# O&M MANUAL FOR WATER SUPPLY SYSTEM

ENERGY MANAGEMENT AND OPERATION & MAINTENANCE OF 16 SELECTED MCs SERVICES INFRASTRUCTURE ASSETS PROJECT

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PITCO (PRIVATE) LIMITED

## Contents

# 1. INTRODUCTION

The Manual on Operation and Maintenance for Water Supply Systems is a long-felt need for the sector. At present, there is no technical manual on this subject to benefit the field personnel and to help the municipal corporations (MCs) prepare their own specific O&M manuals or programs suitable for their organizations.

## 1.1. OBJECTIVE OF OPERATION AND MAINTENANCE

The objective of efficient operation and maintenance of a water supply (WSS) system is to provide safe and clean drinking water to consumers in an adequate and desired quality, at a convenient location and time, and as economically as possible on a sustainable basis.

In an engineering sense, operation refers to hourly and daily operations of the components of a system such as plant, machinery and equipment (valves etc.) which is done by an operator or his assistant. This is a routine work. The term maintenance is defined as the art of keeping the plant, equipment, structures and other related facilities in optimum working order. Maintenance includes preventive maintenance or corrective maintenance, mechanical adjustments, repairs and corrective action and planned maintenance. Often repairs, replacements and corrections of defects (of material or workmanship) are considered as actions excluded from preventive maintenance. In some organizations the normal actions taken by operation staff are considered as maintenance activities whereas a separate unit or cell does repairs and replacements. Often both corrective and preventive maintenance are included in the job functions of operators and limits to which operators are expected to do normal maintenance are set forth for various equipment. Budgetary provisions of operation and maintenance organizations also incorporate heads of expenditure under maintenance for cost of spare parts and cost of labour or contract amount for repairs and replacements.

Operation and maintenance of water distribution systems are done in a very complex environment with numerous (and often conflicting) services to deliver, influencing factors, requirements and stake- holder relationships. Factors making municipal service provision a challenging task are shown in Figure 1.

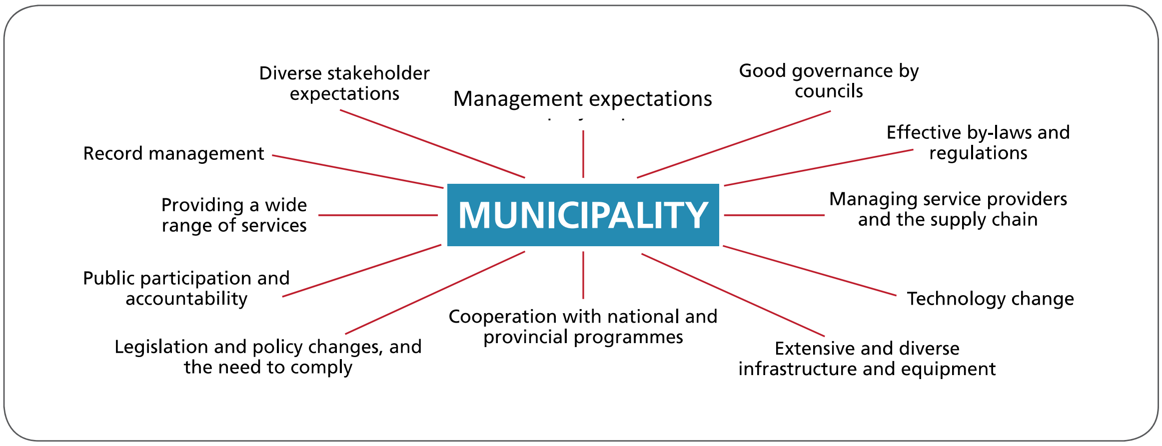



*Figure 1-1 The numerous challenges facing municipalities in providing services*

It is worth noting some of the factors adding to the complexity of operating and maintaining water distribution systems:

A ***wide range of services*** needs to be provided by municipalities, often to a growing and diverse population.

In addition, most municipalities are struggling with three critical deficiencies: old and deteriorating infrastructure, a lack of resources and a lack of capacity [d] (including properly trained personnel and institutional knowledge). The lack of resources and capacity often forces municipalities to focus on the most critical problems and neglect crucial operation and maintenance functions that have longer-term impacts. This, in turn, leads to further deterioration of infrastructure and a downward spiral of escalating inefficiency.

## 1.2. OBJECTIVE OF THE MANUAL

The current Manual on Operation and Maintenance is intended to serve as a guide to strengthen the technical, operational, and managerial skills of the staff responsible for the operation and maintenance of WSS as per acceptable norms of quantity, quality, sustainability, reliability, and cost.

This manual is intended for the managerial and field staff the MCs in charge of the operation and maintenance of the drinking water supply systems.

The procedures mentioned in the manual are intended to be guidelines for ensuring effective O&M of the water supply systems. This manual is not exhaustive but will serve as a reference volume for the MCs to develop their O&M programs to suit their specific problems, depending on the size and location of the water supply system.

# 2. O&M OF WATER SUPPLY SOURCES

The objectives of operation and maintenance of sources of water supply schemes are:

1. The water sources must be able to provide water that has been treated and is safe to consume.
2. Perennial water sources that guarantee sustainable supply should be used.
3. There should be no compromise on water quality.
4. There should be little to no interruption in the water supply systems as a result of water source depletion.
5. As little money as possible should be spent on the upkeep and restoration of the water sources.
6. Accurate records of the water sources should be kept so that their performance over time may be assessed.
7. In order to ensure dependability and continuity a routine program of preventive maintenance, a rigorous long-range plan of source inspection and monitoring should be adopted to identify problems.
8. Survey maps must be obtained, or created, and updated from time to time, for all potential water sources, including canal, lakes, reservoirs, wells, and springs, among others.

## 2.1. WATER SOURCES FOR THIS PROJECT

Water sources in this project are mainly ground water Tubewells dependent upon aquifer conditions.

### 2.1.1. Aquifer

- Aquifers are layers of rock and soil with water flowing through their small pores. For the most part, there are not giant caves under earth's surface containing violent rivers of water flowing quickly through them. Ground water drips slowly and gently through the small spaces within rocks, between rocks, and between loose materials such as sand and gravel.

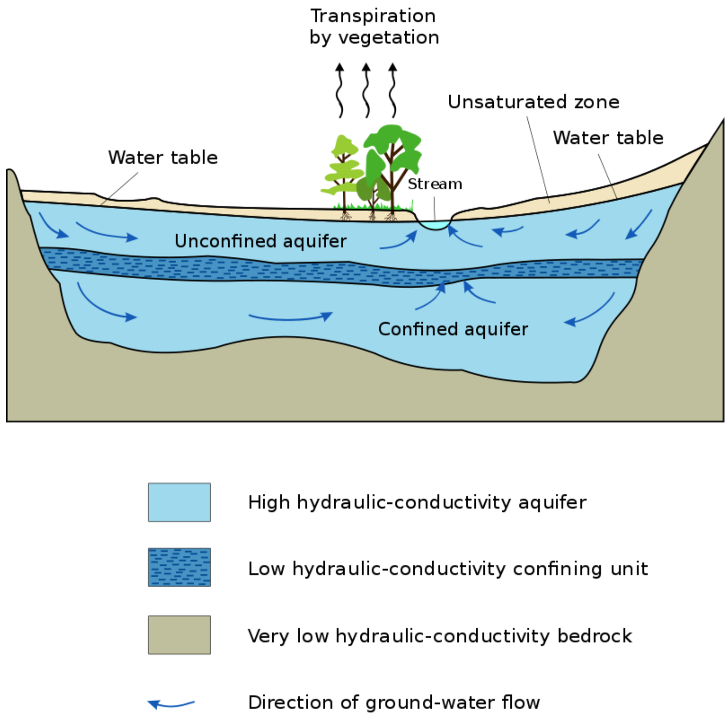



*Figure 2-1 Aquifer*

- An unconfined aquifer can receive water directly from the surface, while a confined aquifer is trapped between two layers of rock.

- A good aquifer for the installation of a well-screen is a *permeable layer* below the groundwater table.
- During drilling you may come across different aquifers at different depths, separated by *impermeable layers.*
- When water is pumped from a well, the water table is generally lowered into a cone of depression at the well. Groundwater normally flows down the slope of the water table towards the well.

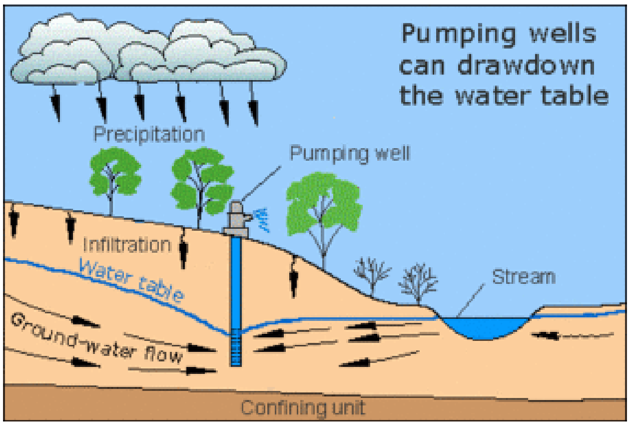


*Figure 2-2 Pumping well*

### 2.1.2. Drilling a bore for a tube well

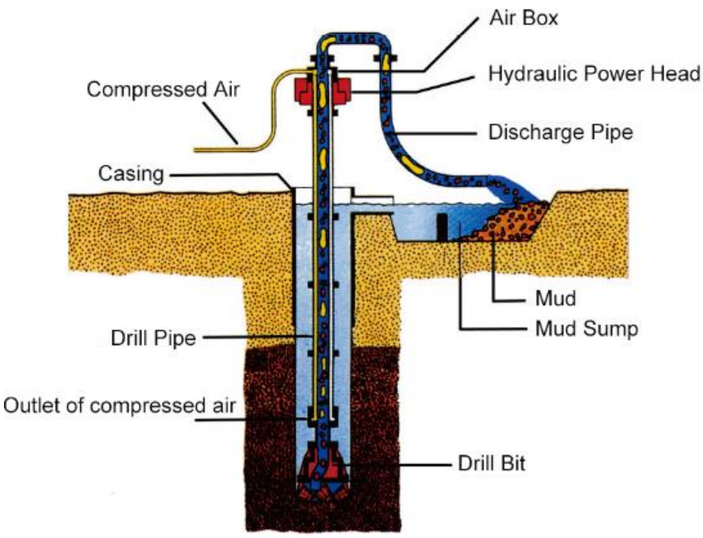


*Figure 2-3 Drilling bore*

- Drilling fluid or muddy water flows from the mud pit down the borehole outside the drill rods and passes upward through the bit.
- Cuttings are carried into the drill rods and discharged back into the mud pit.
- Reverse circulation requires a lot of water and sediment-handling, as the boreholes are large in diameter.
- Stability of the borehole depends on the positive pressure from the fluid in the borehole annulus.

## 2.2. STEPS FOR DESIGN OF A TUBE WELL

The design of a tube well involves the following steps:

- Analysis of samples of the underground formation obtained from various depths and the preparation of a well log.
- Design of housing pipe and well casing
- Design of well screen
- Design of gravel pack
- Design for sanitary protection

### 2.2.1. Bore size & Well depth

- Bore size may be, at least, 5 cm bigger in diameter than the casing pipe
- Bore size= outside dia of casing pipe + (2 x gravel pack thickness)
- **Well depth**
  Depends upon the locations of water-bearing formations
- **Desired yield of the well**
  Economic considerations
  Hydraulic conductivity of the aquifer material

#### 2.2.1.1. Analysis Of Particle Size Distribution of The Aquifer

- Effective Size "d10" The term 'effective size' is defined as formation particle size, where 10 per cent of the sand is finer and 90 per cent coarser.
- d10=0.25mm? 90% sand grains > 0.25 mm, 10 % sand grains < 0.25 mm.

### 2.2.2. Design of Housing Pipe and Well Casing

#### 2.2.2.1. Diameter of housing pipe

• Diameter should be at least 5 cm more in diameter than the nominal diameter of the pump.

#### 2.2.2.2. Depth of housing pipe

- Pump should be always submerged in water.
- Pump must be set a few meters below the lowest drawdown level.
- Diameter of Well casing pipe is fixed by the permissible velocity of water through the pipe. Most suitable velocity – 1.5 to 2.5 m/s.

#### 2.2.2.3. Sanitary Seal

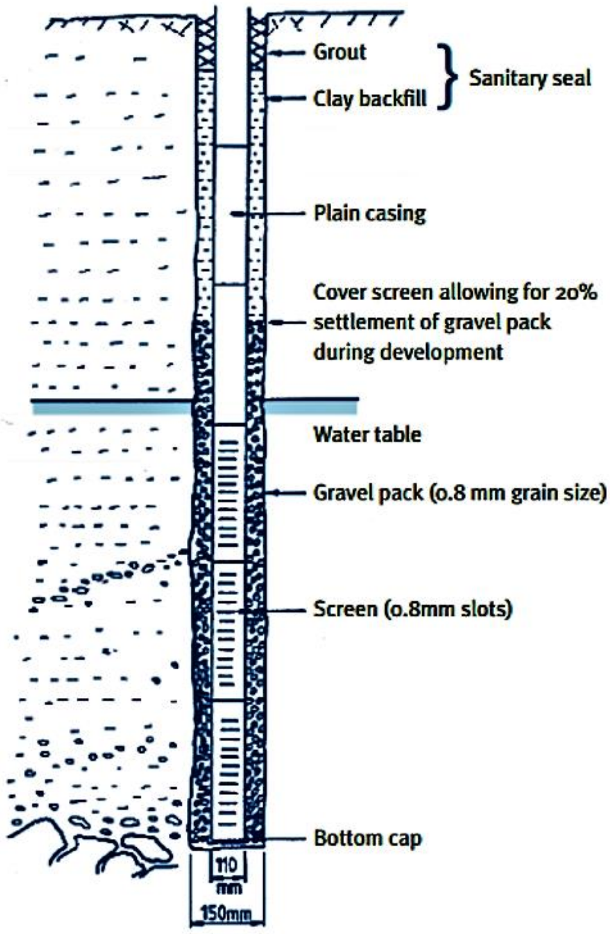



*Figure 2-4 Sanitary seal*

- *Pathogens (bacteria, viruses and parasites)* and chemicals *move* downward with the infiltrating (rain)-water through permeable soil layers to the groundwater.
- To prevent pathogens and chemicals from entering the filter screen and polluting the second aquifer *a sanitary seal* has to be placed.
- The *sanitary seal* is made of cement or bentonite (natural clay which swells to many times its dry volume when wetted) which will seal (close) again the impermeable layer.

### 2.2.2.4. Design of well screen

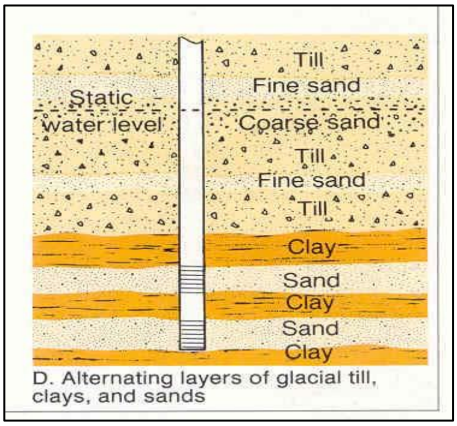



*Figure 2-5 Well screen*

- The basic requirements of a well screen is:
  It should be resistant to corrosion and deterioration
  It should be strong enough to prevent collapse
  It should offer minimum resistance to the flow of water
  It should prevent excessive movement of sand into the well

#### 2.2.2.4.1. Slot Opening

- Well screen slot openings is determined by matching the size of the opening with the grain-size distribution of the material surrounding the screen.
- Slot size varies from as low as 0.2 mm to as large as 5mm
- ab) Gravel-Pack Wells
- Slot opening –± 10%

#### 2.2.2.4.2. Calculating Screen length

- Calculation of possible well yield for the design of screen length $Q = \pi D \times L \times Sop \times (1 - Clogr) \times V$
- Q: Possible well yield (m3/sec)
  D: Well Dia (m)
  L: Screen length (m)
  Sop: Opening ratio of screens (10%)
  Clogr: Clogging ratio of screens (%)
  V: Inflow velocity into screens (USA standard = 0.03 m/sec)
- Total length of screens is designed to be about 30 % of the total length of deep wells, and also, the inflow speed of groundwater into screens is supposed to be V= 0.03 m/sec. (USA standard value). In addition, the total length of screens is concretely designed so as to acquire planned pumping rate.

#### 2.2.2.4.3. Clogging ratio

- With the passage of time the screen clogs and flow reduce. Normally people design tube well without considering this deterioration but if you want that your well is producing the satisfactory yield even after say 10 years, it will be better to consider 30% clogged screen.

#### 2.2.2.4.4. The gravel packs

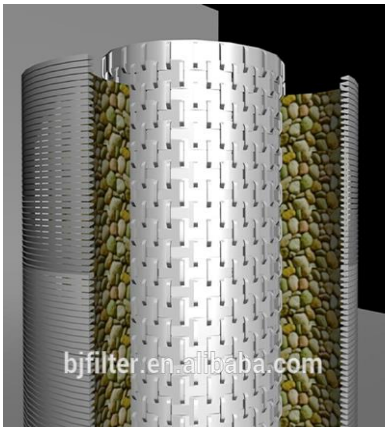



*Figure 2-6 Gravel packs*

- The annular space between the well screen, well casing, and borehole wall is filled with gravel or coarse sand (called the *gravel pack* or *filter pack*).
- The gravel pack prevents sand and fine sand particles from moving from the aquifer formation into the well.
- The gravel pack does not exclude fine silt and clay particles; where those occur in a formation it is best to use blank casing sections.
- The uppermost section of the annulus is normally sealed with a bentonite clay and cement grout to ensure that no water or contamination can enter the annulus from the surface.

(i) it stabilizes the aquifer tapped by the well,

(ii) it avoids/minimizes sand pumping,

(iii) it allows to use a large screen slot with a maximum open area, and

(Iv) it provides a zone of high permeability surrounding the well screen, which increases the well radius (known as 'effective radius' of the well) and well yield.

When a well screen of a pumping well is to be surrounded by an artificial gravel pack, the size of the screen openings is decided based on the size of the gravel used for gravel packing.

#### 2.2.2.4.5. Design criteria of gravel pack

- The mean grain size of the pack material bears a specific relationship to the mean grain size of the formation material.
- A) Uniform aquifer P A ratio= 50 % $size\ of\ gravel\ pack$/ 50% $size\ of\ aquifer$.
- P A ratio should lie between 9 and 12.5
- B) Graded Aquifer
- P A ratio= 50 % $size\ of\ gravel\ pack$/50% $size\ of\ aquifer$
- should lie between 12 and 15.5
- THE gravel pack should be clean. Grains should be smooth and round (flat particles should be avoided). It should be uniform in size.

### 2.2.2.5. Development of a Tube well

- The development of tube well is essential process to obtain an efficient and long –lasting well.
- It involves removal of finer material from around the well screen, thereby enlarging the passages in the water-bearing formation to facilitate entry of water.
- Development increases the effective radius of the well and, consequently, its yield.

- The grain size of the artificial pack and the slot size of the screen are matched to provide an area of much higher permeability in the zone immediately outside of the screen.
- This high permeability zone reduces the head losses necessary to get the desired flow and reduces the chances of incrustation.
- The artificial pack provides superior control over the movement of fine sand grains toward the well and permits a wider range of sand sizes to be screened.

**(a) Objectives of development:**

- Repair to damage done to the formation by drilling operation and restore the original hydraulic conductivity of the aquifer.
- To increase the porosity and permeability of the water bearing formation in the vicinity of the well by removing finer material of aquifer.
- To stabilize the formation around well screen to yield sand free discharge.

### 2.2.2.6. Methods of well development

- Over pumping
- Surging and pumping with air-compressor
- Back washing
- High velocity jetting

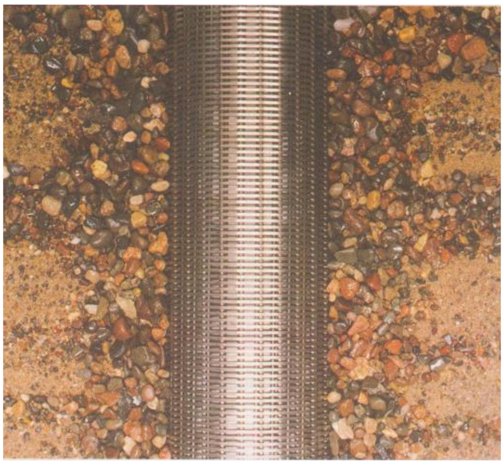


*Figure 2-7 Properly developed natural packed screen well*

#### 2.2.2.6.1. Air Development (air surging and pumping)

- Several techniques for the air development of wells exist. However, all inject air into the borehole such that aerated slugs of water are lifted irregularly out the top of the well casing.
- Air pressure may be cycled on and off to create a surging action desirable in well development.
- Sufficient air pressure will result in a continuous flow of aerated water out the top of the well, removing sediment and fine particles from the borehole.

#### 2.2.2.6.2. Over pumping and backwashing

- Over pumping is the simplest method of removing fine particles from formations. The theory is that if a sand free yield can be achieved by over pumping then a sand free flow will be the result when pumping at the normally expected lower rate.

- Backwashing requires the introduction of water back into the well. Backwashing reverses water flow and helps in the dilution, agitation and removal of sediment, fine particles and drilling fluids.
- Washing and backwashing reverses the flow in the borehole during development. This reversal causes the collapsing of bridges in the particles of the near well area. This is desirable because collapsing these bridges further removes fines from the near well creating a cleaner flowing well.

### 2.2.3. Performance monitoring of Tube wells.

According to available data the specific capacity of wells should be measured at regular intervals either monthly or bi-monthly and it should be compared with the original specific capacity. As soon as 10 to 15% decrease in specific capacity is observed steps should be taken to determine the cause and accordingly corrective measures should be taken. Rehabilitation procedures should be initiated before the specific capacity has declined by 25%. A check list given below can be used to evaluate the performance of a well:

i) Static water level in the production well,

ii) Pumping rate after a specific period of continuous pumping,

iii) Specific capacity after a specified period of continuous pumping,

iv) Sand content in a water sample after a specified period of continuous pumping,

v) Total depth of the well,

vi) Efficiency of the well,

vii) Normal pumping rate and hours per day of operation,

viii) General trend in water levels in wells in the area,

ix) 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 in need of attention.

## 2.3. O&M OF GROUND WATER WELLS

### 2.3.1. Preventive Maintenance

The specific capacity of wells should be monitored regularly, either monthly or bimonthly, and it should be compared to the original specific capacity, according to the data that is currently available. When a 10 to 15% decline in specific capability is noticed, action should be taken immediately to identify the cause and implement the necessary corrective measures. It is best to start rehabilitation operations before specific capacity of a well has dropped by 25%. To assess a well's performance, utilize the check list provided below:

i) Production well's static water level

ii) Pumping rate following a predetermined amount of time of nonstop/continuous pumping

iii) Particular capacity following a predetermined amount of time of continuous pumping

iv) Sand concentration in water following a predetermined amount of time of continuous pumping

v) Well's total depth

vi) Well's efficiency

vii) Typical pumping rate and daily operating hours

viii) Typical water levels in the wells in the area

ix) Drawdown caused in the production well due to operation of neighboring wells

Preventive maintenance programme begins with well construction records showing geological condition, water quality and pumping performance.

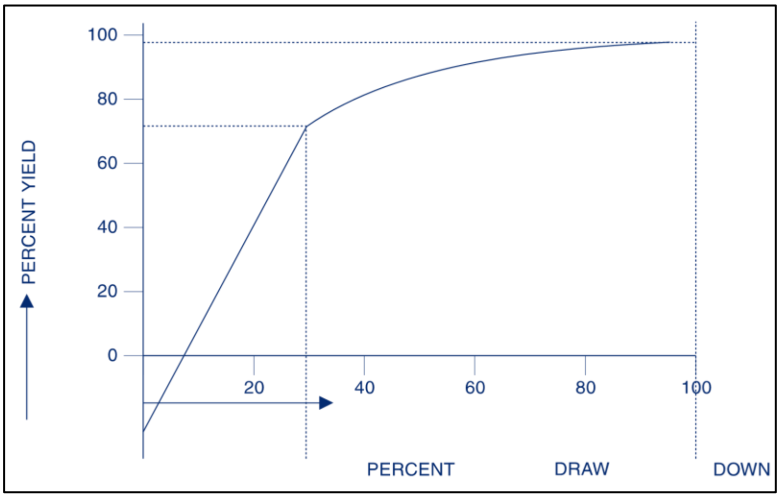



*Figure 2-8 Drawdown and percent yield*

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). According to this curve there is a straight line up to certain stage of draw down beyond, which the draw down increases disproportionately to yield. The end point of straight line is the point of optimum efficiency for the operation of well as shown in the attached figure. This is generally found to be 70% of yield at draw down which can be created

A well needs attention if any of the first seven conditions mentioned above noticeably changes.

Review of well construction records that demonstrate the geological state, water quality, and pumping performance are the first step in a preventive maintenance program. When a well is tested and put into service, data on its most effective and efficient operating range should be supplied.

### 2.3.2. Static Water Level and draw down

- The water level in a well that is not being pumped will rise to an elevation determined by the type of aquifer and surrounding geologic conditions. This is called the static water level and can vary from year to year, depending on recharge to the aquifer.
- When a pump is turned on, the water will drop to what is called the pumping water level.
- The difference between the static water level and pumping water level is the drawdown in the well.
- Drawdown generally will increase through time due to the screen openings becoming plugged and lowering of water table.

An electrical depth gauge or ultrasonic water level meter can be used to measure the pumping level and drawdown of a tube well.

When using an electrical depth gauge to measure the depth, a metallic cloth tape suspends an electrode in the tube well. The metallic tube well casing is where the conductor terminal clip is fastened. The galvanometer indicates that the electrical circuit is complete when the electrode hits the water's surface. On the tape, the corresponding depth is read.

Sonic depth meter is the most widely used tool for measuring SWL, pumping water level, and drawdown. The sonic depth meter employs the air present in the well to transmit an acoustic signal towards the water surface. This signal is introduced into the well casing via a top opening in the well cap that measures 5/8 inches or more in diameter. After being reflected from the water surface, the signal is detected, and its round-trip time is measured. By multiplying this time with the velocity of sound and dividing the result by two, the depth-to-water can be determined in either feet or meters, depending on the chosen mode.

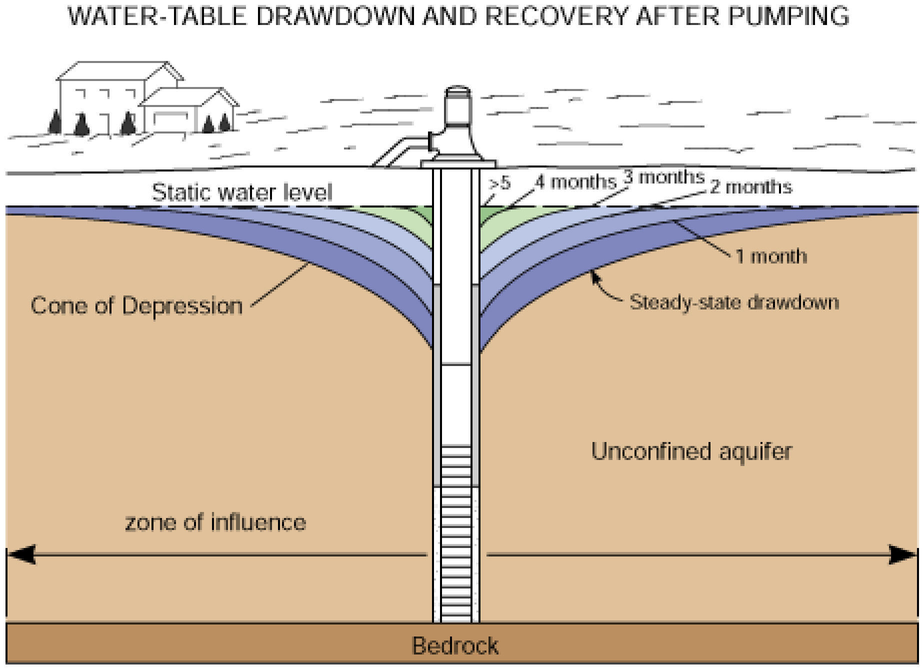



*Figure 2-9 Drawdown and recovery*

### 2.3.3. Well yield & specific capacity

After construction, a well will produce a certain flow rate at a given amount of drawdown. The total flow it can produce is called the "well yield. "Specific capacity is calculated by dividing the flow rate by the drawdown. The units of specific capacity are gallons per minute per foot of drawdown (gpm/ft) or cusec/ft.

### 2.3.4. Reasons for Well Failure

Failures of wells can result from poor design, shoddy construction and operation, improper maintenance and repair, failures brought on by mechanical and chemical causes, and unfavorable aquifer conditions. The following categories describe the primary causes of source failure:

(i) Improper design, such as using the wrong screen and gravel pack sizes and incorrectly directing the well site, might cause interference

(ii) Improper construction, including the possibility that the bore is not vertical, the joints are leaky, the well screen is positioned incorrectly and has uneven slots, and the cement slurry seal is not built properly to stop inflow from the saline aquifer

(iii) Screens that have been exposed to water's chemical activity have corroded/ruptured

(iv) Poor operation, such as excessive pumping or poor maintenance

(v) Unfavorable aquifer conditions that cause the water table to drop and the quality of the water to worsen

(vi) Mechanical malfunction, such as the falling of foreign items, such as the pumping assembly and its parts

(vii) Incrustations brought on by water's chemical action

### 2.3.5. Tube well and Bore Well Rehabilitation

The correction of the conditions listed in I through (iii) above is a highly challenging and expensive process. Hence, a cost-benefit analysis should be used to determine whether to renovate an old well or build a new one. The following corrective actions can be used to address the condition indicated at (iv) to (viii).

#### 2.3.5.1. Faulty Operation

The operation of the tube well should be such that the level of the pumping water always remains above the well screen. If the well screen is exposed due to excessive pumping, incrustation and corrosion may occur. Over pumping causes an excessive amount of drawdown, which may result in differential hydrostatic pressures and well screen rupture. Inattention to timely maintenance and upkeep could lead to the tube well performing poorly. Thus, it should be assured that the tube well is operated at its designed capacity and that prompt repair and maintenance are done before any irreversible damage is done.

