public financing and new players are entering the market.

In an infrastructure-intensive sector, improving access and service quality to meet the SDGs cannot be done without massive investment. Around the developing world, the water sector is chronically under-funded and inefficient in addition to giving low priority to sanitation. In this context, Public-Private Partnerships (PPPs) can be a mechanism (among others) to help Governments in funding the much needed investment and deploying technologies and efficiency that can improve the performance and financial sustainability of the water and sanitation sector.

Governments are currently using private firms in the water and sanitation sector increasingly to finance and operate bulk water supply and wastewater treatment. New technologies and innovations such as desalination and wastewater re-use are currently being increasingly introduced, where traditional water sources have become scarce. Utilities are drawing on specific expertise, such as Non-Revenue Water (NRW) reduction and pressure management, to promote efficiency and improvement of services. Private investors and providers are increasingly becoming local and regional, and so raising competition and pushing down charges.

Most utilities are increasingly turning to the private sector for turnkey solutions to the designing, building and operating water and wastewater treatment plants, and in some cases they also provide financing. With new technologies such as membrane filtration and in wastewater treatment; utilities have faced challenges in finding the capacity to operate and maintain these facilities and in selecting the most appropriate technology.

Where a utility has the funds or is seeking financing to develop water or wastewater treatment plants but wishes to draw on the private sector to Design, Build and Operate (DBO) a facility, then the DBO approach is used.

The International Financial Institutions (IFIs) are being asked to finance such approaches. In response, the WB has recently developed a suite of documents for DBO deployment in water and sanitation projects, including an initial selection document; a Request for Proposal (RFP) with DBO document based on The International Federation of Consulting Engineers (FIDIC), an acronym for its French name Fédération Internationale Des Ingénieurs-Conseils) Gold Book and a guidance note with guidance on when the DBO approach is appropriate and how to approach such projects; draft framework for Employer Requirements and draft Terms of Reference for Consultancy support to carry out the requisite studies and develop the documents (WorldBank, 2010).

1.1.4 International Water Law

The URT is riparian to the following trans-boundary International River Basins: Congo River Basin, Kagera River Basin, Nile River Basin and Zambezi River Basin. These water sources are managed using international law on trans-boundary resources.

International law is a culture of communication that “constitutes a method of communicating claims, counter-claims, expectations and anticipations, as well as providing a framework for assisting and prioritizing such demands” (Shaw, 2008). International water law is the law of non-navigational uses of international watercourses.

In international water law, there are two substantive principles that ought to be taken into consideration when sharing international waters:

- The principle of equitable utilization which is a more subtle version of the doctrine of absolute sovereign territory. It argues that a (nation) state has absolute rights to all water flowing through its territory.
- The principle of no significant harm is the delicate version of the doctrine of both absolute riparian integrity (every riparian state is entitled to the natural flow of a river system crossing its borders) and historic rights (where every riparian state is entitled to water that is tied to a prior or existing use) (Wolf, 1999).

There are two relevant international water conventions for trans-boundary water cooperation. The 1997 Convention on the Law of the Non-navigational Uses of International Watercourses (i.e. UN Watercourses Convention, 1997), and the 1992 UNECE Convention on the Protection and Use of Trans-boundary Watercourses and International Lakes (i.e. UNECE Water Convention, 1992) which recently broadened its membership beyond the EU to a global audience. In March 2016, Water Convention became a global multilateral legal and Inter-Governmental framework for trans-boundary water cooperation that is open to accession by all UN member states. The soft law of the SDGs provides further impetus to the management of trans-boundary water resources directly through Goal 6.5: “Implement integrated water resources management at all levels, and through trans-boundary cooperation as appropriate”, and indirectly through

Goal 16: "Promote peaceful and inclusive societies for sustainable development". In this case, the contribution of designers and engineers is in the provision of tools and information or data to support the needed decision making.

The management of water resources that entails extraction of shared international water resources in the form of rivers, lakes, seas and oceans as sources are guided by International Conventions and/or Protocols that have to be subsequently ratified by respective national Parliaments before they become enforceable. Because Tanzania is a member of the EAC, SADC and the African Union, it has ratified a number of the conventions and/or protocols that are associated with water resources management and water supply and sanitation services. At an African level, Tanzania fully subscribes to the Agenda 2063 that ensures African development is guided by African experts to attain the aspirations of "The Africa that we want" with respect to water supply and sanitation services. Furthermore, as a member of the United Nations, Tanzania's water supply and sanitation services are guided by the UN SDGs of 2015 as well as the UNFCCC (2015) as mentioned earlier on.

1.2 Development Agenda and Water and Sanitation Sector in Tanzania

The Tanzania Development Agenda includes the Tanzania Development Vision (TDV) 2025). The realization of TDV is carried out through Five Year Development Plans. Currently, the GoT is implementing the Second Five Year Development Plan (FYDP II), 2016/17 – 2020/21.

The Government adopted the TDV in the mid-1986s for socio-economic reforms and the same continues to be implemented to date. Better and improved water and sanitation services contribute to one of the attributes of Vision 2025, which is on high quality livelihood. Thus, the review and update of this manual better shapes the future in which water and sanitation services will be delivered to enhance the health and improved livelihoods of normal citizens who are a critical national labour force.

The FYDP II has integrated development frameworks of the first Five Year Development Plan (FYDP I, 2011/2012-2015/2016) and the National Strategy for Growth and Reduction of Poverty (NSGRP/MKUKUTA II, 2010/2011-2014/2015) further extended to 2015/2016 - 2019/2020. The FYDP II is built on three pillars of transformation: industrialization, human development, and implementation effectiveness, and is aligned to the relevant SDGs. Importantly, industrialization places high demand on utility supplies e.g. energy and water, so subscribing on addressing the SDG Goals 6: on water and sanitation.

Chapter 4 of the FYDP II, sub-chapter 4.3.4 on Water Supply and Sanitation Services sets key targets by 2020 as follows: Access to safe water in rural areas, 85%; regional centres and Dar es Salaam, 95%. Proportion of rural households with improved sanitation facilities, 75%; regional centres, 50% and Dar es Salaam, 40%. Non-revenue water (NRW) for regional centres, 25%; for Dar es Salaam, 30%. The Key targets by 2025 are: Access to safe water in rural areas, 90%; regional centres and Dar es Salaam, 100%. Proportion of rural households with improved sanitation facilities, 85%; regional centres, 70% and Dar es Salaam, 60%. Non-revenue water (NRW) for regional centres, 20%; for Dar es Salaam, 25%. One of the tools towards achieving the key targets of water supply and sanitation is the effective application of the DCOM manual.

The Government has a comprehensive framework for sustainable development and management of water resources where there is an effective policy, legal and institutional framework. The water sector policy and strategy contains operational targets to be achieved in terms of coverage and timescale for improving water resources management, water supply and sanitation. The targets are reflected in the National Water Sector Development Strategy (NWSDS) of 2006. Based on the targets of the ruling party manifesto on water coverage for rural areas and urban areas are 85% and 95% by 2025, respectively which are also articulated in the WSDP.

In the context of water supply and sanitation services in Tanzania Mainland, the Water Supply and Sanitation Authorities (WSSAs), in collaboration with Rural Water Supply and Sanitation Agency (RUWASA), are responsible for management of water supply and sanitation services mostly in the urban, towns and rural areas as well as in areas that used to be managed by National Water Utilities. The water sector status report of 2017/18 has set water coverage targets of 95% for Dar es Salaam, 90% for other WSSAs and rural areas, 85%.

The Community Based Water Supply Organisations (CBWSOs) are the basic units responsible for management of water supply and sanitation services in rural areas under the overall coordination of RUWASA. The WSSAs are regulated by the Energy and Water Utilities Regulating Authority (EWURA), while CBWSOs are regulated by the RUWASA under the Ministry of Water that is in turn responsible for rural water supply and sanitation services in Tanzania. As part of the on-going reforms in the MoW, a number of small WSSAs have been clustered with urban WSSAs leading to reduction of WSSAs from 130 to 71. RUWASA has been charged with the task of supervising the operations of 50 small town WSSAs in addition to the CBWSO managed projects.

The regulatory role of WSSAs is provided by the Energy and Water Utilities Regulatory Authority (EWURA) and to some extent by RUWASA. With regard to sanitation, the water sector status report 2017/18 has estimated an average coverage of sewerage systems to be 30% (2018) in urban areas. On sanitation achievements, the same report indicates that by 2018, safely managed sanitation was available to only 21.2% of the population compared to the target of 25%. When this is compared to the SDG target of 100% by 2030, it can be seen that Tanzania is lagging behind by far.

1.2.1 National Water Policy

The National Water Policy (NAWAPO) of 2002 guides the management of the water sector in Tanzania with major emphasis being on the active participation of communities, the private sector and the local governments in protecting and conserving water sources, supplying water and management of water and sanitation infrastructure. Currently, the review of the NAWAPO is at fairly advanced stages.

The main objective of the National Water Policy of 2002 was to develop a comprehensive framework for sustainable development and management of the Nation's water resources, in which an effective legal and institutional framework for its implementation was put in place. The policy aimed at ensuring that water beneficiaries participate fully in planning, construction, operation, maintenance and management of community based domestic water supply schemes. This policy sought to address cross-sectoral interests in water, watershed management and integrated and participatory approaches for water resources planning, development and management. Also, the policy laid a foundation for sustainable development and management of water resources in the changing roles of the Government from service provider to that of coordination, policy and guidelines formulation, and regulation. Other objectives of the water policy included: increasing the productivity and health of the population through the assurance of improved water supply and sanitation services to the water users and to identify and preserve water sources.

1.2.2 Legal and Institutional Framework for Water Supply and Sanitation Services

Basically, the water and sanitation sector is governed by two main broad legal frameworks namely:

I. Water Resource Management Act No.11 of 2009
II. Water Supply and Sanitation Act No. 5 of 2019

In the institutional framework, there are several organs under the Ministry of Water, which coordinate water supply and sanitation delivery service: the Directorate of Program Preparation, Coordination and Delivery Unit (PCDU), Directorate of Water Resources Management, Basin Water Boards (BWBs), Directorate of Water Supply and Sanitation, Directorate of Water Quality Services, Rural Water Supply and Sanitation Agency (RUWASA) and Water Supply and Sanitation Authorities (WSSAs). Special attention is hereby paid to RUWASA as, in collaboration with respective regional or district authorities is responsible for planning and managing, and supervising the rural water supply and sanitation projects, including financial and procurement management, as well as monitoring and evaluation for contracting consultants and local service providers to assist with planning and implementation of the projects at the district level and in the communities.

Through implementation of WSDP I and II (up to 2019) projects, the role or participation of the beneficiaries in planning, construction, operation, maintenance and management of community based domestic water supply schemes was guaranteed in most of the implemented projects through establishments of COWSOs in every completed project that was given all the mandate of making sure the project is sustainable. Among the lessons learnt from the implementation of WSDP I & II projects was the need for engineers and consultants to use the MoW Design manuals in order to reduce or eliminate the many design flaws already observed.

However, according to the Water Supply and Sanitation Act No. 5 of 2019, the COWSOs were replaced by CBWSOs and these are expected to have the frontline responsibility for sustaining rural water supply and sanitation services on behalf of the beneficiaries (communities). The members of CBWSOs are drawn from the users but their qualifications and experiences have been better specified under the Act No.5. The minimum qualifications of the technical staff employed by CBWSOs has also been explicitly specified to ensure they have the requisite capability and experience. Their roles as well as the assumed responsibility of CBWSOs are also explicitly highlighted in the Act No.5 as well as the roles of RUWASA at different levels.

1.2.3 Coverage and Access to Water Supply Services

While the responsibility for provision of sanitation services in rural areas is principally under the Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC); following enactment of the Water and Sanitation Act No. 5 of 2019, RUWASA has also been given some responsibility to coordinate delivery of sanitation services in areas that are under its jurisdiction. In areas served by former National Project Water Utilities (WSSA), it is expected that the MoHCDGEC will liaise closely with both the latter and RUWASA to deliver sanitation services. It is estimated that by 2019, on average 21.2% of Tanzanians had access to safely managed sanitation (MoW AGM, 2019) against a National target of 25%.

1.2.4 Policy Environment for Water and Sanitation Services in Tanzania

The management of water resources in Tanzania is guided by the National water policy of 2002 (URT, 2002) that has been in use over the last 18 years and was further articulated by the National Water Sector Development Strategy of 2006 - 2015 (URT, 2008) and the WSDP of 2006-2025. There are currently efforts to update the national water policy by the Ministry responsible for Water. The most important national legislation guiding water resources management include the Water Resources Management Act No.11 (URT, 2009) and all subsequent amendments as well as the various regulations prepared by the Ministry responsible for Water.

The Water Supply and Sanitation Act No.5 (URT, 2019) and the associated regulations prepared by the Ministry responsible for Water guide the development of water supply and sanitation services in Tanzania. The users of this manual are referred to the URT website for further information. As regards sanitation, the Public Health Act of 2009 and The Health Policy of 2007 provide the relevant legal guidance. Other relevant guiding documents include The National Guidelines for Water, Sanitation and Hygiene for Tanzania Schools (MoEST, 2016), National Guidelines for Water, Sanitation and Hygiene in Health Care Facilities (MoHCDGEC, Oct. 2017), Guidelines for the Preparation of Water Safety Plans (MoW, Oct. 2015), National Guidelines on Drinking Water Quality Monitoring & Reporting (MoW, Jan. 2018) and Guidelines for the Application of Small-Scale, Decentralized Wastewater Treatment Systems; A Code of Practice for Decision Makers (Mow, Dec. 2018). Another Swahili document is titled "Mwongozo wa Ujenzi wa Vyoo Bora na Usafi wa Mazingira" (Guidelines for Construction of Toilets and Sanitation), (MoHCDGEC, 2014).

1.2.5 Major Stakeholders in Water Supply and Sanitation Projects

Effective and efficient implementation of water supply and sanitation projects will be achieved through the contribution of a number of stakeholders. The stakeholders of significant importance are described below.

(a) Regulatory Authorities

In order to ensure the smooth implementations of water supply and sanitation projects, various regulatory authorities have been established from time to time. The latter, monitor professional conduct of the different parties involved in water and sanitation projects. These include:

- Public Procurement Regulatory Authority (PPRA),
- Tanzania Bureau of Standards (TBS),
- Engineers Registration Board (ERB),
- Contractors' Registration Board (CRB),
- Energy and Water Utilities Regulating Authority (EWURA),
- The National Environmental Management Council (NEMC).

(b) Contractors and Consultants

Contractors are the firms that perform the actual construction of the water projects according to the agreed terms in the contracts. Consultants/Project Managers are firms that design water supply and sanitation projects and supervise the construction works depending on the terms and conditions specified in their respective contracts. Moreover, the consultant, on behalf of the client, approves completed structures with regards to the specifications given and the standards required as elaborated in chapter twelve of Volume I of the DCOM manual

(c) National Water Supply and Sanitation NGOs and networks

The following is a sample list of Non-Governmental Organizations (NGOs) that deal with water supply and sanitation services in Tanzania and hence have a contributing role to the Ministry of Water (MoW):

- Association of Tanzania Water Suppliers (ATAWAS),
- Tanzania Water Supply and Sanitation Network (TAWASANET),
- Tanzania Global Water Partnership (GWPTZ).

1.2.6 Water Supply and Sanitation Public Private Partnership in Tanzania

The national water policy (NAWAPO) of 2002 (URT) envisaged devolution elements to be introduced as well as public and civil service reforms. It had assumed that the Central Government would provide technical and financial support, coordination and regulation of water supply development while the private sector was expected to support the communities in planning, design, construction and supply of materials, equipment, spare parts and to support operations in some cases. The Development Partners (DPs), NGOs and CBOs were expected to provide funding and technical assistance to supplement the Government's efforts through basket funding.

In support of the Government the Public-Private Partnership (PPP) the policy of 2009 as also supported by EWURA which prepared the PPP guidelines for water supply and sanitation (EWURA, 2017) and the relevant legislation that was stipulated in NAWAPO 2002, the MoW has created the necessary environment for supporting the private sector such that, a sizeable proportion of the works, services and goods are procured from private sector Service Providers (SPs) hence assisting the Government in fulfilling its roles.

Essentially, one of the successes of NAWAPO 2002 has been the inclusion of the private sector in water supply and sanitation projects implementation. Notwithstanding the good experiences, the MoW (2018) indicated that even though the Water Sector Development Programme (WSDP) Project Implementation Manual gave a lot of opportunities to the private sector that procured most of the works, field experience has shown that the capacity of the private sector in Tanzania is limited in terms of having only a few staff and thereby failing to supervise the works properly.

On the other hand, the Ministry of Water organized a forum on enhancing public private partnership in the water sector. This was held in Dar es Salaam from 19 to 20 July 2018. In this forum, discussions were held with the private sector stakeholders where experiences, challenges and recommendations were obtained with regard to implementation of rural water supply projects in Tanzania. The forum was a follow up of the Five-Year Development Plan (FYDP) 2016/17-2020/21. The fourth priority area of the FYDP is strengthening project implementation effectiveness, which earmarked water supply and sanitation one of the key interventions for achievement. In the forum, the following key issues were captured:

(a) Contract management issues such as delays in decision making by the client,
(b) Payment problems,
(c) Procurement problems,
(d) Policy issues on Tax exemption for imports,
(e) Political interference in the execution of works,
(f) Knowledge gap on current technology available for groundwater exploration based on quality and quantity of water,
(g) Shortage of contractors with capacity to execute water supply projects,
(h) Database issues especially on water resources information, which often end up with over- or under- designing water supply facilities.
(i) Design specifications based on the use of obsolete technologies was identified as a critical problem.

Privatization of some or all functions of Operation and Maintenance can be considered to achieve: (i) efficiency (ii) economy (iii) professionalism and (iv) financial viability of the system. In order to achieve the above stated objectives, the private entrepreneur needs to possess: (i) adequately trained, qualified staff for operation and supervision of the services (ii) equipment, material, testing and repairing facilities (iii) experience in operating similar systems (iv) financial soundness (v) capacity to meet the emergency situations.

In order to assist service providers/operators in ensuring financial viability of their projects through Public-Private Partnerships, the following were recommended:

(a) The MoW, through the established in-house Design Unit should provide an option for on demand engagement of the private sector at the project level, in cases where in-house capacity or technology is limited;
(b) Enhancement of awareness on other operational modes in PPP as per water policy;
(c) Where applicable, private operators should be engaged in operation and maintenance of water supply and sanitation services after due diligence; The same applies to contracting personnel with specialized skills for the repair and maintenance of specialized equipment or instrumentation as specialized services for maintenance of such equipment instead of employing additional staff. Such a practice may ensure proper functioning of the equipment with least cost;

Private operators should be supervised closely to avoid challenges in operation and maintenance of water supply and sanitation projects (i.e. water supply connections, facilities and finances).

1.3 RATIONALE FOR PREPARATION OF THE FOURTH EDITION DCOM MANUAL

The need to review and update the 2009 Design Manual was emphasised during the Private-Public Partnership (PPP) stakeholders' meeting hosted by the MoW in 2018. During that meeting, the issue of providing designs/specifications that use old technologies in procurement was indicated as a concern as well as stressing the need to adopt the latest and appropriate technology. Among the Recommendations of the Special Committee on Audit of WSDP I & II projects in rural areas in Tanzania (URT, Nov. 2018), the need to review and update the design manual and to ensure that all consultants use it was emphasized. The four volumes of the DCOM manual have been prepared in order to facilitate effective complimentary planning, design, construction supervision as well as operation and maintenance of water supply and sanitation projects for urban, peri-urban and rural areas of Tanzania.

The manuals will also assist the staff of the Ministry responsible for water and sanitation projects to effectively undertake their supervisory and coordination roles and the consultants to undertake designs using the guidelines recommended in the MoW manual. For Urban and National WSSA or RUWASA staff who may be involved in design, construction supervision of projects using the Force Account mode of implementation, the four manuals will prove to be useful in facilitating step by step supervision.

On the other hand, for staff who will be implementing water supply and sanitation projects, the manuals will provide guidance on how they should involve all the principal stakeholders including the Community Based Water Supply Organisations (CBWSO) as foreseen in both the NAWAPO (URT,2002) as well as the NWSDS (URT, 2008). The manuals have been formatted in order to be more user friendly by allowing navigation within and across the manuals as well as having the capability to navigate into or from website links with ease using subject indices that enable a user to search for the needed information almost instantly. It is hoped that, the manuals will contribute towards improvement of the contract management capacity of the staff involved in project management and will eliminate the recurring problem of consultants designing water supply and sanitation management projects that are below minimum quality standards.

1.4 ABOUT THE FOURTH EDITION OF DCOM MANUAL

The 4th edition of the DCOM Manual was prepared in 2020, following the review and updating of the Third Edition of the Water Supply and Wastewater Disposal Design Manual of 2009. The former manual was prepared in three separate volumes. These volumes included eight chapters on water supply, three chapters on wastewater disposal and one chapter on water pipelines standards and specifications. It should be remembered that the 2nd Edition of the Design Manual that was titled Design Manual for Water Supply and Waste and Waste

Water Disposal was prepared in July 1997 in two volumes with eight chapters and three chapters, respectively. The 1st Edition of the Design Manual was prepared in 1985/86, a few years after the conclusion of the International Water and Sanitation Decade that ended in 1981. Thus, the current edition of the DCOM is adequately informed by previous edition reviews which incorporate topical and existing challenges and issues.

A Special Committee of twelve members from The Ministry of Water, RUWASA, University of Dar es Salaam (UDSM), The Nelson Mandela African Institution of Science and Technology (NMAIST) and Private Sector undertook the preparation of the four volumes of this manual. The process of preparing the design manuals entailed a number of participatory consultations with key stakeholders from the water and sanitation sector as well as from Ministries of Education, Science & Technology, Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC), President's Office Regional Administration and Local Government (PORALG) as well as Consultants, Contractors, Materials suppliers and Development Partners. It also involved undertaking an extensive search of literature from libraries, conference proceedings, and journal publications, websites of various entities and design manuals from various global, East African and SADC countries.

1.5 ORGANISATION OF THE 4TH EDITION DCOM MANUAL

The 4th Edition of the DCOM Manual has been prepared in four separate volumes that are divided as follows:

- **Volume I** which presents Design of Water Supply Projects organized into thirteen chapters;
- **Volume II** that dwells on Design of Sanitation Projects and is divided into six chapters;
- **Volume III** titled Construction Supervision for Water Supply and Sanitation Projects has been structured into five chapters; and
- **Volume IV** titled Operation and Maintenance for Water Supply and Sanitation Projects is organized into nineteen chapters. This Volume IV is organized into five parts as indicated below, and can be used as separate packages for training of different groups of users from the water sector:

  Part A: Essentials of Operation & Maintenance,

  Part B: O&M of the Water Supply Sources and Network,

  Part C: O&M of Water Treatment, Water & Wastewater Quality Compliance,

  Part D: O&M of Sanitation Projects,

  Part E: Water Audit, Revenue and Community Participation Management.

1.6 PURPOSE OF THIS VOLUME

The purpose of this volume is to guide well engineers, operators, management, technical staff, consultants, Government planners and contractors in-charge of the O&M of either a complete water supply and sanitation project or any component of the same as presented under routine operation functions, preventive maintenance, corrective maintenance and reactive maintenance undertakings. Volume IV of the DCOM Manual has also provided the opportunity for links or hyperlinks to many other websites and to use the subject index provided at the end of the volume to make instant searches and references.

This volume will guide the strengthening of the technical, operational and managerial capabilities required of concerned personnel as they operate and maintain water supply services as per acceptable norms of quantity, quality, sustainability, reliability and cost.

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Chapter 2

LIFE CYCLE COST AND SERVICE DELIVERY APPROACH

2.1 LIFE CYCLE COST APPROACH

Life Cycle Cost (LCC) represents the aggregate costs of ensuring the equitable and sustainable delivery of adequate, drinking water, sanitation and hygiene services to a population in a specified geographical area. These costs include not only the cost of constructing a system but also what it costs to maintain them in the short and long-term, to replace, extend and enhance them as well as the indirect support costs of the enabling environment, viz. capacity building, planning and monitoring at village, district and regional level, not just for a few years, but at least for the project design period or more.

The delivery of sustainable services requires that financial support systems are in place to ensure that infrastructure can be renewed and replaced at the end of its useful life, and to deliver timely breakdown repairs, along with the capacity to extend and improve the delivery system and improve service delivery in response to changes in demand. Thus the 'life cycle approach' is flexible enough to build, sustain, repair and renew the water and sanitation systems through the whole of their cycle of use.

The Life Cycle Cost Approach (LCCA) seeks to raise awareness on the importance of LCC in achieving adequate, equitable and sustainable drinking water and sanitation services; to make reliable cost information readily available and to mainstream the use of LCC in drinking water and sanitation governance process at every level.

LCCA is a step towards increasing the efficiency and effectiveness of investment in the WASH sector, to find a balance between the allocation of money for new infrastructure to increase coverage, and allocation for major repairs and rehabilitation of drinking water and sanitation infrastructure such as to maintain the basic level of service. The LCCA can be useful for monitoring and costing sustainable WASH services by assessing pertinent costs and comparing them against the levels of service provided, how the same can be achieved maximally with least spending.

2.1.1 Cost Components

The following cost components should generally be considered:

(a) ***Capital expenditure (CapEx) - hardware and software***: includes the concrete structures, pumps, pipes, treatment units, etc. to develop and extend water supply and sanitation service coverage. On software, costs should include community mobilisation, awareness raising and capacity development programme.

(b) ***Operating and Minor Maintenance Expenditure (OpEx)***: are the requirements for recurring regular, ongoing expenditure viz. labour, fuel, chemicals, material and purchases of bulk water meters as well as sewage collection/ disposal facilities (5% to 20 % of capital investments),

(c) ***Capital Maintenance Expenditure (CapManEx)***: focus on asset renewal, replacement and rehabilitation; works other than routine repair and maintenance and replacements that keep the system running smoothly,

(d) ***Cost of Capital (CoC):*** refer to the cost of financing a programme/project and include . the cost of accessing the funds needed to construct a system,

(e) ***Expenditure on direct support (ExDs)*** includes expenditure on both pre-and post-construction support activities,

(f) ***Expenditure on indirect support (ExIDS)***include the macro-level support, capacity building, policy, planning and monitoring that contribute to the sector working capacity and regulation but are not particular to any programme or project,

(g) ***Total Expenditure (TotEx)*** is determined on the basis of fixed assets and aggregates of the costs of all the components indicated above.

2.2 SERVICE DELIVERY APPROACH

A service delivery approach is a concept for ensuring the sustainability of drinking water and sanitation services. It seeks to improve the record of the project– and implementation- focused approaches, in which users initially enjoy good services after construction of drinking water supply and sanitation systems. But without support and proper asset management, the system quickly starts to deteriorate until it collapses completely. Sometime in the future, a new system is by necessity, built by another agency. In a service delivery approach, a water and sanitation system is maintained indefinitely through a planned process of low intensity administration and management, with occasional capital-intensive intervention to upgrade the service level and to replace specific infrastructure at the end of its useful life

A service delivery approach aims to provide long term services. Thus it goes hand in hand with life cycle costing, which accounts for costs over the entire life cycle of a service; both the initial engineering and construction of infrastructure and the software (capacity building, institutional support, financial planning) and maintenance required to sustain a certain level of drinking water and sanitation services delivery into the indefinite future. A service delivery approach requires defining the roles and responsibilities for multiple actors working at different levels for improved coordination and harmonization of all pertaining activities.

2.2.1 Why Does Service Delivery Approach Matter

In the early 1990s, an estimated 30% to 40% of water supply systems in developing countries including Tanzania were not functional. This non-functionality rate has not changed much to-date, and studies indicate that a similar proportion of the system, particularly hand pumps, either do not function at all or are working at sub-optimal levels. Because of the existent and emerging failures of service delivery in the water sector, the following problems have emerged:

(a) Throughout the World, approximately one in three water supply and sanitation systems are not working. Hundreds of millions of shillings have been wasted on infrastructure investment, and millions of people have returned to fetching water from distant and unsafe sources to the detriment of their health, education and livelihoods,

(b) True infrastructural life-cycle costs are poorly understood and are not planned for, resulting in extended down time or complete abandonment of systems, while funding for major repairs or replacements are sought,

(c) Community management as the predominant service delivery model has had limitations and is inherently unsuited to scaling up efficient service delivery.

Development partners and NGOs have often taken their own approaches to implement water supply projects, building systems without ensuring the needed institutional structures to sustain long term services. The rural water sector remains weak, despite significant investment to develop and sustain it.

2.3 SYSTEM MANAGEMENT

2.3.1 Need for Effective Management

The lack of effective management or poor management is the single biggest factor which leads to the low or non- performance of water supply and sanitation systems/facilities. This is clearly evident when there are no well-defined objectives, no long term planning, no short term programming or budgeting. Hence, there is a need for guidance to all managers in-charge and supervisors of the O&M of drinking water supply systems to formulate and implement activities aimed at improving the efficiency and effectiveness of O&M. The ultimate objective of the managers' roles shall be to provide to the consumers the best quality service at the lowest cost.

2.3.2 Systems Approach to Management

2.3.2.1 Approach

In a systems approach, each water supply and sanitation organisation is considered as an overall agency within which is a range of organizational systems.

Each organizational system is known by its area of specific action and represents specific functions. These systems can be implementation, operational, planning, administrative support (transport, supplies, etc.), financial, human resources and management information. These main systems can be further classified according to the differences in decision making and information processes, inputs, outputs, interactions and interconnections. The processing of information linked to the needed management activities is the basis for determining targets, fixing priorities, schedules, responsibilities, distribution of resources and management of the entire decision-making process.

2.3.2.2 Advantages of the Systems Approach

The following are the advantages of systems approach in project management:

- It enables managers to describe and organize the service framework of a water supply and sanitation agency and to allocate due resources so that targets can be achieved.
- It forms the basis for management to control and measure results, take corrective actions, formulate new parameters and effectively distribute new resources.
- It enables managers to study the functioning of the concerned agency, and discern the relationships between various wings of the agency.

2.3.2.3 Operational System

The objectives of an agency's operational system are:

To establish standards for the delivery of water and sanitation services that are satisfactory in respect of quality, quantity, continuity, coverage and cost,

- To maintain installations and/or fixing of equipment in such a manner as will ensure that they can be operated satisfactorily, function efficiently and continuously, and last as long as possible at lowest cost, and
- To produce and disseminate information on existing water supply and sanitation services, and their component units with specific reference to their functioning and adequacy to meet the needs of users, thus enabling the agency to evaluate the performance of installations in place and the effectiveness of the services provided.

2.3.2.4 Component Elements

The component elements of a water supply and sanitation operational system are collection, treatment, storage and distribution of water including customer support. The main functions of O&M are to:

(a) Ensure that the installations and equipment are operated efficiently to produce and distribute quality drinking water,

(b) Monitor and ensure the smooth operations and functioning of installed facilities,

(c) Monitor the agency's services focusing on quality, continuity and coverage of water supply,
(d) Carry out needed maintenance efficiently and economically,
(e) Monitor the performance of all equipment and evaluate their effectiveness and regular maintenance,
(f) Ensure the timely gathering of information on needed maintenance pointing out potential problems such as weakness of structures, unreliability of equipment and with particular focus on identifying obsolete equipment and determining how long the facilities can function usefully before their full replacement,
(g) Ensure that the maintenance objectives and standards are set-forth so that due repair and replacements can yield maximum benefit at minimum cost.

2.3.2.5 Management Information Systems

Management Information System (MIS) is defined as a formal system of making available, to the management, accurate, timely, sufficient, and relevant information to facilitate decision making such as to enable the organisation to carry out the specified functions effectively and efficiently in tune with the organisation's objectives. Organisations have many information systems serving at different levels and functions. Each agency is expected to decide which information is relevant and evolve its own procedures for the collection, measurement, recording, storage and retrieval of accurate data. The MIS can be developed through the use of available software.

The efficient and effective performance of an agency depends on having a clear relationship between management activities such as planning, organisation, selection and training of staff, coordination, direction and control of the functions of the agency. The interaction between individuals at different management levels, together with the use of relevant information in the decision making process which is important for the agency's performance. Each of the management levels has different focal centres of decision making and each of these is and should always be supported by a management information system.

2.3.2.6 Database of Water Supply and Sanitation Projects

To achieve efficient and effective performance of water supply and sanitation projects, a database for the projects is required for analysis and use as fit. This helps in determining the life of the schemes, time schedule for augmentation of each component, sustainability of sources, and the system. Moreover, in order to provide safe drinking water and efficient sanitation services in adequate and desired quantity and quality, at adequate pressure and convenient locations and time and as economical as possible on a sustainable basis. The data can be collected with the help of manual or automatic systems or software with some remote measurements as explained in Chapter Sixteen.

Chapter 3

OPERATION AND MAINTENANCE OBJECTIVES FOR WATER PROJECTS

3.1 THE CONCEPT OF OPERATION AND MAINTENANCE

The two core activities of "operation" and "maintenance" as applied to water projects are very different in nature. "Operation" refers to hourly and daily operations of the components of a system such as plant, machinery and equipment (valves etc.) as undertaken by an operator or his assistant. This is routine work. It encompasses direct access to the system by the user (e.g. operating the hand pump), to the activities of any technical operational staff as a routine function (e.g. operators of headworks, motorised pumps, treatment plant, machinery and equipment, conveying mains, service reservoirs and distribution system, etc.). Operation includes the planning and control of the extraction/collection, treatment, conveyance, and delivery of water, and/or the collection, treatment, and disposal of effluent. It also covers the management of clients and public relations, legal system, personnel, commercial, and accounting functions

"Maintenance", on the other hand, is defined as the art/act of keeping the structures, plants, machinery and equipment and other facilities in an optimum working order (WHO, 2005;). Maintenance requires skills, tools and spare parts (Carter, 2009). Maintenance, may be Preventive, Corrective or Reactive:

- *Preventive maintenance* - includes work that is planned and carried out on a regular basis to maintain and keep infrastructure in good condition, such as network inspection, flushing of the water wells and water lines, disinfection of water tanks, cleaning and greasing of mechanical parts and replacement of parts with a limited lifespan. Preventive maintenance not only extends the lifetime of WASH infrastructure but also saves costs in the long-term as it reduces the frequency of costly breakdowns and also reduces the frequency with which expensive reactive maintenance or emergency backup solutions are required (Harvey 2015). It sometimes also includes minor repairs and replacement of parts as dictated by the routine monitoring and inspections.

  It is essential to schedule preventive maintenance to ensure the routine smooth operations and health of the system. This can be done by way of routine check-up inspections. The camp manager or the person in charge of the WASH services will need to ensure that the technician is doing his/her job well regularly and is always alert. The key to ensuring effective plant and equipment maintenance is to make certain that responsibilities are clearly defined and maintenance personnel have the tools and skills to do their job effectively.

- *Corrective maintenance* - includes replacing or repairing parts or something that was done incorrectly or that needs to be changed; an example is the reallocation of a pipe route or replacement of a faulty pump.
- *Reactive maintenance* – is a reaction to a crisis or public complaint; and normally occurs because of failure and or the malfunctioning or breakdown of equipment. Responsive maintenance should allow for a quick and efficient response to WASH-related problems that occur suddenly. This is best handled by mobile WASH teams that should be properly trained and equipped (with spare parts and tools) to immediately respond to infrastructure failure or breakdown and to handle emerging situations promptly (Harvey 2015, IOM, NRC and UNHCR 2015).

The project manager will need to ensure that the operator/technician is always alert and does his job well. If undertaken correctly and on a regular schedule, preventive measures can reduce the risk of costly repairs. The key to ensuring effective plant and equipment maintenance is to make certain that responsibilities are clearly defined and maintenance personnel have the tools and skills to do their job effectively. It is also essential to schedule preventive maintenance.

3.2 OBJECTIVES OF OPERATION AND MAINTENANCE

The overall aim of O&M is to ensure efficiency, effectiveness and sustainability of WASH facilities (Castro et al., 2009). The specific objective of an efficient operation and maintenance (O&M) in relation to a water supply and sanitation system is to provide safe drinking water and sanitation as per designed quality and quantity, with adequate pressure at convenient locations and time at competitive cost on a sustainable basis as well as sustainability of sanitation services. The O&M is a crucial element of sustainability and its lack is a frequent cause of failure of water supply and sanitation service facilities (DFID, 1998). If O&M of Water, Sanitation and Hygiene (WASH) services is not prioritised by the key actors, infrastructure may deteriorate quickly and the affected population may lose access to facilities that serve their basic needs (European Commission, 2014). Hygiene levels, too, are adversely affected by poor O&M (UNICEF Jordan 2016; IOM, NRC and UNHCR, 2016).

Advantages of O&M activities:

- To ensure that the project is sustainable in the long-term;
- To enable the correct provision of services and benefits to end-users;
- To prevent a water supply and sanitation projects from creating environmental and health hazards and from collapsing;

- To ensure that end-users are made directly responsible for the O&M of the installed facilities, hence promoting and enhancing community ownership of a water project.

Disadvantages of O&M activities:

- O&M costs time and money, and therefore a provision for financing O&M has to be planned before the project starts operating.

Why Maintenance?

Maintenance of facilities is essential in order to prevent failure of components and instead extending the useful life of the facilities and minimizing disruptions in services. Good maintenance involves the following:

(a) Quick repair/replacement of any failed component;
(b) Up-to-date training of maintenance personnel;
(c) Adequate inventory of parts and tools needed for repairs;
(d) Efficient mobilization practices in emergencies; and
(e) Valve exercising (single most important form of preventive maintenance for reliability of a service).

3.3 OPERATION AND MAINTENANCE SCENARIOS

It has been observed that the lack of attention to important aspects of Operation & Maintenance (O&M) of water supply and sanitation projects in several locations often leads to their being dysfunctional or in deterioration of the useful life of the systems necessitating premature replacement of many components, thus incurring huge losses to users or the government. As such even after creating such assets by investing millions of Tanzanian Shillings, the concerned experts and or technicians fail to provide proper services effectively to the community for which the facilities have been constructed but have become dysfunctional or are underutilized most of the time.

Some of the key issues contributing to poor O&M have been identified as follows:

(a) Lack of finance, equipment, material, and inadequate data on Operation & Maintenance,
(b) Poor system design; and inadequate workmanship,
(c) Multiplicity of agencies and, overlapping responsibilities,
(d) Inadequate numbers of operating staff,
(e) Illegal tapping of water,
(f) Inadequate training for concerned personnel,
(g) Low attraction of maintenance jobs in career planning,
(h) Lack of staff performance evaluation and regular monitoring,
(i) Inadequate emphasis on preventive maintenance,
(j) Lack of O&M manual,
(k) Lack of real time field information.

Therefore, there is a need for clear–cut sector policies and legal framework and clear demarcation of responsibilities and mandates for O&M for all water supply schemes or sanitation projects.

3.4 HOW TO IMPROVE OPERATION AND MAINTENANCE

Efficient and effective operation depends on sound water supply and sanitation strategies which comprise:

- Water and sanitation safety plans to ensure good quality of water, hygienic and safe wastewater disposal and waste reuse practices,
- Standard Operating Procedures (SOP) including who does what and when, and to identify associated annual expenses and revenues; and
- Service improvement plans to set out future investments to ensure improved and sustainable service delivery.

3.4.1 Water Safety and Safely Managed Sanitation Plans

Water Safety Plan (WSP) serve to shift the focus from end-of-pipe testing to improved operational management, with water quality testing used to verify outcomes. They provide a means of prioritizing improvement programme based on health outcomes. Most importantly, water and sanitation safety plans bear in mind and address bacteriological contamination which is the biggest water quality related threat to public health, especially infant mortality.

The main objectives of a water safety plan include protecting human health and ensuring good water supply practices which minimize contamination of water sources , the reduction or removal of contamination through appropriate treatment processes and the prevention of contamination in the overall distribution network as well as the domestic distribution system. These objectives are applicable to all water supply chains, irrespective of their size or complexity and are achieved through:

(a) Enhanced understanding of each specific system and its capability to supply water that meets health-based targets;
(b) Identification of potential sources of contamination and how they can be controlled;
(c) Validation of control measures employed to mitigate potential hazards;
(d) Instituting a system for monitoring control measures within the water system;
(e) Taking timely corrective actions to ensure that safe water is consistently supplied; and
(f) Undertaking verification of drinking-water quality to ensure that the WSP always runs correctly and achieves the performance level and meets the required and relevant national, regional and local water quality standards and objectives.

The WSPs are an effective way of ensuring that water supply is safe for human consumption and that it meets health based standards and other safety regulatory requirements. WSP is based on a comprehensive risk assessment and risk management approach in all the steps in a typical water supply chain from catchment to consumer (Source: https://sswm.info/sswm-solutions-bop-markets/improving-water-and-sanitation-services-provided-public-institutions-2/water-safety-plans)

A water safety plan may involve surveying the water supply system from source to storage / treatment to distribution to households (also known as sanitary survey) so as to identify actual and potential sources /causes of contamination and corresponding operational control measures to reduce possible risks. The controls have to be monitored to check and ensure that all the components of the projects are in smooth working order; otherwise remedial actions must be taken accordingly. The URT (2015a, b) provides guidelines for the preparation of water safety plans - resilient to climate change for urban water supply utilities and rural water supply services in order to proactively identify the longer-term risks involving water supply systems such as increasing water scarcity or pollution amongst others. The same approach can be applied to sanitation systems/ facilities. Safely managed sanitation calls for ensured safety of the workers involved and all the pertaining sanitation components through the whole service delivery/value chain.

3.4.2 Standard Operating Procedures

A standard O&M function involves:

(a) Operating staff,
(b) Supervisory staff.

While the former actually run the system, the latter engage in monitoring the operations and providing managerial support.

It is difficult to propose a rigid organisational structure model for use in all places. It is possible to vary the staffing from place to place based on site-specific requirements, availability of suitable manpower and existing working practices.

Standard Operating Procedures are essential for identifying what local operators should do in terms of routine O&M related to water sources, conveying, pumping, storage and water/sewage treatment units, distribution systems and sanitation systems including household water/sewer connections as well as relevant management practices. Annual budgetary operation expenses and incomes levels and annual surplus/deficit should always be recorded and the data maintained. A member of staff with good experience and required skills would be needed to train operators and assist them whenever problems arise. In-house training may be carried out to staff in the fields of pump mechanic, pump operators, welding, plant operator, plumbing, masonry, and carpenter depending on the type of facility involved and in operation.

Often the tasks required can overwhelm a local operator or overseer who may have only basic skills and limited experience, but by providing basic orientation in terms of hands-on training the same can build confidence to do the job well.

When the plan or programme containing pertinent procedures is prepared for each piece of equipment, the person to oversee this action is to be identified. This person's job description should contain reference to the maintenance plan/programme. The job descriptions for all operating personnel shall clearly define the limits up to which the staff can carry out normal maintenance. The job description of the Supervisor/Manager shall include the requirement to ensure that the operating personnel conform to the defined limits and thus ensure the safety of all equipment. The personnel who are already available or chosen to carry out the actions defined in the programme may have to be trained as indicated in Section 4.2.2. On the job training is always preferred to class room training.

A job description shall be prepared for each operator, and shall contain detailed instructions as to how he/she should carry out the actions required of him/her in the operation and maintenance plan. The training shall evolve a personnel management policy, which will ultimately provide for job training followed by performance evaluations and promotions. The supervisors shall be trained to train the operators. Every operator who is assigned a job in the operation and maintenance plan/programme shall be given appropriate (on the job) training on how to perform the actions assigned to him/her. Encouragement can be offered by way of incentives to those who have improved their performance after successful training.

3.4.3 Service Improvement Plans

It is important to define management and service delivery improvement modalities and actions for improved accounts, billing and revenue collection for both water supply and sanitation services.

Chapter 4

OPERATION AND MAINTENANCE STRATEGY

4.1 INTRODUCTION

The large investments made to construct utilities intended to provide facilities for water supply and sanitation are becoming generally unproductive, mainly on account of poor maintenance. If this anomaly continues unchecked even after years, these projects can become defunct, and a large amount of money will be required to replace and rebuild the system and its components and to control occurrence of interruptions in service provision due to the breakdowns of equipment. The water supply and sanitation boards/departments are not able to ensure that the maintenance staff follow valid modes of operation and practices of O&M. Generally, the managements of Water supply and sanitation systems in Water Supply and Sanitation Authorities (WSSAs) receive relatively low priority. Further, the lack of funds coupled with the lack of enthusiasm/motivation among the operation and maintenance staff to keep projects in good working conditions as well as the lack of adequate training of staff may be the main reasons for the poor status and poor performance of water supply and sanitation projects in the country.

The O&M aims to ensure the smooth, uninterrupted and sustained provision of water supply and sanitation services with the guarantee that:

(a) The useful life of the water supply and sanitation facilities needs to be extended and their service quality enhanced;
(b) The health of the population must be maintained;
(c) The quality of the environment must be preserved and protected; and
(d) The marginalized should benefit.

Even so, there are undesirable consequences of poor O&M and include:

(a) Intermittent water supply due to wastage and depletion of sources;
(b) Poor water quality due to inadequate treatment and contamination;
(c) Deterioration of pipes, equipment, and services;
(d) Increases in the costs of maintenance and
(e) Failure to secure consumers' acceptance of increases in tariffs.

The actions which are considered and are essential for the good operation and maintenance (O&M) of WASH facilities and services include the following (REDR, 2016):

(a) Ensuring that all water supply infrastructure do function well and that the lifespan of water supply facilities is maximized;
(b) Maintaining cleanliness and ensuring good level of hygiene for WASH facilities;
(c) Carrying out regular de-sludging;
(d) Promoting hygiene to foster a sense of accountability for the maintenance of hygienic conditions and thereby winning the people`s motivation to properly maintain and efficiently and effectively operate WASH facilities;
(e) Supervising and facilitating the participation and empowerment of ownership for the maintenance of latrines, toilet sanitary facilities;
(f) Instituting mechanisms for and ensuring the control of flies;;
(g) Ensuring continued and safe access and adequate lighting of sanitary facilities.

The basic considerations for O&M of water supply and sanitation system are as follows:

(a) Preparation of O&M Plan:
    (i) The plan involves a list of routine tasks, specific tasks at regular intervals including inspection of the system (daily, weekly, quarterly, annually etc.);
    (ii) The plan also involves the preparation of a checklist for operation, supervision and maintenance.
(b) Preparation of a map of water supply network and sanitation services for a town/village starting with and including the water source, head works, treatment and distribution network. However, it should be noted that the maps for maintenance purposes are of a smaller scale and have more detailed information. These have to show the location of service pipes, valves, house connections, etc. enabling efficient reaction when problems occur. If made by computer, the maps can be created with different sorts of information and overlaid, which is convenient for analyses (e.g. separate maps showing topography, houses and streets, pipe network, sewer network, electricity and gas, etc.).
(c) Institutional arrangements and hiring adequate human resource and capacity building;
(d) Management of Stores for the availability of tools, parts/spares, equipment, basic materials, etc.;
(e) Maintenance of records and details of materials/tool/equipment purchased to include date of purchase, manufacturer details, cost of purchase, warranty, dates for part replacement, etc.; and

(f) Financial Arrangements to encompass working out average annual O&M expenditures and working out financial arrangements inclusive of user charges, utility's own fund, other grants, etc.

4.2 PREPARATION OF OPERATION AND MAINTENANCE PLAN

A plan has to be prepared for the smooth operation and maintenance of every major unit as well as the totality of projects as a whole. The overall operation and maintenance plan should be made project-wise to meet the needs of the various individual units. The plan must encompass procedures for routine tasks, checks and inspection at set intervals viz. daily, weekly, quarterly, semi-annually or annually.

4.2.1 Development of Individual Unit Plans for Smooth Overall Operation and Maintenance

Individual plans must be prepared scheme-wise for all units and all pieces of equipment must be indicated. Each unit must have a plan with fixed responsibility, timing of action, ways and means. Generally actions recommended by the manufacturer or by the site engineer in charge who has installed the equipment or who has supervised the installation should be included. Often the contractor's recommended operation and maintenance procedures at the time of design/ construction will be a good starting point for preparing a sound plan for a unit. This plan has to be followed by the O&M staff and will be the basis for supervision/ inspection. It also may be used for the evaluation of the O&M status and the delivery of the desired outcomes.

The agency in-charge of O&M for water supply and sanitation projects shall become service oriented. It is essential that the organization responsible for O&M has well qualified, trained, experienced, motivated and efficient staff for improved and efficient and effective performance.

4.2.2 Plans for Capacity Building of Operation and Maintenance Personnel

A befitting staff training programme can be organized through different water supply and sanitation utilities. The personnel who are already available or chosen to carry out defined actions as contained in the programme may have to be trained or retrained through special courses or through "on the job training "to ensure that all personnel are adequately trained to carry out the functions and activities listed in the maintenance plan. The training should first and initially focus on supervisors who should in turn train the operators.

4.2.3 Spares and Tools Provision Plan

It is essential to always ensure the availability of spare parts for every project like stand-by pump-sets, minimum numbers of different sizes of pipe fittings assessed on the basis of lengths of pipe-lines, all sizes of nuts and bolts, bearings, valves, fittings, pipe pieces of different sizes & materials, electrical spares for water supply and wastewater like miniature circuit breakers (MCBs), relays, motors etc. The availability of adequate spare parts for needed repairs and replacements must be ensured by ordering early ensuring their delivery by organizing a clear and preferably computerized inventory system. The list of spare parts to be procured can be drafted on the basis of manufacturer's recommendations/ consumption rate for material in previous years. The spare parts procured should be of requisite nationally approved standards, with due proper quality checks for assurance.

4.2.4 Water Audit and Leakage Control Plan

The availability of portable water (underground and surface) is very limited. There are considerable losses in the water produced and distributed through leakages in pipelines, valves, public taps unauthorized service connection etc. The average percentage of Non-Revenue Water (NRW) in many water supply and sanitation utilities ranges from 15 to 55 percent. Thus, large amounts of water can be wasted and this also translates into loss of revenue or water service related resources. It is therefore, essential to plan the conservative use of water i.e. water supply and wastewater/sewerage systems auditing/ leakage control through metering, improved O&M practices and awareness intervention.

4.2.5 Plan for Efficient Use of Power

In water projects, power charges can be as high as 30 to 50% of the total O&M costs. Hence, an efficient use of power with matching reduction of wastage of the resource will go a long way towards efficient functioning of the utility. This could be achieved through systematic energy audit in order to identify the possible means to save energy and reduce unnecessary consumption above the star rating equipment/Power capacitors.

4.2.6 Plan for Sound Financial Management System

It is essential to establish a sound financial management system to make water supply and sanitation projects financially viable. This can be achieved by controlling expenditure and increasing the incomes levels through the preparation of annual budgets, based on realistic estimates. The full cost recovery for O&M through user charges may be adopted. However, EWURA and RUWASA are responsible for giving approval for tariff levels relating to water supply and sanitation services depending on the O&M expenditure ceilings and the socio-economic condition of water users.

4.2.7 Plan for Education and Information Communication Relating to Water and Sanitation Services

Information Education Communication (IEC) activity is an essential part of awareness building for every community in the effort to ensure enhanced awareness about safe and clean drinking water as well as efficient sanitation facilities. Awareness building for effective use of water and safely managed sanitation services can be generated among water service consumers through plays, social media, electronic media, print media and wide publicity. The utility organizations should prepare befitting Information-Education-Communication materials and use the services of voluntary organizations/NGOs to create the needed awareness among water services users as well for the general public.

4.2.8 Role of Voluntary /Non-Government Organization

The role of Voluntary /Non-Government organizations (NGOs) can have important roles especially in the creation of public awareness on issues like water conservation, sanitation, proper use of water and the need to pay sustainably for water and sanitation services at affordable levels. Water users committees may be formed through the active support of NGOs to periodically review local problems relating to water services and advice the CBWSOs on needed improvements and for the upkeep of utilities within their jurisdiction and also encourage the people to regularly pay for water and sanitation services and encourage the public to maintain hygienic habits such as regularly washing hands and using toilet facilities at family and community levels.

4.2.9 Reporting and Records Keeping

A reporting and records systems need to be developed and should be realistic and relevant to the operational issues in particular situations and should focus on production, storage, and treatment or disposal sites or re-use of materials. The most efficient way to keep records is to plan for essential data, prepare the data formats and appoint persons to fill in the data, record pertinent frequencies and review and report and submit the reports to relevant authorities.

Reports and records keeping systems shall be enforced such as to list all the basic data about each piece of equipment including the d the history of the equipment. In each area of O&M, from a list or template of operations and maintenance, such data can be identified or extracted for record keeping and reporting as appropriate.

Examples include:

(a) pamphlets/manuals of pumping equipment, including pump curves;
(b) As-built plans of the system or plans and engineering drawings;
(c) Capital expenditure records;
(d) Water meter data such as meter type, when installed, and serial number; and

(e) Well designed, logs and results of pumping tests.

A reporting system shall be provided for the operator to inform the supervisor / manager about existing and potentially emerging problems of each equipment which requires attention for repair or replacement by the relevant crew or other specialized service personal.

Advantages of keeping records

These include:

(a) To maintain the necessary inventory of the materials used and required,

(b) To maintain reports of total cost of repairs and replacements in previous years along with breakdown of material and labour costs with due amount spent on outside utilities/agencies for repairs and replacements,

(c) Information and alert for the replacement of damaged pipelines and manhole covers,

(d) To maintain records on when exposed piping was last painted and the cost of materials and labour cost thereof, and

(e) To maintain reports on the un-served areas for extension of water pipelines which need inter-connection

Chapter 5

WATER SUPPLY AND SANITATION PROJECTS

5.1 TYPES OF WATER SUPPLY SCHEMES

Effective Operation and Maintenance calls for an understanding of the types of water supply schemes. The types of water supply schemes are given below:

(a) Open wells/ Sanitary dug well/ rain water harvesting collections,
(b) Hand pumps schemes,
(c) Gravity flow piped water supply schemes,
(d) Power pump scheme,
(e) Hand pump fitted with mini power pump schemes or pump and tank scheme based on bore wells or sanitary dug wells,
(f) Single habitation and multi habitation piped water supply schemes based on surface and ground water,
(g) The sources of single village and multi habitation piped water supply schemes. These may be an open well, protected shallow wells, boreholes, infiltration wells, infiltration galleries, rivers, dams, reservoir, and canals.

The water sources that are applicable in Tanzania have been presented in Volume I. It is advised that the user of this volume should consult Volume I for more details and guidance.

5.2 COMPONENTS OF WATER SUPPLY SCHEMES

Piped water supply schemes comprise the following components, the details of which are illustrated in Figure 5.1:

(a) Source/ intake works,
(b) Raw water storages and sumps,
(c) Transmission system,
(d) Treatment plan,
(e) Pumping machinery,
(f) Disinfection plan,
(g) Balancing Reservoir,
(h) Distribution system,
(i) Water testing laboratories /storage facilities & operators quarters (depending on the size of the scheme),
(j) Clean water storage/ Reservoir.

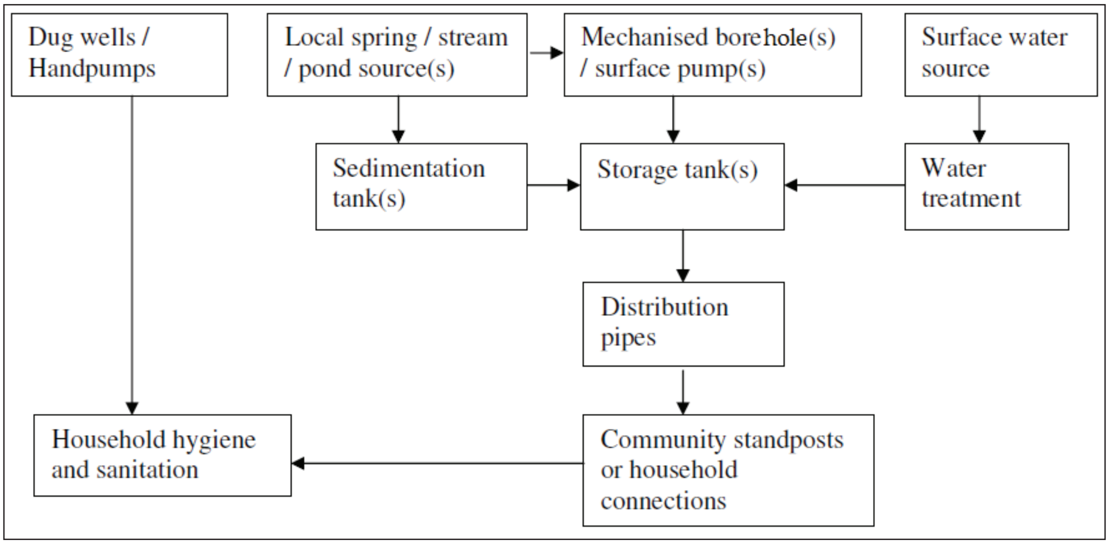

Figure 5.1: A Typical Flow Diagram Showing a Water Supply System with Different Types of Units/Schemes to Delivery Points for O&M Surveillance Activities

(Source: GoI, 2013).

5.3 COMPONENTS OF SANITATION SCHEMES

The components of sanitation schemes/services and their details have been illustrated in Volume II.

PART B: OPERATION AND MAINTENANCE OF THE WATER SUPPLY SOURCES AND NETWORKS

Chapter 6

SOURCES OF WATER SUPPLY

6.1 TYPES OF SOURCES

Rain, snow, hail, sleet precipitate upon the surface of the earth as meteorological water and may be considered as original sources of all the water supplied to the earth. Water for drinking and other uses occurs in the form of surface water and ground water.

The following are the common sources of water for human and other activities:

- Surface sources: a) Rivers, canals, b) streams, c) reservoirs and impoundments, d) lakes;
- Sub surface sources: a) Infiltration wells, b) Infiltration galleries, and local springs;
- Ground water sources: a) Open wells/protected shallow wells/boreholes.

This chapter covers the basic concepts and procedures for proper O&M of water sources and pertinent equipment used for water sources and for the preparation of water for distribution. It covers O&M of surface water (infiltration galleries, rivers, springs, etc.) and ground water (wells, boreholes, etc. and their pumps, motors and chlorinators). Three aspects should be considered in appraising water resources, e.g. water quantity, quality, and reliability.

6.1.1 Surface Water

Surface water accumulates mainly as a result of direct runoff from precipitation (rain or snow). Precipitation that does not enter the ground through infiltration or is not returned to the atmosphere by evaporation, flows over the ground surface and is classified as direct runoff water. Direct runoff is water that drains from saturated or impermeable surfaces, into stream channels, and then into natural or artificial storage sites or into the ocean in coastal areas. In addition, to serving domestic water needs, a reservoir may be used for flood control process and drought mitigation, for hydroelectric power generation, and for agricultural purposes.

The quantity of available surface water depends largely on the intensity & duration of rainfall and also varies considerably between wet and dry years. Surface water supplies may be further divided into rivers, lakes and reservoir supplies. Dams are constructed to create artificial storage. Surface water can be conveyed from canals/ open channels to the schemes through intake structures/flow regulator and transmission pipes by gravity/pumping. The style of management of lakes and reservoirs used for domestic water supplies varies widely depending on the local conditions.

The probability of contamination of surface water is very high. The factors affecting water qualities are wastewater, agricultural waste, domestic and industrial discharge, grazing of livestock, and drainage from mining areas. The method of water treatment depends on the raw water quality and ranges from disinfection only to complete treatment.

6.1.2 Springs

When groundwater makes its way to the earth's surface and emerges as small water holes or wet spots, this feature is referred to as a spring. The use of springs as the main source of community water supply is applicable whenever a spring occurs and its yield in terms of quantity and quality is sufficient. However, to maintain water quality, protection of the spring in a catchment zone has to be ensured permanently to avoid contamination. Although springs only need little operation and maintenance, monitoring of water quality has to be conducted regularly (Meuli & Wehrli, 2001).

In many rural areas, spring water is often accessed without having effected spring protection measures or having installed appropriate catchment systems. As a consequence, the spring may get contaminated and water quality may not meet the accepted and approved criteria and standards for drinking water. A properly tapped spring can improve a community's water supply substantially if combined with adequate protection measures. If a natural spring is the source of the Utility's water, then the area should be enclosed with a fence to prevent animals from contaminating the water and polluting the surrounding area.

6.1.2.1 Different Types of Springs

The different types of springs are indicated below (Adapted from Smet & Wijk, 2002; https://sswm.info/arctic-wash/module-4-technology/further-resources-water-sources/springs):

- Gravity Depression Springs- occur in unconfined aquifers. Where the ground surface dips below the water table, any such depression will be filled with water,
- Gravity Overflow Springs- A larger and less variable yield from gravity springs is obtained where an outcrop of impervious soil, such as a solid or clay fault zone, prevents the downward flow of the groundwater and forces it up to the surface,
- Artesian Springs- artesian groundwater is prevented from rising to its free water table level by an overlaying impervious layer. It is usually under constant pressure and constantly seeks its way to the surface.

Advantages

The different types of springs have the following advantages:

(a) High water quality,
(b) Fairly low construction costs where pumping is not required (gravity-based distribution system),
(c) Very little effort and cost ae needed for their operation and maintenance,
(d) High reliability of water flow and no seasonal variations (only artesian springs),
(e) O&M can be carried out by a local caretaker of the water source,

Disadvantages

Despite their advantages, springs also have disadvantages including:

(a) The risk of contamination, especially for gravity springs,
(b) The need for ensured spring protection,
(c) Unstable flow, mostly dependent on rainfall (only gravity springs),
(d) Increases of water yield is not possible,
(e) Possibility of a spontaneous disappearance of the spring,
(f) Location of the spring may not be convenient or easily accessible for water to a community
(g) Opportunities for spring tapping are limited to specific regions (depending on topography, geology and hydrology).

6.1.2.2 The Spring Box

To enhance the utility of a spring as a source of water for human use, as well as to protect it from erosion, it should be provided with a spring box, which is a concrete structure that serves three purposes:

(a) Protects the water source from contamination;
(b) Facilitates the collection of the water; and
(c) Enables sediments to settle at the bottom instead of being carried with the water.

Care must be taken during the construction of a spring box, to avoid or uproot surrounding trees whose roots could eventually damage the concrete spring box. The design should include a drain (or washout) pipe and a valve that will allow it to be drained easily for regular maintenance.

6.1.2.3 Operation and Maintenance of Springs

According to Meuli & Wehrle (2001), spring catchments need very little effort in operation and a lot less maintenance than other water catchment systems. A simple design combined with high-quality construction for all structures in the catchment area will keep maintenance requirements to a minimum. Nevertheless, all spring catchments need periodic check-ups. To ensure water quality from these sources and to avoid operational problems at the catchment, a monthly control is vital. Minor jobs like basic repairs or monitoring activities can be planned and carried out by the operator (HELVETAS N.Y.). In case of major repairs (e.g. wet spots around the catchment, leaks at the spring chamber, etc.), the responsible service provider should be consulted. The following aspects have to be checked and ascertained during regular visits to the catchment area (HELVETAS N.Y.):

(a) **At the protection zone:**
- (i) The fence protecting the area,
- (ii) The installed diversion drainage above the catchment,
- (iii) Wet spots indicating a leakage from the catchment,
- (iv) Prohibition of trespassers such as human activity such as farming in the intake area.

(b) **At the Spring Box/Chamber:**
- (i) Leakage at the chamber,
- (ii) The firmness of the manhole cover,
- (iii) Assured blockage at the supply line - water comes through the reserve (overflow) pipe,
- (iv) The ventilation,
- (v) The water quality and quantity (tested without equipment),
- (vi) Size of Sedimentation in the chamber,
- (vii) Yield of the spring in relation with the data of the previous years.

6.1.2.4 Common Spring Box Failures and Remedies

Table 6.1 lists the common causes of failure in a spring box and its surroundings with clear suggestions for their remedies.

Table 6. 1: Common Spring Box Failures and their Remedies

Defect	Remedy
1. Crack or leak.	1. Plug crack or leak with Portland cement mortar.
2. Damaged overflow and screen vents.	2. Replace damaged screen with a new one.
3. Clogging of drainage canal.	3. Clean drainage canal from all obstructions and check its slope.
4. Dilapidated fence.	4. Replace all worn-out posts and repair the fence.
5. Reduced spring discharge due to clogging	5. Clean the “eye” of the spring.

(Source: World Bank, 2012)

6.1.2.5 Maintenance of Spring Boxes

The following are standard methods of maintaining spring boxes:

(a) If properly installed, thereafter spring boxes require little maintenance. It is recommended that the water quality be checked before it is put to use. Water quality should also be checked at least once a year, and more often if needed,

(b) The uphill diversion ditch should be inspected regularly in order to ensure that it is not eroded and that it is adequately diverting surface runoff away from the spring box,

(c) For hillside collection boxes, the uphill wall should be periodically inspected to ensure that it is not eroded and its structural robustness is maintained,

(d) The animals barring fence should always be kept in good repair. If animals are allowed to get close to the spring, they could contaminate the water and the spring, and consequently cause compaction of soil, leading to decreased flow rates,

(e) The cover should be checked frequently to ensure that:
    (i) it is in place and watertight,
    (ii) water is not seeping out from the sides or from underneath the spring box, and
    (iii) the screening is in place on the overflow pipe.

6.1.2.5.1 Repairing a Spring Box

When the concrete sides of the spring box show damage, the following steps should be taken:

(a) Drain the spring box. If it was originally constructed with a drain pipe and valve, drain the water and repair it. If the box does not have a drain pipe or if the leaks are below the water level of the drain pipe, you must siphon the water out. If the volume of water is too big for a water hose to siphon the water out, you will have to use a water pump,

(b) Mix an appropriate amount of water and concrete. Quick setting cement will prove helpful. Trowel the concrete onto the cracks of the damaged areas on both the inside and outside of the box. c) Attend to the spring box to keep water from damaging the newly laid concrete, which usually takes 5 to 6 hours to cure. If you had to siphon the water out, make sure that the hose does not clog or stop siphoning, or that the pump does not stop working.

6.1.2.5.2 Removing Sediment and Disinfecting a Spring Box

Once a year, the system should be disinfected and the sediment removed from the spring box as follows:

(a) Open the valve on the outlet pipe, allowing the spring box to drain,

(b) Remove any accumulated sediment from the box and wash the interior walls with a chlorine solution. The solution for washing the spring box should be mixed at a ratio of 10 litres of water with 0.2 L chlorine bleach,

Caution: *Chlorine and chlorine compounds irritate the eyes and skin. Wear protective clothing and equipment such as gloves and safety glasses when dealing with or handling chlorine.*

(c) After the spring box has been cleaned, 100 mg/l chlorine should be added directly to the water in the spring box, followed by a second application after 12 hours. These consecutive applications should provide for adequate disinfection. If possible, water samples should be analyzed periodically to detect any contamination and taking appropriate treatment measures.

6.1.3 Intake Structures

An intake is a device or structure placed in a surface water source to permit withdrawal of water from the source and its discharge into an intake conduit through which it will flow into the water treatment works system. The types of intake structures should consist of intake towers, submerged intakes, intake pipes or conduits, movable intakes, and shore intakes. Intake structures over the inlet ends of intake conduits are necessary to protect against wave action, floods and stoppage of water flow.

Intake towers are used for large waterworks drawing water from lakes, reservoirs and rivers. Navigation, ice, pollution, and others interfere with the proper functioning of the intake tower due to either a wide fluctuation in water level or the desire to draw water at a depth to source water of the best quality and avoid clogging or for other reasons. Typical intake structures can be seen in Volume I (Appendix L) of the DCOM Manual.

6.1.3.1 Problems and Necessary Steps in Operation

Some of the problems that may arise during the operation of Intakes are given below, and therefore necessary steps should be taken to set right the same:

(a) Fluctuations in water level, water withdrawal at various depths,
(b) Hydraulic surges, ice, floods, floating debris, boats and barges,
(c) Withdrawal of water of the best available quality to avoid pollution, and to provide structural stability,
(d) Operation of racks and screens to prevent entry of objects that might damage pumps and treatment facilities,
(e) Minimising damage to aquatic life,
(f) Preservation of space for equipment cleaning, removal and repair of machinery, Storing, movement and feeding of chemicals,
(g) Screens should be regularly inspected, maintained and cleaned,
(h) Mechanical or hydraulic jet cleaning devices should be used to clean the screens,

(i) Intake structures and related facilities should be inspected, operated and tested periodically at regular intervals,
(j) Proper service and lubrication of intake facilities is important,
(k) Operation of gates and valves.

Some of the causes of faulty operation are as indicated below:

(a) Settlement or shifting of supporting structures which could cause binding of gates and valves,
(b) Worn, corroded, loose or broken parts,
(c) Lack of use,
(d) Lack of lubrication,
(e) Improper operating procedures,
(f) Vibration,
(g) Design errors or deficiencies,
(h) Failure of power source or circuit failure, and
(i) Vandalism.

6.1.3.2 Safety

When working around intake structures proper safety procedure involving use of electrical and mechanical equipment and water safety should be observed. Proper safety procedures should be documented and included in the manual containing the operating procedure.

6.1.4 Dams

This section explains about the Operation and Maintenance (O&M) of dams. It provides procedures, guidance and standard forms for the normal operation and maintenance of the facilities. The Emergency Action Plan (EAP) should be utilized for unusual and emergency conditions. The purpose of the O&M Manual is to ensure adherence to approved operating procedures over long periods of time and during changes in operating personnel. The discussion presented in this volume is related to earthfill and rockfill dams which are the main concerns as stated in other volumes of the DCOM Manual.

6.1.4.1 Operational Procedures

Reservoir Operations

Reservoir operating data, such as Elevation-Storage and Emergency Spillway Rating Curve, are provided and should be prepared and used during operation of the facility.

Filling Schedule

Filling will begin during rainy seasons. This period, the dam owner should be aware to regulate the control gates unusual floods which may result in failure hazard. First filling of an earthfill dam is a critical event whereby dam failures can occur. Due to this fact, the dam operator should regulate the outlet structure to safeguard the embankment dam.

Release Schedule

A decision is made to begin releasing water based on the rainfall, moisture conditions, and water demand. The outlet structure is inspected and cleaned of debris or sediment if present, and the gates are adjusted based on demand.

Flood Operation

At the earliest possible indication of abnormally heavy rainfall or runoff in some catchment or basins, the dam attendant should station himself at the dam and open the outlet to its full capacity guided by the relevant approved operational and security protocols. If it appears likely that high outflows from the emergency spillway will occur, a warning should be given to the downstream residents to prepare for evacuation as outlined in the Emergency Action Plan.

Control Gates

The control gates should be operated as per designed schedule and protocol. The release schedule should be well designed and reviewed periodically to meet the intended downstream water demand.

6.1.4.2 Monitoring and Inspection

General

Dam Instrumentation refers to a variety of devices installed within, on, or near the dam to monitor structural behaviour during construction, initial filling and subsequent operation. Instruments provide a means for detecting abnormal conditions which could lead to major problems.

This section describes the instrumentation at a Dam, the methods and frequency of data collection, transmittal of data, and procedures to evaluate the data. Timely evaluation of instrumentation readings is critical if an abnormal condition is to be detected to allow for effective corrective action. The Dam operator is primarily responsible for collecting and reporting instrumentation readings. Periodic owner inspections should be performed by the Dam operator. Inspection of a Dam and appurtenances will be scheduled and followed:

- Schedule depending on the complexity of the project (may be monthly or seasonally),
- Yearly for routine operation and maintenance inspections,

- Periodically (not to exceed five years) for comprehensive inspections and engineering reviews,
- After critical events including severe rain or wind storms, earthquakes, or periods of extremely high storage.

Monitoring Piezometers

The piezometers are used to monitor the pore pressure of the dam foundation. guide for reading taking and measuring should be well defined and the dam attendant should take readings regularly as per design.

Drains and Seepage

- Remove debris in and around the weirs to prevent clogging,
- Remove debris and repair the small drainage channels leading to the weirs so that water is properly directed and contained within the channels,
- Clean algae and dirt from the weir staff gauges to allow easy reading,
- Keep the weirs level to assure accurate readings.

Yearly Inspections

As the dam owner, should assign personnel to conduct the annual operation and maintenance inspections. Inspections of the embankment should occur when the reservoir is full, while inspections of the outlet works should occur while it is empty. The dam owner should prepare a checklist to be deployed during inspection of the dam and appurtenances

Periodic Owner Inspections

An informal Owner Inspection should be performed twice yearly (at the beginning and end of the rain seasons). The inspection should include a systematic review of the conditions at each dam including the outlet works including the spillway. Digital photographic records of project features should be included with the inspection files. The checklist should be prepared by the dam owner.

Periodic Engineer Inspections

Inspections by a qualified engineer should also be performed if unusual conditions occur or after critical events, such as earthquakes or extremely high reservoir storage levels. This is termed as Comprehensive Facility Review (as per Water Resources Management Dam Safety Regulations Gazetted through Government Notice 237 of 2013). The Dam operator should follow the guideline provided by the Ministry of Water in conducting the Comprehensive Facility Review (CFR) of the dam and its appurtenances.

Critical Event Inspections

The dam should be inspected during or immediately following the occurrence of critical events, such as severe rain or wind, earthquakes or periods of extremely high reservoir elevation. If emergency conditions are observed, the responses outlined in the Emergency Action Plan (EAP) should be implemented. Emergency conditions include erosion threatening the integrity of the dam, seepage that is cloudy or excessive and/or extremely high water surfaces. Inspection by a qualified engineer should be performed to evaluate the impact of critical events on the dam. Spillway erosion seems to be a common feature in most dams constructed in rural areas in Tanzania.

Even if the water surface level is not at a high elevation at the time of an earthquake, it is possible that the dam could suffer some ill-effects from the earthquake (associated with seepage performance) that will not show up until higher reservoir elevations are subsequently reached. Therefore, heightened awareness and possible monitoring would be appropriate following an earthquake whenever the reservoir is rising to elevations that have not been previously experienced since the occurrence of the earthquake. Specific changes to monitoring schedules would need to be established on a case-by-case basis in light of the magnitude of the earthquake, reservoir elevation at the time of the earthquake, and apparent damage sustained by the dam as a result of the earthquake.

6.1.4.3 Maintenance

Critical Conditions

The following conditions are critical and require immediate repairs or maintenance under the direction of a qualified engineer. The critical repairs or maintenance needs to address the specific conditions encountered and are not covered in this O&M Manual. Critical conditions should trigger a response as outlined in the Emergency Action Plan.

- Erosion, slope failure or other conditions which are endangering the integrity of the dam,
- Piping or internal erosion as evidenced by increasingly cloudy seepage or other symptoms,
- Spillway erosion, blockage or restriction,
- Excessive or rapidly increasing seepage appearing anywhere near the dam site.

Periodic Maintenance

The following items should be noted in the operations log and added to the work schedule whenever they are noted during Operational Inspections or Periodic Inspections. The following maintenance items should be completed as soon as possible after identification (at least annually):

(a) Remove bushes and trees from the embankment and abutments,
(b) Repair erosion gullies,
(c) Repair defective gates or valves,
(d) Repair deteriorated concrete or metal components,
(e) Maintain riprap or other erosion protection.

Continued maintenance should also be performed for the following items:

(a) Test, clean and lubricate gates and valves,
(b) Inspect and maintain instrumentation and gauging equipment,
(c) Remove debris from the dam area and emergency spillway approach and exit channel,
(d) Remove debris from embankment face and from areas around the intake structures,
(e) Clean and remove debris from seepage weirs and small drainage ditches.

Embankment Maintenance

(a) Fill erosion gullies with properly compacted cohesive soil material. Seed or riprap repaired area to stabilize from future erosion,
(b) Fill rodent burrows with slurry of soil, cement and water. Remove the rodents,
(c) Maintain grass cover by spraying weed killers, fertilizing and watering as needed,
(d) Remove brush, bushes and trees from embankment and refill with compacted soil,
(e) Add or repair riprap where displacement or other damage occurs,
(f) Maintain grading of the embankment crests to prevent potholes, rutting or other potential for standing water to accumulate,
(g) Maintain fences to provide site security and to exclude livestock from the embankments,
(h) Repair and re-vegetate damaged embankment surfaces,
(i) Perform regular inspections of the embankments and abutments to identify potential maintenance items.

Outlet Maintenance

(a) Test gates and valves semi-annually,
(b) Lubricate gates and valves annually or as recommended by the manufacturer,
(c) Repair defective gates and valves to ensure smooth operation and prevent leakage,
(d) Repair deteriorated concrete or metalwork,
(e) Remove debris from the outlet channels annually, inspect and repair erosion protection,
(f) Repair and verify calibration of water measurement equipment.

6.2 GROUNDWATER

The groundwater sources are used as follows:

(a) Dug well / protected shallow well,

(b) Borehole.

6.2.1 Operation and Maintenance Activities for a Dug Well/Protected Shallow Well

Good O&M seeks to avert well failures, which are usually indicated by reduced (if not complete loss of) pump discharge, or deterioration in the quality of the water. Good O&M actually begins even before a well is put into operation. Before actually operating a well, the utility must determine/obtain the following information which will guide its well operating and O&M procedures:

(a) Safe pumping level,
(b) Pump curves,
(c) Well design,
(d) Location of discharge line shut-off valve and pressure gauge.
(e) Specific capacity: is a quantity that which a water well can produce per unit of drawdown. It is normally obtained from a stepped drawdown test. The specific capacity of a well is also a function of the pumping rate it is determined at. Due to non-linear well losses the specific capacity will decrease with higher pumping rates. This complication makes the absolute value of specific capacity of little use; though it is useful for comparing the efficiency of the same well through time (e.g., to see if the well requires rehabilitation).

6.2.1.1 Operation and Maintenance Resources for a Dug Well

Unskilled labour is required for daily tasks and for collecting user charges. Semi-skilled labour (Well Operator) is needed to carry out weekly and monthly O&M tasks; a private fitter or plumber may be needed to repair the well pulley. Skilled labour (mason) is needed to work with the caretaker on yearly O&M tasks and to repair the concrete apron and support posts for the pulley.

Materials and equipment include the bucket and rope, fencing, support posts, brush, digging and hand tools, cement, pulley and pulley shaft and bearings, and masonry tools to be provided to the operators.

6.2.1.2 Operation and Maintenance of a Dug Well

Daily, monthly and annual activities should include the following O&M activities for dug wells:

(a) **Daily Activities**

- (i) Check for any debris in the well by regular visual inspection and remove it,

(ii) Clean the concrete apron,
(iii) Clear the drains,
(iv) Check that the gate is closed,
(v) Check the condition of the rope, pulley, bucket and fence by regular visual inspection and replace when needed,
(vi) Observed problems to be reported to the CBWSOs,
(vii) Disinfection.

(b) **Monthly/Quarterly activities**
(i) Replace the bucket and other parts as needed,
(ii) Check the concrete apron and well seal for cracks and repair them with cement mortar as needed,
(iii) Record the water level with a rope-scale and report to the CBWSO leadership or superiors,
(iv) Lubricate the components with grease periodically,
(v) Verify any structural damage and repair it as per need,
(vi) De-silting of dug wells periodically as required, especially during rainy season.

(c) **Annual activities**
(i) Dewater the well and clean the bottom,
(ii) Inspect the well walls and lining, and repair as needed,
(iii) Check the water level and deepen the well as needed,
(iv) Check the support posts for the pulley and repair as needed.

6.2.2 Mechanized Boreholes

6.2.2.1 Boreholes and Dug Wells with Pump Sets

A borehole is a type of water well in which a long 100–350 mm diameter stainless steel tube or pipe is bored into an underground aquifer. The depth of the wells depends on the depth of the water level in the aquifer.

Boreholes may be fully cased and screened in overburden/alluvium strata and the top of the borehole shall be sealed to prevent pollution through percolation of water into the borehole. After installation of the bore, the top of the borehole at the riser pipe shall be caped to prevent contamination of the borehole by surface water and debris etc. An isolation valve and non-return valve are fitted on a horizontal section of the delivery pipe, adjacent to the bore well to prevent the backflow. Typically, the pump house or fabricated panel box is located next to the borehole and is housed with the control panel for operation of the electric pump. Motor service frequency in terms of running hours shall be usually specified as per catalogue and indicated to the operator. The manufacturer's O&M manuals should essentially be followed. Appendix 1 illustrates the maintenance of different types of boreholes.

6.2.2.2 Operation and Maintenance of a Borehole

(a) Daily:

(i) Operate pump starter and isolation valve,
(ii) Check reading on ammeter is normal – stop pump if electric motor is drawing too much current,
(iii) Verify whether adequate water is being delivered,
(iv) Continue to check voltmeter and ammeter readings during the day.

(b) Monthly/Quarterly:

(i) Clean the pump house,
(ii) Check for leaks in the rising main,
(iii) Testing water quality using a Field Test Kit.

(c) Annually:

(i) Remove the pump and rising main from the well and inspect,
(ii) Check pipe threads and re-cut corroded or damaged threads,
(iii) Replace badly corroded pipes,
(iv) Inspect electric cables and check insulation between cables,
(v) Record servicing and maintenance in log book,
(vi) De-silt borehole if required,
(vii) Check screen and clear as needed.

Appendix 2 illustrates the troubleshooting for boreholes problems.

6.2.2.3 Preventive Maintenance/Pumping Tests results

According to available data, the specific yield of wells should be measured annually and compared with the original specific yield by the hydrogeologist/driller and the record of the same shall be maintained. As soon as 10 to 15% decrease in specific yield is observed, steps should be taken to determine the cause and corrective measures should be taken accordingly. Rehabilitation procedures should be initiated before the specific yield has declined by 25%. A checklist given below can be used to evaluate the performance of a well:

(a) Static water level in the production well,
(b) Pumping rate after a specific period of continuous pumping,
(c) Specific yield after a specified period of continuous pumping,
(d) Sand content in a water sample after a specified period of continuous pumping
(e) Total depth of the well,
(f) Efficiency of the well. The efficiency of a pumping well is expressed as the ratio of aquifer loss (theoretical drawdown) to total (measured) drawdown in the well. A well efficiency of 70% or more is usually considered acceptable while a value of 65% is being accepted as the minimum efficiency (Kresic, 1997). A perfectly efficient well, with perfect well screen and where the water flows inside the well in a frictionless manner would have 100% efficiency,

(g) Normal pumping rate and hours per day of operation,
(h) General trend in water levels in wells in the area,
(i) Draw down created in the production well because of pumping of nearby wells.

A significant change in any of the first seven conditions listed above indicates that a well or pumping rate is required. For, preventive maintenance programme well construction records showing geological condition, water quality and pumping performance shall be collected. The data of optimum and efficient limit of operation should be available which is created at the time of testing and commissioning of the well. This data is normally in the form of a discharge draw-down curve (called yield draw down curve). The pumping water level and draw down can be measured with the help of an electric depth gauge of an airline gauge.

6.2.2.4 Pumping tests

Pumping tests are carried out to determine the safe pumping yield, which establishes how much groundwater can be taken from a well, and what effects pumping will have on the aquifer and neighbouring well supplies. It is one of the design parameters for selecting the pump to be used.

The pumping tests are usually done by well drilling contractors who are knowledgeable and who possess the required tools and equipment for the tests. It is rare for a utility/WSSAs/RUWASA to conduct this test itself. However, should this become necessary, the general procedure for conducting such a test as illustrated in Appendix 3 shall apply. Once the safe pumping level is established, it should be compared with the design pump curves of the equipment to be used. This will guide the operational parameters for pumping water from the well.

6.2.2.5 Causes of Wells Failure

Well may fail due to inadequate design, faulty construction and operation, lack of timely maintenance. The main causes for source failure are categorized as under:

(a) Incorrect design: for instance use of incorrect size of screen and gravel pack, wrong pin pointing of well site resulting in interference;
(b) Poor construction e.g. the bore may not be vertical; the joints may be leaky, wrong placement of well screen, non-uniform slots of screen, improper construction of cement slurry seal to prevent inflow from Saline aquifer;
(c) Corrosion of screens due to chemical action of water resulting in rupture of screens;
(d) Faulty operation e.g. over pumping, may causes the rupture of strainer casing pipes due to piping action of water, poor maintenance;
(e) Adverse aquifer conditions resulting in lowering of the water table and deterioration of water quality;

(f) Mechanical failure, e.g. falling of foreign objects including the pumping assembly and its components;
(g) Encrustations due to chemical action of water;
(h) Inadequate development of wells;
(i) Placement of pump sets just opposite the strainer casing pipes, causing entry of silt by rupturing slots of pipes.

6.2.2.6 Monitoring of Silt Coming out with Water During Pumping from Source

Indication for silting

(a) Appearance of fine silt with water is an early indication of silting,
(b) Reduction in depth of borehole/ open well,
(c) Reduction in yield of borehole.

Causes for silting

(a) Over pumping,
(b) Improper sitting of casing pipe,
(c) Improper jointing of casing pipes,
(d) Placement of pump sets just opposite the strainer casing pipe,
(e) Poor development of bore wells.

Suggestions to overcome silting

(a) Periodical inspection of a borehole,
(b) Additional length of casing pipe may be inserted in the case of improper borehole assembly installation,
(c) Flushing of borehole,
(d) Re-development of borehole,
(e) Replacement of pump sets with proper duty condition, with respect to the safe yield of the borehole.

6.2.2.7 Rejuvenation of Boreholes

A decision whether to rejuvenate an old well or construct a new one based on the cost benefit analysis. The following remedial measures can be taken for correcting the situation as mentioned in Section 6.2.3.2 (preventive maintenance).

6.2.3 Faulty Operation

Borehole should run in such a way that the pumping water level should always remain above the level of well screen. Over-pumping will expose the well screen, which may result in encrustation and corrosion. Over pumping results in excessive draw down which may cause differential hydrostatic pressures, leading to rupture of well screen. Negligence in timely repair and maintenance may result in poor performance of the tube well. Therefore, before any permanent damage is done to tube well it should be ensured that the tube well is operated at its designed capacity and timely repair and maintenance are done.

6.2.3.1 Adverse Aquifer Conditions

In adverse aquifer conditions where water table has depleted but the quality has not deteriorated, wells can generally be pumped with considerably reduced discharge.

6.2.3.2 Mechanical Failure

The falling of pumping set assembly and its components into the borehole can be minimized by providing steel wire holdings throughout the assembly length including pumping set or by providing and clamping a steel strip around the pumping assembly. However, in spite of proper care, sometimes foreign objects and pumping set assembly components may fall in the well. In corrosive water the column pipe joints and pump parts may get progressively weakened due to corrosion, get disconnected and fall into the well. However where well screen is not damaged, then by proper fishing the fallen objects can be taken out of the well making it functional again. Following are the one of the method taken for fishing out the fallen objects in the boreholes:

(a) **Impression Block**: An impression block is used to obtain an impression of the top of the object before attempting any fishing operation. Impression blocks are of many forms and design. An impression block made from a block of softwood turned on a lathe. The diameter of the block is 2 cm less than that of drilled hole. The upper portion is shaped in the form of a pin and driven to fit tightly into the box collar of a drill pipe. To ensure further safety, the wooden block is tied with wire or pinned securely to the collar. Alternatively, the block could be fixed to a bailer. A number of nails are driven to the lower end of the block with about 1 cm to projecting out. A sheet metal cylinder of about 5 to 7 cm is temporarily nailed around the block to hold molten wax, which is poured into it. Warm paraffin wax, soap or other plastic material poured into the cylinder is left to cool and solidify. The metal cylinder is then removed; the nail heads hold the plastic material to the block. To locate the position of a lost object, the impression block is carefully lowered into the hole until the object is reached. After a proper stamp is ensured, the tool is raised to the ground surface, where the impression made in the plastic material is examined for identifying the position of the lost object and designing or selecting the right fishing tool.

(b) **Fishing Tools to Recover Fallen Objects:** The term 'fish 'describes a well drilling tool, pump component or other foreign body accidentally fallen or struck in bore wells. The type and design of fishing tools required for a specific job, depends on the positioning at which it is lying in the well and the type of object to be lifted/ fished. However, series of fishing tools suitable for different jobs are available in the market, which could be adapted or modified to suit a particular requirement. The following are some of the methods of fishing process:

(i) External catch

Fishing tools that engage the fish on its outer diameter. These tools help to recover equipment down hole by using a grapple or by threading directly to its outside surface.

(ii) Internal catch

Fishing tools that engage the fish in its inner diameter. Similar to external catch tools, this is achieved by a grapple or by threading directly to the fish's inside surface.

6.2.3.3 Gripping and Releasing Mechanism

The bowl of the overshot is designed with helically tapered spiral section on its inside diameter. The gripping member (Spiral grapple or basket grapple) is fitted in to this section. When an upward pull is exerted against a fish, an expansion strain is spread evenly over a long section of the bowl and the compression strain is spread evenly over a long section of the fish. No damage or distortion occurs to either the fish or the overshot. This design permits a far stronger tool with a smaller outside diameter than is possible with an overshot that employs a single tapered section which supports slips.

A spiral grapple is formed as a left hand helix with a tapered exterior to conform to the helically tapered section in the bowl. Its interior is whickered for engagement with the fish.

A Basket grapple is an expandable cylinder with a tapered exterior to conform to the helically tapered section in the Bowl, its interior is whickered for engagement with the fish. Two types of basket grapple are available to meet the need for catching various types of fish.

The basket grapple with long catch stop has an internal shoulder located at the upper end to stop the fish the best catch position. It is designed to stop and catch collars and tool joints with sufficient length left below the grapple to allow the joint to be packed off with a basket control packer.

Grapple controls are of two types

Spiral grapple controls are used with spiral grapples basket controls are used with basket grapples. Grapple controls are used as a special key to allow the grapple to move up and down during operation while simultaneously transmitting full torque from the grapple to the bowl.

Spiral Grapple controls are always plain:

Basket grapple controls may be either plain or include a pack off in addition to the pack off mill teeth is included. In operation, the overshot functions in the same manner, whether dressed with spiral grapple parts or basket grapple parts.

During the engaging operation, as the overshot is rotated to the right and lowered, the grapple will expand when the fish is engaged, allowing the fish to enter the grapple. Thereafter with rotation stopped and upward pull exerted, the grapple is contacted by the tapers in the bowl and its deep wickers grip the fish firmly.

During the releasing operation, a sharp downward pump places the larger portion of the bowl tapers opposite the grapple breaking the hold. Thereafter, when the overshot is rotated to the right and slowly elevated, the wickers will unscrew the grapple off the fish.

Operation

Engaging and pulling the fish connect the overshot to the fishing string and run it in the hole. As the top of the fish is reached, slowly rotate the fishing string to the right and gradually lower the overshot over the fish. Allow the right hand torque to stock out of the fishing string and pull on the fish by elevating the fishing string. If the fish does not come, start the circulating pumps and maintain a heavy upward strain while fluid is forced through the fish.

6.2.3.4 Releasing from the Fish

Drop the weight of the fishing string heavily against the over shot, then simultaneously rotate to the right and slowly elevates the fishing string until the overshot is clear of the fish. To release from a recovered fish, follow the same procedure while holding fish below the overshot.

6.2.3.4.1 Rotary Taper Taps

Rotary taper taps are simple, rugged, dependable internal catch fishing tools.

Operation:

Run the taper tap in the hole to the top of the stuck fish. Apply less than one point of weight; rotate the tap until the tapered threads have engaged the fish. Stop rotation and pull the fish from the hole.

Rotary taper, Taps are furnished in two types:

Plain or skirt type, plain taper taps do not have a skirt thread provided on the shoulder. Skin type tapers taps are threaded for a skirt. A skirt is used when the hole size is drastically different from the fish size. The taper tap can be dressed with a skirt or a skirt and oversize guide. This will allow for the taper tap to be guided into the fish more easily during the fishing operation.

6.2.3.5 Re-Development of Boreholes

Sometimes due to carelessness at the time of construction, proper development of the boreholes is not done which results in constant inflow of the sand particles causing choking of the filtering media and strainers. Such boreholes need re-development. The re-development of borehole will have following effects:

(a) Re-development of well involves removal of finer material from around the well screen, thereby enlarging the passages in the water-bearing formation to facilitate entry of water;
(b) Re-development removes clogging of the water-bearing formation;
(c) It increases the porosity and permeability of the water-bearing formation in the vicinity of the borehole;
(d) It stabilise the formations around the well screen so that the borehole will yield sand-free water;
(e) Re-development increases the effective radius of the well and, consequently, its yield.

6.2.3.5.1 Methods of Re-development

Following are the methods of well re-development:

(a) Over-pumping with pump,
(b) Surging with surge block and bailing,
(c) Surging and pumping with air compressor,
(d) Back-washing,
(e) High-velocity jetting,
(f) Dynamiting and acid treatment.

For rehabilitation purpose any suitable method of re-development can be used as mentioned above. The largely used method is surging and pumping with compressed air.

6.2.3.6 Operation and Maintenance Activities of Mechanized Boreholes

(a) Daily O&M activities

(i) Clean the pump house,
(ii) Check available Voltage in every phase,
(iii) Check reading on ammeter is normal – stop pump if electric motor is drawing too much current and report problems, open isolation valve,
(iv) Check power factor,
(v) Confirm water is being delivered,
(vi) Check for leaks in the rising main,
(vii) Continue to check voltmeter and ammeter readings during the day,
(viii) Maintain pumping log book and history sheets of tools, plants & equipment's,

(ix) Observe the abnormal sound of pumping machinery by listening the changes in noise level.

(b) Weekly activities at the tank

Testing water quality using a Field Test Kit (for small schemes only).

(c) Monthly activities

Billing and collection, and deposit with the water authorities/water committees (for small schemes only).

(d) Annual activities may include

(i) Remove the pump and rising main from the well and inspect,
(ii) Check pipe threads and re-cut corroded or damaged threads,
(iii) Replace badly corroded pipes,
(iv) Inspect electric cables and check insulation between cables,
(v) Check as per recommendations of manufacturer's operational manual.

6.2.3.7 Operation and Maintenance Resources for Mechanized Boreholes

Semi-skilled labour (pump operator) is required for pump operation, billing and collection. Skilled labour is required for pump and motor servicing and maintenance. Materials and equipment include pipes for the rising main, tools for maintenance and repair, oil for the motor, spare parts for the motor and electrical control panel. Finances would typically be from the household paying water charges, or CBWSOs resources and Government funds.

6.2.4 Artificial Re-Charging of Under Ground Source

The yield in the source can be improved by artificial recharging structures. Artificial recharge of ground water can be achieved by the following:

(a) Stream flow harvesting comprising of:

- Gully plugging /small boulder dams,
- Loose stone check dams (LSCD),
- Dams.

(b) Surface flow harvesting:

- Tank,
- Ponds.

(c) Direct recharge

- Recharge of wells,
- Through injected wells,
- Through roof top rainwater harvesting structures.

Note: The O&M of such structures may be done as per the sustainability practices and manuals.

6.2.5 Infiltration Wells and Their Maintenance

Infiltration well is located in river beds where sufficient sand depth is available. These wells are sunk up to the depth where hard strata are met with. The porous concrete portion will facilitates infiltration of water in to the well. The diameter generally varies from 3 m to 5 m. The regular inspection of infiltration well needs to be conducted.

If illegal sand mining is done around or near the well, there is the possibility of the structure getting tilted to one side. To obviate this problem, it is essential to protect the infiltration well from sand mining. Sometimes the wells may get tilted due to sand erosion during flood times and to overcome this problem packing of sand bags around the wells should be done. It should be ensured that flood water does not enter into the well through the manhole cover during flood times and hence the manhole cover must be made water tight. Water quality test and specific yield of the well should be conducted during pre- rainy season and post rainy season period to assess the quality of water and the yields.

6.2.6 Infiltration Gallery

An infiltration gallery is a horizontal well which is used to collect naturally filtered water. It consists of a main collection sump and perforated pipe water collectors, which are surrounded by a blanket of sand and gravel (Appendix 4). The pipe should be driven into the well with proper slope to ensure continuous flow and the well points (horizontal drain) should be well under water table in dry season. Infiltration galleries need soils which are permeable to allow sufficient sub-surface water to be collected. The gallery should be surrounded with a gravel pack to improve flow towards it and to filter any large particles that might block the perforation.

Infiltration gallery is often used in conjunction with other water supply scheme as a means of increasing the quantity of water intake in areas of poor water yield in this instance one or more galleries are built which drain into the central point, such as a hand dug well or spring box. These are called collector wells, it is important to protect it from contamination by locating it uphill and the minimum safe distance from any source of contamination.

6.2.6.1 Operation of Infiltration Gallery

Water enters the perforated pipe collectors and then flows by gravity to the main collection sump or well. From this sump or well, water is pumped out to the distribution system.

6.2.6.2 Maintenance of Infiltration Gallery

The following O&M aspect shall be followed:

(a) Never exceed the design pumping rate- not more than 60% of the yield. Higher pumping rate could cause fine sediment to enter the filter and reduce the opening size of slots and the sand may enter screen and block the part of intake opening causing more sand pumping,

(b) Do not let the gallery unused for longer time since it may tend to lower the hydraulic conductivity of filter pack,

(c) The maintenance of galleries involves back washing and chemical treatment. The back washing time required can be 5-10 minutes. For back washing, compressed air can also be used.

6.2.6.3 Sanitary Inspection of Infiltration Gallery

Sanitary inspection of infiltration Gallery is required to be conducted in once a year by water supply agency, particular attention should be paid to the catchment area of the gallery, especially with shallow galleries. The water collected in infiltration galleries has often not had as much filtration as well or spring water thus may be more vulnerable to contamination. Water quality testing should be done twice a year, once in the wet season and once in the dry season. The water at various points in the gallery, at the collector well or sump and the distribution system should also be tested.

6.2.6.4 Common Causes and Corrective Measures for Infiltration Gallery Failure

(a) **Clogging of the Filter Bed** – The clogging of the filter blanket surrounding the collector pipes is indicated by the lowering of the water level in the main sump/well while pumping at the normal rate. This clogging is due to the deposition of fine silt on the filter blanket. The clogging material usually can be dislodged by surging, using compressed air or a force pump. If these methods will not work, the only remedy is to dig up and clean the sand/gravel blanket.

(b) **Poor Quality of Water Yield** – The most probable cause of the deterioration in water quality is a defective filter bed, which allows contaminants to pass through. The water yield may be rendered safe again either by repairing the filter bed or by continuous chlorination.

6.2.7 Groundwater management

Groundwater and surface water are closely linked such that all water should be managed as one resource. Managing groundwater resources is primarily aiming at sustainable development of the resource for various users. A key issue of sustainable groundwater is balancing the available resources with the increasing demands of water use. It should be noted that water is an economic as well as social good. To that end, the following resources management objectives are crucial:

- Balancing groundwater recharge against abstraction is the main emphasis of groundwater management.
- Groundwater protection from pollution.

For effective groundwater management, stakeholder's involvement is very important.

Groundwater management studies are conducted in following levels:

- Preliminary examination- based largely on judgement by experienced personnel.
- Reconnaissance- this study considers possible alternatives in the formation of a water management plan to meet a defined need for an area, including estimates of benefits and costs.
- Feasibility- This study requires detailed engineering, hydrogeologic, and economic analyses together with cost and benefit estimates to ensure that the selected project is an optimum development.
- Define project- this involves planning studies necessary for defining specific features of the selected project.

In conducting groundwater basin investigations, the following data are needed:

- Topographic (contour maps, aerial photographs, benchmarks)
- Geologic (surface and subsurface)
- Hydrologic (surface inflow and outflow, precipitation, changes in surface storage, changes in soil moisture, change in groundwater storage)

A suite of observation wells coupled with a selection of abstraction wells normally comprise a monitoring network, which should be designed so as to provide the required access to the groundwater resource. Monitoring networks and systems are classified into three main (but not mutually exclusive) groups, and are specifically designed and operated to:

- detect general changes in groundwater flow and trends in groundwater quality, and bridge gaps in scientific understanding of the groundwater resource base (Primary Systems)
- assess and control the impact of specific risks to groundwater (Secondary and Tertiary Systems).

Table 6. 2: Types of Data Required for Groundwater Management

Type of Data	Baseline Data (From Archives)	Time-Variant Data (From Field Stations)
Groundwater Occurrence and aquifer properties	• Water well records (hydrogeological, logs, instantaneous groundwater levels and quality), • Well and aquifer pumping tests.	• Groundwater level monitoring, • Groundwater quality monitoring.
Groundwater use	• Water well pump installations, • Water-use inventories, • Population registers and forecasts, • Energy consumption for irrigation.	• Water well abstraction monitoring (direct or indirect), • Well groundwater level variations.
Supporting Information	• Climatic data, • Land-use inventories, • Geological maps/sections.	• Riverflow gauging, • Meteorological observations, • Satellite land-use surveys,

Chapter 7

TRANSMISSION MAINS

7.1 GENERAL OBJECTIVE OF TRANSMISSION MAINS

The overall objective of transmission mains is to deliver raw water and treated water from the source to the treatment plants and to the storage reservoirs respectively for supply into the distribution networks. Transmission of raw water and treated water is through pipes. Transmission through pipes can be either by gravity flow or by pumping.

The objective of O&M of transmission mains is to achieve optimum utilization of the installed capacity of the transmission system with minimum transmission losses and at minimum cost. To achieve this objective the water supply organization has to develop operational procedures to ensure that the system can operate satisfactorily, function efficiently and continuously and last as long as possible at lowest cost. District Metering Areas (DMAs) which are separated by bulk meters to monitor users and water losses are also used.

7.2 TRANSMISSION THROUGH PIPES

All valves installed in the transmission main should be inspected regularly to ensure that there is no leakage otherwise leakage should be attended. Many water supply utilities in rural as well as urban areas, practice passive leakage control, meaning that they repair only those leaks that are visible. This is clearly not enough since 90% of the leaks are usually not visible on the surface. This means that it takes too long, often many years, until the utility is aware that there is a leak. Since awareness timing largely determines the volume of water lost from a pipe burst, utilities need a strategy to reduce the time for awareness. If attending leakage requires stoppage of flow through pipes, the same can be attended on a pre-fixed monthly shutdown day.

7.3 COMMON TYPES OF WATER SUPPLY PIPES

Various pipes are generally used for water supply projects in the country. The selection, installation and specification of pipes should be based on field conditions and used according to the water supply or sanitation project requirements. Failure to abide to the specified conditions may lead to different operational problems.

7.4 PROBLEMS IN TRANSMISSION MAINS

7.4.1 Leakage

Water or sewage is often wasted through leaking pipes, joints, valves and fittings of the transmission system either due to bad quality of materials used, poor workmanship, and corrosion, age of the installations or through vandalism. This leads to reduced supply and loss of pressure. Review of flow meter data will indicate possible leakages (Chapter Sixteen). The leakages can be either visible or invisible. In the case of invisible leaks, sections of pipeline can be isolated and search carried out for the location of leaks.

Most common leaks are through the valves and joints. Leaks in joints may occur where the bolts have become loose and gland packing/rubber ring is not in position. Leaks through air valves occur due to improperly seated ball either due to the damage of the liner/seal or due to abrasion of the ball, or due to entrapped sand particles.

Causes of NRW (Chapter Seventeen) differ from case to case but most often it is a leakage that appears due to improper maintenance of the network. Undetected and control of leakages in the transmission and distribution systems will result in a dissatisfaction of the water demand or leading to unrealistic higher consumption rates to the consumers. Also, high pumping costs or other operational problems may arise during delivering of water to points of use due to the need for increased water pressure and the resulting increased leakages. Therefore, leakage control is important for revenue water and for preventing environmental damages (e.g. water seepage to roads embankment leading to potholes and other infrastructure damages).

7.4.2 Air Entrapment

Air in free form in rising main collects at the top of the pipeline and then goes up to higher points. Here, it either escapes through air valves or forms an air pocket which in turn, results into an increase or head loss. Other problems associated with air entrapment are: surging, corrosion, reduced pump efficiency and malfunctioning of valves or vibration. In some cases bursting of pipes may occur due to air entrapment. Air entrapment normally reduces the effective diameter of the pipe.

There should always be air release valve chambers with cover slabs for the protection of the air valve and it should always be kept leakage free and dry. Frequent inspection should be conducted to check, whether air valves are functioning properly and to ensure that there is no leakage through air valves.

7.4.3 Water Hammer

Water hammer in water supply systems occurs due to rapid closure of valves and sudden shut off or unexpected failure of power supply to the pumps. The pressure rise due to water hammer may have sufficient magnitude to rupture the transmission pipe or damage the valves fixed on the pipeline. Care should be taken to open and close sluice valves gradually. A common remedy is to install surge protectors.

7.4.4 Lack of System Maps and Records

System maps and records are very important to the project operators and managers. Generally, maps showing the actual alignments of transmission mains and location of other pipes and the valves on the ground may not be readily available due to inadequate records keeping. The location of pipes and the valves on the ground becomes difficult in the absence of such updated maps and thus, these need to be prepared and updated from time to time. Some minimum information about the location and size of pipes and valves and the direction of opening of valves is required to operate and maintain the system efficiently.

7.5 OPERATION AND MAINTENANCE ACTIVITIES

7.5.1 Operation Schedule

(a) **Mapping and inventory of pipes and fitting:** An updated transmission system map with location of valves, flow meters and pressure gauges is the primary requirement of operation schedule. The valves indicated in the map should contain direction to open; number of turn to open, make of valve and date of fixing. The hydraulic grade lines are to be marked to indicate the pressure in the transmission system. They can be used for identifying high pressure or problem areas with low pressure.

(b) **System pressure:** It is essential to maintain a continuous positive pressure in the main at the time of transmission of water in the pipeline. Low pressure locations have to be investigated if necessary by measuring pressure with pressure gauge and any problem detected relating to pressure should be fixed immediately.

(c) **System Surveillance:** The maintenance staff of the respective department/ section of the water organization should go along the transmission line frequently so as to accomplish the following objectives:

    (i) To detect and correct any deterioration of the transmission system,
    (ii) To detect if there is encroachment of transmission system failures,
    (iii) To detect and correct if there is any unauthorized tapping of water,
    (iv) To detect and correct if there is damage to the system by vandalism and so on.

7.5.2 Maintenance Schedule

A maintenance schedule is required to be prepared to improve the level of maintenance of water transmission mains through improved co-ordination and planning of administrative and fieldwork accompanied by the use of adequate techniques, equipment and materials for field maintenance and/or inspection.

It is important to note that, the schedule should be flexible so that it can achieve team action with the available resources (staff, vehicles and tools). Co-ordination of activities is required for spares and fittings, quality control of materials used and services rendered.

Training of maintenance staff shall, apart from the technical skills, include training to achieve better public relations with consumers and the public in general.

7.5.2.1 Activities of Maintenance Schedule

(a) Develop and conduct a surveillance programme for leaks in pipelines, pipe joints and valves;
(b) Develop and conduct a water quality surveillance programme. The order is bacteriological parameters followed by chemical parameters and then some physical parameters as recommended by MoW guidelines (URT, 2018). For establishment of chemical dosing daily tests must be done;
(c) Develop and conduct a programme for locating and repairing leaks including rectifying cross connections if any, arrange for flushing, cleaning and disinfecting the mains;
(d) Establish procedures for setting up maintenance schedules and obtain and process the information provided by the public and the maintenance teams about the pipeline leaks;
(e) Establish repair procedures for standard services and with provision for continuous training of the team members;
(f) Procure appropriate machinery, equipment and tools for repair of leaks and replacement of pipes and valves;
(g) Allocate suitable transport, tools and equipment to each maintenance team;
(h) Establish time, labour following activities are to be included in the schedule and material requirement and output expected, time required and other standards for each maintenance task, and
(i) Arrange for monitoring the productivity of each maintenance team.

A preventive maintenance schedule has to be prepared for:

(a) Maintenance of the pipelines with particulars of the tasks to be undertaken, works not completed, and inspection of works completed;
(b) Servicing of valves, expansion joints etc.;
(c) Maintenance of valve chambers;
(d) Maintenance of record of tools, materials, labour, and
(e) Review from time to time costs required in carrying out each task.

7.5.2.2 Activities for Preventive Maintenance

(a) *Servicing of fittings, air release valves and chambers:* Periodical servicing is required for pipelines, fittings, air release valves, pressure release valves, sluice valves, gate valves, T-joints, washout valves, expansion joints, flow meters, chambers and pressure gauges. Corrosion of valves is the main problem in some areas and can cause failure of bonnet and gland bolts. Leaks from spindle rods occur and bonnet separates from the body. Stainless steel bolts can be used for replacement and the valve can be wrapped in polythene wrap to prevent corrosion. Manufacturer's catalogues may be referred and servicing procedure should be prepared for the periodical servicing.

(b) *List of spares:* List of spares procured for the transmission mains shall be prepared and the spares shall be procured and kept for use. The spares may include pipes and fittings such as check nut, spindle rods, bolt and nuts are flanged joints, gaskets for flanged joints for all sizes of sluice valves, consumables like gland rope, grease, cotton waste, jointing materials like rubber gaskets, spun yarn, pig-lead and lead wool, etc.

(c) *List of tools*: The maintenance staff shall be provided with necessary tools/ equipment for attending to the repairs in the transmission mains. These tools may include key rods for operation of sluice valves, hooks for lifting manhole covers, pipe wrench, spanner set, ring spanner set, screw drivers, pliers, hammers, chisels, caulking tools, crow bars, spades, dewatering pumps and the like.

7.5.3 Maintenance of Pipelines

Pipeline bursts/main breaks can occur at any time and the O&M department/ section shall have a plan for attending to such events. This plan must be written down, disseminated to all staff and the organization must always be in readiness to implement the plan immediately after the pipe breaks are reported.

After a pipe break is located, determine which valve is to be closed to isolate the section where the break has occurred. Some important consumers may be on the transmission mains and having an industrial process dependent on water supply which cannot be shut down as fast as the water supply lines are cut off and should be notified about the break down. These consumers have to be informed about the probable interruption in water supply and also the estimated time of resumption of water supply.

After the closure of the valve, the dewatering/mud pumps are used to drain the pipe breakpoints. The sides of trenches have to be properly protected before the workers enter the pit. The damaged pipe is removed, and the accumulated silt is removed from inside the pipe and the damaged pipe is replaced and the line is disinfected before bringing into use. A report shall be prepared following every pipe break about the cause of such break, the resource required. The report must be documented well for future reference.

7.5.3.1 Scouring of Pipeline

Scouring is done to clean the transmission lines by removing the impurities or sediment that may be present in the pipe. This is particularly essential in the case of transmission lines carrying raw water. This can be done by opening washout valves or by air scouring (but requires both more equipment and energy supply) or by using various automated or semi-automated devices supported by ICT-mediated technologies including CCTV.

7.5.3.2 Leakage Control

- Visible leaks: The maintenance staff during surveillance operation can report visible leaks found by him or third parties to his superiors. Critical areas where leaks often occur have to be identified and appropriate corrective measures have to be implemented:
- Invisible leaks: Leak detection equipment have to be procured for detection of non-visible leaks and action to control these leaks should be initiated to control the overall problem of water loss.

Global estimates of leakage come from an annual balance of the delivery and metered consumption for the whole network. Bursts of main pipes can be detected by the flow measurements at water supply points. To enable leak detection, parts of the system have to be inspected over a period of several hours or days, depending on the size of the water supply district. Some of the simple methods of finding leakages in water supply mains include:

(a) **Visual observation**

This method is the simplest and most applicable leak detection technique for use in small water supply systems. This requires being alert to the following signs of leaks:

(i) Appearance of wet spots during the dry season,
(ii) Greening of patches of ground in areas where plants normally do not grow,
(iii) Abnormal drops in pressure.

(b) **Finding exact position of leaks**

(i) Flow and pressure measurements do not indicate the exact location of leaks. In the case of severe breaks, water may appear on the surface, but more often leak detection techniques have to be applied. The most popular are: acoustic (sound) method,
(ii) leak noise correlation,
(iii) tracer techniques.

For example, after finding the approximate location of leaks in the water distribution system, their exact location can be determined by using a sounding rod without damaging the pipe. Leaks in water pipes usually make sound, small leaks make more noise than large ones. The sounding rod is a pointed metal rod used to relay to the observer the sound caused by leaks in buried pipes.

Detection and control of leakages in sewerage systems

This is done as in drinking water conduits and more reference can be obtained in Section 15.5.2 of this DCOM Manual.

7.5.3.3 Chlorine Residual Testing

A minimum free chorine residual of 0.2–0.5 mg/l is needed to be maintained at the consumer or water point. Absence of residual chlorine could indicate potential presence of contamination in the transmission mains.

The following steps which are required to be taken include:

(a) Testing of residual chlorine,
(b) Checking the chlorination equipment at the start of the transmission system,
(c) Searching for source of contamination along the transmission system which has caused the increase in chlorine demands,
(d) Immediate rectification of the source of contamination.

7.5.4 Engaging Contractors for Maintenance

Due to inadequate trained O&M staff in line department/section, the operation and maintenance of transmission mains and other components of the scheme, if required, may be done by out sourcing/awarding Contracts for Comprehensive Annual Maintenance for any specified period e.g. 5 -10 years.

7.5.5 Records and Reports

The following records and reports need to be maintained properly all the time:

(a) Updated transmission mains maps with alignment plans. Longitudinal and sectional plans,
(b) Record of daily readings of flow meter at upstream and downstream end of the pipeline,
(c) Record of water level of reservoir at both upstream and downstream end of the transmission system,
(d) Pressure reading of the transmission mains,
(e) Identification of persistent low pressure locations along the pipeline,
(f) Record of age of pipes,
(g) Identified pipelines to be replaced,
(h) Identified source of leaks,
(i) Record of Bulk meter/water meter reading before the delivery into an overhead tank,
(j) Record of residual chlorine,
(k) Record on when the pipeline leaks were repaired or pipe changed and the cost of materials and labour cost thereof.

Chapter 8

DRINKING WATER STORAGE TANKS

The main function of Service Reservoirs (SR) or Storage Tanks is to cater for daily demands and especially peak demands of drinking water. Operator checks the amount of drinking water in the storage reservoir and the corresponding water levels at particular times of the day. Procedures for operating the Service Reservoir will depend upon the design of its storage capacity and on the water demand balance.

8.1 PROCEDURES FOR OPERATION OF SERVICE RESERVOIRS

Service Reservoirs have to be operated as per the design requirements. Generally, the service reservoirs are constructed at elevated places to supply water during periods of high water demand and hence the SRs are filled in low water demand period. At times pumps may be used only for filling the SR before the next supply timing or can be used also during supply hours to maintain the levels in the SR. Normally, small changes in the distribution system such as pipeline extensions or the addition of few more connections will not require additional storage requirement. Major system changes such as addition of larger size of main pipelines and increase in large number of connections may require additional storage.

8.1.1 Operation of Service Reservoirs during Abnormal Conditions

Abnormal operating conditions arise:

- Whenever demand for water goes up suddenly due to fire demand, or due to excessive demand on one command area/zone of a system,
- Due to failure or breakdown of water supply of another zone of the distribution system,
- Breakdown or out of service pumps or pipelines or power breakdowns or out of service SRs.

The operator must have a thorough knowledge of the distribution system emanating from the SRs. Closure or adjustment of valves at strategic points in the distribution system can focus or divert the flow of water towards the affected areas. Emergency plans must be developed in advance to cope with such situations.

8.1.2 Storage Level and Capacity

Most of the distribution systems establish a pattern of levels for assuring the required supplies at the required pressures. The maximum water levels to be maintained in the SR at each morning should be known to ensure that the system demands are met for the day. It is also desirable to have an indication of levels of SR in the pump house or any appropriate place easily accessible by the operator through use of SCADA systems.

Usually water levels are read at the same time each day and the readings recorded. Checks of water levels at other times of the day will enable one to determine if any unusual consumption conditions have occurred. If any significant increase in consumption is anticipated the operations should ensure a corresponding increase in supply into the SR.

In case of intermittent supply, timings for supply of water in the areas are fixed in advance in large command areas. The water can be supplied to sub-zones during particular fixed hours by operation of the necessary valves.

Routine valve operations are normally done at the SRs. Problems in operation of valves in SRs can also be caused by valve seat getting jammed, and hence it cannot be opened, or non-seating of valves, and hence cannot be closed properly. Sometimes two valves are fixed in series on the outlet and the downstream valve only one is usually operated. Whenever the valve under operation is jammed, the upstream valve is closed and the jammed valve is repaired. Such an arrangement enables repair of valves without emptying the SR.

In some SRs a bypass line is provided direct from the inlet line to the outlet line for drawing water without feeding the service reservoirs (SR). Identification of the valves as to their intended purpose such as inlet, outlet, scour/washout, by-pass etc. and their direction of opening are to be prominently marked. The operator/ manager shall ensure that all valves in a SR are in good working condition and are operated as per the schedule for such operation.

8.1.3 Water Quality at Service Reservoirs

Water from all SRs should be periodically sampled to determine the quality of water that enters and leaves the SR. Sampling data can help in setting up periodic cleaning of SR. Common cause of physical water quality problems includes collection of sediment, rust and chemical precipitates. Water quality in the SR may also deteriorate due to excessively long periods of stagnant conditions. Whenever seasonal demand rises, residual chlorine to be maintained properly.

8.2 PLANS FOR OPERATION AND MAINTENANCE OF SERVICE RESERVOIRS

The plan for O&M of the service reservoirs shall contain operational procedures, maintenance procedures and the manufacturer's information in respect of the instruments/devices.

8.2.1 Procedures for Operations

The operational procedures will inter-alia contain:

(a) Information of design details for the reservoir such as: capacity in litres, size and depth of storage; size of piping/locations of control valves of inlet, outlet, scour and overflow; source of feeding the reservoir; hours of pumping or gravity feeding into the reservoir; rate of flow into the reservoir; hours of supply from the reservoir and quantity to be supplied from the reservoir; areas to be served/ supplied; highest and lowest elevations to be commanded from the SR and the water levels to be maintained in the SR for command of the entire area,

(b) Key plan showing the alignment of pipe connections, by pass lines, interconnections and location of valves, flow meters, pressure gauges and alignment of out-fall drain to lead off the scour and overflow water from the reservoir,

(c) Schedule of suppliers' names, addresses and telephone numbers of the equipment installed in the SR such as valves, flow meters, level indicators, etc.,

(d) Step by step operating instructions indicating how to operate and control various valves located on the inlets and outlets, so as to ensure the required quantity of water is supplied to the command areas at the desired pressures during the period required to be displayed,

(e) A record sheet for each valve showing direction for turning, number of turns, inspections, repairs and whether opens or closed. The direction of operation of valves shall be clearly marked as "open" or "close",

(f) The name of the valve and piping such as washout, inlet, outlet, by pass, overflow etc. shall be painted clearly and repainted regularly. In the case of mechanized operation of valves, the steps to include starting, running and stopping the operations,

(g) Different inlet pipes in the service reservoir from different source should be marked with different colour paint.