#### 2.3.5.2. Unfavourable Aquifer Situations

Wells can typically be pumped with a significantly reduced flow in unfavorable aquifer conditions where the water table has decreased but the water quality has not deteriorated.

#### 2.3.5.3. Mechanical Failure

The falling of pumping set assembly and its components into the bore hole can be minimized by providing steel wire holdings throughout around 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. These foreign & falling objects may damage the well screen resulting into failure of 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 steps taken for fishing out the fallen objects in the bore holes:

#### *(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. Figure 3.1 illustrates an impression block made from a block of soft wood 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. Several nails are driven to the lower end of the block with about 1 cm of it 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.

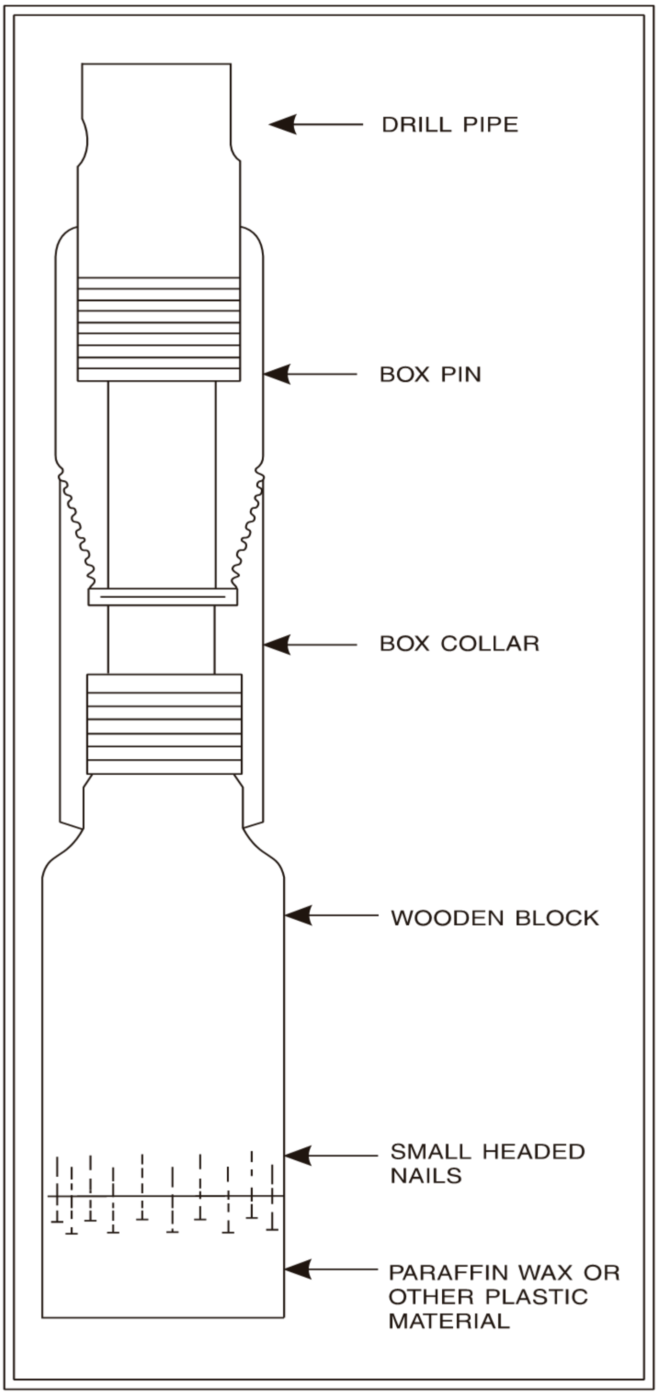



*Figure 2-10 Impression block*

### *(b) Fishing Tools to Recover Fallen Objects*

'The term 'fish', as used in tube well technology, describes a well drilling tool, pump component or other foreign body accidentally fallen or struck in bored wells & wells. The type of fishing tools required for a specific job will depend on the object to be lifted and the position in which it is lying in the well. It may often be necessary to design a fishing tool to suit a particular job. 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.

#### 2.3.5.4. Incrustation

##### 2.3.5.4.1. Identifying the Incrustation Issue

Chemical incrustation is indicated by a gradual reduction in yield of the well. However, it can also happen with a gradual lowering of the water table due to over-pumping or inadequate ground water recharge. This fact can be verified by studying the behaviour of the ground water level over the service period of the tube well. Incrustation in the form of slime produced by iron bacteria decreases well yield due to clogging of the well screen and casing. Incrustation also clogs the fractures & fissures of rocky zone of well which is prevalent in bore wells. This trouble can be identified from the performance curves of the well. In this case the reduction in well yield is somewhat more rapid. Water quality analyses are used to identify the type of incrustation.

##### 2.3.5.4.2. Incrustation Types

The different types of incrustation, in order of how frequently they occur, are discussed below:

- Precipitation of calcium and magnesium silicates, sulphates, and carbonates.
- Precipitation of iron and manganese hydroxides, oxides, and other compounds.
- Slime created by slime-producing iron bacteria and other species.
- Deposition of soil components – clay and silt (Mechanical Incrustation).

**(a) Magnesium and Calcium**

One of the minerals that is most frequently encountered is calcium carbonate. Its solubility is influenced by the water's pH, temperature, pressure, and the amount of free carbon dioxide present. Some of the dissolved carbon dioxide is released from solution when pumping, which results in the creation of a low-pressure zone surrounding the well. Once some calcium bicarbonate has been transformed back into calcium carbonate, cement-like material is deposited on the screen as well as in the sand and gravel surrounding it. A shell that may be several centimeters thick develops around the screen as a result of this incrustation. A meter or more of partial incrustation may reach the formation that holds water. The carbonate scales may also contain additional materials such as aluminum silicates, iron compounds, and organic material in addition to the sand grains that are cemented together surrounding the well. Even though it often makes up only a minor portion of the deposit, calcium carbonate serves as the deposit's primary binder. Ninety percent of incrustation cases involve this kind of deposit.

**(b) Salts with iron and manganese**

Iron and manganese bicarbonates are more water soluble than their hydroxides. The ground water in incrusting places is typically fully charged with these salts. The insoluble iron and manganese hydroxides are thought to precipitate out when the fluid's velocity increases close to the well, upsetting the equilibrium. They are puffy and jelly-like. The dissolved oxygen in the water can then cause oxidation, which results in the formation of hydrated oxides. Whereas ferric oxide is reddish brown like typical crust, hydrated ferrous oxide is a black sludge. Moderately soluble in water, ferrous bicarbonates become more soluble in acidic water. Nevertheless, alkaline or somewhat acidic water does not allow for the solubility of ferric salts. Hence, a decrease in acidity might also lead to the precipitation of iron salts. When ferrous bicarbonates come into contact with oxygen, they also oxidize, forming the insoluble ferric hydroxide.

$$4\ Fe(HCO_3)2 + O_2 + 2\ H_2O = 4\ Fe(OH)_3 + 8\ CO_2$$

Since air can enter the area of daily water table depletion and oxidize the salts there, oxidation is more pronounced in intermittently operated tube wells. Under such circumstances, iron oxide may gradually coat aquifer sand particles, diminishing void spaces and limiting the formation's potential for storage.

Manganese clogging happens much less commonly. Insoluble manganese hydroxide, which precipitates as a sooty or dark brown deposit, is created when soluble manganese bicarbonates and oxygen combine.

In general, waters can be categorized as incrusting if they have more than 400 ppm of bicarbonates, 100 ppm of sulphates, or 400 ppm of silicates. Incrusting water is defined as having 2 ppm iron or 1 ppm manganese. Iron can also be dissolved in water by the well casing itself.

### (c) Bacteria

*Figure 2-11 Iron bacteria on bowl assembly*

In addition to the iron in solution, iron bacteria feed on carbon compounds like bicarbonates and carbon dioxide as they develop adhering to the aquifer's screen or voids. Their growth is aided by the release of carbon dioxide, a lack of oxygen, and darkness. They transform dissolved iron into the insoluble ferric state during the course of their life cycle. This is either deposited in a jelly-like sheath that covers the bacteria or in the emptiness of the aquifer that surrounds the screen. This slime can clog the aquifer's pores and filter slots. They may also develop in water pipes and clog them. The oxidation of manganese compounds into an insoluble state can also be caused by similar bacteria.

The sulphates in groundwater can occasionally be converted to hydrogen sulphide by sulfate-reducing bacteria. The resulting hydrogen sulphide assaults the iron pipes and transforms into insoluble iron sulphide, which then forms scale.

**(d) Deposits of clay and silt (Mechanical Incrustation)**

Sometimes, clay and silt particles might slide onto the screen and clog it in the same way. This could also choke the rocky zone's fissures and cracks, which are common in bore wells. This congestion could result from poor development, poor design, or poor construction.

#### 2.3.5.4.3. Incrusted Tube Wells and Bore Wells Rehabilitation

Before choosing the course of treatment, it is imperative to identify the type of incrustation. This can be accomplished by analyzing the well water that is pumped out and by looking at aquifer samples collected near the well screen. Incrustation samples collected from other wells in the same formation provide excellent information.

Effective chemical interaction with the deposit on the well screen and in the nearby aquifer is the most crucial element in chemical treatment. Just those areas of the aquifer where there is the least resistance to the chemical solution tend to be penetrated, i.e., that are comparatively unclogged. In order to push the solution into places that give resistance, it is crucial to forcefully stir and surge the solution. It can be necessary to repeat a treatment a few times, and the second or subsequent treatment will clear the areas that are more severely congested.

Acids, chlorine, dispersion agents, etc. can be used to clean corroded wells. Sulphuric and hydrochloric acids can effectively dissolve carbonates while only partially eliminating iron and manganese oxides. Silts, clays, and iron and manganese oxides can all be dispersed by glassy phosphates. Slime and bacterial growth can be removed with chlorine.

The following list of techniques for restoring incrusted wells includes:

#### 2.3.5.4.4. Treatment With Hydrochloric Acid

**(a) Inhibitor**

Hydrochloric acid treatment removes mineral scale of the carbonate kind. Well treatment typically makes use of commercial grade, 28% strength concentrated hydrochloric acid. An appropriate inhibitor that aids in the fast dissolving of calcium and magnesium carbonates should be present. Moreover, it lessens how quickly acid attacks mild steel well casings. As a result, there is little chance that the pipe will sustain any harm while being treated. If prevented and acid cannot be found, an inhibitor manufactured at home can be employed. Usually, a 100-litre solution of acid and around 0.7 kg of gelatin in warm water is sufficient.

**(b) The method of treatment**

1. It comprises of a plastic pipe with a diameter of 2 to 2.5 cm that is long enough to reach the well's bottom. The pipe is lowered into the well while being supported by the proper clamps. A funnel inlet and overflow mechanism with a T-joint are included on the pipe's upper end. Any unexpected blow out is taken care of by the overflow pipe.
2. As previously mentioned, a hydrochloric acid solution is made. The amount of acid solution needed for a single treatment should be 1.5 to 2 times the amount of water in the well's screened area. Acid is poured into the well until it reaches the bottom 1.5 meters of the screen. More acid is then poured after raising the acid-feeding pipe to a height of roughly 1.5m. Water and acid will readily combine when swirled, despite the fact that acid is heavier than water and will displace it. This allows the acid to be easily diluted.
3. Acid treatment's efficacy depends on how well the chemical interacts with deposits in the nearby aquifer and on the well screen. Chemical penetration will use the route with the least amount of resistance. As a result, treating a choked aquifer is challenging. In order to force the acid solution into the aquifer formations that are providing resistance, it is crucial to vigorously stir and surge the acid solution. A surge plunger should be used to stir the acid solution in the well for one to two hours after it has been poured. Then it's time to bail out the solution. Bailing continues until the water is nearly clear.
4. The procedure is repeated with the same amount of acid in the second stage of treatment. Before dumping out the water, the surging is continued for a longer period of time. Usually, two sessions are enough to get the desired effects. Neighboring wells within a 60-meter radius shouldn't be used while the acid is being treated.

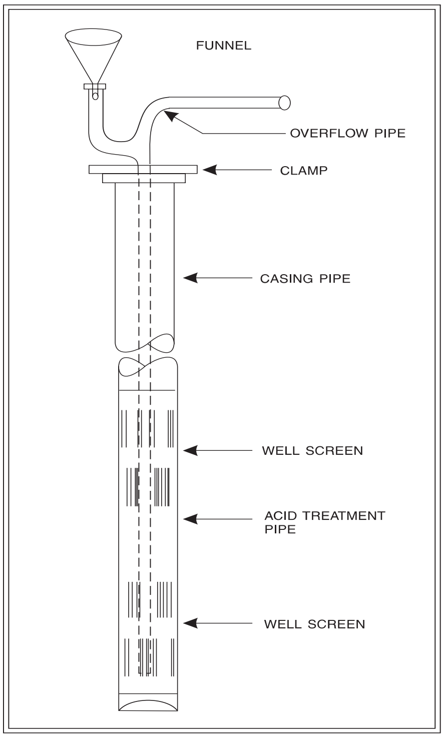



*Figure 2-12 Set up for acid treatment*

**(C) Safety precautions**

If handled carelessly, hydrochloric acid can cause serious eye damage and damage to skin. Similar to this, gas creation when acid is put into a well can result in suffocation, which can be lethal. As a result, the sick should be treated with the appropriate caution. The vicinity of the pump house should have good ventilation. Rubber gloves and safety masks should be used by everyone handling the acid. To counteract the effects of acid if it accidentally falls on the body, a box of baking soda is always kept on hand.

### 2.3.5.4.5. Treatment With Sulphamic Acid[1]

I. When calcium carbonate is the main incrusting substance, sulphamic acid and hydrochloric acid are utilized. While costing more than hydrochloric acid, it provides a lot of advantages. It has a number of benefits, including the fact that it is less aggressive, manageable, and does not assault M.S. Hydrochloric acid is corrosive to well casings. As a result, mild steel screens or casings with deposits of calcium and magnesium salts are frequently treated with sulphamic acid. Commercially, sulphamic acid ($NH_2SO_3H$) is offered in granular and pelletized forms. It has a wetting agent and a corrosion inhibitor, and it is sold under various trade names. Also, a color indicator is added to the pellet, which, once the incrustation has completely dissolved, will cause the solution's color to change from violet to orange yellow. Because sulphamic acid dissolves in water, the diluted solution doesn't release any noxious fumes or irritate the skin.

II. Using a plastic or iron conduit, sulphamic acid in granular form is poured into the well. To dissolve the item in water, it is stirred after being so poured. On occasion, it is mixed with water to a 20% solution and poured into the well. In this instance, the solution is first made. Using a 200-liter drum to dissolve one bag of acid (powder or pellets) at a time. It is suggested to pour

[1] https://www.cmpethiopia.org/content/download/2213/9427/file/PART%20A-MODULE-B-%20Description%20of%20water%20sources%20for%20water%20supply.pdf

the solution into the tube well's bottom end. A 25 mm or other suitable diameter PVC syphon tube is used for this, with one end of the tube kept in a funnel on top of another 25 mm pipe that has already been lowered into the tube well's bottom through the area between the pump and well casing. The sulphamic acid solution tank is where the siphon's end should be maintained. Then, using the pipe, the solution is poured into the tube well. A valve placed at the end of the delivery pipe regulates the rate of feeding the solution, allowing it to enter the tube well gradually and prevent an early quicker chemical reaction. The feeding rate is controlled to add the full solution over the course of two to three hours. The solution is allowed to stay in the tube well for about 24 hours.

III. If the acid is available in pelletized form, modest amounts of the pellets could be dropped straight into the well. As the reaction progresses, more granular material is added to the well to maintain the requisite strength of the solution. The reaction might be finished with surge in 16 to 24 hours. Following this 16–24-hour period, which includes 4–6 hours of chemical addition, the well is developed using a pump or compressed air. This will dislodge the chemical that has become embedded on the tube well screen and the nearby aquifer. The water from the tube well is then pumped out. Until clean water is acquired, intermittent pumping is continued for around 10 hours.

IV. The amount of water in the well determines how much sulphamic acid is needed. A tube well should typically add 7 to 10% of the weight of the water in the well in sulphamic acid, according to standard recommendations. Hence, the amount of water in a tube well with a 20 cm diameter and a 100 m water column is the entire amount of sulfuric acid needed for a treatment is roughly 250kg, or 3.14 m3. To enhance the effectiveness of the acid, it is frequently preferable to add a corrosion inhibitor and a wetting agent (low detergent soap). The amounts of both of these additions are roughly 10% of the weight of sulphamic acid each. The corrosion inhibitor stops the acid's ability to corrode the well pipe's metal. The wetting agent enhances the acid's cleansing and dispersion abilities. Wetting agents with names like Fluronic F-68 or Pluronic L-62 are frequently utilized. When using the two additives with the acid, it is important to combine them in a bucket with clean water to create a thick but pourable slurry before adding it through a tube to the well.

**(d) Conditions required for acid treatment**

The following are the principal conditions for treating water wells with acid:

i) The well screen's metal needs to be constructed such that the acid won't corrode it.

ii) To prevent electrolytic corrosion, which occurs when a bi-metallic alloy is used, the well screen must be made of a single metal.

iii) In order to choose the best course of action for well treatment, it is important to have a basic understanding of the type of incrusting material. The reasons of incrustation can be determined by examining samples of incrustations from different wells in the same formation. Analyzing the water quality is also helpful for learning more about the type of incrusting material.

iv) The well treatment site requires adequate ventilation.

v) During the treatment process, wells nearby (within 30 meters of the well) must be shut off.

The acid used in all treatments must be handled carefully. When working in a small space, such as a pump house, adequate ventilation should be given. The disposal of the wastewater that is pumped out during treatment should be adequately provided for. Domestic wells, ponds, and other water sources utilized for human or livestock consumption must be kept clear of wastewater. After being diluted, the trash won't harm plants. During acid treatment, the waste is pumped using a procedure of rapid surging followed by slow pumping until the water is clear and smell- and foam-free.

#### 2.3.5.4.6. Problems in Aquifers That may not Respond to Acid Treatment

Although though acid treatment of water wells is generally suitable, the following aquifer conditions may prevent any discernible improvement:

I. Limited shallow aquifers that frequently experience overdraft.
II. Narrow, deeply submerged aquifers on the verge of overdevelopment.
III. Low permeability aquifers with high operating heads.

The effectiveness of acid treatment or other development strategies to boost the productivity of water wells must be determined through controlled pumping studies that examine well efficiency and aquifer hydraulic parameters.

#### 2.3.5.4.7. Treatment for Glassy Phosphate

For well treatment, glassy phosphate or polyphosphates are utilized when incrustation-causing elements include iron oxide, manganese oxide, silt, and clay. One of the most often utilized polyphosphates is sodium hexametaphosphate $(NaPO_3)_6$. The incrusting substance is not broken down, and neither boiling nor fuming occurs. When combined with vigorous agitation, phosphates' cleansing and dispersing qualities help break up the incrusting substance. As a result, the incrustation is simply pumped out and is scattered. Little amounts of calcium hypochlorite are also added to it. By chlorinating the well, it aids in the destruction of any iron bacteria or other similar organisms that might be present in the well water.

### *(a) Treatment method*

In a tank or drum, a solution of glassy phosphate is made. The quantity of water in the well determines how much glassy phosphate needs to be added. Typically, 1000 gallons of well water require 15 to 30 kg of vitreous phosphate. Instead of just dumping it, it should be dissolved in water by being suspended in a tank in a cotton net or gunny bag. It is ideal to use 1.2 kilograms of calcium hypochlorite in every 1000 liters of water. It aids in the destruction of iron bacteria and other organisms. The prepared solution is then added to the well. The chemical will help loosen and distribute the deposits inside the pipe as well as outside by vigorously surging after this. Via the perforations in the screens, the dispersed material exits. A surge plunger, compressed air, or horizontal jetting can all be used for surging. If the well's installed pump is left in place, it can be used for surging. Although it is not very efficient, pumping might be employed for convenience. By beginning and stopping the pump as frequently as possible, you can perform a surge. During almost four hours, operation is continued. After that, the pump is turned off for around two hours. Twice or three times the process is carried out. Surging is carried out repeatedly after the chemical has been in the well for around 24 hours. After that, the waste is pumped out and the well is properly flushed. Surging is done a few times at a time while the well is being washed out, and pumping is kept up until reasonably clean water is obtained. The entire process can be repeated two or three times with new charges of calcium hypochloride and polyphosphates. The chemical can be used without any particular safety precautions and is quite safe to do so.

### *(b) Biofouling caused by hydrogen sulphide ($H_2S$) removal:*

Groundwater sulfate-reducing bacteria convert sulphates in the water to hydrogen sulphide, which creates the foul odor known as biofouling. The approach stated above can be used to get rid of this biofouling. Super chlorinating water is another method for getting rid of this.

### 2.3.5.4.8. Treatment With Chlorine

The most effective treatment for wells covered with bacterial growth and slime deposits is chlorine. Acid may destroy the germs, but it cannot get rid of the slime. In addition to killing the bacteria, chlorine also oxidizes the organic slime, which loosens it.

For the treatment of chlorine, calcium hypochlorite Ca $(OCI)_2$ is frequently utilized. It comes in powder form and has a free chlorine content of roughly 70%. The required amount often ranges from 20 to 25 kg for deep wells. You can also use sodium hypochlorite, or NaOCI. Occasionally chlorine gas in a water solution is also employed, although its use calls for specialized equipment.

***Treatment method***

To achieve the right chlorine concentration, the desired amount of the chemical is either directly injected into the well or dissolved in water. In the case of large wells, chlorine solution can be delivered gradually into the well over a period of around 12 hours using a plastic pipe with a modest diameter. For this, between 14 and 18 kg of chlorine will be needed. Less chlorine is needed in small wells, therefore the application time can be cut in half.

When there is water around, chlorine is corrosive. So, it needs to be handled cautiously to prevent damage to the pump, well casing, and screen. Although the pump need not be taken apart, it should be checked to make sure that no portion of the pump, well casing, or screen is receiving liquid directly from the plastic tubing containing concentrated chlorine solution. In order to force the chlorine solution into the water-bearing formation, enough water (50 to 100 times the amount of water currently in the well) is added to the well as soon as the chlorine solution is introduced. After that, the well is pumped using one of the common methods. The same can be used for surging if the pump has not been removed, albeit it is not particularly successful. Three or four successive procedures may be necessary for a well to successfully undergo chlorine treatment.

### 2.3.5.4.9. Treatment With Hydrochloric Acid and Chlorine in Combination

Treatment with hydrochloric acid and then chlorine is quite efficient. The chlorine aids in the removal of the slime that iron bacteria have left behind while the acid easily dissolves the carbonates. The acid treatment is carried out first, then the other two treatments. It's possible for the cycle to happen twice or more.

### 2.3.5.4.10. Inadequate Well Development

Occasionally during construction, owing to negligence, sufficient tube well development is not done, producing a steady input of sand particles to choke the filtering media and strainers. Such tube wells require renovation. The following implications of tube well’s redevelopment:

1. Rehabilitation of a well entails the removal of finer material from the area surrounding the well screen, resulting in the enlargement of the passageways in the water-bearing formation to promote water entrance.
2. The obstruction in the water-bearing formation is cleared through redevelopment.
3. The water-bearing rock next to the well becomes more porous and permeable as a result.
4. In order for the well to produce water free of sand, it stabilizes the formations close to the well screen.
5. The well's effective radius and yield both grow as a result of redevelopment.

### 2.3.5.4.11. Redevelopment Techniques

The techniques for well redevelopment are as follows:

i. Excessive pump use

ii. Surge blocking and bailing when surging

iii. Using an air compressor to pump and surge
iv. Back-washing
v. High-speed jetting
vi. Acid treatment and use of dynamite

Any suitable form of redevelopment can be employed for rehabilitation purposes, as was already mentioned. Using compressed air to surge and pump is the most common technique. This technique combines pumping and surging by using compressed air. During the procedure, a significant amount of air is abruptly released into the well casing pipe, causing a powerful surge. Pumping is carried out using a standard air lift pump. The submergence ratio (together with two airlines in water divided by its entire length) is crucial for a well's effective rebuilding. The recommended submergence ratio for achieving the greatest outcomes should be around 60%. If the appropriate submergence ratio is not kept, development efficiency rapidly declines.

The necessary equipment for pumping and surging operations includes a tank of the necessary size, an air compressor, drop pipes, and flexible high-pressure air hoses for supplying compressed air to the air pipes, pressure gauges, relief valves, quick-opening walls in the tank outlets, tee joints, and pipe jointing material.

Normally, air compressors of 500 cum. per hour at 7kg/cm2 to 800 cum. per hour at 17kgs/ cm2 are used for development/redevelopment work of the tube well. When an air compressor with insufficient capacity is used to develop a well, appropriate development is impossible in certain circumstances, and the wells get sick soon after being put to use. Only by using the process of well development, also known as redevelopment of the well, can these tube wells be restored.

#### 2.3.5.4.12. Submergence Requirement of the Airline and Selection of Air Compressor

For achieving successful development/redevelopment of a well, submergence requirement of the airline is given below in table 2-1[2].

*Table 2-1 Submergence requirement of airline*

| Lift m | Maximum submergence % | Optimum submergence % | Minimum submergence % |
|---|---|---|---|
| 6 | 70 | 66 | 55 |
| 10 | 70 | 66 | 55 |
| 15 | 70 | 66 | 50 |
| 20 | 70 | 64 | 50 |
| 25 | 70 | 6 | 50 |
| 30 | 70 | 60 | 45 |
| 40 | 65 | 60 | 45 |

[2] https://www.scribd.com/doc/66007276/CPHEEO-Manual-on-Operation-and-Maintenance-of-Water-Supply-Systems-2005

| | | | |
|---|---|---|---|
| 50 | 65 | 60 | 45 |
| 60 | 60 | 50 | 40 |
| 70 | 55 | 50 | 40 |

#### 2.3.5.4.13. Air-Compressor Selection

The need for pressure and capacity are the two main considerations when choosing an air compressor for well development or renovation. The length of the air pipe below the static water level is used to calculate the necessary air pressure. The compressed air must force all the water out of the pipe before air can be evacuated from the lower end. To do this, before beginning to pump water, the air pressure needs to be higher than the water pressure. When the airline is submerged in water, the needed compressor pressure will be just a little bit higher.

For each liter of water pumped at the projected rate, there should be around 0.28 m3/l of free air available, according to a helpful rule of thumb for estimating compressor capacity.

#### 2.3.5.4.14. Redevelopment Methodology

The following actions must be taken in order to develop the tube well again:

- Drop the air line and drop pipe into the well until they are submerged to the required depth. The air line should be kept about 30 cm above the bottom of the drop pipe, which should be kept about 60 cm above the bottom of the screen.
- Until the discharge water is sand-free, turn on the air from the compressor and the well that is pumped using the traditional air lift principle.
- After that, the airline is lowered until it is about 30 cm below the bottom of the drop pipe. This is done by closing the valve between the tank and the compressor. Hence, the airline is in the same position as when using the back-washing technique.
- To fast let compressed air from the tank into the well, the air valve is immediately opened. Water tends to flow outward through the well screen apertures as a result of this. until the water being discharged from the well is largely free of sand, the air pipe is lifted once more, and the cycle is repeated. One surging procedure is finished with the aforementioned backwashing and pumping operation.
- Once the well section has been produced over the entire length of the screen, the complete assembly is lifted to a height of roughly one meter and the process is repeated.
- The airline is then once more lowered to the well's floor and the machinery is used as a pump to flush out any possible sand buildup inside the screen.

Typically, all poorly developed wells that were drilled in alluvial formations can be successfully rebuilt using this technique. With good results, this technique has also been applied to sick wells dug in rocky formations. Disbursing chemicals like polyphosphates have also been proven to be helpful in recovering poorly developed wells that were drilled in alluvial formations using redevelopment techniques.

### 2.3.5.5. Incrustation and Corrosion Prevention

#### 2.3.5.5.1. Incrustation Prevention

In wells when the water is contaminated with unwanted substances, incrustation cannot be totally avoided, but it can be postponed and maintained under control by minimizing the draw-down. This prevents a significant leak of carbon dioxide and controls the precipitation of carbonates in well screens. The well should be correctly designed in order to minimize aquifer losses in order to limit head loss to a minimum. The aquifer should be completely penetrated by a screen with a sizable open space. This also leads to decreased entrance velocities, which slows down the precipitation of carbonates and iron salts. Reduce the pumping pace and lengthen the pumping time. Instead, then pumping a few large wells at exorbitant flow rates, the required amount of water can be acquired from multiple wells. Last but not least, even if the discharge has not fallen off, the screen should still be cleaned sometimes, say once a year. This final element is crucial because it might be quite challenging to totally eliminate partial choking.

#### 2.3.5.5.2. Corrosion Prevention (Corrosion-Resistant Paint and Coating Application)

By painting the steel pipes with anti-corrosive paints when the tube well is being built, corrosion can be greatly reduced. To prevent corrosion, non-corrosive casing pipes and strainers (such PVC pipes and strainers) can also be used while building tube wells. Aluminum, asphalt, red lead, and coal tar are a few materials that are frequently used in paints and coatings to prevent corrosion. These days, the industry also offers a variety of epoxy paints for this use.

Two techniques for administering cathodic protection against corrosion of mild steel pipelines are as follows:

a) sacrificial anode

b) Impressed current

c) Sacrificial anode: For wells, cathodic protection, which is described below, is used.

A metal with a higher negative potential than the material of the pipe to be protected is employed as the anode in the sacrificial anode system of cathodic protection. Electrons' flow from the anode to the cathode is established by the metal pipe acting as the cathode and the water in between as the electrolyte. The metal ions in the solution are deposited at the cathode as the anode slowly dissolves during electrolysis. As a result, the anode's metal is sacrificed in order to preserve the main pipe (well pipe) from corrosion. Sacrificial anodes require no power and are simple to install. They work well in corrosive water to extend the service life of mild steel tube wells. The anodes must be routinely replaced when they reach the end of their useful life, though.