8.2.2 Maintenance of Service Reservoirs

- Service Reservoirs (SRs) have to be inspected regularly and the line department can prescribe frequency of inspections. Inspection can be done once every two weeks and once a month during the rainy and dry seasons respectively.

- Leakage from structure of SR and through the pipes and valves has to be attended to on priority. It is advisable to resort to pressure grouting to arrest leaks from structures, and
- sometimes an additional coating of cement mortar plastering is also done using water proof compound to arrest leaks from the structure.

Maintenance is concerned with mainly protection against corrosion both externally and internally. Corrosion of roof slab of reinforced cement concrete (RCC) reservoirs due to the effect of chlorine is also common. Internal corrosion is prevented by cleaning and painting at regular intervals. Toxic paints should not be used for painting interior surface of SRs. Food grade epoxy painted shall only be used for internal surface of SRs. Anticorrosive painting (epoxy) is also done to the interiors when corrosion due to chlorine is expected. Painting of steel tanks once in a year and external painting with waterproof cement paint for exteriors of reinforced concrete tanks once in 5 years is usually done. The inside of painted SR shall be disinfected before putting into use for a period sufficient to give chlorine residuals of at least 0.2 mg/l. Manhole covers and vent pipes shall always be properly placed and maintained

The maintenance procedures shall include step by step procedure for every piece of equipment in SRs such as pipes inside the tank (In-let, out-let, wash-out, over-flow) valves, specials and flow meters following the procedures as per the manufacturers' catalogues.

(a) Pipes (Inlet, outlet, washout, overflow) and specials

(i) All the pipe fittings should be leak proof, any leakage nearby reservoir may affect the safety of reservoir,

(ii) Overflow pipe should be connected with the distribution system after the sluice valve installed on delivery pipeline,

(iii) Concrete platform as protection works shall be provided around the service reservoir, if not provided, so as to safeguard the reservoir foundation from any leakages/overflow of water.

(b) Valves

All valves should be inspected regularly in specified frequency of inspection and following activities shall be undertaken:

(i) Lubrication is required to be done regularly,

(ii) Spindles that develop leaks should be repacked,

(iii) Rust and sediment in the valve is removed by shutting the disc hard in the seat, then opening about a quarter way and closing tightly several times; the increased velocity usually flushes the obstructions away,

(iv) Valve chambers of the SR also require maintenance to ensure that the interiors of chambers are not silted up and also ensure that the covers are in good condition and are in position,

(v) Sluice valve chamber shall not be water logged.

(c) Cleaning of Reservoirs

Routine inspection is the best way to determine when a tank requires maintenance and cleaning. A visual inspection can be made from the roof manhole with water level lowered to about half full or less. Alternatively a detailed inspection can be made after draining the tank and then cleaning or washing. Best time of the year to take up cleaning of SRs is during the period of lowest water consumption. The following activities are normally involved in cleaning of a tank/SR:

(i) Make alternate arrangement for water supply to consumers served by the SR,

(ii) Close the inlet line before commencing cleaning of SR,

(iii) Do not empty SR. and always keep minimum water level at 200-300 mm in the SR,

(iv) Close the outlet valve so that no water will be used while the tank is being cleaned,

(v) Drain and dispose of the remaining water and silt,

(vi) Wash the interior of tank walls and floor with water hose and brushes,

(vii) Inspect the interior of walls and ceiling of tank for signs of peeling off or deterioration,

(viii) Apply disinfectant (Supernatant of Bleaching powder) to the walls and floor before start of filling the tank/SR,

(ix) The higher frequency of cleaning of SR depends on the extent of silting, development of bio films and results from water quality monitoring. Generally cleaning of Service Reservoir may be periodically done,

(x) Date of last cleaning and the next due date of cleaning may be displayed on the outer surface of the SRs.

8.2.3 Records and Reports

8.2.3.1 Record System

A record system has to be developed which should be realistic and apply to the operating problems involved at the particular SR site. The most efficient way to keep records is to plan what data is essential and then prepare the formats followed by the persons to fill the data, frequency and to whom the record is to be sent for review and report. Sample records to be maintained at a SR site are given below for guidance. The following details shall be recorded:

8.2.3.2 Records of Maintenance

The records on each of the following maintenance/repair works along with the cost of materials and labour shall be maintained along with date:

(a) Water levels in the SR,

(b) Time and relevant operation of control valves with time of opening and closure or throttling position of the valves,

(c) Daily flow meter readings both on the inlets and outlets,

(d) At least one a day Residual chlorine readings of inflow water and outflow water.
(e) Gland ropes of the valves/Spares at the SR were changed,
(f) Manhole covers were changed/replaced,
(g) Water level indicator was repaired or replaced,
(h) Reservoir was cleaned,
(i) Out-fall drain for scour and overflow was last cleaned,
(j) Ladder was changed, when the structure of the reservoir was last repaired to attend to structural defects or arrest leakage,
(k) Reservoir/Pipes was last painted,
(l) Total cost of repairs and replacements at the SR in previous year along with breakup of material cost and labour cost with amount spent on outside agencies for repairs and replacements.

Chapter 9

DISTRIBUTION SYSTEM

The overall objective of a distribution system is to deliver safe drinking water to the consumer at adequate residual pressure in sufficient quantity at convenient points and to achieve continuity and maximum coverage at affordable cost. Normally, the operations are intended to maintain the required supply and pressure throughout the distribution system. Critical points are selected in a given distribution system for monitoring of pressures by installation of pressure recorders and gauges.

9.1 ISSUES CAUSING PROBLEMS IN THE DISTRIBUTION SYSTEM

(a) Intermittent System

The distribution system is usually designed as a continuous system but it is often operated as an intermittent system in many supply areas. Intermittent supply creates doubts in the minds of the consumer's about the reliability of water supply. During the supply period, the water is stored in all sorts of vessels for use in non-supply hours, which might contaminate the water. Often, when the supply is resumed, the stored water is wasted and fresh water again stored. During non-supply hours, polluted water may enter the supply mains through leaking joints and pollute the supplies. Further, this practice prompts the consumers to always keep open the taps of both public stand posts and house connections leading to wastage of water whenever the supply is resumed. Intermittent systems and systems which require frequent valve operations are likely to affect equitable distribution of water mostly due to operator negligence.

(b) Non-Availability of Required Quantity of Water

Failure of source or failure of power supply may cause reduced supplies. Normally, the distribution affected reservoirs are designed for filling in about 8 hours of pumping and whenever the power supply is the pumping hours are reduced and hence the distribution reservoirs are not filled up leading to reduced supply hours and hence reduced quantity of water.

(c) Low Pressure at Supply Point

Normally peak demand is considered ranging from 2 to 3, whereas the water supply is given only for a different duration, leading to large peak factors and hence affecting the pressures in the distribution system. This is common with most water supply systems.

(d) Leakage of Water

Large quantity of water is wasted through leaking pipes, joints, valves and fittings of the distribution systems either due to bad quality of materials used, poor workmanship, and corrosion, age of the installations or through vandalism. This leads to reduced supply, loss of pressure and deterioration in water quality.

Maintenance of appropriate positive pressure at all times to all consumers is the main concern of O&M. Negative pressure can cause contamination of water and very high pressure damages the pipelines. Low pressure may be avoided by taking the following steps:

(i) Purposefully or accidently, a line valve is left closed or partly closed or blockage due to any material causing loss of pressure,
(ii) Too high velocities in small pipelines,
(iii) Low water level in SR,
(iv) Failure of pumps/Booster pumps (either due to power failure or mechanical failure) feeding the system directly.

(e) Unauthorized Connections

Illegally connected users will contribute to the reduction in service level to authorized users/ consumers and deterioration of quality of water. Sometimes, even legally connected users draw water by sucking through motors causing reduction in pressures.

(f) Extension of Service Area

Due to extension of service area without corresponding extension of distribution mains, the length of house connections will be too long leading to reduction in pressures.

(g) Age of the System

With age, there is considerable reduction in carrying capacity of the pipelines due to encrustation. In most of the places, the consumer pipes get corroded or precipitates and leaks occur resulting in loss of water and reduced pressure and pollution of supplies

(h) Lack of Records

Records of replacement of fittings/pipes/valves, scouring of entire distribution system, system maps, designs of the network and reservoirs and historic records of the equipment installed in the distribution system are often not available, whereas some minimum information is required to operate and maintain the system efficiently.

9.2 OPERATIONAL SCHEDULE

9.2.1 Mapping and Inventory of Pipes and Fittings in the Water Supply System

Availability of updated distribution system maps with contours, location of valves, flow meters and pressure gauges or taping points is the first requirement for preparation of operation schedule. The agency should set up routine procedures for preparing and updating the maps and inventory of pipes, valves and consumer connections. The maps shall be exchanged with other public utilities to contain information on other utility services like electricity, communications etc.

9.2.2 Field Survey and Distribution Network Simulation

Existing maps are used or conventional survey is employed for preparation and up-dating of maps. As an alternative to traditional survey and map preparation, 'total station method is gaining popularity. Total station instruments can be used for survey and mapping of villages where data is not readily available.

The use of modern databases such as Geographical Information Systems (GIS), more and more detailed information can be included in analyses, specifically for monitoring of the network operation and maintenance. This is particularly very useful in cases where there is a huge amount of data and scenarios where manual/hardcopy analyses are not easy to handle or to understand properly.

The use of GIS coupled with Global Positioning System (GPS) in water distribution system management can also greatly enhance the amount and accuracy of data available. The GIS maps are becoming readily available and the GIS system can receive any additional information that becomes available after any replacement, connection or disconnection or expansion of the system has taken place. In this way, these maps enable multiple use: providing direct input for the computer model (hydraulic), accurate billing information and the location of system components that are malfunctioning and have to be repaired, etc.

Evaluation of Hydraulic Conditions

A continuous evaluation of the hydraulic conditions of the water supply system can be done by the O&M personnel after obtaining the data on water volumes in the reservoirs, flow meter readings from and into the reservoirs connected to a transmission system and compared with the expected performance. This evaluation shall lead to identification of operational problems and/or system faults. Depending on the type of problems actions have to be initiated to ensure that the system functions as per the requirement.

Simulation of Distribution Network

Operations have to be planned for specific circumstances such as failure at source, failure of pumps, leakages or bursts. Criteria have to be determined on the basis of analysis of the effects of particular operations on the hydraulic configuration of the water supply transmission system. These effects can be seen in simulated operating conditions. Mathematical simulation models can be developed from basic data on the network such as length, size, flow, characteristics of pumps, valves, reservoir levels etc. This approach can be very useful for analysing the effects of variables on large and complex water supply transmission and distribution systems.

9.2.3 Routine Operations of the Water Supply Distribution System

The efficiency and effectiveness of a water supply system depends on the operating personnel's knowledge of the variables that affect the continuity, reliability, and quantity of water supplied to the consumers. The operational staff should be able to introduce changes in the hydraulic status of the system as required depending on those variables promptly and effectively. Routine operations shall be specified which are activities for adjusting the valves and operation containing procedures for operating the distribution system. It should contain procedures to obtain, process, and analyze the variables related to water flows, pressures and levels as well as the consequences of manipulating control devices, such as operation of valves and/or pumps so that the hydraulic status of the system can match the demand for water. When operators change their shifts, information on valve closure and opening must be exchanged.

9.2.4 Operations in Break Downs and Emergencies

Operations other than routine i.e. during breakdowns and emergencies have to be specified and should be carried out in specific circumstances when normal conditions change i.e. when flows, pressures and levels and operation of pumps change.

9.2.5 Measurement of Flows, Pressures and Levels

It will be necessary to monitor regularly operational data concerning flows, pressures and SR levels to assess whether the system is functioning as per requirements. Analysis of data may reveal overdraw of water to some reservoirs and or bulk consumers. At such places, appropriate flow control devices may be introduced to limit the supplies to the required quantity. A list of priority points in water supply system have to be identified such as installation of meters to measure flows, pressures and levels. A detailed map showing location or each measuring point has also to be prepared. The degree of sophistication of the devices used at each measuring point with regard to indication, integration, recording, transmission and reception of data depends mainly on the skills of the O&M personnel available with the agency and affordability of the agency.

9.2.6 Sampling for Quality of Water

The agency operating the water supply system is charged with the primary responsibility of ensuring that the water supplied to the consumer is of an appropriate quality. To achieve this objective, it is necessary that the physical, chemical, bacteriological and microbiological tests are carried out at frequent intervals. Samples should be taken at different points on each occasion to enable one to make an overall assessment. In the event of epidemic or danger of pollution, more frequent sampling may be required, especially for bacteriological quality. For each distribution system, a monitoring programme has to be prepared showing the location of sampling points. Based on historic records of a system it will be possible for the manager of the system to decide locations for bacteriological sampling and residual chlorine testing. Reference can be made to Section 7.5.2.1 item (ii) and MoW guidelines URT (2018).

9.3 MANAGEMENT OF EVENTS OF WATER SHORTAGE

The objective of developing a programme for managing in times of shortage of water is to reduce the excessive use of water particularly when the source is limited due to the adverse seasonal conditions. Basically, it involves ensuring that a water conservation policy is developed and implemented among water consumers. The following activities can be considered while formulating such a water management project:

(a) Installation of accurate water meters and establishment of a realistic tariff structure to encourage water conservation and prevent wastage of water. Common customer meter chambers can be useful as they assist to minimize tempering of individual/house connection meters,
(b) Introduction of restrictions on use of flushing, showers and other household fittings,
(c) Introduction of devices to limit water consumption in flushing of toilets,
(d) Enforcement of restrictions on use of treated water for watering lawns, cooling, construction, washing of vehicles, etc.,
(e) Encouragement and/or enforcement of the reuse of treated industrial effluents and wastewater,
(f) Development and implementation of public education programmes to encourage water conservation,
(g) Limit of length of service lines (house connections) is usually made as short as practically possible depending on how far is the distribution main.

9.4 SYSTEM SURVEILLANCE

Surveillance of distribution system is done to detect and correct the following:

(a) Sanitary hazards,
(b) Deterioration of distribution system facilities,

(c) Encroachment of distribution system facilities by other utilities such as sewer and storm water lines, power cables, telecom cables etc. and
(d) Detecting and correcting damages of the system facilities by vandalism.

9.5 MAINTENANCE SCHEDULE

(a) A maintenance schedule is required to be prepared to improve the level of maintenance of water distribution networks and house connections through improved co-ordination and planning of administrative and field work and through the use of adequate techniques, equipment and materials for field maintenance,
(b) The schedule has to be flexible so that it can achieve team action with the available vehicles and tools,
(c) Co-ordination of activities is required for spares and fittings, quality control of materials used and services rendered,
(d) Training of maintenance staff shall include training to achieve better public relations with consumers apart from the technical skills.

9.6 ACTIVITIES IN MAINTENANCE SCHEDULE

Following activities are to be included in the schedule:

(a) Establishment of procedures for setting up maintenance schedules and obtaining and processing the information provided by the public and the maintenance teams,
(b) Formation of maintenance teams for each type of service with provision for continuous training,
(c) Establishment of repair procedures for standard services,
(d) Specification of appropriate tools,
(e) Allocation of suitable transport, tools and equipment to each team,
(f) Establishment of time, labour and material requirement and output expected; time required and other standards for each maintenance task, and
(g) Monitoring the productivity of each team.

9.7 PREVENTIVE MAINTENANCE SCHEDULE

A preventive maintenance schedule for servicing of valves and maintenance of valve chambers, maintenance of the pipelines: may include the tasks, set priorities, issue of work orders for tasks to be performed, list of scheduled tasks not completed, record of when the tasks are completed and maintaining a record of tools, materials, labour and costs required to complete each task.

9.8 LEAKAGE CONTROL

Wastage of water in the system and distribution network occurs by way of leakage from pipes, joints & fittings, reservoirs and overflow from reservoirs &

sumps. The objective of leakage control programme is to reduce the wastage to a minimum and minimize the time that elapses between the occurrence of a leak and its repair. The volume of water lost through each leak should be reduced by taking whatever action technically and economically feasible to ensure that the leak is repaired as quickly as possible. To achieve this, the organization shall prescribe procedures for identifying, reporting, repairing and accounting for all visible leaks.

It will be beneficial for the water utilities or authority or RUWASA if the procedures involve the conscious and active participation of the population it serves apart from its own staff. The management has to process the data and evaluate the work on detection and location of leaks and for dissemination of the results and initiate actions to control the overall problem of water loss. Interim measures for reduction/control of leakage can be initiated by controlling pressures in the water distribution system where feasible.

9.8.1 Leakage Through House Connections

Leakage can be controlled at the point of house connection and in the consumer pipe by adopting correct plumbing practices and improving the methods used for tapping the main and giving house connection and strict quality control on the pipe material used for house connection. An analysis of leaks in house connections and investigation of reasons for leaks in the house connections shall be carried out to initiate action on reducing the leakage through house connections.

9.8.2 Procedures for Detecting Visible Leaks

The water supply utility or authority or RUWASA has to establish procedures whereby the population served by the agency notifies the visible leaks. The water supply staff can also report visible leaks found by them while carrying out other works on the water supply system. Water supply utility or authority or RUWASA has to establish procedures for prompt repair of leaks and for attending efficiently and accurately to the leaks. Critical areas where leaks often occur have to be identified and appropriate corrective measures have to be implemented. Effective use of SCADA should be investigated.

9.8.3 Procedures for Detecting Invisible Leaks

Establishment of procedures for detecting and locating non-visible leaks shall be compatible with the technological, operational and financial capability of the utility or authority or RUWASA. Selection and procurement of equipment for detection and location of leaks must take into account the cost-effectiveness and the financial capability of the organization.

9.9 CROSS CONNECTIONS

Contaminated water through cross connections of water supply lines with sewers and drains is a problem prevailing widely. Intermittent supply further aggravates the problem since, during non-supply hours polluted water may reach the supply mains through leaking joints, thus polluting the supplies. In certain instances, when there are extremely high water demands, the pressures in the supply mains are likely to fall below atmospheric pressure, particularly when consumers start use of pumps with direct suction from the supply mains, a process that is regarded to be illegal.

Regular survey has to be undertaken to identify potential areas likely to be affected by cross connections and back-flow. All field personnel should be constantly alert for situations where cross connections are likely to exist. After identifying the cross connections, remedial measures taken up which can include: providing horizontal and vertical separation between the water main and the sewer/drain providing a sleeve pipe to the consumer pipes crossing a drain, modifying the piping including changing corroded piping with non-corrodible piping, providing double check/non-return valves at the consumer end. The various types of materials of pipe & specifications are being used in the distribution system and specific requirements of maintenance are to be followed as per water supply authority/utility/RUWASA/Manufacturer's recommendations.

9.10 PLUMBING PRACTICES FOR DRINKING WATER SUPPLY

The internal plumbing system of the consumer shall conform to the National recommendations and also particularly to the by-laws of concerned water supply authority/utility/RUWASA. The various types of plumbing materials are being used and require different maintenance practices. The utility can regulate up to the connection to supply mains. It is recommended to use licensed plumbers.

Therefore, specific requirements of maintenance are to be followed as per the Manual/ Manufacturer's recommendations or water supply authority/utility/ RUWASA recommendations/specifications indicated in Volume I.

9.10.1 Quality of Pipe Material for House Connection

The water supply authority/utility/RUWASA shall ensure that the connection and communication pipe from the street main up to the consumer premises is laid as per correct plumbing practices and must adopt improved methods for tapping the main. Strict quality control is required on the pipe material used for house connection. The by-laws shall lay down rules for defining the ownership and responsibility for maintaining the point of connection and the communication pipe. In several utilities, the communication pipes are leaking since they are corroded; however these are not replaced by the consumer or by the utility particularly where the O&M responsibility for consumer pipe rests with the consumers.

9.10.2 Contamination through House Connection

While laying the consumer connection pipes there are is a need to avoid contamination of water supplies. This can be achieved by maintaining horizontal and vertical separation between the water supply communication pipe and the sewer/drain. In some instances, a sleeve pipe may be required to be provided to the consumer pipes crossing a drain. It is always recommended to provide a non-corrodible pipe material for the consumer connection. Contamination by possible back flow can also be prevented by ensuring provision of double check/ non-return valves at the consumer end.

9.10.3 Rules for Consumer Connections

The water supply authority/utility/RUWASA shall formulate rules for sanctioning of consumer connection, tapping the mains and laying the connection piping. Water supply utility shall undertake inspection of the consumer premises before releasing the connection to ensure that the internal plumbing system of the consumer conforms to the requirements. Water supply authority/utility/RUWASA shall supervise the process of drilling/tapping of the mains for giving connection and laying of the consumer piping.

The process of submission of applications for connections by consumers and carrying out the connection work through licensed plumbers is also prevalent in some utilities. In such cases, the water supply authority/utility/RUWASA shall formulate procedures for licensing the plumbers including the qualifications to be possessed by the plumber, facilities and tools to be available with the plumber for the work to be undertaken by the plumber. The water supply authority/utility/ RUWASA shall closely observe the quality of materials used and works done by him and he should act as per procedures laid down in the bye laws/regulations for approval of the connection works, renewal or cancellation of the plumbers' licenses or any other requirement depending on their performance or non-performance.

9.11 CHLORINE RESIDUAL TESTING AT CONSUMER END

A minimum chlorine residual of about 0.2 - 0.5 mg/l at the selected monitoring point/ consumer's end is often maintained to ensure that even a little contamination is destroyed by the chlorine. Hence, absence of residual chlorine could indicate potential presence of heavy contamination. If routine checks at a monitoring point are carried out, required chlorine residuals and any sudden absence of residual chlorine should alert the operating staff to take up prompt investigation. Immediate steps to be taken are:

(a) Re-testing for residual chlorine,
(b) Checking chlorination equipment,
(c) Searching for the potential source of contamination, which has caused the increased chlorine demand, and
(d) Immediate stoppage of supplies from the contaminated pipelines.

9.12 SAMPLE RECORDS TO BE MAINTAINED BY THE WATER SUPPLY UTILITY

Sample records to be maintained by the water supply utility are given below for guidance:

(a) Updated system map,

(b) Pressure and flow readings at selected monitoring points,

(c) Persistent low pressure or negative pressure areas,

(d) Age of pipes/quality of pipes,

(e) Pipelines to be replaced,

(f) Presence of undesirable materials,

(g) Water budget for each zone served by one SR,

(h) Number of connections given,

(i) Number of meters out of order

(j) Quantity measured at outlet of reservoir,

(k) Quantity distributed/measured or billed,

(l) Water budget for each zone served by one SR

(m) Source of leaks and persistent leak points,

(n) Status of bulk meters - functioning or not,

(o) Status of consumer meters,

(p) Facilities for repairs of consumer meters,

(q) Number of unauthorized connections,

(r) Residual chlorine levels at the pre-selected monitoring points,

(s) Bacteriological quality of the water sampling points,

(t) Persistent areas where residual chlorine is absent/where water samples are found contaminated,

(u) Record of carrying out repairs on the following:
   (i) The pipe line leaks or replacement of pipes,
   (ii) Change of gland ropes of the valves in distribution system,
   (iii) Record on man hours spent on routine operations in the distribution system in the previous year and the cost thereof.

9.13 RECORD KEEPING

(a) To maintain necessary inventory of the materials used and required. Record of total cost of repairs and replacements in previous years along with breakdown of material and labour costs with the amount spent on outside agencies for repairs and replacements,

(b) Replacement of damaged manhole covers,

(c) Record on when the exposed piping was last painted and the cost of materials and labour cost thereof, and

(d) Record of the un-served areas - extension of pipelines- need for interconnection.

Chapter 10

PUMPING MACHINERY

10.1 GENERAL

Pumping machinery and pumping stations are very important components in water supply and sanitation projects. Pumping machinery is subject to wear, tear, erosion and corrosion due to the nature of their functioning and therefore is vulnerable to failure. Generally, more numbers of failures or interruptions in water supply and sanitation projects are attributed to pumping machinery than any other component. Therefore, correct operation and timely maintenance and upkeep of pumping stations and pumping machinery are both of vital importance to ensure continued existence of uninterrupted water supply and sanitation services. Sudden failures can be avoided by timely inspection, follow up actions during observations of inspection and planned periodic maintenance. Downtime can be reduced by maintaining an inventory of the fast moving spare parts. Efficiency of pumping machinery decreases due to normal wear and tear. Timely action for restoration of efficiency can keep energy bills within a reasonable optimum limit. In case there is no standby pump provision, suitable water pumps with identical duty shall be provided as 100% standby in case of a single pump set and two or more pumps with a minimum of 50% standby along with all necessary accessories like cables, control panels, safety equipment, valves and fittings. Providing a minimum of 50% standby pump set will help in operating the schemes in initial stages until stabilization is achieved.

In case of depletion of sources during dry season or rains failure, the design engineer should ensure that schemes can be operated partially without throttling of pumps. While replacement of motors/ pumps is done, it must be insisted to provide star rated motors to have energy savings. Generally, as the pumps are scheme specific, (i.e. discharge & head fixed depending upon the requirements), the question of standardization with regard to minimizing the inventory does not arise. To ensure better performance/effective cost savings, energy audit and water and sanitation audit needs to be done for every project.

Annual monitoring of handed over projects must be done by the department that implemented the projects. Proper record keeping is also very important. A log book should be maintained covering the following items:

(a) Timings when the pumps are started, operated and stopped during 24 hours,
(b) Voltage in all three phases,
(c) Current drawn by each pump-motor set and total current drawn at the installation,
(d) Frequency,
(e) Readings of vacuum and pressure gauges,
(f) Motor winding temperature,
(g) Bearing temperature for pump and motor,
(h) Water level in intake/sump,
(i) Flow meter reading,
(j) Daily Power factor over 24 hours duration, and
(k) Any specific problem or event in the pumping installation or pumping system (e.g. burst in pipeline, tripping or fault, power failure).

10.2 COMPONENTS OF A PUMPING STATION

The components of a pumping station can be grouped into three groups as follows:

(a) Pumping machinery

Pumps and other mechanical equipment, i.e. valves, pipe works, vacuum pumps, motors, switchgears, cables, transformers and other electrical accessories.

(b) Ancillary Equipment

(i) Lifting equipment,
(ii) Water hammer control device,
(iii) Flow meters,
(iv) Diesel generating set.

(c) Pumping stations

(i) Sump/intake/well/tube well/borehole,
(ii) Pump house,
(iii) Screens,
(iv) Penstock/gate.

10.2.1 Type of Pumps

The following types of pumps are used in water supply and sanitation systems:

(a) Centrifugal pumps,
(b) Vertical turbine pumps,
(c) Oil lubricated,
(d) Self-water (pumped water) lubricated,

(e) Clear water lubricated,
(f) Submersible pumps,
(g) Vertical bore well type pump-motor set,
(h) Mono bloc open well type pump-motor set,
(i) Jet pumps,
(j) Reciprocating pumps.

10.2.2 Important Points for Operation of the Pumps

Various types of pumps are in use and the specification of O&M schedule provided by the manufacturers shall be followed. However, the following points shall be observed while operating the pumps:

(a) Dry running of the pumps should be avoided,
(b) Centrifugal pumps have to be primed before starting,
(c) Pumps should be operated only within the recommended range of the head-discharge (duty) characteristics of the pump,
(d) If a pump is operated at a point away from the designated duty point, the pump efficiency normally reduces,
(e) Operation near the shut off point should be avoided, as the operation near the shut off causes substantial recirculation within the pump, resulting in overheating of water in the casing and consequently, overheating of the pump,
(f) Voltage during operation of pump-motor set should be within ± 10% of the rated voltage. Similarly, current should be below the rated current as per specification of the name plate on the motor,
(g) Whether the delivery valve should be opened or closed at the time of starting should be decided by examining the shape of the power-discharge characteristics of the pump. Pumps of low and medium specific speeds draw lesser power at shut off head and power required increases from shut off to a normal operating point. Hence in order to reduce the starting load on the motor, a pump of low or medium specific speed is started against closed delivery valve. Normally the pumps used in water supply schemes are of low or medium specific speeds. Hence, such pumps need to be started against closed delivery valves. The pumps of high specific speed draw more power at shut off. Such pumps should be started with the delivery valves open,
(h) The delivery valve should be operated gradually to avoid sudden change in flow velocity which can cause water hammer pressures. It is also necessary to control the opening of the delivery valves during pipeline - filling period so that the head on the pump is within its operating range to avoid operation on low head and consequent overloading. This is particularly important during charging of the pumping mains initially or after shutdown. As the head increases, the valve shall be gradually opened,

(i) When the pumps are to be operated in parallel, the pumps should be started and stopped with a time lag between the two pumps to restrict change of flow velocity to a minimum and to restrict the dip in voltage in the incoming feeder. The time lag should be adequate to allow stabilizing the head on the pump, as indicated by a pressure gauge,

(j) When the pumps are to be operated in series, they should be started and stopped sequentially, but with minimum time lag. Any pump, next in sequence should be started immediately after the delivery valve of the previous pump is even partly opened. Due care should be taken to keep the air vent of the pump next in sequence open, before starting that pump,

(k) The stuffing box should let a drip of leakage to ensure that no air is passing into the pump and that the packing is getting adequate water for cooling and lubrication. When the stuffing box is grease sealed, adequate refill of the grease should be maintained,

(l) The running of the duty pumps and the standby one should be scheduled carefully so that no pump remains idle for a long period and all pumps are in ready-to run condition. Similarly, unequal running should be ensured so that all pumps do not wear equally and become due for overhaul simultaneously. If any undue vibration or noise is noticed, the pump should be stopped immediately and causes of the vibration or noise be checked and rectified,

(m) By-pass valves of all reflux valves, sluice valves and butterfly valves shall be kept in the closed position during normal operation of the pumps,

(n) Frequent starting and stopping should be avoided because, each start causes overloading of the motor, starter and contactors. Though overloading lasts for a few seconds, it reduces the lifetime of the equipment.

10.2.2.1 Undesirable Operations

The following undesirable operations should be avoided:

(a) Operation at Higher Head-The pump should never be operated at a head higher than the maximum recommended. Such operation results in excessive recirculation in the pump, overheating of the water and the pump. Another problem, which arises if a pump is operated at a head higher than the recommended maximum head, is that the radial reaction on the pump shaft than the recommended maximum head, is that the radial reaction on the pump shaft increases causing excessive unbalanced forces on the shaft which may cause failure of the pump shaft. As a useful guide, appropriate marking on pressure gauge be made. Such operation is also inefficient as pump efficiency at higher head is normally low,

(b) Operation at Lower Head-If pump is operated at lower head than recommended minimum head, radial reaction on the pump shaft increases causing excessive unbalanced forces on the shaft which may cause failure of the pump shaft. As a useful guide, appropriate markings on both the pressure gauge and the ammeter should be made. Such operation is also inefficient as efficiency at lower heads is normally low,

(c) Operation on higher suction lift. If a pump is operated on a higher suction lift than the permissible value, pressure at the eye of the impeller and the suction side falls below the vapour pressure. This results in convention of water into vapour. These vapour bubbles during passage collapse resulting in cavitation if the pump, pitting on the suction side of the impeller and casing as well as excessive vibrations. In addition to mechanical damage due to pitting, discharge of the pump also reduces drastically,

(d) Throttled operation-At times if the motor is continuously overloaded, the delivery valve is throttled to increase the head on the pump and to reduce power drawn from the motor. Such operation results in inefficient running as energy is wasted in throttling. In such cases, it is preferable to reduce the diameter of the impeller which will reduce the power drawn from the motor. Installation of variable voltage & variable frequency (VVVF) drive as a remedial measure is recommended,

(e) Operation with strainer/foot valve clogged-If the strainer or foot valve is clogged, the friction loss in the strainer increases to high magnitudes which may result in pressure at the eye of the impeller falling below water vapour pressure, causing cavitation and pitting similar to operation at a higher suction lift. The strainers and foot valves should be periodically cleaned, particularly during the rainy season,

(f) Operation with occurrence of Vortices-If vibration continues even after taking all precautions, vortex may be the cause. All parameters necessary for ensuring vortex-free operation should be checked.

10.2.2.2 Starting the Pumps

The following points should be checked before starting the pump:

(a) Power is available in all 3 phases,

(b) All connections are properly thimbled,

(c) Trip circuit for relays is in a healthy state,

(d) Check voltage in all 3 phases,

(e) The voltage in all phases should be almost the same and within ± 10% of the rated voltage, as per permissible voltage variation,

(f) Check functioning of the lubrication system specifically for oil lubricated and clear water lubricated vertical turbine pumps and oil lubricated bearings,

(g) Check stuffing box to ensure that it is packed properly,

(h) Check and ensure that the pump is free to rotate,

(i) Check over current setting if the pump is not operated for a week or longer periods,

(j) Before starting, it shall be ensured that the water level in the sump/intake is above the low water level and inflow from the source or preceding pumping station is adequate.

10.2.2.3 Stopping the Pump

(a) Stopping the Pump under Normal Condition

Steps to be followed for stopping a pump of low or medium specific speed are as follows:

- (i) Close the delivery valve gradually (sudden or fast closing should not be resorted to which can give rise to water hammer pressures),
- (ii) Switch off the motor,
- (iii) Open the air vent in case of Vertical Turbine (VT) and submersible pump,
- (iv) Stop lubricating oil or clear water supply in case of oil lubricated or clear water lubricated VT pump as applicable.

(b) Stopping after Power Failure/Tripping

If power supply to the pumping station fails or trips, actions stated below should be immediately taken to ensure that the pumps do not restart automatically on resumption of power supply. Though no-volt release or under volt relay is provided in the starter and the circuit breaker, possibility of its malfunctioning and failure to open the circuit cannot be ruled out. In such eventuality, if the pumps starts automatically on resumption of power supply, there will be sudden increase in flow velocity in the pumping main causing sudden rise in pressure due to the water hammer which may prove disastrous to the pumping main. Secondly, due to sudden acceleration of flow in the pumping main from no-flow situation, acceleration head will be very high and the pumps shall operate near the shut off region during the acceleration period which may last for a few minutes for long pumping mains and cause overheating of the pump. Restarting of all pumps simultaneously shall also cause overloading of the electrical system. Hence, precautions are necessary to prevent auto-restarting on resumption of power.

Following procedure should be followed:

- (i) Close all delivery valves on delivery piping of the pumps if necessary, manually as actuators cannot be operated due to non-availability of power,
- (ii) Check and ensure that all circuit breakers and starters are in the open condition i.e. off-position,
- (iii) All switches and circuit breakers shall be operated to open i.e. off-position,
- (iv) Open the air vent in case of a vertical turbine or submersible pump and close the lubricating oil or clear water supply in case of oil lubricated or clear water lubricated vertical turbine pump. Information about power failure should be given to all concerned, particularly to the upstream pumping stations to stop pumping so as to prevent overflow.

10.3 PUMPING MACHINERY MAINTENANCE

(a) Daily

- Clean the pump, motor and other accessories,
- Check coupling bushes/rubber spider,
- Check stuffing box, gland, etc.

(i) Routine observations of irregularities

The pump operator should be watchful and should take appropriate action on any irregularity noticed in the operation of the pumps. Particular attention should be paid to following irregularities:

- Changes in the sound of a running pump and motor,
- Abrupt changes in bearing temperature,
- Oil leakage from the bearings,
- Leakage from the stuffing box or mechanical seal,
- Changes in voltage,
- Changes in current,
- Changes in vacuum gauge and pressure gauge readings,
- Sparks or leakage current in motor, starter, switch-gears, cable, etc.,
- Overheating of the motor, starter, switch gear, cable, etc.

(ii) Record of operations and observations

A log book should be maintained to record the observations, which should cover the following items:

- Timings when the pumps are started, operated and stopped during 24 hours,
- Voltage in all three phases,
- Current drawn by each pump-motor set and total current drawn at the installation,
- Frequency,
- Readings of vacuum and pressure gauges,
- Motor winding temperature,
- Bearing temperature for the pump(s) and motors,
- Water level in the intake/sump,
- Flow meter reading,
- Daily Power Factor (PF) over 24 hour's duration,
- Any specific problem or event in the pumping installation or pumping system (e.g. burst in pipeline, tripping or fault, power failure),

(b) Monthly Maintenance

(i) Check free movement of the gland of the stuffing box; check gland packing and replace if necessary. Clean and apply oil to the gland bolts.

(ii) Inspect the mechanical seal for wear and replacement if necessary. Check condition of bearing oil and replace or top up if necessary.

(c) Quarterly Maintenance

(i) Check alignment of the pump and the drive. The pump and motor shall be decoupled while correcting alignment, and both the pump and motor shafts shall be pushed to either side to eliminate effect of end play in bearings.

(ii) Clean oil lubricated bearings and replenish with fresh oil. If bearings are grease lubricated, the condition of the grease should be checked and replaced/replenished to the correct quantity. An anti-friction bearing should have its housing so packed with grease that the void space in the bearing housing should be between one third to half. A fully packed housing will overheat the bearings and will result in reduction of life of the bearings.

(iii) Tighten the foundation bolts and holding down bolts of the pump and motor mounting on the base plate or frame.

(iv) Check vibration level with instruments if available; otherwise by observation.

(v) Clean flow indicator, other instruments and appurtenances in the pump house.

(d) Annual Inspections and Maintenance

A very thorough, critical inspection and maintenance should be performed by trained operators/engineers once in a year. Following items should be specifically attended:

(i) Clean and flush bearings with kerosene and examine for flaws that may have developed if any, e.g. corrosion, wear and scratches. Check end play. Immediately after cleaning, the bearings should be coated with oil or grease to prevent ingress of dirt or moisture,

(ii) Clean bearing housing and examine for flaws, e.g. wear, grooving etc. Change oil or grease in the bearing housing,

(iii) Examine shaft sleeves for wear or scour and necessary rectifications. If shaft sleeves are not used, shaft at gland packing's should be examined for wear,

(iv) Check stuffing box, glands, lantern ring, and mechanical seal and rectify if necessary,

(v) Check clearances in the wearing ring,

(vi) Check impeller hubs and vane tips for any pitting or erosion,

(vii) Check interior of volute, casing and diffuser for pitting, erosion, and rough surface,

(viii) All vital instruments i.e. pressure gauge, vacuum gauge, ammeter, voltmeter,

(ix) Undertake performance test of the pump for discharge, head efficiency.

10.3.1 Maintenance Schedule for Motors

(a) Daily

(i) Clean the external surface of the motor,
(ii) Examine earth connections and motor leads,
(iii) Check temperature of the motor and check whether overheated. The permissible maximum temperature is above the level which can be comfortably felt by hand. Hence, temperature observation should be taken with a Resistance Temperature Detector (RTD) or a thermometer. (Note: In order to avoid opening up motors, a good practice is to observe the stator temperature under normal working conditions. Any increase not accounted for, by seasonal increase in ambient temperature, should be suspected),
(iv) In case of oil ring lubricated bearings,
(v) Examine bearings to check whether oil rings are working,
(vi) Note bearing temperature,
(vii) Add oil if necessary,
(viii) Check for any abnormal bearing noise,
(ix) Note pump vibration if any.

(b) Monthly

(i) Check belt tension. In case where this is excessive it should immediately be reduced,
(ii) Blow dust from the motor,
(iii) Examine oil in oil lubricated bearings for contamination by dust, grit. (This can be judged from the colour of the oil),
(iv) Check functioning and connections of anti-condensation heater (space heater),
(v) Check insulation resistance.

(c) Quarterly

(i) Clean oil lubricated bearings and replenishes fresh oil. If bearings are grease lubricated, the condition of the grease should be checked and replaced/replenished to correct quantity,
(ii) Anti-friction bearings should have its housing so packed with grease that the void space in the bearing housing should be between one third to half. A fully packed housing will overheat the bearing and will result in reduction of life of the bearing,
(iii) Wipe brush holders and check contact faces of brushes of slip-ring motors. If contact face is not smooth or is irregular, file it for proper and full contact over slip rings,
(iv) Check the insulation resistance of the motor,
(v) Check tightness of the cable gland, lug and connecting bolts,
(vi) Check and tighten foundation bolts and holding down bolts between motor and the frame,
(vii) Check vibration level with instrument if available; otherwise by observation.

(d) Half Yearly

- (i) Clean winding of the motor, bake and varnish if necessary,
- (ii) In case of slip ring motors, check slip-rings for grooving or unusual wear, and polish with smooth polish paper if necessary.

(e) Annual Inspections and Maintenance

- (i) Clean and flush bearings with kerosene and examine for flaws that may have developed, if any, e.g. wear and scratches. Check end-play. Immediately after cleaning, the bearings should be coated with oil or grease to prevent ingress of dirt or moisture,
- (ii) Clean bearing housing and examine for flaws, e.g. wear, grooving etc. Change oil or grease in bearing housing,
- (iii) Blow out dust from the windings of motors thoroughly with clean dry air. Make sure that the pressure is not so high as to damage the insulation,
- (iv) Clean and varnish dirty and oily windings. Re-varnish motors subjected to severe operating and environmental conditions e.g., operation in dust-laden environment, polluted atmosphere, etc.,
- (v) Check condition of the stator, stamping, insulation, terminal box, fan, etc.,
- (vi) Check insulation resistance to earth and between phases of motor windings, control gear and wiring,
- (vii) Check air gaps,
- (viii) Check resistance of earth connections.

10.3.2 History Sheet

Similar to the history sheet of the pump, history sheet of the motor should be maintained. The history sheet should contain all important particulars, records of periodic maintenance, repairs, inspections and tests. It shall generally include the following:

- (a) Details of motor, rating, model, class of duty, class of insulation, efficiency curve, type test result and type test certificate, etc.,
- (b) Date of installation and commissioning,
- (c) Addresses of manufacturer & dealer with phone & fax number and e-mail addresses,
- (d) Brief details of monthly, quarterly, half yearly and annual maintenance and observations of inspections about insulation level, air gap, etc.,
- (e) Details of breakdown, repairs with fault diagnosis,
- (f) Running hours at the time of any major repairs.

10.3.3 Low Voltage Starters, Circuit Breakers and Panel

Note: Circuit diagram of the starter/breaker should be pasted on the door of the switch gear and additional copy should be kept on record.

(a) Daily

(i) Clean the external surface,
(ii) Check for any spark or leakage current,
(iii) Check for overheating.

(b) Monthly

(i) Blow the dust and clean internal components in the panel, and breaker,
(ii) Check and tighten all connections of cables, wires, jumpers and bus-bars. All carbon deposits shall be cleaned,
(iii) Check relay setting.

(c) Quarterly

(i) Check all connections as per circuit diagram,
(ii) Check fixed and moving contacts and clean with smooth polish paper, if necessary,
(iii) Check oil level and condition of oil in the oil tank. Replace the oil if carbon deposit in suspension is observed or the colour is black,
(iv) Check insulation resistances,
(v) Check conditions of insulators.

(d) Yearly

(i) Check and carry out servicing of all components, thoroughly clean and reassemble,
(ii) Calibrate voltmeter, ammeter, frequency meter, etc.

10.3.4 High voltage Breakers Contactors and Protection Relays

Note: Circuit diagram of the breaker/relay circuit should be pasted on the door of switch gear and additional copy should be kept on record. Maintenance schedule specified for Low voltage breakers are also applicable to High voltage breakers and contactors. In addition, the following important points shall be attended for High voltage breakers and contactors.

(a) Monthly

(i) Check spring charging mechanism and manual cranking arrangement for operation,
(ii) Clean all exposed insulators,
(iii) Check trip circuit and alarm circuit,
(iv) Check opening & closing timing of the breaker.

(b) Quarterly

(i) Check control circuits including connections in marshalling boxes of breakers and the transformer,

(ii) Check oil level in Minimum/Low Oil Circuit Breaker (M/LOCB)/High Voltage Oil Circuit Breaker (HV.OCB) and top up with tested oil,

(iii) Yearly / Two yearly testing of protection relay with Direct Current (D.C) injection shall be carried out once in year,

(iv) Servicing of High voltage breaker and contactor shall be carried out once in 2-3 years,

(v) Check dielectric strength of oil in the breaker and replace if necessary,

(vi) Check male & female contacts for any pitting and measure contact resistance.

10.3.5 Transformer and Transformer Substation

Maintenance schedule as follows shall be applicable for transformer and sub-station equipment e.g. lightning arrestor, Air Break (AB) switch, Drop Off (DO) or horn gap fuse, sub-station earthing system. This section is particularly useful for the large schemes. Instructions of district/region/zone electricity department and chief electrical inspector shall be followed.

(a) Daily Observations and Maintenance

(i) Check winding temperature and oil temperature in the transformer and record. (For large transformers above 1000 kV, the temperature should be recorded hourly),

(ii) Check leakages through current/potential transformer unit, transformer tank and High/Low voltage bushings,

(iii) Check colour of silica gel. If silica gel is of pink colour, change the same by spare charge and reactivate old charge for re-use.

(b) Monthly

(i) Check oil level in the transformer tank and top up if required,

(ii) Check relay contacts, cable termination, connections in marshalling box,

(iii) Check operation of AB switch and DO fuse assembly,

(iv) Clean radiators free from dust and scales,

(v) Pour 3-4 buckets (6 to 8 buckets in hot season) of water in earth pit. Watering shall be increased to once in a week in hot seasons. Watering shall be increased to once in a week in hot seasons. Shall preferably contain small amounts of salt in solution,

(vi) Inspect lightning arrestor and High/Low voltage bushing for cracks and dirt.

(c) Quarterly

(i) Check dielectric strength of transformer oil and change or filter if necessary.

(ii) Check insulation resistance of all equipment in the sub-station, continuity of earthings and earth leads,

(iii) Check operation of tap changing switches.

10.3.6 Pre-rain and Post-rain Checks and Maintenance

- Check insulation resistance of the transformer,
- Test transformer oil for dielectric strength, sludge etc. If necessary, filtration of oil shall be carried out before the rainy season,
- Oil shall be tested for dielectric strength after rainy season.

(a) Half-Yearly

(i) Check dielectric strength of transformer oil in current/potential transformer and filter or change oil if necessary,

(ii) Check contact faces of Air Break (AB) switch and Drop Out/Horn Gap fuse; apply petroleum jelly or grease to moving components of AB switch.

(b) Annual

(i) Measure resistance of earth pit. Resistance shall not exceed 1 ohm,

(ii) Check bus bar connections, clean contact faces, change rusted nut bolts,

(iii) Calibrate the protection relay for functioning. Check relay setting and correct if necessary,

(iv) Ensure that the sub-station area is not water-logged. If required, necessary earth fillings with metal spreading at the top shall be carried out once in a year. Check drainage arrangement to prevent water logging in sub-station area and cable trenches,

(v) Test transformer oil for acidity test.

(c) Special Maintenance

(i) Painting of transformer tank and steel structure of the sub-station equipment shall be carried out after every two years,

(ii) The core of the transformer and winding shall be checked after 5 years for the transformer up to 3,000 kVA and after 7–10 years for transformers of higher capacity.

10.4 OPERATION AND MAINTENANCE ACTIVITIES OF SELECTED PUMPS

10.4.1 Submersible Pumps

The operation and maintenance of submersible pumps are given below. **Appendix 5** illustrates the details of troubleshooting for these pumps.

10.4.1.1 Operations

- Submersible pumps may be operated manually with a switch located above ground level or automatically with a pressure switch, electrodes or float control devices,
- Submersible pumps should always be operated below the water level,
- The pump should be installed higher than the well screen to prevent pump break suction which my lead to a burned pump motor.

Inspection procedure for key components

The installation of a new pump brings with it the expectation that it will operate consistently. Most operators are content with starting a pump and observing it run, like that is enough to see that the pump is operational. It is very vital to inspect the pump immediately on start-up, and also to do frequent inspections on it. Inspections assist in picking up faults early, when they occur before they become catastrophic. Routine preventive maintenance inspections can help address possible issues before they become major (or even catastrophic) events.

In most cases, four major components should be inspected in submersible pumps:

- Alarm monitoring,
- Pressure flow checks,
- Visual Inspection:
    - Inspect for clogging debris on suction inlet,
    - Check pump exterior for dents, corrosion and abrasion,
    - Clean off.
- Corrosion by inspecting valve threads.

Below is an inspection checklist for submersible borehole pumps:

(a) Check electrical condition of insulation on power cable(s) and on all phases of the motor,
(b) Check for any loose or faulty electrical connections within the control panel,
(c) Measure resistance between stator windings (in ohms),
(d) Check voltage supply between all phases of the electrical control panel,
(r) Check voltage balance (Vac) between all phases on the load side of the pump / mixer control panel with pump / mixer running,
(f) Check amperage draw on all phases of the motor (in amps),
(g) Check condition and operation of the motor thermal protection control system (if equipped),
(h) Remove pump / mixer from the lift station for physical inspection,
(i) Check condition of upper and lower shaft seals (inspect condition of motor / stator housing, if applicable),
(j) Check condition and operation of leakage and bearing sensors (if equipped),
(k) Check for worn out or loose impeller or propeller,

(l) Check impeller wear rings (rotating & stationary),
(m) Check for any unusual noise in the upper and lower bearings,
(n) Clean, reset and check operation of the level control system (if equipped),
(o) Check for physical damage of power and control cables,
(p) Check for correct shaft rotation,
(q) Check operation of valves and the associated equipment.

Table 10.1 summarizes the common problems of submersible pumps and their remedies.

Table 10.1: Common Troubleshooting for Submersible Pumps

Problems	Motor overhead	Control overhead
Pump motor fails to start	Low voltage	
	Fuse blown or loose connections	Replace fuse and rectify connections
	Motor control box not in proper position	Place it in proper position
	Cable, Splice or motor winding may be wet	Verify with ohmmeter and rectify
	Corrosion in pump	Remove corroded parts
Low or no water delivery	Pump not submersible	Lower the unit into well
	Leak in discharge pipe	Repair leaks
	Clogging or cession in check valve	Clean or replace valve
	Pump worn out by abrasion	Replace the pump
	Strainer/impeller clogged with sand or scales	Clean the parts
	Corrosion in discharge pipe	Replace it or remove corroded parts
Pressure valve fails to shut	Defects in switch	Adjust or replace pressure switch
	Leaks in discharge pipe	Repair the leaks

(Source: Pradhikaran, 2012)

10.4.1.2 Maintenance and Repair

To begin a maintenance job analysis, the assigned person needs the following information:

(a) Pump motor unit size and type;
(b) Static and pumping water level of the well;
(c) Size of drop pipe and/or drop cable;
(d) Pump setting;
(e) Discharge pressure required;
(f) Capacity pumped;
(g) Line voltage; and
(h) Operating Manual.

10.4.2 Centrifugal Pumps

10.4.2.1 Operations

To operate a centrifugal pump, certain procedures need to be followed, which are found in the manual supplied by the manufacturer. They generally involve the steps outlined below:

10.4.2.2 Steps in Operating the Centrifugal Pumps

(a) Before starting the motor, make sure that the discharge gate valve is closed;

(b) If the pump is not self-priming or has defective suction line or foot valve, add priming water. Priming displaces the air in the suction line or drop pipe of the pump with water;

(c) Allow the pressure to build up, and then slowly open the discharge valve. Doing this slowly avoids water hammer, which could destroy the pipes and valves;

(d) Start the pump motor;

(e) After the pressure has built up, slowly open the discharge gate valve. In case the pump has been primed with water, waste the water pumped during the first 1-2 minutes by opening the drain valve;

(f) Make a routine check for faults in the operation of the system (abnormal noise, vibration, heat, and odour).

10.4.2.3 Maintenance and Repair

Bearings, gears and other pump moving parts should be lubricated on a regular schedule, using the lubricants recommended by the supplier. The following are specific actions to remedy centrifugal pump problems:

(a) Low Pump Efficiency

If the pump performance tests reveal that the pump is operating at significantly lowered efficiencies, the pump should be pulled out, inspected and repaired or reconditioned. This work is best referred for servicing to the manufacturer or a pump repair specialist.

(b) Packing Adjustment

The water flowing through the stuffing box should be maintained at a level just enough to prevent overheating. The gland nuts should be loosened or tightened one-quarter turn only to allow the packing to equalize against the pressure.

(c) Checking and Adjusting Misaligned Head Shaft

Pump vibrations could indicate a misalignment of the head shaft. This can be checked by the following procedure:

(i) Remove the motor dust cover, motor head nut and key, and take out the motor drive flange.

(ii) Check if the head shaft is concentric with the motor hollow shaft bore.
(iii) If needed, adjust by using shims.

Other common problems and their remedies are summarized in Appendix 6.

10.4.3 Jet Pumps

10.4.3.1 Operations

Jet pumps can be operated manually or automatically with a pressure switch, electrodes or a float control switch.

10.4.3.2 Operating the Non-Self-Priming Jet Pump

(a) Initially inspect the assembly. Make sure that the power supply to the motor is off;
(b) Check lubrication. Make sure that the pump rotates fully by manually turning the shaft. (For more details, refer to the pump manual);
(c) Remove pressure gauge bushing and prime pump with clean water. Never start the motor until the pump has been filled with water;
(d) Replace pressure gauge bushing and close the discharge gate valve;
(e) Start the pump motor. Note build-up of pressure in the pressure gauge. Open the discharge valve slowly;
(f) If discharge pressure is lost and fails to build up again after a short time, the system still contains air. Stop the pump motor and repeat operating procedures starting from item (c). It may be necessary to repeat the procedure several times until the system is completely filled with water.

10.4.3.3 Operating the Self Priming Pump

Routinely inspect the assembly. Make sure power supply to motor is off.

10.4.3.4 Maintenance of Jet Pumps

The manufacturer or equipment supplier always provides the client with the Operation and Maintenance manual upon purchase of their product. Refer to this manual for the proper operation and maintenance of the pump. The matrix for centrifugal pumps may be also used as a guide for troubleshooting operational problems of jet pumps. Additional troubleshooting information for jet pump problems is presented in Appendix 7.

10.4.4 Vertical Turbine Pumps

(a) Pumps should be properly primed before starting,
(b) Air vent to be fully opened before starting,
(c) Correct rotation of the pump,

(d) Pump should not be operated, if ratchet pins are missing,
(e) Bowl assembly is completely submerged.

10.4.4.1 Inventory of Materials for Submersible, Centrifugal and Vertical Turbine Pumps

The following is the list of fast moving materials for Submersible, Centrifugal, and Vertical Turbine Pumps:

(a) Submersible pumps: Impellers
(b) Centrifugal pumps: Impellers, diffusers, bearings, gland packing's
(c) Vertical turbine pumps: thrust bearings, gland packing, head shaft, intermediate shaft, bearing spider, bowl assemble, impeller.
(d) Motors: Bearings
(e) Moulded Case Circuit Breaker (MCCB), Relay, tripping circuit, fuses.
(f) Transformer: Oil

10.4.5 Hand Pumps

Figures 10.1 illustrate the typical types of hand pumps. The maintenance of a hand pump is identified in two categories.

10.4.5.1 Minor Repairs

The repairing of hand pump which does not require lifting of hand pump assembly is treated as minor repair. The minor repairs of a hand pump may be made by a semi-skilled care taker/CBWSOs). This type of repairing involves replacement of handle nut & bolts, repairing of chain, bearing. Appendix 8 illustrates the troubleshooting of Hand pumps.

10.4.5.2 Major Repairs

The repairing of a hand pump which involves pulling out and cleaning of the hand pump assembly is treated as a major repair; this type of repairing can be carried out by hand pump specialist from RUWASA or the water supply and sanitation utility.

The daily, monthly and annual activities should include the following O&M activities:

(a) Weekly

- (i) Check the fittings such as nuts, bolts and handle assembly and tighten them,
- (ii) Check the axle bolt and tighten as needed,
- (iii) Make sure the lock nut is tight,
- (iv) Make sure the hand pump is firm on its base,

(v) Check the flange bolts fastening the water chamber to the pedestal are tight,
(vi) Testing water quality using a Field Test Kit.

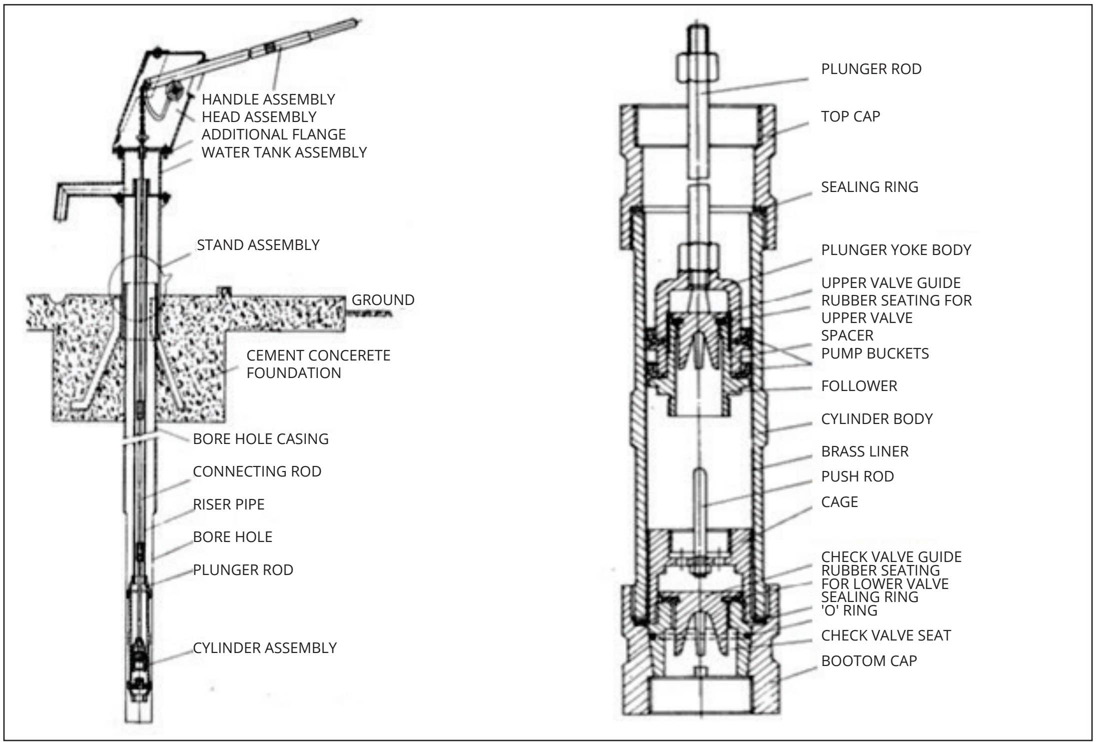

Figure 10.1: India Mark II (left) and Cylinder Assembly of India Mark III Hand Pump (Right)

(Source*:* India Operational and Maintenance Manual 2013).

(b) Monthly Activities

(i) Tighten the handle axle nut and lock nut,
(ii) Check for loose or missing flange bolts and nuts and tighten as needed,
(iii) Open the cover and clean inside the pump,
(iv) Check the chain anchor bolt for proper position and tighten if needed,
(v) Verify whether hand pump is firm on its base and fix it if needed,
(vi) Open the cover and clean inside the pump,
(vii) Verify rusty patches, clean with a wire brush and apply anticorrosive paint,
(viii) Check for loose or missing flange bolts and nuts and tighten as needed,
(ix) Check the chain anchor bolt for proper position and tighten if needed,
(x) Look for rusty patches, clean with a wire brush and apply anticorrosive paint,
(xi) Find out whether the hand pump base is loose and arrange for repair of the foundation as needed,

(xii) Measure the static water level,
(xiii) Grease all components.

(c) Annual Activities

(i) Verify the discharge of water,
(ii) Verify the handle position and repair if needed,
(iii) Verify whether guide bush, roller chain is not excessively worn out and replace if needed,
(iv) Verify whether Discharge is satisfactory,
(v) Verify whether Handle is shaky,
(vi) Verify whether Guide bush is excessively worn out,
(vii) Verify whether Chain is worn out,
(viii) Verify whether Roller chain guide is excessively worn out,
(ix) Discharge is satisfactory,
(x) Check all parts of the hand pump for wear and tear / damages, replace damaged parts and reassemble the hand pump,
(xi) Measure the well depth,
(xii) All the components of the hand pump to be checked for wear and tear/ damages and damaged parts replaced and hand pump re-assembled,
(xiii) Washing and cleaning of the components of the hand pumps should be done with water and bleaching powder, if required instead of mixture of water and kerosene,
(xiv) The repairs to the hand pump platforms to be done as and when needed and need not be on daily basis.

10.4.5.3 Disassembly, Inspection and Reassembly of Hand Pump

10.4.5.3.1 Disassembly

Disassembly of the hand pump may be required from time to time if major problems are faced as follows:

(a) Loose pump head cover bolt,
(b) Remove inspection cover from head assembly,
(c) Insert chain coupling supporting tool,
(d) Lift the handle to the top position and disconnect chain from handle by removing the “nylon” nut and bolt (i.e., nylon insert lock nut),
(e) Take out handle axle; while removing use the handle axle punch to protect the axle thread and remove the handle from the head assembly,
(f) Remove flange bolts from the head assembly,
(g) Remove head assembly from the water tank,
(h) Place the connecting rod vice on to the water chamber top flange and tighten vice against connecting rod and allow the head assembly to sit on the connecting rod vice,
(i) Disconnect the chain assembly from connecting rod,
(j) Support connecting rod with connecting rod lifter, loosen connecting rod vice and remove; gently lower connecting rod to sit on check valve; remove connecting rod lifter,

(k) Loose water tank nuts and bolts and remove water tank bottom flange bolts,
(l) Lift water tank by using tank pipe lifter and lifting spanners,
(m) Fit self-locking clamp and remove water tank,
(n) Join plunger assembly to check valve by turning the rod lifter in clock wise direction,
(o) To take out water from the pipe, remove the rod lifter; join the rod lifting adaptor to the connecting rod; place head assembly over water tank and fix handle to the lifter
(p) Remove water from riser pipe by pushing down handle suddenly,
(q) Lift handle upwards slowly and disconnect connecting rod lifting adapter and take out head assembly,
(r) Tighten the connecting rod lifter to the connecting rod and lift the connecting rod and fix the connecting rod vice,
(s) Hold the connecting rod, slowly loosen the rod vice and lift the connecting rod; tighten the vice and repeat the process until it is possible to remove the connecting rod; repeat the process until the last connecting rod with plunger and check valve is pulled out,
(t) Separate the check valve from the plunger,
(u) Unscrew the plunger from the check valve,
(v) Remove all the parts of the check valves and clean them.

10.4.5.3.2 Inspection

Inspection for reassembly covers the following:

(a) Check the water tank for leakage or damage,
(b) Wash and clean all parts with a mixture of water and bleaching powder,
(c) The stand assembly should be on a perfect level – check with a spirit level,
(d) Check the coupler for broken threads,
(e) Check flanges and spout pipe for cracks and leakage,
(f) Check the handle axle, bearings and chain; apply grease to the bearings and chain.

10.4.5.3.3 Reassembling

Reassembling involves the following:

(a) Ensure parts are clean and dry, and moving parts are lubricated with oil and grease,
(b) Check 'O' ring and cup seal and replace as needed,
(c) Remove cover of casing pipe for fixing stand assembly,
(d) Place stand assembly over casing pipe and make sure that it is vertical and check level of flange by spirit level,
(e) Fix water tank assembly on the stand flange by tightening the nuts and bolts,
(f) Join the check valve and plunger,
(g) Connect the plunger to the connecting rod,

(h) Insert the plunger assembly connected with the check valve in the riser pipe and connect the riser coupler to the water tank,
(i) Insert the lower end of the connecting rod in the riser pipe, and place the connecting rod over the water tank and fix it to the vice,
(j) Join the connecting rod pieces as per the requirement and insert in the riser pipe,
(k) Remove the connecting rod vice from the water tank by holding the top end of the connecting rod,
(l) Fix the connecting rod lifter to the top end of the connecting rod and rotate in the direction of the arrow so as to separate the check valve from the plunger and ensure that it reaches the bottom plate,
(m) Make a mark by hack saw on the connecting rod at the level of the water tank,
(n) Lift the connecting rod assembly, fix the connecting rod vice and tighten the connecting rod,
(o) Cut the connecting rod as per the marking after removing the connecting rod lifter,
(p) Smoothen with the help of a file the cut surface of the connecting rod,
(q) Make necessary threads on the top most end of the connecting rod,
(r) Fix the middle flange on the top of the water tank and ensure that all four corners coincide,
(s) Tighten the check nut at the top of the connecting rod,
(t) Screw the chain on to the connecting rod,
(u) Place the chain coupling supporting tool on the middle flange and remove the rod vice,
(v) Place the middle flange and set flanges with water tank,
(w) Place head assembly over the middle flange and tighten by spanner,
(x) Place handle assembly and insert the handle axle by handle axle punch,
(y) Lift the handle for fixing chain and tighten chain anchor bolt and nylon nut fully (i.e., nylon insert lock nut); remove chain coupler supporting tool by lowering the handle,
(z) Lift handle up and apply grease on the chain,
(aa) Lower down the handle and fix inspection cover and tighten the cover bolt fully by the crank spanner.

10.5 OPERATION AND MAINTENANCE OF SOLAR SYSTEMS

10.5.1 Solar system

General

After the system has been installed and commissioned, focus shifts to O&M throughout its lifetime. System operation can be optimized by closely monitoring and recording key system parameters (data logging), enabling operators to assess system performance or demand changes.

One crucial aspect of maintenance is warranties, usually against defective components or poor workman-ship. Under the defects liability period of 1 to 2 years, any items that fail, are not installed to standard, or are damaged by natural calamities must be corrected on site at cost to the contractor/supplier/ installer.

Component usual warranty period

Solar panels	25 years,
Pump/motor	2-5 years,
Inverter	5-10 years,
Remaining components	1-2 years.

During the warranty period, the supplier is also expected to check system components and perform preventive maintenance at least quarterly (in any case, neither pumps nor panels require heavy maintenance, with panels only needing periodic cleaning) to attend to user complaints within a reasonable period of time, and to resolve any system breakdowns within 3 days. In addition to component warranties, the supplier may also provide a performance warranty on the system as a whole, ensuring that it will meet or exceed the design performance for a number of years.

Sustainability of Solar Water Pumping (SWP) has been a challenge in many countries and especially in rural areas, with systems failing often within a short time after commissioning due to lack of proper O&M. It is therefore increasingly common for communities to establish comprehensive maintenance contracts with suppliers during warranty periods, and it is a good practice to extend such contracts beyond the warranty period. Suppliers should further secure system sustainability by training system operators, namely on basic plumbing skills useful for repairing leakages in the pipe network and in handling the advanced inverters and sensors common in modern solar pumping systems. The rural water supplies audit (URT, 2018b) recommended introduction of such capacity building programme in identified zonal centres of RUWASA.

Since solar panels have no moving parts that could be affected by rust or break down, solar power requires very limited maintenance, other than regular dusting. Cleaning the solar panels with water is recommended to remove any dirt or dust.

Operation and Maintenance Guidelines

Solar PV pumping systems are characterized by their simplicity, unattended operation, and low maintenance requirements compared to conventional systems. Except for the pump itself, there are no moving parts that would require periodic maintenance and incur additional costs every time maintenance is performed.

In the case of battery usage for energy storage, which is not recommended, maintenance and battery replacement would be required every three to four years on average. There are some modern batteries that can live up to 8 years but are still considered expensive and would require very delicate preventive maintenance that might not be present in typical solar PV pumping applications (mainly in rural and remote regions).

For the other components, the PV modules are considered sturdy and strong enough to withstand harsh environmental conditions coming with a warranty of 10 years, an expected lifetime of more than 25 years, and normally an efficiency maintenance guarantee that ensures efficiency drop doesn't exceed 20% over the period of 25 years. The pump normally lives for more than 8 years and can reach 14 years if well maintained.

Usually it is sold with a 2 year-warranty and spare part availability. Other than that, only occasional inspection and regular maintenance is required, at no cost, to make sure the system is doing fine and avoid losses due to dust or other residues sticking to the panel. It is essential to properly operate and maintain the pumping system to achieve high efficiency and reliable operations.

Operation Guidelines

(a) The pump should be switched off when not in operation;
(b) The pump should never run dry. It is critical to make sure the suction is primed before turning on the surface pump;
(c) The pump should be properly mounted and fixed on the base-plate to withstand vibrations and avoid unwanted noise that could also reduce the lifetime of the pump;
(d) The pump should be used daily for at least 15 minutes to avoid problems;
(e) Pump should be covered adequately for weather protection. In a pump pit adequate air venting system (passive or active) should be in place;
(f) The surface pump should be kept away from water at all times;
(g) The pump should not be switched on and off too often. There should be at least 15 seconds between a switch off and a switch on;
(h) Foot-valve should be of minimum 2" (50 mm) size so as to minimize suction losses;
(i) Sharp bends should be avoided in the pipelines to avoid unnecessary pressure drops;
(j) Delivery and suction pipelines should be air-tight;
(k) In case of thunders and strong wind, panels should be kept in the zero-tilt position (applicable only for tracking systems);
(l) The cover of the main junction box should not be left open;
(m) No loose wires should be un-insulated.

Regular Maintenance
Monthly

- Panel Cleaning: Clean the panels regularly to avoid particles, leaves, and other residues from blocking the sun. Panels can be cleaned with a plain piece of cloth with some water when available;
- Panel Inspection: Inspect the PV panels to make sure there are no cracks or damages.

Biannual

- Shadow Prevention: Check the panels for any shadow and perform necessary trimming of trees if necessary;
- Wiring inspection: Check wires regularly for fraying, splitting, or damage.

Annual

- Valves Inspection: Check and clean the foot-valve,
- Electrical Components Check: Check switches, fuse, wiring, junction box and connections.

Biennial

- Pump Inspection: For surface pumps, carbon brushes need to be checked and replaced every two years.

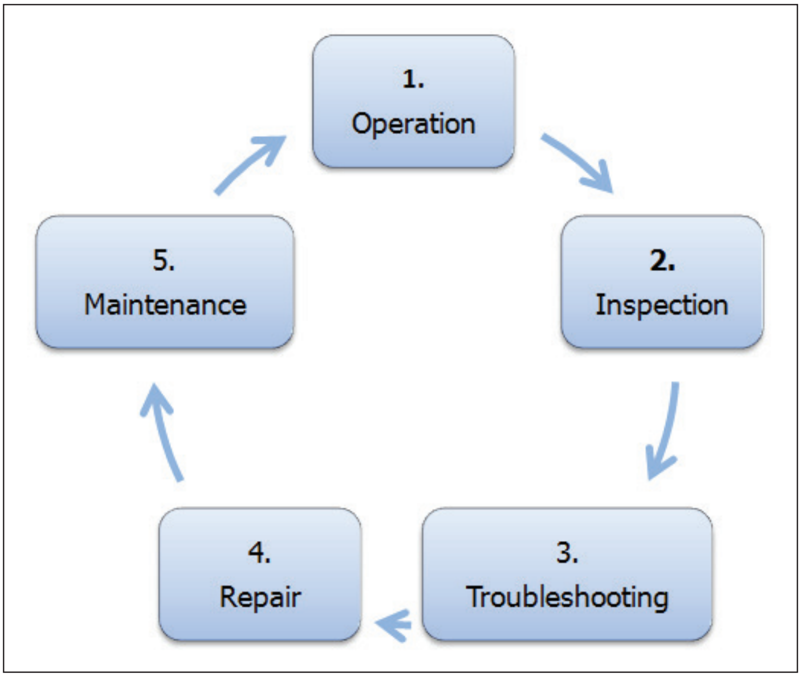

Figure 10. 2: Operation and Maintenance Cycle for Solar Water Pumping

10.5.2 Inspection

Every system regardless of the type, must be inspected periodically. It is an important aspect for good operation of the system. System inspection should be conducted at least once a year depending on the size and intricacies of the system. Planned inspection, prompt timely maintenance and in some cases inspection and maintenance can be carried simultaneously especially when the inspectors also double up as maintainers. It is also highly recommended that the inspectors also triple as repair experts of the system.

Inspection procedure for key Components
Solar panels

(a) **Check the solar panels for dirt and cracks**,
   (i) Dirt accumulates on the solar panels over time, as they are exposed to the environment. Cracks may be due to vandalism or heavy hailstorms.
   (ii) If there are cracks on the panels, one should consider replacing those panels
   (iii) Dirt can be cleaned off the surface using clean water and a cloth. Soap should not be applied.

(b) **Electrical cables**
   (i) Check to see if all electrical cables are still intact, loose cables should be tightened up.

(c) **Tilt Angle**
   (i) In fixed solar arrays this may not be necessary, unless there is suspicion of tilt on angle if inclined. This should be corrected, to avoid dust accumulation on flatter inclines, and reduced solar absorption on steeper inclines.

10.5.3 Inspection Checklist

Inspection checklist gives guidance and easiness to the operator to do inspection. It saves times and increases accuracy as it includes all important elements to be checked. Appendix 9 presents the solar arrays and accessories inspection checklist.

10.5.4 Paperwork

In all inspections the importance of paperwork and record keeping cannot be over emphasized. It is prudent upon every inspector to keep and maintain a good record of the system, as this will form a major part of maintenance decision making.

Table 10.2: A Sample Record Status of the System

Item Description	Available	Not Available	Comments
Operation and maintenance manual for system on site or available			
Service record for system on site or available			
Flow diagram and sequence of operation on site or available			
Photographs taken and placed in service record			
This inspection record filed in service record			

10.5.5 Troubleshooting a Solar Powered Water Supply System

This section of the manual contains information that may be used to determine what is wrong with a solar powered water supply system. Troubleshooting techniques have also been explored. Troubleshooting a Solar Powered Water Supply System should involve more than looking for an obvious problem, or replacing components at random in an attempt to get the system working again. This is particularly true of Solar Powered Water Supply Systems. What is required is a systematic procedure that carefully "troubleshoots" the system until the problem is located and remedied.

Cause or Symptom

What may appear to be the cause of a problem may actually be a symptom of another problem. For example, if a pump is not pumping water, you can replace a pump while the problem is the electric cable that supplies current and voltage to the pump. Replacing the pump, will not solve the problem but result in wasting money and time for a simple problem. Never assume that a system is completely without faults after correcting a problem. Spend a few more minutes observing and inspecting the system. This will save time doing a return job. Or even a bigger job caused by an escalated problem which could have been spotted during the first visit.

Recommended troubleshooting

Good troubleshooters follow the below listed steps or a variation of them. The steps include:

(a) Planning:
   - (i) Planning takes off with brainstorming the possible causes of the problem,
   - (ii) This includes the tools and materials used to diagnose the fault,

(iii) It also includes the resources to be allocated for finding and fixing the fault, such as money, time and labour.

(b) Cause /Source finding:

(i) This is the investigation /diagnosis phase,

(ii) Start with checks that will have low impact on the system,

(iii) Proceed in a systematic, organized and logical manner,

(iv) Isolate the results of testing to the component being tested,

(v) Sometimes the only way to determine if a component is working properly or not is to replace it and see what happens. Remember that this may fix the symptom but it can fail to turn up the real cause of a problem.

(c) Repairing:

(i) Repairs can be made on a "quick fix/temporary repair" basis, doing as little as possible to get the system running again,

(ii) Another approach is to replace major portions of the system to be absolutely certain the problem is gone,

(iii) The correct approach is to determine what is the real cause of the problem is, and make repairs that solve that problem so that it does not happen again. Whether to repair or replace defective components depends on the cost and availability of the component,

(iv) Generally, the more expensive and difficult it is to obtain something, the more appropriate the repair of the component,

(v) If the part is cheap and readily available, it generally will be replaced,

(vi) If repairs can be made to the defective component, it can become the new replacement the next time this same component fails in this or other systems.

(d) Testing:

(i) After the cause of the problem has been identified and corrected, inspect and test the entire system,

(ii) This confirms that the new components are working, and that no other problems exist,

(iii) The defective components should be tested as well. The best time is usually before rebuilding. As an example, if a control works fine on a test bench, but not at all at the site, a problem exists at the site that will not let the new control work there either,

(iv) If the part is truly defective, look for the reason it failed. For example, did the pump control unit get wet? Will the new control unit also get wet and fail?

(e) Recording:

(i) The last part of troubleshooting is record-keeping,

(ii) Maintenance and repair records are kept to maintain a history of each system.

Troubleshooting records should be part of that written history. In addition, writing down the troubleshooting process preserves that information for the person who found the problem.

Table 10.3: Troubleshooting Chart

Item	Problems	Symptoms	Causes	Actions	Comments
Solar Tower and Accessories	Performance decline in Solar powered system Low water pressure	Solar not producing initial Power Reduced flow rate in transmission	Loose wiring Dirty or damaged solar panels System overheating	Replace terminals and attend to loose wiring, Clean solar panels and replace damaged panels, Check heat fade.	
Submersible Borehole Pump	Pump not working	Pump will not start	Blown fuses, Fried breakers, disconnected splice connection, Motor fried, Pump not turning	Replace fuses, Replace breakers, Install new splice, Replace motor/fix motor, Fix pump	
Valves	Leakages	Water seeping out of the valve	Broken valve, Loose fitting	Replace valve, Tighten valve	

10.5.6 Repair Works

This section includes information on the repair or replacement of solar powered potable water supply system components. The first section lists common components and whether to repair or replace them. Then, specific procedures for particular components are described. The section ends with a sample repair record sheet. During repair works, one normally asks questions of whether to repair or replace. Some components, such as Solar Panels, can never be repaired, and must be replaced. Others, such as mounting racks and supporting steels, are usually repaired rather than replaced. However, most components can be repaired/replaced. In general, the decision to repair or replace is based on:

- Availability of replacement parts,
- Lead time for replacement parts,
- Cost of replacement parts,
- difficulty of repair.

Table 10.4: Repair or Replace Choice Table

Component	Repair	Replace	Rationale	Comments
Solar Panels		X	For optimum performance and warranty coverage damaged solar panels ought to be replaced	It is important to replace panels with similar new panels.
Solar Tower	X		Normally this is fabricated, and repair works are sufficient when defects are spotted.	Re-weld broken welds and prime or paint with oil-based paint to prolong life of the weld.
Wiring		X	Worn out wires should be replaced to avoid short circuiting	Wiring and splicing kits should be replaced.
Inverter	X	X	If inverter has suffered minor damages it can be fixed, but If major it should be replaced. Adhere to warranty provisions	The inverter has a shorter life than the Solar Panels. So, at some point it will have to be replaced
Motor	X		Motors should either be repaired or replaced depending on gravity of damage, attempting to fix it should be first priority.	
Pumps	X	X	If pumps are broken, they can be fixed, but if they dropped into the well and can't be fished out, they should be replaced	
Pump Control Unit	X	X	If components are faulty, the unit can be repaired, if the fault is major like a lightning strike, the whole unit ought to be replaced	

Table 10.5 presents a typical repair worksheet.

Table 10.5: Repair Worksheet

REPAIR WORKSHEET FOR SOLAR POWERED WATER SUPPLY SYSTEM					
General Information					
Site Name				**Contacts**	
Date:				Cell phone	
Service Provider				Order No	
				Invoice Number	
Client					
				Physical Address	
				Postal Address	
				Email:	
				Fax:	
Work Preamble					
Original Symptom / Fault reported					
Reported by					
Reported to					
Date reported					
Work					
Items inspected or troubleshoot					
Findings					
Items repaired				**Items replaced**	

Works Value					
Hours Spent					
Travelling					
Materials used and Value					
Total Works Value					
Service Provider's Report					

10.5.7 Maintenance

This is the most important section; it answers the question of how can the system be kept working. To the layman, it is perceived as the only section that ought to be given attention and disregard all the other sections. It cannot be over-emphasized how important preventive maintenance can be. It involves a great deal of pro-activeness. Every system ought to have a regular maintenance schedule that is appraisable. Some information on minor repairs is given; however, if major repairs are necessary, use repair information in Section 10.5.6. If a system has not been maintained, or has not been operational for some time, it is suggested to perform a system inspection, using Section 10.5.2, and to make necessary repairs before starting a regular schedule of maintenance.

Maintenance procedures

Preventive Maintenance activities are the core element of the maintenance services to a reticulated solar powered potable water supply system. It comprises regular visual and physical inspections, as well as verification activities with a specific task periodicity of all key components which are necessary to comply with the operating manuals and recommendations issued by the Original Equipment Manufacturers (OEMs). It must also maintain the equipment and component warranties in place and reduce the probability of failure or degradation. This maintenance will be carried out at predetermined intervals or according to the prescribed OEM manuals. These are included in a detailed Annual Maintenance Plan (AMP) which provides an established time schedule with a specific number of iterations for carrying out the maintenance. Tables 10.6 - 10.10 gives some of the tools that can be used.

Table 10.6: Example of Maintenance Contact List

Company Name	Artisan Name	Position/ Trade	Telephone	Cell phone	Email
Maji Pumps & Irrigation	Mariam Joseph	Plumber			
	Issa Abdalla	Plumber			
	Richard Jane	Builder			

The maintenance contact list (Table 10.6) is easy to use at local level as it only outlines contacts of responsible maintenance team. As such it can be used by the water system users committee for further details of maintenance.

Equipment manufacturer's manuals

The equipment manufacturer's manuals shall and will be attached in this section. The manuals should be used by the operations/maintenance team as reference. Preventive maintenance can be scheduled periodically from weekly to monthly and annually. Tables 10.7 - 10.10 outline the steps to be taken and tools used in performing preventive maintenance exercises.

Wire control kit

Recommended daily operational duties/preventive maintenance

Based on the layout and operation of the system, several parameters for inspection and action were developed and set to respond to routine challenges of the system. Some of these actions to be performed can be categorized as daily, weekly, monthly and annually:

The weekly preventive maintenance has been skipped because it is similar to the daily tasks.

Preventive maintenance logbook

All maintenance activities should be written down on a maintenance log book or log sheet. The logbook as Table 10.7 should be used to keep records of the maintenance on the system.

Table 10.7: Preventive Maintenance Logbook

Action to be done	Frequency	Last service (Date)	This service (Date)	Preventive maintenance procedure
Clean solar panel array	Monthly			Use pressurized spray washer to clean solar panels
Inspect solar panel array	Weekly			Walk around solar tower
Inspect electric wire cable connection	Monthly			Check cables by touching and feeling for loose connections and damages
Inspect structural Integrity of tower	Monthly			Look for structural damage to tower, check for corrosion/ oxidation. Remove rust with wire brush and paint off tower to coat against rust
Inspect inverter and control unit	Weekly			Read fault lights on inverter if any.

Ensuring security of the system may require conducting an assessment of the security within the system. Table 10.8 can be used to do such an assessment check.

Table 10.8: Security Assessment

Item No:	Activity description	Yes /No
1	Are all critical facilities fenced, including control houses, solar panel tower, and are gates locked when appropriate?	
2	Are warning signs erected/non tampering signs	
3	Do you have a neighborhood watch program for your water system?	
4	Are your wellheads sealed properly?	
5	Are well vents and caps screened and securely attached?	
6	Are observation, test, and abandoned wells properly secured to prevent tampering?	
7	Is your surface water source secured with fences or gates?	
8	Do water system personnel visit the source?	
9	Are tank ladders, access hatches, and entry points secured?	
10	Are vents and overflow pipes properly protected with screens and/or grates?	

Spare Parts Management

Spare Parts Management is an inherent and substantial part of O&M. it shall be used throughout the lifespan of the system. Table 10.9 is the tool that will be used to record available spares for the system by the maintenance team. From the water sales, 10 percent of the revenue generated from the system shall be kept as a reserve to purchase the spare parts. The major components like pumps, solar panel array, solar controller, water meter can be insured for damage and vandalism and this is elaborated in the risk management section of volume III of the DCOM Manual.

Table 10.9: Spare Material Management List

Item No:	Spare Material	Sub Description	In Stock	Utilized	Remaining /Balance	Comments
1	Solar Panels	Poly crystalline 320 Watts Grundfos				
2	Solar Controller					
3	Pump	Grundfos Submersible pump				
4	Isolation Valves	Cobra gate valves:				
		80 mm				
		65 mm				
		50 mm				
		40 mm				

Operators notes

This section of the manual is intended for the use of the project (Water System Operator) who is in charge of operating the potable water supply project to guide them through the tasks of the Operator. It gives explanations of the facility structure and then explains the tasks of the operators, and things to bear in mind when operating facilities. It also provides in part, troubleshooting information.

Operator's duties

The operator is the key person in the operation of the system. He has important roles that he/she has to execute on a daily basis. The roles encompass the following:

(a) Operate the system properly or as designed,
(b) Patrol and inspect the system daily and weekly,
(c) To write the operation records, this consists of operational data,
(d) To correspond with the Maintenance In-charge/Project Coordinator,

(e) Be a link between the customers and the Maintenance In-charge/Project Coordinator,
(f) Collect and collate issues from the customers.

The sustainability of the system hinges mainly on the management aptitude of the operator. The operator is expected to safeguard the system and keep all records of the system operation.

Detailed regular operational duties for the water operator:

Solar Panel Array

- Inspect cable wiring interconnecting solar panels,
- Inspect inverter,
- Inspect dirt /dust accumulation on solar panels,
- Inspect structural integrity of solar panels tower.

Water Control Unit and pump

- Check control unit for fault reporting,
- Observe sound and performance of submersible pump,
- Inspect pump for leaks,
- Observe water meter and record readings off it.

Maintenance tools

Maintenance tools should be kept inside the kiosk house and locked. A tool inventory should be conducted every month to establish the condition of the tools and also establish any lost tools. The plumbers should pay for lost tools. The tools should be used in maintaining the water project and should not be used for any other work outside the project. This practice prolongs the tool lifespan. Generally, tools should be used for the job they were designed for, wrong tools should not be used for any job.

Reporting and communication

Reports are major sources of the information. In implementing the projects, reports are a pre-requisite in order to know the implementation status and make a rational decision timely if the need arises. Operator needs to record the operational status of the system daily. The data will form a part of the project O&M monthly report. When faults are detected, it should be communicated to the Maintenance In-charge immediately. The Maintenance In-charge then coordinates repair work, depending on the type of repair required.

The steps below outline the communication chronology in the project:

(a) The water customers or water operator discover or notice a breakdown in the water supply system,
(b) They notify the Maintenance In-charge/Project Coordinator swiftly,
(c) The water operator requests for repair of the system,

(d) The water operator notifies the Maintenance In-charge/Project Coordinator of the parts that are required to repair the breakdown,
(e) The Maintenance In-charge/Project Coordinator avails funds for fixing the breakdown,
(f) The Maintenance In-charge/Project Coordinator procures the materials needed to attend to the breakdown,
(g) The Maintenance In-charge/Project Coordinator provides spare parts to the plumber to expedite repairs,
(h) The plumber then expedites works on the repairs,
(i) The plumber then prepares and submits a repair report to the Maintenance In-charge/Project Coordinator,
(j) The Maintenance In-charge/Project Coordinator avails money and pays the plumber for the repairs,
(k) The system is back to operation again.

Repair manual

In this section of the O&M manual, discussion will be based on repair procedures for certain components of the water system.

Sample repair works record or report sheet

Table 10.10 is a sample of a record sheet on any repair works that ought to be done on the system. It is very important to know the name of the technical person who attended to the fault. Date on which the fault was attended. The location of the repair is also important in order for the operators to pick up trends if any, on fault re occurrences.

Table 10.10: A Sample Repair Works Report Sheet

Name................................	**Name of Project............................**	
Surname............................	**Name of Section............................**	
DATES (dd/mm/yyyy)		
Date of Breakdown	Date Reported	Repair Works Executed ....
ISSUES		
Specific issues with the item	Cause(s) of the issues	
REPAIRS		
What kind of repair works have been done on this system?		

ITEM		
	SUMMARY	
	Is the system functional again?	
	FINANCES	
	How much was paid for the service and recorded	Labour Only Tshs.................................. In words............................

10.5.8 Variables Influencing Performance of Solar Water Pumping (SWP)

The simplified SWP algorithm presented for understanding the sizing dynamics is good for static design conditions. In reality, there are several input variables that are not constant and thus affect SWP performance over the number of the years. To be rigorous, sizing algorithms must evaluate the conditions over the course of a whole year to determine when the limiting design conditions occur. Below are some of the key variables:

(a) Seasonal changes in solar radiation. Essentially, SWP water output is more or less proportional to the irradiation. First-pass sizing is usually based on average insolation for the year, or perhaps the worst month of the year. It is necessary to assess the output for days when radiation will be less than the annual average, and less than the monthly average. Tilt angle optimization is required;

(b) Seasonal changes in pumping head. Similarly, drops in water levels will affect pump output. Water output is more or less indirectly proportionate to the pumping head. Too conservative an estimation of water level will result in system over-sizing;

(c) Sunny versus cloudy days. Average insolation is insufficient. A key variable is the amount of cloud cover and intermittency of the sunshine. Especially, variable speed drives coupled with AC pumps tend to suffer degraded performance under stop-start solar conditions, since they require minimum power conditions start-up, and take considerable time to spool up once threshold levels are reached. So while 2 days might have the same amount of cumulative insolation, a clear morning with zero sun in the afternoon is likely to yield far higher water output than an intermittently cloudy day. Derating for this kind of local variability is important for certain motor pump types in particular;

(d) Seasonal changes in water demand. Experience shows that demand is not constant throughout the year. For human consumption, the variations are low (25%), but for livestock and irrigation the variations can be significant, up to 80%, with zero demand in very wet seasons. The analysis of these variables can be cumbersome.

Chapter 11

AUDIT AND CONSERVATION OF ENERGY

11.1 INTRODUCTION

Energy is very scarce and short supply commodity particularly in many of the areas in Tanzania and its cost is spirally increasing day-by-day. Generally, pumping installations consume a huge amount of energy wherein proportion of the energy cost can be as high as 40 to 70% and even more of the overall cost of operation and maintenance of water works. The need for conservation of energy, therefore cannot be ignored. All possible steps should be identified and adopted to conserve energy and reduce energy consumption and loss, and cost so that water tariffs can be kept as low as possible and gaps between high cost of production of water and prices affordable by consumers can be reduced. Some adverse scenarios in energy aspects as follows are quite common in pumping installations:

(a) Energy consumption is higher than the optimum value due to reduction in efficiency of the pumps,
(b) Operating point of the pumps is not in-line with the best efficiency point (b.e.p.),
(c) Energy is wasted due to increase in head loss in pumping systems, (e.g. clogging of strainers, encrustation in column pipes, encrustation in pumping mains),
(d) Selection of uneconomical diameter of sluice valves, butterfly valves, reflux valves, column pipe, drop pipe in pumping installations,
(e) Energy wastage due to operation of electrical equipment at low voltage and/or low power factors.

Such inefficient operation and wastage of energy should be avoided to cut down energy costs. It is therefore, necessary to identify all such shortcomings and causes. The following measures should be adopted in management of energy:

(a) Conduct thorough and in-depth energy audit covering analysis and evaluation of all equipment, operations and system components which have bearings on energy consumption, and identifying scope for reduction in energy costs,
(b) Implement measures for conservation of energy,
(c) Energy audit as implied is auditing of billed energy consumption and how the energy is consumed by various units, and sub-units in the installation

and whether there is any wastage due to poor efficiency, higher hydraulic or power losses, etc. and identification of actions for remedy and correction,

(d) In respect of the sources like infiltration wells, open wells, collector wells, the working head can be decided based upon the suction head, delivery head, frictional loss with reference to the pipe materials used and other losses,

(e) In respect of borehole sources, while submersible pump sets are used, the pump suction depth may be fixed with reference to the final spring achieved during drilling,

(f) Working of head of pumps should be made in a conservative way,

(g) If the head of the pump is excess of the actual requirement, then pump impeller shall be trimmed as recommended in section 6.2.2.3 of this DCOM Manual,

(h) In large pumping stations, pumps with variable frequency should be used,

(i) With low power factor loads, the current flowing through electrical system components is higher than necessary to do the required work. In order to achieve power factors greater than 0.9 power capacitors of required capacity should be installed on all the installation of pumping machinery,

(j) Electric motors usually run at a constant speed, but a Variable Frequency (speed) Drive (VFD) allows the motor's energy output to match the required load. This achieves energy savings depending on how the motor is used. When one uses a control valve or regulator, one lose energy because the pumps are always operated at high speed.

11.2 SCOPE OF THE ENERGY AUDIT

Energy audit includes the following actions, steps and processes:

(a) Conducting in depth energy audit by systematic process of accounting and reconciliation between the following:
    (i) Actual energy consumption,
    (ii) Calculated energy consumption taking into account rated efficiency and power losses in all energy utilizing equipment and power transmission system as explained below.

(b) Conducting performance test of pumps and electrical equipment if the difference between actual energy consumption and calculated energy consumption is significant and taking follow up action on conclusions drawn from the tests,

(c) Taking up discharge test at rated head if test in (b) above is not being taken,

(d) Identifying the equipment, operational aspects and characteristic of power supply causing inefficient functioning, wastage of energy, increase in hydraulic or power losses etc. and evaluating increase in energy cost or wastage of energy,

(e) Identifying solutions and actions necessary to correct the shortcomings and lacunas in (d) and evaluating cost of the solutions,

(f) Carrying out economic analysis of costs involved in (d) and (e) above and drawing conclusions whether rectification is economical or otherwise,

(g) Checking whether pump operating point is near best efficiency point and whether any improvement is possible,

(h) Verification of penalties if any, levied by power supply authorities e.g. penalty for poor power factor, penalty for exceeding contract demand. Broad review of following points for future guidance or long term measure:
   - (i) C-value or f-value of transmission main,
   - (ii) Diameter of transmission main provided,
   - (iii) Specified duty point for pump and operating range,
   - (iv) Suitability of pumps for the duty conditions and situation in general and specifically from efficiency aspects,

(v) Suitability of ratings and sizes of motor, cable, transformer and other electrical appliances for the load.

11.2.1 Study and Verification of Energy Consumption

(a) All Pumps Similar (Identical)

- (i) Examine few electric bills in immediate past and calculate total number of days, total kWh consumed and average daily kWh (e.g. in an installation with 3 numbers working and 2 numbers standby if bill period is 61 days, total consumption 549,000 kWh, then average daily consumption shall be 9000 kWh),
- (ii) Examine log books of pumping operation for the subject period, calculate total pump - hours of individual pump sets, total pump hours over the period and average daily pump hours (Thus in the above example, pump hours of individual pump sets are: 1(839), 2(800), 3(700), 4(350) and 5(300) then as total hours are 2989 pump-hours, daily pump hours shall be 2989 ÷ 61 = 49 pump hours. Average daily operations are: 2 numbers of pumps working for 11 hours and 3 numbers of pumps working for 9 hours),
- (iii) From (i) and (ii) above, calculate mean system kW drawn per pump set (In the example, mean system power drawn per pump set = 9000 / 49 i.e. 183.67 kW),
- (iv) From (i), (ii) and (iii) above, calculate cumulative system kW for minimum and maximum number of pumps simultaneously operated. (In the example, cumulative system kW drawn for 2 numbers of pumps and 3 numbers of pumps operating shall be 183.67 x 2 = 367.34 kW and 183.67 x 3 = 551.01 kW, respectively),
- (v) Depending on efficiency of transformer at load factors corresponding to different cumulative kW, calculate output of transformer for loads of different combinations of pumps. (In the example, if transformer efficiencies are 0.97 and 0.975 for load factor corresponding to 367.34 kW and 551.01 kW, respectively, then outputs of transformer for the

loads shall be 367.34 x 0.97 i.e. 356.32 kW and 551.01 x 0.975 i.e. 537.23 kW, respectively),

(vi) The outputs of transformer, for all practical purpose can be considered as cumulative inputs to motors for the combinations of different numbers of pumps working simultaneously. Cable losses, being negligible, can be ignored,

(vii) Cumulative input to motors divided by number of pump sets operating in the combination shall give average input to motor (In the example, average input to motor shall be 356.32 ÷ 2 i.e. 178.16 kW each for 2 pumps working and 537.23÷ 3 i.e. 179.09 kW each for 3 pumps working simultaneously),

(viii) Depending on efficiency of motor at the load factor, calculate average input to the pump. (In the example, if motor efficiency is 0.86, average input to pump should be 178.16 x 0.86 i.e. 153.22 kW and 179.07 x 0.86 i.e. 154.0 kW),

(ix) Simulate hydraulic conditions for combination of two numbers of pumps and three numbers of pumps operating simultaneously and take separate observations of suction head and delivery head by means of calibrated vacuum and pressure gauges and/or water level in sump/well by operating normal number of pumps i.e. 2 number and 3 numbers of pumps in this case and calculate total head on the pumps for each operating condition. The WL in the sump or well shall be maintained at normal mean water level calculated from observations recorded in log book during the chosen bill period,

(x) Next operate each pump at the total head for each operating condition by throttling delivery valve and generating required head. Calculate average input to the pump for each operating condition by taking appropriate pump efficiency as per characteristic curves,

(xi) If difference between average inputs to pumps as per (viii) and (x) for different working combinations are within 5% - 7%, the performance can be concluded as satisfactory and energy efficient,

(xii) If the difference is beyond limit, detailed investigation for reduction in efficiency of the pump is necessary,

(xiii) Full performance test for each pump shall be conducted as per procedure,

(xiv) If for some reasons, the performance test is not undertaken, discharge test of each single pump at rated head generated by throttling delivery valve needs to be carried out,

(xv) If actual discharge is within 4% - 6% of rated discharge, the results are deemed as satisfactory,

(xvi) Test for efficiency of pumping machinery after each repairing shall be taken. If necessary inefficient machinery should be replaced by energy efficient / star rated machinery.

(b) Dissimilar Pumps

Procedures for energy audit for dissimilar pumps can be similar to that specified for identical pumps except for adjustment for different discharges as follows:

(i) Maximum discharge pump may be considered as 1(one) pump-unit,

(ii) Pump with lesser discharge can be considered as fraction pump-unit as ratio of its discharge to maximum discharge pump. (In the above example, if discharges of 3 pumps are 150, 150 and 100 litres per second, respectively, then number of pump-units shall be respectively 1, 1 and 0.667). Accordingly the number of pumps and pump-hours in various steps shall be considered as discussed for the case of all similar pumps.

11.3 MEASURES FOR CONSERVATION OF ENERGY

Measures for conservation of energy in water pumping installation can be broadly classified as follows:

(a) Routine Measures

The measures can be routinely adopted in day to day operation and maintenance.

(b) Periodical Measures

Due to wear and encrustation during prolonged operation, volumetric efficiency and hydraulic efficiency of pumps reduce. By adopting these measures, efficiency can be nearly restored. These measures can be taken up during overhaul of pumps or planned special repairs.

(c) Selection Aspects

If during selection phase, the equipment i.e. pumps, piping, valves etc. are selected for optimum efficiency and diameter, considerable reduction in energy cost can be achieved.

(d) Measures for System Improvement

By improving system so as to reduce hydraulic losses or utilized available head hydraulic potentials, energy conservation can be achieved. Example is the use of rainwater harvesting through storages as supplementary to the main water supply system, saves lot of energy.

11.3.1 Routine Measures

(a) Improving Power Factor

Generally as per guidelines of power supply authority, average power factor (PF) of more than 0.9 is to be maintained in electrical installations. The power factor can be improved to level of 0.97 or 0.98 without adverse effect on motors. Further discussion shows that considerable saving in power cost can be achieved if PF is improved. The low power factor may attract penalty by respective power supply authorities.

(b) Operation of Working and Standby Transformers

As regards operation of working and standby transformers, either of two practices as below is followed:

- (i) One transformer on full load and second transformer on no-load but, charged,
- (ii) Both transformers on part load.

(c) Voltage Improvement by Voltage Stabilizer

If motor is operated at low voltage, the current drawn increases, resulting in increased copper losses and consequent energy losses.

(d) Reducing Static Head (Suction Side)

A study shows that energy can be saved if operating head on any pump is reduced. This can be achieved by reducing static head on pumps at suction end or discharging end or both. One methodology to reduce static head on pumps installed on sump (not on well on river/ canal/lake source) is by maintaining WL at or marginally below FSL, say, between FSL to (FSL - 0.5 m) by operational control as discussed below.

- (i) Installation where inflow is directly by conduit from dam,
- (ii) In such installations, the WL in sump can be easily maintained at FSL or slightly below, say, FSL to (FSL - 0.5 m) by regulating valve on inlet to sump,
- (iii) Other installations.

(e) Keeping Strainer or Foot Valve Clean and Silt Free

Floating matters, debris, vegetation, plastics, gunny bags etc. in raw water clog the strainer or foot valve creating high head loss due to which the pump operates at much higher head and consequently discharge of the pump reduces. Such operation results in:

- (i) Operation at lower efficiency as operating point is changed. Thus, operation is energy wise inefficient,
- (ii) Discharge of the pump reduces. If the strainer/foot valve is considerably clogged, discharge can reduce to the extent of 50% or so,
- (iii) Due to very high head loss in strainer/foot valve which is on suction side of the pump.

(f) Replacement of existing Mercury Vapour Lamps & Sodium Vapour Lamps by LED or solar lamps

11.3.2 Periodic Measures

(a) Restoring Wearing Ring Clearance

Due to wear of wearing rings, the clearance between wearing ring increases causing considerable reduction in discharge and efficiency. Reduction in discharge up to 15-20% are observed in some cases. If wearing rings are replaced, the discharge improves to almost original value. Initial leakage through wearing rings is of the order of 1 to 2% of discharge of the pump. Due to operation, wearing rings wear out causing increase in clearance which increases leakage loss and results in consequent reduction in effective discharge of the pump. A study shows that even though discharge is reduced, power reduction is very marginal and as such the pump operates at lower efficiency. Reduction in discharge up to 15% to 20% is not uncommon. Thus the pumps have to be operated for more number of hours causing increase in energy cost.

(b) Reducing Disk Friction Losses

Disk friction losses in pump accounts for about 5% of power consumed by the pump. A study shows that if surfaces of the impeller and casing are rough, the disk friction losses increase. If casing is painted and impeller is polished, disk friction losses can be reduced by 20% to 40% of normal loss. Thus as disk friction loss is about 5% of power required by the pump, overall saving in power consumption will be 1% to 2%. For large pump the saving can be very high.

(c) Scrapping down Encrustation inside Column Pipes

Due to operation over prolonged period, encrustation or scaling inside the column pipe develops causing reduction in inside diameter and making surface rough. Both phenomenon cause increase in friction losses. If scrapping of encrustation is carried out whenever column pipes are dismantled energy losses can be minimized.

11.3.3 Selection Aspects

(a) Selection of star rating motor pump

Nowadays, three star/five star rating pump sets are available in the market, which can save 10-15% of power, can be used in place of normal pumping machinery.

(b) Optimum Pump Efficiency

Optimum efficiency of pump can be ensured by appropriate selection such that specific speed is optimum.

(c) Optimisation of Pipe appurtenance

Sluice Valve/Butterfly Valve and Non-Return Valve on Pump Delivery 'K' values of sluice valve and non-return valve are 0.35 and 2.50 respectively which amount to combined 'K' valve of 2.85. Due to very high 'K' value, head loss through these valves is significant and therefore, it is necessary to have optimum size of valves.

(d) Delivery Pipe for Submersible Pump

As delivery pipe for submersible pump is comparatively long and therefore, head loss in delivery pipe is considerable, it is of importance to select proper diameter. Optimum design velocity is around 1.1 - 1.5 m/s. However, pipe diameter should not be less than 50 mm.

11.3.4 Concept for Energy Audit

Energy Audit is a vital link in the entire management chain. The energy manager, while proposing various courses of action and evaluating their consequences, requires a detailed information base to work from energy audit attempts to balance the total energy inputs with its use and serves to identify all the energy streams in the system and quantifies energy usages according to its discrete function.

Energy audit is an effective tool in defining and pursuing comprehensive energy management programmes. It has positive approach aiming at continuous improvement in energy utilization in contrast to financial audit which stresses to maintain regularity. Energy audit provides answer to the question – what to do, where to start, at what cost and for what benefits?

Energy audit helps in energy cost optimization, pollution control, safety aspects and suggests the methods to improve the operating and maintenance practices of the system. It is instrumental in coping with the situation of variation in energy cost availability, reliability of energy supply, decision on appropriate energy mix, decision on using improved energy conservation equipment, instrumentations and technology. It has been established that energy saving of the order of 15 to 30% is possible by optimizing use of energy by better housekeeping, low cost retrofitting measures and use of energy efficient equipment at the time of replacements. The developed countries' industry consumes more energy as compared to the developing countries. The energy audit provides the vital information base for overall energy conservation programme covering essentially energy utilization analysis and evaluation of energy conservation measures.

PART C: OPERATION AND MAINTENANCE OF WATER TREATMENT, WATER AND WASTEWATER QUALITY COMPLIANCE

Chapter 12

WATER TREATMENT

The principal objective of water treatment in water supply industry is to produce water that is fit for domestic use from a raw water source throughout the water supply system to the consumers. The raw water available from sources particularly surface water sources is normally not suitable for drinking purposes. Thus, raw water needs treatment to produce safe and potable drinking water. Some of the common treatment processes of the conventional treatment facilities include the following:

(a) Pre-treatment – Scum and floating matters removal, Screening (fine and coarse), Sand trap, Grit removal, Pre-chlorination,

(b) Primary treatment – Sedimentation, Primary filtration, Floatation, Aeration.

(c) Secondary treatment – Coagulation, Flocculation, Clarification, Filtration, Softening, Reverse Osmosis, Capacitive De-Ionisation (CDI), Ion Exchanger, De-fluoridation, Adsorption, Constructed wetlands.

(d) Tertiary treatment – Disinfection, Softening, Utra-filtration, Microfiltration, Nano-filtration, Water conditioning, Water polishing.

12.1 PRE-TREATMENT

12.1.1 Scum and Floating Materials Skimmer

This is the unit operation that enables the manual or automated removal of the scum and floating matter ahead of the screening units. These are designed to skim the entire width of the approach area ahead of the screens. It is one of the most popular styles of scum skimmers used is the scum pipe. It is used in 90%-95% of applications. The other 5% of the time when a skimmer is needed, a helical or paddle wheel skimmer is used. The removal of scum during clarification is an essential step to decrease organic loadings and scum build up in subsequent treatment processes.

The rotating scum troughs and skimmers efficiently remove all grease, scum and floating material from the water surface in rectangular clarifiers and settling basins. Engineered for both corrosion-resistance and strength, the Scum removal systems are available in non-metallic or metallic designs. The scum skimming blade directs the scum through the opening and into contact with the helical blade, and the helical blade is rotated by the drive unit in a manner tending to keep the scum in the trough while moving the scum lengthwise along the trough to a discharge point outside the tank. In a further embodiment, the trough contains a sloped portion rising above the liquid level to allow the liquids to drain from the scum being transported (Tank Enviro Systems website:

https://www.tankenviro.com.au/products/scum-removal).

12.1.2 Screening/Straining

This unit operation consists of fine screens and coarse screens which perform the task of removal of all fine and coarse materials that may block the screen or damage downstream appurtenances or machines. This is a physical, pre-treatment process used to remove weeds, grass, twigs, bilharzial snails and other freshwater crustacean as well as coarser particles including plastics, tins and others so that they do not enter the pumping, treatment, or supply system. Screens are placed at the entrance to the intake of a water supply project

12.1.3 Grit Removal Channels

The purposes of grit channels in the water and wastewater treatment plants are as follows:

- To protect pumps and other mechanical parts from excessive wear and tear,
- To avoid undue clogging/filling up of subsequent unit operations,
- To differentially remove grit but not the organic particulates in water.

Grit channels are used for peak flow. They should be used either one at a time, or every day. Grit channels should be cleaned every day. Proper and efficient removal of silt in grit channels will improve the functioning of treatment.

12.1.4 Sand Traps

This pre-treatment unit is designed to trap sand after water has been guided into the intake chamber in order to reduce the potential for wear and tear as well as silting up the unit operations that are located downstream of the intake structure. The minimum diameter of such sand traps is 75 mm and the bigger the main intake pipe, the bigger is the flushing pipe for sand.

12.1.5 Pre-chlorination

This is a unit operation that is used for purposes of controlling algae growth in raw water and the process of preparation of the chemical to facilitate dosing should include the standard preparation of the aqueous solution as done during disinfection. This is often added upon establishment of occurrence of algal blooms during certain periods of the year as confirmed by laboratory tests undertaken daily. The amount of the dose should be established daily in order to pre-determine the pre-chlorination dose that has to ensure no interference with downstream unit operations in case the flow sheet involves biological treatment processes like slow sand filter or others.

12.1.6 Pre-Sedimentation Unit

Pre-sedimentation is the removal of coarse suspended matter (such as grit) depending merely on gravity. This type of sedimentation typically takes place in a reservoir, grit basin, debris dam, or sand trap at the beginning of the treatment process. The pre-sedimentation removes most of the sediment from the water at the pre-treatment stage and it reduces the load on the coagulation/flocculation basin and on the sedimentation chamber, as well as reducing the volume of coagulant chemicals required to treat the water.

For the treatment of highly turbid raw water during the rainy season, solids loadings including larger particles decreased substantially with the application of Pre-sedimentation in the water treatment plant during the rainy season (Kwak et al., 2010). Contaminants from raw water could be removed step-by-step following sequential treatment processes. The selection and arrangement of different treatment processes are of great importance for achieving high contaminant removal efficiency. Pre-sedimentation has various effects on water treatment plant operation, and the produced water depends on raw water quality.

(Source:https://www.researchgate.net/publication/323643034_Pre-sedimentation_tank_effects_on_water_treatment_unit_operation)

12.1.7 Tube Settlers

A set of small diameter tubes (inclined about 60°) having a large wetted perimeter relatively to wetted area when introduced in conventional sedimentation tank, provide laminar flow condition and with low surface loading rate yield good settlement of solids. The tubes which are inclined at about 60 degree found to yield good results. The tubes may be square, circular, hexagonal, diamond shaped, triangular, rectangular shaped. In most of the sedimentation tank the shape will be of thin sheets. There is also another type of settlers widely known as Lamella settlers.

12.1.8 Water Pre-conditioning

Water pre-conditioning can entail a number of pre-treatments undertaken prior to pre-chlorination which is often the final step in pre-treatment. This unit operation involves adjustment of the pH upstream in order to ensure the chemicals used during further treatment processes are dosed to water that has the correct pH range for maximum efficiency.

12.2 PRIMARY TREATMENT

12.2.1 Sedimentation

Sedimentation is a physical water treatment process using gravity to remove suspended solids from water. Solid particles entrained by the turbulence of moving water may be removed naturally by sedimentation in the still water of lakes and oceans. Settling basins are ponds constructed for the purpose of removing entrained solids by sedimentation. Clarifiers are tanks built with mechanical means for continuous removal of solids being deposited by sedimentation.

Sedimentation tank is used as a component of a modern system of water supply or wastewater treatment. It allows suspended particles to settle out of water or wastewater as it flows slowly through the tank by gravity, thereby providing some degree of purification. Suspended materials may be particles, such as clay or silts, originally present in the source water.

12.2.2 Lamella Plate Settlers (Inclined Plate Settlers)

A lamella clarifier or inclined plate settler (IPS) is a type of settler designed to remove particulates from liquids. They are often employed in primary water treatment in place of conventional settling tanks. They are commonly used in industrial water treatment. Unlike conventional clarifiers they use a series of inclined plates. These inclined plates provide a large effective settling area for a small footprint. The inlet stream is stilled upon entry into the clarifier. Solid particles begin to settle on the plates and begin to accumulate in collection hoppers at the bottom of the clarifier unit. The sludge is drawn off at the bottom of the hoppers and the clarified liquid exits the unit at the top over a weir.

Lamella clarifiers can be used in a range of industries including mining and metal finishing, as well as used to treat groundwater, industrial process water and backwash from sand filters. Lamella clarifiers are ideal for applications where the solids loading are variable and solids sizing is fine and are more common than conventional clarifiers at many industrial sites due to their smaller footprint. Lamella clarifiers are also used in the municipal wastewater treatment processes (https://en.wikipedia.org/wiki/Lamella_clarifier).

12.2.2.1 Operation and Maintenance of Lamella Settlers

Properly designed and constructed Lamella plate settlers require minimal operator attention. However, provisions for access and the maintenance should be considered. Access Lamella plate settlers basically require little maintenance. Access walk ways over the basin area if not provided already needs to be provided during maintenance depending upon the requirement of the maintaining agency.

12.2.2.2 Maintenance

Lamella plate equipment sedimentation basin does not require any adjustment by the operating staff. Normal maintenance is dependent on the materials selected for construction. Periodic disassembly of the plate pack system is recommended if painted carbon steel equipment is used. Stainless steel construction however minimizes routine maintenance. If process upset such as coagulant over dose or biological growth occurs, the basin may have to be drained and or plate cleaned with high pressure hose.

12.2.2.3 Record Keeping

Daily operations log of process performance and water quality characteristics should:

(a) Record inflow and outflow turbidity and inflow temperature,

(b) Process production inventory (amount of water processed and volume of sludge produced),

(c) Process equipment performance (type of equipment in operation, maintenance procedures performed and equipment calibration).

12.2.2.4 Cleaning and Maintenance of Lamella Clarifiers

It is important to carry out cleaning the Lamella Plate Settlers in order to improve the performance of the lamellar modules and ensure a greater longevity of the installation.

(a) Emptying procedure before cleaning

(i) While the decanter is still filled with water, start spraying the surface of the lamellar module with pressurized water: pressure should not exceed 6 to 8 bar. Modules should be washed on an ongoing basis. Therefore, it is recommended to have more than 1 worker carrying out the cleaning. In order to water down the lamellas correctly, it is recommended that the maintenance workers walk on the surface of the lamellar modules using wood. In this way, modules are prevented from breaking. These ruptures do not influence performance but they affect the visual aspect of the installation. As the surface of the lamellar module is being sprayed, the water level in the clarifier must descend progressively, especially while the descent affects the length/height of the modules. Close the valves (for short intervals of time) to ensure homogeneous washing. This will dilute any organic matter deposited/adhered on the walls of the pipes and avoid its drying that could reduce the particle slippage, thus impairing the effectiveness of the process;

(ii) During the emptying of the clarifier, don't stop spraying the water from the surface downwards, and keep the scraper in operation and the sludge purge pumping because the process tends to produce a lot of solid sedimentation. Perfect sludge collection will ensure greater lamellar performance;

(iii) Once the clarifier has been emptied, proceed to internal inspection of the equipment. To enter inside the clarifier, you can remove one of the lamellar packs to place a staircase or any other appropriate element to help you go down. It is usually necessary to disarm part of the Ant-Flotation System (AFS) to be able to remove the module;

(iv) It is important to clean rain gutter channels, especially if they are tubular and with holes.

(b) Parts of the Lamella Settler/Clarifier that need reviewing

(i) Supporting structure review: if the structure is iron-made, check for any sign of corrosion or degradation;

(ii) Review the structure-supporting brackets to ensure that the profiles are correctly fastened to the walls of the clarifier;

(iii) Make sure that the lamellas are properly leaning on the supporting structure;

(iv) Find out if any of the areas in the lamellar module are still clogged with sludge. Should it be the case, make sure to clean them insistently as they will be the most prone to mud accumulation, which can affect the supporting structure;

(v) Review the bottom scraper, its state, the wear of wheels or skates, the state of the concrete. Find out if any replacement is needed.

(c) Recommendations

(i) Before entering the clarifier for inspection purposes, we recommend to make sure that the supporting beams of the lamellar modules have not yielded: sometimes when designing the support structure, only the weight of the lamellar module is taken into account, leaving aside the weight of the sludge. But 1m^3 of lamellas, when empty, may weigh 50 kg, however, with 100% sludge, it can weigh up to 1,300 kg. For safety reasons, it is recommended to check the supporting structure before entering the clarifier;

(ii) The plant operators know their sludge production and will safely determine when the clarifiers need cleaning. However, it is recommended to carry out maintenance at least 1-2 times a year;

(iii) Once the clarifier is clean, it is absolutely necessary to refill it with water. Otherwise, continuous and long-term exposure to the sun may alter the molecular chain of raw materials, causing damages or deformations on the medium term;

(iv) Even if lamellas present a constant thickness of 1 mm, they are protected against UV and welded with our system of reinforcement by points, it is advisable to strictly respect the previous recommendation;

(v) Should the modules need to be left outdoors without water for longer periods of time, it is recommended to cover them with a tarpaulin to avoid direct contact with the sun;

(vi) Please consider that a lamella clarifier produces approximately 4 times more sludge than a clarifier without lamellar modules. Based on this, it is indispensable to equip the clarifier with a perfect lower sludge extraction system to prevent it from collapsing and avoid the sludge to invade clean water collection channels.

12.2.3 Slow Sand Filtration Plant

A Slow Sand Filter Plant consists of a box which is rectangular or circular in shape made either of concrete or masonry. This box is normally one component in a treatment process which may involve preliminary settlement of solids and / or roughing filters and post chlorination. Typically the slow sand filter plant consists of two rectangular operating in parallel, one filter unit is kept in operation and other for maintenance. The filter units also comprise pipe fittings, under drains and graded gravel to support the filter's sand bed. A flow indicator is used for checking the flow rate. The turbidity of the inlet water is checked to ensure the water is of an acceptable turbidity to prevent rapid blocking of the filter. Turbidity is also measured at the outlet to check the filter is functioning properly. The supervising manager carries out daily bacteriological tests on the filtered water.

12.2.3.1 Operation and Maintenance of Slow Sand Filter

(a) Daily activities

(i) Check the rate of filtration on the flow indicator – adjust the rate of filtration as needed by turning the filtered water valve;
(ii) Check the water level in the filter – adjust the inlet vale as needed to maintain a constant water level;
(iii) Remove scum and floating material by further opening the inlet valve for short time;
(iv) Check the water level in the clear well;
(v) Sample and check water turbidity – if the inflow turbidity is too high close the intake; if the outflow turbidity is too high report to the supervisor;
(vi) Testing water quality;
(vii) Complete the log book;
(viii) Testing Water Quality: Daily monitoring of water quality may be done whether it is slow sand filter or rapid sand filter. If the water supply scheme is having laboratory at the water treatment plant site, water quality testing both the raw water and treated water may be carried out daily.

(b) Weekly activities

Clean the water treatment plant site.