Magnesium, zinc, aluminum, tin, or their alloys may be used to make the anodes. They come in commercially available lengths of 1 to 3 m and diameters of 1.5 to 8 cm. A common alloy with Al 90%, Zn 7%, and Sn 3% content has been found to be adaptable in the cathodic protection of tube wells by research findings. There are various alloys that can be cast in 1 cm diameter steel core pipes. The ends of the anode rods are threaded to allow for connection to one another by sockets or couplings.

(b) Impressed Current: This approach uses anodes that are buried in the ground far from a mild steel pipeline to conduct electricity from the current source to the pipeline. Although the efficacy of this technique to protecting wells has not yet been demonstrated, it is widely utilized to protect mild steel pipelines in water delivery projects.

#### 2.3.5.6. Artificial Recharging of Ground Water

The following can be done to artificially recharge ground water:

i) Stream flow harvesting, which includes using anicuts and gully plugging

ii) Surface flow harvesting using Tanks and Ponds

iii) Direct recharge via injection wells and rainwater harvesting structures

### 2.3.6. Causes of Failure of Wells

The main causes for source failure are categorized as under:

I. 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.

II. Physical blockage. An accumulation of sand, silt and other materials inside the well screen can reduce water flow into a well.

III. Faulty operation e.g. over pumping, poor maintenance.

IV. Adverse aquifer conditions resulting in lowering of water table and deterioration of water quality.

V. Mechanical failure e.g. falling of foreign objects including pumping assembly and its components.

VI. Biological blockage. Naturally occurring common soil bacteria are found in almost all aquifers and are the cause of biological screen blockage.

VII. Chemical blockage. Chemical blockage results from the deposition of minerals in the form of scales or incrustation on the well screen. It also cements parts of the gravel pack and aquifer materials on the outside of the screen.

VIII. Inadequate development of wells.

IX. No matter how screen blockage happens, it increases the drawdown and pumping energy requirements.

### 2.3.7. Deep well turbine pump

- Deep well turbine pumps are basically centrifugal pumps which are used for high head, high efficiency and constant flow.
- The bowel assembly is submerged in the fluid to be pumped.
- Pumps push fluid to the surface through a column pipe and then through a head assembly.
- Increase or decrease of bowel assemblies changes the head efficiency of the pump.
- column pipes and column shafts are also interchangeable and used according to the required head efficiency.

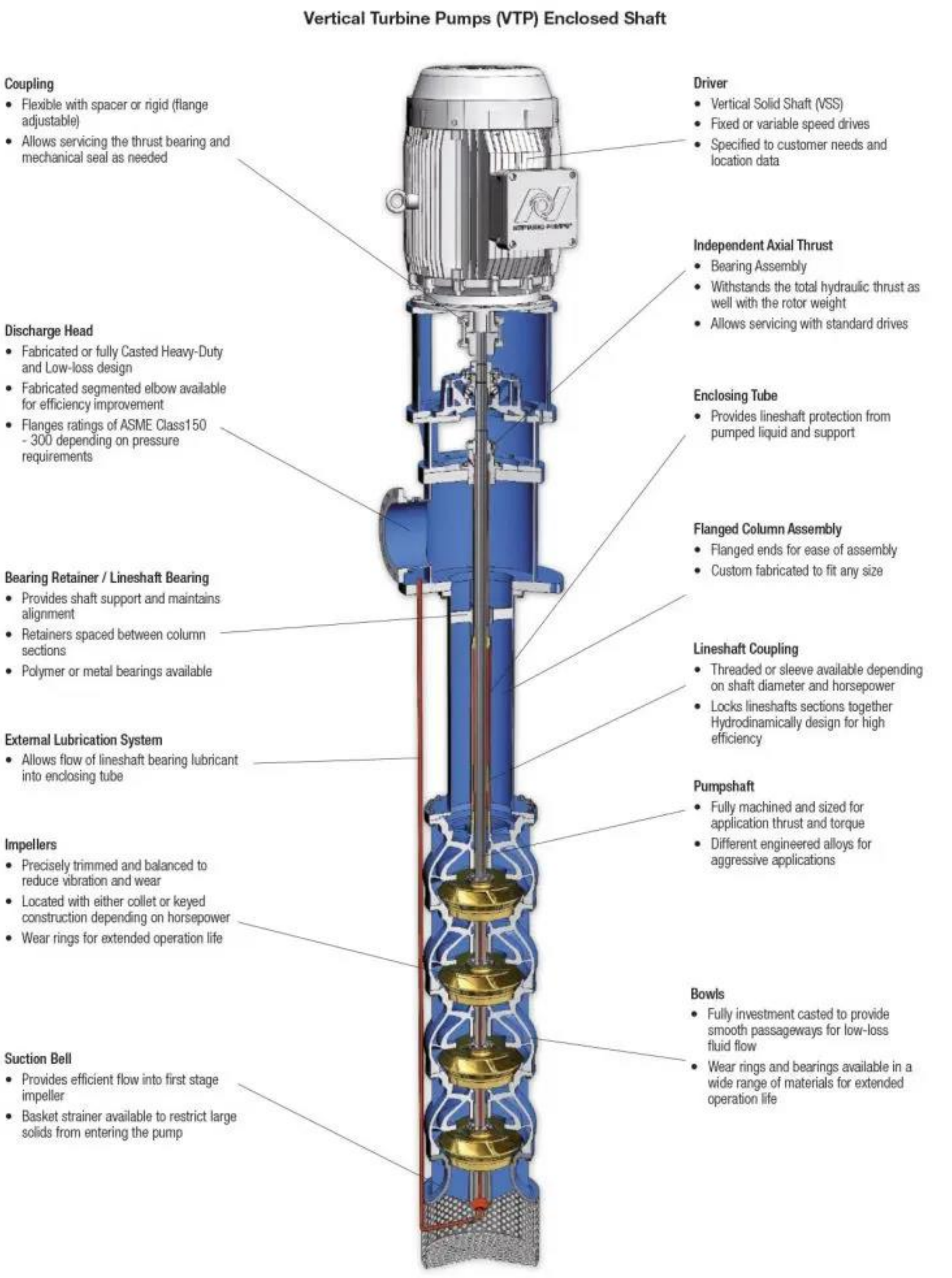
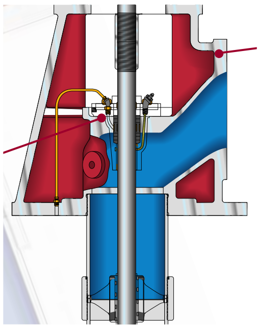
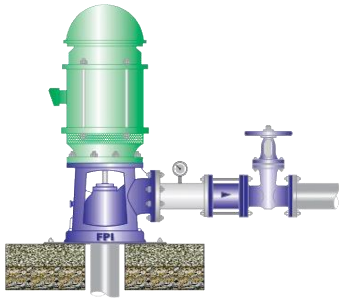



*Figure 2-13 Turbine pump*

### 2.3.7.1. Parts of vertical turbine Pump

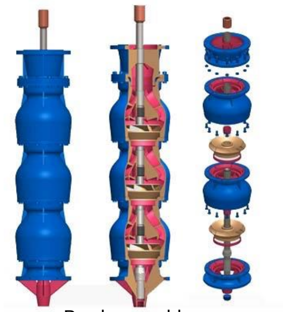


Stuffing Box:



Discharge head.

Flanged bowls and impellers



Bowl assembly

*Figure 2-14 Parts of a Turbine Pump*

### 2.3.7.2. Screen/filter

*Figure 2-15 Fiberglass Screen*

# 3. O&M OF WATER TRANSMISSION SYSTEM

## 3.1. GENERAL

### 3.1.1. Transmission System Objective

The overall objective of a Transmission system in this project is to deliver water abstracted from the source(ground water tube wells) and disinfected before supplying to transmission and distribution networks. Transmission of water is by pipes. Transmission through pipes is by pumping.

The objective of O&M of transmission system is to achieve optimum utilization of the installed capacity of the distribution system with minimum transmission losses and at minimum cost. To attain this objective the MCs is to ensure that the system can operate satisfactorily, function efficiently and continuously, and last as long as possible at lowest cost.

Routine and emergency operating procedures should be in writing and clear to all operators with the authority to act in emergencies. Further specific operational procedures are required for inspecting, monitoring, testing, repairing and disinfecting the system as well as for locating the buried pipes and valves. System records and maps should be updated and have sufficient details of the system facilities.

### 3.1.2. Usual Situations

#### 3.1.2.1. Usual Procedures

In normal operations, the required water is transmitted within the available head or within the pumping head. Routine activities include the opening and closing of valves at reservoirs from which water is transmitted, as well as the turning on and off of pumps (in the case of pumping mains) from which transmission mains originate. Routine operations also involve the operation of chlorinators where they are installed.

#### 3.1.2.2. Record of Water Levels, Pressures, And Flow

**(a) Pipes**

At the transmitting and receiving reservoirs, a record of the valve operations, water levels, and flows are maintained. At the beginning and end of transmission pipes, flow meters are fitted to track the flows. Both the water levels in the reservoirs from which the pipes transport water and the water levels in the reservoirs that receive it are monitored using either automatic equipment or visual gauges.

**(b) Pumps associated with pipe system**

Pump log book is maintained at each Tube well and operation hours (start time, closing time), power shut down, any repair required etc. is recorded in it.

**(c) Continuity**

Operators must ensure that water is transmitted continuously and according to specifications. The flow meter readings, reservoir water levels, and transmission main pressures are typically recorded and sent to the control room. In order to carry out the operations correctly, the operators must assure the accuracy of the measuring instruments for flows, pressures, and levels. The MC will be able to assess how well the transmission system is operating after analyzing the records.

## 3.2. PIPE MATERIAL FOR WATER SUPPLY NETWORK USED IN PMDFC PROJECT

### 3.2.1. HDPE Pipe

HDPE pipe is used for all sizes of new water supply main and distribution lines. Polyethylene is a thermoplastic polymer consisting of long hydrocarbon chains. It is the most common type of plastic and is used for various applications including plastic bags and bottles. High-density polyethylene (HDPE) actually has only a slightly higher density than low-density polyethylene (LDPE), but due to differences in the chemical bonding, it has greater strength and can handle higher temperatures. HDPE is a commonly used pipe material that is tough, flexible and corrosion resistant. HDPE pipe is flexible and can thus be supplied in rolls instead of straight lengths. This means fewer joints, which is an advantage if the jointing is done well. However, the welding used to join HDPE pipes requires a high level of workmanship, which is sometimes difficult to achieve in the field.[3]

### 3.2.2. Description of HDPE Pipe

- Polyethylene (PE) pipe was first used as pressure pipe in the US in the 1950s. This first material was high density polyethylene (HDPE), which were prone to stress cracking and had poor resistance to rapid crack propagation (RCP). It was improved with the passage of time.

**PE 100 is the third generation of pipe grade PE**.
It has an optimum balance of three key properties:

- **Minimum Required Strength (MRS)** – this provides long-term strength and creep resistance.
- **Stress crack resistance** (sometimes referred to as slow crack growth resistance).
- **Rapid crack** propagation resistance.
- HDPE PE100 pipe is easy to install, light, flexible, corrosion-free and has a service life of up to 100 years. It can be jointed using butt fusion or electrofusion to create a leak-free pressure network for gas or water.
- For the trenchless applications butt fusion is most widely used because this results in a smooth exterior profile with no protrusions that might cause difficulties in pulling the pipe into the ground or host pipe.

### 3.2.3. Major specifications of PE-100 covered in ISO-4427

*Table 3-1 Major specifications of PE-100*

| S.NO | Characteristics | Requirement |
|---|---|---|
| 1 | Minimum Required Strength (MRS) | 10 mpa |
| 2 | Hydrostatic Design Basis (HDB) Pressure | 1600 psi (11 MPa) |
| 3 | Allowable Compressive Strength | 7.93 MPa |
| 4 | Tensile Strength at Yield | 23mpa |
| 5 | Density (Compound) | 959 kg/m3 |
| 6 | Modulus of Elasticity (50 years): | 200mpa |
| 7 | Elongation at break | > 600% |
| 8 | Flexural Modulus | 1000 Mpa |
| 9 | Poisson’s Ratio | 0.45 |
| 10 | Thermal Expansion Co-efficient | 1.3 x 10-4 °C-1 |

### 3.2.4. ISO grades of HDPE pipe

- Polyethylene is available in various classes and is frequently specified with a number indicating the minimum tensile strength of the material in N/mm$^2$(MPA) at 20°C over 50 years:
- PE40 means 4 MPA strength
- PE63 means 6.3 MPA strength

[3] *Manual-on-O&M-of-water-supply-systems-GOI-2005.pdf*

- PE80 means 8 MPA strength
- PE100 means 10MPA strength

Countries which use the metric system and follow ISO as standards designate HDPE pipe as *Polyethylene Pipe (PE)* and ASTM Standards nomenclature refers to it as *High Density Polyethylene Pipe (HDPE)*.

- **SDR pipe : "Standard Dimensional Ratio"**
- The SDR is the "Standard Dimensional Ratio" and refers to the geometry of the pipe. SDR is defined as the ratio of the nominal outside diameter to the nominal wall thickness.
- SDR = dn/en
- Where dn is the nominal outside diameter of the pipe and en is the nominal (minimum) wall thickness of the pipe. Therefore, a higher SDR indicates a thinner-walled pipe at any given diameter.
- **MOP = 20 MRS / C (SDR – 1)**
- Example : What is the MOP or pressure rating of an SDR21 PE100 water pipe?
- For PE100 the MRS = 10 MPa. For water applications the minimum recommended service design coefficient 'C' is 1.25.
- **Maximum operating pressure (MOP) = 20 * 10 / 1.25 (21 - 1)**
- MOP = 8 bar. Similarly if SDR is 17 its Maximum operating pressure will be = 20*10/1.25(17-1)=10 bar

### 3.2.5. PE-100 Pipe Dimensions

*Table 3-2 PE-100 Pipe Dimensions*

**PE-100 PIPE DIMENSIONS CONFIRMING TO ISO 4427**

| Outer Diameter | SDR-21 | SDR-17 | SDR-11 | SDR-9 |
|---|---|---|---|---|
| | PN-8 | PN-10 | PN-16 | PN-20 |
| | WALL THICKNESS | | | |
| Mm | Mm | Mm | mm | Mm |
| 110 | 5.3 | 6.6 | 10 | 12.3 |
| 125 | 6 | 7.4 | 11.4 | 14 |

### 3.2.6. HDPE Joints & Fittings

- Any part used to join two sections of pipes. Joints and Fittings are available in the same materials as those of water supply pipes.
- Detachable piece of pipe or tubing that connects to another piece of pipe or connects two such pieces.

**Types of HDPE Fittings:**

**Elbow:** Used to change the direction of flow between two pipes. Generally available with an angle of 22.5˚, 45˚ and 90˚. Reducer elbows are used if pipe sizes are different.

**Concentric Reducer:** A cone shaped with gradual decreasing around the pipe but air may accumulate resulting in cavitation.

**Eccentric Reducer:** One edge is parallel to the connecting pipe due to which air accumulation is not possible.

**Tee**

This is T shaped fitting with one inlet and two outlets. Outlets are arranged at 90 degrees to the inlet. It can combine flow from two inlets to one outlet. If 3 sides are same in size, called at equal tee, otherwise its called as unequal tee.

**Cross:** Contains four openings, generally used for fire sprinkler systems.

**Coupling:** Used to connect pipes of same diameter. It is also helpful if the pipe is broken or leakage occurs.

**Compression Coupling:** Regular coupling which is provided between pipes and prevents the leakage through gaskets or rubber seals.


*Figure 3-1 Various fittings of HDPE pipe*

**Union**: Functions similar to coupling but coupling can not be removed after fixing. Union consists of male nut and female ended threads so it can be removed easily.

**Adapter:** Used to connect pipes that do not have special ends. The adapters make them threaded either male or female. They are generally used for copper and PVC pipes. One end of adapter is plain which is welded or glued to plain end of pipe.

**Cap:** It has the same function as the Plug but the difference is, plug contains male threads and cap contains female threads. Available in rubber, copper, steel, plastic.

## 3.3. DESIGN BASIS OF THE WATER SUPPLY PROJECT

### Total Average Water Demand

Design of Water Supply is based upon total average day demand (that is the total of domestic, non-domestic water demand and unaccounted-for water), equal to **39.6 GPCD**.

### Design Flow

Design flow is taken as peak hourly flow for distribution network. It is 2.25 times the average day demand.

### Design Horizon

The project has two phases:

i. 1st phase for water demand of 2032

ii. 2nd phase for water demand of 2050

**Velocity**

The maximum flow velocity in the pipelines would not exceed 1.5 meters/sec.

**Pressure in the network**

The pressure in the distribution network shall be at least 14 m (1.4 bar) in all parts of the network including the remotest and highest points to deliver sufficient quantities of water. The maximum pressure will be 40 m.

**Location of Valves**

Isolating valves in transmission pipeline(s) shall be placed as per the below detail:

**Transmission Pipeline(s):**

- Isolating valves at every 2000 m
- Air valves at crest points and in constant rising pipelines (of moderate slope) at every 1000 m
- Washouts at the lowest points of the pipelines or section

**Chlorination**

- Free residual chlorine of about 0.2 mg/l will be maintained at the farthest point in the pipe network.

**Distribution Network problems and solutions**

## 3.4. O&M ASPECTS OF MAIN PIPING AND DISTRIBUTION SYSTEM

### 3.4.1. Water distribution system Problems

#### 3.4.1.1. Water Leakage

**Joints Leakage of HDPE Pipe**

- Excessive deflection and Joint misalignment
- Welding jointing weakness due to misalignment, incorrect welding procedure or impurities.
- Excessive internal working or water hammer pressures Exposure to solvents
- Difficult to find nonmetallic pipe underground

viii. **Loose fittings**

#### 3.4.1.2. Leakage Through Appurtenances

The glands of sluice valves are the source of the majority of leaks. Moreover, leaks can happen through expansion joints if the gland packing is out of place and the bolts have come free. Air leaks through air valves happen when the ball is not properly seated, which leads to gasket damage, ball abrasion, leaks through the gland of the isolating sluice valve, or leaks through the small orifice.

#### 3.4.1.3. Entrainment of air

Free-form air in a rising main will gather at the pipeline's top and then rise to higher points. Here, it will either create an air pocket or exit through air valves. The size of the air pocket will increase as there is more air collection. As water moves more quickly through the pipe, its cross-sectional area will decrease. The development of an air pocket will cause more head loss. Surge, corrosion, decreased pump performance, and faulty valves or vibrations are other issues related to air entrainment. In a few rare instances, air entrainment may also lead to pipes exploding.

#### 3.4.1.4. Water Hammer

The transmission pipe could be ruptured, or the pipeline's valves could be harmed by the pressure increase brought on by water hammer. When valves close quickly and the power to the pumps is abruptly cut off or fails unexpectedly, water hammer develops in the water delivery systems.

#### 3.4.1.5. The System's age

The carrying capacity of the pipelines, especially unlined CI, MS, and GI pipes, significantly decreases with time, leading to corroded pipes and leaks, which in turn lead to decreased amount and pressure.

#### 3.4.1.6. Exposure to sunlight

Exposure to sunlight can damage certain materials such as HDPE, and thus care should be taken not to lay these pipes above ground or leave them exposed to the sun.

#### 3.4.1.7. Negative pressures

In extreme cases the demand exceeding the system capacity can lead to pressures in the system dropping below atmospheric, i.e. become negative. This is a particularly undesirable situation, as negative pressures will suck in contaminated water from outside the system when a hole or crack is present in the pipe. Sources of contaminated water include sewage and chemical spills, ground water surrounding pipe leaks and flooded chambers.

Air sucked into the system may stir up sediments and produce discolored water, and air flowing through water meters cause reading errors and may damage meter by exceeding their maximum flow rates.

If negative pressures are severe, pipe linings may be cracked or damaged, and in large diameter pipes may even cause pipe collapse.

#### 3.4.1.8. Pumping directly from the network

Consumers experiencing low supply pressures previously definitely have a pump installed to boost the pressure to their properties. However, connecting the suction side of a pump directly to the network exacerbates the problem in two ways:

• While the pump may boost the pressure in the building it is installed in, the increased demand on the system lowers the pressure further for other nearby consumers, and thus reduces their level of service.

#### 3.4.1.9. Excessive pressures

Pressures that are too high can also cause problems, including higher leakage rates (leakage has been found to be very sensitive to system pressure), more new leaks forming, reduction in pipe service life.

#### 3.4.1.10. Low velocities

The residence time of water in the system (i.e. the time it takes water to move from the water Tube wells to the consumer) should be kept as short as possible since longer residence times increases the risk of chlorine depletion and disinfection byproduct formation.

Mmunicipalities should introduce a systematic flushing program to remove accumulated sediments from affected pipes.

Sediments serve as a food source for bacteria and create a hospitable environment for microbial growth. If not removed these materials may cause water quality deterioration, taste and door problems, or discoloration of the water. This is particularly evident if the sediments are disturbed by sudden changes in the flow of water, for instance as a result of a pipe break.

#### 3.4.1.11. . Air in the system

Air can enter the distribution system dissolved in the water, when the system is drained for maintenance purposes or during negative pressure events. Air trapped when the distribution system is operational is compressed due to the pressure in the system. When these air bubbles are released through a tap or leak in the pipe, they rapidly expand when the pressure is released, causing a sudden 'explosion' that may unexpectedly accelerate water exiting the system, or even damage system components.

#### 3.4.1.12. . Contamination during construction and repairs.

When a section of the distribution system is isolated and opened to connect new pipes or repair existing pipes, the system is vulnerable to polluted water, soil and other substances entering it. Thus, it is essential that construction crews are well trained to prevent pipes from being contaminated during construction, and that repaired pipes are thoroughly flushed and disinfected before they are reconnected

#### 3.4.1.13. Animals or insects

may enter reservoirs when air vents and access openings are not properly sealed and protected with a fine mesh. Animals may fall in the water and drown, defecate in the water or bring in other external materials that may pollute the water in the reservoir.

#### 3.4.1.14. Cross-connections and backflow

Cross-connection means any actual or potential connection or structural arrangement between a drinking-water system and any other source or system through which it is possible to introduce into the distribution system contaminated water, industrial fluid, gas or substances other than the intended drinking-water with which the system is supplied. Cross-connections constitute a serious public health risk. There are numerous well documented cases of cross-connections that contaminated drinking-water and resulted in serious illness (USEPA, 2002a; Craun et al., 2006).

#### 3.4.1.15. Lack of Records

In general, maps that illustrate the precise alignment of transmission mains are difficult to find. In the absence of system maps, finding pipes and valves on the ground becomes challenging. To run and maintain the system effectively, a minimum amount of knowledge regarding the positioning of pipes and valves, their sizes, and the direction in which they open, among other things, is needed.

### 3.4.2. Operation Schedule for Transmission System

#### 3.4.2.1. Water Supply System Pipes and Fittings - Mapping and Inventory

The first prerequisite for creating an operation schedule is the availability of updated maps of the transmission system that show the locations of the valves, flow meters, and pressure gauges. The organization has to establish regular practices for creating and updating maps and inventories of any pipes, valves, and tapings found on transmission mains. The maps, which also include details on the placement of other utility services like power, communications, etc. with regard to the alignment of transmission, must be shared with other public utilities.

Maps of valve locations not only show where the valves are, but also the direction to open the valve, how many spins to open it, the type of valve, and the date the valve was fixed. There are occasionally also accessible plan and profile drawings that display the depth of the pipe, the placement of the pipe both vertically and horizontally, and the distance from a reference point. Furthermore, hydraulic gradient lines must be drawn to show the system's pressures. They can be used to locate high pressure or low-pressure trouble spots.

**Field Survey:** To prepare and update maps, traditional survey methods or already-existing maps are employed. Total station approach is becoming more and more popular as a substitute for conventional surveying and map-making. When data is not readily available, total station devices can be used to survey and map pipelines.

#### 3.4.2.2. Sampling for Water Quality

The organization in charge of running the water supply system is in duty of making sure that the water delivered to the user is of the proper quality. Physical, chemical, and bacteriological tests must be conducted on the water samples obtained at regular intervals in order to accomplish this goal. To enable an overall assessment, samples should be collected at several locations throughout the transmission system on each occasion. More regular monitoring may be needed, especially for bacteriological quality, in the event of an outbreak or danger from contamination.

#### 3.4.2.3. System Surveillance

The transmission system is being watched.

- To identify and address sanitary risks.
- To identify and address any transmission system facility deterioration.
- To identify utility encroachment on transmission system facilities, such as sewer and storm water lines, electricity cables, telecom cables, etc.
- To identify and address vandalism-related damages to the system's facilities.

These are routinely checked. All of these inspections are also performed on infrastructure related to above-ground water, including valves, valve chambers, and exposed pipelines. Any action or circumstance that could harm the water facility or the quality of the water must be investigated, and remedial measures must be performed. Searching for unauthorized building activity on or close to the utility's pipelines that could endanger the mains physically is another aspect of surveillance. The utility/MC's crew must closely monitor any excavation, digging, or blasting near the mains.

### 3.4.3. Updated Schedule of Maintenance

The degree of maintenance of the water transmission system must be raised through better administrative and field work coordination and planning, as well as the application of appropriate methods, tools, and materials for field maintenance. The schedule must be adaptable to enable teamwork with the equipment and vehicles at hand. For the quality control of the materials used, services provided, and spare parts and fittings, coordination of operations is necessary. Along with technical abilities, maintenance employees must receive training in improving their public interactions with customers.

#### 3.4.3.1. Schedule for Preventative Maintenance

Preparing a preventative maintenance schedule requires:

i) Pipeline maintenance, including information on activities to be carried out, jobs not finished, and tasks accomplished

ii) Valves, expansion joints, etc. maintenance

iii) Valve chamber maintenance

iv) Keeping a record of the equipment, supplies and labor and the costs associated with completing each activity

**(a) Valves' maintenance**

Even after closing tightly, seating of valves that are subjected to repeated operations is prone to develop leaks or allow the flow to continue downstream. It will be necessary to do routine maintenance on valves, expansion joints, flow meters, and pressure gauges. In some places, the main issue is valve corrosion, which can lead to gland and bonnet bolt failure. Spindle rod leaks cause the bonnet to come apart from the body.

To replace the valve, stainless steel bolts can be used. To stop corrosion, polyethylene wrap can be applied on the valve.

**(b) Manufacturers' catalogues**

For the routine servicing, complete servicing procedures should be created, and the manufacturer's catalogues may be consulted. In addition to the technical information provided by the manufacturers of the equipment utilized in the transmission system, such as sluice valves, BF valves, air valves, pressure gauges, flow meters, etc., these processes must include the manufacturer's name, address, telephone number, etc. Along with the handbook, these equipment's test certifications, inspection reports, and warranty certificates must be retained.

**(c) Spares List**

It is crucial to create a list of essential spare parts for the transmission system, and the parts must be purchased and stored for future use. Spare check nuts, spindle rods, assorted bolts, nuts and washers for flanged joints, gaskets for flanged joints for all sizes of sluice valves installed in the transmission system, spare manhole covers, and consumables like gland rope, grease, cotton waste, jointing material like rubber gaskets, spun yarn, pig lead, and lead wool are just a few of the possible spares that should be kept on hand.

**(d) Equipment List**

It is important to identify and supply the maintenance workers with the tools and equipment they need to properly fix and cure both common faults and to make repairs and replacements easier on a transmission system. Some of the tools for the maintenance work in a Transmission system: Key rods for operation of all sluice valves, hooks for lifting manhole covers, pipe wrench of appropriate sizes (200, 300 or 450 mm) DE spanner set, ring spanner set, screw drivers, pliers, hammers, chisels, caulking tools for lead and spun yarn, ladles and pans for melting and pouring lead joints, excavation tools such as crow bars, spades, iron baskets, buckets and de-watering pumps Excavators, cranes, diesel welding sets, welding electrodes, gas cutting equipment, and gas cylinders will also be needed for large diameter transmission systems.

**(e) Maintaining Appurtenance Chambers**

Valve chambers must be inspected to make sure they are not broken, packed with dirt, or covered in asphalt. Theft of valve chamber covers, vandalism that breaks them, accidents that cause damage to the valve itself or inadvertent falls into open valve chambers must all be addressed immediately. Water utility’s/MC’s employees must pay continual attention to road repair projects since valves may become lost or occasionally the valve chambers in the roadways need to be rebuilt to fit the newly resurfaced road surface. Cross-country pipeline valve chambers are likely to be modified to collect water and are likely to be impacted by floods, as well as by industrial and agricultural activity. Water quality will be impacted by leaks at these locations due to cross connections, so these leaks must be fixed right away.

## 3.4.4. Pipeline Maintenance

### 3.4.4.1. Pipeline Bursts/Main Breaks

Anytime a pipeline bursts or a main break, the MC must have a plan in place for responding to the situation. This strategy must be documented, communicated to all parties involved, and the MC must always be prepared to carry it out as soon as a pipe break is notified. Once a pipe break has been detected, decide which valve has to be stopped in order to isolate the affected area. Important users who may be connected to the transmission system and have industrial processes that depend on water supply and cannot be stopped as quickly as the water supply lines are cut off need to be informed of the problem. These customers must be made aware of the potential water supply interruption as well as the anticipated time of restoration.

Dewatering/mud pumps are used to drain the pipe break points after the valve is closed. Before the workers enter the pit, the sidewalls of the trenches must be securely protected. The clogged silt inside the pipe is cleaned, and the broken pipe is removed.

Before putting the line into use, the damaged pipe is restored, and the area is cleaned. Following each pipe break, a report detailing the circumstances of the breach and the available resources must be created.

In order for the MC to follow up with steps for avoiding such breaks and also change their strategy to address similar breaks in the future, it is necessary to know the time and money required for rectification and the time and cost required for repairs, etc.

#### 3.4.4.2. Pipelines' Flushing and Cleaning

Flushing is used to clean transmission lines by getting rid of any silt or contaminants that may be inside the pipe; this is especially important when it comes to transmission lines that transport raw water. Pipelines carrying raw water frequently need to be flushed.

##### 3.4.4.2.1. Flushing and disinfection of lines according to AWWA Specification 651.

Chlorine dosage shall be at least 25 mg/l and shall be retained in the line at least 24 hours, at which time the chlorine residual at pipe extremities and other respective points shall be at least 10 mg/l. The main shall be flushed as soon as possible after chlorination is complete (within 24 hours). If less than 10 mg/l is obtained after the initial 24 hour, the disinfection procedure shall be repeated until a 10 mg/l residual is obtained.