(c) Monthly activities

(i) Shut down the filter unit – remove scum and floating material;
(ii) Brush the filter walls; close the inlet, filtered water and distribution valves;
(iii) Drain water to 20 cm below the sand level;
(iv) Increase the filtration rate in the other filter to 0.2 m/h;

(v) Clean the drained down filter bed – wash boots and equipment before use; scrape upper 2-3 cm in narrow strips and remove scrapings from filter;
(vi) Check, and service, exposed inlet and drain valves; remove cleaning equipment and level sand surface; check and record depth of sand bed;
(vii) Adjust inlet box to the new sand level;
(viii) Re-start the filter – open the recharge valve; check sand surface and level as needed;
(ix) When water is 20 cm above the sand, open the inlet valve;
(x) Open the filtered water valve and stop when filtration rate reaches 0.02 m/h;
(xi) Open waste valve for outflow water to flow to waste;
(xii) Open filtered water valve to increase filtration rate every hour by 0.02 m/h until a rate of 0.1 m/h is reached;
(xiii) Adjust and check flow daily until safe to drink;
(xiv) Close waste valve and open distribution valve to pass filtered water into the supply;
(xv) Decrease filtration rate of other filter to 0.1 m/h;
(xvi) Wash the filter scrapings and store the clean sand.

(d) Quarterly activities - cleaning of filter

(i) Close the water inlet and allow the filter to discharge clear water for at least 8-10 hours;
(ii) Close the treated water outlet valve;
(iii) Open the waste water outlet till the water in the filter bed reaches up to 0.1-0.2 mm from bottom;
(iv) Remove wastage on top of the filter;
(v) Remove the sand as little as possible, not more than 20-30 mm (the *Schmutzdecke*). Wastage can be removed manually or with mechanical equipment. Care should be taken to avoid any contamination while removal of waste in the filter tank by observing hygiene and cleaning it as quickly as possible;
(vi) Level the sand in the filter;
(vii) Re-start the filter by opening inlet valves and outlet valves.

After sand cleaning is done for 20-30 times, the depth of sand layer will decrease and needs to replace.

(e) Annual activities

(i) Check if filter is water tight: close all valves and fill filter box from inlet valve until it overflows – close valve;
(ii) leave for 24 hours and check if water level reduces; if filter box leaks, report for repair;
(iii) open filtered water valve to fill outlet chamber and when full, close valve; leave for 24 hours and check if water level reduces; if chamber leaks, report for repair;

(iv) open drain valve to empty filter; clean the clear well in the outlet chamber;
(v) restart filter as per the monthly clean plan.

(f) Every two – three years, activities

(i) Re-sand the filter units – clean the filter as in a monthly filter clean;
(ii) open drain valve to empty water from the sand bed;
(iii) remove strip of old sand to one side;
(iv) place new clean sand on top of exposed gravel, and level;
(v) place old sand on top of the new sand to the correct depth of 0.8 m in total, and level the surface;
(vi) continue in strips until filter is re-sanded; adjust inlet box to new sand level;
(vii) Re-start the filter as per the monthly clean plan.

(g) Random checks

Checks on the functioning of the plant by supervising staff including turbidity tests through a turbidity meter, and bacteriological tests of the filtered water.

(h) Record keeping

Records have to be kept for the following activities:

(i) Daily Source water quality,
(ii) Daily Treated water quality,
(iii) Names of chemicals used,
(iv) Rates of feedings of chemicals,
(v) Daily consumption of chemical and quality of water treated,
(vi) Dates of cleaning of filter feds, sedimentation tank and clear water reservoir,
(vii) The date and hour of return to full service (end of re-ripening period),
(viii) Raw and filtered water levels (measured each day at the same hour) and daily loss of head,
(ix) The filtration rate, the hourly variations, if any,
(x) The quality of raw water in physical terms (turbidity, colour) and bacteriological terms (total bacterial count, *E.Coli*.) determined by samples taken each day at the same hour,
(xi) The same quality factors of the filtered water,
(xii) Any incidents occurring e.g. plankton development, rising Schmutzdecke, and unusual weather conditions,
(xiii) Precautions must be taken to minimize the chances of pollution of the filter bed surface by the labourers themselves.

12.2.3.2 Re-Sanding

Re-sanding becomes necessary when the depth of the sand bed drops to its minimum designed level (usually about 0.5 – 0.8 m above the supporting gravel, depending on the grain size of the filter sand/medium). This depth is usually indicated by a marker (such as a concrete block or a step in the filter box wall) set in the structure during the original construction to serve as an indication that this level has been reached and that sanding has become due. After scraping, add new clean sand up to a level shown in Figure 12.1 and place back the old sand that was scraped off the top. The old sand will reduce the number of days needed for ripening the filter.

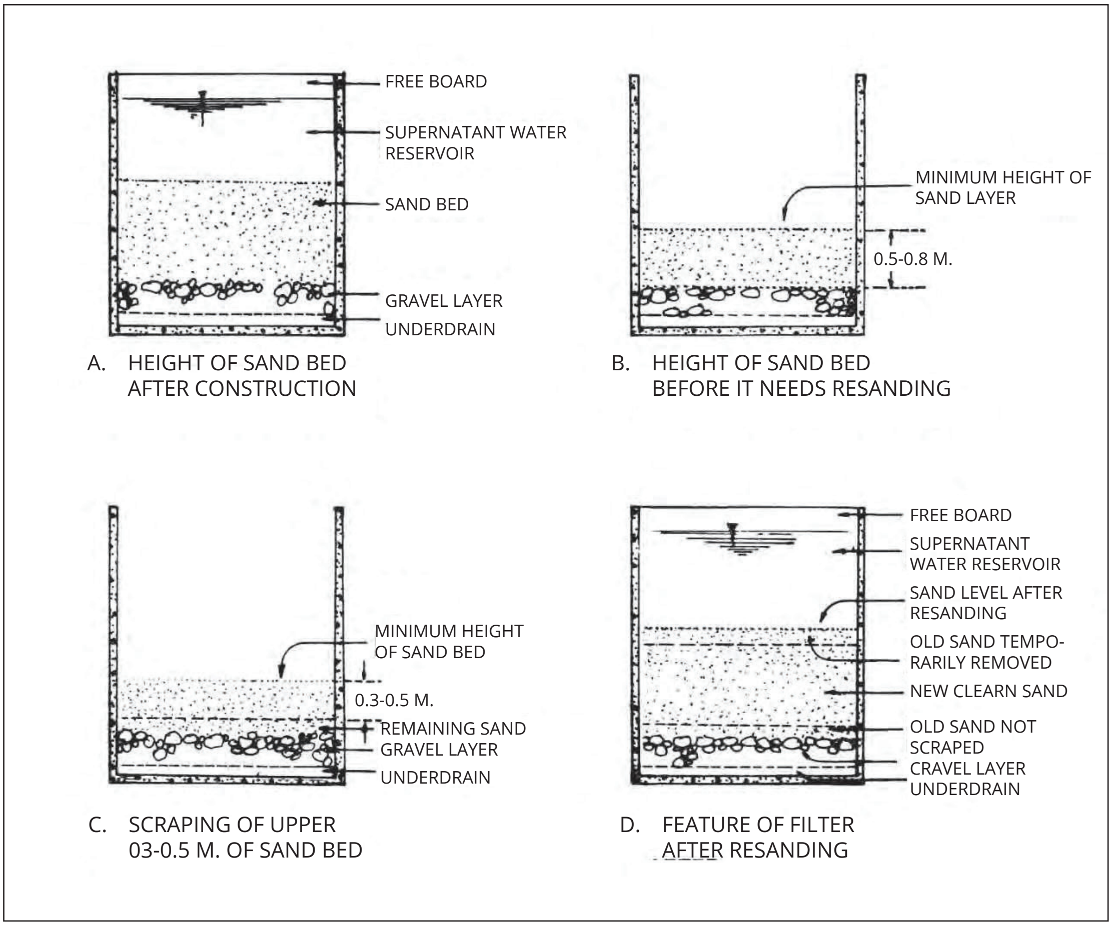

Figure 12.1: Details of Cleaning and Re-sanding of the SSF

(Source: World Bank, 2012)

12.2.4 Roughing Filters

Operation of Roughing Filter Unit

Roughing Filter (RF) can easily be operated and maintained by trained local operators/technician/artisans. It does not depend on external inputs provided the necessary materials and tools are available. The daily activities of the caretaker are preferably supported by occasional visits of a supervisor attached to the operation and maintenance section of the governmental institution responsible for the water supply system. Important maintenance work should be carried out at the time when village participation can be involved. This is of particular importance with regard to manual cleaning of the RF.

Flow Pattern: For operational and economic reasons, it is recommended to continuously operate a RF-SSF plant at constant filtration rates for 24 hours/day. In case of a pumped Scheme, a raw water balancing tank is required. Removal of the coarse solids is a positive side effect of such a tank.

12.2.4.1 Roughing Filter Cleaning

Filter efficiency is not constant but may increase at the start of filter operation and certainly decreases when solid matter accumulates excessively in the filter. Hence, periodic removal of this accumulated matter restores filter efficiency and keeps the filter in good running condition. Hence, periodic removal of this accumulated matter is required to restore efficiency and possibly hydraulic filter performance. Filters are cleaned either hydraulically or manually, and the cleaning methods are dependent on the way solids accumulate in the filter. Hence, the cleaning procedures will therefore have to be adapted to the different filters.

12.2.4.2 Roughing Filter Maintenance

Major incidents are often the result of minor causes. This saying also applies to roughing filter maintenance. Filter maintenance is not very demanding as the pre-filters do not include any mechanical parts apart from the valves. Nevertheless, maintenance should aim at maintaining the plant in good condition right from the beginning. External assistance for maintenance work can usually be avoided if the following work is carried out properly by the local operator:

(a) periodic upkeep of the treatment plant's premise (grass cutting; removal of small bushes and trees which could impair the structures by their roots; removal of refuse);
(b) soil protection against erosion (especially surface water intake structures, the wash water drainage channels and surface runoff);
(c) repairing fissures in the walls of the different structures and replacing the chipped plaster;
(d) application of anti-corrosive agents to exposed metal parts (V-notch weirs, gauging rods, pipes);
(e) checking the different valves and drainage systems, and occasionally lubricating their moving parts;
(f) weeding the filter material;
(g) skimming off floating material from the free water table;
(h) washing out coarse settled material (distribution and inlet boxes);
(i) controlling the ancillaries and replacing defective parts (tools and testing equipment).

The term "periodic" does not only apply to the first point in this check list but to all of them. Proper maintenance of the treatment plant guarantees long-term use of the installations at low running costs.

12.2.5 Bank Filtration

Bank filtration is a water treatment technology that consists of extracting water from rivers by pumping wells located in the adjacent alluvial aquifer. During the underground passage, a series of physical, chemical, and biological processes take place, improving the quality of the surface water, substituting or reducing conventional drinking water treatment.

The efficiency of BF depends on local conditions including the hydrology and hydrogeology of the site, the geochemistry of water (from both the river and the aquifer), the geochemistry of microbial populations, and associated metabolic activity. This is the reason why it is difficult to define general procedures for identifying appropriate sites to implement the BF technique, as well as the expected efficiency of the process.

Optimal BF cleaning frequency

In general, the typical cleaning frequency is 7-8 years. Based on practical knowledge, the cycle cannot exceed ten years. As this deterioration of the filter layer is a function of the well operation (velocity of the bank filtrate, volume of produced water), a production load-based cleaning cycle.

12.2.6 Floatation Plant

A Dissolved Air Flotation (DAF) system creates microscopic air bubbles that are attached to incoming raw water and wastewater particles in order to float them. Once floated, they are separated from the raw water wastewater and skimmed from the top and into the float scum chamber. The treated water and wastewater then exits from near the bottom of the DAF. The DAF creates air bubbles with a sub-system called a Recycle Air Dissolving (RAD) system. Proper operation of the RAD system is key to DAF performance. The standard configuration RAD system is designed to take treated effluent from the DAF effluent end, pump and pressurize it into the RAD pressure vessel where it is subject to compressed air pressure. The air pressure then dissolves air into the water to become "saturated recycle". Once saturated the recycle is introduced into the DAF inlet reaction chamber where it co-mingles with raw incoming water and wastewater. When the recycle is co-mingled with water and wastewater the pressure of the saturated recycle is released and bubbles form and are enmeshed with the wastewater particles.

Recycle Air Dissolving Operation

The RAD creates bubbles by maintaining pressure and an air/water interface in the RAD pressure vessel (stainless steel vertical vessel pictured above right). The interface is maintained by a dual level sensor located in the RAD clear sight tube. When the dual float sensors are wet, the logic says the level is rising and the air pressure supply solenoid is energized and air pressure is added to the RAD vessel. When the dual sensor floats are dry, the logic says the air pressure is excessive and the air supply solenoid is de-energized allowing the level to rise.

The level will constantly hunt between (slightly above and below) the two sensor floats. This is normal.

Note: The level sensors MUST be maintained clean. If allowed to foul and malfunction the RAD pressure vessel will fill with water and bubbles will NOT be created. They are easy to remove and clean while the RAD is operating by closing the isolation valves and venting pressure with the sight tube drain valve. The supply air pressure regulator must be maintained at minimum 10 psi above the RAD pressure. If the RAD flow rate valves are adjusted the supply air pressure must be checked to ensure it'

12.2.7 Aeration

Aeration is a unit process in which air and water are brought into intimate contact. Turbulence increases the aeration of flowing streams. Aerators bring water and air in close contact in order to remove dissolved gases (such as carbon dioxide) and oxidizes dissolved metals such as iron, hydrogen sulphide, and volatile organic chemicals (VOCs). Aeration unit is often the first major process at the treatment plant. During aeration, constituents are removed or modified before they can interfere with the treatment processes.

12.2.7.1 Operation and Maintenance of Aerators

Two general methods may be used for the aeration of water. The most common in use is the water-fall aerators. Through the use of spray nozzles, the water is broken up into small droplets or a thin film to enhance counter current air contact. In the air diffusion method of aeration, air is diffused into a receiving vessel containing counter-current flowing water, creating very small air bubbles. This ensures good air-water contact for "scrubbing" of undesirable gases from the water.

12.2.7.2 Operation of Cascade aerator equipment

Cascade Aerators induct air into a water flow in order to oxidize iron and reduce dissolved gases. With Cascade Aerators, aeration is accomplished by natural draft units that mix cascading water with air that is naturally inducted into the water flow. Cascade water is pumped to the top of the aerator, and cascades over a series of trays. Air is naturally inducted into the water flow to accomplish iron oxidation and some reduction in dissolved gasses. Cascade Aerators are of non-corroding, all aluminium or stainless construction and have no moving parts, making them maintenance free and inexpensive to buy and operate.

12.2.7.3 Maintenance of Aeration Equipment

Proper maintenance of aerators is another important area in water treatment activities. Maintenance is on the following elements;

1. Waterfall Aerators

The recommended maintenance procedures for waterfall-type aerators (cascade or step, and tray or splash pan) is as follows:

(a) Weekly

- (i) Inspect the aerator surfaces for algae or other growths, precipitated iron oxide, and for non-uniformity of water distribution and staining;
- (ii) Clean when necessary;
- (iii) Treat with copper sulphate or hypochlorite solution to destroy growths.

(b) Every 6 months

- (i) clean and repair tray aerators, removing the trays as necessary;
- (ii) Inspect the coke tray aerators for biological growths and coke deterioration;
- (iii) Replace the coke if the cleaning is not effective. Repair the screen and enclosures if necessary.

(c) Annually

- (i) Repair or replace the surfaces on cascade or step aerators;
- (ii) Injection or Diffuser Aerators Injection or diffuser aerators may be either porous medium design or injection nozzles;
- (iii) Porous Ceramic Diffusers.

2. Porous ceramic diffusers-plate or tube aerators

The maintenance procedures for porous ceramic diffusers-plate or tube is as follows:

(a) Upon evidence of the non-uniform distribution of air or clogging that impairs operation,

- (i) dewater the tank;
- (ii) inspect; and
- (iii) clean diffusers if necessary.

(b) Every 6 months,

- (i) drain the aeration tank and inspect the diffusers for joint leaks, broken diffusers, and clogging;
- (ii) Porous ceramic diffusers may suffer clogging of either the waterside or the air side (underside);
- (iii) for waterside (porous plate diffusers), use oxidizing acids to clean organic growths from the plate surface.

Note: Chlorine gas introduced into the air line at intervals between inspections will help hold down organic growths. Removable plates should be soaked in 50 percent nitric acid. Plates grouted in place cannot be treated with nitric acid; use chromic acid (made by adding 1 gram of sodium dichromate to 50 ml of sulphuric acid). Pour approximately 2 fluid ounces on each plate 2 days in a row.

Warning: Acids must be handled carefully. DO NOT pour water into sulphuric or chromic acid, as it will explode or splatter. Such acid will cause severe burns to the skin and clothes. ALWAYS pour acid SLOWLY into the water, while stirring continuously. Acid treatment should only be done only under supervision of a chemist or other qualified personnel.

a) *Source:http://constructionmanuals.tpub.com/14265/css/Maintenance-of-Aeration-Equipment-294.htm*
b) *https://cdn2.hubspot.net/hubfs/541513/Brochures/Brochure-Aerators.pdf*

12.3 SECONDARY TREATMENT

12.3.1 Clarification

Clarification is a process of removing all kind of particles, sediments, oil, natural organic matter and colour from the water to make it clear. A clarification step is the first part of conventional treatment for water and wastewater treatment. It usually consists of physical and/or chemical treatment. Coagulation is normally followed by flocculation in a clarifier, which could be circular or rectangular in shape. After clarification water is then ready for filtration.

12.3.2 Coagulation and Flocculation

The term coagulation and flocculation are often used to describe the process of removal of turbidity caused by fine suspension, colloids and organic colours, i.e. non-settle able particles from water.

12.3.2.1 Coagulation

(a) Chemical Coagulants Commonly Used in Treatment Process

Coagulant chemicals are in two main types including primary coagulants and coagulant aids. Primary coagulants neutralize the electrical charges of particles in the water which causes the particles to clump together well as coagulant aids add density to slow-settling flocs and add toughness to the flocs so that they do not break up during the mixing and settling processes. Primary coagulants are always used in the coagulation/flocculation process while coagulant aids, in contrast, are not always required and are generally used to reduce flocculation time.

Chemically, coagulant chemicals are either metallic salts (such as alum) or polymers. Polymers are man-made organic compounds made up of a long chain of smaller molecules. Polymers can be cationic (positively charged), anionic (negatively charged) or non-ionic (neutrally charged). Table 12.1 shows some of the common coagulant chemicals and lists whether they are used as primary coagulants or as coagulant aids. The various coagulants are used in treatment process. The common coagulants used in water works practices are salt of aluminium *viz.* filter alum and liquid alum, sodium aluminate, Poly Aluminium Chloride (PAC), Calcium Hydroxide Calcium Oxide and chlorinated copperas which are an equimolecular mixture of ferrous sulphate and ferric chloride being obtained by chlorinating ferrous sulphate.

The commonly used coagulant is commercial grade ferric-alum (solid), However, recently, Poly-Aluminum Chloride is also inducted as a coagulant as it gets properly dispersed, does not have any insoluble residue and effect on the settling tanks, requires less space (<50%). However, it has disadvantage of less effective for colour removal.

Table 12.1: Types of Coagulants/Aids

Chemical Name	Chemical Formula	Primary Coagulant	Coagulant Aids
Aluminum sulphate (Alum)	$Al_2(SO_4)_3 \cdot 14\ H_2O$	X	
Ferrous sulphate	$FeSO_4 \cdot 7\ H_2O$	X	
Ferric sulfate	$Fe_2(SO_4)_3 \cdot 9\ H_2O$	X	
Ferric chloride	$FeCl_3 \cdot 6H_2O$	X	
Cationic polymer	Various	X	X
Calcium hydroxide (Lime)	$Ca(OH)_2$	X*	X
Calcium oxide (Quicklime)	CaO	X*	X
Sodium aluminate	$Na_2Al_2O_4$	X*	X
Bentonite	Clay		X
Calcium carbonate	$CaCO_3$		X
Sodium silicate	Na_2SiO_3		X
Nonionic polymer	Various		X

*****Used as a primary coagulant only in water softening processes.*

(Source: Belmont Water Treatment Association as cited in the Water Supply Design Manual, Uganda, 2013).

(b) Tips for Selection of Coagulant

Coagulation is a physical and chemical reactions occurring between the alkalinity of the water and the coagulant added to the water, which results in the formation of insoluble flocs. The most important consideration is the selection of the proper type and amount of coagulant chemical to be added to raw water. Over-dosing as well as under-dosing of coagulants may lead to reduced solids removal efficiency. This condition may be corrected by carefully performed Jar tests and verifying process performance after making any change in the process of the coagulation process.

(c) Aluminium Sulphate Coagulant

Aluminium sulphate is a chemical compound with the formula Al2(SO4)3. Aluminium sulphate is mainly used as a flocculating agent in the purification of drinking water and wastewater treatment plants, and also in paper manufacturing. It is recommended to be used as the coagulant of choice in Tanzania

(d) Use of Aluminium Sulphate

Two solution tanks, one for mixing and the other for dosing, between them holding 48 hours of supply, should be provided. The solution strength should be in the range of 5-10%.The solution tanks could be equipped with hand agitators as shown in Figure 12.2.

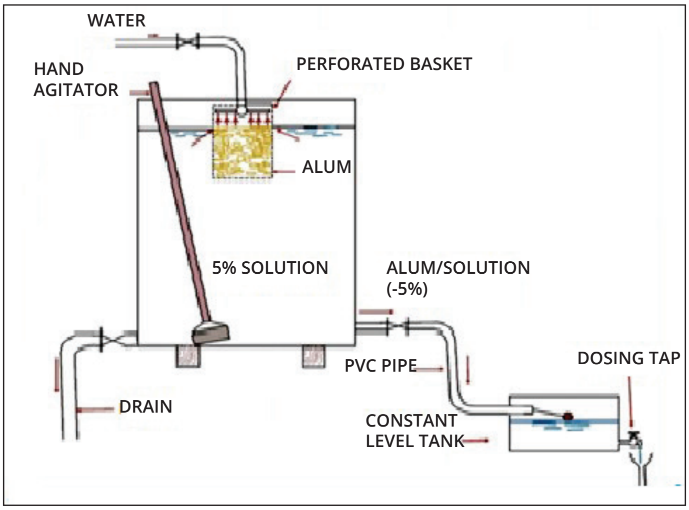

Figure 12.2: Dosing Arrangement for Alum

If the alkalinity of the raw water is low, the pH can be appropriately adjusted by adding soda ash in the correct proportions, as determined after carrying out laboratory experiments called “jar tests”. The strength of the soda ash solution required is usually in the range of 1-10%.The solution tanks for soda ash should also hold a total of 48 hours of supply. The chemical solutions should be fed into the raw water by means of gravity dossers, floating balls or other similar simple devices. Dosing pumps should be used only in exceptional cases.

(e) The Jar Test

To determine the correct chemical dosage for aluminium sulphate solution and for water disinfection, jar testing is recommended (normally Jar test experiments are done in the Laboratory). Jar testing entails adjusting the amount of treatment chemicals and the sequence in which they are added to samples of raw water held in jars or beakers. The sample is then stirred so that the formation, development, and settlement of floc can be watched just as it would be in the full scale treatment plant. Jar testing should be done seasonally (temperature), monthly, weekly, daily, or whenever a chemical is being changed, or new pumps, rapid mix motors, new floc motors, or new chemical feeders are installed. There is no set requirement for how often jar testing should be conducted, but the more it is done the better the plant will operate. Optimization is the key to running he plant more efficiently.

(f) Dosing of the coagulant at a spot of maximum turbulence

Rapid mix of coagulant at a spot of maximum turbulence, followed by tapered flocculation in three compartmentalized units allows a maximum of mixing(reduced short circuiting), followed by a period of agglomeration intended to build larger fast settling flocs.

(g) Mixing

The mixing is the process to mix all the coagulant in water rapidly and instantaneously especially in waters with high alkalinity so as to achieve complete homogenization of a coagulant in the water to be treated. Mixing of the coagulant can be satisfactorily accomplished in a special coagulant tank with mixing devices or in the influent channel or a pipeline to the flocculation basin with high flow velocity which produces necessary turbulence.

To accomplish the mixing, following methods can be used:

(i) Hydraulic mixing,
(ii) Mechanical mixing,
(iii) Diffusers and grid system,
(iv) Pump-blenders.

(h) Storage of Aluminium Sulphate

Aluminium sulphate should be stored in a secured, cool, dry, well-ventilated area, removed from oxidising agents, alkalis, most metals, heat or ignition sources and foodstuffs. Ensure containers are adequately labelled, protected from physical damage and sealed when not in use. Check regularly for leaks or spills (if in a solution form). Large storage areas should have appropriate fire protection and ventilation systems.

(i) Health Hazards and Disposal of Waste Solution and Sludge

Aluminium sulphate is categorised as a slightly corrosive, irritant and hazardous substance. This product has the potential to cause adverse health effects with over long exposure time. Use safe work practices to avoid eye or skin contact and inhalation. It may hydrolyse (with addition of water) to sulphuric acid, a strong tissue irritant. If released to water environment; aluminium salts will slowly be precipitated as aluminium hydroxide. This may lower the pH of receiving waters with toxic effects to aquatic organisms. It is not expected to bio- accumulate. Water plants may experience chronic toxicity at around 25 ppm. Before disposal, neutralise the solution with lime, weak alkali or similar. For small amounts, absorb with sand or similar and dispose of to an approved landfill site

12.3.2.2 Flocculation

(a) Flocculation Basin– Operation

The objective of a flocculation basin is to produce a settled water of low turbidity which in turn leads to reasonably longer service period of filter plant.

(b) Clari-flocculator

The flocculators may be circular, square or rectangular. The best flocculation is usually achieved in a compartmentalized basin. The compartments (most often three) are separated by baffles to prevent short circuiting of the water being treated. The turbulence can be reduced gradually by reducing the speed of the mixers in each succeeding tank or by reducing the Surface area of the paddles. This is called tapered-energy mixing. The reason for reducing the speed of the stirrers is to prevent breaking apart the larger flocs, which have already formed. If the floc is broken up nothing is accomplished and the filter gets overloaded.

(c) Coagulation – Flocculation Process Action

Typical jobs performed by an operator in the normal operation of the coagulation-flocculation process include the following:

(i) Monitor process performance,
(ii) Evaluate water quality conditions (raw and treated water),
(iii) Check and adjust process controls and equipment, and
(iv) Visually inspect facilities.

(d) Interaction with Sedimentation and Filtration

The processes of coagulation-flocculation are required to precondition or prepare non settle able particles present in the raw water for removal by sedimentation and filtration. Small particles (particularly colloids), without proper coagulation-flocculation are too light to settle out and will not be large enough to be trapped during filtration process. Since the purpose of coagulation–flocculation is to accelerate particle removal, the effectiveness of the sedimentation and filtration processes, as well as overall performance depends upon successful coagulation - flocculation.

(e) Examination of the Floc

(i) Examine the water samples at several points, en-route the flow line of the water. Look at the clarity of the water between the flocs and study the shape and size of the flocs. Observe the floc as it enters the flocculation basins which should be small and well dispersed throughout the flow;

(ii) Tiny alum floc may be an indication that the chemical dose is too low. A ‘popcorn flake’ is a desirable floc. If the water has a milky appearance or a bluish tint, the alum dose is probably too high. As the floc moves through the flocculation basins, the size of the floc should be increasing. If the size of the floc increases and then later starts to break up, the mixing intensity of the downstream flocculator may be too high. Thus, the speed of these flocculators needs to be reduced or otherwise the coagulant dosage may be increased;

(iii) Examine the settlement of the floc in the sedimentation basin. If a lot of flocs are observed flowing over the laundering weirs the floc is too light for the detention time. By increasing the chemical dose or adding a coagulant aid such as a polymer to produce heavier and larger flocs. The appearance of the fine floc particles passing over the weir could be an indication of too much alum and the dose should be reduced. For precise evaluation only one change can be made at a time and evaluate the results.

(f) Record keeping

Records of the following items should be maintained:

(i) Source water quality (pH, turbidity, temperature, alkalinity, chlorine demand and colour;
(ii) Process water quality (pH, turbidity, and alkalinity);
(iii) Process production inventories (chemicals used, chemical feed rates, amount of water processed, and amount of chemicals in storage);
(iv) Process equipment performance (types of equipment in operation, maintenance procedures performed, equipment calibration and adjustments);
(v) A plot of key process variables should be maintained. A plot of source water turbidity vs. coagulant dosage should be maintained. If other process variables such as alkalinity or pH vary significantly, these should also be plotted.

(g) Safety considerations

In the coagulation-flocculation processes, the operator may be exposed to the associated hazards with following:

(i) Electrical equipment,
(ii) Rotating mechanical equipment,
(iii) Water treatment chemicals,
(iv) Laboratory reagents (chemicals),
(v) Slippery surfaces caused by certain chemicals,
(vi) Flooding,
(vii) Confined spaces and underground structures such as valve or pump vaults (toxic and explosives gases, insufficient oxygen).

Strict and constant attention must be given to safety procedures. The operator must be trained with general first aid practices such as mouth-to-mouth resuscitation, treatment of common physical injuries, and first aid for chemical exposure (chlorine).

(h) Laboratory Tests

Water quality indicators for the operation of flocculation process include turbidity, alkalinity, chlorine demand, residual chlorine test, colour, pH, temperature, odour and appearance and need to be tested. In multi-habitation or big schemes, a provision of automatic water testing equipment or onsite laboratory at treatment plant may be established and maintained for the purpose.

12.3.3 Rapid Sand Filtration Plant

This is a process in which water flows onto the top of the filter media and is driven through it by gravity. In passing through the small spaces between the filter's sand grains, impurities are removed. The water continues its way through the support gravel, enters the under-drain system, and then flows to the reservoir. It is the filter media which actually removes the particles from the water. The filter media is routinely cleaned by means of a backwashing process.

Rapid sand filtration (RSF) is a relatively sophisticated process usually requiring power-operated pumps for backwashing or cleaning the filter bed, and some designs require flow control of the filter outlet. A continuously operating filter will usually require backwashing about every two days or so when raw water is of relatively low turbidity and at least daily during periods of high turbidity. Because of the higher filtration rates, the area requirement for a rapid gravity filtration plant is about 20% of that required for Slow Sand Filters (SSF).

Initial filtering performance can be re-achieved through a cleaning of the filter bed. This is usually conducted through backwashing: the flow of water is reversed, so that treated water flows backwards through the filter. The sand is re-suspended and the solid matter is separated in the surface water. Often, air is injected additionally to support the cleaning process (WHO 1996). As soon as most particles are washed out and the backward flowing water is clear, the filter is put back to operation. Clearly, relatively large quantities of sludge are generated through backwashing and require some form of treatment before discharge into the environment (UNEP 1998).

Rapid sand filtration is a highly effective method to remove turbidity if it is correctly applied (Brikke & Bredero 2003). Equally, solids formed during pre-treatment, i.e. coagulation-flocculation, are filtered. A well-operated RSF reduces turbidity to less than 1 NTN and often less than 0.1 NTU (WHO 1996). Regarding the removal of most other contaminants, the RSFs are ineffective. If combined with adequate pre-treatment measures and final disinfection, rapid sand filtration usually produces safe drinking water.

(a) Filter sand

Filter sand is defined in terms of effective size and uniformity coefficient. Effective size is the sieve size in mm that permits 10% by weight to pass. Uniformity in size is specified by the uniformity coefficient which is the ratio between the sieve sizes that will pass 60% by weight and the effective size.

Check shape size and quantity of filter sand to the followings:

- (i) Sand shall be of hard and resistant quartz or quartzite and free of clay, fine particles, soft grains and dirt of every description,
- (ii) Effective size shall be 0.4 to 0.7 mm,
- (iii) Uniformity coefficient shall not be more than 1.7 nor less than 1.3,
- (iv) Ignition loss should not exceed 0.7 per cent by weight,
- (v) Soluble fraction in hydrochloric acid shall not exceed 5.0% by weight,
- (vi) Silica content should be not less than 90%,
- (vii) Specific gravity shall be in the range between 2.55 to 2.65,
- (viii) Wearing loss shall not exceed 3%.

12.3.3.1 Interaction with Other Treatment Processes

The purpose of RSF is to remove particulate impurities and floc from the raw water. In this regard, the filtration process is the final step in the solids removal process which usually includes the pre-treatment processes of coagulation, flocculation and sedimentation. The degree of treatment applied prior to filtration depends on the quality of water.

Operation and Backwashing

Rapid Sand Filters should be washed before placing them into service.

- (a) A filter is usually operated until just before clogging or breakthrough occurs or a specified time period has passed (generally 24 hours). After a filter clogs/ breakthrough occurs, the filtration process should be stopped and the filter be taken out of service for cleaning or backwashing;
- (b) The surface wash system should be activated just before the backwash cycle starts to aid in removing and breaking up solids on the filter media and to prevent the development of mud balls. The surface wash system should be stopped before completion of the back-wash cycle to permit proper settling of the filter media;
- (c) A filter wash should begin slowly for about one minute to permit removing of an entrapped air from the filter media, and also to provide uniform expansion of the filter bed. After this period, the full backwash rate can be applied. Sufficient time should be allowed for cleaning of the filter media. Usually when the backwash water coming up through the filter becomes clear, the media is washed. This generally takes from 3 to 8 minutes. If flooding of wash water troughs or carryover of filter media is a problem, the backwash rate must be reduced.

A filter is usually operated until just before clogging or breakthrough occurs or a specified time period has passed (generally 24 hours). After a filter clogs/ breakthrough occurs, the filtration process is stopped and the filter is taken out of service for cleaning or backwashing.

Surface Wash: In order to produce optimum cleaning of the filter media during backwashing and to prevent mud balls, surface wash (supplemental scouring) is usually practiced. Surface wash systems provide additional scrubbing action to remove attached floc and other suspended solids from the filter media.

12.3.3.2 Operation and Maintenance of Rapid Sand Filters

Operation of a rapid sand filter consists of flow control, regular backwashing and cleaning. The period between backwashes depends on the quality of the influent water and normally lies between 24 – 72 hours (UNEP 1998).The cleaning process requires an interruption of the purification process of 5 - 10 minutes per filter bed. Several parallel filter units are required to guarantee constant water supply. The backwash process must be observed carefully; in particular the rate of flow must be controlled to avoid erosion of the filter medium. Periodic repacking of the filter bed may be required at infrequent intervals to ensure efficient operation (UNEP 1998). Operation and maintenance thus requires skilled and highly reliable workers. Table 12.2 illustrates the details of RSF operation and maintenance.

Table 12.2: Operation and Maintenance Details of RSF

Working principle	After being pre-treated (coagulation-flocculation), freshwater flows through a sand- and gravel bed. Hereby, particles are removed through a physical filtering process.
Capacity/adequacy	Large urban areas where land area is limited and chemicals, electricity and skilled labour are easily available.
Performance	4’000 – 12’000 litres per hour per square metre of surface (WHO 1996); generally only removes solids and suspended particles; requires pre-treatment (coagulation-flocculation) and post-treatment (disinfection).
Costs	In general, construction, operation and maintenance costs for rapid sand filters are significantly higher than costs for slow sand filters (UNEP 1998).
Self-help compatibility	Rather low, highly technical facilities, chemicals and energy required.
O&M	Very frequent cleaning (every 24 - 72h) and skilled operators required.
Reliability	Highly reliable if properly operated.
Main strength	Rapid and efficient in removing turbidity.
Main weakness	Not effective for the removal of bacteria, pre-treatment (e.g. coagulation/flocculation) and final disinfection (e.g. chlorine) are therefore needed.

12.3.3.1.1 Operating Procedures

From a water quality point of view, filter effluent turbidity is a good indication of overall process performance. However, monitoring the performance of each of the individual water treatment process including sedimentation is must in order to check water quality or performance changes. Operations are considered to be normal within the operating ranges of the plant, while unusual or difficult to handle condition is abnormal operating condition. In normal operation of the sedimentation process one must monitor the following;

(a) *Turbidity of inflow and out flow of Water in the Sedimentation Basin*: Turbidity of inflow water indicates the floc or solids loading to the sedimentation basin while turbidity of outflow water of the basin indicates the effectiveness or efficiency of the sedimentation process. Low levels of outflow water turbidity to be achieved to minimize the floc loading on the filter.

(b) *Temperature of inflow water:* is important as the water becomes colder, the settling of particles become slow. To compensate for this change, jar tests should be performed and accordingly, the coagulant dosage is to be adjusted to produce a heavier and thus a settle-able floc. Another possibility is to provide longer detention times when water demand decreases.

(c) *Visual checks of the sedimentation process:* should include observation of floc settling characteristics, distribution of floc at the basin inlet and clarity of outflow settled water spilling over the weirs. An uneven distribution of floc or poorly settling floc is an indication of a raw water quality change or there is operational problem.

(d) *Process Actions/ steps are as indicated below:*
   (i) Monitor process performance.
   (ii) Evaluate turbidity and make appropriate process changes.
   (iii) Check and adjust processes equipment (change chemical feed rates).
   (iv) Backwash filters.
   (v) Evaluate filter media condition (media loss, mud balls, cracking),
   (vi) Visually inspect facilities.

12.3.3.1.2 Important Process Activities and Precautions

Process performance monitoring is an on-going activity. Check for any treatment process changes or other problems which might affect filtered water quality, such as a chemical feed system failure. Measurement of head-loss built up in the filter media may give a good indication of how well the solids removal process is performing. The total designed head loss from the filter influent to the effluent in a gravity filter is usually about 3 meters. At the beginning of the filtration cycle the actual measured head loss due to clean media and other hydraulic losses are about 0.9 m. This would permit an additional head-loss of about 2.1 m due to solid accumulation in the filter.

The rate of head-loss build up is an important indication of process performance. Sudden increase in head loss might be an indication of surface sealing of the filter media (lack of depth penetration).Early detection of this condition may require appropriate process changes such as adjustment of chemical filter aid feed rate or adjustment of filtration rate. Monitoring of filter turbidity on a continuous basis with an online turbidity meter may be adopted for obtaining continuous feedback on the performance of the filtration process. In most instances it is desirable to cut off (terminate) filter at a predetermined effluent turbidity level. Preset the filter cut-off control at a point where breakthrough occurrence is noticed/ tested.

In the filter process, time for completion of normal filter process may be calculated on the basis of the following parameters:

(a) Head-loss;
(b) Effluent turbidity level;
(c) Elapsed run time;
(d) A predetermined value established for each above parameter as a cut off point for filter operation may be checked and when any of the selves is reached, the filter should be removed from service and backwashed;
(e) At least once a year, the filter media must be examined and evaluate its overall condition;
(f) Measure the filter media thickness for an indication of media loss during the back-washing process;
(g) Mud ball accumulation in the filter media to evaluate the effectiveness of the overall back-washing operation.

12.3.3.1.3 Routine observations

(a) The backwash process to qualitatively assess process performance,
(b) For media boils (uneven flow distribution) during backwashing, media carry over in to the wash water trough, and
(c) Clarity of the waste wash-water near the end of the backwash cycle,
(d) Upon completion of the backwash cycle, observe the condition of the media surface,
(e) Check for filter sidewall or media surface cracks,
(f) Routinely inspect physical facilities, equipment as part of good house-keeping and maintenance practices,
(g) Correct or report the abnormal equipment conditions to the water supply utility/agency for maintenance action.

Never bump upon filter to avoid back-washing. Bumping is the act of opening the backwash valve during the course of a filter run to dislodge the trapped solids and increase the length of filter run. This is not a good practice. Shortened filter runs can occur because of air bound filters. Air binding will occur more frequently when large head losses are allowed to develop in the filter. Precautions should be taken to minimize air binding to avoid damage to the filter media.

12.3.3.1.4 Record Keeping

A daily operations log of process performance data and water quality characteristics shall be recorded and maintained accurately for the following items:

(a) Process water quality (turbidity, colour, PH and alkalinity);
(b) Process operation (filters in service, filtration rates, loss of head, length of filter runs, frequency of backwash, backwash rates, and UFRV unit filter run volume);
(c) Process water production (water processed, amount of backwash water used, and chemicals used);
(d) Percentage of water production used to backwash filters;
(e) Process equipment performance (types of equipment in operation, equipment adjustments, maintenance procedures performed, and equipment calibration).

12.3.3.1.5 Start-up and Shutdown Procedures

(a) Routine Procedures

Most plants keep all filters into service except unit under backwash operation and maintenance. Filter units are routinely taken off line for backwashing when the media becomes clogged with particulates, turbidity break through occurs or demands for water are reduced.

(b) Implementation of Start-up and Shut-down Procedures

Filter check-out procedures:

(i) Check operational status of filter;
(ii) Be sure that the filter media and wash water troughs are clean of all debris such as leaves, twigs, and tools;
(iii) Check and be sure that all access covers and walk-way gratings are in place;
(iv) Make sure that the process monitoring equipment such as head-loss and turbidity systems are operational;
(v) Check the source of back-wash to ensure that it is ready to go.

12.3.3.1.6 Preventive Maintenance Procedures

Preventive maintenance programmes are to assure the continued satisfactory operation of treatment plant facilities by reducing the frequency of break-down failures. Routine maintenance functions of operator may include:

(i) Keeping electric motors free of dirt, moisture and pests (rodent sand birds);
(ii) Assuming good ventilation (air circulation) in equipment work areas;

(iii) Checking pumps and motors for leaks, unusual noise and vibrations or overheating;
(iv) Maintaining proper lubrication and oil levels;
(v) Inspecting for alignment of shafts and couplings;
(vi) Checking bearings for overheating and proper lubrication;
(vii) Checking the proper valve operation (leakage or jamming);
(viii) Checking automatic control systems for proper operation;
(ix) Checking air/vacuum relief systems for proper functioning, dirt and moisture;
(x) Verifying correct operation of filters and back-washing cycles by observation;
(xi) Inspecting filter media conditions (look for algae and mud balls and examine gravel and media for proper gradation);
(xii) Inspecting filter underdrain system (be sure that the under drain openings are not becoming clogged due to media, corrosion nor chemical deposits).

12.3.3.1.7 Safety Considerations

(a) Electrical Equipment

(i) Avoid electric shock (use preventive gloves),
(ii) Avoid grounding yourself in water or on pipes,
(iii) Ground all electric tools,
(iv) Lock-out and tag electrical switches and panels when servicing equipment.

(b) Mechanical Equipment

(i) Use protective guards on rotating equipment,
(ii) Don't wear loose clothing around rotating equipment,
(iii) Keep hands out of energized valves, pumps and other pieces of equipment,
(iv) Clean –up all lubricant and chemicals pills (slippery surfaces cause bad falls).

(c) Open Surface Filter

(i) Use safety devices such as hand rails and ladders,
(ii) Close all openings and replace safety gratings when finished working,
(iii) Know the location of all life preservers and other safety devices.

(d) Valve and Pump Vaults, Sumps, Filter galleries

(i) Be sure that all underground or confined structures are free of hazardous atmospheres (toxic or explosive gases, lack of oxygen)by checking with gas detectors,
(ii) Work in well ventilated structures (use air circulation fans).

12.3.4 Sedimentation

Sedimentation tank, also called settling tank or clarifier, component of a modern system of water supply or wastewater treatment. A sedimentation tank allows suspended particles to settle out of water or wastewater as it flows slowly through the tank, thereby providing some degree of purification. The purpose of sedimentation process is to remove suspended particles so as to reduce load on Filters. If adequate detention time and basin surface area are provided in the sedimentation basins, solids removal efficiencies can be achieved more than 95%. However, it may not always be the cost effective way to remove suspended solids.

In low turbid water sources (less than about 10 NTU) effective coagulation, flocculation and filtration may produce satisfactory filtered water without sedimentation. In this case, coagulation-flocculation process is operated to produce a highly filterable tiny floc, which does not readily settle due to its small size; instead the tiny floc is removed by the filters. There is, however, a practical limitation in applying this concept to higher turbidity conditions. If the filters become overloaded with suspended solids, they will quickly clog and need frequent back washing. This can limit plant production and cause degradation in filtered water quality. Thus, the sedimentation process should be operated from the standpoint of overall plant efficiency. If the source water turbidity is only 3 mg/l, and the jar tests indicate that 0.5 mg/l of coagulant is the most effective dosage, then one cannot expect the sedimentation process to remove a significant fraction of the suspended solids. On the other hand, source water turbidity in excess of 50 mg/l will probably require a high coagulant dosage for efficient solids removal and the suspended particles and alum floc should be removed by sedimentation basin.

12.3.4.1 Sedimentation Basins

The Basin can be divided into four zones viz. Inlet; Settling; Sludge and Outlet zone. The basins may be of the following types:

(a) Rectangular basins,
(b) Circular and square basins,
(c) High Rate Settlers (Tube Settlers),
(d) Solid Contact Units (Up-flow solid-contact clarification and up-flow sludge blanket clarification).

12.3.4.2 Process Actions

In rectangular and circular sedimentation basins, it is generally possible to make a judgment about the performance of the sedimentation process by observing how far the flocs are visible beyond the basin inlet. When sedimentation is working well, the floc will only be visible for short distance. When the sedimentation is poor, the floc will be visible for a long distance beyond the inlet.

In up-flow or solid-contact clarifiers, the depth of the sludge blanket and the density of the blanket are useful monitoring tools. If the sludge blanket is of normal density (measured as milligrams of solids per litre of water) but is very close to the surface, more sludge should be wasted. If the blanket is of unusually light density, the coagulation-flocculation process (chemical dosage) must be adjusted to improve performance.

With any of the sedimentation processes, it is useful to observe the quality of the effluent as it passes over the weir. Flocs coming over at the ends of the basin are indicative of density currents, short circuiting, sludge blankets that are too deep or high flows. The clarity of the outflow is also a reliable indicator of coagulation-flocculation efficiency. Process equipment should be checked regularly to assure adequate performance. Proper operation of sludge removal equipment should be verified each time for its operation, since sludge removal piping systems are subject to clogging. Free flowing sludge can be readily observed if sight glasses are incorporated in the sludge discharge piping. Otherwise, the outlet of the sludge line should be observed during sludge pumping. Frequent clogging of sludge pipe requires increasing frequency of sludge removal equipment and this can be diagnosed by performing sludge solids volume analysis in the laboratory.

12.3.4.3 Sludge Management

12.3.4.3.1 Sludge characteristics

Water treatment sludge is typically alum sludge, with solid concentrations varying from 0.25 to 10% when removed from a basin. In gravity flow sludge removal systems, the solid concentration should be limited to about 3%. If the sludge is to be pumped, solids concentrations should be high as 10% for readily transportation. In horizontal flow sedimentation basins preceded by coagulation and flocculation, over 50% of the floc will settle out in the first third of the basin length. Operationally, this must be considered when establishing the frequency of the operation of sludge removal equipment.

12.3.4.3.2 Sludge Removal Systems

Sludge which accumulates on the bottom of the sedimentation basins must be removed periodically for the following reasons:

- To prevent interference with the settling process (such as re-suspension of solids due to scouring);
- To prevent the sludge from becoming septic or providing an environment for the growth of microorganisms that create taste and odour problems;
- To prevent excessive reduction in the cross sectional area of the basin (reduction of detention time).

In large scale plants, sludge is normally removed on an intermittent basis with the aid of mechanical sludge removal equipment. However, in smaller plants with low solid loading, manual sludge removal may be more cost effective. In manually cleaned basins, the sludge is allowed to accumulate until it reduces settled water quality. High levels of sludge reduce the detention time and floc carries over to the filters. The basin is then dewatered (drained), most of the sludge is removed by stationary or portable pumps, and the remaining sludge is removed with squeegees and hoses. Basin floors are usually sloped towards a drain to help sludge removal. The frequency of shutdown for cleaning will vary from several months to a year or more, depending on source water quality (amount of suspended matter in the water).

In larger plants, a variety of mechanical devices can be used to remove sludge including:

- Mechanical rakes,
- Drag-chain and flights,
- Travelling bridge.

Circular or square basins are usually equipped with rotating sludge rakes. Basin floors are sloped towards the centre and the sludge rakes progressively push the sludge toward a centre outlet. In rectangular basins, the simplest sludge removal mechanism is the chain and flight system.

12.3.4.3.3 Sludge Disposal

Disposal of waste from the water treatment plants has become increasingly important with the availability of technology and the need for protection of the environment. Treatment of waste solid adds to the cost of construction and operation of treatment plants.

Waste from the Water treatment plants comprise of:

- Sludge from sedimentation of particulate matter in raw water, flocculated and precipitated material resulting from chemical coagulation, or residuals of excess chemical dosages, plankton, etc.,
- Waste from rinsing backwashing of filter media containing debris, chemical precipitates, straining of organic debris and plankton and residual of excess chemical dosages, etc.; and
- Waster from regeneration processes of ion exchange softening treatment plant containing cation of calcium, magnesium and unused sodium and anion of chlorides and sulphates originally present in the regenerate.

12.3.4.3.4 Disposal Method

In continuous sludge removal, the feasibility of discharging of water treatment plant sludge to existing sewer nearby should be considered. For lime softening plant sludge, the reclamation by calcining and reuse can be explored. These sludge from clarification units using irons and aluminium coagulant can be dewatered by vacuum filtration. However the method of waste disposal shall conform to the pollution control norms.

12.3.4.3.5 Reuse of Sludge

A large quantity of sludge is generated each year from water treatment plants in Tanzania. Disposing the sludge to the nearest watercourse is the common practice, especially by many urban water utilities, which accumulatively rise the aluminum concentrations in water and consequently in human bodies. Landfill disposal of the sludge is impractical because of the high cost of transportation and depletes the capacity of the landfill. The use of sludge in construction industry is considered to be the most economic and environmentally sound option. Due to the similar mineralogical composition of clay and water treatment plant sludge, various researchers have studied on the reuse of sludge in clay-brick production as a partial substitute for clay in brick manufacturing. However, concluded that by operating at the temperature commonly practiced in the brick kiln, 50 percent was the optimum sludge addition to produce brick from sludge-clay mixture. The produced bricks properties have proved superior to those available in the market.

(Source: https://www.researchgate.net/publication/295548404_Reuse_of_Water_Treatment_Plant_Sludge_in_Brick_Manufacturing)

12.3.4.4 Start-up and Shutdown Procedures

In the event of requirement for shut down or start-up of processes on account of maintenance or a major equipment failure, proper procedures must be followed as per recommendations of the manufacturer of the plant and equipment. The procedures, in general, are given below:

(a) Start up Procedure

(i) Check operational status, mode of operation of equipment and physical facilities:
- Check that basin valves are closed,
- Check that basin isolation gates are closed,
- Check that launder weir plates are set at equal elevations,
- Check to ensure that all trash, debris and tools have been removed from basin.

(ii) Test sludge removal equipment:
- Check that mechanical equipment is properly lubricated and ready for operation,
- Observe operation of sludge removal equipment.

(iii) Sedimentation basin filled with water:
- Observe proper depth of water in basin,
- Remove floating debris from basin water surface.

(iv) Start sample pumps,

(v) 5) Perform water quality analyses,

(vi) Operate sludge removal equipment. Be sure that all valves are in the proper position & operational.

(b) Shut down Procedures

- (i) Stop flow to sedimentation basin. Install basin isolation gates,
- (ii) Turn off sample pump,
- (iii) Turn off sludge removal equipment,
- (iv) Shut off mechanical equipment and disconnect where appropriate,
- (v) Check that valves are in proper position& operational,
- (vi) Lock out electrical switches and equipment,
- (vii) Dewater basin, if necessary;
- (viii) Be sure that the water table is not high enough to float the empty basin.
- (ix) Open basin drain valves,
- (x) Grease and lubricate all gears, sprockets and mechanical moving parts which have been submerged immediately following dewatering to avoid seize up.

12.3.4.5 Equipment

(a) Types of support equipment – Operation and Maintenance

The operator should be thoroughly familiar with the operation and maintenance instructions issued by the manufacturer for each specific equipment *viz*. flow meters and gauges valves control systems; water quality monitors such as turbidity meters; sludge removal equipment; sludge and sump pumps.

Equipment Operation

- (i) Check the following: Proper lubrication and operational status of each unit,
- (ii) Excessive noise and vibration, overheating and leakage,
- (iii) Pumps suction and discharge pressure.

12.3.4.6 Safety Considerations

(a) Electrical Equipment

- (i) Avoid electric shock,
- (ii) Avoid grounding yourself in water or on pipes,
- (iii) Ground all electric tools,
- (iv) Use a lock out and tag system for electric equipment or electrically driven mechanical equipment.

(b) (ii) Mechanical Equipment

- (i) Keep protective guards on rotating equipment,
- (ii) Do not wear loose clothing around rotating equipment,
- (iii) Keep hands out of valves, pumps and other equipment,
- (iv) Clean up all lubricant and sludge spills.

(c) (iii) Open Surface water – filled structures

- (i) Use safety devices such as hand rails and ladders,

(ii) Close all openings,
(iii) Know the location of all life preservers.

(d) Valve and Pump Vaults, Sumps

(i) Be sure all underground or confined structures are free of hazardous atmosphere (Toxic or explosive gases, lack of oxygen),
(ii) Work only in well ventilated structures,
(iii) Take proper steps against flooding.

12.3.4.7 Corrosion Control

All metallic parts which are prone to corrosion must be protected. Corrosion can be controlled to a large extent by applying anti corrosive paints on the steel pipes at the time of construction of the borehole. Non-corrosive casing pipe and strainers (Such as PVC pipes and strainers) can also be used at the time of construction of borehole to avoid corrosion. Some commonly used paints/ coatings to control corrosion are of aluminium, asphalt, red lead and coal tar.

12.3.4.8 Preventive Maintenance

Such programmes are designed to assure the continued satisfactory operation of treatment plant by reducing the frequency of breakdown failures. Typical steps should include:

(a) Keeping electric motors free of dirt and moisture;
(b) Assuring good ventilation at valve and pump vaults, sumps;
(c) Checking pumps and motors for leaks, unusual noise and vibrations, overheating or signs of wear;
(d) Maintaining proper lubrication and oil levels;
(e) Inspecting alignment of shafts and couplings;
(f) Checking bearings for overheating and proper lubrication;
(g) Checking for proper valve operation;
(h) Checking for free flow of sludge in sludge removal collection and discharge systems;
(i) Good housekeeping.

12.3.5 Operation and Maintenance for Defluoridation

Fluoride compounds, usually calcium fluoride, are naturally found, usually in low concentration in water. However, water from underground sources can have higher levels of fluoride to the level that it becomes a health hazard. Defluoridation process is both difficult and expensive, more details and standards can be found in Volume I.

The decision on whether or not to include defluoridation in a water supply scheme considers both number of potential consumers, alternative sources, the financial consequences both in capital and running and whether or not there is a possibility to dilute the water containing the fluoride as a means of reducing the concentration. Defluoridation is necessary when the fluoride concentration is higher than acceptable limits. The methods presented in Volume I may be considered for attaining defluoridised water.

For the absorption method, the following are the procedures:

(a) Check filter against growth of algae (if exposed to sunlight),
(b) Check blocked filter by sedimentation,
(c) Check fluoride saturation,
(d) Check treated water quality (fluoride concentration) once per quarter.

12.4 TERTIARY TREATMENT

12.4.1 Disinfection

Drinking water is disinfected to kill bacteria, viruses and parasites, which may exist in the water and may cause illness and disease like *Campylobacter, Cholera, Amoebic Dysentery, Giardia* (beaver fever) and *Cryptosporidium*. These organisms usually get into drinking water supplies when source of waters such as lakes or streams, community water transmission pipes or storage reservoirs are contaminated by animal waste or human sewage. Generally, deep wells are safer than shallow wells if chemical contamination is absent. In fact, shallow dug wells are often as contaminated as lakes or streams. The disinfection of potable water is almost universally accomplished by the use of gaseous chlorine or chlorine compounds. Chlorine is easy to apply, measure and control. It persists reasonably well and it is relatively inexpensive. Other methods of disinfection are also available viz. ozone, ultra-violet light, chlorine dioxide, silver ionization.

12.4.2 Chlorination

The primary objectives of the chlorination process are disinfection, taste and odour control in the system, preventing the growth of algae and other micro-organisms that might interfere with coagulation and flocculation, keeping filter media free of slime growths and mud balls and preventing possible built up of anaerobic bacteria in the filter media, destroying hydrogen sulphide and controlling sulphurous taste and odour in the finished water, removing iron and manganese, bleaching of organic colour.

Dosage: Effective chlorine dose should be such that sufficient chlorine is there to react with organic matter, ammonia, iron, manganese and other reducing substances in water and at the same time leave sufficient chlorine to act as algaecide. Dose required for this purpose may be over 2mg/L Post chlorination dose can be adjusted to obtain minimum 0.2to 0.5 mg/l residual chlorine in potable water at consumer end.

12.4.2.1 Effectiveness of Chlorination

Generally, chlorination without filtration or other pre-treatment is effective and adequate only under the following conditions:

(a) The degree of bacteriological pollution of the water is moderate, reasonably uniform, and not imbedded in suspended solids, for example, within the bodies of worms;
(b) The turbidity and colour of the water do not exceed 5-10 units;
(c) The content of iron or manganese or both do not exceed 0.3 mg/L; and
(d) Taste- or odour-producing substances are absent or do not require chlorine doses that inevitably produce a chlorine taste in the treated water.

There is a contact period of at least 20 minutes between the point of chlorination and the first service connection supplied with the water. In cases where water is pumped directly from the source (e.g. well) into the distribution system, chlorine may be applied.

12.4.2.2 Chlorination Guideline

(a) Chlorine solutions lose strength while standing or when exposed to air or sunlight. Make fresh solutions frequently to maintain the necessary residual.
(b) Maintain a free chlorine residual of 0.3 mg/l after 30 minutes contact time. Residual chlorine should be measured every day.
(c) Once the chlorine dosage is increased to meet greater demand, do not decrease it unless the raw water quality improves.
(d) When there is a risk of cholera or an outbreak has already occurred, maintain the chlorine residuals as follows:
    (i) Distribution system: 0.5 mg/l
    (ii) Tanker trucks at filling point: 2 mg/l

12.4.2.3 Chlorination Methods

Disinfection is carried out by applying chlorine or chlorine compounds. The methods of application are as follows:

(a) Preparing weak solution by bleaching powder,
(b) Preparing weak solution by electrolysing brine solution,
(c) By adding chlorine either in the form of gas or solution prepared from dissolving chlorine gas in small feed of water.

12.4.3 Disinfection by Bleaching Powder

Bleaching powder or calcium hypochlorite is a chlorinated lime, which contains about 25 to 34% of available chlorine by weight. Chlorine being a gas is unstable and as such it is mixed with lime to retain its strength for a longer period, as far as possible. The bleaching powder is hygroscopic in nature. It loses its chlorine strength rapidly due to poor storage and hence should not be stored for more than three months. The method of chlorination by bleaching powder is known as hypo-chlorination. The combined action of hypochlorous acid and hypochlorite ion brings about the disinfection of water.

12.4.3.1 Preparation of Solution

The concentrated solution of bleaching powder is prepared in one or two tanks of capacity suitable for 24 hours requirement. The tank inside should be of glazed tiles or stoneware and should be covered. The tank should be under shade and not direct to sunlight.

(a) The powder is first put on a perforated slab placed longitudinally inside the tank at a higher level, with respect to bed level of tank;
(b) Water is sprinkled on the powder through a perforated pipe above this perforated slab;
(c) The solution of bleaching powder and water now enters the tank. The solution is rotated for thorough mixing of powder with water by a hand driven/motor reduction gear operated slow speed stirrer is now ready for use as disinfectant;
(d) The precipitates of calcium hydroxide settle at the bottom of the tank. The supernatant water, which contains OCl, Cl^- plays important role in disinfection;
(e) For effectiveness of chlorination, contact period of at least 4 hours should be maintained.

12.4.3.2 Dosing of Solution

The solution is discharged to a small measuring tank at a lower level through PVC pipe or any other material resistant to chlorine. The level of water in this tank is maintained constant through a float valve. The solution is dosed to the clear water channel by gravity at the time of entry to clear water reservoir. The dose has to be monitored properly, depending on the desired residual chlorine required in clear water reservoir. The waste precipitates at the bottom of tanks are taken out occasionally by scour valve.

12.4.3.3 Safety precautions

(a) The operating personnel should use hand gloves, aprons and other protective apparel, while handling and mixing;
(b) The valves, stirrer, tanks, plumbing arrangements require renovation at every 6 months or so.

12.4.4 Chlorination by Gaseous Chlorine

Elemental chlorine at a normal pressure is a toxic, yellow green gas, and is liquid at high pressure. Chlorine gas is released from a liquid chlorine cylinder by a pressure reducing and flow control valve operating at a pressure less than atmospheric pressure. The gas is injected in the water supply pipe where highly pressurized water is passed through a venture creating a vacuum that draws the chlorine in to the water stream. Adequate mixing and contact time must be provided after injection to ensure complete disinfection of pathogens. It may be necessary to control the water pH. A basic system consists of chlorine cylinder mounted with vacuum regulator, chlorine gas injectors, and a contact tank or pipe. Prudence or state regulation would require that a second cylinder and gas regulator be provided with a changeover valve to ensure continuity of disinfection. Additional safety and control system may be required.

Chlorine is very effective for removing almost all pathogen and is appropriate for both a primary and secondary disinfectant. The limitation with this is it is dangerous gas that is lethal at concentrations as low as 0.1 per cent air by volume.

12.4.4.1 Working Safely around Chlorine Gas

Any water utility that uses chlorine should have written procedures for its chlorine system operation. Even the use of powdered chlorine should have written procedures.

Before starting any chlorination process, the following precautions should be taken:

(a) If a faucet with good flowing water is not available close by, make ready a 5- gallon container of fresh water, but make sure it is away from the chlorine cylinder or storage area. This is to ensure that if the chlorine accidentally comes in contact with your eyes or skin, you can flush the affected areas with copious amounts of fresh water for at least 10-15 minutes,

(b) Flush the chlorine out. Do not just soak the affected surface. If you get some of the chlorine solution in your eyes, flush it out and immediately see your doctor,

(c) Wear the prescribed safety clothing and equipment, specifically:
   - (i) Goggles to protect your eyes from contact with the chlorine in any form,
   - (ii) Rubber gloves and rubber boots certified for use around the chemical to protect your hands and feet,
   - (iii) Waterproof suit, coveralls or a full-length apron.

12.4.4.2 Housekeeping/Chlorine Storage

(a) Use signs to clearly identify all areas where chlorine is used or stored. Only qualified personnel should be permitted to enter these areas,

(b) Do not store materials that may react violently with chlorine in the same room as chlorine. Put up visible warning signs prohibiting persons from taking these materials where the chlorine is stored,

(c) Do not store chlorine near busy roadways or where vehicles operate. Chlorine reacts with carbon monoxide to produce phosgene, an extremely poisonous gas,

(d) Store chlorine cylinders and containers in a cool, dry, and relatively isolated area, protected from weather and extreme temperatures:
   - (i) When storing cylinders and containers outside, shield them from direct sunlight,

(ii) When storing chlorine containers inside, store the containers in a well-ventilated building, away from any heat sources.

(e) Use cylinders and containers on a “First-In, First-Out” basis,

(f) Clearly tag or mark empty cylinders and separate them from full cylinders,

(g) Determine the most appropriate location for emergency equipment. Emergency equipment and a faucet should be available in a readily accessible location, but not inside the chlorine room because a worker (and emergency response staff) trying to use the emergency equipment or faucet during a chlorine leak risks further exposure,

(h) Store cylinders upright and secure them against tipping over and rough handling. Cylinders will discharge vapour when upright and discharge liquid when upside-down. Since chlorine gas tends to sink, provision should be made for low-placed ventilation near the floor that allows it to dissipate outward, as well as high-placed ventilation that allows the chlorine mist (the gas mixed with air) which tends to go upward, also to dissipate.

12.4.4.3 Handling Chlorine Cylinders

(a) Handle containers with care while moving or storing them. Do not drop or allow containers to strike objects,

(b) Use new gaskets as recommended by the chlorine supplier each time a cylinder or container is connected,

(c) Follow the chlorine supplier’s recommended disposal procedures for leaking containers. Do not modify, alter, or repair containers and valves. Only the supplier should carry out these tasks,

(d) Ensure that cylinders have valve protection hoods in place when not connected to a system,

(e) Do not lift a cylinder by its valve protection hood. The hood is not designed to carry the weight of a cylinder,

(f) If possible, open valves by applying a steady force to a 200 mm (8 in) wrench, without applying an impact force and without using an extension on the wrench. If this does not work, apply a light impact force by smacking the wrench with the heel of your hand,

(g) Do not use a wrench longer than 200 mm (8 in) to open or close valves. To prevent valve damage that could cause leaks do not use tools such as pipe wrenches or hammers. Valves on cylinders are designed to deliver full volume after one complete counter clockwise turn. Valves may be damaged if turned beyond this point. Immediately return containers with damaged or inoperable (but not leaking) valves to the supplier,

(h) If the valve is very difficult to open, loosen the packing nut slightly. Tighten the packing nut after the valve is opened or closed.

(Source: https://www.slideshare.net/esmeraldoerandio/rural-water-supply-volume-iii-operation-and-maintenance-manual-PHILLIPINES)

12.4.5 Electro-chlorinator

Chlorine is instantly produced by electrolyzing brine solution. Common salt is mixed with water to prepare brine solution. This solution is passed through an Electrolyser of electrodes comprising of anodes and cathodes, which are energised by D.C. current to produce NaOCl. This solution of sodium hypo chlorite is used as disinfectant. Basically, the electro chlorinator set comprises of two compartments; one comprising of brine solution tank, electrolyser, cooler, etc. and the other comprising of compact panel board (rectifier). Normal life of electro chlorinator is 12 years provided reconditioning of the electrodes at regular interval of four years is carried out.

12.4.6 Other Disinfectants

The other chemical based disinfectants generally in use are ionized silver coating, gaseous chlorine, ozone, chloramine, potassium permanganate and hydrogen peroxide. Alternatives to chemical disinfection, such as UV irradiation, are also being used for disinfection of drinking water.

12.4.7 Ozonation

Ozone is very strong oxidiser and powerful disinfecting property. Avery small concentration of ozone in water makes it free from bacteria, virus and pathogen much faster and with lesser concentration in a most effective manner. Ozone, an allotrope of oxygen having three atoms to each molecule, is a powerful oxidizing and disinfecting agent. It is formed by passing dry air through a system of high voltage electrodes. The major elements of an ozonation system are:

(a) Air preparation of oxygen feed,
(b) Electrical power supply,
(c) Ozone generation usually using a corona discharge cell consisting of two electrodes,
(d) Ozone context chamber, and
(e) Ozone exhausts gas destruction.

Advantages of ozonation system is that it requires shorter contact time and doses than chlorine, ozone does not directly produce halogenated organic materials unless a bromide ion is present. Limitations of ozonation system, ozone gas is unstable and must be generated onsite. A secondary disinfectant, usually chlorine, is required because ozone does not maintain an adequate residual in water.

12.4.8 Operation and Maintenance for Ultra-filtration, Micro filtration and Nano filtration

Basically, ultrafiltration and microfiltration are the protection mechanism of nanofiltration and these should precede Nano filtration, for more details refer Volume I. Because application of membrane filtration technology is still rare in Tanzania at the moment, the current edition of the manual refers designers to the manufacturers of membrane filters for all design specifications sample websites of the manufacturers are provided at the end of this DCOM Manual .

Chapter 13

TREATMENT FOR SPECIAL WATER SOURCES

Algae, arsenic, cyanobacteria, fluoride and natural organic matters are among water quality parameters that require special treatment to ensure the water produced meet the recommended conditions. Also, because iron as Fe^{2+} is found in some groundwater, its Operational and Maintenance for iron removal plants (IRPs) is presented in this chapter.

13.1 ALGAL CONTROL

Algae are unicellular or multi-cellular chlorophyll bearing plants without any true root, stem or leaves. They may be microscopic unicellular colonial or dense mat-forming filamentous forms commonly inhabiting surface waters. Their growth is influenced by a number of factors, such as mineral nutrients, availability of sunlight, temperature and type of reservoir. During certain climatic conditions, there is an algal bloom which creates acute problems in treatment processes and production of potable water. The algae commonly encountered in water purification plants are diatoms, green algae, and blue green algae and algal flagellates. Algae may be seen floating (plankton) in the form of blooms. The problems caused by algae are as follows:

(a) Many species of algae produce objectionable taste and odour due to characteristic coil secretions. These also impart colour ranging from yellow-green to green, blue-green, red or brown;
(b) Profuse growth of algae interferes with chemical treatment of raw water by changing water PH and its hardness;
(c) Some algae act as inhibitors in process of coagulation carried out for water purification;
(d) Some algae clog filters and reduce filter run;
(e) Some algae produce toxin sand their growth in drinking water reservoirs is harmful for humans and livestock;
(f) Some algae provide shelter to a large number of bacteria, some of which may be pathogenic;
(g) Some algae corrode metal tanks, forming pits in their walls;
(h) Algae may also cause complete disintegration of concrete in contact with them;

(i) Prolific growth of algae increases organic content of water, which is an important factor for the development of other organisms.

13.1.1 Remedial Measures

(a) Preventive Measures

Preventive measures should, therefore, be based on control of those factors such as:

(i) Reduction of food supply,
(ii) Change of the environment or exclusion of sunlight though they are not always practicable,
(iii) Clear water reservoir, service reservoir s and wells may be covered to exclude sunlight, but such a remedy is obviously inapplicable in the case of large reservoir of raw water,
(iv) Turbid water prevents large penetration and thereby reduces algal population,
(v) Activated carbon reduces algal population by excluding sunlight but disappearance of activated carbon in the raw water may support algal growth again.

(b) Control Measures

Adequate records of number, kind and location of algae becomes handy for algal growth control. Algaecide dose used should be harmless to humans, have no effect on water quality, should be inexpensive and readily available and easy to apply. The most commonly used algaecides are copper, sulphate and chlorine/ bleaching powder.

Pre-Chlorination

Chlorine treatment is relatively cheap, readily available and provides prolonged disinfecting action. Though chlorine is generally used for disinfecting potable water it can also be used as an algaecide. Pre-chlorination has specific toxic effect and it causes death and disintegration of some of the algae. It also assists in removal of algae by coagulation and sedimentation. It prevents growth of algae on basin walls and destroys slime organisms on filter sand thus prolonging filter and facilitating filter washing.

Dosage: Effective chlorine dose should be such that sufficient chlorine is there to react with organic matter, ammonia, iron, manganese and other reducing substances in water and at the same time leave sufficient chlorine to act as algaecide. Dose required for this purpose may be over 5 mg/L. With chlorine treatment essential oils present in algae as well as organic matter of dead algae are liberated this may lead to development of odour and colour and taste. In such cases break point - chlorination is required. Post chlorination dose can be adjusted to obtain minimum 0.2 mg/ L residual chlorine in potable water at consumer end.

Method of Application: Chlorine is preferably applied as a strong solution of chlorine from chlorinator. Slurry of bleaching powder can also be used. For algal growth control, generally, chlorine is administered at the entry of raw water before coagulant feeder.

13.2 IRON REMOVAL PLANTS (IRPS)

Two types of such plants are described below:

13.2.1 Compact Plant

The process involves spray aeration through a grid of pipes to flush out CO2, H2S and to improve pH level. Trickling of aerated water through a contact catalytic media *viz.,* limestone of 20 mm size or a combination of MnO2 (Manganese dioxide) and lime; or hard coke, MnO2 and limestone. The relevant processes are:

(a) Sedimentation,
(b) Filtration through rapid gravity filter,
(c) Disinfection.

The structure consists of ordinary masonry or concrete. The aerator with contact media may be placed at the top of the sedimentation tank. Sedimentation tank may be rectangular with a length to breadth ratio of 3:1. The detention time may be around 3-5 hours. The surface loading may be around 25 $m^3/day/m^2$. Filter media shall consist of sand with effective size 0.5-0.7 mm and a depth of 750-1,000 mm over a 450-600 mm deep gravel 3 to 50 mm size.

13.2.1.1 Operation and Maintenance

The nozzles/orifices attached to the aeration pipe grid shall have their angles so adjusted as to ensure maximum aeration and to prevent loss of water. These nozzles/orifices shall require regular manual cleaning to remove incrusted iron.

(a) The residual iron deposits from inside the pipe grid shall be flushed out by opening end plugs or flanges. These operations should be repeated at least once in 2 months,
(b) The limestone and other contact media require manual cleaning and washing at least once in 45-60 days,
(c) The contact media bed should not remain exposed to sun for a long time to prevent hardening of bed by iron incrustation,
(d) The sedimentation tank inlet baffle wall opening shall be cleaned of iron slime at least once in 45-60 days,
(e) Sedimentation tank bed should be regularly scoured for removal of sludge,

(f) Floc forming aid (coagulant aid) may be used for better coalescing and agglomeration,
(g) The rapid gravity filter should have a water depth of about 1.2-1.5 m,
(h) Since iron deposits create incrustation of filtering media, at least 100-150 mm of tops and layer of sand shall be scrapped and replenished with fresh sand at least once on 60 days. The whole bed may require replacement once in 2 years or so,
(i) The characteristics of iron flocs are different from those of surface (river) water flocs. Due to the aeration process and contact of water with air, there may be incrustation of filter bed by residual oxidized deposits. To avoid this, common salt may be mixed with standing water and after 1-2 hours, the filter may be backwashed for better results and longevity of sand bed.

13.3 PACKAGE TYPE IRON REMOVAL PLANT (IRP)

The process incorporates the following steps:

(a) Dosing of sodium aluminates solution to the raw water pumping line, to raise pH up to the optimum level and to ensure subsequent coagulation, as it is an alkaline salt,
(b) Injection of compressed air for oxidation of dissolved iron,
(c) Thorough mixing of raw water, sodium aluminates and compressed air for proper dispersion in a mixing chamber of mild steel (MS) welded cylindrical shell equipped with one MS perforated plate fitted inside through which the mixture flows upward,
(d) Passing the mixture through an oxidation chamber of MS shell, in which a catalytically media of MnO_2 (Manganese dioxide) is sandwiched between two MS perforated circular plates. (Through which the mixture flows),
(e) Passing the above mixture in to a MS welded cylindrical shell type of filter in which dual media comprising of Anthracite Coal or high graded bituminous coal, 3-6 mm size, is placed at the top and finer sand of 0.5-1.00 mm size with 98% silica content is placed at the bottom, over a gravel supported bed. At the bottom is the under drainage system. Backwashing is done by air agitation followed by backwash with water,
(f) Disinfection.

Operation and Maintenance

(a) Sodium aluminate should be so mixed as to raise the pH up to 8.5-9.5,
(b) The quantity of compressed air should be so regulated as to achieve the optimum oxygen level,
(c) The MnO_2 (Manganese dioxide) may need replacement every 6-9 months,
(d) The inside of both the mixing chamber and oxidizing chamber should be coated with epoxy resin to avoid corrosion and incursion,
(e) The filtration rate should be controlled within a range of 100-125 lpm /m^2,

(f) The inlet pipe at the top should be fitted with a cylindrical strainer to obviate the possibility of loss of anthracite coal during washing,

(g) After backwashing, rinsing of filtering media for at least 5 minutes has to be done to resettle the filtering media before normal functioning.

Where the iron content is very high the whole media like MnO2 (Manganese dioxide), anthracite coal, sand, gravel, strainers etc. require replacement and replenishment at least once a year for effective functioning and performance. The interior epoxy painting should also be done simultaneously.

Resources for O and M of Iron Removal Plant

(a) Unskilled labour required for re-sanding. Semi-skilled labour (caretakers) is required for plant operation. Skilled labour (supervising manger) is required for supervision,

(b) Materials and equipment include sand, basic tools, valve replacement and spares, flow indicator, turbidity apparatus, bacteriological testing equipment,

(c) Finances would typically be from the water organization revenue,

(d) The most widely used IRP in the rural area for removing excess iron from drinking water source is based on oxidation, sedimentation and filtration,

(e) Specific Treatment Technologies.

13.4 BRACKISHNESS REMOVAL PLANT

Membrane based desalination plants are mostly known as Reverse Osmosis (RO) plants. The RO design plant technology is dependent on parameters the manufacturer wants to address in a given area.

Based on the above process each of the manufacturers has designed the treatment units with variable components and design parameters. It is important that O&M manual is obtained from the manufacturer and a guide booklet for field level operators prepared with simple language for their easy understanding. In all such treatment plants the telephone number of the operator should be painted on the building/machinery for contacting them during breakdowns.

Common operational problems of reverse osmosis include fouling of the membrane if they are not sufficiently protected by the unit operations that are located upstream. It is not uncommon to have either ultrafiltration or microfiltration units upstream of reverse osmosis.

Chapter 14

DRINKING WATER AND WASTEWATER QUALITY MONITORING, SURVEILLANCE AND COMPLIANCE

Drinking water quality monitoring and surveillance of a water supply schemes entails the continuous monitoring of public health along with vigilant assessment and control of safe potable water supply. The Ministry of Water has developed a National Guidelines on Drinking Water Quality Monitoring and Reporting of 2018 which will be reviewed from time to time. The guideline which may be downloaded from the Ministerial website (https://www.maji.go.tz/pages/guidelines) provides systematic steps to be considered during undertaking of water quality monitoring from the catchment/source throughout the water supply system up to the consumer. Also, the quality of portable water has to meet the latest edition of TBS Standards.

14.1 IMPORTANCE OF GOOD WATER QUALITY

Safe potable water is the first step to promote good health of the community. Experience has shown that community health and water quality are directly related to each other and an improvement of drinking water quality is followed by an improvement in the community's health. Human activities; rapid industrialization and agrochemical contamination increasingly affect the quality of water resources. Moreover, infant mortality, mostly from diarrheal and other water borne and water related diseases are of great concern. In spite of the significant achievements in improvement of water supply and sanitation services, many factors render good quality water unsafe by the time it reaches the consumers. Poor operation management and unsatisfactory sanitary practices are the major key areas responsible for water contamination. Water quality management and surveillance practices ensure safe water supply to the consumers.

14.2 DEFINITIONS

While describing water quality, certain terms are frequently used, which are to be clearly understood and correctly used. Some of the definitions are given below:

(a) Pollution - is the introduction into water of substances in sufficient quantity to affect the original quality of water, make it objectionable to sight, taste, smell or make it less useful,

(b) Contamination- is the introduction into water of toxic materials, bacteria or other deleterious agents that make the water hazardous and therefore unfit for human use (degradation of water quality),

(c) Potable Water - that is satisfactory for drinking purposes from the standpoint of its chemical, physical and biological characteristics. Palatable Water that is appealing to the sense of taste, sight and smell. Palatable water need not always be potable,

(d) Parts per million (ppm) or milligrams per litre (mg/l) - these terms are used to express the concentrations of dissolved or suspended matter in water. The parts per million (ppm) is a weight to weight or volume to volume relationship. Except in highly mineralized water, this quantity would be same as milligram per litre. This is preferable, since it indicates how it is determined in the laboratory,

(e) pH of water - is an expression of the Hydrogen ion concentration. Alkaline water has with pH of above 7 and acidic water has pH of below 7 whereas water with pH 7 is neutral. Physiological effect - having effect on the normal functions of the body. Pathogens disease - producing organisms,

(f) Bacteria - a group of universally distributed, essentially unicellular micro-organisms lacking chlorophyll,

(g) Virus - the smallest form capable of producing infection and diseases in human beings,

(h) Coliform Bacteria - group of bacteria predominantly inhabiting the intestine of human beings and animals, but also occasionally found elsewhere. Used to indicate presence of faecal-pollution,

(i) Enteric - having its normal habitat in the intestinal tract of human beings or animals,

(j) Chlorine Residual - chlorine remaining in the water at the end of a specified period that is not combined with other chemicals and is available to disinfect any additional contaminants introduced to the water,

(k) Chlorine Demand - the difference between the amounts of chlorine added to water and amount of residual chlorine remaining in the water at the end of a specified period.

14.3 WATER SUPPLY AND SURVEILLANCE AGENCIES

A water utility is responsible for maintaining the safety of water supplied to the community from the source to the point of consumption. The main objectives of water quality monitoring are:

(a) To determine the quality of water in its natural state in view of its present and future needs,

(b) To assess the suitability of water for the required use,

(c) To find out the pathways for pollution, if any.

Operational and Regulatory Monitoring of water quality involves field and laboratory testing of water samples collected from various points in the water supply system, including the source, water purification plants, service reservoirs distribution systems and consumer end. Continuous water quality monitoring involves good operating practices and preventive maintenance, as well as the regular routine testing and monitoring of water quality to ensure compliance with standards.

Surveillance is an investigative activity undertaken by a separate agency, to identify and evaluate factors posing a health risk to drinking water. Surveillance requires a systematic programme of surveys that combine water analysis and sanitary inspection of institutional and community aspects, and reporting system. Sanitary inspection of water supply system should cover the whole system including water sources, rising mains, treatment plants, storage reservoirs, and distribution systems; to identify the most common risks and shortcomings in the water supply. Moreover, surveillance is concerned with all sources of water used for domestic purpose by the population, whether supplied by a water supply utility/agency or collected from other individual sources. So it is important to inspect and analyse all sources of water used and intended to be used for human consumption. Surveillance agency should communicate to the water supply utility/agency and pinpoint the risk areas and give advice for remedial action. It should also maintain good communication and co-operation with water supply utility/agency for detection of risk areas and remedial action for betterment of the water supply.

14.3.1 Planning and Implementation

Systematic planning, keeping in view the fundamental objectives, is necessary for successful implementation of drinking water quality control programme.

14.3.2 General Considerations and Strategies

Quality control activities should be initiated as per the norms of national and international guidelines for laboratory analysis. Surveillance agency should carry out periodic surveillance of all aspects of water quality safety including sanitary inspection and spot checks and result should be reported to the concerned water supply organization to implement remedial action when and where necessary.

Water supply surveillance can be planned in a progressive manner considering the availability of resources. It should start with a basic programme, which could generate useful data to plan advanced surveillance as resources, and conditions permit. The initial pilot scale programme should cover minimum basic strategies including fewer water quality parameters that provide a reasonable degree of public health protection and should be widely applicable. Careful planning of training and resource provision is very essential right from the beginning.

14.3.3 Surveillance Programme

Principally, surveillance activities are similar but the actual extent may differ between urban and rural communities; and according to the types of water supply. They should be adapted to local conditions; availability of local finances, infrastructure and knowledge. Water supply provider and surveillance agencies, depending on resources available with them, will develop the programme for monitoring and surveillance of drinking water quality. Following factors should be taken into consideration while implementing of surveillance activities:

(a) The type and size of the water supply systems,
(b) The existing and available equipment,
(c) Local employment practices and the level of training,
(d) Opportunities for community participation,
(e) Accessibility of systems keeping in view of geographical and climatic conditions,
(f) Communication and transport facilities available.

14.3.4 Information Management

The flow of information between and within the water supply and surveillance agencies is necessary to maximize the quality of service to the consumer and protection of public health. The report provided by the surveillance agency to water supply providers may include but not be limited to:

(a) The summary reports of condition of water supply and water quality analysis,
(b) Highlight those aspects, which are considered inadequate to sustain the safety of water and needs urgent action,
(c) Recommendation of remedial action in case of emergency.

14.3.5 Community Based Monitoring and Surveillance

Community participation is an essential component of the monitoring and surveillance framework. As the primary beneficiaries, community can play an important role in surveillance activity. They are the people who may first notice the problems in water supply system and report it to the concerned water supply utility/agency or take remedial action if possible. Establishing a genuine partnership with the community creates a climate of trust and understanding, which generates interest and enthusiasm. It also provides a good foundation for other educational activities such as promotion of good hygiene practices.

Health department or water supply utility/agency should help in providing necessary training while community water committee or health committee can supervise the work. The community participation includes:

(a) Assisting field workers in water sample collection, including sample location points, existing damaged networks, causing/likely to cause contamination of drinking water,
(b) Assisting in data collection,
(c) Monitoring water quantity, quality, and reporting findings to surveillance staff regularly,
(d) Ensuring proper use of water supply,

(e) Setting priorities for sanitation and hygiene and educate community members,
(f) Undertake simple maintenance and repair work. Refer problems which require special attention to the water utility,
(g) Disseminate results and explain the implications with respect to health with the objective to stimulate involvement in actions to keep water clean, safe and wholesome.

14.3.6 Surveillance Action

Surveillance action comprises of:

(a) Investigative action to identify and evaluate all possible factors associated with drinking water, which could pose a risk to human health,
(b) Ensure preventive action to be taken to prevent public health problem,
(c) Data analysis and evaluation of the surveys,
(d) Reporting to the concerned authorities the outcome.

14.3.7 Sanitary Survey

Sanitary survey is a periodic audit of all aspects of all the water supply system. Systematic programme of sanitary surveys includes sanitary inspection, water quality analysis, and evaluation of data and reporting.

Sanitary Inspection Report

The sanitary inspection report shall cover the following:

(a) Identify potential sources and points of contamination of the water supply,
(b) Quantify the hazards attributed to the source and supply,
(c) Provide a clear, graphical means of explaining the hazards to the operator/ user,
(d) Provide clear recommendations for taking remedial actions, to protect and improve the supply,
(e) Provide basic data for use in systematic, strategic planning for improvement
(h) Moreover, inspection reports should not be restricted to water quality but should take in to account other service condition such as coverage, cost, condition and quantity.

Such surveys are important from the point of view of operation and maintenance.

14.4 WASTEWATER QUALITY MONITORING

Systematic planning as well as keeping in view the fundamental objectives is necessary for successful implementation of wastewater effluent discharges quality control programme.

14.4.1 General Considerations and Strategies

Quality control activities should be initiated as per the norms of national standards and international guidelines for laboratory analysis. Surveillance agency should carry out periodic surveillance of all aspects of wastewater effluent quality discharges including sanitary inspection and spot checks and results should be reported to the concerned utility as well as the regulator to implement remedial action when and where necessary.

Wastewater effluent surveillance can be planned in a progressive manner considering the availability of resources. It should start with a basic programme, which could generate useful data to plan advanced surveillance as resources, and conditions permit. The wastewater effluent quality discharges should comply with the latest edition of Tanzania Standards, TZS 860, Limits for Municipal and Industrial Wastewaters. The standards prescribe the permissible limits for municipal and industrial effluents discharged directly into water bodies (i.e. receiving water bodies) (EWURA, 2014).

The initial pilot surveillance scale programme should cover minimum basic strategies including fewer wastewater effluent quality parameters that provide a reasonable degree of public health protection and should be widely applicable. Careful planning of training and resource provision is very essential right from the beginning.

14.4.2 Monitoring Programme

Principally, monitoring activities should be adapted to local conditions; availability of local finances, infrastructure and knowledge. WSSA/Agency responsible for wastewater/sanitation management and Surveillance agencies (e.g. EWURA or RUWASA), depending on resources available with them, will develop the programme for monitoring and surveillance of wastewater effluent discharges quality. The following factors should be taken into consideration while implementing of wastewater quality surveillance activities:

(a) The type and size of the wastewater /sanitation systems,
(b) The existing and available equipment,
(c) Local employment practices and the level of training,
(d) Opportunities for community participation,
(e) Accessibility of systems keeping in view the geographical and climatic conditions,
(f) Communication and transport facilities availability.

14.4.2.1 Wastewater Quality Monitoring Parameters

The selection of parameters that constitute the wastewater quality monitoring programme is to be made on the basis of the latest edition of Tanzania Bureau of Standards: TZS 860. The parameters proposed for regular check monitoring by the Water Supply and Sanitation Authorities (WSSAs)/RUWASA/other agencies should be those required by the latest edition of EWURA water and wastewater quality monitoring guidelines:

(a) Ammonium,
(b) Biological Oxygen Demand (BOD),
(c) Chemical Oxygen Demand (COD),
(d) Colour,
(e) Faecal Coliforms,
(f) Nitrate,
(g) pH,
(h) Phosphorus,
(i) Total Coliforms,
(j) Total Suspended Solids (TSS).

The above list of parameters subjected to regular monitoring could be expanded (to include some metals) to take into account the nature of the quality of wastewater collected from industrial, commercial or residential establishments by the sewerage network or brought to the wastewater treatment plants by vacuum trucks. Chemical parameters should be added to the list for monitoring in consultation with Energy and Water Utilities Regulatory Authority (EWURA) or RUWASA or Basin Water Boards and the National Environment Management Council (NEMC).

14.4.2.2 Audit Monitoring

The Audit Monitoring is to provide information necessary to determine whether or not all the parametric values specified in the latest edition of TZS 860. Limits for Municipal and Industrial Wastewaters are being complied with.

The selection of parameters that constitute the Audit Monitoring is to be made on the basis of the latest edition of TBS Standards TZS 860. All such parameters must be subjected to audit monitoring, unless it can be established that the nature of the wastewater coming from the sewered area are not expected to contain some of the parameters to be excluded.

EWURA or RUWASA or any outsourced Agency will carry out monitoring as an external auditor and WSSAs/UWSSAs will conduct monitoring as an internal auditor.

14.4.2.3 Sampling Locations and Sampling Frequency

Since the effluent standards apply to Municipal, WSSAs, Utility and Industrial effluents discharged directly into water bodies, it implies that sampling locations should be points at which the effluent leaves the wastewater treatment plants just before it enters the receiving water bodies. Sampling locations and sampling frequency should be those required by the latest edition of EWURA water and wastewater quality monitoring guidelines.

14.4.3 Information Management

The flow of information between and within the WSSA/Agency responsible for sanitation management and surveillance agencies (i.e. EWURA or RUWASA & NEMC) is necessary to maximize the quality of service to the consumer and protection of public health. The report provided by the surveillance agency to wastewater management may include but not be limited to:

(a) The summary reports of condition of wastewater and effluent or faecal sludge quality analysis,
(b) Highlight those aspects, which are considered inadequate to sustain the quality of wastewater/sludge and needs urgent action,
(c) Recommendation of remedial action in case of emergency.

14.4.4 Community Based Wastewater Quality Monitoring and Surveillance

Community participation is an essential component of the Wastewater quality monitoring and surveillance framework. As the primary beneficiaries, community can play an important role in wastewater surveillance activity. They are the people who may first notice the problems in wastewater / sanitation projects and report it to the concerned WSSA/Utility/agency or take remedial action if possible. Establishing a genuine partnership with the community creates a climate of trust and understanding, which generates interest and enthusiasm. It also provides a good foundation for other community educational activities such as promotion of good hygiene practices.

The health department or WSSA/Utility responsible for wastewater/ sanitation should help in providing necessary training while CBWSO or the community health committee can supervise the work. The community participation includes:

(a) Assisting field workers in effluent/discharges sample collection, including sample location points, existing damaged sewers or treatment plants, causing/likely to cause contamination of the environment,
(b) Assisting in data collection,
(c) Monitoring wastewater effluent/discharges quantity, quality, and reporting findings to surveillance staff regularly,
(d) Ensuring proper disposal of effluent /discharges and sludge,
(e) Setting priorities for sanitation and hygiene and educate community members,
(f) Undertake simple maintenance and repair work. Refer problems which require special attention to the WSSA/Utility or regulatory agency,
(g) Disseminate results and explain the implications with respect to health with the objective to stimulate involvement in actions to keep environment clean, safe and wholesome.

14.4.5 Wastewater Quality Monitoring Surveillance Action

Surveillance action comprises of:

(a) Investigative action to identify and evaluate all possible factors associated with wastewater effluent discharges and sludge disposal, which could pose a risk to human health and environment in general,
(b) Ensure preventive action to be taken to prevent public health problem,
(c) Data analysis and evaluation of the surveys,
(d) Reporting to the concerned authorities or the regulator the outcome.

14.4.6 Wastewater Effluent Quality Survey

Wastewater effluent quality survey is a periodic audit of all aspects of all the wastewater and sanitation systems. Systematic programme of surveys includes sanitary inspection, wastewater effluent discharges and faecal sludge quality analysis, and evaluation of data and reporting.

14.4.7 Wastewater Quality Inspection Report

The wastewater quality inspection report should cover the following:

(a) Identify potential sources and points of contamination due to wastewater effluent discharges and sludge,
(b) Quantify the hazards attributed to the ground water sources, water supply network, and storm water,
(c) Provide a clear, graphical means of explaining the hazards to the operator/ user,
(d) Provide clear recommendations for taking remedial actions, to protect and improve the effluent discharges and sludge handling /disposal,
(e) Provide basic data for use in systematic, strategic planning for improvement. Moreover, inspection reports should not be restricted to wastewater effluent/ discharges quality but should take into account other service condition such as coverage, cost, condition and quantity. The wastewater quality surveys are important from the point of view of operation and maintenance.

PART D: OPERATION AND MAINTENANCE OF SANITATION PROJECTS

Chapter 15

OPERATION AND MAINTENANCE OF SANITATION PROJECTS

15.1 OPERATION AND MAINTENANCE REQUIREMENTS FOR SANITATION SYSTEMS

Operation and maintenance (O&M) activities, encompass not only technical issues, but also managerial, social, financial and institutional issues, must be directed towards the elimination or reduction of the major constraints which prevent the achievement of sustainability (Brikke, 2000). Operation and maintenance is a crucial element of sustainability and a frequent cause of failure of sanitation service facilities in the past. Many failures are not caused by technical reasons only, they may also result from poor planning, inadequate cost recovery, or the outreach inadequacies of centralised agencies (DfID, 1998).

Operation and maintenance has been neglected in the past, it has been discussed and introduced after a project completion. This neglect or delay in applying proper operation and maintenance has adversely affected the credibility of the investments made, the functioning of the services, the well-being of rural populations, and the development of further projects. However, the importance of O&M has gained considerable visibility over the past few years, and it appears that policy-makers and project designers are now more conscious of the direct links between improved O&M practices and the sustainability of sanitation services. There is also greater recognition of the need to approach these projects in a comprehensive way, emphasizing not only the design and construction but also post-construction activities (Brikke, 2000).

Design for Operation and Maintenance

The ease of operation and maintenance of a facility is central to its sustainability and must be given careful consideration in design. Some operation and maintenance issues are location-specific, but urban and rural projects differ fundamentally in the complexity of the technologies involved. In rural areas, the concept of Village Level Operation and Maintenance Management (VLOM) is a philosophy which has been gaining favour over the years. The VLOM approach restricts technology choices to those that can be operated and maintained within the community for which the intervention is intended. In urban situations, where supply systems will generally be more complex, the design and technology chosen will shape the long-term operation and maintenance requirements. When designing a sewerage system, the engineer must, for instance, take into account operation and maintenance factors such as the availability of chemicals for treatment, spare parts, and equipment, the reliability of power supplies, and the availability of local skills and capacity to undertake O&M.

The standardization of equipment, parts, designs, construction methods, etc., has many benefits. It makes design simpler as choices are made from a limited range of options. In the short term, this may marginally increase construction costs as the standard designs may not be perfectly suited to the situation. But it requires lower skill levels in the design process, and repetitive construction of the same item improves quality. Operation and maintenance benefits too: Limiting the range of spare parts increases the quantity of each item that is required (i.e. more of a few items rather than less of many). This encourages local manufacture because the limited range reduces start-up costs and the increased quantity improves profitability. Standardization also reduces the number of skills required to install and maintain the piece of equipment, thus increasing the probability of local craftsmen being able to carry out the work.

15.2 COMMUNITY MANAGEMENT FOR OPERATION AND MAINTENANCE

In order to ensure the sustainability of the sanitation and improved sanitation solution, it is necessary to have a community ownership and management approach, making the end-users directly responsible for the operation and maintenance of the installed facilities. Successful operation and maintenance requires following an "owner's manual" prepared by the contractor and engineer at the onset of the planning process. This should spell out a schedule and procedures for maintenance and should also include methods to carry out tasks, such as book-keeping, paying employees, collecting bills (utility management), inspection, replacement of parts, etc., giving an integral framework for operation and maintenance (NETSSAF, 2008).

15.3 CAPACITY BUILDING TO ENSURE PROPER OPERATION AND MAINTENANCE

Households and members of the community need to be informed about the system that has been put in place for a proper operation. When new user-interfaces or management approaches have been introduced, such as Urine Diversion Dehydration Toilets (UDDT) or a new system for composting of kitchen waste, which heavily relies on the correct operation from the user's side, the end-users have to be properly trained to ensure that they will operate the systems correctly.

At district level, communities and their organizations (Community-Based Water Supply Organizations - CBWSOs) that will undertake O&M and/or management of local infrastructure need training on technical matters, accounting and simple financial management, basic contract procedures, and monitoring and reporting. NGOs that will become involved in the programme need similar training, but at a more advanced level, as they are probably going to have to train the participating communities (EAWAG 2005).

Local operators and caretakers need to be trained for the proper operation of the new infrastructure. In this case, hands-on training is desired in order to ensure the full understanding and the awareness of the implications of the new system. Private operators or local engineering companies that will take care of the maintenance of the sanitation systems should be also trained in the type of maintenance activities that have to be carried out periodically.

15.4 ORGANIZING AND PLANNING OPERATION AND MAINTENANCE

Organizing for O&M does not represent a huge task, but it does require a certain level of planning, commitment and monitoring. The aspects to be organized are:

- What: the activity which is to be carried out
- When: the frequency of this activity
- Who: the human resources required for the task
- With what: what are the materials, spare parts, tools and equipment needed

Table 15.1 gives an idea of the type of tools which have to be developed to support the operation and maintenance of the envisaged new sanitation infrastructure. The example relates to the O&M of a septic tank (adapted from Castro, 2009):

Table 15.1: The Operation and Maintenance Requirements of a Septic Tank

Activity	Frequency	Human Resources	Materials & Spare Parts	Tools & Equipment
Cleaning squatting pan/ seat & building	Daily	Household	Water	Brush, water, container
Unblock U-trap when blocked	Occasionally	Household	Water	Flexible brush or other flexible materials
Inspect if entry pipe is still submerged (for aqua privies)	Regularly	Household	Water	Stick
Inspect floor, squatting pan/ seat & U-trap	Monthly	Household		
Repair squalting pan/seat, U-trap or building	Occasionally	Household	Cement, sand, water, nails, local building materials	Bucket or bowl, trowel[6], saw, hammer, knife

Activity	Frequency	Human Resources	Materials & Spare Parts	Tools & Equipment
Control vents	Annually	Household	Rope or wire, screen material, pipe parts	Scissors or wire-cutting tools, pliers, saw
Empty tanks	Every 1 – 5 years	Service crew	Water, fuel, lubricants, etc.	Vacuum tanker (large or mini) or MAPET equipment[7], if possible

(Source: Castro, 2009)

Applicability

Operation and maintenance is required to ensure the sustainability of any project in which a new infrastructure has been put into place.

15.5 OPERATION AND MAINTENANCE REQUIREMENTS FOR SANITATION UNITS

Different sanitation units have different operation and maintenance requirements. This section presents O and M requirements for different sanitation units.

15.5.1 Septic Tank

Operation

The daily discharges made from a property into a septic tank or treatment plant will affect the efficiency of the system. Discharges of disinfectants and strong chemicals will kill bacteria in the tank and hence prevent the decomposition of the solids. It is therefore very important to consider the effects of cleansing products on the bacteria. A simple list is given below to highlight measures that will improve the efficiency of a septic tank:

(a) Discharges of rainwater to the septic tank are not recommended. The turbulence caused by the high flows will disturb solids in the vessel and allow them to be carried out into the ground (causing the soak away to block). Rainwater also causes considerable dilution of the bacterial matter thereby reducing the efficiency of the tank. If possible rainwater should be drained to a surface water drain, stream or separate soak away,

(b) Prevent the discharge of non-degradable matter into the tank, such as nappies, condoms, sanitary towels, etc. that will not decompose. Avoid all discharges of oils and cooking fats, which will congeal inside the tank and will not be digested by the bacteria. Oils entering the tank from washing up can largely be ignored,

(c) Volatile liquids such as petrol, acetone, methylated spirits, paraffin, etc. must never be discharged into the drainage system mainly due to their high flammability,

(d) Chemical discharges including cleaning agents have considerable effects on the bacterial treatment of sewage dependent upon their concentration, quantity and frequency of use. With mild detergents such as washing powders, etc. a minimum dilution factor of 50 parts water to 1 part detergent is recommended. Whilst good personal hygiene should always be maintained, disinfectants, acids, bleaches, chlorine and strong detergents must only be used where absolutely necessary.

Maintenance

Periodically the sludge and scum will build-up to such an extent that it needs removing. The frequency of these sludge removal visits is dependent on the use, size and type of the septic tank. As a general guide older brick or concrete structures (often fitted with rectangular metal covers) will require emptying approximately once every 2 years, whilst fibreglass tanks (often fitted with diamond shaped access covers) or pre-cast concrete cylindrical tanks will need emptying at least every 12 months. A traditional septic tank contains no mechanical parts and should not require any other regular maintenance unless problems occur. It is a good idea when emptying brick / concrete tanks to leave the top layer of sludge within the vessel and to remove the solids from the base of the tank. This allows the bacteria to quickly re-establish when the tank fills again. Modern packaged sewage treatment plants are likely to require more frequent emptying (at least once every 6 months). These systems will also require the servicing of any mechanical parts within the vessel. It is recommended that the manufacturers' advice be sought on the maintenance of these plants. Most large drainage contractors offer a septic tank emptying service and there is a wide range of companies advertising in the classified directories that may also be able to carry out appropriate servicing on packaged sewage treatment plants. In Tanzania, the emptying services are offered by both the municipal or town councils or private providers.

15.5.2 Sewers

Consistent and thorough maintenance of the collection system will enable the system to serve its stated life. Preventive maintenance is talked about, but seldom practiced by some agencies. Decades of neglect, or grossly inadequate maintenance of some systems, are two reasons why wastewater collection systems now require billions of dollars worth of rehabilitation and upgrading over the next 20 years.

Cause of sewer dysfunctions:

(a) Collection systems and service connections were not installed as designed. Problems are caused by faulty construction, poor inspection and low-bid shortcuts,

(b) The pipe joints were made rigid. Earth movement, vibration from traffic, settling of structures and construction disturbance (all occur from time to time) require a flexible pipe material or joint that can maintain tightness. Joints had opened, cracked and/or sheared thus allowing debris and infiltration into the sewer,

(c) Corrosion of sewer pipes and manholes from either the trench bedding and backfill or the wastewater being transported by the collection system was a factor neglected during design. A major cause of corrosion in wastewater collection systems and treatment plants is hydrogen sulphide gas,

(d) Potential damage to pipe joints by plant roots was not known or was neglected during design. Although root intrusion into sewers is age-old, it was assumed that if the joint was watertight, it would be root tight. People did not realize that roots would be attracted by moisture and nutrient vapour unless the joints were vapour tight (which means airtight). Roots can enter a pipe joint or walls microscopically (through extremely small holes or cracks); thus, open or leaking joints are not necessary for root intrusion in collection systems,

(e) Collection system environments are ideal for root growth. In this environment, roots enter, expand and open joints and cracks. Root growth is a principal cause of pipe damage that allows infiltration and exfiltration. This creates a major concern for health and pollution control authorities because of wastewater treatment plant overload and groundwater pollution,

(f) The out of sight, out of mind nature of wastewater collection system. Local taxpayers have invested more money in underground sewers why has this great taxpayer investment been so grossly neglected? Because it is out of sight, and so, out of mind,

(g) Poor records regarding complaints from the public or the date and location of stoppages that had to be cleared can result in an ineffective maintenance programme. Good records, regular analysis of the records, and use of this information can produce a cost-effective preventive maintenance programme.

Operation and maintenance of wastewater collection systems in an emergency basis has been the usual procedure and policy in many communities and districts. Planned operation and preventive maintenance of the collection system has been delayed or omitted, in spite of desires by collection system operators. Municipal officials tend to neglect collection systems as long as complaints are not excessive. To please constituents, officials often demand street and sidewalk repairs to be done by collection system crews, but seldom have they ever demanded preventive work on the collection systems.

Inspection and testing are the techniques used to gather information to develop operation and maintenance programmes to ensure that new and existing wastewater collection systems serve their intended purposes on a continuing basis. Inspection and testing are necessary to do the following:

(a) Identify existing or potential problem areas in the collection system,

(b) Evaluate the seriousness of the detected problems,
(c) Locate the position of problems, and
(d) Provide clear, concise and meaningful reports regarding the observed problems.

Sewer Leakage Control

Leaky sewers have to be considered as potential sources for groundwater contamination in urban areas. Two major purposes of inspecting and testing are to prevent leaks from developing in the wastewater collection system and to identify existing leaks so they can be corrected. The existence of leaks in a wastewater collection system is a serious and often expensive problem. When a sewer is located below under a water table, infiltration can take place and occupy valuable capacity in the sewer and the downstream treatment plant. Sewers located above a water table can ex-filtrate, allowing raw wastewater to pollute the soil and groundwater.

Guidance for manhole inspections and sewer inspections are presented herein. The information provided if employed is a good starting point for an inspection. Manhole inspections should yield a report with the following information at the minimum:

(a) Exact location of the manhole;
(b) Diameter of the clear opening of the manhole;
(c) Condition of the cover and frame, including defects that would allow inflow to enter the system;
(d) Whether cover is subject to ponding or surface runoff;
(e) The potential drainage area tributary to the defects;
(f) Type of material and condition of the chimney corbel cone and walls;
(g) Condition of steps and chimney and frame-chimney joint;
(h) Configuration of the incoming and outgoing lines (including drops); and
(i) Signs of frame-chimney leakage or damage to the frame's seal.

Additionally, the following data can be obtained by entering the manhole and using equipment such as CCTV, portable lamps, mirrors, rulers, and probe rods:

(a) Type of material and condition of apron and trough;
(b) Any observed infiltration sources and the rate of infiltration;
(c) Indications of height of surcharge;
(d) Size and type of all incoming and outgoing lines; and
(e) Depth of flow indications of deposition and the characteristics of flow within all pipes.
(f) The condition of the manhole shaft;
(g) Any leakage in the channel;
(h) Any leakage between the manhole wall and the channel;
(i) Any damage or leakage where pipeline connects to the manhole; and
(j) Any flow obstructions.

Planning is required to define the inspections goals. Inspections are performed to:

(a) Identify maintenance problems,
(b) Determine general sewer conditions,
(c) Identify extraneous flows.

Methods for Controlling Sewer Leaks

Methods for controlling leaks in the sewer collection system can be summarized as follows:

(a) *Chemical grouting:* A soil sealing process which employs a two-part liquid chemical grout that solidifies after curing. The grout is remotely applied under pressure to leaking joints or laterals and small cracks in sewers and manholes to seal the voids within the soil surrounding the exterior of the pipe at the point of leakage,
(b) *CIPP (cured-in-place) lining:* An internal liner is formed by inserting a resin-impregnated felt tube through the manhole into the sewer. The liner is then expanded against the inner wall of the existing pipe and allowed to cure,
(c) *Fold and form liner:* A folded thermoplastic pipe is pulled into place through a manhole and then rounded, using heat, steam and air pressure to conform to the internal diameter of the existing pipe,
(d) *Slip lining:* An access pit is excavated adjacent to an existing sewer and a liner pipe of slightly smaller diameter is slid into the existing pipe to create a continuous, watertight liner between the two manholes,
(e) *Pipe bursting:* An access pit is excavated adjacent to an existing sewer and the pipe is broken outward by means of an expansion tool. A flexible liner pipe of equal or larger diameter is pulled behind the bursting device as a replacement sewer.

It is important to take note that, with exception of the *chemical grouting*, the other methods are more expensive.

Sewer Cleaning

The purpose of sewer cleaning is to remove foreign material from the sewer and generally is undertaken to alleviate one of the following conditions:

(a) Blockages (semisolid obstructions resulting in a virtual cessation of flow). These generally are dealt with on an emergency basis, although the underlying cause can be treated pre-emptively;
(b) Hydraulic capacity. In some cases, sediment, roots, intrusions (connections or other foreign bodies), grease, encrustation and other foreign material restrict the capacity of a sewer, causing surcharge or flooding. Cleaning the sewer may alleviate these problems permanently, or at least temporarily;
(c) Pollution caused by either the premature operation of combined wastewater overflows because of downstream restrictions to hydraulic capacity or

pollution caused by the washing through and discharge of debris from overflows during storms;

(d) Odour caused by the retention of solids in the system for long periods resulting in, among other things, wastewater turning septic and producing hydrogen sulphide;

(e) Sewer inspections, where the sewer needs to be cleaned before inspection. This requirement most often occurs when using in-sewer CCTV inspection techniques;

(f) Sewer rehabilitation where it is necessary to clean the sewers immediately before the sewer being rehabilitated.

Common sewer cleaning methods include:

(a) Jet rodding,
(b) Manual rodding,
(c) Winching or dragging,
(d) Cutting, and
(e) Manual or mechanical digging.

The method usually is determined in advance and is normally contingent on the pipe type and size and on the conditions expected in the pipe.

Record Keeping

Record keeping of sewer maintenance, inspections and repairs meets several needs of the sewer system. Records help simplify and improve work planning and scheduling, including integrating recurring and on-demand work. Measuring and tracking of workforce productivity and developing unit costs for various activities are a few of the record keeping benefits. Records of sewer maintenance, service line maintenance, and sewer main and service line repairs should be kept and maintained.

15.5.3 Grease Trap

Greasy waste that accumulates in the grease trap must be removed regularly. The frequency of cleaning will vary depending on the type of food served and how active one's residence or business is. Regular cleaning keeps a grease trap working properly and will prevent clogging in kitchen drains and pipes. The procedures for grease removal are:

(a) Inspect the grease trap at least every three days and clean it promptly if the contents show the top 30% of the liquid depth is occupied by greasy waste;

(b) Every grease trap is different and must be inspected regularly to determine if cleaning is required. If very little waste builds up in one week or if the surface layer is liquid oil only, the grease trap may not be functioning effectively;

(c) Check for proper design as outlined in this DCOM Manual and modify or replace the trap if necessary. Small grease traps may be cleaned by hand by scooping the top waste layer into a watertight bag or container or applying hot water;

(d) It is not necessary to empty the grease trap completely; remove only semi-solid layer of greasy waste on the top of the liquid surface;

(e) Clean the trap at a time when wastewater will not be passing through it. Take care not to leave lumps of grease in the trap as this may lead to clogging;

(f) Handle the greasy waste carefully to avoid contamination of food preparation or storage areas. Warning signs and safety barriers should be erected around the floor and large grease traps during cleaning;

(g) Replace grease trap cover promptly and clean the surrounding area with a disinfectant;

(h) The grease trap waste container should be tightly sealed and disposed of with other kitchen refuse. DO NOT dispose of the grease trap waste in the toilet, gulleys, surface channels or manholes;

(i) Record maintenance activities in a log book. Clogging of the inlet or the pipes connecting the two chambers of the grease trap is not a common occurrence but if this happens, any obstruction can be pushed out from the open top of the pipe extending above the liquid surface. Kitchen wastewater also carries pieces of solid waste that are heavier than water. In a grease trap, these solids fall to the bottom and form a layer of settled material. It is necessary to remove this bottom layer of settled waste occasionally; otherwise the grease trap capacity will be reduced.

(j) Carefully remove and dispose of this bottom material in the same manner as for the top layer of greasy waste;

(k) Cleaning a grease trap is not a very pleasant job and staff members responsible for this task should be encouraged to carry it out promptly as required and thoroughly.

15.5.4 Screening and Grit Removal

Screen

Manually cleaned screens require frequent raking to prevent clogging. Cleaning frequency depends on the characteristics of the wastewater entering a plant. Some plants have incorporated screening devices, such as basket-type trash racks, that are manually hoisted and cleaned. Mechanically cleaned screens usually require less labour for operation than manually cleaned screens because screenings are raked with a mechanical device rather than by facility personnel. However, the rake teeth on mechanically cleaned screens must be routinely inspected because of their susceptibility to breakage and bending. Drive mechanisms must also be frequently inspected to prevent fouling due to grit and rags. Grit removed from the screens must be disposed of regularly.

Grit Removal

Collected grit must be removed from the chamber, dewatered, washed, and conveyed to a disposal or re-use site. Some smaller plants use manual methods to remove grit, but grit removal is usually accomplished by an automatic method. The four methods of automatic grit removal include inclined screw or tubular conveyors, chain and bucket elevators, clamshell buckets, and pumping.

A two-step grit removal method is sometimes used, where grit is conveyed horizontally in a trough or channel to a hopper, where it is then elevated from the hopper to another location. Aerated grit chambers use a sloped tank bottom in which the air roll pattern sweeps grit along the bottom to the low side of the chamber. A horizontal screw conveyor is typically used to convey settled grit to a hopper at the head of the tank. Another method to remove grit from the chamber floor is a chain and flight mechanism. Once removed from the chamber, grit is usually washed with a hydro cyclone or grit classifier to ease handling and remove organic material. The grit is then conveyed directly to a truck, dumpster, or storage hopper. From there, the grit is taken to a landfill or other disposal or re-use facility.

15.5.5 Biogas Settlers

In settlers that are not designed for anaerobic processes, regular sludge removal is necessary to prevent septic conditions and the build-up and release of gas which can hamper the sedimentation process by re-suspending part of the settled solids. Sludge transported to the surface by gas bubbles is difficult to remove and may pass to the next treatment stage.

Frequent scum removal and adequate treatment/disposal, either with the sludge or separately, is also important. Anaerobic settlers do have to be emptied less frequently as the organic material is partly transformed into gas. Accumulated slurry in the bottom of the reactor needs to be desludged every two to five years, depending on the type of the reactor (UNEP 2002, MANG 2005). For the operation and maintenance of anaerobic biogas settlers, operational requirements are very low and no professional operator is required as long as the plant is well maintained by skilled users. Starting with the seeding of some sludge from a septic tank or another anaerobic digester speeds up the digestion and prevents the digester from running acid (SASSE, 1998).

15.5.6 Anaerobic Baffled Reactor

An Anaerobic Baffled Reactor (ABR) requires a start-up period of several months to reach full treatment capacity since the slow growing anaerobic biomass first needs to be established in the reactor. To reduce start-up time, the ABR can be inoculated with anaerobic bacteria, e.g., by adding fresh cow dung or septic tank sludge. The added stock of active bacteria can then multiply and adapt to the incoming wastewater. Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the ABR.

Scum and sludge levels need to be monitored to ensure that the tank is functioning well. Process operation in general is not required, and maintenance is limited to the removal of accumulated sludge and scum every 1 to 3 years. This is best done using a motorized emptying and transport technology. The desludging frequency depends on the chosen pre-treatment steps, as well as on the design of the ABR. ABR tanks should be checked from time to time to ensure that they are watertight.

15.5.7 Anaerobic Filter

An anaerobic filter (AF) requires a start-up period of 6 to 9 months to reach full treatment capacity since the slow growing anaerobic biomass first needs to be established on the filter media. To reduce start-up time, the filter can be inoculated with anaerobic bacteria, e.g., by spraying Septic Tank sludge onto the filter material. The flow should be gradually increased over time. Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the anaerobic filter. Scum and sludge levels need to be monitored to ensure that the tank is functioning well. Over time, solids will clog the pores of the filter. As well, the growing bacterial mass will become too thick, break off and eventually clog pores. When the efficiency decreases, the filter must be cleaned. This is done by running the system in reverse mode (backwashing) or by removing and cleaning the filter material. Anaerobic filter tanks should be checked from time to time to ensure that they are watertight.

15.5.8 Up-flow Anaerobic Sludge Blanket Reactor

The Up-flow Anaerobic Sludge Blanket (UASB) is a Centralized Treatment technology that must be operated and maintained by professionals. A skilled operator is required to monitor the reactor and repair parts, e.g., pumps, in case of problems. Desludging is infrequent and only excess sludge is removed every 2 to 3 years.

15.5.9 Settling-thickening Tanks

Constant monitoring and adaption accordingly are always required. In the design phase a series of assumptions are made in order to design the operation. The operation cycle consists of 1) faecal sludge loading, 2) thickened faecal sludge compaction, and 3) bottom sludge and scum removal. Pump failure is a common issue so it is important that it is installed in such a way that it can be accessed without pumping out the tank contents. Pumps should be selected based on the solids concentration of the thickened layer and available energy source. To alleviate frequent problems with pumping, solids are frequently removed by front loaders. Designing for manual removal using shovels is not recommended due to the difficult nature of removal.

The Total Suspended Solids (TSS) concentration of the supernatant will guide one in the treatment performance of the settling-thickening tank. If the TSS concentration is not suitable for the subsequent effluent treatment technology, a change in design, incoming faecal sludge, inlet/outlet design and/or more frequent desludging might be required.

15.5.10 Unplanted Sludge drying beds

Operation and maintenance to consider for unplanted sludge drying beds include:

(a) Sand and gravel must be washed prior to placing it in the filter to remove dust particles which could cause clogging of the beds,
(b) When loading it is very important not to exceed the recommended loading rates (hydraulic or solids),
(c) Faecal sludge can only be loaded onto the sludge drying beds once during each drying cycle. Partially dewatered faecal sludge forms a crust on the surface that prevents liquid from passing down to the sand layer and percolating through the drying bed,
(d) Incorrect loading can lead to ponding or clogging of beds. If clogging occurs, the entire sand and gravel layer needs to be washed or replaced,
(e) Solids removal is labour intensive, so adequate time needs to be estimated to ensure that loading cycles can be maintained,
(f) During solids removal, measures need to be taken to minimize the sand loss, as the sand layer is slowly removed, it needs to be replaced,
(g) Electrical operation and maintenance must be included if pumps are used for loading of the drying beds. Examples are spare parts and fuel,
(h) It is important to monitor the leachate as an indicator of the sludge drying bed performance (e.g. total volumes, TS concentration).

15.5.11 Planted Sludge Drying Beds

The following list presents key considerations for operation and maintenance of planted sludge drying beds:

(a) It is important to have trained operators who operate and maintain the sludge drying beds, especially during the acclimation period;
(b) During loading, make sure the faecal sludge is well distributed, especially during the start-up to ensure the filter media is not disturbed;
(c) Plant survival is crucial for treatment performance;
(d) During the start-up, the solids loading rates and feeding intervals need to be further evaluated to ensure adequate frequencies and loadings for plant health;
(e) Optimal plant densities and harvesting frequencies should be evaluated;
(f) Harvest plants by cutting them at the surface; avoid pulling them out because this will damage the root system and drying bed filter material;
(g) Monitor the drainage system and effluent for treatment performance and any possible changes;
(h) Remember that wildlife might be attracted to the plants, so fencing and measures to decrease possible vector-borne diseases might be required.