- **Amount of chlorine required for disinfection of pipeline is determined as follows:**
- Million gallons x 8.34 x mg/l dosage = lbs (pounds of 100% chemical to use)
- **Active leak detection** should be con- ducted to find pipe leaks.
- **Repairs**: Reported or discovered component failures should be repaired as soon as possible
- **Dead-end mains** should be avoided as they often cause stagnant water that create water quality problems through a loss of disinfectant residuals and increased sedimentation. Water is wasted when dead-end pipes have to be flushed regularly to remove accumulated sediments.

#### 3.4.4.3. Cross Connections

Water contamination caused by connections between water supply lines and sewers and drains is a widespread issue. It is necessary to conduct routine surveys along the transmission system's alignment to find prospective spots that could be impacted by cross connections and backflow. Every field employee needs to be on the lookout for circumstances when cross connections are likely to occur. Cross connections can occur in places like densely populated areas and slums without sanitation services that are near transmission lines. Upon the discovery of the cross connections, corrective action is conducted, including separating the water main from the sewer/drain in both the horizontal and vertical planes.

#### 3.4.4.4. Record Keeping

It is better to record the following information of water supply system for better maintenance and easiness for parts replacement:

- **Water supply main Lines (6 inch and above)**
  - Size, material, length. Design software used, field pressure testing details. Flange standards used, type and size of valves used.
  - Pipe leakage and burst repair record.
  - Pressure testing record
  - Line wise Location of gate valves record
- **Chlorinators:**
  - Type, manufacturer, rate of injection of hypochlorite solution.

- Model number, make and year of procurement.
- Main specifications like impeller material, shaft material, pump bearing numbers, suction and delivery port size of the pump and actual suction and delivery pipe size and material used at site.
- Motor Type, HP/KW and efficiency, motor bearings number.
- **Motor Control Panel:** Type of starter, capacity, ratings of main breaker, ratings of 3 Contactors and overload relay, what other protections are installed?
- **Power cables:** Type, size and current carrying capacity and manufacturer.

- **Valves**
  - **Gate Valve:** Type of gate valve, metal seated or resilient seated? Size, International design standard, pressure rating, material of body, disc/wedge, stem. Flange standard
  - **Check Valve:** Type of check valve, metal seals or resilient seals, size, International design standard, pressure rating, material of body, disc, shaft, counterweight, Flange standard
  - **Air Valve:** Type of air valve, Air release valve or Air/vacuum valve, size, International design standard, pressure rating, material of body, float etc. Flange standard.
- **Flow meter & Domestic water meters:**
  - Meter type and size, material, certified according to which standard, OIML, ISO, or MID? Q3 and accuracy class according to OIML or ISO and accuracy curve, Q3/Q1=R

### 3.4.4.5. Valves used for water supply lines in this project

#### 3.4.4.5.1. Gate or Sluice valves

*Figure 3-2 Gate Valve*

##### (a) Gate Valves problems

- Wear and Corrosion. corrosion can cause the disc to stick.
- Wear of the seat seals over time.
- Unexpected pressure spikes in the pipeline.
- Foreign or abrasive debris in the pipeline
- The seat of a metal seated gate valve has a pocket that can entrap solids and prevent the valve from closing fully.
- The resilient seat type greatly reduces this problem because it has no pocket in the body in which the gate seats.

- The disc is encapsulated with a resilient material (usually vulcanized rubber) that presses against the smooth, body of the valve.
- The valve is restricted to nearly horizontal pipelines. These valves are suitable up to 200psi.

### (b) Leakage from gate valves

- **Gate valve** mostly leak from the gland. This is due to a build up of deposits against the seal and the seal getting a bit displacement. The water valve stem passes through a “packing” nut and washer, which provide a watertight seal.
- Over time, though, this packing material can harden or disintegrate. And when this happens, it won't form a solid seal and will cause leaking.

*Figure 3-3 Packing Leaking of a Gate Valve*

### (C) Maintenance of Gate valves

- **Use lubrication**:
- As time goes by, the steel gate valve will start to get stuck. Periodically lubricate the stem of the valve wheel. Any type of spray lubricant can do the work.
- **Be wary of rust:**
- It can stick the disc. Use wire brush to scrape the rust off of the metal. Paint the steel gate valve to avoid rust.
- **Operate the valve periodically:**
- Make regular valves turning program
- **Replace the seat seals:**
- If worn out over time.
- The seat of a metal seated gate valve has a pocket that can entrap solids and prevent the valve from closing fully. The resilient seat type greatly reduces this problem because it has no pocket in the body in which the gate seats.

### (d) Necessity of valves turning

*Figure 3-4 Gate valve fitted on a pipeline*

- ❖ It is desirable to turn each valve in the system at least once per year.
- ❖ Many utilities have a regular valve-turning program in which a percentage of the valves are opened and closed on a regular basis.

### 3.4.4.5.2. Leakage from Butterfly valves

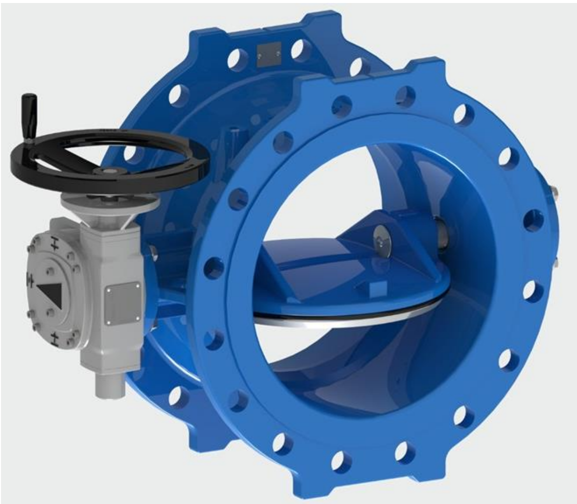


*Figure 3-5 Leakage from Butterfly Valve*

- Some installed **butterfly valves** are **oversized or undersized** and that may be the cause of leakage.
- Any misalignment during installation can change its pressure rating capability which can lead to valve leakage.
- Valve seat are covered in dirt or the valve stem and disk is rusted.
- Seat is scored.
- Seal is damaged.
- Insufficient actuator movement.
- Worn stem packing.
- Gasket between valve body and bonnet is damaged

### 3.4.4.5.3. Check valves

For unidirectional flow

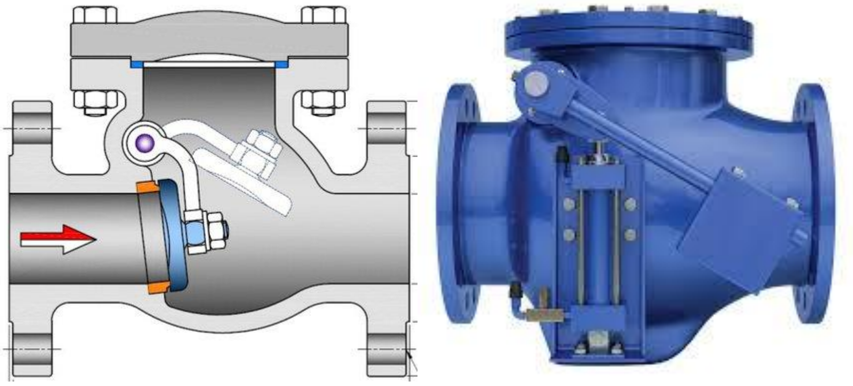


*Figure 3-6 Check valves*

Check valves have either resilient seals or metal-to-metal seals.

- The goal of a resilient seat is to provide a long-lasting, drop-tight seal.
- For better resistance to temperature, EPDM is often used.
- For pressure applications less than 150 psig, resilient seats will provide the best service.
- For pressures above 300 psig, a metal seated

**(a) Leakage from Swing Check Valve**

I. **Incorrect installation and assembly**
Our tip? Remember to take note of flow capacity and the positioning and orientation of the valve during installation.

II. **Insufficient maintenance**
Regular maintenance is a sure-fire way to safeguard against failing valves. Look out for any signs of wear and check the pipeline for debris, which can get stuck in the valve and cause damage to the internal mechanisms.

III. **Reverse flow**
This can be extremely costly and dangerous when it occurs at the pump discharge, causing the pump to spin backwards, which damages the pump and valve over time.

### 3.4.4.5.4. Air valves

*Figure 3-7 Air valve*

This project will use combination Air valves. It Combines the functions of both the Air/Vacuum and Air Release Valves.

Air valves in pipeline systems serve two primary functions.

I. Release of accumulated air that comes out of solution within a pressurized pipeline.

II. To admit air into the system when the internal pressure of the pipeline drops below atmospheric pressures.

III. By admitting air into the pipeline help prevent the pipeline from experiencing excessive deflection and/or collapse as well as help prevent the formation of a full vacuum condition in which vapor cavities may form from the fluid vaporizing

**Faulty Air valve at a tube well:**

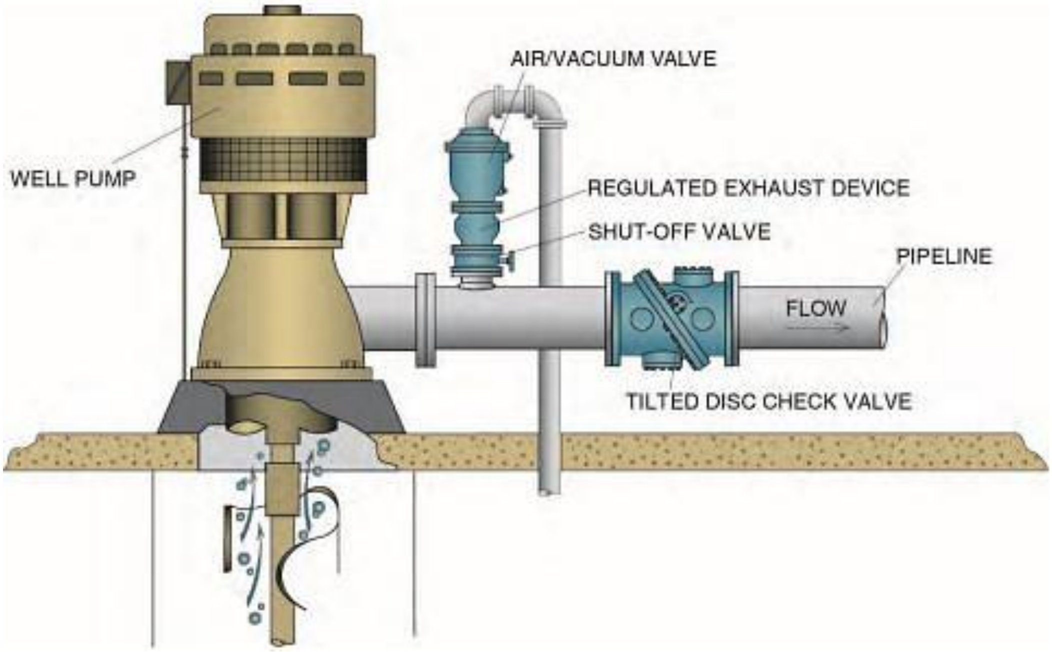



*Figure 3-8 Air Valve at discharge pipe of a tube well*

- At tube well startup, the pipeline contains air. As the pipeline is filled, much of the air will be pushed downstream in a pressurized pipeline that can damage the pipe.

- Air Valves are mounted upstream of the check valve and are designed to vent the air before the check valve is pushed open by the pump pressure.
- When the pump stops, the Air Valve will reopen and admit air into the pump column to prevent the formation of a vacuum as the water column drains.

### 3.4.4.6. WATER HAMMER OR SURGE

- A water hammer occurs when water suddenly changes direction.
- It can cause very high pressures in pipes. The surge pressure is additive to the static pressure in the pipe.
- It can cause burst pipes, damaged supports and pipe racks, and leakage at joints.
- For example, if a flow of 8 ft./sec is suddenly stopped in a pipe, a surge pressure as high as 400 psi above the static pressure may be produced.

*Figure 3-9 Leaking joint*

#### 3.4.4.6.1. Water hammers due to Check valve

- After pump stoppage, the flow reverses and may flow backwards through the check valve. Second the closure member suddenly shuts off the reverse flow.
- The change in flow velocity turns into pressure which instantaneously stretches the pipe wall causing the audible water hammer sound wave. For every 1ft/sec change in velocity, there will be approximately a 50 psig pressure spike. It may produce an audible noise that will carry across the building annoying operating personnel or even neighboring houses.

**(a) Source of Air in the pipelines**

- Water contains about 2 percent air by volume based on normal solubility.
- Variations in flow velocity caused by changing pipe diameters and partially open valves may cause rise in temperature or a drop in pressure and dissolved air to come out of solution.
- Air can enter through equipment such as pumps, fittings, and valves when vacuum conditions occur.

**(b) Air becomes a physical obstacle**

- The air pocket is compressed by the water acting against it.
- The sudden and rapid change in fluid velocity when the air pocket dislodges creates a pressure spike.
- The water increases velocity and across the span of the air pocket often shears away parts of, or the whole of the air pocket. Once free in the system again, the air pocket will then travel downstream with unpredictable results.

- When the traveling air pocket finds a home again at another bend, or high point of the pipeline, its' sudden arrest there creates another surge event.

3.4.4.6.2. Practical Remedial measures for MCs during operation of water supply system:

- Slow down the check valve closure It should take 5 seconds per inch diameter, or more.
- Reduce the pumping velocity. This can be done using a larger pipe diameter or lower flowrate. Changing diameter of pipe will be costly and impracticable for MCs, therefore pumping rate may be controlled by regulating control valve.

### 3.4.4.7. Flanges

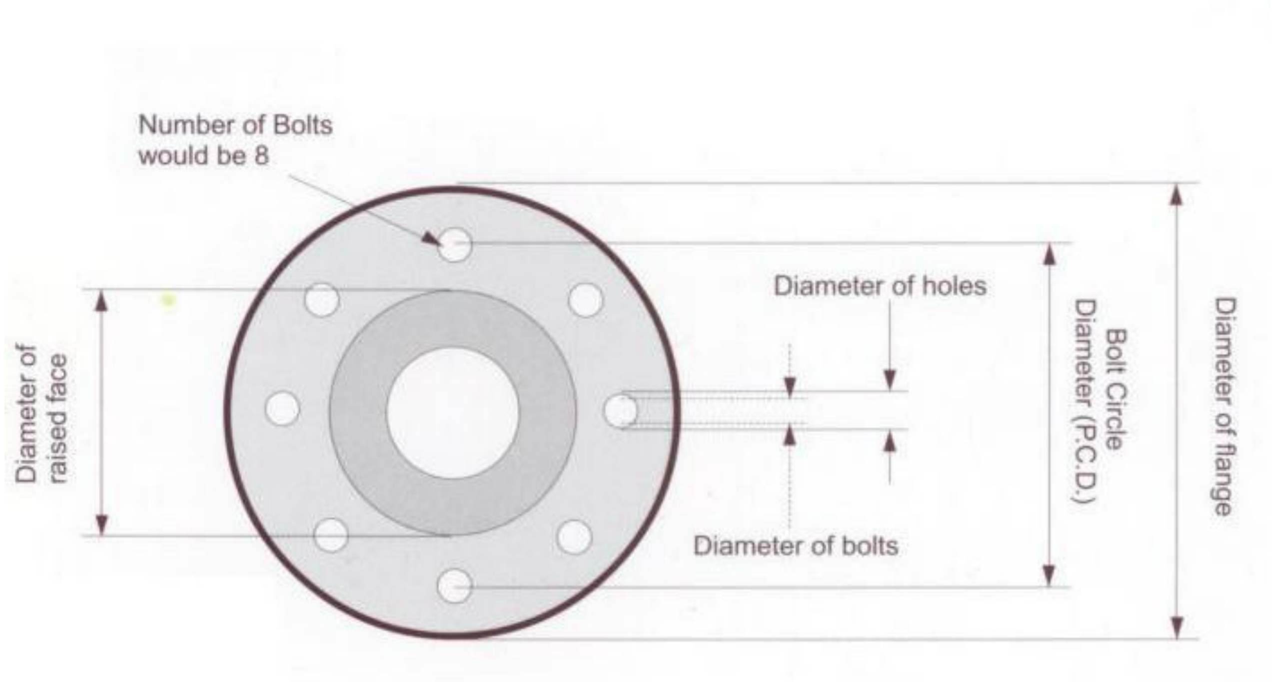



*Figure 3-10 Flanges drawing*

Flanges are commonly used to connect valves into pipework making it easier for removal and maintenance. There are many common flange standards and flanges within the same standard can either be flat (commonly cast iron, ductile iron) or raised face (commonly cast steel and stainless steel). Below is a reference table for critical flange dimensions to help identify what standard you have.

Whenever you need flanges, following are mainly of two International Standards:

- ASME-ANSI B16.5
- OR EN 1092



*Figure 3-11 EN and ASME flanges*

Each standard has some difference of dimensions therefore one flange does not fit at the place of other. MCs should keep the record of flange standards so that replacement is easy and without time consuming. For understanding the issue, a comparison table for 600 mm size of flanges made on the standard of ASME -ANSI B16.5, EN 1092 and BS 10 is produced below:

*Table 3-3 Flanges Dimensions*

| Standard | Class | Flange dia | Bolt dia | Flange thickness |
|---|---|---|---|---|
| ASME B16.5 | 150 | 813 | 35 | 48 |
| EN 1092 | 10 | 780 | | 42 |
| BS 10 | 10 | 840 | 36 | 54 |

### 3.4.5. O&M Aspects of Reservoirs

#### 3.4.5.1. SERVICE RESERVOIRS O&M PLAN

The operational guidelines will include, among other things:

- The reservoir's capacity in gallons, size, and depth of storage; the size of the piping for the inlet, outlet, scour, and overflow; the sizes and locations of the control valves for the inlet, outlet, and scour; the source of the reservoir's feeding; the number of hours the reservoir will be pumped or fed by gravity; the rate of flow into the reservoir; the number of hours the reservoir will be supplied with; the quantity to be supplied from the reservoir.
- A structural drawing of the reservoir and a layout drawing displaying the location of valves, flow meters, pressure gauges, by-pass lines, and interconnections as well as the alignment of pipes leading off the reservoir's scour and overflow water.
- A list of the names, addresses, and phone numbers of the suppliers that provided the valves, flow meters, level indicators, and other equipment that was installed in the reservoir.
- Step-by-step instructions on how to operate the different valves on the inlets and outlets to make sure the needed amount of water is given to the command regions at the desired pressures for the duration of the supply period.
- A record sheet for each valve that lists the number of turns, the number of inspections, the repairs made, and whether the valve is open or closed. Valve direction of operation must be identified clearly as "open" or "close."
- The names of the valve and piping, such as washout, inlet, outlet, bypass, and overflow, must be clearly painted and refreshed on a regular basis.

- The procedures for automated valve operation include starting, running, and terminating the operations.
- Instructions for when valves cannot be operated because of issues with authorities so that they can be informed and given additional instructions.

#### 3.5.6.2. Maintenance Procedures

Every piece of equipment used in reservoirs, including valves and flow meters, must be covered step-by-step in the maintenance procedures, which should ideally follow the instructions provided in the manufacturer's catalogues.

(a) Valves

- All valves ought to be routinely inspected and used.
- The management is required to outline the inspection schedule.
- To lubricate the packing gland and soften the packing, a tiny amount of penetrating oil is poured down the spindle.
- Repacking should be done on valve spindles that develop leaks during turning.
- The valve's rust and silt can be cleaned by securely closing the disc in the seat, opening the valve halfway, and then closing it again multiple times. The increased velocity usually flushes the obstructions out of the valve.
- The reservoir valve chambers also require maintenance to keep the interiors clear of silt and to make sure the covers are in place and in good shape.

#### 3.5.6.3. Service Reservoir Cleaning

The easiest method to know whether a tank needs repair and cleaning is through routine inspection. The roof manhole can be used for a visual check when the water level is at or below half full. Instead, a thorough inspection can be performed after draining and cleaning or washing the tank. The best time of year to start cleaning reservoir is when water usage is at its lowest.

Cleaning a reservoir often involves the following tasks:

- Make other arrangements for the reservoir clientele's access to water.
- Before starting the cleaning of the reservoir, shut off the inlet line.
- Withdraw water from the reservoir till 200–300 mm of water remains.

  Shut the outflow valve to prevent the usage of water while cleaning the tank.
- Take a sample of the water and dirt or silt that has built in the tank, analyze it biologically, and check for worms and snails. Find the cause of any snail and worm infestations and get rid of it.
- Drain and get rid of any leftover water and sand.
- Use a water hose and brushes to clean the walls and floor of the tank.
- Examine the interior of the tank's walls and ceiling for degradation or flaking paint.
- Before beginning to fill the reservoir, apply a disinfectant (supernatant of bleaching powder) to the walls and floor.
- How often reservoir needs to be cleaned depends on the degree of silting, the formation of biofilms, and the findings from water quality monitoring.

## 3.5. DOCUMENTS AND REPORTS

### 3.5.1. Record System

It is necessary to create a record-keeping system that is applicable to the operational issues present at the specific reservoir site and is realistic. The most effective way to preserve records is to decide what information is crucial, then arrange the forms, people to fill them out, frequency, and recipients of the records for inspection and reporting. These are some examples of records that should be kept at reservoir sites as guidelines.

#### 3.5.1.1. Keeping Records of the Operations

The following should be noted:

- Hourly water levels in the reservoir (for all compartments).
- The timing of control valve action, including the timing of their opening and closing or their throttling position.
- Readings from the inlets and outputs of the flow meters every hour.
- Intake and output water residual chlorine levels every hour.
- The cost of and the number of man-hours devoted to ordinary tasks at the SR in the preceding year.

#### 3.5.1.2. Reports

A report assessing the facility's O&M can be created once all pertinent data has been gathered. The report can point out problems with the SR and its add-ons, the structure, valves, and other equipment, or for the replacement of faulty valves, other equipment, or expansions to the storage capacity where the existing capacity is insufficient, should then be planned for future repairs.

# 4. O&M OF DISTRIBUTION SYSTEM

## 4.1. A DISTRIBUTION SYSTEM'S GOAL

A distribution system's overall goal is to provide consumers with clean water at an appropriate residual pressure in sufficient quantities at convenient locations, accomplish continuity and maximum coverage, and do it at a reasonable cost. The organization must develop operational procedures to ensure that the system can be operated satisfactorily, efficiently, constantly, and, to the greatest extent possible, at the lowest cost in order to achieve this goal.

All operators of the authority to act in emergencies should be able to read, comprehend, and follow written routine and emergency operating procedures. Also, special operating methods are needed for identifying the subterranean pipes and valves, as well as for inspecting, monitoring, testing, repairing, and sanitizing the system. System records and maps should be up to date and contain enough information about the system's facilities, their state, any necessary and completed routine maintenance, problems discovered, and corrective measures taken. The organization will be able to examine the effectiveness of its services and the efficiency of its installations through the analysis of the data and will be able to determine whether these factors are sufficient to satisfy the needs of its customers.

## 4.2. OPERATIONAL SCHEDULE

### 4.2.1. Regular Water Supply Distribution System Activities

The operating staff's understanding of the factors affecting the continuity, dependability, and volume of water provided to consumers determines the efficiency and efficacy of a water delivery system. The operating team should be able to quickly and efficiently implement adjustments to the hydraulic condition of the system as needed depending on those variables. The actions for adjusting valves and pump operation to the current circumstances must be indicated as routine operations (flows, pressures, levels and operation of pumps). The use of valves and pumps will require schedule-controlled operation. The schedule must provide instructions on how to run the distribution system. In order for the hydraulic status of the system to match the demand for water, it should include procedures for obtaining, processing, and analyzing the variables related to water flows, pressures, and levels as well as the effects of manipulating control devices, such as operation of valves and or pumps. when utilizing Information on valve closure and opening must be communicated when shifts are changed.

### 4.2.2. Activities Under Abnormal Conditions

Operations that are not routine, i.e. When usual conditions vary, such as when flows, pressures, and levels change or when a pump's functioning changes, specific procedures that should be followed during breakdowns and crises must be defined.

### 4.2.3. Measuring Flows, Pressures and Levels is Covered

To determine if the system is operating in accordance with requirements, it will be necessary to routinely monitor operational data regarding flows, pressures, and levels. Data analysis may show that some reservoirs and/or bulk consumers are being overdrawn of water. Such locations may have the proper flow control mechanisms installed to keep supplies to the necessary level. The installation of meters to measure flows, pressures, and levels is one of the water delivery system's top priorities. Moreover, a thorough map with the locations of each measurement point must be created. The level of complexity of the instruments utilized at each measurement point in terms of indication, integration, recording, and transmission

The receiving of data primarily depends on the MC's ability to afford itself and the competence of the O&M staff it has on hand.

#### 4.2.3.1. Evaluation of Hydraulic Conditions

After gathering information on water volumes and flows at various locations in the system, as well as water pressures and levels in the reservoirs, and comparing with anticipated performance, O&M professionals can undertake a continuous review of the hydraulic conditions of the water supply system. This assessment should help identify any operational issues or system flaws. Actions must be taken depending on the nature of the issues to guarantee that the system performs as needed.

#### 4.2.3.2. System Pressures

The primary goal of O&M is to maintain a constant positive pressure at all times (during consumer supply times). Negative pressures, particularly in the case of intermittent supplies, can contaminate water sources. Pipelines and valves may be harmed by extremely high pressures, but this problem can be remedied with pressure reduction valves. Consumer complaints concerning low pressures must be looked into right away, and if necessary, pressures must be measured using pressure gauges. Low pressures could exist in the following situations:

- A line valve that has been purposefully or mistakenly left partially closed or blocked by any material that reduces pressure.
- Unreasonably high velocities in narrow pipelines.
- The SR's low water levels.
- Directly feeding the system failure of pumps or booster pumps (either from a mechanical or electrical failure).

#### 4.2.3.3. Location of Valves

Isolating valves in distribution network(s) shall be placed as per the below detail:

- On all branches from feeder mains
- Between feeder pipes and hydrants
- Not more than 3 valves at a cross
- Not more than 2 valves at a tee
- Preferably at a uniform distance from pipe intersections
- Not further apart from each other in a line than 400 m
- Air valves at all crest points
- Washouts at all valley points

#### 4.2.3.4. Chlorination

- Free residual chlorine of about 0.2 mg/l will be maintained at the farthest point in the pipe network.

## 4.3. MAINTENANCE PLAN

The degree of maintenance of water distribution networks and house connections must be improved, and this may be done by better coordinating and planning the administrative and field operations, as well as by using the right methods, tools, and materials for field maintenance.

- The schedule must be adaptable to enable teamwork with the equipment and vehicles at hand.
- Coordinating operations is necessary for the quality control of the materials utilized, services provided, and spare parts and fittings.

- In addition to technical abilities, maintenance employees must receive training to improve public relations with customers.

## 4.3.1. Maintenance Schedule Activities

The following activities need to be scheduled:

- Developing protocols for creating maintenance schedules, gathering information from the general public and maintenance staff, and processing that data.
- The creation of maintenance teams with provisions for ongoing training for each type of service.
- Development of repair protocols for common services.
- Specification of suitable tools.
- Giving each team access to the appropriate transportation, tools, and equipment.
- Determining the amount of time, labor, and materials needed, as well as the output anticipated; determining the time needed and other standards for each maintenance task; and
- Keeping track of each team's output.

### 4.3.1.1. Servicing Valves

Even after shutting tightly, the seating of valves that have been subjected to repeated operations is likely to become leaky or allow the flow to continue downstream. Valves on fire hydrants and public taps, as well as flow meters and pressure gauges, will need regular maintenance. In some places, valve corrosion is a major issue that can lead to gland and bonnet bolt failure. Spindle rod leaks cause the bonnet to come apart from the body. To replace the valve, stainless steel bolts can be used. To stop corrosion, polyethylene wrap can be applied on the valve.

### 4.3.1.2. Manufacturers' Catalogues

Comprehensive servicing methods must be created for periodic servicing, and the manufacturer's catalogues may be consulted. In addition to the technical information provided by the manufacturer of the equipment used in the distribution system, such as sluice valves, Butterfly (BF) valves, air valves, pressure gauges, flow meters, etc., the catalogues must include the manufacturer's name, address, phone number, etc. Along with the manual, the test certificates, inspection reports, and warranty certificates for this equipment must be retained.

### 4.3.1.3. List of Spares

A list of the spare parts needed for the distribution system must be created, and those parts must be purchased and stored for future use. The minimum level at which replenishments should be started should be indicated on the list. The following is a possible list of the spare parts that should be maintained on hand:

Spare manhole covers, spindle rods, check nuts, washers, gaskets for flanged joints on all sizes of sluice valves placed in the distribution system, miscellaneous bolts, nuts, gland rope, grease, cotton waste,

A distribution system's spun yarn, and lead wool are all consumables.

### 4.3.1.4. Tools List

Maintenance workers must be given the relevant tools for both routine issues and assisting repairs and replacements. These tools must be identified.

Key rods for all sluice valves, hooks for raising manhole covers, pipe wrenches of the proper diameters (200, 300, or 450 mm), a double ended (DE) spanner set, a ring spanner set, screwdrivers, and other equipment are some of the supplies needed for maintenance work on a distribution system.

Pliers, hammers, chisels, caulking tools for lead and spun yarn, ladles and pans for melting and pouring lead joints, and digging implements like crow bars, spades, iron baskets, buckets, and dewatering pumps are all examples of instruments used in excavation.

#### 4.3.1.5. Valve Chambers for Appliances Maintenance

Valve chambers must be inspected to make sure they are not broken, packed with dirt, or covered in pavement. Theft, breakage, or accidently shattered valve chamber covers can cause harm to the valves or even cause a person to fall into an open valve chamber. Such circumstances require immediate correction. Water utility employees must pay continual attention to road repair projects since valves may become lost or occasionally the valve chambers in the roadways need to be rebuilt to fit the newly resurfaced road surface.