15.5.12 Co-composting

Co-composting needs to be monitored continuously in order to ensure adequate temperature and moisture content to achieve the treatment objectives. In addition, specific operational and maintenance concerns include:

(a) When turning the pile, all parts must be exposed to a high temperature in order to kill off the pathogens,
(b) The temperature is regulated by turning the pile more often if the temperature is too high. If too low, more water potentially needs to be added and/or the mass of moist input material needs to be increased,
(c) The aerobic condition in the pile is facilitated by the heap-turning frequency, which is context-dependent and needs to be determined by trial and error,
(d) Mycelium (clumps of white threads) and small insects are present to break down complex organic material and particles,
(e) Odour problems can be a sign of too high a moisture content and can be reduced by increased turning and the addition of coarse material,
(f) It may be necessary to cover co-compost piles to either protect from, or to maintain, humidity,
(g) Large amounts of flies, insects and rodents must be avoided. Covering the pile could reduce the number of flies, insects and rodents gathering,
(h) Compost as a product is sieved to separate coarse and fine compost. The coarse compost is re-used in the next round of co-composting while the fine compost is ready to be used as a soil amendment.

15.5.13 Co-treatment of Faecal Sludge with Wastewater

Implementation of co-treatment needs to be carefully monitored. Re-evaluate the treatment capacity and performance frequently to monitor for any unforeseen change in influent values. The risk of failure cannot be stressed enough, as co-treatment has been the cause of many treatment plant failures.

15.5.14 Effluent Treatment Technologies

The operation and maintenance of the effluent treatment has to be carried out by qualified staff according to the selected treatment options, for example, if the biological nature of the treatment is complex and sensitive to inflow fluctuation. If transferring or innovative technologies are selected, they need to be closely monitored so that the operation can be adapted as needed.

15.5.15 Waste Stabilization Ponds

Operation and maintenance of waste stabilization ponds

The operation of the waste stabilization ponds (WSPs) includes the commissioning (starting up), maintaining and monitoring its performance.

Starting up of waste stabilization ponds

Anaerobic ponds have to be filled with raw sewage and seeded with sludge from conventional sewage treatment plant or septic tank. After filling and seeding then the pond should be gradually loaded up to the design-loading rate. The pond contents should have a pH above 7 to allow the development of methanogenic bacteria. Add lime or soda ash to rise the pH in the pond if necessary. If the sewerage system is new and the flow rate as well as the loading rate to the anaerobic pond is low, then the sewage may be by-passed till the flow rate and the loading rate from the sewerage systems satisfies the condition to be discharged in the WSP. It is important to have by-pass from the anaerobic pond that will be used during desludging. It is also recommended to commission the WSPs during the beginning of the hot season so as to allow quick establishment of microorganisms of importance for the waste stabilization ponds.

The facultative WSP should be commissioned before the anaerobic WSP in order to avoid odour during the release of anaerobic pond effluent to an empty facultative WSP. During the start-up of the facultative and maturation WSPs, they should be filled with freshwater (from tap, river or wells). This will allow gradual development of algae and heterotrophic bacteria population. However, primary facultative ponds must be seeded as the anaerobic WSP. If fresh water is not available, the secondary facultative and maturation WSPs should be filled with raw sewage and leave them for three to four weeks to allow development of the microbial population.

Maintenance

Maintenance for the WSPs should be carried regularly to avoid odour, flies and mosquitoes nuisance. The routine maintenance involves:

(a) Removal of screenings and grit from the inlets and outlets works,
(b) Cutting grass on the embankment and removing it so that it should not fall in the WSPs,
(c) Removing floating scum and floating macrophytes from the surface of the maturation and facultative WSPs,
(d) Spraying scum on the surface of anaerobic WSPs and should not be removed as it helps the treatment processes,
(e) Removal of any accumulated solids in the inlets and outlet works,
(f) Repair any damaged embankment as soon as possible,
(g) Repair any damage on fence and gate.

The operator must be given precise information on what to do at the WSP site. A clear form should be prepared showing the tasks to be performed by the operator that should be counter-checked by the foreman/supervisor weekly. Mara (1987) recommends that, for proper operation of the WSPs there should be a manager, assistant manager, engineers, works foreman, laboratory chemist, assistant laboratory chemist, technicians, artisan and the clerk. The number of staff depends on how extensive the project is and also on the population served as well as the degree of mechanisation aspired for.

Anaerobic WSPs requires desludging when they are one third full of the sludge by volume.

$n = V/3Ps$ ....(15.1)

Where, V is the volume of the anaerobic pond (m^3), P is the population served, s is the sludge accumulation rate (m^3/person year) and n is the interval in years (every few years).

The value of "s" is usually 0.04 m^3/person year. Sometimes the precise time to desludge the anaerobic WSP is determined by the use of the "white towel". Mara (1987) recommends the desludging frequency to be annually. The sludge from the pond may be disposed into sludge lagoon or tankers that transport to the landfill site, agricultural land or other suitable disposal area. The disposal of sludge should be undertaken in accordance with the local regulations.

Monitoring and evaluation of the performance

Frequent monitoring of the final effluent quality of a WSP system has the following importance:

(a) Regular assessment as to whether the effluent is complying with the local discharge or re-use standards,
(b) To detect any sudden failure or if the WSP effluent has started to deteriorate and may help to give the causes and the remedial actions to be taken.

Two levels of monitoring are recommended, Level 1 representative samples of the final effluent should be taken at least monthly or weekly and should be analysed for those parameters for which effluent discharge or re-use requirements exists. Level 2 when level 1 show that the effluent is failing to meet the standards, a more detailed study is necessary. 24-hour flow weighted composite samples are preferable for most of the parameters to be analysed, although grab samples are necessary for some (pH, temperature and faecal coliforms). The methods for collecting composite samples are as follows:

(a) Automatic sampler, which takes samples every after one to two hours with subsequent manual flow weighting if this is not done automatically,
(b) Taking grab samples every one to three hours with subsequent manual flow weighting,
(c) Taking column sample near the outlet of the final WSP.

A full evaluation of the performance of the WSP systems can be is a time consuming and an expensive process and requires experienced personnel to interpret the results. Details on how to collect samples for evaluation of the performance of the WSP is given by Mara (1987). The evaluation of the WSP performance has the following significance:

(a) Provides information on how the WSP is under loaded or overloaded,

(b) Indicate how much further loading may safely be added to the system as the community increases,
(c) Indicate how the future design be improved in the region.

15.5.16 Constructed Wetlands

Commissioning

The commissioning of the constructed wetland involved putting substrate, filling the wetland to the level required, and planting macrophytes. Sometimes commissioning of the wetland is referred to as the time from planting to the date where the wetland is considered operational. Operation during this period should ensure an adequate cover of the wetland vegetation. Water level within the wetland during this time needs to be controlled carefully to prevent seedlings from being desiccated or drowned. Once the plants have been established, the water level may then have to be raised to operational level. Plant loss may occur during the commissioning and hence must be transplanted.

Operation

The operation of the constructed wetland depends on the type of wetland and the number of preliminary treatment units used for wastewater treatment. Constructed wetlands are designed to be passive and low maintenance, not requiring continual upkeep. Constructed wetlands are however dynamic ecosystems with many variables that require managing and problem may occur when; the operator does not understand operation and maintenance, the wetland is overloaded either hydraulically or organically, unavoidable disasters such as flooding and drought, the wetland is plagued by weed problems and if excessive amount of sediments, litter and pollutants accumulate and are not removed from the wetland.

The management of the constructed wetlands consists of four tasks as shown in Table 15.2.

Table 15.2: Management of Constructed Wetland

Tasks	Example
Operational control	Varying water level and discharge
Monitoring	Water quality, habitat, flora and fauna
Inspection	Structures and embankments
Maintenance	Repair damage of the structures and control weeds growth

Not all constructed wetlands are similar as they can be designed for a range of objectives. These objectives will determine the kind of the operation and maintenance activities to be undertaken. Operation and maintenance of the constructed wetland therefore need to be tailored to a particular constructed wetland, reflecting desired objectives and site specific constraints such as local hydrology, salinity, climate and relevant aspects of public safety. The essential elements of the operation and maintenance of the constructed wetland include:

- Description of the wetland and its objectives,
- List of tasks or management,
- Monitoring activities which include inspection checklist.

The operation of the constructed wetland after commissioning must include:

(a) Maintenance of the embankments,
(b) Removal of litter and debris,
(c) Check the flow rate to the constructed wetland if it is in accordance with the design,
(d) Remove any blockages in the inlet and outlet works,
(e) Replace plants as required,
(f) Remove any unwanted weed species from the constructed wetland,
(g) Plants should be checked for any sign of diseases,
(h) Protect deep open water,
(i) Correct erosion and slumping,
(j) Check any signs of over flooding for subsurface flow constructed wetlands.

These may be prepared in form of a checklist that will direct what maintenance is required and should be contacted immediately.

Monitoring

Monitoring selected performance parameters should provide enough information to measure performance in meeting wetland objectives. If water quality improvement is the primary objective, then the performance indicator should be either presented as concentration or loads at the outlet or a comparison of inflow and outflow also in terms of concentration or loads. If motoring indicates that the system is not working according to the design objectives, then corrective measures must be applied. Improvement of water quality may be assessed by monitoring a range of inflow and outflow water quality parameters. The useful parameters for monitoring the wetland performance are: DO, BOD, COD, total phosphorous, orthophosphorous, total nitrogen, total kjeldhal nitrogen, ammonia nitrogen, oxidized nitrogen, faecal coliforms, pH, suspended solids, electoral conductivity and heavy metals. Flow rate to and from the constructed wetland must be measured. Sampling may be done using automatic samplers or manual sampling. Sometimes samples within the wetland must be taken for the purposes of comparison.

Decommissioning and refitting

Decommissioning and refitting of the constructed wetland may take place if its design lifetime is over. At the end of the design life, a wetland will be either refitted or decommissioned if no longer required. Refitting may be required when accumulation of wetland sediments is adversely affecting the wetland performance or changing the catchments conditions require modifications of the wetland. Major refits may include the removal of accumulated peat, including aquatic plants and the replacements of substrates. Decommissioning of the wetlands may be required if the land which supports it is resumed for other purposes, or if the wetland is unable to function to satisfy its original design objectives.

15.5.17 Trickling Filter

A skilled operator is required to monitor the filter and repair the pump in case of problems. The sludge that accumulates on the filter must be periodically washed down to prevent clogging and keep the biofilm thin and aerobic. High hydraulic loading rates (flushing doses) can be used to flush the filter. Optimum dosing rates and flushing frequency should be determined from the field operation.

The packing must be kept moist. This may be problematic at night when the water flow is reduced or when there are power failures. Snails grazing on the biofilm and filter flies are well known problems associated with trickling filters and must be handled by backwashing and periodic flooding.

15.5.18 Activated Sludge (AS)

Highly trained staff is required for maintenance and trouble-shooting as plants. The mechanical equipment (mixers, aerators and pumps) must be constantly maintained. A continuous supply of oxygen and *sludge* is essential (WSP, 2008). Control of concentrations of *sludge* and oxygen levels in the aeration tanks is required and technical appliances (e.g. *pH*-meter, *temperature*, oxygen content, etc.) need to be maintained carefully. As well, the *influent* and *effluent* must be constantly monitored and the control parameters adjusted, if necessary, to avoid abnormalities that could kill the active *biomass* and the development of detrimental organisms which could impair the process (e.g. filamentous *bacteria*).

Two of the most serious problems with the activated-*sludge* process are: (1) a phenomenon known as bulking, in which the *sludge* from the aeration tank will not settle, and (2) the development of biological surface foam (Crites & Tchobanoglous, 1998). Bulking can be caused either by organisms that grow in filamentous form instead of *flocs* and will not settle, or the growth of *micro-organisms* that incorporate large volumes of water into their cell structure, making their density near that of water. Foaming is caused most often by the excessive growth of an organism called Nocardia (Crites & Tchobanoglous, 1998). Filamentous organisms can be controlled by the addition of chemicals (e.g. chlorine or *hydrogen peroxide*) to the recycled *activated sludge*; the alteration of the dissolved-oxygen concentration in the aeration tank; the addition of *nutrients* and growth factors to favour other *micro-organisms* etc. Nocardia can be controlled by avoiding the recycling of the skimmed foam or the addition of a chemical agent (e.g. polymers or chlorine) on the surface (Crites & Tchobanoglous, 1998).

15.6 RESOURCE RE-USE AND RECOVERY

The essential features of resource re-use and recovery have been covered in detail in Section 3.7 of Volume II and hence this is not further discussed in this volume.

15.7 PERFORMANCE MONITORING

There are two types of performance monitoring to be considered. The first type is "compliance monitoring". This type of monitoring is meant to determine whether sanitation projects comply with the standards and indicator parameter values in the Regulations. The compliance monitoring samples should be analysed in accredited laboratories. The second type is "operational monitoring" to check that treatment works and distribution networks are operating effectively to deliver sanitation services that meet the standards as specified by TBS (TZS 860) and to provide early warning that a treatment process is failing or there is a problem in the system. The operational monitoring samples need not be analysed in accredited laboratories. They may be analysed in small laboratories/ benches at treatment works provided the methods are properly calibrated and subject to analytical quality control. Regulated Water Utility (RWU) should have separate pre-determined compliance and operational monitoring programmes prescribed by either EWURA or RUWASA.

15.7.1 Compliance Monitoring

(a) Monitoring categories

There are two categories of compliance monitoring – check monitoring and audit monitoring – to determine compliance with the standards and indicator parameter values in the standards. Check monitoring should be carried out relatively frequently for a limited range of parameters. Audit monitoring has to be carried out less frequently for all the parameters, including those parameters subject to check monitoring. This means that for some parameters the monitoring frequency is the sum of the check and audit monitoring frequencies.

(b) Criteria for check monitoring parameters

The purpose of check monitoring is regularly to provide information on some selected wastewater quality parameters, in order to determine whether or not sanitation system complies with the relevant parametric values laid down in TZS 800. The parameters for check monitoring are as specified by TBS.

(c) Criteria Audit monitoring parameters

The purpose of audit monitoring is to provide the information necessary to determine whether or not all the parametric values specified in TZS 860 are complied. All such parameters must be subject to audit monitoring unless specified otherwise, for a period of time to be determined by it, that a parameter is not likely to be present in a given supply in concentrations which could lead to the risk of a breach of the relevant parametric value.

15.7.2 Operational Monitoring

Each entity must have an operational monitoring programme for each of its sanitation system. This programme is entirely separate from the compliance sampling programme. Operational monitoring is sampling and analysis carried out to check that sanitation infrastructure are operating effectively to comply with the standards and to provide early warning that the sanitation system is deteriorating, or failing or there is a problem in the system. In general operational monitoring programme should consist of the following elements:

(a) Monitoring of the source water for parameters that provide a general indication of water quality, which if their concentration or value changed significantly would indicate that there could be deterioration in source water quality. It should also include any parameters that the treatment works is specifically designed to remove;

(b) Monitoring of the coagulation, settlement and filtration processes for those parameters that provide evidence of the effectiveness of treatment such as jar tests for optimum coagulation conditions, coagulant residual, pH value and turbidity;

(c) Monitoring of the disinfection process for those parameters that provide evidence of the effectiveness of disinfection such as chlorine residual, pH value and microbiological parameters;

(d) Monitoring of the water leaving the treatment works for parameters that the works is designed to remove that are not adequately monitored by the compliance monitoring such as nitrate if nitrate removal id practiced; and

(e) Monitoring within the distribution network for parameters that provide evidence that there is no deterioration or contamination within distribution that are not adequately monitored by the compliance monitoring such as chlorine residual.

PART E: WATER AUDIT, REVENUE AND COMMUNITY PARTICIPATION MANAGEMENT

Chapter 16

WATER METERS, INSTRUMENTATION TELEMETRY AND SCADA

16.1 WATER METERS

A water meter is a scientific instrument for measurement of the quantity of water distributed to the consumers or sewage pumped. In Tanzania, water meters are used to measure the volume of water used by residential, institutional, industrial, as well as commercial buildings and public water points/kiosks that are supplied with water by a public water supply system. Water meters can also be used at the water source, and throughout a water system to determine flow through that portion of the system. Water meters can be used to measure wastewater quantities. Water meters measure flow in cubic metres (m^3) on a mechanical or electronic register. Some electronic meter registers can display rate-of-flow in addition to total usage. A water meter also fulfils the need to know accurately the water produced and distributed. Water meter is always specified in two accuracies i.e. lower range and upper range accuracies. The upper range and lower range accuracies are 2% and 5% of the actual quantity respectively for the water meter.

Water meters having sizes from 15 mm to 50 mm as per TBS standards are considered to be **Domestic water meters** and sizes from 50 mm and above as per TBS are considered to be **Bulk water meters**. There are different types of water meters such as mechanical water meter, electro-mechanical, ultra-sonic water meters. However, prepaid water meters are highly recommended nowadays for domestic as well as public water points that operate as kiosks. Public water points can have one or more taps.

16.1.1 Sizing of Water Meters

In general the sizing of water meters is done according to the guidelines given in **TZS 782-5: 2015- ISO 4064-5: 2014**, the main considerations on the characteristics of the water flow and quality have to be known, before a suitable meter type with the right specifications can be chosen to fulfil this task. These are as follows:

(a) Water meter has to be selected according to the flow to be measured and not necessarily to suit a certain size of water supply mains,

(b) The maximum flow shall not exceed the maximum flow rating,
(c) The nominal flow shall not be greater than the nominal flow rating,
(d) The minimum flow to be measured shall be within the minimum starting flow of the meter,
(e) Low head loss, long operating flow range, less bulky and robust meter shall be preferred.

16.1.2 Installation of Ordinary Water Meters

In order to ensure proper working of the meters, TBS has given guidelines in TZS 782-5: ISO: 4064-5:2015 for their installation as per the drawing given in it. The following guidelines should be borne in mind while installing the meters:

(a) Assure accuracy of water meter on a meter test bench at minimum and permanent flow rates before installation,
(b) The water meter being a delicate instrument shall be handled with great care. Rough handling including jerks or fall is likely to damage it and affects its accuracy,
(c) The meter shall be installed at a spot where it is readily accessible. To avoid damages and over run of the meter due to intermittent water supply system, it is always advisable to install the meter, so that the top of the meter is below the level of the communication pipes so that meters always contain water, when there is no supply in the line. Also, the minimum straight length condition as per the drawing shall be observed,
(d) The meter shall preferably be housed in a chamber with a lid for protection; it should never be buried underground nor installed in the open nor under a water tap so that water may not directly fall on the meter. It should be installed inside inspection pits, built out of bricks or concrete and covered with lid. It should not be suspended,
(e) The meter shall be so installed that the longitudinal axis is horizontal and the flow of water should be in the direction shown by the arrow cast on the body,
(f) Before connecting the meter to the water pipe, it should be thoroughly cleaned by installing in the place of the water meter a pipe of suitable length and diameter and letting the passage of a fair amount of water flow through the pipe work to avoid formation of air pockets. It is advisable that the level of the pipeline where the meter is proposed to be installed should be checked by a spirit level,
(g) Before fitting the meter to the pipeline, check the union's nuts in the tail pieces and then insert the washers. Thereafter, screw the tail pieces on the pipes and install the meter in between the nuts by screwing. In order to avoid its rotation during the operation, the meter should be kept fixed with suitable non-metallic clamps. Care should be taken that the washer does not obstruct the inlet and outlet flow of water,
(h) The protective lid should normally be kept closed and should be opened only for reading the dial,

(i) The meter shall not run with free discharge to atmosphere. Some resistance should be given in the down side of the meter if static pressure on the main exceeds 10 m head,

(j) A meter shall be located where it is not liable to get severe shock of water hammer which might break the system of the meter,

(k) Owing to the fine clearance in the working parts of the meters they are not suitable for measuring water containing sand or similar foreign matter and in such cases a filter or dirt box of adequate effective area shall be fitted on the upstream side of the meter. It should be noted that the normal strainer fitted inside a meter is not a filter and does not prevent the entry of small particles, such as sand,

(l) In case of intermittent water supply to SR and schemes with storage at higher elevation, the bulk water meter may be provided with a suitable air valve before the meter in order to reduce inaccuracy and to protect it from being damaged.

16.1.3 Installation of Prepaid Water Meter

The following guidelines should be used while installing the prepaid water meters:

(a) Before installing the prepaid meter first check its accuracy on a meter test bench at minimum and permanent flow rates. It will be costly to install a water meter that might underperform from the day of installation,

(b) The installation has to strictly follow the manufacturer's instructions,

(c) Unless the instructions allow for downpipes or an installation at an angle, most water meters require a horizontal installation. A water meter mounting position different to the instructions given by the manufacturer increases the friction of moving parts,

(d) Install the meter at pipe level. The location of the meter should be such that it is not possible for air pockets to develop in the meter, for instance the meter should not be located at high points in the pipeline or operated under half full pipe conditions. The installation on top of a standpipe could lead to the meters reading air flow,

(e) Fix the meter between two straight un-obstructed pipes: the upstream pipe's length should equal to 10 times the pipe diameter and the downstream pipe's length should be equal 5 times the pipe diameter,

(f) The pipe diameter should not be reduced directly in front and behind the prepaid water meter,

(g) All regulations of the flow (e.g. operation of gate valve) should be realized after the meter.

16.1.4 Operation and Maintenance of Ordinary Water Meters

Regular maintenance of water meters include cleaning of dirt box or strainer time to time, replacement of gaskets upon its wear and tear, cleaning of chamber where meter is installed and preventing water seepage in it, verifying whether it is indicating correct reading cleaning of spare parts when disassembled for any repairs or verification with detergents solution in warm water. Normally, general maintenance and repairs recommendations are given by the manufacturer.

16.1.4.1 Functional Principles of Water Meters

Water meters are divided into two classes:

- Volumetric water meters, when the volume is mechanically measured through a known volume of a measuring chamber, and
- Inferential water meters, when the meter determines the velocity from variables such as pressure differences across a devices like and orifice plate, transit time of sound waves, changes in magnetic field.

In general, domestic meters should be taken out of service every 5 to 7 years and completely overhauled. The systematic inspection and replacement of consumption meters is an important aspect of routine maintenance. Records should be kept on the condition of meters to guide future procurement and enable the Utility to take measures against water loss. Representative pothole checking of service connections within 5 years of service (avoid leaks due to deterioration) should also be done. Normally, general maintenance and repairs recommendations are given by the manufacturer. Table 16.1 illustrates the troubleshooting of water meters.

Table 16.1: Typical Troubleshooting of Water Meters

Problem	Probable Cause	Solution
Meter reads in reverse direction	Meter is installed in reverse direction	Re-install it
No recordings in meter	Impeller to register link broken	Undertake service/repairs
Pointer moves but no change in indicator	Pointer and drum link missing, drum defect	Undertake service and repairs
Meter runs slow or fast	Inlet flow disturbance, magnets might have worn out	Clean the external filter/dirt box. Undertake servicing
Leakage in bush/gland	Deformity in gland	Undertake service/repair
Regulator, head/body leakage	Washer is damaged. Screws are loose	Service/repair

(Source: Pradhikaran, 2012)

16.1.4.2 Inspection of Water Meters

(a) Clean all water meter parts thoroughly;
(b) Make sure the gear train runs freely;
(c) Check the action of the disc in the chamber;
(d) Remember that friction is just as detrimental to correct registration (reading) as slippage;
(e) Store meters away from heat;

(f) Use a calibrated meter as a standard of comparison for tolerances and clearances;
(g) After every repair, retest the meter for accuracy;
(h) If necessary, call the manufacturer for advice

16.1.4.3 Types of Water Meter Testing

(a) *Meter Shop Test* – pull out meter and send it to testing laboratories/shops for testing /recalibration (equipment and service available usually at large utilities).
(b) *Volumetric Method* (no dismantling) – using a container with known volume, a variance of +/- 4% should be pulled out for recalibration)
(c) *Using a Calibrated Test Meter* – the meter should be put in series with a calibrated meter. In principle, readings should be the same. Record the difference; +/- 4% off should be re-calibrated.

16.1.4.4 Water Meter Testing (If a Test Bench is Available)

(a) Install/fix water meter on Test bench;
(b) Open supply valve, close end valve and inspect for leaks;
(c) Record the initial reading;
(d) Open end valve, run the test and close end valve at desired volume.
(e) Record the final reading;
(f) Compute meter accuracy;
(g) Identify Over/Under registering meters;
(h) Calibrate by adjusting regulator or rheostat (+/-);
(i) Re-test the water meter;
(j) Seal the water meter cover and regulator plug.

16.1.4.5 Metering Accuracy

For accurate water flow measurements, various characteristics of the meter have to be known, before a suitable meter type with the right specifications can be chosen to fulfil this task. The characteristics are as follows:

- Metering accuracy according to Water quality: Metering accuracy is significantly affected by suspended solids and depositions. Dirty water will cause under-registration e.g. with Positive Displacement Meters as well as with Velocity Meters. The Positive displacement meters may stop when a particle bigger than the spare space between the piston/disc and the chamber passes through the strainers of the meter. For Velocity meters, the depositions may cause over registration at medium-high flows and under registration at low flows. However, on the long term, deposits from suspended particle can grow so large that they can prevent the impeller from rotating, temporarily or permanently, causing a severe under registration of the meter

- Metering accuracy according to Flow range/Rangeability (consumption pattern): Water meter measure accurately only flow rates that lie within its rangeability (Meter accuracy according to (TZS 782-5: 2015- ISO 4064-5: 2014). Flow rates beneath the specified minimal flow will be registered inaccurately or not at all. Operating a meter at either minimal or maximum flow rate, will reduce the life span of the meter and change its accuracy curve. While in the later case impact is seen sooner
- Metering accuracy according to Oversized Meter– results in High non-revenue water. If the water meter is too large, the flow rates might be lower than the minimum flow rate and cause under-registration will be significant even from the first day of installation. Also oversized meters are more costly than rightly sized meter.
- Metering accuracy according to Undersized Meter –results in accuracy and high pressure loss. If the meter is too small, the degradation of the accuracy will be accelerated. While the meter might be accurate at the beginning, in the short period of time, the pieces in contact with them, will break down leading to significant metering errors. Undersized water meters can cause excessive pressure loss.
- Metering accuracy according to Metrological Class

The Metrological class defines the accuracy of a water meter. There are old and new standard norms of the Metrological classes. Until 2003-2004, the metrological classes of meters were defined by the Standard (TZS 782-5: 2015- ISO 4064-5: 2014). This Standard, defines a meter by its Nominal Flow (Qn), called Qn, and Accuracy Class. There are 4 accuracy classes A, B, C, D. Each class sets a range of flow rates on which the meter must maintain its accuracy. A is the narrowest, D is the widest. Each meter operates accurately for its designed flow ranges, e.g. a Class A meter can be absolutely suitable if the consumptions are done according to a very narrow range of flow rates, which is often the case for irrigation.

Requirement for accuracy:

The Norm is demanding compliance of meters with the following accuracy limits for different flow rates:

(a) +- 5% accuracy between Minimum and Transitional Flow
(b) 2 % between Transitional and Maximum Flow

Table 16.2: Definition of Flow Rates

Flow rates	Description
Minimum Flow (Qmin)	Minimum flow that can be registered by the meter within 5% accuracy
Transitional Flow (Qt)	Flow at which the meter inaccuracy is not more than 2%
Nominal Flow (Qn)	depends on meter size (refer to table underneath)
Maximum Flow (Qmax)	2 x Qn

Note: Qn is the nominal flow rate as half the maximum flow rate

Pressure drops: The meters must not have a pressure drop higher than 1 bar at the maximum flow and 0.25 bar at the nominal flow.

Please note: If the regular water flow rate is around or above the Maximum flow rate for which the meter has been designed, the measuring unit of the meter will be damaged progressively till it stops to work.

16.1.5 Operation and Maintenance of Flow Meters

Flow meters were described in Volume I. Regular monitoring of flow meters include periodic checking of range and zero setting, bearing wear out checking, deposits in flow meter, corrosion of attached pipes etc. Some of the general troubleshooting is listed in the Table.16.3.

Table 16.3: General Troubleshooting of Flow Meters

Probable Cause	Solution
Problem: Erratic Reading	
Operating below lower ranges	Replacement of meter, change range setting
Lower static pressure	Remove air trap
Clogged impulse piping	Clear choke up
Air trap in impulse piping	Remove air trap
Frequent air trap in impulse piping	Change piping slope/change meter
Problem: Inaccurate Reading	
Pipeline internally encrusted	Clean internal surface of pipeline/replace
Scaling at tapping points	Clean the tapping points
Orifice edge blunt	Replace orifice plate
Mismatch of flow meter and pipeline	Remove the mismatch
Gathering of concrete piece, bricks, debris etc at orifice	Remove the external particles
Leakage in flanged coupling	Rectify the leakage

(Source: Pradhikaran, 2012)

16.1.6 Operation and Maintenance of Ordinary Bulk Water Meters

Ordinary bulk flow meters are used at intakes, treatment works and in the distribution systems at reservoirs and bulk supply. They are installed for purposes of monitoring large flows of water for water system management and commercial billing purposes. They are normally equipped with helical vanes with pulse outputs for operation with various auxiliary equipment. Different body length sand material types are available to meet all requirements.

Combination meters are manufactured for installations where wide variation in flow can be expected, such as in multi-story buildings, hospitals, schools, offices and other places where both low and high flows can occur due to several consumptions users. These wide flow ranges are measured by using a built-in changeover valve together with small residential meters and large bulk meter.

Large commercial single jet meters are also available which have a low flow capability, which makes them ideal for revenue collection. Electromagnetic water meters are also available which are designed for measuring bulk flows in a wide range of applications including irrigation management of agricultural land. All bulk meters should be tested to ensure that they meet approved standards.

16.1.7 Operation and Maintenance of Prepaid Water Meters

Prepaid water systems are an effective and efficient way of collecting water tariffs and offer a high level of convenience to both the users and local water supply authorities. They save time and do not require unnecessary paperwork. Moreover, the systems minimize cash transactions and, therefore, contribute to the transparency of the tariff collection. In rural areas in Tanzania, the management of these prepaid systems has been strengthened with the formation of Community-Based Water Supply Organisations (CBWSOs). Prepaid meters have been operating successfully in the Districts of Kishapu, Karatu and Babati.

Most prepaid water meters use a mechanical water meter, coupled to an electronics module with a credit meter and a water control valve. When water flows, pulses are generated by a probe connected to the mechanical meter. The pulses are converted into credits that are subtracted from the total credits loaded by the customer. The valve closes when credit is exhausted or if there is tampering with the components. Prepaid systems use rotating piston and multijet water meters. The accuracy of these meters can be easily affected by grit, sand, and air; and frequent supply interruptions raise the risk of malfunction. This is a significant vulnerability for prepaid metering systems especially in urban areas, where there are ageing networks, discontinuous supply, and low pressure fluctuations. Electromagnetic and ultrasonic prepaid meters are technically better suited to networks with supply interruptions**.** These models are also highly accurate, resilient to pressure changes, air, and grit have no moving parts.

(a) Prepaid Public Standpipes

A customer using a standpipe, kiosk or water point loads credit bought from designated vendors using a programmed metal key, a smartcard, or a keypad. Dallas keys, or Buttons, are currently the most widely used, and consist of a computer chip mounted in a stainless steel container that looks like a large watch battery. Programmed keys and smartcards allow for a two-way exchange of data. A credit vendor loads credit onto the customer's Dallas key using a point-of-sale device, and uploads consumption data from the customer's prepaid meter for analysis later. This data can be used to track consumption trends and flag exceptions (unusually high or low consumption) or for follow-up. Numerical tokens and keypads are one-way only, and require separate data collection to track consumption.

(b) Individual Domestic Connections

The customers use their own prepaid meters, and load credit using a tag, smartcard, or keypad. The tag, card, or code can only be used on the specific meter for which it is programmed. Once the credit is loaded into the meter's memory, customers do not have to use the key each time they draw water. A growing number of utilities acknowledge that regular monthly meter reading is essential to collect consumption data to calculate their water balance, reconcile sales, and monitor Non Revenue Water (NRW). Some utilities now insist that each prepaid device includes a conventional/post-paid mechanical meter, if necessary, in addition to an electronic meter. If the prepaid unit fails for any reason, the mechanical meter can still be read and supports conventional billing and payment.

(c) Prepaid Bulk Meters for Commercial and Institutional Customers

The Prepaid Bulk flow meters are used where wide variation in flows can be expected, such as in multi-story business buildings, hospitals, schools, offices and other places where both low and high flows can occur due to several consumptions users. These wide flow ranges are measured by using a built-in changeover valve together with small residential meters and large bulk meter. All bulk flow prepaid meters should be tested to ensure that they meet approved standards. A representative of the customer loads credit using a tag, smartcard, or keypad. The meter needs to be designed for far higher volumes than domestic meters and far greater accuracy, given the volumes. The large volumes of water sold to commercial and institutional customers comprise a significant source of income for water supply service providers in most urban towns.

Figure 16.1(a) & (b): E-Water Point in Sangara Village, Babati. A token used by E-Water Users to Get Water

16.1.8 Testing and Calibration of Water Meters

The testing & calibration of a water meter is essential before putting it into use as it is a statutory requirement and may be done periodically in order to ascertain its performance. It is likely that its accuracy of measurement may deteriorate beyond acceptable limits in the course of its use.

A meter suspected to be malfunctioning is also tested for its accuracy of measurement. The testing is done as per TZS 782-2: ISO 4064-2:2014. A faulty meter if found to be repairable, is repaired and tested and calibrated for its accuracy before installation .The metering accuracy testing is carried out at Qmin, Qt & Qmax, separately where:

(a) Qmin: Lowest flow rate at which the meter is required to give indication within the maximum permissible error tolerance. It is determined in terms of numerical value of meter designation in case of ISO 4064.
(b) Qt: The flow rate at which the maximum permissible error of the water meter changes in value.
(c) Qn: Half the maximum flow rate Qmax.
(d) Qmax: The higher flow rate at which the meter is required to operate in a satisfactory manner for short periods of time without deterioration.
(e) The accuracy of water meters is divided into two zones i.e.
    (i) Lower measurable limit in which ±5% accuracy from minimum flow to transitional flow (exclusive), and
    (ii) Upper measurable limit in which ±2% accuracy from transitional flow (inclusive) to maximum flow.

The procedure for conducting the above test is as follows:

Water meter is fixed on a test bench horizontally or vertically or in any other position for which it is designed and with the direction of flow as indicated by arrow on its body. By adjusting the position of regulating valve on the upstream side, the rate of flow is adjusted. At the desired rate of flow, the difference in pressure gauge readings fitted on upstream and downstream side of the water meter is noted. The flow is now stopped with regulating valve and measuring chamber is emptied and zero water levels on manometer attached to measuring chamber is correctly adjusted. Initial reading of the water meter from its recording dial is noted. Now the flow at the set rate is passed through the water meter and the discharge is collected in the measuring chamber. After passing the desired quantity of water through the meter, the flow is once again stopped. The discharge as recorded by measuring chamber is noted. The final reading of the water meter is noted. The difference between the initial and final readings of the water meter gives the discharge figure recorded by water meter. Now the discharge recorded by measuring tank is treated as ideal. The discharge recorded by water meter is compared with this ideal discharge. If the quantity recorded by water meter is more than the ideal, the meter is called running fast or vice versa.

The difference in the quantity recorded by the meter from the ideal quantity is considered as the error. This error is expressed in percentage. If the limits of error for the meter exceed that specified in the TZS/ISO standards concerned the meter is readjusted by the regulator if it is available in the meter. A change in position of the regulating screw will displace the error curve (calibration curve) in parallel to former the position. With the closing of the regulating orifice the curve will shift upward while opening the same will lower the curve. If the curve does not get into acceptable limit the meter is not used. Some of the organizations are accepting accuracy limit for repaired water meter double the value of new water meters at respective zones i.e. for upper zone accuracy is ±4% & for lower zone accuracy is ±10%. In Tanzania, the Agency for Weights and Measures as per relevant Law.

16.1.9 Repairs, Maintenance and Troubleshooting of Water Meters

The water meters are mechanical devices, which normally deteriorate in performance over time. Water meters in good working conditions are the basis to determine the water network efficiency and for accurate billing. The fact that a meter does not show outward signs of any damage and has a register that appears to be turning, does not mean that the meter is performing in a satisfactory manner. It is necessary to ascertain the following preventive cares for water meters after proper installation:

(a) Preventive maintenance:

- (i) Proper handling, storage and transportation of water meters,
- (ii) To clean the dirt box or strainer wherever installed,
- (iii) To replace the gaskets, if any;
- (iv) To clean the chamber in which the meter is installed and keep free from flooding, & seepage,
- (v) To remove the meter for further internal repair/replacement if it does not show correct reading pattern.

(b) Breakdown maintenance:

Replacement of broken glass, lid and fallen wiper wherever provided: These are the only basic breakdowns observed during periodical inspection. If a meter found not working, then it shall be removed immediately and sent to the meter service workshop. In meter workshops normally following steps are performed to carry out the repairs:

- (i) Disassembling of water meters including strainer, measuring unit, regulator, registering device,
- (ii) Clean all disassembled spare parts in detergent solution in warm water,
- (iii) Inspect the cleaned parts and replace worn parts and gaskets, if any,
- (iv) Inspect the meter body spur threads and cover threads,
- (v) Inspect the sealing surface on meter body and paint the meter body, if necessary,
- (vi) Inspect the vane wheel shaft pinion, bearing & pivot,
- (vii) Inspect the vane wheel chamber,
- (viii) Reassemble the water meter properly after reconditioning,
- (ix) Calibrate & test the repaired water meter for leakage & accuracy as per ISO:4064-2:2014,TZS 782-2:2018,
- (x) Make entry in the life register of that water meter for keeping history record.

16.1.10 Prevention of Tampering of Water Meters

In order to prevent tampering, following precautions should be taken:

(a) The water meters, shall be installed properly in the chamber with lock and key or in the cast iron covers with lock and key in order to avoid tampering,
(b) The water meters must be sealed properly,
(c) The water meters shall not allow reversible flow; it should register flow in forward directions only,
(d) The water meter dials should be easily readable without confusions,
(e) The lid, glass of water meters must be made up of tough materials as per ISO: 4064-4:2014, TZS 782-4:2018 and shall be replaced timely,
(f) The wiper or dial as far as possible is avoided,
(g) In case of magnetically coupled meters, the proper material to shield magnets must be provided in order to avoid the tampering of such meter by outside magnets in the vicinity of the meter,
(h) Periodic inspection/checking at site is essential to ensure the proper working of the meter,
(i) Special sealing arrangements may be necessary and provided for bulk meters where by unauthorized removal of the meter from the connection can be detected.

In addition to the above, to tackle the problems of tampering, suitable penalty provisions/clauses shall be there in the rules or the water supply agreement with the consumer. This will also discourage the consumer tendencies of neglecting water meter safety.

16.1.11 Automatic Water Metering Systems

Water meter is a cash register of a water supply agency/authority/utility. Consumption based water rates require periodic reading of meters except in remote or automated meter reading of meters. Except in remote or automated meter reading these readings are usually done by meter readers visiting consumers premises one by one and noting down the indicator reading by the meter. These readings are recorded manually in books or on cards and later keyed in manually to a customer accounting or billing system. In some cases, meter readers use Hand held Data Entry Terminals to record meter readings. Data from these devices are transferred electronically to a billing system. In other cases, key entry has been replaced by mark-sense card readers or optical scanners.

In case the environment of meter reading is not favourable to the meter reader as the water meters are at times installed in underground chambers; these chambers are filled in many cases with water, reptiles or insects. In some consumers connect their electrical earth terminal to water supply utility/authority/agency pipe which endangers the safety of the meter reader or premises are not accessible to the meter reader. The solution to the above difficulties is to install automatic system to read meters and process the results by computer.

The data can be captured by the meter readers from the meter in one of the following ways:

(a) Manual entry into meter books,
(b) Manual entry into portable hand held entry terminals or recorders,
(c) Direct electronic entry from meter registers either into portable data terminals or display units from which readings are transcribed in the field,
(d) Telemetry link through radio, telephone.

16.2 INSTRUMENTATION

Some instrumentation is expected to be applied in the following areas:

16.2.1 Level Measurement

Instrumentation facilitates coordination of various water parameters, which are essential for optimization of water supply & treatment plant. One of the important parameters amongst them is water level measurement, which is carried out at various locations viz. water reservoir, inlet chamber, open channel, alum feeding tank, lime tank, filter beds, air vessel, sump well, etc. This measurement is accomplished in water works by two following ways:

(a) Direct Method,
(b) Inferential Method.

16.2.2 Pressure Measurement

In water supply networks, pressure parameter plays a very important role in order to get sufficient water to the consumers. Similarly in flow measurement by differential pressure type flow meter, differential pressure measurement across the primary element is the main physical parameter to inter-link with the flowing fluid. This pressure or differential pressure measurement is accomplished with the help of the following methods in water works:

(a) Manometers,
(b) Elastic Pressure Transducers,
(c) Electrical Pressure Transducer.

16.2.3 Capacitors

Capacitors are needed to be provided invariably in all the pumping stations for maintaining required power factor thereby saving of energy. Pre-requisites for satisfactory functioning of capacitors ensure the following points:

(a) A capacitor should be firmly fixed to a base,
(b) Cable lugs of appropriate size should be used,
(c) Two spanners should be used to tighten or loosen capacitor terminals. The lower nut should be held by one spanner and the upper nut should be held

by the spanner to avoid damage to or breakage of terminal bushings and leakage of oil,

(d) To avoid damage to the bushing, a cable gland should always be used and it should be firmly fixed to the cable-entry hole,

(e) There should be a clearance of at least 75 mm on all sides for every capacitor unit to enable cooler running and maximum thermal stability. Ensure good ventilation and avoid proximity to any heat source,

(f) While making a bank, the bus bar connecting the capacitors should never be mounted directly on the capacitor terminals. It should be indirectly connected through flexible leads so that the capacitor bushings do not get unduly stressed,

(g) Ensure that the cables, fuses and switchgear are of adequate ratings.

16.2.3.1 Operation and Maintenance of Capacitors

(a) The supply voltage at the capacitor bus should always be near about the rated voltage. The fluctuations should not exceed ±10% of the rated voltage of the capacitor,

(b) Frequent switching of the capacitor should be avoided. There should always be an interval of about 60 seconds between any two switching operations,

(c) The discharge resistance efficiency should be assessed periodically by sensing, if shorting is required to discharge the capacitor even after one minute of switching off. If the discharge resistance fails to bring down the voltage to 50 V in one minute, it needs to be replaced,

(d) Leakage or breakage should be rectified immediately. Care should be taken that no appreciable quantity of imp- regnant has leaked out,

(e) Before physically handling the capacitor, the capacitor terminals shall be shorted one minute after disconnection from the supply to ensure total discharging of the capacitor,

(f) Replace capacitor if bulging is observed.

16.2.4 Water Hammer Control Devices

Maintenance requirements of water hammer devices depend on type of water hammer control device, nature of its functioning, water quality, etc. Type of water hammer control devices used in water pumping installations is as follows:

(a) Surge tank and/One-way surge tank,

(b) Air vessels (air chamber),

(c) Zero velocity valve and air cushion valve,

(d) Surge anticipation valve (surge suppressor),

(e) Pressure relief valve.

General guidelines for maintenance of different types of water hammer control devices as follows:

(a) Surge Tank and One-Way Surge Tank

Quarterly:

- (i) Water level gauge or sight tube provided shall be inspected, any jam rectified,
- (ii) All cocks and sight tube flushed and cleaned.

Yearly:

The tank shall be drained and cleaned once in a year or earlier if frequency of ingress of foreign matter is high.

(b) Valve maintenance:

- (i) Maintenance of butterfly valve, sluice valve and reflux valve shall be attended,
- (ii) *Painting:* Painting of surge tanks shall be carried out once in 2 years.

Air-Vessel

Daily:

- (i) Check air-water interface level in sight glass tube,
- (ii) The air water level should be within range marked by upper and lower levels and shall be preferably at middle,
- (iii) Check pressure in air receiver at interval of every 2 hours.

Quarterly:

- (i) Sight glass tube and cock shall be flushed,
- (ii) All wiring connections shall be checked and properly reconnected,
- (iii) Contacts of level control system and pressure switches in air supply system shall be cleaned.

Yearly:

- (i) The air vessel and air receiver shall be drained, cleaned and dried,
- (ii) Internal surface shall be examined for any corrosion etc. and any such spot cleaned by rough polish paper and spot-painted,
- (iii) Probe heads of level control system shall be thoroughly checked and cleaned *accessories:* Maintenance of panel, valves and air compressor etc. shall be carried out as specified for respective appurtenances.

Zero-Velocity Valves and Air Cushion Valve

Foreign matters entangled in valve shall be removed by opening all hand holes and internal components of the valves including ports, disk, stem, springs, passages, seat faces etc. should be thoroughly cleaned and checked once in 6 months for raw water and once in a year for clear water application.

16.3 TELEMETRY AND SCADA SYSTEMS

16.3.1 Manual Monitoring

Normally the managers of O&M of water supply scheme monitor levels in service reservoirs, pressures and flows in a distribution system, and on operation of pumps such as hours of pumping and failure of pumps and monitor water quality by measuring residual chlorine. The line department/unit usually uses the telephone line or wireless system to gather the data, uses his discretion gained with experience and takes decisions to ensure that the system is operating with required efficiency. Manual collection of data and analysis may not be helpful in large undertakings if water supply utilities have to aim at enhanced customer service by improving water quality and service level with reduced costs. This is possible if the management acquires operational data at a very high cost.

16.3.2 Telemetry

The inspection, monitoring and control of O&M of a water supply utility/authority/agency can be automated partially through telemetry. Telemetry enables regular monitoring of the above data on real time basis and the data is provided to anyone in the organization who can review the data and take decision. In Telemetry system, probes/sensors are used and sense, generate signals for the level, pressure and flow in a given unit and transmits the signals by radio/by Telephone. Normally radio link is used and telephone line with a modem is used as spare communication. Microwave satellite or fiber-optic transmission systems are also used for data transmission. The water pumping stations may communicate via a cable buried with the pipe. However there may be locations where the main power may not be available and hence solar panels with a battery charger are used to power the remote terminal unit (RTU) and the radio. In urban areas RTU s can communicate on cell phones and or packed radio networks. For remote locations satellite technology is also available.

(a) Data for Collection by Telemetry

The data includes levels in service reservoirs, pressures and flows in a distribution system, flows/quantity of delivered into a SR and data on operation of pumps such as voltage, amperes, energy consumed, operating times and down times of pumps and chlorine residuals. In a telemetry system up-to the minute real time information is gathered from remote terminal unit located at the water treatment plant, reservoir, flow meter, pumping station etc. and transmitted to a central control station where the information is updated, displayed and stored manually or automatically.

(b) Processing Data from Telemetry

The meter readings from reservoirs are useful information for managing the distribution system and helps in preventing overflow from reservoirs. However, the effectiveness of telemetry in pumping operations is dependent on reliability of instrumentation for measuring flows, pressures, KWh meters. Standard practice is to calculate pump efficiency and water audit calculations on a monthly basis. Telemetry can also be used to supervise water hammer protection system wherein the pump failures are linked to initiate measures to prevent occurrence of water hammer.

(c) SCADA Systems (Supervisory Control and Data Acquisition)

Supervisory Control and Data Acquisition (SCADA) systems provide control functionality and alarms at water supply scheme sites which in many cases are very remote. These systems were often used to solve single problems such as reducing power cost, or improving control of a particularly complex operation. The installation of SCADA has subsequently been seen as a means to satisfy a variety of increasing pressures such as consumer demands, regulatory requirements, and to also satisfy the need to reduce operational costs. The deployment of SCADA systems has been extended to cover large water supply schemes and has been found very effective.

An important challenge to the commercial success of the organization is to harness the data collection power of the SCADA systems to provide a wealth of operational information to all levels of the organization. Past systems that have been installed in some of the water treatment plants have failed to meet expectations regarding data availability. This has primarily been attributed to difficulties associated with merging traditional engineering and new IT methodology, and a lack of system openness in data interconnectivity and communications.

(d) Remote Terminal Units (RTU)

A Remote Terminal Unit (RTU) is a microprocessor-controlled electronic device that interfaces objects in the physical world to a SCADA by transmitting telemetry data to the system and/or altering the state of connected objects based on control messages received from the system. Modern RTUs are usually capable of executing simple programmes autonomously without involving the host computers of SCADA system to simplify deployment, and to provide redundancy for safety reasons. An RTU in a modern water management system will typically have code to modify its behaviour when physical override switches on the RTU are toggled during maintenance by maintenance personnel. This is done for safety reasons; a miscommunication between the system operators and the maintenance personnel could cause system operators to mistakenly enable power to a water pump when it is being replaced, for example.

Chapter 17

WATER AUDIT AND LEAKAGE CONTROL

17.1 DEFINITION OF WATER AUDIT

Water audit of a water supply scheme can be defined as the assessment of the capacity of total water produced by the Water Supply and Sanitation Authority (WSSA)/Community Based Water Supply Organization (CBWSO) and the actual quantity of water distributed throughout the area of service by the WSSAs/CBWSOs. Therefore, this leads to an estimation of the losses otherwise known as Non-Revenue Water (NRW) and the Un-accounted-For Water (UFW). NRW is the expression used for the difference between the quantity of water produced (or supplied) and the quantity of water billed or accounted for. The unaccounted-for water (UFW) is the part of the NRW that remains after deducting the unbilled but authorised consumption. Examples of such consumption are the water used for backwashing of filters, flushing of pipes, washing streets, firefighting, public taps and fountains, parks etc. The volume used for these purposes is usually marginal compared to the total water supplied, which makes the difference between UFW and NRW small in many systems.

Water audit in a water supply system is broadly, similar in nature to the energy audit and determines the amount of water lost from source of water to the distribution system including losses at users' taps due to leakages and other reasons such as theft, unauthorized or illegal withdrawals from the systems and thus, these losses costs the water utility. Complete water audit plan gives a detailed profile of a water supply system including its distribution system and water users, thereby facilitating easier and effective management of the resources with improved reliability. It helps in undertaking a correct diagnosis of the problems faced and suggests optimum solutions. It is also an effective tool for realistic understanding and assessment of the system's performance level, efficiency of the service and the adaptability of the system for future expansion & rectification of faults during modernization.

Elements of the water audit include a record of the amount of water produced, total water supplied, water delivered to metered users, water delivered to unmetered users, water losses and suggested measures to address water loss (through pinpointing & minimising leakages and other unaccounted for water losses).

Generally, the following are the recommended steps of a water audit exercise:

(a) To conduct a water audit of the water distribution system and water accounting practices etc. and validation,
(b) Preparation of worksheets and sample calculations for each step of the water audit,
(c) To identify, measure and verify all water consumption and losses,
(d) To identify and control apparent losses in metering and billing operations, and recover missed revenues,
(e) To implement a leakage and pressure management programme to control real losses, conserve water and contain costs,
(f) Develop plans to assemble the proper resources, information and equipment to launch a sustained accountability and loss-control programme,
(g) Prepare a game-plan for setting short, medium and long-term goals and estimate the returns on investment.

Leak detection programme is a tool that helps in minimizing leakages and tackling small problems before they scale-up to major ones. These programmes lead to:

(a) Reduced water losses,
(b) Improved reliability of the supply system,
(c) Enhanced knowledge of the distribution system,
(d) Efficient use of existing supplies,
(e) Better safeguards to public health and property,
(f) Improved public relations,
(g) Reduced legal liability,
(h) Reduced disruption, thereby improving levels of service to customers, and
(i) Improved financial performance.

17.2 APPLICATION OF WATER AUDIT

Application of water audit process in domestic/ municipal sector may consist of various steps including water audit, interventions for water conservation/ leakages/ losses control, regulatory framework & community involvement and evaluation of effectiveness of the interventions undertaken.

17.2.1 Water Audit Methodology

A reliable water audit methodology was developed jointly by the American Water Works Association (AWWA) and International Water Association (IWA) in the year 2000. The water balance of this methodology is given in Table 17.1 and it shows schematically, the various components in which water volumes (typically one year) are tracked.

The water balance tracks – from left to right – how a water supply agency/ utility supplies water volumes from source to customer and provides the format for the utility to quantify amounts of billed and lost water. Fundamental to the AWWA/ IWA Water Audit methodology is the distinction that treated drinking water goes to two places: authorized consumption by consumers (its intended use) and a portion to losses (through inefficiencies). Within the component of losses, two broad types exist:

Apparent Losses are the "paper" losses that occur in utility operations due to customer meter inaccuracies, billing system data errors and unauthorized consumption. In other words, this is the water that is consumed but is not properly measured, accounted or paid for. These losses cost utilities revenue and distort data on customer consumption patterns.

Real Losses are the physical losses of water from the distribution system, including leakage and storage overflows. These losses inflate the water utility's production costs and stress water resources since they represent water that is extracted and treated, yet never reaches beneficial use.

Table 17.1: Various Components of Water Volumes Tracked (Typically One Year)

System Input Volume (corrected for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
	Water Losses		Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
		Apparent Losses	Unbilled Unmetered Consumption	
			Unauthorized Consumption	
			Customer Metering Inaccuracies Data Handling Errors	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer metering	

(Source: AWWA/IWA, 2000)

17.2.2 Planning and Preparation

Planning and preparation shall include the data collection element and the preparation of sketch plans for the distribution centres and other locations for the installation of the flow meters. Also included within this shall be the confirmation of flow rates for the bulk meter locations which has been carried out by the use of portable ultrasonic flow meters.

(a) Preliminary Data Collection

The water distribution drawings are to be studied and updated. The number of service connections is to be obtained and in the drawings of the roads, the exact locations of service connections marked. The district and sub-district boundaries are suitably fixed taking into consideration the number of service connections, length of the mains, and pressure points in the main. The exact locations of valves, hydrants with their sizes should be noted on the drawings.

The above activities will help in planning the conduct of sounding of the system for leaks or for fixing locations for conduct of pressure testing in intermittent water supply system before commencement of leak detection work or for measuring pressure and leak flow in the continuous water supply system.

(b) Pipe Location Survey

Electronic pipe locators can be used during survey. These instruments work on the principle of Electromagnetic signal propagation. It consists of a battery operated transmitter and a cordless receiver unit to pick up the signals of pre-set frequency. There are various models to choose from. Valve locators are metal detectors that are available which can be used to locate buried valves.

17.2.3 Verification and Updating of Maps

Mapping and inventory of pipes and fittings in the water supply system: If the updated maps are available and bulk meters are in position, network survey can be taken up as a first step. Otherwise maps have to be prepared and bulk meters fixed. The agency should set up routine procedures for preparing and updating maps and inventory of pipes, valves and consumer connections. The maps shall be exchanged with other public utilities and also contain information on other utility services like electricity, communications etc.

17.2.4 Installation of Bulk Meters

The major activity during the overall water audit will be bulk meter installation at those points on the distribution network where water enters the system. It is expected that bulk meters will be required at the following locations:

(a) All major system points (e.g. raw water inlet, clear water outlet, main distribution branch, SRs, etc.),
(b) Major transfer mains which are expressly required for audit,
(c) At distribution centres, the most appropriate meter position is on the outlet pipe from the service reservoir. Installation of a meter at this point will allow measurement of flows into the system not only if supplies are coming from the service reservoir but also if they are being pumped directly from the clear water reservoir (CWR),
(d) The size of the meter can be determined by flow of water, size of pipeline and meter manufacturer's specifications having consideration of the following:
    (i) Number of properties served,

(ii) Per capita consumption (litres/person/day),
(iii) Population density,
(iv) Meter manufacturer's specifications.

Hours of supply-meter sizes must be decided according to current supply hours or size of the pipe. Future changes to the system operation may require the substitution of some bulk meters with those of a smaller size, due to reductions in flow over longer supply hours.

It is expected that bulk meters installed in locations where supply is rationed will tend to over-read. This is because when supplies are turned on, the air present in the pipes can cause the meter to spin. This problem may be overcome through the use of combined pressure and flow loggers. Flow through the meter will be recorded in the normal way. However, analysis of the pressure and flow plots together will enable the identification of that period of time when a flow is recorded at zero pressure. This time should correspond to the period when the meter is spinning, and the true flow through the meter over a period of time can therefore be calculated.

17.2.5 Monitoring of the Production System

The assessment of the leakage rates through the various features of the water supply system should be undertaken. These will include raw water transmission system, reservoirs, treatment plant, clear-water transmission system, inter-zone transmission system, boreholes/ sources of water supply. Details are provided in Chapter Seven and Nine.

17.2.6 Transmission System

The methodology adopted to make an assessment of the level of losses in the transmission system is to install insertion probes/bulk meter at both ends of each section of the main being monitored, thus monitoring both the inflow and outflow of the section. This monitoring should be done for a minimum period of 7 days. The difference of inflow and outflow will indicate the losses in the transmission main. The advantage of this method is that the trunk main need not be taken out of service.

Another way to measure leakage is to close two valves on the main. 25mm tapping are made on either side of the upstream valve and a small semi-positive displacement flow meter is connected between the two tapings. Flow through this meter will indicate the leakage in the main between the two closed valves. It must be ensured that the downstream valve is leak proof. The approximate position of any leakage measured can be determined by the successive closing of sluice valves along the main in the manner of a step test.

17.2.7 Reservoirs

To reduce or avoid any leakage or consequent contamination in reservoirs, the reservoirs should be periodically tested for water tightness, drained, cleaned, washed down and visually inspected. The losses in water storage structures can be monitored for a particular period noticing the change in the level gauges when the structure is out of use i.e. there is no inflow and outflow of water during this monitoring period.

The most reliable method for measurement of leakage from a service reservoir is to fill it to full level and isolate it from supply and to measure change in level over suitable time period. Suitable equipment to measure reservoir levels could be chosen like:

(a) Sight gauges,
(b) Water level sensors (as per manufacturer's instruction),
(c) Float gauges,
(d) Submersible pressure & level transducers (as per manufacturer's instruction).

17.2.8 Treatment Plant and Performance Monitoring

Performance monitoring refers to the assessment of water quality delivered from a device/process, and it requires analysis of a number of different parameters that are often dependent on the final use of the water. Users are advised to consult the relevant water quality standards or requirement on the uses of the water. The losses in a treatment plant can be monitored by measuring the inflow into the plant and outflow from the plant with the help of mechanical electronic flow recorders. The difference of inflow and outflow for the monitoring period will indicate the water losses in the plant. In case the loss is more than the design limit, further investigation should be carried out for remedial measures.

Performance monitoring refers to the assessment of water quality delivered from a device/process, and it requires analysis of a number of different parameters that are often dependent on the final use of the water. Users are advised to consultant the relevant water quality standards or requirement on the uses of the water.

17.2.9 Boreholes

In conjunction with the programme of bulk meter installation is the operation to monitor the approximate yield from the boreholes. This exercise can be carried out by the installation of semi-permanent meters to the boreholes on a bypass arrangement similar to that for the bulk meters. This can be effected by utilizing the smaller diameter bulk meters. Insertion probes or the portable ultrasonic flow meters will be used for measurement of flows on the common feeder mains.

17.2.10 Monitoring of the Distribution System

Distribution system comprises of service reservoirs, distribution mains & distribution lines. Metered, unmetered (flat rate), public stand posts, hydrants, illegal connections water audit of the distribution system consists of:

(a) Monitoring of flow of water from the distribution point into the distribution system,

(b) Consumer meter sampling i.e. District Metering Area (DMA) and estimating metered use by consumers, if any,

(c) Estimating losses in the appurtenances and distribution pipeline network including consumer service lines.