### 4.3.2. Pipeline Maintenance Schedule

#### 4.3.2.1. Main Breaks

Anytime a pipeline bursts or a main break, the MC must have a plan in place for responding to the situation. This strategy must be documented, communicated to all parties involved, and the MC must always be prepared to carry it out as soon as a pipe break is notified. Once a pipe break has been found, a choice must be made regarding which valve should be shut off in order to isolate the affected area. Every consumer should be made aware of the break and informed of the likely interruption in water supply as well as the anticipated time of water supply resumption (some important consumers may have industrial processes dependent on water supply that cannot be shut down as quickly as the water supply lines are cut off). Dewatering/mud pumps are used to drain the pipe break points after the valve is closed. Before the workers enter the pit, the sidewalls of the trenches must be securely protected. The damaged pipe is taken out, the internal buildup of silt is cleaned out, the damaged pipe is replaced, the line is cleaned, and then it is ready for use. In order for the MC to follow up with measures to prevent similar breaks and/or adjust their plan to address such breaks in the future, a report regarding the cause of each pipe break, the resources required for rectification, the time and cost required for repair, etc., must be created.

#### 4.3.2.2. Pipeline Flushing

Flushing is used to clean distribution lines by getting rid of any silt or contaminants that may be inside the pipe. It is frequently required to cleanse terminal tubes regularly to prevent consumer complaints about taste and odour. It is advised to establish and implement a flushing schedule so that water mains are flushed before customers begin to complain. The frequency of flushing can be planned by taking into account customer complaints and the types of deposits discovered during cleaning. The proper operation of the treatment process and cleaning of the service reservoirs supplying water to the distribution system must also be planned in conjunction with the flushing of the distribution system because flushing the distribution system is not the only solution for problems with water quality. Flushing typically takes place when there is little water demand and the conditions are favorable. The flushing will run smoothly and without any hiccups because to advance planning and positive public relations.

#### 4.3.2.3. Pipeline Cleaning

In rare cases, mechanical cleaning tools like swabs and pigs are employed to clean the water if flushing does not work. In pipes with severe tuberculation or hardened scales, scrapers or brushes are utilized. Before beginning lining tasks, scrapers and brushes are occasionally employed.

reduce leakage through house connections, an analysis of leaks in house connections and an inquiry into the causes of leaks in the house connections must be done.

## 4.4. WATER CONTAMINATION COMPLAINTS

**(a) Rusty water**

- Cement mortar linings on the interior of cast iron or steel pipe can, however, be susceptible to accelerated degradation under some water chemistry conditions and add rust to water.
- Chlorine can form very stable substances, such as kitchen salt (NaCl). Chlorine can also form very reactive products, such as hydrogen chloride (HCl).
- When hydrogen chloride dissolves in water it becomes hydrochloric acid. The hydrogen atom gives off one electron to the chlorine atom, causing hydrogen and chlorine ions to form. These ions react with any kind of substance they come in contact with, even metals that corrosion resistant under normal circumstances. Concentrated hydrochloric acid can even corrode stainless steel. This is why it is stored either in glass or in plastic.

**(b) Taste and odor**

- Some microbes, such as actinomycetes and iron and sulfur bacteria, are common in pipe biofilm.
- These may detach into the water and proliferate in the system, frequently leading to taste, color, and odor problems in drinking water.

### 4.4.1. Water Leakage

**(a) Joints Leakage of HDPE Pipe**

- Excessive deflection and Joint misalignment
- Welding jointing weakness due to misalignment, incorrect welding procedure or impurities.
- Excessive internal working or water hammer pressures Exposure to solvents
- Difficult to find nonmetallic pipe underground

### 4.4.2. Contamination via House Connection

Water supply contamination must be avoided when installing the consumer connection pipes. This can be accomplished by keeping a vertical and horizontal distance between the water supply line and sewer/drain line.

In rare cases, it may be necessary to provide a sleeve pipe to the consumer pipes that cross a drain. For the consumer connection, it is advised to use non-corrodible pipe material. By ensuring that double check/non-return valves are present at the consumer end, contamination from potential back flow can also be avoided.

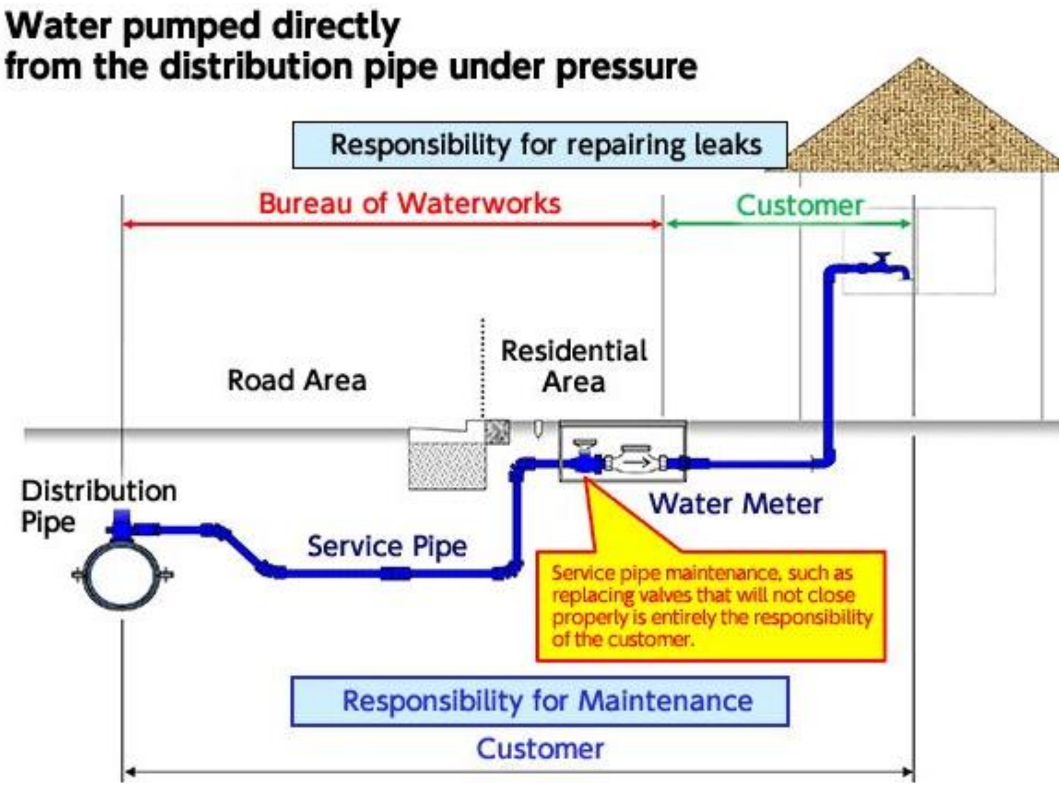



*Figure 4-1 Consumer connection*

If there is a leakage from house connection:

- Check ferrule
- Check bends
- Check valves
- Check couplings
- Check if line is passing through septic tank

Water leaks from pipes, joints, valves and fittings of the service connection either due to bad quality of materials used, poor workmanship, corrosion, age of the installations or through vandalism:

i. **Unauthorized connections:** Illegal connections are not installed as per standard practice therefore start leaking.

ii. **Age of the system:** With age particularly CI, MS and GI pipes get corroded and leaks occur resulting in loss of water and reduced pressure and pollution of supplies.

**iii. High Water Pressure:**

iv. **Corroded Pipes** if metal pipes are used

**v. Damaged Pipe Joints**

One of the most vulnerable areas of a pipe is its joints.

*Figure 4-2 HDPE pipe joints leaking*

Vi. **Service line passes through septic tank:** The service lines of consumers are old and sometimes pass-through house sewage pits and start leaking.

*Figure 4-3 Pipe leaking underground*

vii. **Underground Movements:** The growth of tree roots, flooding and even small earthquakes can shift the placement of your pipes. As the ground moves, your pipes can twist, bend, crack or separate altogether-causing underground leaks.

### 4.4.3. Unauthorised access

by people, particularly at reservoirs, resulting in accidental or even deliberate contamination of the water.

### 4.4.4. Unauthorised connections:

Unauthorised connections by the consumers are a major source of pollution because neither good material is used nor SOP for connection is followed.

## 4.5. REPAIR OF PIPELINE

Maintaining the transmission and distribution mains correctly is one of a water undertaking's most crucial duties in order to avoid waste and supply users with a steady pressured flow of drinkable water. Preventing harm to public property, which can result from improper pipe repair, is similarly vital.

Leakages and malfunctions can be prevented by careful planning and the application of corrective procedures.

### 4.5.1. Action Plan Implementation

For the repair operation, arrangement of labor, supplies, equipment, transportation, illumination, safety precautions, communication, pipes with fittings, etc.

The arrangements are subject to local conditions and a number of variables. Among other elements that should be taken into account are;

(i) The significance, usefulness, and functionality of the impacted pipeline in relation to the piping network. It's possible that this is the system's sole transmission main. One of the two or several parallel transmission mains could be the culprit. The initial part of the distribution system may be the only main supplying water to the rest of the service area. It can be a distribution pipe that only serves a small portion of the system.

(ii) The pipe's size and construction. These are crucial elements that influence the scope of the necessary repairs.

(iii) The pipeline's depth. More labor is needed to repair deeper pipelines

(iv) The subsurface water table. If the pipe is laid much below the local water table, extra effort will be needed to dewater the trenches excavated for repair.

(v) Unexpected additional elements

These considerations will determine how much labor, supplies, equipment, machinery, tools, pipes, specific fittings, etc. are needed. A list of items that will satisfy the need for a large transmission main, which is vital to the water supply system, is provided below[4]. This should only be used as a general guideline. Depending on the circumstances in your area, you may determine your exact requirement.

**Material**

Bolts and nuts, rubber insertion, gaskets, electrodes, wool, cotton waste, Manila rope, gland rope, wooden sleepers, engine oil, a canvas hose, a PVC hose pipe Wire slings, grease, M.S. plates, diesel, kerosene, firewood, sand, spun yarn, M seal, and sandbags are some examples of the supplies mentioned.

### 4.5.2. Procedure for welding of HDPE pipe: ISO 21307:2017

#### What is fusion welding?

- Butt fusion welding technique and Electric fusion (EF) are used to join HDPE pipes.
- Butt fusion is a combination of temperature and force resulting in two mating surfaces flowing together to produce a joint.
- Fusion bonding occurs when the joint cools below the melt temperature of the material.

#### STEPS of welding

- Peering
- Checking alignment
- Facing
- Heating
- Fusion
- Cooling of Joint

### 4.5.3. Welding Preparation:

The welding zone must be protected from unsuitable weather conditions (e.g.humidity effects, wind and temperatures below 0°C).

[4] https://www.scribd.com/document/325264101/Pipeline-Repair

#### 4.5.3.1. Alignment of pipes:

- The pipes must be aligned when they are clamped into the mirror welder in such a way that the surfaces are in the same plane (parallel) to each other. Position the pipe in a way that approx. 40mm is protruding behind the last clamp. By doing this, you will have approx. 10 to 15mm to shave from, and the remaining 25 to 30 mm should be sufficient for welding.

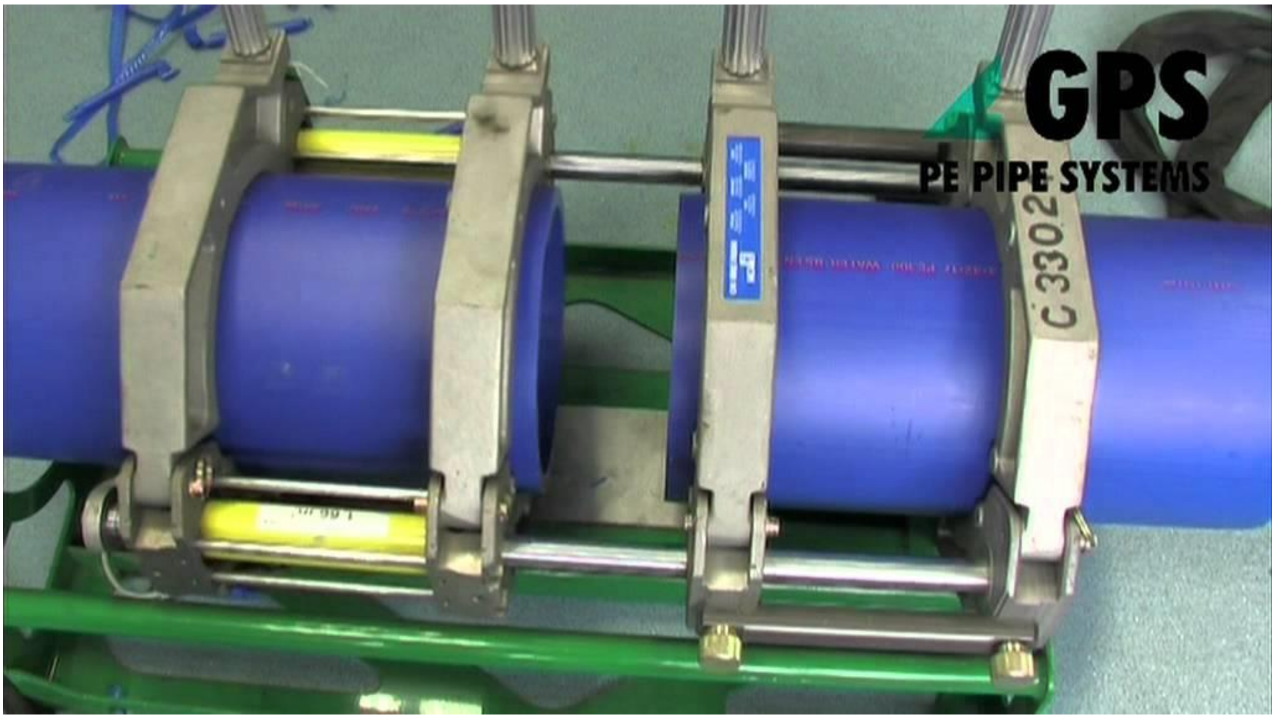



*Figure 4-4 Aligning the HDPE pipe for welding*

#### 4.5.3.2. Shaving of surfaces:

- After the dry matching is completed, open up the pipes and introduce the shaver. Turn the shaver on and adjust to suitable speed.
- Press the two pipes together, and shave until a continuous strip of HDPE is peeling off on both sides of the shaver. Once constant peeling off is observed, release the pressure on the pipes and separate the pipes. Do not turn off the shaver until the pipes are apart. If the shaver is stopped during shaving, the shaver will create an end cut-mark and the shaving operation will have to be repeated.
- Once the pipes are correctly aligned, separate the pipes again for cleaning. Remove chips inside the pipes on both sides, all chips scattered under the pipes, and also inside the machine. Remove the chips by using a brush or a small hook made out of a thin steel wire. Do not touch the shaved pipe ends, always clean the surface with a clean rag and mineral spirits/alcohol before you introduce the mirror plate.

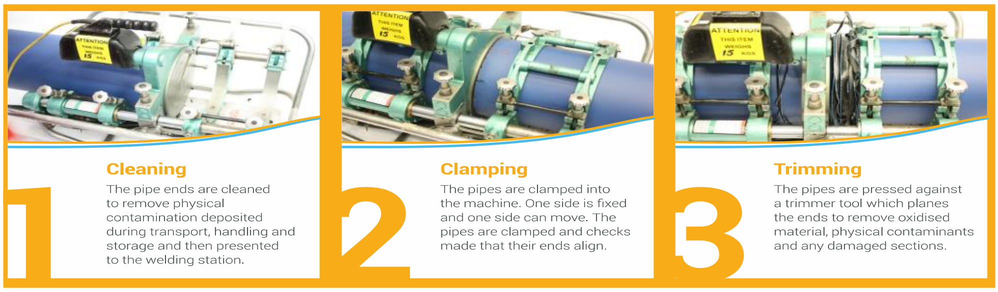



*Figure 4-5 Cleaning, clamping and trimming the HDPE pipe for welding*

### 4.5.3.3. Heating of Surface:

- Push the pipes together against the mirror and raise the pressure to the Bead-up pressure. This pressure needs to be maintained until the Bead-up height has been reached. The bead up height is the height of the bead, which is pressing up against the mirror.
- As soon as the Bead up height has been reached, release the pressure down to the Heat Soak pressure. Heat soak pressure is the pressure maintained during the Heat Soak time.
- As soon as the heat soak time has elapsed, separate the pipes, remove the mirror, and then press together.

*Figure 4-6 Heating of surface with heater for welding of HDPE pipe*

### 4.5.3.4. Fusion of Surfaces:

- This operation has to be done quite fast, since there is actually a time limit “Transfer time” from the removal of the mirror until the two pipes are pressed together and reached the Fusion pressure. Fusion pressure is the pressure that shall reach during the Transfer time and maintained during the Cooling time.

### 4.5.3.5. Cooling of Joint:

- Cooling time is the time in which the pipe has to be left undisturbed. Under no circumstances shall the clamps be opened or the pressure released until the cooling time has elapsed.

### 4.5.3.6. Checks of Weld Seam:

- The mirror-welding machine, if coupled to a data log, will give a printout confirming the parameters used during welding of a specific seam and approval/rejection of the welded seam.

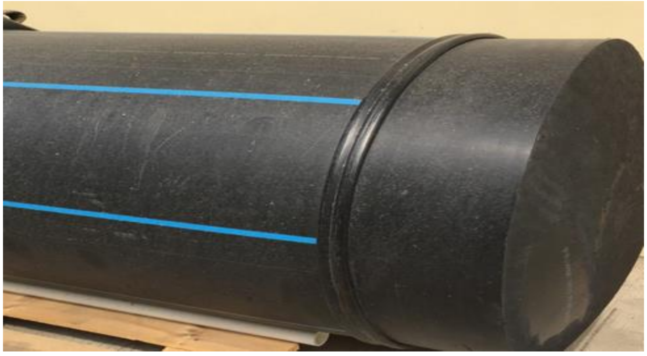


*Figure 4-7 Butt Join*

### 4.5.3.7. Jointing of HDPE Pipe with Fittings

*Figure 4-8 Jointing of HDPE Pipe with fitting*

- **Joining HDPE with Fittings**
  - All the joints and fittings of HDPE are joined to the pipe by using heat fusion joining technique as per ASTM F 2620/ISO21307. The internal surface of the joint/ fitting and external surface of the pipe are heated simultaneously to their fusion temperature using heating machine. The parts are joined and then allowed to cool.

### 4.5.3.8. Single low pressure welding parameters - ISO 21307:2017(E)

*Table 4-1 Single low pressure welding parameters*

| Parameter | Unit | Value | Value for 200 mm pipe | Typical value |
|---|---|---|---|---|
| Heater plate temperature | °C | 225 ± 10 | | |
| Minimum heat soak time | S | (13,5 ± 1,5) × en | 245.7 | 218-273 |
| Heat soak pressure | Mpa | Only drag pressure | 30 psi | normally 30 to 50psi |
| Maximum heater plate removal time | S | See ISO 12176-1 | | |

| Parameter | Unit | Value | Value for 200 mm pipe | Typical value |
|---|---|---|---|---|
| Fusion jointing pressure | Mpa | 0,17 ± 0,02<br>+ drag pressure | | |
| Minimum cooling time in the machine under pressure, for wall thickness< 18mm | Min | en + 3c | 18.2+3=21.2 | 16 sec minimum |
| Minimum cooling time in the machine under pressure, for wall thickness≥18mm | Min | 0,015×en^2−0,47×en +20c | | |

*Table 4-2 Single low pressure welding parameters*

| Observed Condition | Possible Cause |
|---|---|
| Excessive double bead width | Overheating; Excessive joining force |
| Double bead v-groove too deep | Excessive joining force Insufficient heating; Pressure during heating |
| Flat top on bead | Excessive joining force; overheating |
| Non uniform bead size around pipe | Misalignment; worn equipment; Incomplete facing |
| One bead larger than the other | Misalignment Component slipped in clamp; worn equipment Defective heating tool; Incomplete facing dissimilar material – see note above. |
| Beads not rolled over to surface | Shallow v-groove – Insufficient heating & insufficient joining force<br>Deep v-groove – Insufficient heating & excessive joining force |
| Beads too small | Insufficient heating; Insufficient joining force |
| Beads too large | Excessive heating time |
| Squarish outer bead edge | Pressure during heating |
| Rough, sandpaper-like, bubbly, or pockmarked melt bead surface | Hydrocarbon contamination |

### 4.5.4. The most common mistakes in Butt fusion welding

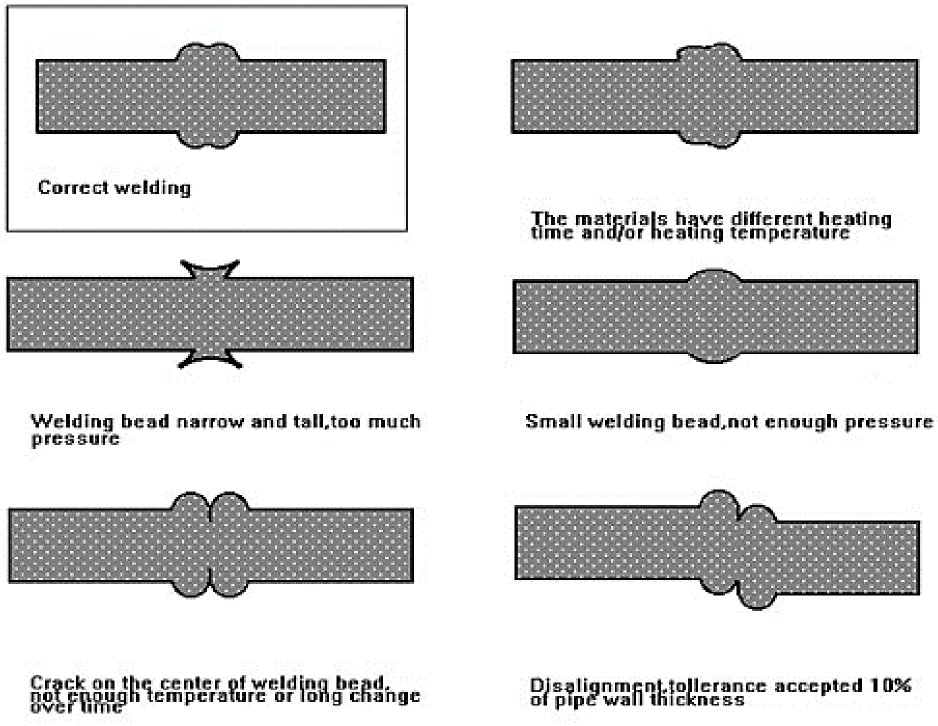



*Figure 4-9 Mistakes in Butt fusion welding*

### 4.5.5. Testing on joints

**Destructive joint integrity testing**

- hydrostatic pressure testing at 80 °C for 1 000 h in accordance with ISO 1167-1, ISO 1167-3 and ISO 1167-4 (or another test in accordance with national or local standards);
- high-speed tensile testing in accordance with ASTM F2634 (or another test in accordance with national or local standards).

**Nondestructive joint integrity testing**

- The fusion joint shall be examined visually and it shall have:
- proper alignment with no part of the mating pipe having mismatch in excess of 10 % of the pipe wall thickness;

a uniform double roll back bead that is consistent with the fusion procedure being used

# 5. DRINKING WATER QUALITY MONITRING AND SERVIELLANCE

Monitoring and observing the quality of the drinking water supply involves diligent evaluation and control of the provision of safe drinkable water as well as ongoing surveillance of public health.

## 5.1. SUPPORT SYSTEM

Programs for monitoring and surveillance need a laboratory, office, transportation, financial backing, and concerned staff.

### 5.1.1. Monitoring and Surveillance

Community involvement is crucial to the framework for monitoring and surveillance. The community can take a significant part in surveillance activities as the main beneficiaries. They are the ones who might identify water supply issues first and notify the appropriate authorities or, if appropriate, take corrective action.

Feld employees must get prior training before they can recognize sanitary risks connected to the water supply and how to report them.

### 5.1.2. Laboratory

The key support system for water quality surveillance is the laboratory. To assess the effectiveness of water utility services in terms of water quality, a well-located, well-equipped analysis laboratory with knowledgeable employees is absolutely necessary.

In general, water samples should be tested as quickly as possible to prevent sample quality degradation, particularly for microbiological examination

### 5.1.3. Financial Support

The amount of money allocated for maintaining/monitoring water quality and its surveillance should be sufficient, taking into account the size of networks, the region covered, etc.

### 5.1.4. Staffing

The number of employees needed for the water supply monitoring and surveillance program varies greatly depending on the size, ecological, and financial conditions of the facility/MC.

Due to seasonal factors, such as rainfall where unchlorinated water sources are present, the level of fecal contamination may differ significantly between subsequent samples. The water quality of samples taken across the piped water delivery system at various sites occasionally varies. Higher fecal coliform counts (>100/100 ml) are a certain sign of contaminated sewer water, which may be the result of cross contamination or a pipe leak. Data from sanitary inspections may corroborate the suspicion. The situation needs to be fixed right away.

### 5.1.5. Water Quality to be met

*Table 5-1 Water quality required according to Punjab Environmental Quality Standards*

| Sr.No. | Organisms | Standard Value (PEQs) | WHO STANDARDS |
|---|---|---|---|
| 1 | Total Coliform<br>Thermo tolerant/Fecal Coliform<br>E-Coli | Must not be detectable in any 100 ml sample | Must not be detectable in any 100 ml sample |
| 2 | Colour | <15TCU | <15TCU |
| 3 | Odour | Nonobjection able | Nonobjection able |
| 4 | Taste | Nonobjection able | Nonobjection able |
| 5 | Turbidity, NTU, Max | <5 | <5 |
| 6 | pH value | 6.5 to 8.5 | 6.5 to 8.5 |

| Sr.No. | Organisms | Standard Value (PEQs) | WHO STANDARDS |
|---|---|---|---|
| 7 | Total Hardness ($CaCo_3$) mg/l, Max | <500 | |
| 8 | Chlorides mg/l, Max | ≤250 | ≤250 |
| 9 | Residual, free chlorine, mg/l Min | 0.2 to 0.5 at consumer end 0.5 to 1.5 at source | ≥ 0.5 mg/l at source and at consumer end 0.2 mg/l. |
| 10 | Total Dissolves Solids mg / l Max | <1000 | <500 |
| 11 | Nitrate (as NO3 −) | 50 | 50 |
| 12 | Nitrite (as $NO_2$), mg/l Max | ≤3 | ≤3 |
| 13 | Copper (as Mn) mg/l Max | 2 | 2 |
| 14 | Maganese (as Mn) mg/l Max | 0.5 | 0.5 |
| 15 | Fluoride (as F) mg/l/ Max | 1.5 | 1.5 |
| 16 | Mercury (as Hg) mg/l Max | 0.001 | 0.006 |
| 17 | Cadmium (as Cd) mg/l Max | 0.001 | 0.003 |
| 18 | Selenium (as Se), mg/l Max | 0.01 | 0.01 |
| 19 | Arsenic (as As), mg/l Max | ≤0.05 | 0.01 |
| 20 | Cyanide (as CN), mg/l Max | 0.05 | 0.07 |
| 21 | Lead (as Pb), mg/l Max | 0.05 | 0.01 |
| 22 | Zinc (as Zn), mg/l Max | 5 | 3 |
| 23 | Chromium mg/l, Max | 0.05 | 0.05 |
| 24 | Iron as fe | 0.2 | 0.2 |

#### 5.1.5.1. Introduction

The disinfection of drinking water at this project will be carried out using chlorine compounds like sodium hypochlorite solution.

Chlorine (sodium hypochlorite solution) is simple to use, measure, and regulate. It endures well and is not very expensive.

#### 5.1.5.2. Purpose of disinfection of drinking water

- Disinfection is used in water treatment to reduce pathogens to an acceptable level.
- Three categories of human enteric pathogens are of concern in drinking water.
- Disinfection must be capable of destroying all three.
- Microorganisms commonly associated with waterborne disease include:
- bacteria

- viruses (e.g., Hepatitis A, poliovirus A)
- protozoa (e.g., *Cryptosporidium, Giardia*).
- **Chlorine** in one of its forms is the most common disinfectant used in the world. It is available commercially in pressurized vessels that contain both liquified and gaseous fractions.
- **Sodium hypochlorite** (NaOCl), also known as bleach, is a liquid form which will be used in this project.
- Chlorine has the advantage of being both an effective disinfectant and its residual can protect the supply downstream from the disinfection point.

#### 5.1.5.2.1. Residual chlorine (or free chlorine, or free available chlorine)

- Chlorine remaining after disinfection has taken place
- Presence of residual chlorine indicates that:
  - disinfection has occurred
  - the disinfected water has a degree of residual protection from microbial recontamination (e.g., during storage and distribution)
  - a range of residual chlorine concentration between 0.2 to 0.5mg/L should be targeted at all points in the distribution network
- WHO recommends that a minimum residual chlorine concentration of 0.2 mg/L is maintained to the point of delivery to the consumer.

#### 5.1.5.2.2. Minimum required contact time for effective disinfection

- For effective disinfection, the WHO recommends at least 30 minutes contact time, where the residual chlorine concentration is ≥0.5 mg/L and the pH of the water is <pH 8.

#### 5.1.5.2.3. Chlorine demand

- When chlorine is added to water, it reacts with any organic and inorganic material (chlorine reactive substances)
- during these reactions, chlorine is consumed referred to as the 'chlorine demand'
- as chorine is consumed during these reactions, the concentration of chlorine decreases
- It is important to understand how much chlorine will be consumed during the disinfection process:
  - This allows you to estimate how much chlorine you need to add to the drinking-water at the water treatment plant to ensure there will be sufficient residual chlorine present in the water to protect the water during storage and distribution
  - if the water has a higher concentration of chlorine reactive substances, the chlorine demand will be higher
  - if the water has a lower concentration of chlorine reactive substances, the chlorine demand will be lower

#### 5.1.5.2.4. Chlorine demand of water is constantly changing

- Chlorine demand of water is constantly changing ⇒ Changes as water quality changes
- Examples of events that influence the chlorine demand include....
- Introduction of contamination post treatment (e.g. leaking/bust water main, accumulation of sediment or microbial biofilm within water mains)

### 5.1.5.2.5. Water Chlorination System Parts

- Reliable chlorine water treatment systems typically include the following parts:
- A chlorine solution tank that holds liquid chlorine safely and keeps out debris. A good tank should also protect children and pets from accidental exposure.
- A proportional injection system to add the correct amount of chlorine to the water being treated.
- A large chlorine contact tank to allow the chlorine sufficient time to contact and treat the water. The tank should be large enough to supply a 15-20 minute supply of treated water at peak flow.