17.2.10.1 Monitoring Flow into the Distribution System

A bulk meter of the appropriate type and size is installed at the outlet pipe of the service reservoir or at the point where the feeding line to the area branches off from the trunk main. If water from the DMA flows out into another zone a valve or meter is to be installed at this outlet point.

Furthermore, DMAs (District Metered Areas) can be helpful in managing pressures well as NRW. At the inflow to the DMAs, pressure reducing valves can be installed, and the pressure in every DMA can be adjusted to the required level. There is no ideal size for a DMA. The size, whether it is 500 or 5,000 service connections, is always a trade-off. The decision has to be made on a case-by-case basis and depends on a number of factors (e.g., hydraulic, topographic, practical and economic).

The size of DMAs has an impact on the cost of creating them. The smaller the DMA, the higher the cost. This is because more valves and flow meters will be required and maintenance is costlier. However, the benefits of smaller DMAs are that:

- New leaks can be identified earlier, which will reduce awareness time;
- Location time can be reduced because it will be faster and easier to pinpoint the leak; and
- As a by-product, it is easier to identify illegal connections.

Topography and network layout also play an important role in DMA design and size. Therefore, there will always be DMAs of different sizes in a distribution network. An important influencing factor is the condition of the infrastructure. If mains and service connections are fragile, then bursts will be more frequent and the optimal DMA will be relatively small. On the other hand, in areas with brand new infrastructure, DMAs can be larger and still manageable.

According to the recommendations of the International Water Association's (IWA) Water Loss Task Force, if a DMA is larger than 5,000 connections, it becomes difficult to discriminate small bursts (e.g. service connection bursts) from variations in customer night use. In networks with very poor infrastructure conditions, DMAs as small as 500 service connections might be warranted. A calibrated hydraulic model should always be used for DMA designs irrespective of the size of the DMAs.

17.2.10.2 Customer Meter Sampling

Water audit is a continuous process. However, consumers' meter sampling can be done on a yearly basis by review of all existing bulk and major consumers for revenue. A correlation between the production/power consumed in the factory viz-a-viz water consumption can be evaluated by:

(a) Sampling of 10% of all bulk and major consumers,
(b) Sampling of 10% of small or domestic consumers,
(c) Series meter testing of large meters suitably according to standards, calibrated meters.
(d) Testing of 1% large and 1% domestic meters,
(e) Estimating consumption at a representative 5% sample of Water Points (WPs) and unmetered connections by carrying out site measurements.

All non-functioning and broken meters in the sample areas will be replaced and all meters may be read over a week. This information will be brought together with information derived from the workshop and series testing in order to estimate the average water delivered and correction factors for consumer meters. These factors can then be extrapolated to the rest of the customer meter database.

17.2.10.3 Losses in Customer Service Lines and Appurtenances

Losses can be calculated by deducting the following from the total quantity by the following:

(a) Metered consumption,
(b) Illegal connection consumption (assuming metered use),
(c) PSP use,
(d) Free supply, use in public toilets, parks etc.

17.2.11 Analysis

The information of the results of monitoring the distribution system together with the results of the bulk metering exercise will be consolidated and brought together to produce the water balance report and the overall water audit report. These results may be interpreted in financial terms. Further exercise will be done to classify the water consumed/wasted/lost in financial terms with relation to the current and future level of water charges. This exercise will be carried out as a result of the field tests and the review of existing records forming part of the overall water audit.

This water audit will provide sufficiently, accurate area wise losses to priorities the area into three (3) categories viz.

(a) Areas that need immediate leak detection and repair,
(b) Areas that need levels of losses (NRW) to be closely monitored,
(c) Areas that appear to need no further work at the current time.

It is recommended that cursory investigation should be carried out in the areas that appear to have the least levels of losses (NRW), locating any major leaks, followed by the leak repairs would reduce the losses (NRW) levels further. After water audit of few cities/ villages, it has been reported that the components of NRW may generally be as follows (GoI, 2013):

(a) Leakage (physical losses) 35 to 50%,
(b) Meter under-registration 10 to 15%,
(c) Illegal/unmetered connections 3.5 to 6%,
(d) Public use 1.5 to 3.5%.

17.3 LEAKAGE CONTROL

The overall objective of leakage control is to diagnose how water loss is caused and to formulate and implement action to reduce it to technically and economically acceptable minimum. Specifically the objectives are:

- To reduce losses to an acceptable minimum,
- To meet additional demands with water made available from reduced losses thereby saving in cost of additional production and distribution,
- To give consumer satisfaction,
- To augment revenue from the sale of water saved.

(a) Water Losses

The water losses can be classified into two categories:

- Physical losses (Technical losses),
- Non-physical losses (Non-technical losses/Commercial losses).

(i) Physical Losses (Technical Losses)

This is mainly due to leakage of water in the network and comprises of physical losses from pipes, joints & fittings, reservoirs & overflows of reservoirs & sumps.

(ii) Non-Physical Losses (Non-Technical Losses)

Theft of water through illegal, already disconnected connections, under-billing either deliberately or through defective meters, water wasted by consumer through open or leaky taps, errors in estimating flat rate consumption, public stand posts and hydrants.

(b) Leakage Detection and Monitoring

The major activities in the leak detection work in the distribution system:

- Preliminary data collection and planning,
- Pipe location and survey,

- Assessment of pressure and flows,
- Locating the leaks,
- Assessment of leakage.

17.4 BENEFITS OF WATER AUDIT AND LEAK DETECTION

Water audits and leak detection programmes can achieve substantial benefits, including the following:

(a) Reduced Water Losses

Water audit and leak detection are the necessary first steps in a leak repair programme. Repairing the leak will save money for the utility, including reduced power costs to deliver water and reduced chemical costs to treat water.

(b) Financial Improvement

A water audit and leak detection programme can increase revenues from customers who have been undercharged, lower the total cost of whole sale supplies and reduce treatment and pumping costs.

(c) Increased Knowledge of the Distribution System

During a water audit, distribution personnel become familiar with the distribution system, including the location of main and valves. This familiarity helps the utility to respond to emergencies such as main breaks.

(d) More Efficient Use of Existing Supplies

Reducing water losses helps in stretching existing supplies to meet increased needs. This could help defer the construction of new water facilities, such as new source, reservoir or treatment plants.

(e) Safeguarding Public Health and Property

Improved maintenance of a water distribution system helps to reduce the likelihood of property damage and safeguards public health and safety.

(f) Improved Public Relations

The public appreciates maintenance of the water supply system. Field teams doing the water audit and leak detection or repair and maintenance work provide visual assurance that the system is being maintained.

(g) Reduced Legal Liability

By protecting public property and health and providing detailed information about the distribution system, water audit and leaks detection help to protect the utility from expensive law suits.

Chapter 18 REVENUE INCLUDING BILLING AND COLLECTION

Revenue management system is an important aspect of any water supply system as it governs the financial and technical sustainability to the utility. Apart from fixing a tariff structure, billing and collection of revenue play an important part in the overall administration.

18.1 TARIFF FIXATION

Tariffs are instruments for recovering the cost of providing adequate water supply service to customers and must reflect not only the fixed costs of the supply system but also its operating expense and long-term sustainability. Tariff rates must satisfy the following requirements:

(a) **Adequacy:** The revenues generated from a water rate schedule must be sufficient to meet the revenue requirements of the Utility. The rates should be able to promote the Utility's financial viability and growth,

(b) **Public Service:** The tariffs must be set at a reasonable level that reflects the Utility's role as a public utility providing a public service,

(c) **Equitable and Socialized Pricing:** The tariffs must equitably distribute the cost of the service to all classifications and sizes of connections. Their structure should define a relatively low fixed rate for some minimum level of consumption to benefit the low income users, and higher rates for those who use greater quantities of water,

(d) **Affordability Level:** The tariff rates must be kept affordable to the Low Income Group (LIG). For this reason, the minimum and maximum charges may be specified for the average income of the LIG within the service area,

(e) **Water Conservation:** The tariff rates must encourage the wide water usage needed to attain economies of scale, but must also discourage unreasonable and wasteful usage of water,

(f) **Enforceability:** The tariff rates must be fair, reasonable and transparent. They should be justifiable and acceptable to the consumers.

For this reason, the practice is for the water tariff to be fixed by the Utility in consultation with the users, considering basically the capacity of the users to pay and costs of the O&M, as well as other relevant factors.

(Source: https://www.slideshare.net/esmeraldoerandio/rural-water-supply-volume-iii-operation-and-maintenance-manual-PHILLIPINES).

The water supply charges in urban utilities are proposed by the respective utility and approved by EWURA after completing its regulatory procedures. Tariffs in small towns and rural water supply schemes are approved by RUWASA. Tariff setting takes into account the ability of the system to meet the following expenditures:

(a) O&M cost (Recurring and non- recurring establishment cost),
(b) Depreciation,
(c) Debt services and doubtful charges,
(d) Asset replacement fund.

It is recommended that the tariff structure should be reviewed periodically/ annually to cater for changes in the market.

18.2 CATEGORIES OF CONSUMERS

Among the different categories, the domestic consumers are the privileged class of people in terms of supply of water and of consumer's collection of taxes mainly because they use water for their healthy existence. The other categories include commercial complexes, Hotel/restaurants, Industries/ Bulk consumers/ offices/institutions; largely use water and are usually charged with a higher tariff. Therefore, the distribution of cost incurred on the maintenance of such a system for each class of consumers including un-privileged people should be logically and appropriately determined with reference to the level of service rendered. Finally, a projected income on account of water charges should take into account the various factors itemized in the previous section.

18.3 METHODS OF LEVYING WATER CHARGES

The methods of levying water charges can be any one or more of the following:

(a) Metered consumption of water,
(b) Non-Metered System:
    (i) Fixed charge per house per month (depending upon the size of the house) or per connection per month, or
    (ii) Fixed charge per family per month or per tap per month/per household, or
    (iii) Percentage of payable value of the property.

18.4 DISTRIBUTION OF BILLS TO THE CONSUMER

The distribution of bills to customers may be done either electronically through customer's mobile phone (especially in urban areas) or can be done by operators specially authorized for this purpose or meter readers and bills can be distributed at the time of meter reading.

18.4.1 Payment of Bills by Consumer

The payments can be accepted at any one or more ways of the following:

(a) Counters at water utility office,
(b) At bank / banks authorized for accepting payments,
(c) Via customer mobile number through authorized Commercial Banks,
(d) Door to door/on the spot recovery by authorized person (in case of delayed/ accumulated bills),
(e) Payment via the mobile phones using MPesa, Tigo Pesa, T-Pesa, Halopesa or Airtel Money for Tanzania (2019).

18.4.2 Delayed Payments

Since water is being treated as a commodity consumed, the advance billing is generally not carried out. It is therefore 'a must' to levy penalty/interest on the delayed payments of the bills. Computerization overcomes many of the defects in the manual system, is fast and gives control on the system.

Chapter 19

COMMUNITY PARTICIPATION AND COMPLIANT REDRESSAL SYSTEM IN OPERATION AND MAINTENANCE OF WATER SUPPLY AND SANITATION PROJECTS

19.1 INSTITUTIONAL ROLES AND RESPONSIBILITIES

The Ministry, Water Utility/Agency, Local Governments and Communities cannot succeed on their own. They need to co-operate in the whole process of provision of water supply and sanitation services. In ensuring co-operation, each stakeholder should understand the roles and responsibilities they can play in the overall process. Other internal and external stakeholders may include line departments/sections responsible for O&M in the utility/agency, training institutions, and the local private sector and NGOs. In this context, community has a great role in operation and maintenance of the water supply and sanitation projects in ensuring sustenance of services.

19.1.1 Roles of Ministries

(a) Coordination of various ministerial departments, i.e. MoW, PO-RALG, MoEST, MoW
(b) Provide managerial and technical backstopping on implementation of water and sanitation projects in the community,
(c) Facilitate in establishing clear communication lines between water committees with service providers and any agency offering backstopping skills,
(d) Provide frameworks to the water organizations on tariff setting in water and sanitation projects that is undertaken by EWURA and RUWASA,
(e) Undertaking major repairs and augmentations,
(f) Review of the operation and maintenance manual,
(g) Review of aspects of sustainability of water supply and sanitation projects,
(h) Allocating special funds to execute contingency plans so that the water supply schemes are not affected by inadequate power supply, adverse seasonal conditions like drought periods and natural calamities like earthquake, floods, etc.

19.1.2 Roles of Urban and Local Government Authorities

(a) Sensitize communities in contributing towards meeting O&M costs,

(b) Facilitate in ensuring security and safety of water sources and supply systems,
(c) Support management of water and sanitation projects,
(d) Preparation of by-laws,
(e) Liaising with Ministry of Lands regarding water sources conservation.

19.1.3 Roles of Basin Water Boards

(a) Provision of technical backstopping on implementation of water supply and sanitation schemes, especially in the aspect of water sources and adaptation to climate change impacts,
(b) Water sources protection and pollution control,
(c) Provide guidelines and standards for construction and maintenance of water source structures,
(d) Approve, issue and revoke water use and discharge permits (compliance);
(e) Monitor and enforce water use and discharge permits and pollution prevention measures;
(f) Monitor compliance to the water use and discharge permits granted,
(g) Promote water use efficiency to all stakeholders,
(h) Put a mechanism to ensure that, the infrastructure of water management are properly maintained and a comprehensive preventive maintenance system is in place,
(i) Develop its own water quality-monitoring programme, adhere to it and publish the results for the public,
(j) Put in place and publish a workable water demand management system,
(k) Put in place mechanisms for water sources protection and conservation of the environment/catchments.

19.1.4 Roles of the Regulators (EWURA and RUWASA)

In Tanzania, two regulators can be identified for urban and rural and suburban areas respectively and these are EWURA and RUWASA.

19.1.4.1 Energy and Water Utilities Regulatory Authority (EWURA)

The roles of EWURA for urban and National WSSA including the following in relation to water supply and sanitation services shall be to:

(a) Exercise licensing and regulatory functions in respect of water supply and sanitation services;
(b) Establish standards relating to equipment attached to the water and sanitation system;
(c) Establish guidelines on tariffs chargeable for the provisions of water supply and sanitation services;
(d) Approve tariffs chargeable for the provision of water supply and sanitation services;

(e) Monitor water quality and standards of performance for the provision of water supply and sanitation services;
(f) Initiate and conduct investigations in relation to the quality of water and standards of service given to consumers;
(g) Conduct studies necessary for administrative or management purposes;
(h) Collect and compile data on licensees as it considers necessary for the performance of its functions;
(i) Issue orders or give directions to any person granted a license in respect of a regulated activity under this Act or other written law;
(j) Charge levies, and fees applicable to Water Authority and other sector participants in respect of regulatory activities of the EWURA charged in accordance with section 41 of the Energy and Water Utilities Regulatory Authority Act;
(k) Establish or approve standards and codes of conduct in respect of: (i) licensees; (ii) consumers; and (iii) public safety;
(l) Promote the development of water supply and sanitation services in accordance with recognized international standard practices and public demand;
(m) Prescribe rules and declaration and cause the same to be published in the Gazette and in at least one Kiswahili and one English newspaper circulating in a water authority's area of jurisdiction; and
(n) Perform other functions which are incidental or ancillary to the major functions.

19.1.4.2 Roles of Rural Water and Sanitation Agency (RUWASA)

The roles of RUWASA are as outlined in the water supply and sanitation Act No. 5 of 2019 follows:

(a) Development and sustainable management of rural water supply and sanitation projects.
(b) Plan, design, construct and supervise rural water supply projects;
(c) Conduct ground water survey including prospecting and explorations, and undertake drilling operations including water well flushing and pumping test, and rehabilitation of water wells;
(d) Design and construct dams of different types and carry out geotechnical and soil investigation for dam construction and other civil engineering structures;
(e) Monitor and evaluate performance of community organizations in relation to rural water supply and sanitation services;
(f) Promote and sensitize rural communities on sanitation, hygiene education and practice as well as protection and conservation of rural water sources;
(g) Provide financial and technical support to community organizations (CBWSOs) for major maintenance of rural water supply schemes;
(h) Provide support to community organizations in relation to management, operation and maintenance of rural water supply schemes;

(i) Advise the Minister on issues related to rural water supply and sanitation;
(j) Facilitate participation of communities in the identification, planning, construction and
(k) Management of rural water and sanitation projects;
(l) Facilitate private sector engagement in the provision of the rural water supply and sanitation services;
(m) Facilitate training and capacity building to community organizations in financial, technical and management of rural water supply schemes;
(n) Register and regulate the performance of community based water supply organizations.

19.1.5 Roles of Water Supply and Sanitation Authorities

(a) Monitor operations and maintenance of the water and sanitations networks and respond immediately on any system default,
(b) Implement the tariffs set by the regulator (EWURA/RUWASA) in accordance with the type of the water supply and sanitation projects,
(c) Study community perception towards the services provided,
(d) Redress/Mitigate community complaints on the services provided,
(e) Collaborate with LGAs and communities (CBWSOs) in running the water supply and sanitation projects,
(f) Access managerial and technical backstopping on implementation of water supply and sanitation projects in the community from regulators (EWURA/RUWASA),
(g) Establish clear communication lines between the CBWSOs and service providers and any agency offering backstopping skills,
(h) Rehabilitate dilapidated infrastructure.

19.2 COMMUNITY PARTICIPATION AND MOTIVATION IN MAINTENANCE OF WATER SUPPLY AND SANITATION PROJECTS

The task is to build confidence and general awareness among the community for taking up the management of water facilities for their satisfaction water supply protection and sustainability of system. Community mobilization can be taken up through different activities and with different focus groups. Upon undertaking such activities, the community may contribute the following:

(a) Participate in conservation of water sources, water supply and sanitation infrastructures,
(b) Pay for water supply and sanitation services provided,
(c) Provide feedbacks to the water supply utility/agency on the functionality or failure of the water supply and sanitation projects.

19.2.1 Roles of Service Providers

(a) Ensure availability of appropriate and quality system spare parts and tools,
(b) Provide technical backstopping on operationalization and maintenance of water supply and sanitation schemes in the community.

19.2.2 Roles of Academic and Research Institutions

(a) Collaborate and coordinate researches on finding solutions pertaining to socio-economic and technological factors influencing or affecting the sustainability of water and sanitation projects,
(b) Training operators in management of the projects,
(c) Innovating new means of enhancements of water supply and sanitation projects.

19.2.3 Roles of NGOs and CBOs

(a) Sensitize community to trigger the sense of ownership and protection water and sanitation facilities,
(b) Educate community on integration and good water and sanitation practices,
(c) Provide managerial and technical backstopping on implementation of water and sanitation schemes in the community as provided for in the Water Supply and Sanitation Act No. 5 of 2019.

19.2.4 Roles of CBWSOs

The CBWSOs are legal water organizations established for the purpose of operating and managing water supply projects. The recent water sector reform through Water Act No. 5 of 2019 has changed the organization structure and administrative systems. Technical teams comprising of a technician and an accountants at certificate levels who are employed rather than volunteers, now manage these organizations. The role of water committee comprising of representative from beneficiaries is to monitor the efficiency of the technical team.

Roles of CBWSOs includes to:

(a) Own movable and immovable properties including public taps and waterworks;
(b) Manage, operate and maintain public taps and waterworks and provide an adequate and safe supply of water to its consumers;
(c) Determine rules for the use of public taps and or waterworks by consumers;
(d) Install water meters for the purpose of measuring the amount of water supplied to a public tap or a consumer;
(e) Charge consumers for the water supplied from public taps and or waterworks;

(f) Limit the access of any persons from the water source, public taps or from supplies from the waterworks who are not complying with the rules, regulations or the constitution of the community organization;

(g) Consult and cooperate with the village council or any other institution responsible for land to plan and control the use of land in the immediate vicinity of the water points and or waterworks; and

(h) Do such other thing or enter into any transaction which, in the opinion of the Community Water Committee is necessary and proper in carrying out its obligations.

19.3 COMPLAINT COMMUNICATION AND REDRESSAL SYSTEM

Deficiency in maintenance and service delivery may occur in water supply and sanitation projects components maintained. In such a complex scenario, general public who intend to make a compliant on deficiency in maintenance of the project may not be aware who is the concerned authority to set right the deficiency and to whom to make the complaint. RUWASA will be the body which will review any appeals from the consumers.

19.3.1 Complaint Communication

The procedure for lodging complaints should be as follows:

(a) A complaint cell may be created in the water supply utility and RUWASA office equipped with necessary soft & hard skills duly giving adequate publicity about the nature of the complaint can be made and also the details such as E-mail address/ fax number/ telephone number/ postal address, etc. of the complaint cell,

(b) As being done in the case of emergency need of Police/ Fire service , a three digit toll free number may be assigned for lodging urgent complaint through Telephone/ mobile phone,

(c) A member of general public who instantly comes across any leakage/ overflow or any deficiency in maintenance of the schemes may lodge a complaint to the three digit number,

(d) Immediately after receipt of the complaint, a compliant number will be assigned and informed to the complainant, if the complaint is received by phone/E-mail.

19.3.2 Redressal System

Complaint received may be examined and determine which maintenance agency/unit is within an hour of receipt of the compliant. It may be informed either by phone/ e-mail to the department/utility/WSSA/RUWASA or to the local area (CBWSOs). If the complaint is received through post, also the above system may be adopted.

(a) The respective maintenance agency should intimate the stage of action taken the next day to the complaint cell,

(b) The cell will create necessary files/ documents in computer and register the name and address of complainant, mode of receipt of compliant, assigning of complaint number, agency who is attending the complaint, present stage of action taken, etc.,

(c) The complaint cell may inform the facts such as who is the agency attending the complaints, their contact number and stage of action taken to the complainant, the next day after receipt of complaint (by phone/SMS/E-mail),

(d) The respective maintenance agency should report final stage of action taken within two days to the complaint cell (by phone/SMS/E-mail),

(e) The complaint cell may inform the final action taken, to the complainant immediately after receipt of details received from the concerned maintenance agency,

(f) EWURA or RUWASA may review the status of complaints received every week.

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APPENDICES

APPENDIX 1: MAINTENANCE OF DIFFERENT TYPES OF BOREHOLES

Type of Borehole	Activities	Probable Cause	Suggestions
Down-the-hole (DTH) Bore	Silting	Over pumping, reduction of yield, improper sitting of casing pipe etc.	✓ Inspection of the bore well to assess the performance of yield. ✓ Replace the pump-set of proper duty-condition match with the yield of the bore well. ✓ The appearance of fine silt with water is also an early indication of silting. ✓ Further pressing of the whole pipe assembly in the case of shallow casings will arrest the silting. ✓ In the case of hard rock bore well, flushing with compressor from the bottom will arrest/remove the silt
	Decrease in yield	Adverse seasonal conditions, clogging of pores, parallel exploitation in the neighboring well, sinking of new well in close proximity etc.	✓ Periodical flushing is essential for free flow of water ✓ Adhering to strict spacing norms to avoid interference of pumping wells. ✓ The well may also be subjected to Hydro- fracturing. ✓ Removal of silt and clay through ✓ Chemical/acid wash.
	Drying up (very low yield) of bore well	-As above-	✓ Periodical flushing, Hydro-fracturing etc. ✓ In case of defunct even after flushing it can be used as recharge well.

Type of Borehole	Activities	Probable Cause	Suggestions
Drilling Rig (DR) with Mild Steel (MS) casing	Mechanical Failure	Falling of foreign objects, pump assembly etc.	✓ Mechanical devises to lift the objects. ✓ Borehole camera can also supplement excellent information of the cause and remedy. ✓ Removal of silt and clay through ✓ Chemical/acid wash. Sometimes re-drilling may also prove to be success. ✓ In case no remediation is possible the bore ✓ well may be utilized for recharge.
	Silting	Over pumping	✓ Periodical inspection of the bore well to assess the performance of the well.
	Decrease in yield	Adverse aquifer condition,	✓ Periodical flushing is essential for free flow of water in the aquifer.
	Mechanical Failure		✓ As given for DTH Bore
		Incrustation/ corrosion to screens etc.	✓ Removal of incrustation through Acid wash.
	-	-	✓ Systematic chemical sampling (quality testing) of the bore water must be Undertaken.
	-	-	✓ Surroundings of the bore well should kept clean and tidy.
DR with Reinforced Cement Concrete (RCC) casing (Not common)	As narrated in DTH bore		✓ As narrated in DTH bore.
For Poly Vinyl Chloride (PVC) casing bores (Not more than 150 m depth)	As narrated for DR bores with MS casing		✓ As narrated in DTH bore

Type of Borehole	Activities	Probable Cause	Suggestions
Deep & Shallow Bore	Silting	Over pumping	✓ Periodical inspection of the bore well to assess the performance of the well ✓ Periodical flushing is essential for free flow of water in the aquifer
	Decrease in yield	Adverse aquifer condition	
	Drying up of bore well	Incrustation & silting of fractures & fissures	✓ Casing should be inserted up to the weathered zone
	Mechanical Failure	Falling of foreign objects	✓ Removal of silt and clay through chemical wash
			✓ In case of drip in the yield the well may be subjected to hydro-fracturing ✓ In addition, the points described under Mechanical failure in DTH bore may also be followed

(Source: GoI, 2013)

APPENDIX 2: TROUBLESHOOTING FOR BOREHOLE/TUBE WELLS

Problem	Problem Cause	Remedies
Silting of borehole Decrease in water yield/ discharge Mechanical Failure	Over pumping, adverse aquifer conditions, incrustation of screens and aquifers, falling of foreign objects in the bore, damage of mild steel screens due to corrosion	Deeping to appropriate level, repair/replacement of damage parts, cleaning by chemicals

(Source: Pradhikaran, 2012)

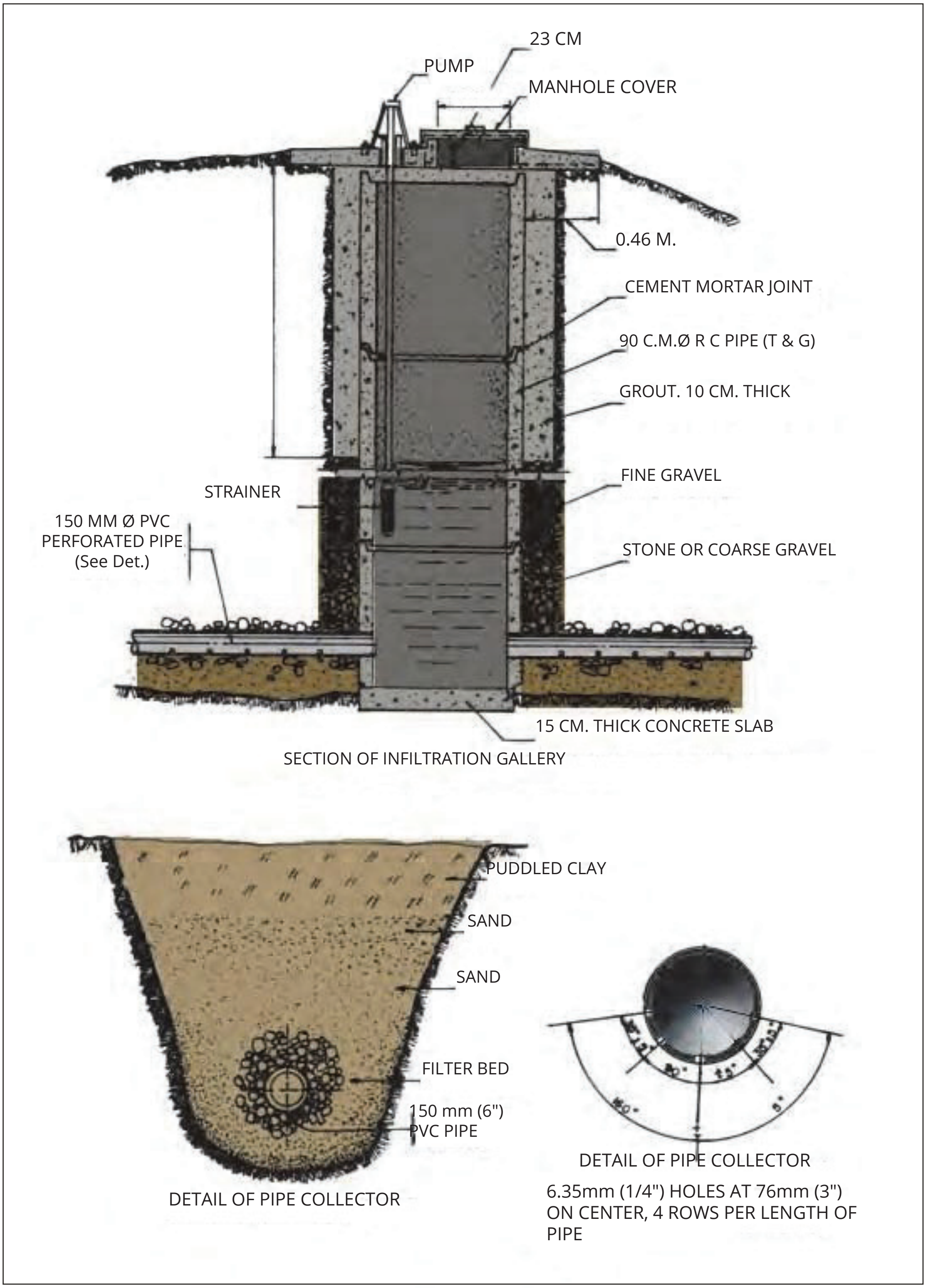
APPENDIX 3: PUMPING TESTS PROCEDURE

1. Prior to starting the pump, measure and record the static water level.
2. After starting the pump, measure the corresponding water levels. Discharge should be greater than the required yield and should be maintained at a constant rate during the entire duration of the test for 24 hours. Measurement intervals should be as follows:

Time from Start of Pumping (min)	Time Intervals Between Measurements (min)
0 – 15	0.5 – 1
10 – 15	1
15 – 60	5
60 – 300	30
300 – end of test	60

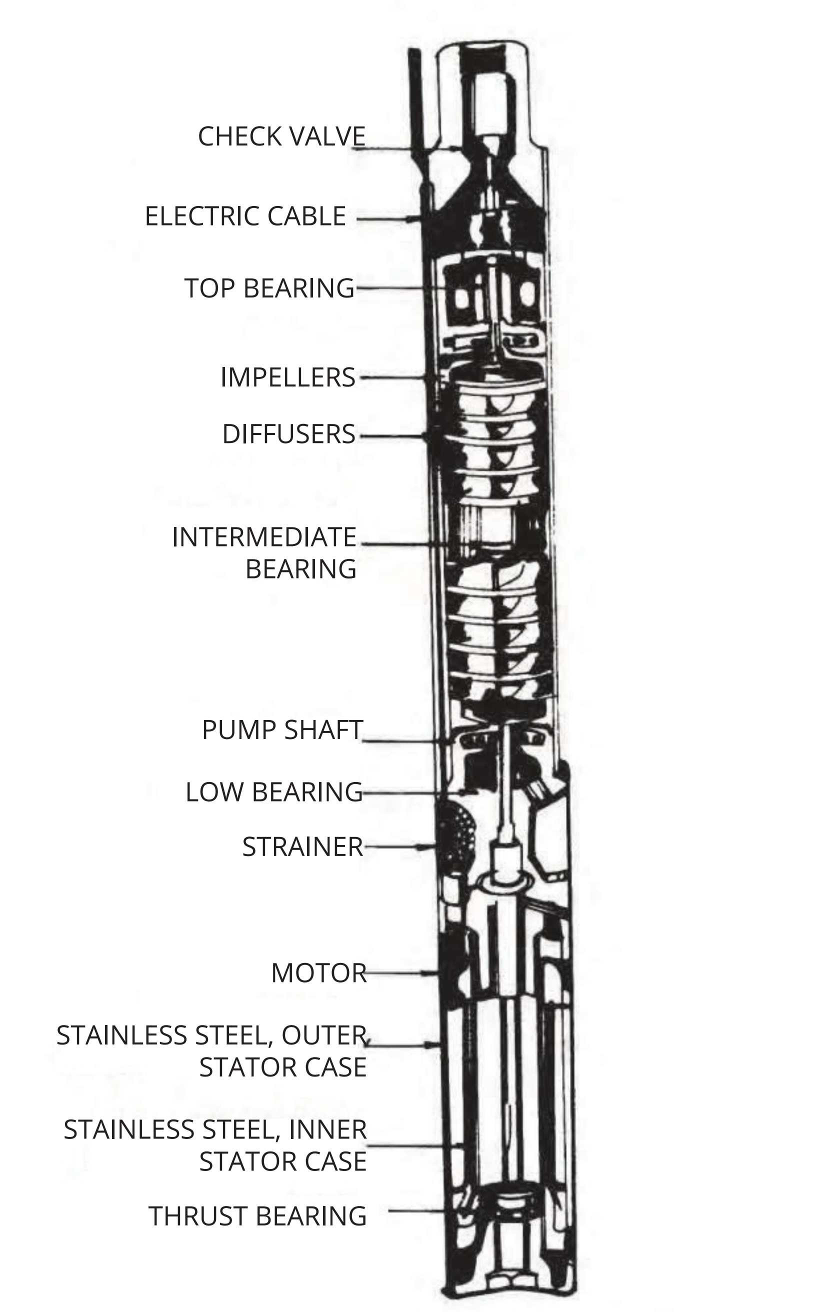
3. Simultaneous with the water level measurements, take measurements of discharge.
4. Monitor nearby wells to determine effects during pumping.
5. Right after the end of the pumping test, measure the water level recovery.
6. Plot data obtained from the test on a semi-logarithmic paper showing the time in the abscissa (x axis) and the drawdown in the ordinate axis (y axis).

APPENDIX 4: DETAILS OF INFILTRATION GALLERY

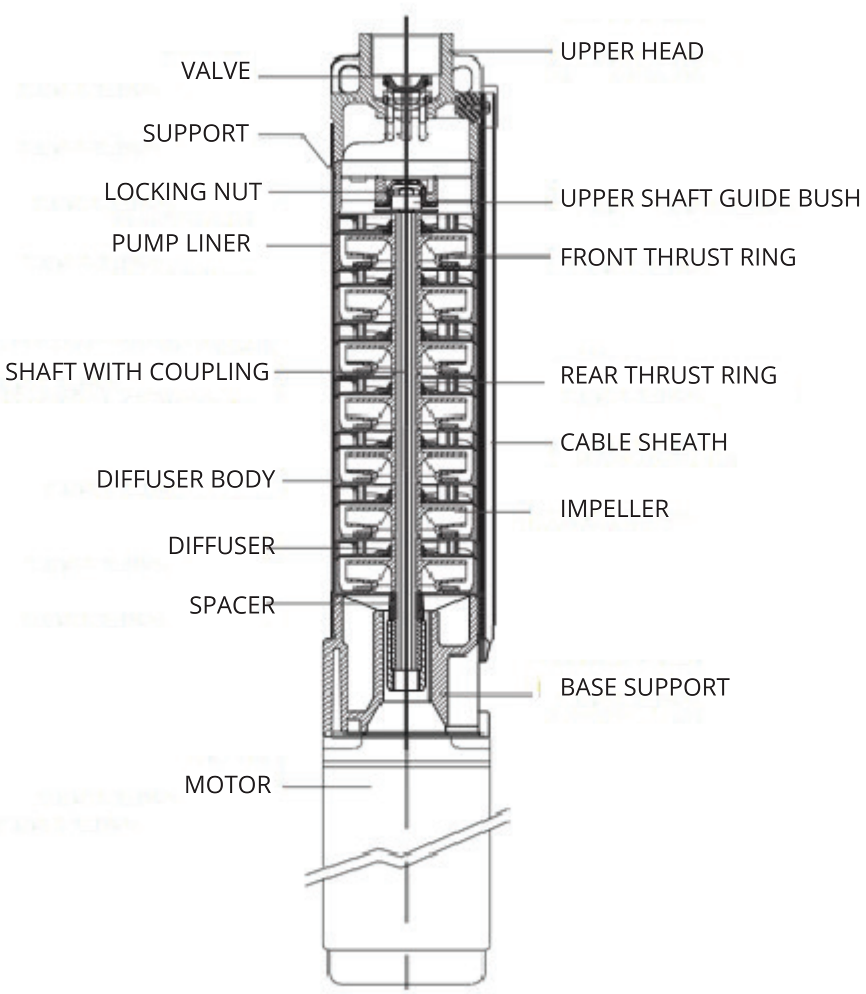


(Source: The World Bank, 2012)

APPENDIX 5: DETAILS OF A SUBMERSIBLE PUMP AND THEIR TROUBLESHOOTING



(Source: World Bank, 2012)



DETAIL OF SUBMERSIBLE PUPM

(Source: www.dabpumps.com)

Common Troubles of Submersible Pumps and Their Remedies

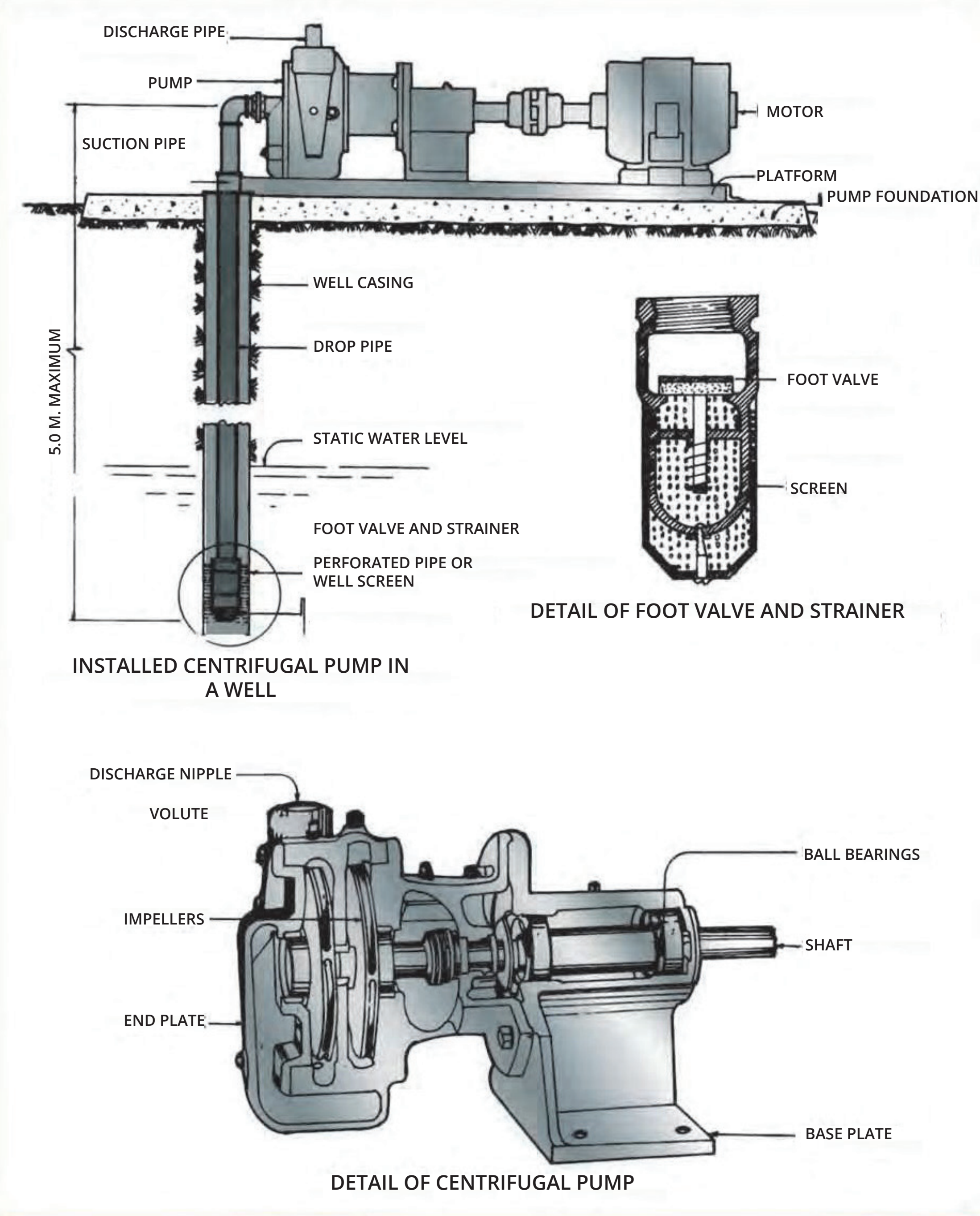
The matrix below summarizes the common problems of submersible pumps and their remedies

Trouble	Likely Causes	Remedies
Pump motor fails to start	Motor Overload	Overloaded contacts close automatically. Check cause of overload.
	Low voltage	Check voltage.
	Blown fuse, broken or loose connections	Check fuses, relays, electric condensers and all electrical connections.
	Motor control box not in proper position	Ensure box is in right position.
	Damaged cable installation	Locate and repair the damaged cable.
	Cable, splice or motor windings may be grounded or wet.	Check the ground by using an ohmmeter. If grounded, pull out the unit and inspect cable and splice. Cut the unit loose from the cable and check each part separately using an ohmmeter.
	Pump stuck by corrosion or abrasive	Pull out pump, examine and remove foreign matter.
Pump runs but delivers little or no water	Pump not submerged	Lower the unit into the well or replace by a smaller capacity pump.
	Discharge pipe may be leaking	Examine discharge line by pulling out one joint at a time.
	Check valve may be clogged or corroded	Pull out pump and clean or replace check valve.
	Pump badly worn- out by sand or abrasive	Replace pump. Clean well thoroughly of abrasive before putting the new unit in.
	Strainers or impellers clogged with sand or scale	Pull out pump unit and remove the scale/ sand.
	Scaled or corroded discharge pipe	Replace pipe.
Pressure valve fails to shut	Switch may be defective or out of adjustment	Adjust or replace pressure switch.
	Discharge pipe may be leaking	Raise unit one pipe joint at a time until leak is found. Repair leaks.

(Source: World Bank, 2012)

APPENDIX 6: CENTRIFUGAL PUMPS AND THEIR TROUBLESHOOTING

A typical centrifugal pump and its component parts are shown below:



(Source: World Bank, 2012)

Other common problems and their remedies are summarized in the matrix below:

Trouble	Likely Cause of Trouble	Remedy
Pump Motor fails to start	Blown fuse or open circuit breaker.	Replace fuse or reset circuit breaker.
	Motor or starting switch out of order.	Inspect /repair. Refer to equipment supplier or experienced mechanic or electrician.
	Break in wiring.	Repair circuit wires.
	Stuffing box may be binding or tightly packed	Check packing by manually rotating shaft.
		Loosen packing nut just enough to allow a slow seepage of water and free the shaft.
	Scale or sand in the impeller.	Open pump and remove scale by acid treatment and/or sand.
Pump runs but delivers no water	Pump lost first priming.	Repeat priming. Follow manufacturer's priming instructions.
	Pump repeatedly loses priming due to leaky drop pipe or suction pipe.	Pull out drop pipe and seal the leaks.
	No water at source due to over pumping	Reduce pumping rate or deepen the well.
	Collapse of well casing or screens	Replace with new one. If diameter of old casing is large, insert new casing inside the damaged casing. Consult driller.
	Clogging of well screens	Surging or acid treatment. Consult driller.
Pump runs but delivers only a small amount of water	Well not yielding enough water.	Do pumping test or deepen the well.
	Air leaks in suction pipe.	Pull the drop pipe from the well & seal leak/s.
	Incrustation or partial clogging of well screens.	Surging or acid treatment. Consult driller.
	Impeller is worn out or lugged with scale or trash.	Open the pump and clean/replace impellers.
	Foot valve may be obstructed.	Clean foot valve.
Noisy Pump	Bearing or other working parts of pumps are loose or need to be replaced	Tighten or replace defective parts.
	Pump motor is loosely mounted.	Tighten mounting.
	Low water level in well.	Reduce pumping rate.
	Presence of air in suction line.	Repair air leaks.

(Source: World Bank, 2012)

APPENDIX 7: JET PUMPS AND THEIR TROUBLESHOOTING

The troubleshooting information for jet pump problems is presented in matrix below.

Problem	Likely Causes of Trouble	Remedy
Pump runs but delivers only a small amount of water	Nozzle – diffuser or jet may be partially plugged with scale or trash.	Remove and clean.
	Pressure regulator for jet may be set too low for existing water level.	Set regulator for higher pressure.
Pump fails to pump up to full pressure and shut off	Jet pressure regulator is set too low.	Set regulator for higher pressure.
	Jet nozzle is plugged with scale or trash.	Remove and clean jet.
	Water level in well has dropped too low.	Reduce pumping rate; lower jet or find a new source.

APPENDIX 8: TROUBLESHOOTING FOR HAND PUMPS

Following are major problems that may occur in use of hand pumps, possible causes and suggestive remedies:

Problems	Probable cause	Suggestive Remedy
Pump Handle works easily, but water is not delivered	No water in the source	Proper development of boring, lowering of cylinder below water level in boring by increasing the riser pipe and pump rod.
	Pump has lost its priming	Priming of pump.
	Cylinder cup washer are worn out	Replace the cylinder cup washer.
	Opening of pump rod joints	Check and tighten the joints.
	Breakage of pump rod	Replacement of pump rod.
	Hole in suction pipe	Replacement of pipe.
	Leakage at base of cylinder	Check and replaces cylinder gasket.
	Cracking of pump cylinder	Replacement of cylinder.
	Checking/plugging of suction pipe	Dismantle and clear the pipe.
Pump is running, but deliver very low amount of water	Plunger leather worn out	Replace the plunger leather.
	Refill capacity is not enough	Proper development of boring.
	Valve leakage	Repair/ replacement of valves.
Need of many strokes for pumping of water	Pump has lost priming	Prime the pump.
	Cylinder cup seals worn out	Replace the seal.
Pump hand springs up after down stroke	Suction pipe plugged up below cylinder	Remove pump and clean the pipe.
	Suction pipe is too small	Replace it with bigger pipe.
	Water table is below cylinder assembly	Placement of cylinder near water.
Pump is noisy	Pump handle of other working parts are loose	Tighten the parts.
	Improper pump rod size	Replace with appropriate pump rod.
	Pump rod is loose	Tighten the pump rod.
	Top stand of pump stand assembly is not in level	Level the assembly.
	Hand pump stand assembly is loose on ground	Check the assembly and grout it properly with cement concrete.
	Stand assembly requires lubrication	

(Source: Pradhikaran, 2012)

APPENDIX 9: SOLAR ARRAYS AND ACCESSORIES INSPECTION CHECKLIST

Table A.9a: Solar Array and Accessories Inspection Checklist

GENERAL INFORMATION	
Project/System Name:	Contacts:
Location:	
Nearest Town:	Administrative Region:
	Postal Code:
Inspection full name:	Inspection date:
Brief description of weather conditions:	
ADHERENCE TO HEALTH AND SAFETY PROCEDURES	
SAFETY EQUIPMENT TO PERFORM INSPECTION	**DC COMPONENT ENCLOSURE**
The inspector should be well equipped to conduct the inspection	
☐ Yes	Proper conductor sizes and insulation types
☐ No	☐ Yes
Comment	☐ No
ENSURE THAT SYTEM IS OPERATIONAL BEFORE INSPECTION	
IS THE SYSTEM POWERED ON/ OPERATIONAL?	Proper conductor terminations
☐ Yes	☐ Yes
☐ No	☐ No
Comment	DC ratings on DC components
INVERTER	
IS THE INVERTER INDICATING ANY GROUND FAULTS OR OTHER ERROR MESSAGES?	☐ Yes
☐ Yes	☐ No
☐ No	Listed equipment

☐ N/A	☐ Yes
DO NOT PROCEED IF ALL ANSWERS ARE NOT YET COMPLETED	☐ Yes
Comment:	**SINGLE POINT GROUNDING!**
	☐ Yes
	☐ No
	Optional grounding electrode conductor
SYSTEM INFORMATION	Yes
SYSTEM TYPE	☐ No
Tower	**AC COMPONENT ENCLOSURE**
Solar tracking	Isolated Neutral busbar
Ground mount	☐ Yes
Other	☐ No
STAND/TOWER TYPE	Listed components
Stainless Steel	☐ Yes
Coated Steel	☐ No
Galvanized Steel	Labelled disconnects and Circuit Breaker (C/B)
Other	☐ Yes
TOWER/MAST CONDITION	☐ No
Excellent	
Good	
Average	
Comments	

Table A.9b: Solar Modules

SOLAR MODULES	UTILITY DISCONNECT
Note Please indicate with a tick in the box	Labelled
Total capacity Solar Array (KW):	☐ Yes
Solar Module size (watt peak per module): Wp	☐ No
Type of solar module (mono/ polycrystalline):	Visible, lockable, accessible, load break, external handle
Brand of solar module:	☐ Yes
Model of solar module:	☐ No

Cracked glass of PV panel	**APPROPRIATE SIGNS INSTALLED**
☐ Yes	Check for sign identifying PV power source system attributes
☐ No	☐ Yes
White or brown spot bubble of air, moisture behind the glass	☐ No
☐ Yes	Check for sign identifying A.C. point of connection
☐ No	☐ No
Broken back sheeting (white EVA), delamination	☐ No
☐ Yes	Check for sign identifying switch for alternative power system
☐ No	☐ Yes
Junction boxes at backside loose or without cover?	☐ No
☐ Yes	**SOLAR MAIN DISCONNECT**
☐ No	Labelled
Check for physical damage to any PV module	☐ Yes
☐ Yes	☐ No
☐ No	**INVERTER**
Check for loose cable terminations between PV modules	Inverter Manufacturer:
☐ Yes	Inverter Model:
☐ No	Power output (KW/KVA);
Shading on solar panels removed	Inverter Model:
☐ Yes	Type of Inverter (pure or modified sine wave):
☐ No	Brand of Inverter:
	Model Inverter:
	Number of inverters:
PV modules are properly grounded with lugs on each module	Open circuit voltage (Voc):
☐ Yes	Impp (A):
☐ No	
Check surfaces temperatures with IR camera or if using contactless thermometer	Check AC disconnect circuit breaks and its cable connectors temperatutre with IR

Yes	Camera or if using contactless thermometer
No	Yes
No	No
Rear junction box with IR camera or if using contactless thermometer	Check DC circuit connectors temperature with IR camera or if usning contactless thermometer
Yes	Yes
No	No

Table A.9c: Array Installation and Wiring

ARRAY INSTALLATION AND WIRING	
	Check DC disconnect circuit breakers and its cable connectors temperature with IR camera or if using contactless thermometer
Inspect for proper insulation on module wiring	
Yes	Yes
No	No
Proper connectors on array wiring extensions	Check cable connector fasteners for torque values
Yes	Yes
No	No
Proper grounding of array & array mount	Micro Inverters?
Yes	Yes
No	No
Ground conductors installed	N/A
Yes	Is the inverter located in an area which is exposed to direct sun?
No	Yes
Proper insulation on module wiring	No
Yes	N/A
No	Is the inverter operating?
Array mount properly secured and sealed	Yes

- [ ] Yes
- [ ] No

Suitable transition from open wiring to enclosed wiring

- [ ] Yes
- [ ] No

Wrong cable dimension used?

- [ ] Yes
- [ ] No

TOWER STRUCTURE

Is equipment mounted securely, and level?

- [ ] Yes
- [ ] No
- [ ] N/A

Any sign of damage to modules or wiring?

- [ ] Yes
- [ ] No
- [ ] N/A

Results of module hand lift test?

Secure

Not secure

- [ ] N/A

Are footings, support structure, and all braces intact?

- [ ] Yes
- [ ] No
- [ ] N/A

Are conductors loose, touching roof surface or in contact with sharp or abrasive surface?

- [ ] Yes
- [ ] No
- [ ] N/A

- [ ] No
- [ ] N/A

Is the inverter mounted to the manufacturer specifications?

- [ ] Yes
- [ ] No
- [ ] N/A

Defects founded

- [ ] Yes
- [ ] No
- [ ] N/A

Input and output disconnect labelled

- [ ] Yes
- [ ] No
- [ ] N/A

Proper wire sizes?

- [ ] Yes
- [ ] No
- [ ] N/A

Grounded?

- [ ] Yes
- [ ] No
- [ ] N/A

Record accumulated solar energy production since start of operation?

MAIN ELECTRICAL DISTRIBUTION PANEL

Primary service Breaker size: Amps

Primary service Main Busbar Rating: Amps

Inverter Fuse/Breaker Rating: Amps

Electrical Concerns or Code Violations

- [ ] Yes

Conductors follow the mounting rails? with exterior grade sealant?

☐ **Yes**

☐ No

☐ N/A

Conductor plug-and-receptacle connectors are fully engaged between junction boxes?

☐ Yes

☐ No

☐ N/A

Are all zip ties and wire ties rated for UV resitance?

☐ Yes

☐ No

☐ N/A

Are any dissimilar metals being combined?

☐ Yes

☐ No

☐ N/A

Check that all DC wiring from combiner box onward is in dedicated conduit using weather tight fitttings and labeled accordingly?

☐ Yes

☐ No

☐ N/A

Should an additional structural evaluation be conducted based on a limited visual inspection?

☐ Yes

☐ No

☐ N/A

☐ No

☐ **N/A**

Check for cable conditions

☐ Yes

☐ No

☐ N/A

Check cable terminals for burnt marks, hot spot or loose connection

☐ Yes

☐ No

☐ N/A

Check for physical damage

☐ Yes

☐ No

☐ N/A

Number of feeder breakers:

System voltage 220 or 230 VAC:

Check voltage from inverter:

☐ Yes

☐ No

Monitoring Device installed (Volt Meter):

☐ Yes

☐ No

☐ N/A

Monitoring Device installed (Current/Amp meter)

☐ Yes

☐ No

☐ N/A

AC/DC CONNECTIONS	Monitoring Device installed (Frequency Meter):
Source Circuit Combiner Boxes	☐ Yes
☐ Yes	☐ No
☐ No	☐ N/A
DC-rated circuit breakers or fuses with adequate voltage rating	Monitoring Device installed (KWh meter):
☐ Yes	☐ Yes
☐ No	☐ No
Listed equipment	☐ N/A
☐ Yes	Check circuit breaker body temperature with IR camera or if using contactless thermometer
Comment:	☐ Yes
	☐ No
	Check circuit breaker body temperature with IR camera or if using contactless thermometer
WIRING	☐ Yes
Are standard solar wier conductors and appropriate wiring methods used?	☐ No
☐ Yes	
☐ No	Check output cable connection temperature with IR camera or if using contactless thermometer
☐ N/A	
Is conduit rated for its location, with supports properly spaced for the size and type of conduit?	☐ Yes
	☐ No
☐ Yes	Check busbar temperature with IR camera or if using contactless thermometer
☐ No	☐ Yes
☐ N/A	☐ No
Non-metallic sheathed conductors and cables are secured within 12 inches of each box, cabinet, conduit body or other termination?	Check cable connector fasteners for torque values
	☐ Yes
☐ Yes	☐ No

☐ No

☐ N/A

The minimum bending radius of the cable or PV Wire is no more than 5x the diameter of the cable. (i.e. for 0.02 inch diameter, minimum bending radius is 1.0 inches, total bend is 2.0 inches)?

☐ Yes

☐ No

☐ N/A

Do PV Source Circuit free-air conductors have 90 degree C, sunlight, and wet service ratings. Single-conductor cable type and specifically listed and labeled as PV wire is permitted in PV source circuit?

☐ Yes

☐ No

☐ N/A

Where DC PV source circuits are run inside a building, they are in metal conduit from the point of penetration into the building to the first accessible disconnect

☐ Yes

☐ No

☐ N/A

Are any conductors exposed to UV?

☐ Yes

No

☐ N/A

Is a strain relief fitting appropriate for the installation at the junction box or the transition into conduit?

☐ Yes

Positioning of Distribution Panel as per safety stnandard and easy to monitor by the operator?

☐ Yes

☐ No

BONDING SYSTEM

Bonding of the exposed metallic structured of solar PV system to lightining earth

☐ Yes

☐ No

☐ N/A

Check bonding cable conditions

☐ Yes

☐ No

☐ N/A

Check physical bonding conditions

☐ Yes

☐ No

☐ N/A

Check continuity of the bonding to lightining earth

☐ Yes

☐ No

☐ N/A

SIGN AND WARNING LABELS

Warning label(s) installed at the DC Disconnects/Combiner boxes?

☐ Yes

☐ No ☐ N/A Are splices suitable for the location in which they are made? Wet-location wire nuts shall be used even when installed in a waterpoof junction box ☐ Yes ☐ No ☐ N/A Wire nuts shall be used even when installed in a waterproof white or gray and equipment grounding conductors (EGC) shall be green, green/yellow, or bare. ☐ Yes ☐ No ☐ N/A Is the system properly grounded? Is the equipment grounded conductor (EGC) continuous to all metal components, and connected to the main grounding electrode conductor (GEC)? ☐ Yes ☐ No ☐ N/A Are the required Warning label(s) used at the Junction Box? ☐ Yes ☐ No ☐ N/A Check all fuses and circuit breakers on combiner box with IR camera temperature or if using contactless thermometer ☐ Yes ☐ No	☐ No ☐ N/A Warning label(s) installed at the Inverter? ☐ Yes ☐ No ☐ N/A Are labels provided at the Production Meter? ☐ Yes ☐ No ☐ N/A Warning label(s) installed at the AC Disconnect? ☐ Yes ☐ No ☐ N/A Warning label(s) installed at the Sub Panel/ Main Service Panel? ☐ Yes ☐ No ☐ N/A Warning label(s) installed at the Main Service Point of Interconnection/PV Breaker? ☐ Yes ☐ No ☐ N/A Sign Identifying Photvoltaic Power Source, Related Max Power-Point Current, Related Max Power-Point Voltage, Max System Voltage, Short-Circuit Current, and Max Rated Output at DC disconnect? ☐ Yes

Check all cable connectors on combiner box with IR camera temperature or if using contactless thermometer ☐ Yes ☐ No	☐ No ☐ N/A Sign identifying switch for alternative power system? ☐ Yes ☐ No ☐ N/A
OUTBACK INVERTER ROUTINE-MAINTENANCE	**CHARGE CONTROLLERS (BATTERY BACKUP SYSTEMS ONLY)**
Disconnect all circuit breakers and related electrical connections before doing any cleaning or adjustments Have done Not yet	Status/Condition ☐ Yes ☐ No ☐ N/A
Solar modules amy produce hazardous voltages when exposed to light; cover them with opaque material before servicing any connected equipment Hane don Not yet	Input and output disconnects labelled ☐ Yes ☐ No ☐ N/A
If a remote or automatic generator start system is used, disable the automatic starting circuit and/or disconnect the generator from its starting battery while servicing. Have done Not yet	Listed charge controllers ☐ Yes ☐ No ☐ N/A
Comment:	Proper wire sizes ☐ Yes ☐ No ☐ N/A Grounded ☐ Yes ☐ No ☐ N/A Record accumulated solar energy production since start of operation:

	Comment:
	INVERTER ROUTINE-MAINTENANCE
	Check inverter for DC connection in Energy Storage System (ESS)
	☐ Have done
	Not yet
	Check inverter for colling (clean the heat sink if applicable)
	☐ Have done
	☐ Not yet
	Check inverter for fan test (clean it if applicable)
	☐ Have done
	Not yet
	Create maintenance report:
	Keep record of yield monthly, sunny portal, compare yields
	☐ Have done
	☐ Not yet
	Comment:

SUBJECT INDEX

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