## 5.1.5.3. Water Chlorination system used in this project

Chlorination will be carried out at source meaning at Tube wells and dose will be set as per capacity of the tubewell and chlorine demand at particular area.

- Chlorination is done at tubewell source delivery pipe.
- Sodium hypochlorite liquid solution having 18% concentration is used through chlorinators.
- It is relatively safe with respect to chlorine gas.
- Tubewells delivery pipes/main water supply pipes are used as contact reactors. It takes required contact time of half an hour before reaching far end consumers.
- MC staff will monitor the chlorine residual at consumer end.

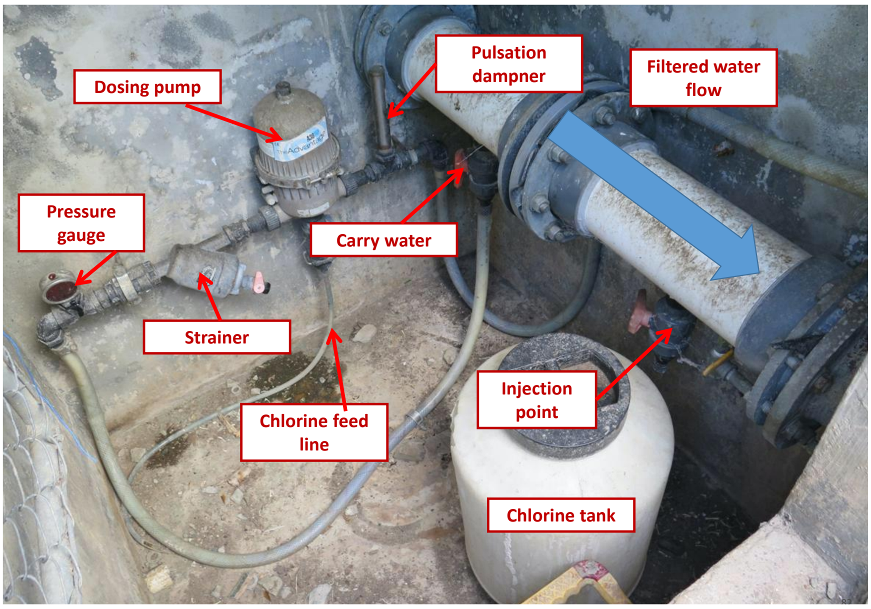



*Figure 5-1 Chlorination set up at a water supply line*

## 5.1.5.4. Sodium Hypochlorite disinfection

- Sodium Hypochlorite solutions naturally decompose and form oxygen bubbles and some salt residue in the tanks and piping causing “Gas off”.
- The higher the ambient temperature – the more difficult Hypo will be to dose.
- The higher the Hypo concentration – the more difficult it will be to dose.
- The smaller the dosing rate – the more difficult Hypo will be to dose.

- The smaller the metering pump – the more difficult Hypo will be to dose.

#### 5.1.5.5. The most common issues with pumping Sodium Hypochlorite solution:

- Off-gassing, which is the formation of gas in the piping system caused by heat, sunlight, low pumping rates, idle time, or a combination of these.
- Priming the pump is problematic when the pump is above the liquid supply container. Normally this occurs when the supply container is removed or changed, and air is allowed into the piping system.
- "Scaling" in the pump lines caused by a layer of reside from chemical imbalance forming around the pipe wall and in severe cases can actually block the line completely.
- Consistent and accurate pump rate delivery may be problematic because many pumps cannot pump "air entrained" liquids.

#### 5.1.5.6. Best practices:

- Store sodium hypochlorite away from heat and sunlight.
- Storage containers should normally contain a maximum of 30 days usage.
- The lower the concentration of sodium hypochlorite, the less chance for troubles.
- Maintain a flooded suction condition if possible. Suction lines should be 2-3 times larger than the pump inlet.
- If a suction "lift" is required, situate the pump as close to the suction source as possible and use a rigid suction line.
- Install an automatic "air-bleed" valve as close to the pump as possible and at the high point of the discharge line.
- Make sure all piping connections are tightly sealed to avoid air or vacuum leaks.
- Use a Peristaltic or "Hose" type pump since it can handle the air in the system better and prime and/or perform a suction lift if properly designed.

#### 5.1.5.7. How to calculate the detention time?

- Detention time (min) = Water storage volume (m3) ÷ Flow (m3/min)
- Ct concept (min.mg/L) = Residual chlorine concentration (mg/L) x Contact time (min)
- WHO recommends a minimum contact time of 30 minutes where the residual chlorine is 0.5 mg/L and the pH is <8 (i.e., 15 min.mg/L)
- For example, if the residual concentration is 0.4mg/l and contact time is 30 minutes, CT value will be=12.0min.mg/L that is less than required. In this case the contact time should be 38 minutes

#### 5.1.5.8. Calculation of the required chlorine dose

- Chlorine dose=Chlorine demand+ Residual chlorine
- If Chlorine demand is **0.5 mg/l** and Residual may be **minimum 0.5 mg/l (WHO standard)**
- Chlorine dose=**0.5+0.5=1mg/l**

$$\text{Chlorine Dose Rate (mL/h)} = \frac{\text{Required chlorine dose (mg/L)} \times \text{Treated water flow rate (m}^3\text{/h)}}{\text{Chlorine liquid concentration (\%)} \div 100}$$

**(A) Calculating chlorinator dose for each Tubewell**

This project (for 16 Cities) has four capacities of ground water Tube wells

- 0.5 cusec
- 1 cusec
- 1.5 cusec
- 2 cusecs

#### 5.1.5.8.1. For 0.5 cusec Tube well

*Assume:*

- Require 1ppm dose,1 mg/L chlorine dose
- Flow rate is 0.5 cusec (51 m3/h)
- Chlorine liquid concentration is 18 %
- Chlorine dose rate =1 x 51/0.18=283.33 ml/h=0.283 L/h
- Actual Chlorine Dose (mg/L) = (283.33 mL/h x 0.18 ) /51 m3/h=0.999=1 mg/l

#### 5.1.5.8.2. For 1 cusec Tube well

- Require 1ppm dose,1 mg/L chlorine dose
- Flow rate is 1.0 cusec (102m3/h)
- Chlorine liquid concentration is 18 %
- Chlorine dose rate =1 x 102/0.18=567 ml/h=0.567 L/h
- Actual Chlorine Dose (mg/L) = (567 mL/h x 0.18 ) /102 m3/h=1 mg/l
- Chlorine Dose (mg/L) calculation if injector is set at say 1 liters/h and concentration is 18% (1000*0.18)/102=1.76mg/l

#### 5.1.5.8.3. For 1.5 cusec Tube well

- Require 1ppm dose,1 mg/L chlorine dose
- Flow rate is 1.5 cusec (152.85m3/h)
- Chlorine liquid concentration is 18 %
- Chlorine dose rate =1 x 152.85/0.18=849.17 ml/h=0.849 L/h
- Actual Chlorine Dose (mg/L) = (849 mL/h x 0.18 ) /152.85m3/h=1 mg/l

#### 5.1.5.8.4. For 2 cusec Tube well

- Require 1ppm dose,1 mg/L chlorine dose
- Flow rate is 2 cusec (204 m3/h)
- Chlorine liquid concentration is 18 %
- Chlorine dose rate =1 x 204/0.18=1133 ml/h
- Actual Chlorine Dose (mg/L) = (1133 mL/h x 0.18 ) /204 m3/h=1 mg/l

Suppose you need to change the dose rate from 1mg/l to 2 mg/l

- Chlorine dose rate =2 x 204/0.18=2267 ml/h
- So, chlorinator will be set at 2.267 l/h

**(B) How to calculate the detention time for a storage?**

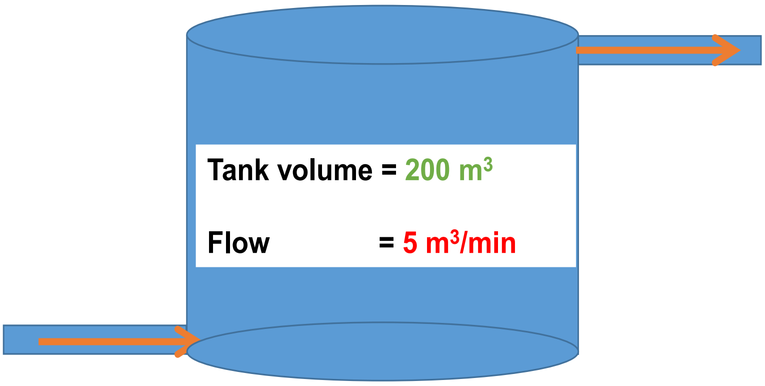



*Figure 5-2 Chlorination at a water reservoir/tank*

- Detention time (min) = Storage volume (m3) ÷ Flow (m3/min)
- Detention time = 200 m3 ÷ 5 m3/min =40 min
- Dose=1*300/0.18=1667ml/h= 1.67L/h

### 5.1.5.9. Chlorine may be checked easily with one of the following meters available in market

**Chlorine test strips**

**Chlorine comparator**

**Chlorine meter**

*Figure 5-3 Chlorination Test equipment*

*Table 5-2 Advantages/disadvantages of chlorination test equipment*

| Test Equipment | Cost | Accuracy/ Resolution | Advantages | Disadvantages |
|---|---|---|---|---|
| Chlorine test strips | M | L | • Easy to use, disposable<br>• No calibration/servicing required | • Poor degree of resolution (e.g., may only measure in 0.5 mg/L increments)<br>• Visual measurement (colour change); open to user interpretation<br>• Requires supply chain for replacement strips |
| Chlorine comparator test kit | M | M | • Easy to use<br>• Durable for field use<br>• No calibration/servicing required | • Visual measurement (colour change); open to user interpretation<br>• Requires reagents (DPD powder), supply chain |
| **Chlorine meter** | **H** | **H** | • High degree of resolution over a wide range (0.05 to 10 mg/L in 0.01 mg/L increments)<br>• Easy to use | • Less durable for field use<br>• -Calibration/servicing<br>• Requires reagents |

Source: *WHO: A guide to strengthening chlorination practices in small- to medium-sized utilities*

### 5.1.5.10. Sampling for Quality of Water in distribution system

The MC 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 and bacteriological tests are carried out for the water samples collected at frequent intervals. The minimum number of samples to be collected from a water supply system should be as prescribed in next section of the Manual on Water Supply & Treatment. Samples should be taken at different points of the transmission system on each occasion to enable overall assessment. In the event of epidemic or danger of pollution more frequent sampling may be required especially for bacteriological quality.

### 5.1.5.11. Principles of microbial monitoring in distribution systems

***(a) Choosing sampling locations***

Larger distribution networks generally require more samples to characterize water quality due to greater differences in network attributes such as flow rates, water retention times, pipe material and pipe age. Larger networks may also receive water from different service reservoirs, and there may be distinct geographical discontinuities, such as two suburbs or towns separated by a major road or river. A common approach is to split larger networks into zones or subdistricts with the view to conducting a verification monitoring regime within each zone that effectively characterizes water quality in that zone.

(b) ***Selection of sampling sites***

A common practice among water utilities is to rotate among designated sampling sites across the distribution system. Here, the aim is to characterize water quality within the zone effectively and enable comparisons of water quality over time for particular sections of the system. Rotation of sampling sites avoids the problem of sampling from the same site each time, which could give a misleading characterization of water quality. It is important that the sampling frequencies and locations are selected to provide the greatest confidence that all parts of the system are operating within the target ranges and, in the case of certain microbial parameters, free from contamination.

The location of sample points across each zone should reflect the number of people served (this is particularly important for microbiological samples). Different parts of the zones may include branch pipelines or loops, different pressure zones or areas receiving water from different sources or different treatment plants.

A day-to-day water verification monitoring programme involves sampling and testing from many locations throughout the distribution network. This commonly includes use of purpose-built sampling fittings located at the boundary with customers' properties (often referred to as "customers' taps"). Not all designated sampling sites need to be sampled on each sampling occasion; rather, a rolling programme where fixed sites plus a selection of randomly chosen sites (e.g. customers' taps) are sampled intermittently is recommended. Augmenting the fixed-site programme with randomly selected sites avoids the risk that changes may arise over time in parts of the system that fall between the fixed sites.

#### 5.1.5.12. Sampling Frequency:

The purpose of microbial monitoring programmes in distribution systems is to ensure that water supplies comply with applicable guidelines, standards or regulations.

Samples should be collected at regular intervals throughout the annual sampling calendar. The more frequent the sample collection, the greater the confidence that sample results will effectively characterize the true water quality within the system. The WHO *Guidelines for Drinking-water Quality* (WHO, 2011) provide guidance on the minimum number of samples for faecal indicator testing in distribution systems.

**Recommended minimum sample numbers per year for *E. coli* testing in piped distribution systems**

*Table 5-3 Recommended minimum samples*

| Population | Total number of samples per year |
|---|---|
| <5 000 | 12 |
| 5 000–100 000 | 12 per 5000 population |
| >100 000–500 000 | 12 per 10,000 population plus an additional 120 samples |
| >500 000 | 12 per 50,000 population plus an additional 600 samples |

Parameters such as chlorine, turbidity and pH should be tested more frequently as part of operational and verification monitoring.

The chances of detecting contamination in systems reporting predominantly negative results for faecal indicator bacteria can be increased by using more frequent presence/absence testing (WHO, 2011).

Presence/absence testing can be simpler, faster and less expensive than quantitative methods; however, its use is appropriate only in systems where the majority of tests for indicator organisms are negative.

The more frequently the water is examined for faecal indicator organisms, the more likely it is that contamination will be detected. Frequent examination by a simple method is more valuable than less frequent examination by a complex test or series of tests (WHO, 2011).

#### 5.1.5.13. Customer satisfaction

Verification includes monitoring consumer satisfaction. This type of verification is often overlooked or undervalued; however, it can be very powerful in detecting faults and measuring improvement. This is particularly true for aesthetic water quality problems in distribution systems.

One method for performing this activity is to establish consumer communication and response procedures and to monitor and document complaints and feedback. These should be analyzed and reported to senior management. Patterns of complaints should always be investigated. Although consumers are subjective and untrained, they can provide reliable reports of water quality problems that enable more rapid follow- up investigation and maintenance by the water utility. There are many examples of situations where consumer complaints and feedback have identified contamination incidents. Outbreaks in Naas (Ireland), Fife (Scotland) and Brushy Creek (Texas, USA) were all detected following customer complaints (Hrudey & Hrudey, 2004). Discolored water, increased turbidity and off-odors can provide evidence of ingress of contamination through backflows from cross-connections, water main breaks and other faults. Recording patterns and frequencies of consumer complaints using a geographic information system–linked database is commonly undertaken to assist in the operational tracking of the water quality issue and identifying the boundary of the affected area[5].

[5] WHO (2011)

# 6. O&M OF PUMPING MACHINERY

## 6.1. INTRODUCTION

### 6.1.1. General

**(b) Operation of Vertical Turbine Pump**

i) Shut the delivery valve before loosening it a little.

   In order to wet and lubricate the line shaft bearings before starting the pump, external water must be allowed if the pump is self-water lubricated and the length of the column assembly is lengthy.

   The clear water lubricating pump should be started before the main pump if the pump is externally lubricated with clear water.

ii) Let air through the delivery/discharge pipe's air vent.

iii) Turn on the motor and verify that the rotational orientation is accurate. Pumps should be immediately shut off if they stop rotating.

iv) Verify that oil is dripping through the sight glass tube and into the pump. The rate of drips per minute. must follow the manufacturer's instructions (often 2-4 drops/minute).

v) Check to see if the column assembly is receiving lubricating clear water from the clear water lubricated pump.

vi) Verify the pressure gauge reading to see if the pump has accumulated the necessary shut-off head.

vii) To make sure that the head does not drop below the recommended limit, the supply valve should be gradually opened in steps once the motor reaches a constant speed and the pressure gauge stabilizes. The cap should be approximately 75% of the duty head for VT pumps (in the absence of recommendations).

viii) Close the air vent if a constant stream of water is released through it.

ix) Verify that the motor's rated current is less than the ammeter measurement.

x) Inspect for excessive noise and vibration.

xi) After operating for about 10-15 minutes, check the bearing temperature, the packing of the box, and watch for vibration.

xii) The voltage should be monitored every half-hour and kept within acceptable limits.

### 6.1.2. Shutting off the Pump

#### 6.1.2.1. Shutting off the Pump under normal conditions

The following steps must be taken to stop a pump with a low or medium specific speed:

i) Gradually close the supply valve (sudden or fast closing should not be resorted to, which can give rise to water hammer pressures).

ii) Turn the motor off.

iii) In the event of V.T., open the air vent.

iv) If the VT pump is oil-lubricated or clear water-lubricated, respectively, stop lubricating the pump with oil or clear water.

#### 6.1.2.2. Stopping Following a Power Failure or Trip

The following procedures should be followed right away if the pumping station's power supply trips or fails, in order to prevent the pumps from automatically restarting when the power is restored.

Safety measures are required to stop auto-restarting upon power restoration.

The steps below should be followed.

i) If necessary, physically close delivery valve on a pump's delivery piping system.

ii) Verify that all starters and breakers are in an open state, or off-position.

iii) All switches and breakers must be turned to the open position, or off.

iv) In case of V.T., open an air vent. Cut off the flow of lubricating clear water.

v) Notify everyone who needs to know about the power outage.

## 6.2. PREVENTIVE MAINTENANCE OF PUMPING MACHINERY

Absence of timely preventive maintenance or improper maintenance can lead to premature equipment failure and excessive wear and tear of fast-moving parts. Premature failure or breakdown like this results in needless increases in repair costs and great suffering for the customers and personnel. Low efficiency and a rise in hydraulic and power losses are some consequences of poor maintenance. The weight of electricity costs rises when the pump is operated inefficiently. So, it is unnecessary to overstate the importance of preventive maintenance.

### 6.2.1. Pump preventive Maintenance

**(a) Pump grease packing**

- Some of the common causes of packing failure are:
- improper flushes,
- incorrect clearances,
- wrong selection of packing,
- faulty installation and maintenance,
- abrasive or corrosive conditions,
- insufficient lubrication, and leakage.
- Abrasives in the fluids being pumped can be kept out of the packing box by using a flushing system. There are, however, other sources of abrasives such as scale in the pipe solids that might be left when water evaporates. These are just as damaging as abrasives in the fluid itself.

**(b) Grease Packing installation**

- Before installing the packing container in the discharge head, check the centering of the shaft at the packing box bore. The shaft should be centered within 1/64". If it is not within that tolerance, the cause of the misalignment needs to be determined and corrected.
- Clean the bore and counterbore in the head. A thin coat of lubricant can be used in the bore and on the gasket to facilitate the assembly. Place the packing container ring gasket in place, then slide the packing container over the shaft and lower it until it is seated on the gasket. Install and tighten the cap screws provided.
- The arrangement of the packing depends on the size of the discharge head, the diameter of the top shaft, and the pressure developed by the pump. Consult the assembly drawing for the correct

arrangement for the particular pump being installed. Note that some pumps require a lantern ring and a compression spring in addition to packing rings.

- Eliminating pressure differentials as much as possible is another way of prolonging packing life, since leakage is directly proportional to pressure differences. One common way of accomplishing this is to use a throttle bearing below the packing and bleed off pressure through a bypass line.
- Shaft runout also causes packing difficulties. Runout can be the result of a bent shaft, a shaft which flexes at high speeds, misalignment, or an unbalanced motor coupling.
- Be sure the lantern ring (if used) is properly positioned; it should be in line with the drilling in the packing box.
- To install a packing ring in the container, lubricate the ring on all sides and wrap it around the shaft, just above the container. Using your fingers, start the ring into the container. Be sure that the ends of the ring do not overlap. When the entire ring is worked flush with the top of the container, carefully and evenly tamp it down into place with your fingers. The gland or split gland may be used as a tamper for the topmost ring.
- Install the required number of packing rings in this manner. Install packing rings with the gaps 180 degrees apart (on opposite sides of the shaft).
- The last ring may have to be installed later, after a period of operation.
- Place the gland or split-gland in the packing container. Insert the gland retainer bolts in the slots in the packing container. If the gland is split, place a clamp over the end of each gland bolt so that it holds the two halves of the gland together. Install nuts on the gland bolts and turn them finger-tight only. Final adjustment of the packing gland is done after the pump is started.
- If there is no shaft coupling between the motor and packing container, install the top shaft water deflector ("water slinger") over the top shaft, and position it a short distance above the gland but well below the driver mounting surface of the discharge head. This water deflector is important, as it will help protect the driver from the spray if there is a major leakage through the packing.
- There is no need to add additional grease while the pump is operational. If the pump remains idle for one month or longer, it is recommended that additional grease be added as described above.
- It is critical to permit enough leakage to keep the packing container running cool. Check for overheating. If the pump runs hot and leakage begins to diminish, stop the pump and permit it to cool down.
- Excessive tightening on the gland nuts is dangerous: the resulting inadequate leakage and lubrication not only burns the packing, but damages the shafts.
- Maintain an adequate water flow to the packing but do not over pressurize. This will cause excessive leakage and over-tightening of the packing, thus damaging the packing and other pump components.
- Make sure the gland nuts are only finger-tight. Allow the pump to run approximately 15 minutes. If the leakage rate is more than desired, slightly tighten the gland nuts.

(C) **The packing adjustment is made only with the pump running**

- Before making another adjustment, allow the packing to equalize against the increased pressure and permit leakage to decrease gradually to a steady rate.
- Pump packing must always leak slightly, but never to the extent of a spray.
- New packing will run a little warmer for the first few hours until the packing has seated. Again, do not over- tighten the gland nuts. The resulting inadequate leakage and lubrication will burn the packing and damage the shafts.

- When the packing has been compressed to the point that the gland is about to contact the upper face of the packing container, remove the gland, add one more packing ring, and readjust. If this fails to reduce leakage to the desired amount, remove all of the packing rings, and repack with new rings[6].

#### 6.2.1.1. Daily Inspections and Upkeep

**(a) Day-to-Day Maintenance**

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

**(b) Observation of irregularities**

The person in charge of operating the pumps should keep an eye out for any irregularities and respond appropriately. Pay close attention to any anomalies that arise after.

i) Variations in the sound of a running motor and pump

ii) Sudden shifts in the temperature of the bearing.

iii) Bearings that are dripping oil

iv) Mechanical seal or stuffing box leakage

v) Voltage swings changes in the present

vi) Variations in the readings of the hoover and pressure gauges

vii) Sparks or leakage current in cables, switchgears, starters, motors, etc.

viii) Motor, starter, switch gear, wire, etc. overheating.

**(c) Operation and observation logs**

The following things should be covered in the hourly observations, which should be kept in a logbook.

i) The times that the pumps are turned on, run, and shut off within a 24-hour period.

ii) Total three-phase voltage.

iii) The overall current drawn at the installation as well as the current drawn by each pump-motor set.

iv) Frequency.

v) Vacuum and pressure gauge readings

vi) Temperature of the motor windings.

vii) Motor and pump's bearing temperatures.

viii) Sump's input water level.

ix) Flowmeter's reading.

x) Daily PF for a period of 24 hours.

xi) Any unique issue or occurrence with the pumping system or installation, such as a pipeline break, a tripping or fault, or a power outage.

[6] peerless pumps: troubleshooting vertical turbine pumps - http://ecoursesonline.iasri.res.in/mod/page/view.php?id=1840

#### 6.2.1.2. Monthly Maintenance

i) Inspect the stuffing box gland for free movement; examine the gland packing and replace as necessary.

ii) Oil the gland bolts after cleaning them.

iii) Examine the mechanical seal for wear and, if necessary, replace it.

iv) Inspect the condition of the bearing oil and, if necessary, refill or top it off.

#### 6.2.1.3. Quarterly Maintenance

i) Verify the drive and pump alignment. To remove the impact of end play in bearings, the pump and motor shafts must be pushed to either side while the alignment is being corrected.

ii) If grease is used to lubricate bearings, the grease's condition should be examined, and the proper amount of grease should be replaced or renewed. The vacant space inside a bearing housing for an anti-friction bearing should be between one third and half full of grease. A fully packed housing will cause the bearing to overheat, which will shorten the bearing's lifespan.

iii) Tighten the mounting bolts for the pump and motor on the base plate or frame, as well as the foundation bolts.

iv) If instruments are available, measure the vibration level with them; otherwise, use observation.

v) The pump house's various equipment and accessories, including the clean flow indicator.

#### 6.2.1.4. Yearly Inspections and Maintenance

Once a year, a very comprehensive, critical inspection and maintenance should be carried out. Particular attention should be paid to the following items.

i) Use kerosene to clean and flush the bearings, and then check for any developed faults, such as corrosion, wear, and scratches. To stop the entry of dirt or moisture, the bearings should be covered with oil or grease right away.

ii) Clean the bearing housing and check it for faults like wear and grooving, among others. Replace the grease or oil in the bearing housing.

iii) Inspect the shaft sleeves for scour or wear and make any necessary corrections. The shaft at gland packings should be inspected for wear if shaft sleeves are not employed.

iv) Inspect the stuffing box, glands, lantern ring, and mechanical seal; make any necessary corrections.

v) Verify clearances before donning a ring.

#### 6.2.1.5. Pump Overhaul

Since the deterioration of a pump depends on the nature of the service, the type of installation the quality of the water handled, the quality of the material used in construction, maintenance, experience with a specific make and type of pump, etc., it is challenging to specify the periodicity or interval for overhaul in terms of period of service in months/years or operation hours.

The following operational hours, however, may be used as a basic guideline for overhauling pumps which have not passed their sufficient design life. Old pumps may be needing overhaul after 6000-9000 hours.

- 12000 hours for a vertical turbine pump
- 15000 for a centrifugal pump

#### 6.2.1.6. PREVENTIVE MAINTENANCE OF MOTOR CONTROL PANELS

- Switchgear: During de-energized maintenance, enclosures are to be cleaned of all loose dirt and debris.
- Insulators, supports, and connectors: Clean all loose dirt with lint-free rags.
- Examine for evidence of moisture that may lead to tracking or flashover while in operation. Repair or replace damaged insulators and supports as necessary.
- Conductors—Examine insulation for signs of deterioration, cracking, flaking, or overheating. Examine all connections for signs of overheating, cracked or broken connectors, and signs of tracking or arcing.

#### 6.2.1.7. Molded-case circuit breakers

- If dirt accumulates on the surrounding edge of the breaker, the heat build-up may not be permitted to dissipate properly and result in nuisance tripping.
- Protective relays: Inspection, maintenance, and testing of protective relays should be carried out. Inspect relays for physical damage and deterioration.

### 6.2.2. Testing Instruments and Tools

The required tools, testing equipment, including specialized tools for repairs and testing should be available at the pumping installation. Depending on the installation's size and significance, their number and particular tools will vary. The following tools and testing equipment must generally be available.

a) Tools

- A ring spanner set, and a double ended spanner set.
- Set of box spanners
- A hammer (of various sizes and functions)
- Set of screwdrivers
- Chisel
- Cutting pliers and nose pliers
- Different-sized flies that land on smooth or uneven areas
- Flexible spanner
- Pipe spanners
- A bearing remover
- Torque ratchet
- Clamps for line shafts, tubes, and column pipes.
- Specialized equipment include grinders, blowers, and drilling machines
- Set of tap and dice.
- Table vice

b) Testing equipment

- Tester for insulation
- Test light

- A tester for earth resistance
- Wattmeter
- A dial gauge.
- Tachometer

## 6.3. PUMPING MACHINERY REPAIR AND MAINTENANCE

### 6.3.1. Reasons of vertical turbine pump shafts break

- Shaft breakage is more often a direct result of the pump's operating conditions.
- Only a very small percentage of shaft failures are due to manufacturing flaws. Vibration is the most commonly caused by cavitation, critical speed, passing vane frequency, and operating outside the pump's best efficiency point.
- Pump bearings begin wear, allowing the shaft to move laterally, causing the shaft to flex and eventually fail.
- The vibration harmonics also puts extra stress on the pump shaft.

**(a) Imbalance** creates problems while the pump is running, though the shaft will measure straight if stopped. It's a source of vibration and will reduce machine, bearing, and mechanical seal life.

- Impeller imbalance is caused by:
- New, never balanced impeller
- Trimmed and not balanced impeller
- Foreign object stuck in vanes
- Vanes bent or out of plane
- Balance holes plugged
- Product build up on impeller

**(b) Misalignment**

- Poor installation, pipe strain, extreme belt tension and sheave misalignment on direct drive pumps all put undue stress on a pump's bearings and shaft.
- Note, in a misalignment scenario, the pump's bearings are more likely to fail before the shaft does. Nonetheless, because misalignment creates bending moments for the shaft, weakening it over time, we've included it here.

**(C) Hydraulic Shock**

- Serious damage can be caused by hydraulic forces. For example, when a check valve slams shut, interrupting the flow of fluid, a massive shock wave results. This shock wave reverses flow and travels back downstream. When the shock wave collides with a pump, assuming the shock is strong enough, the shaft could bend or break instantly or over time.

**(D) Reverse Flow**

- What happens when reverse flow causes a pump's impeller and shaft to turn backwards and the pump suddenly kicks on? You have a stressed or broken shaft.
- This scenario occurs when check valves upstream are partially or completely plugged, or otherwise not functioning properly.

- Is there a pump in your facility that frequently breaks shafts? Something sinister may be at play. Consult an engineer in your area well versed in pumps and fluid hydraulics[7].

### 6.3.2. If the Well is Pumping Air

- The worst-case scenario is that your water table has dropped to a point that is at or below the well pump, and the pump is drawing in air sometime during the pump cycle.
- Another cause would be that the well pump drop pipe (the pipe that connects the pump to the top of the well and the water system) is broken. Drop pipes are made of either iron pipe or plastic PVC or poly pipe. They may become broken/corroded and develop cracks or even in some instances break apart, allowing for air to be sucked in

### 6.3.3. If The Well is Pumping Sand or large amounts of sediment

- Other causes for sand in water can be that the well screen has become degraded and is allowing sand or sediment in from the gravel pack around the well screen.
- Sand can quickly wear out the pump valves and fill up the bottom of the well with sand. In any case, a sudden presence of sand is not a good sign and the cause should be determined.

### 6.3.4. If Water Pressure is low

- There can be many causes of low water pressure including a failing well pump, stuck check valve, partially closed or bad gate/ball valve, and leaking/failing pressure tank. In some cases, iron bacteria clogs up the pipe nipple leading to the pressure switch causing the pressure switch to incorrectly sense the pressure.
- If your well water tests high in iron bacteria, your pump and/or well screen may become clogged with iron bacteria. Having the well cleaned with a special solution designed to remove iron bacteria, slime and scale can often restore the well to a better condition.

### 6.3.5. Trouble Indicators of pump and Possible Causes

#### 6.3.5.1. Insufficient discharge delivered.

- Strainer partially or fully clogged or silted up.
- Inlet bell mouth or suction case insufficiently submerged.
- Total head of system higher than design head of pump.
- Malfunctioning of line valve causing partial or full closure.
- Impeller damaged.
- Impeller locking pin or collet loose.

#### 6.3.5.2. Insufficient pressure developed.

- Excessive amount of air in liquid
- Wrong direction of rotation
- Total head of system lower than pump design
- head.
- Burst or leakage in pumping main.

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[7] https://blog.craneengineering.net/troubleshooting-centrifugal-pumps

### 6.3.5.3. Stuffing box leaks excessively.

- Misalignment.
- Pump (impeller) shaft bent. shutdown or after power failure or tripping
- Shaft or shaft sleeves worn or scored at the packing.
- Gland Packing improperly installed.
- Incorrect type of gland packing for operating conditions.
- Shaft running off center because of worn bearing or misalignment.
- Rotor out of balance, causing vibration.

### 6.3.5.4. Pump requires excessive power.

- Total head of system lower than pump design
- Burst or leakage in pumping main.
- Gland too tight, resulting in no flow of liquid to lubricate gland.
- Rusting of bearing from water in housing.

### 6.3.5.5. Vibration

- Excessive motor or pump imbalance
- Misalignment or eccentricity of rotating parts
- Mounting unstable or uneven
- Faulty bearings (improperly seated, pitted from long periods of idleness, fatigued)

### 6.3.5.6. Abnormal Noise

- Pump bearings running dry
- Broken column bearing retainers
- Broken shaft or shaft enclosing tube
- Impeller dragging on bowl case
- Cavitation due to low submergence
- Foreign material in pump

### 6.3.5.7. Analyzing vibration

- Slow down the pump. Be aware of how the vibration changes with speed.
- If the vibration reduces gradually, it is a sign that unbalance, misalignment, or bent shafting is the cause.
- If the vibration decreases immediately with the electrical power shutoff, the cause is electrical imbalance in the motor.
- When a pump shudders in slowdown, the cause is generally passage through a resonance frequency. But do not jump to conclusions at this point; gather more data.

- If it is hard to rotate the shaft by hand, the suspected causes are misalignment, bad fit, or a bent shaft[8].

### 6.3.6. The best efficiency point of a pump

#### (a) Measurement of efficiency of pumping units

Formula for Pump efficiency ($\eta_p$) =ρ × g × Q × H /(60,000× Kw)
Assume flow rate(Q): $m^3$/min
Head (H): m
Pump power required=KW, ρ is density of water=1000Kg/m3
G=9.81m/s2

- The BEP, or best efficiency point, is the point at which the pump operates at peak efficiency. At the BEP, flow enters and leaves the pump with a minimum amount of flow separation, turbulence, and other losses. The closer a pump operates to its BEP, the less wear the pump will experience, which increases the reliability of the pump.

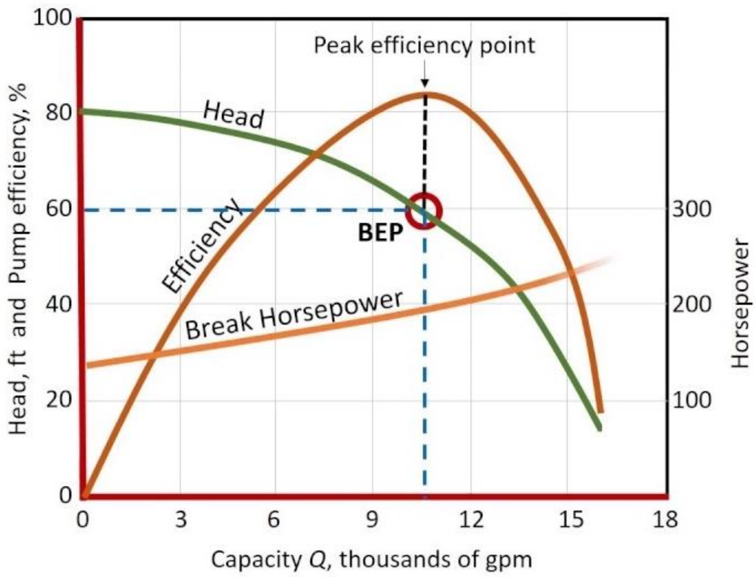


*Figure 6-1 Pump Performance curve*

- In the below image, the BEP is located at the apex of the pump efficiency curve (green line). If a vertical line is drawn from the BEP down to the pump curve (black line), the head and flow rate at the BEP can be determined by looking at where this line is in relation to horizontal and vertical axes[9].

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[8] Deepwll-Turbine-Pump-Final-PDF.pdf KSB DWT.pdf
Water Supply Engineering University of Asia Pacific https-//www.uap-bd.edu › ce › nehreen › ce-331 .pdf
[9] *https://www.pumpsandsystems.com/what-bep#:*

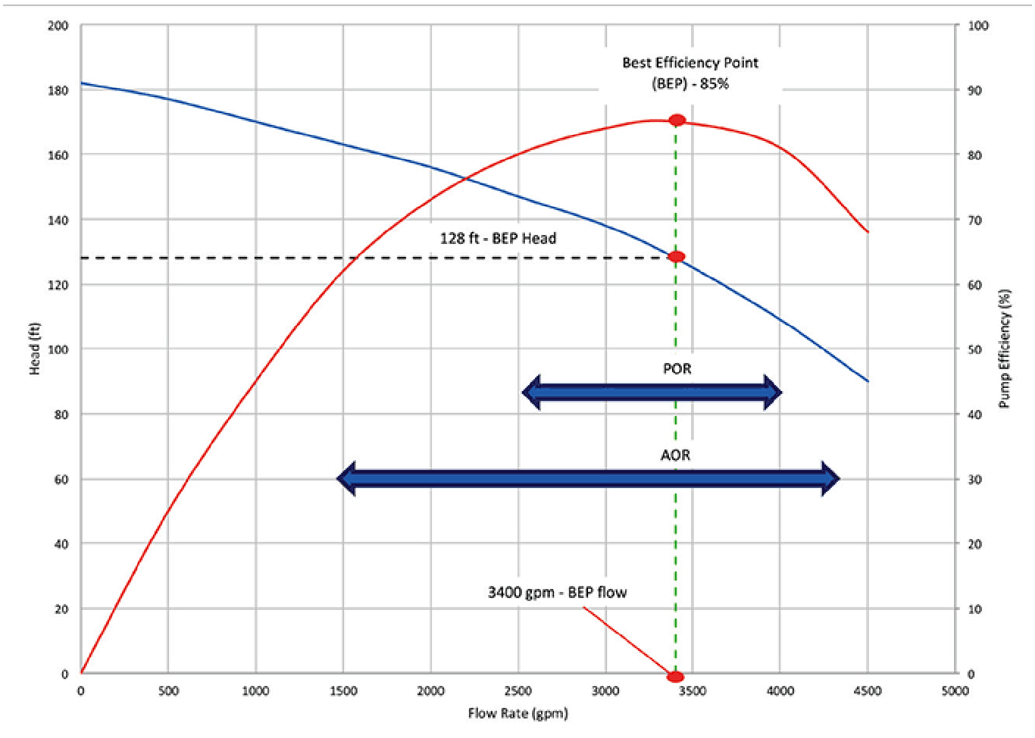



*Figure 6-2 Best efficiency point*

- The Hydraulic Institute (HI) has defined pumps operating regions (ANSI/HI 9.6.3) as flows:
- Preferred Operating Region from 70% to 120% of flow at BEP for most centrifugal pumps.
- Allowable Operating Region (AOR). This is the region that comprises all of the points that this pump can operate at continuously. 40 % of BEP
- The POR is a range of rates of flow the hydraulic efficiency and the operational reliability of the pump are not substantially degraded. Within this region, the design service life of the pump will not be affected by the internal hydraulic loads or flow-induced vibration. Operating a pump within the POR ensures higher reliability and lower energy consumption. A typical range for the POR is shown on in Image wider range of flows, outside the POR, over which the service life of a pump is acceptable, is called the allowable operating region (AOR).

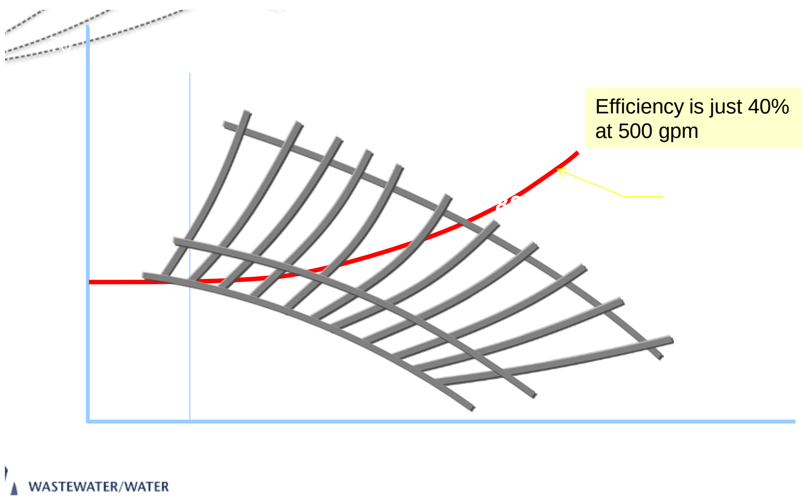



*Figure 6-3 Inefficiency at minimum conditions*

- Pumps are often unstable and inefficient at average or minimum conditions; therefore, best policy is that pumps are operated with in preferred operating region.

## b)NPSH REQUIRED & NPSH AVAILABLE

**NPSH Required (NPSHR):** The minimum pressure required at the suction port of the pump to keep the pump from cavitating is called NPSHR. It is provided by the manufacturer.

NPSHR is the suction pressure necessary to ensure proper pump operation. It is purely a function of the pump design, and although it can be calculated, it is more accurately determined by actual testing. Why does a pump require a positive suction head? Quite simply, it is impossible to design a centrifugal pump that exhibits absolutely no pressure drop between the suction inlet and its minimum pressure point, which normally occurs at the entrance to the impeller vanes. Therefore, all pump systems must maintain a positive suction pressure that is sufficient to overcome this pressure drop. If the pressure is not sufficient, some of the water will change state (liquid to vapor) and cavitation is initiated. Like NPSHA, NPSHR is also a dynamic quantity and increases substantially with pump flow.

You would think that the NPSHR, measured by the pump manufacturer, would be the suction pressure required to prevent cavitation. That used to be the definition, but it is currently defined as the suction pressure at which a particular pump's hydraulic performance is degraded by 3 percent.

Depending on the pump design, Hydraulic Institute(US) recommends an NPSHA / NPSHR margin of 1.1 to 2.5. Some pump experts recommend even more. It is a good idea to check with your pump manufacturer for its specific margin requirement as it relates to a particular pump model and its application.

**NPSH Available (NPSHA):**

The absolute pressure at the suction port of the pump. NPSHA is a function of your system and must be calculated. NPSHA must be greater than NPSHR for the pump system to operate without cavitating. The net positive suction head available to a centrifugal pump combines the effect of atmospheric pressure, water temperature, supply elevation and the dynamics of the suction piping. The following equation illustrates this relationship. All values are in feet of water, and the sum of these components represents the total pressure available at the pump suction.

NPSHA = Ha +/- Hz - Hf + Hv – Hvp

Where:
**Ha** is the atmospheric or absolute pressure
**Hz** is the vertical distance from the surface of the water to the pump centerline
**Hf** is the friction formed in the suction piping
**Hv** is the velocity head at the pump's suction
**Hvp** is the vapor pressure of the water at its ambient temperature

At first glance, the equation for NPSHA looks pretty static, but it is actually quite dynamic. All of the variables can be in a continuous state of change. Velocity head and suction line friction vary as a function of flow. Likewise, atmospheric pressure can vary by several feet depending on weather conditions. Water supply elevation and temperature can vary seasonally. Usually the "worst case" values for each of these components are used when calculating NPSHA[10].

[10] Pumps and System: https://www.pumpsandsystems.com/net-positive-suction-head-npshr-and-npsha.

When a tube well pump operates at less NPSH than required it starts cavitation and we also call it suction break. It is described in the below mentioned figure:

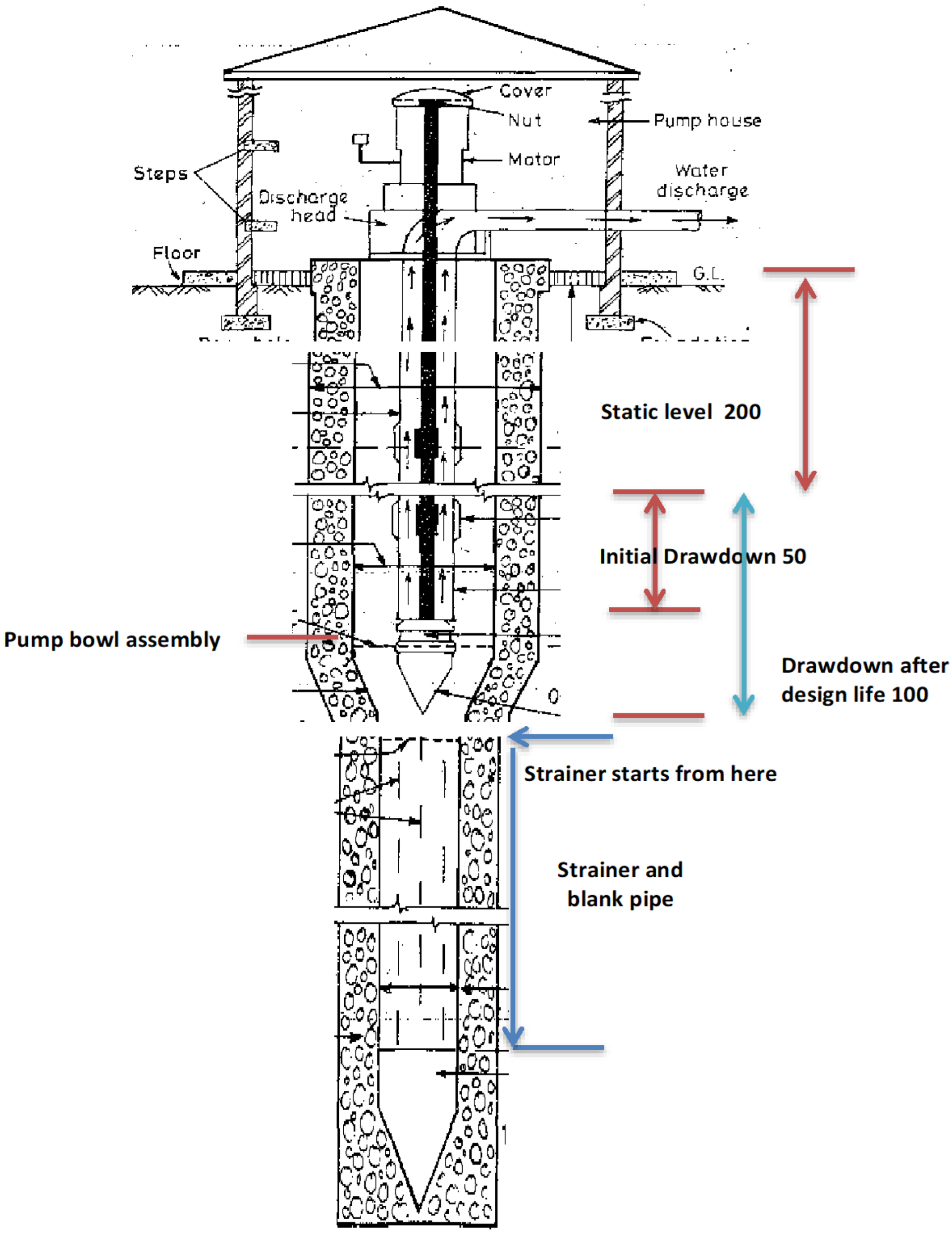



*Figure 6-4 Tube well showing excessive draw down*

### 6.3.7. Motor control Panels

Star Delta Panels are used in this project for control of motors.

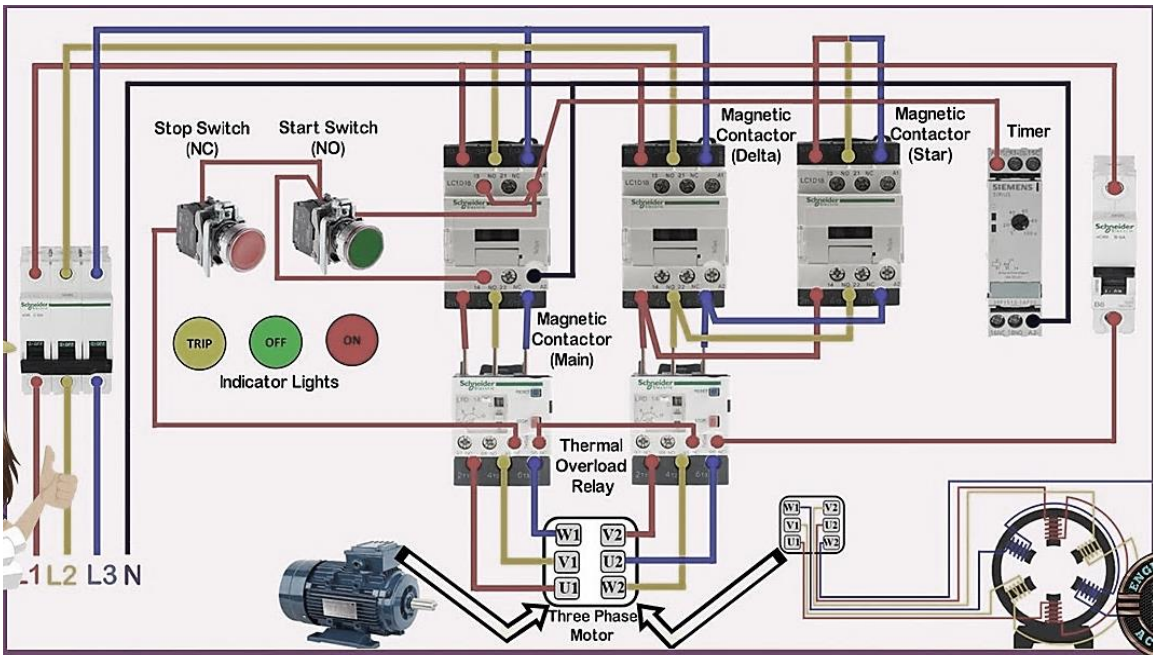
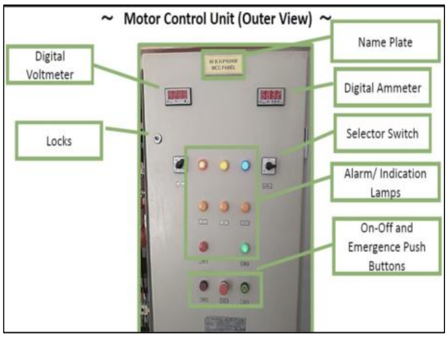



*Figure 6-5 Star delta electric panel*

### 6.3.7.1. Parts of Auto Star Delta control Panel





Digital panel meter

Selector switch


*Figure 6-6 Parts of an ASD Panel*

- **Selector Switch:**

  Used to select among each of three phases to monitor currents and voltages on ampere and voltmeter

- **CTs** are used with ammeter, energy meter, KVA meters Most current transformers have a standard secondary rating of 5 amps with the primary and secondary currents being expressed as a ratio such as 100/5
- **Protective Relays**


Thermal over load relay    Phase failure relay    Over voltage/under voltage relay

*Figure 6-7 Protective Relays*

### 6.3.7.2. Sizing and setting of Contactors & Overload Relay

- **FULL LINE CURRENT IN AN INDUCTION MOTOR**

  If a motor is having Power factor as 0.8
  FLC = KW X 1000/(400*1.732*0.80)
- **Over Load Relay Setting**
- The overload should be sized according to Main Contactor
- Relay Min (70% of FLC Phase)
- Relay Max (120% of FLC Phase) or
- Relay Setting (100% of FLC Line)

  **Making / Breaking Capacity of Contactors:**
- Main Contactor (58% of FLC Line):
- Delta Contactor (58% of FLC Line):
- Star Contactor (33% of FLC Line):

## 6.3.8. Trouble shooting of star delta panel

*Table 6-1Troubleshooting for Starters, Breakers and Control Circuits*

| S.No. | Trouble | Cause |
|---|---|---|
| 1 | If main circuit breaker trips? | • Check all phases<br>• if ok check cable short<br>• and if ok then motor is faulty |
| 2 | If Overload relay trips? | Check current within range if ok check cable damage/short (if not then motor is faulty) |

| S.No. | Trouble | Cause |
| --- | --- | --- |
| 3 | Does under/over voltage relay trips? | Is voltage within range? (if not in range inform Power Company for correction) |
| 4 | Starter/breaker not holding on ON-Position | • Relay contacts are not contacting properly |
| | | • Latch or cam worn out |
| 5 | Starter/breaker tripping within short duration due to operation of overcurrent relay | Overcurrent relay setting incorrect.<br>Moderate short circuit on for out going side.<br>Sustained overload.<br>Loose connection. |
| 6 | Overheating | Poor condition of contacts.<br>Contacts out of proper alignment,<br>Contacts burnt or pitted,<br>Loose power connection.<br>overcurrent or short circuit/earth fault. |
| 7 | Contacts chatter | Low voltage,<br>Poor contact in control circuit,<br>Poor contact in control circuit,<br>Defective or incorrect coil. |
| 8 | Contacts welding | Abnormal inrush of current,<br>Low voltage preventing,<br>magnet from sealing,<br>Short circuit |
| 9 | Noisy magnet (humming) | Low voltage |
| 10 | Open or welded control circuit contacts in over current relay. | Short circuit in control circuit with too large protecting fuses.<br>Misapplication,<br>handling too heavy currents |

*https://www.electrical4u.com › star-delta-starter*

## 6.3.9. O&M of Electric Motors

### 6.3.9.1. Motor performance:

Motor performance depends on three elements such as voltage across terminals, resistance across terminals, and magnetic force. Various factors that affect these elements and change motor performance will be discussed here by way of giving some specific examples.

#### 6.3.9.1.1. Voltage of Power Supply

If only the voltage of power supply changes, the change in motor performance is in direct proportion to that change in voltage.

As is quite apparent from the figure above, the speed lines move parallel to the original while the current almost straight on its line. (Note: however, that these proportional changes are not obtainable any more beyond a certain limit range. )

#### 6.3.9.1.2. Type of Power Supply

Unlike the constant-voltage power supply, the power supply with resistance will have a voltage drop due to its internal resistance, causing the stall current and, therefore, the stall torque to drop with the speed line bottomed to the left.

#### 6.3.9.1.3. Winding Specifications

It's the Winding Specifications that affect motor performances greatly.
Changing the number of turns per slot or the diameter of magnet wire produces results different from each other. Increased number of turns per slot results in a drop in speed in direct proportion. The increased diameter of magnet wire results in increasing stall torque and stall current in inverse proportion of the wire diameter raised to the second power.
(Note: however, that these inversely proportional changes are not obtainable any more beyond a certain limit range.)

When you change the number of turns per slot for the same model motor in practice, the values of cross-sectional area of wire per slot must be close to each other.
Cross-sectional area of wire = $\phi^2$ (diameter of magnet wire) **×** **n** (number of turns per slot)

#### 6.3.9.1.4. Environmental Temperature

Environmental temperature affects the magnetic forces of magnets and the winding resistance, so indicates changes in motor performance.

- **Is** : Stall current
  Because the current changes in inverse proportion to the winding resistance, as the temperature rises, Is falls.
- **Ts** : Stall torque
  Because the magnetic force of magnets becomes weaker with decreasing current, as the temperature rises, Ts falls greatly.

#### 6.3.9.1.5. Type of Magnet

Magnets are available in a wide variety of types, but discussed here taking them as changes in magnetic force.
Changing the anisotropic magnets from wet to dry results in decreasing stall torque (Ts) and increasing no-load speed (N0) due to magnetic force weakened.

### 6.3.9.2. Motor winding issues and their solutions

- It’s always important to identify the real cause of burned windings and not just to replace the electric motor. Motor windings have a different appearance in all these failure situations: single-phase burnout, overload, unbalanced voltage, and voltage spikes. Voltage spike damage occurs more often in motors controlled by variable frequency drives.
- Troubleshooting the most typical winding problems of three phase electric motors
- These problems are all caused by in-plant faults that require correction. A replacement motor can fail sometimes immediately if the in-plant problem isn’t corrected.
- It’s very important to accurately identify problems that require a motor’s removal and replacement. Winding problems that are identified should be documented. A history of the plant’s motor problems (on computer software) will point out problem areas that ran be improved, or even eliminated.

- These winding problems may be found in a three-phase motor:

#### 6.3.9.2.1. Shorted Turns

- A short is a common winding breakdown, and it requires rewinding or replacing the motor. Shorted turns are caused by nicked coil wire, high-voltage spikes, conductive contaminants, overheated winding, aged insulation, and loose, vibrating coil wires.
- The most of the resistance to current flow in an AC motor is furnished by **inductive reactance**. The resistance of the wire in a complete phase is a very small percentage of the motor’s total impedance (resistance plus inductive reactance). Inductive reactance makes each turn very significant in the motor’s ampere demand. Each turn supplies much more inductive reactance than resistance.
- A short forms when one or more turns of a coil are bypassed **because of an insulation breakdown between wires**. The resistance that the shorted turns develop is eliminated from its phase winding, resulting in increased amperes. When there are a few shorted turns in one of the three phases, a closed-loop circuit is formed by the turns within the short. As the motor runs, lines of force (from AC current flow) cut the wires in the closed-loop circuit.

#### 6.3.9.2.2. Ground (winding shorted to frame)

- When a motor is “**grounded**“, the winding is shorted either to the laminated core or to the motor’s frame. The problem is usually found in a slot, where the slot insulation has broken down. Water is the most common cause of a grounded winding. A solid ground requires rewinding or replacing the motor.
- Some causes of slot insulation breakdowns are overheating, conducting contaminants, lightning, age, pressure of a tight coil fit, hot spots caused by **lamination damage** (from a previous winding failure), and **excessive coil movement**.
- A phase-to-phase short is caused by insulation breakdown at the coil ends or in the slots. This type of fault requires rewinding or replacing the motor. Voltage between phases can be very high. When a short occurs, a large amount of winding is bypassed. Both phase windings are usually melted open, so the problem is easily detected.
- Among the causes of interphase breakdown are **contaminants, tight fit (in the slot), age, mechanical damage, and high-voltage spikes**. Coils that form the poles for each phase are placed on top of each other in all three-phase motors.
- Figure 3 is a **concentric-type winding**. The coils don’t share the slots with other poles in some concentric-type windings.

#### 6.3.9.2.3. Phase-to-Phase Short

- A phase-to-phase short is caused by insulation breakdown at the coil ends or in the slots. This type of fault requires rewinding or replacing the motor. Voltage between phases can be very high. When a short occurs, a large amount of winding is bypassed. Both phase windings are usually melted open, so the problem is easily detected.
- Among the causes of interphase breakdown are contaminants, tight fit (in the slot), age, mechanical damage, and high-voltage spikes. Coils that form the poles for each phase are placed on top of each other in all three-phase motors.
- Figure 3 is a **concentric-type winding**. The coils don’t share the slots with other poles in some concentric-type windings.

- Figure 4 is the lap-winding type. The ends of the coils are nested within each other and have phase insulation between the poles. The coils usually share the slots with other poles. Insulation also separates the coils of each phase in the slots.
- Phase-to-phase insulation is important because there is a line voltage potential between **phases** regardless of a motor's horsepower.
- . A phase-to-phase short occurs in the slot more often than at the coil ends. When a breakdown occurs in the slot, copper usually melts and fuses to the slot laminations.
- This copper has to be ground out and removed before the motor is rewound, or it becomes a hot spot and deteriorates the new insulation.

*Figure 6-8 lap-winding type*

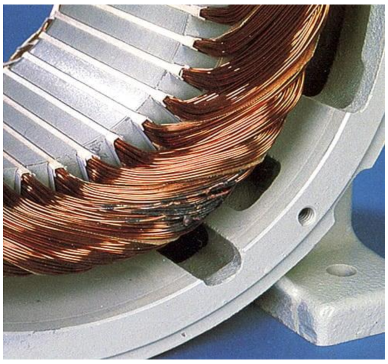


*Figure 6-9 Winding with a phase-to-phase short*

### 6.3.9.2.4. Open Winding

- A common cause of an open winding is **undersized lead lugs**. Charred connections in the motor's connection (terminal) box are a sure indication of this problem. Open windings are also caused by shorted turns, phase-to-phase shorts, ground-to-frame shorts, faulty internal coil-to-coil connections, severe overloads, and physically damaged coils.
- These faults require rewinding or replacing the motor. An open winding will show several different symptoms (depending on the motor's internal connection).
- A wye-connected motor with an open winding will test differently from a delta-connected motor. An open single-circuit winding will be "**single-phased**". Its power will drop to about half, and the motor won't start. If the motor's internal connection is multi-circuit, it will start but will have

reduced power. An open circuit will cause the magnetic circuit to be unbalanced. Under normal load the motor will run more slowly and will overheat.

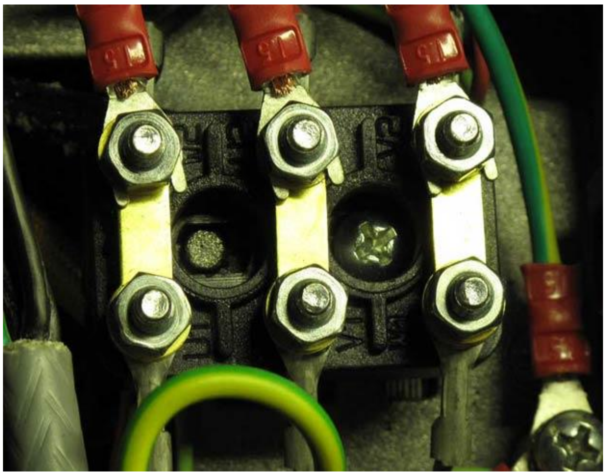


*Figure 6-10 Motor terminal box*

- A micrometer is used to identify this problem. A motor with a high number of parallel circuits, that is, four and eight wye, will show less power loss when one circuit is open. Multiparallel circuit connections are used in motors above 5 horsepower. The windings of a severely overloaded motor (operating on 250 volts) usually become completely charred before an open winding occurs.
- An overloaded motor operating on 490 volts, however, often will have no sign of burned wires before its windings melt open. In either case, the overload protection isn't working, and the motor should be rewound or replaced.
- Motor lead connecting lugs should be thick enough (throughout the connection) to represent the circular mil area (size) of the motor's lead wire. If any part of the lug is too small, it becomes a resistor in series with the motor, and current will be restricted when the motor needs it the most – to start the load.

#### 6.3.9.2.5. Burned Windings from Operating on Single Phase

- When one line of a three-phase power supply opens, the power becomes single phase. If this happens while the motor is running, its power output is cut approximately in half. It will continue to run, but it can no longer start by itself. Like a single-phase motor without its start winding energized, it has no rotating magnetic field to get it started[11].

[11] https://electrical-engineering-portal.com/troubleshooting-winding-problems-three-phase-electric-motors

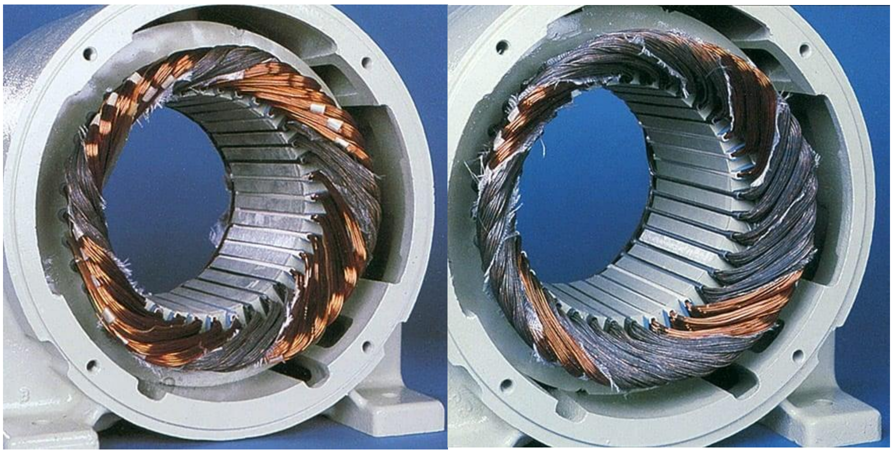


*Figure 6-11 A wye-connected motor that failed because of a single-phase condition. Line 3 is open.*

A delta-connected motor that failed because of a single-phase condition, Line 3 is open

### 6.3.9.3. Preventive Maintenance

*Table 6-2 Preventive Maintenance of Electric motors*

| Maintenance activity | Performance characteristics | Frequency |
|---|---|---|
| Visual inspection | Inspection should look for:<br>• Evidence of damage caused by dirt, loose parts, or foreign objects<br>• Evidence of moisture and/or dirt build-up<br>• Unusual noises, or high vibration<br>• Evidence of degradation of foundation, bed plates, and anchor bolts | 6 months |
| Vibration | Record and trend vibration levels.<br>− This should be done by a trained and experienced technician, preferably a qualified technician. | 6 months |
| Running current | Record and trend all three phase currents and verify the currents are balanced and do not exceed nameplate rating.<br>− Each phase should be within +/- 5% of the average of all three phases. | 12 months |
| Insulation resistance (IR) | Perform IR check between motor leads and ground. This determines condition of the ground insulation. Test voltage(VDC) 500. Acceptable reading >5 mohms | 12 months |

### 6.3.9.4. Troubleshooting for Electric Motor[12]

*Table 6-3 Troubleshooting for Electric Motors*

| S.No. | Trouble | Cause | Remedy |
|---|---|---|---|
| 1. | Hot bearings | • Bent or sprung shaft.<br>• Misalignment<br>• Badly worn bearings<br>• Bearing loose on shaft or in bearing housing<br>• Insufficient grease<br>• Deterioration of grease<br>• Excessive lubricant<br>• Overloaded bearing<br>• Broken ball or rough races. | • Straighten or replace shaft.<br>• Correct coupling alignment.<br>• Replace bearings.<br>• Maintain proper quantity of grease in bearing.<br>• Remove old grease, wash bearings thoroughly with kerosene.<br>• Clean housing thoroughly and replace bearing. |
| 2. | Motor stalls | • Motor overloaded<br>• Low voltage<br>• Open circuit<br>• Incorrect control resistance of wound motor<br>• Mechanical locking in bearings. | • Check any excessive rubbing or clogging in pump.<br>• Correct voltage to rated value.<br>• Fuses blown, check overload relay, starter and push button.<br>• Dismantle and check bearings. Check whether any foreign matter has entered air gap and clean. |
| 3. | Motor does not start | • No supply voltage or single phasing or open circuit or voltage too low.<br>• Motor may be overloaded<br>• Starter or switch/breaker contacts improper<br>• Initial starting torque of load too high.<br>• Rotor defective<br>• Poor stator coil connection<br>• Mechanical locking in bearings or at air gap. | • Check voltage in each phase.<br>• Start on no load by decoupling. Check for cause for overloading.<br>• Examine starter and switch/breaker for bad contact or open circuit.<br>• Remove end shields, checkend connections<br>• Dismantle and repair. Clean air gap if choked. |
| 4. | Motor does not accelerate to rated | • Voltage too low at motor | • Check whether motor suitable for design duty and load. |

[12] https://www.scribd.com/document/261644239/Operation-and-Maintenance-of-Pumping-Machinery

| S.No. | Trouble | Cause | Remedy |
| --- | --- | --- | --- |
| | speed. | terminals because of linedrop.<br>• Improper connection.<br>• Broken rotor bars | • Check voltage.<br>• Leave no lead poorly connected. |
| 5. | Motor takes too long to accelerate. | • Excess loading<br>• Timer setting of starter not correct.<br>• Defective squirrel cage rotor.<br>• Applied voltage too low. | • Reduce load.<br>• Check whether timer setting<br>• of star – delta starter is less than acceleration time required .<br>• Correct the voltage by changing tap on transformer. |
| 6. | Wrong rotation | Wrong sequence of phases | • Inter change connections of two leads at motor or at switchboard for two phases. |
| 7. | Motor overheats while running | • Check for overload<br>• End shields may be clogged<br>• with dust, preventing proper ventilation of motor.<br>• Motor may have one phase<br>• open.<br>• Unbalanced terminal voltage<br>• Weak insulation<br>• High or low voltage<br>• Rotor rubs on stator bore | • If overloaded, check and rectify cause for over loading.<br>• Blow off dust from the end<br>• shields.<br>• Check to make sure that all<br>• leads are well connected.<br>• Check for faulty leads, connections from transformer.<br>• Check voltage of motor and correct it to the extent possible.<br>• Replace worn bearings.<br>• Check for true running of shaft .and rotor. |
| 8. | Motor vibrates after connections have been made | • Motor misaligned<br>• Weak foundations or holding down bolts loose<br>• Coupling out of balance<br>• Defective ball or roller bearings<br>• Single phasing<br>• Excessive end play | • Realign<br>• Strengthen base plate/<br>• Foundation<br>• Balance coupling<br>• Replace bearing<br>• Check for open circuit in all phases |
| 9. | Magnetic noise | • Air gap not uniform<br>• Stator stamping loose<br>• Loose bearings<br>• Rotor unbalance<br>• Crack in rotor bar | • Check and correct bracket fits or bearing.<br>• Retighten stamping.<br>• Correct or replace bearing.<br>• Rebalance on dynamic<br>• balancing machine.<br>• Replace |

### 6.3.10. Power cables

*Table 6-4 Troubleshooting for Cables*

| Trouble | Cause | Remedy |
|---|---|---|
| Overheating | Cable size inadequate. | Provide a cable in parallel to existing cable or higher size cable |
| Insulation burning at connections | Improper termination in lug termination | Check size of lug and whether properly crimpled and correct Check whether only few strands |

### 6.3.11. Flow measurement at Tube wells

Electromagnetic flow meters are recommended for measurement of flow at Tube wells and at each zone of water distribution system in all MCs. This type of flow meter is a smart or electronic meter that measures the flow without any moving part inside therefore its maintenance is quite less and easy. It is operated on a dry battery which has 10 years' service life. In order to give an easy understanding to operators and supervision staff its function and parts are explained below:

#### 6.3.11.1. Electromagnetic Flow Meters

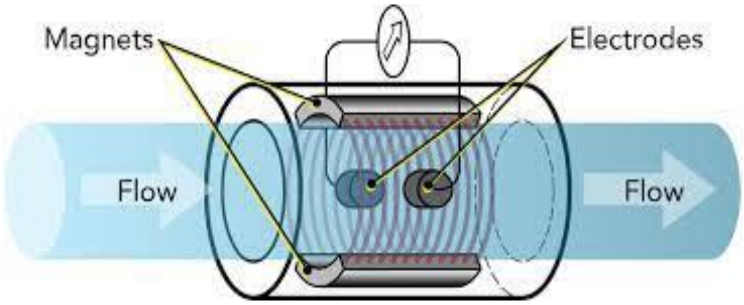



*Figure 6-12 Electromagnetic Flow Meters*

- The operation of electromagnetic meters is based on Faraday's induction law. This law states that a voltage (*E* ) appears between the ends of any conductor passing through a magnetic field.
- The flow of the fluid creates an induced voltage which is proportional to the flow velocity. The induced voltage is directly proportional to flow velocity (*V*), the length of the conductor (*L*) and the intensity of the magnetic field (*B*) that surrounds it.

### Measuring tube

- The metallic metering tube has to be coated with non-conductive material to avoid the electrodes being in short circuit.

- Coating should be Hard rubber or ebonite, Polyurethane, Polytetrafluoroethylene (PTFE) GRP, Ceramics or Teflon/TFA.


*Figure 6-13 Measuring tube of a mag meter*

### 6.3.11.2. Working suitability

- They are very accurate and require the fluid to completely fill the pipe
- Can be used on a wide range of pipe sizes
- These can't give very accurate measurement if water is with high, very low, or variable conductivity.
- ***Electromagnetic meter*** performance is not affected by temperature, pressure, or viscosity. These meters can handle rapid changes in flow.
- They can accurately measure clean fluids like drinking water or those with heavy solids like sewage.
- Excellent low-flow accuracy with just one or two upstream or downstream straight run requirements.

#### (a) Battery operation:

i. Lithium batteries are used mostly with Mag meters
ii. Do not short-circuit, recharge, overcharge or connect with incorrect polarity.
iii. Do not expose to temperature beyond the specified temperature range or incinerate the battery
iv. Do not crush, puncture or open cells or disassemble battery packs.
v. Do not weld or solder to the body of the battery, or the battery packs.
vi. Do not expose contents to water.

#### (b) Name plate information

- DN-Nominal Diameter
- Protection class (IP-)
- Permanent/Nominal flow in m3/h
- Certification
- Year of manufacture and Direction of the Flow[13]

[13] Francisco Arregui, Enrique Cabrera Jr and Ricardo Cobacho: Integrated Water Meter Management

### 6.3.11.3. Technical specifications of Flow meters

*Table 6-5 Technical specifications of Flow meters*

| |
|---|
| Specification for Electromagnetic flow meters |
| General Features: |
| No moving Parts |
| Visual (LCD) display |
| Tamper proof. |
| No reverse flow measurement. |
| Detailed Metrological Specifications: |
| **Specification for Electromagnetic flow meters** |
| **General Features:** |
| No moving Parts |
| Visual (LCD) display |
| Tamper proof. |
| No reverse flow measurement. |
| **Detailed Metrological Specifications:** |
| **Size:** 200mm (8 inch) for 2 cusec and 6 inch for 1 and 0.5 cusec flow |
| **Accuracy:** Class –I of (OIML/ISO) for 2 cusec and1 cusec but for 0.5 cusec it will be class-II. |
| **Material:** Carbon steel |
| **Protection Class:** IP-68 |
| **Specifications** |
| Ambient Temperature: +5° to 55° C |
| Liquid Temperature: up to 50° C |
| working pressure: 1-10 bar |
| Ratio R: $Q_3/Q_1 = 80$ |
| Permanent flow rate ($m^3$/ hr): $Q_3$ = 250 for 2 cusec,160 for 1 & 1.5 cusec and 63 for 0.5 cusec |
| Battery life: Minimum 10 years |
| Installation: Horizontal |

| | |
|---|---|
| Compliance with: ISO 4064-2014 | |
| Certification: | |
| • | OIML: R49 (International Organization for Legal Metrology) by a notified body or |
| • | Type examination certificate by a notified body under DIRECTIVE 2014/32/EU |

*Source: OIML R-49 ISO 4064-1:2014 - Water meters for cold potable*

### 6.3.11.4. Installation position:

#### 6.3.11.4.1. The sensor must always be completely full of water

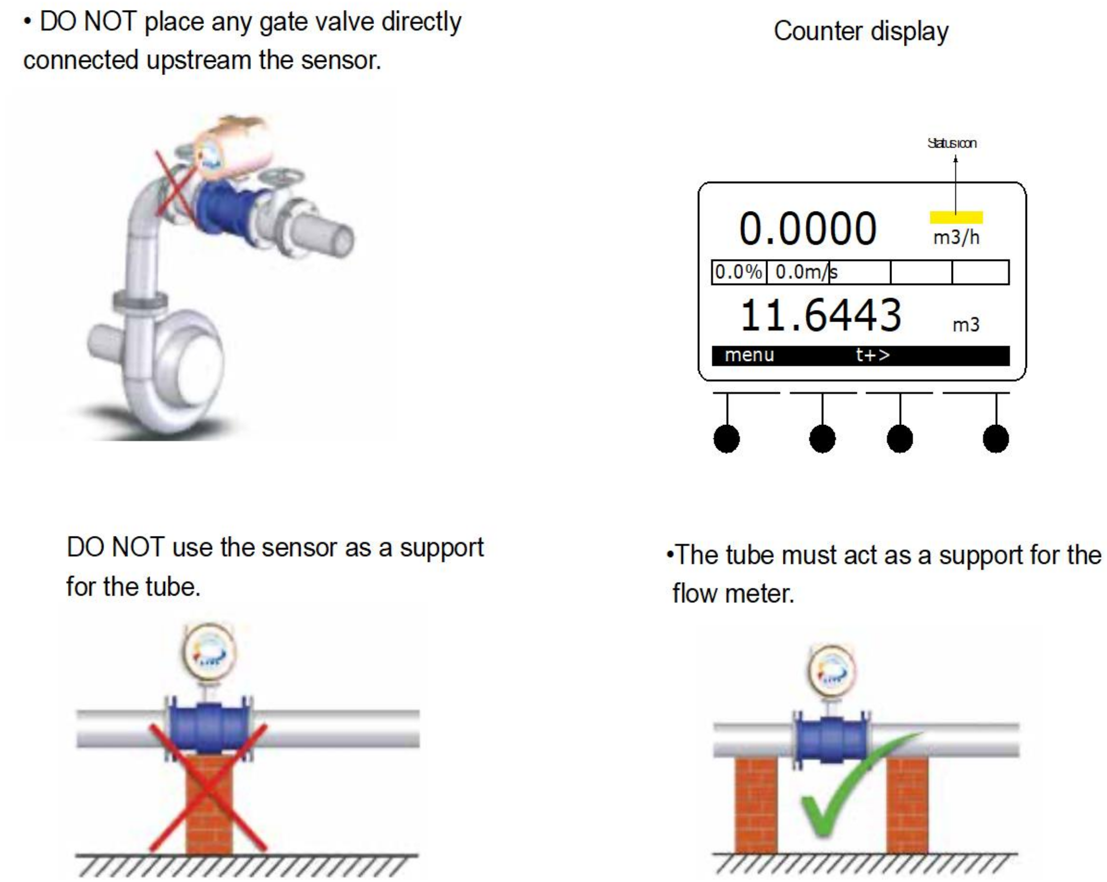



*Figure 6-14 Installation position of flow meters*

### 6.3.11.5. Maintenance of flowmeters

Because this is a smart type of water meter which has no moving part therefore, no specific maintenance is required except correct installation as mentioned above and general cleanliness. The manufacturer/supplier is bound to provide 10 years  dry battery warranty as per OIML R-49/ISO 4064-2014.

# 7. SAVING OF ENERGY THROUGH ENERGY AUDIT

## 7.1. INTRODUCTION

Energy is a very scarce resource, especially in developing and poor nations. Every day, the cost of electricity is increasing dramatically. Energy consumption from pumping infrastructure, which can range from 40% to 70% of the entire cost of operating and maintaining water systems, is frequently high. Therefore, it is impossible to overestimate the significance of energy conservation. It is vital to identify and put into practice all practical energy-saving solutions in order to keep water rates as low as possible and to close the gap between the high cost of providing water and the price that customers can afford. Energy conservation is essential for the welfare of the nation because of the country's energy scarcity, which causes problems with low voltage, load shedding, and early equipment malfunctions.

The following energy-related negative scenarios are frequent in pumping installations:

- Energy consumption is higher than ideal due to a decline in pump efficiency
- The pump's operating point is away from its best efficiency point (B.E.P.).
- An increase in head loss in the pumping system results in energy loss, such as strainer clogging, encrustation in column pipes, and encrustation in the pumping main.
- Choosing sluice valves, butterfly valves, reflux valves, column pipes, drop pipes, etc. in pumping installations that are of an uneconomical diameter.
- Energy loss caused by electrical equipment operating at low voltage or with a low power factor.

Eliminating such inefficient processes and energy waste is crucial to lower energy expenses. Therefore, it is crucial to identify each of these defects and their primary causes, which can be accomplished by carrying out a thorough energy audit.

So, the following strategy must be used in energy management.

i) Perform a comprehensive and in-depth energy audit that includes study and evaluation of all equipment, processes, and system components that have an impact on energy use. This will help to find opportunities for energy cost reduction.

ii) Put energy-saving measures into action.

The term "energy audit" refers to a review of the energy usage that has been invoiced, as well as how the installation's numerous units and sub-units use the energy, whether any of it is lost due to inefficiency, elevated hydraulic or power losses, etc., and the identification of corrective and remedial actions.

Energy conservation is a topic that is addressed by a number of organizations, and these organizations have made significant contributions to the development of energy saving techniques. About the reported measures is covered in this section. The steps, if taken, can reduce energy costs by up to 10% depending on the installation type and degree of energy saving.

## 7.2. ENERGY AUDIT SCOPE

The following discusses the suggested approach and the audit's scope. The suggested frequency of energy audits is every year for large installations, every two years for medium installations; and every three years, for small installations.

### 7.2.1. Energy Audit: Collection OF Data of pumping UNITS

The following procedures, methods, and actions are part of an energy audit:

- Find out the costs of energy and estimate the cost of running the pump.

- per $m^3$ power consumption.
- Document operating times and measure or note the actual flow rate with time to develop profiles of when the pump operates.
- Note or determine the design system maximum and variation in flow rate and system head.
- Obtain flow rate versus system head characteristic curves (if available) from the pump manufacturers to assess the pumping system design and operating points.

### 7.2.2. Survey of Present Condition:

Noting Present condition is necessary for energy audit therefore, following may be noted:

- Excessive water leakage from seals.
- Inspect power cables for any overheating, cracks or damage.
- Inspect Motor & MCU for checking the condition of components and check overheating with infrared thermometer and check loose connections.
- Measure Temperature at motor Bearings.
- Condition of pumping machinery, defective parts and visible shortcomings.

### 7.2.3. Note Information from Performance Curves & Pump Name Plate

*Table 7-1 Energy Audit information*

| Unit | Parameter | Value/detail |
|---|---|---|
| **Pump** | Site/Location | |
| | Pump # | |
| | Year of installation | |
| | Model type | |
| | Design Flow in m3/h | |
| | Design head in m | |
| | Design power in KW | |
| | Original Efficiency | |
| **Electric motor** | Rated output of Electric motor KW | |
| | Rated Current | |
| | Rated voltage | |
| | Motor efficiency | |

### 7.2.4. Energy Audit: Measure Current Operating Parameters of Pumping Machinery

*Table 7-2 Energy Audit current operating parameters*

| S-No | Parameter | Measured Value | How to measure? |
|---|---|---|---|
| 1 | Flow rate in m3/h | | Bulk Flow meter or Portable ultrasonic flow meter |
| 2 | Discharge pressure in psi or bar or mpa | | Pressure gauge at delivery pipe |
| 3 | Static suction head( plus draw down if tubewell) | | By water level meter |
| 4 | Voltage in volts(v) | | By clamp meter |
| 5 | Current in amperes(A) | | By clamp meter |
| 6 | Power factor | | By power analyzer |
| 7 | Power consumed by motor/pump | | By power analyzer |
| 8 | Motor Vibration | | Vibration measurement meter |
| 9 | Energy meter | | Note current reading |
| 10 | Electricity bill | | Note units and bill charged |

### 7.2.5. Calculate total head of tube well pump

Total suction head (static water kevel + Draw down) + pressure gauge reading at delivery of the Tube well + frictional losses (normally very less because delivery pipes are not very long)

### 7.2.6. Pump efficiency measurement

Simple formula for Pump efficiency($\eta_p$) =p*G*Q*H/(KW*60,000)

Q in m3/min, Head (H) in meters, p =Density of water 1000 kg/$m^3$

### 7.2.7. Sum up the information & compare the tube well existing and manufacturer's parameters

*Table 7-3 Energy Audit sum up information*

| Parameters | Original parameters | Current parameters |
|---|---|---|
| Pump head | | |
| Pump power | | |
| Flow | | |
| Efficiency | | |

### 7.2.8. Energy Audit Record sheet for each location/pump

*Table 7-4 Energy Audit record sheet*

| Location of pump------------------- | | | | |
|---|---|---|---|---|
| **Date** | | **Time** | | |
| **Year of installation** | | | | |
| **Pump details** | | Manufacturer ------ | | Model/Type |
| | | Design capacity | | Design head |
| | | | | Actual head at commissioning |
| **Motor details** | | Manufacturer | | Rated output ------- |
| | | Rated voltage 400 | | Actual power consumed at commissioning |
| | | PF-------- | | Rated current ----A |
| **S-No** | **Parameter** | **unit** | **Measured value** | **Remarks** |
| 1 | Flow rate | m3/h | | Bulk flow meter or Utrasonic meter |
| | Duty hours | hrs | | Log book |
| 2 | Total flow in a month | m3 | | Flow rate*hrs |
| 3 | Motor input power | KW | | From energy bill |
| | Total units consumed as per working hrs | | Motor KW*working hours | |
| | From bill Units charged Regular units plus peak | | | From energy bill |
| 4 | Total bill charged (RS) | | | From energy bill |
| 5 | Average Power consumed | kWh/m3 | | |
| 6 | Average Power cost | PKR/m3 | | |
| Observations: | | | | |

### 7.2.9. Energy Audit of tube wells can help in improving of efficiency

- After comparing with original values if we found that Pump flow rate & pressure is reduced.it may be due to :

- Wearing out of impellers
- Impeller loose.
- Wear rings worn.
- It may be the indication of lowering of water table and strainer partially clogged.
- You can take remedial measures accordingly

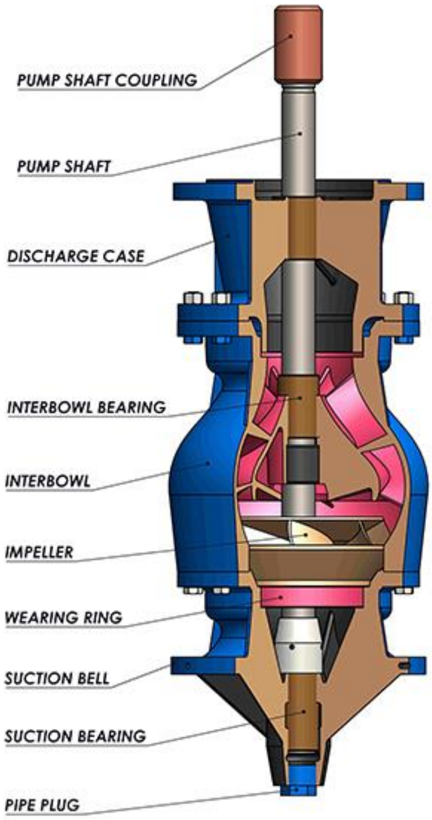



*Figure 7-1 Turbine pump bowl assembly*

### 7.2.10. Example of analysis/findings report for a tubewell

- After comparing with original values we found that Pump flow rate reduced and head is increased and efficiency is reduced from 76% to 50%.
- It is also observed that pump is cavitating.
- As Pump is running out of minimum recommended range of 70% of BEP therefore, we understand that more likely reasons may be:
- Lowering of water table over the years causing excessive head.
- Excessive clogging of strainer
- Cavitation may have resulted in wearing out of impellers, damaged bearings and other parts .

### 7.2.11. Remedial measures

- Tube well log will indicate the possibility of adding one vertical shaft to lower the pump position.
- The tube well bore may be rehabilitated to get the water table raised in case of incrustation by bacteria and chemicals on strainer:

- Physical cleaning with brush
- Chemical cleaning
- A small capacity pump may be installed and tried for operation within recommended range if above rehabilitation efforts are not proved fruitful.

### 7.2.12. Summary of Energy Audit

A summary of each audit may be prepared as below for your record:

*Table 7-5 Summary of Energy Audit*

| Name of Pump /Pump station | Pump number | Existing efficiency | Proposed efficiency | Average Power consumed kWh/m3 | Estimated Savings If efficiency improved | Recommendations | Remarks |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

## 7.3. FOR ENERGY CONSERVATION

### 7.3.1. Increasing the Power Factor

A power factor of 0.8 for example, indicates that only 80% of power supplied to your motor is being used effectively and 20% is being wasted.

- For example if a motor of 50 KW has 0.8 power factor, it will draw current as I=50x1000/(1.732 x400 x0.8)=90.2 A
- But if power factor is 0.9 the motor will draw current as 80.2 A (above formula).
- So 10 A current is reduced by improving PF from 0.8 to 0.9
- Formula for PF=KW/KVA, you can calculate the KVA by formula; KVA=√3x V x I

Automatic power factor correction (APFC) with the appropriate contactors and capacitor banks must be supplied in the panel in order to increase PF to 0.98. The APFC must be installed on both portions of the panel in order to achieve PF correction in both sections of the panel even while the two transformers are operating partially loaded and in parallel.

**(a) L.P.F Penalty:**

Average power factor of a consumer in a month shall not be less than 90%, in case of below 90%, consumer shall pay a penalty and that penalty will be 2% increase in the fixed charges of that month corresponding to 1% decreased in the power factor below 90%

L.P.F penalty is as:=2xMDI Charged in that month x Rate of MDI x (0.9 - Charged P.F)

### 7.3.2. Avoid oversizing the pump and motor

- Pumps, are typically oversized by **20-30%**. As a higher performance in terms of flow and pressure requires more power from the motor, an oversized pump can result in unnecessary energy consumption.
- A pump is generally considered to be oversized when it is not operated within 20 per cent of its Best Efficiency Point (BEP).
- Oversized motors can also contribute to reduce the energy efficiency of the system

**(a) Identifying oversized pump**

- If there is excessive flow noise
- If bearings and seals need frequent replacement
- It has intermittent operation, such as pump cycling

### 7.3.3. Air in pipelines can reduce the efficiency

Air in pipelines can reduce the efficiency of the pumping system. The air trapped at the high points of the system blocks flow, increasing the pressure head and thus the energy required for flow to occur.

### 7.3.4. Improvements in the electrical motor working

- **Over-Heating**

  Around 55% of insulating failures in motors occur due to overheating caused by poor power quality (low voltage), or a high temperature operating environment. Low voltage causes high current & overheating of motor

- **Contamination**

  Contamination **from dust, dirt and chemicals** is one of the leading causes of motor failure. Foreign bodies can dent bearing raceways and balls

- **Vibration**

  The motor positioned on an uneven or unstable surface often causes vibration. Vibration can also be a result of loose bearings, misalignment, or corrosion.

### 7.3.5. Carry out maintenance

- Undertaking routine maintenance can also reduce energy consumption.
- The replacement impeller is vital, as increased wear increases leakage and therefore the pump efficiency decreases.
- Check for seal leaks on a regular basis.
- Check pump vibration periodically to ensure that it is not excessive.
- Partially closed valve or some other obstruction in the discharge line may be cleared
- Ruptured suction line may be repaired
- Clogged impeller may be cleared
- Excessive suction lift may be reduced

### 7.3.6. Avoid wrong sizing of delivery pipe

- Discharge diameter can be calculated by the following formula.
- D in mm =146 ×√Q/V
- Q: Discharge Quantity (m3/min)
- V: Flow Velocity (m/s), V is generally kept from 1.5 to 2.5m/s
- If you choose more velocity, the diameter will be less. It means excessive frictional head losses will be generated causing decrease in efficiency
- Delivery pipe size is often given by the manufacturer in the pump performance curves also

### 7.3.7. Controlling flow of an oversized pump with throttle valve is not recommended

**Throttle Valves:** Throttle valves provide flow control in two ways: by increasing the upstream backpressure, which reduces pump flow, and by directly dissipating fluid energy. By increasing the backpressure on a pump, throttle valves make a **pumping system less efficient.**

### 7.3.8. Impeller trimming: Cost effective solution to control oversizing

- If a pump is oversized, trimming the impeller is a relatively cost-effective way of reducing the pressure and flow that is produced.
- Whilst trimming the impeller is much more energy efficient than using a throttling valve to achieve the required duty, as an impeller is shaved, the clearances between it and the casing get larger, making it less efficient than a full-sized impeller. For that reason, variable speed drives are often the preferred choice when it comes to energy efficiency.
- it should be limited to about 75 per cent of the pump's maximum impeller diameter, and as the impeller is shaved, the clearances between it and the casing become larger, resulting in greater flow recirculation and reduced pumping efficiency if it is shaved excessively.

#### 7.3.8.1. Impeller Trimming means like choosing small dia impeller

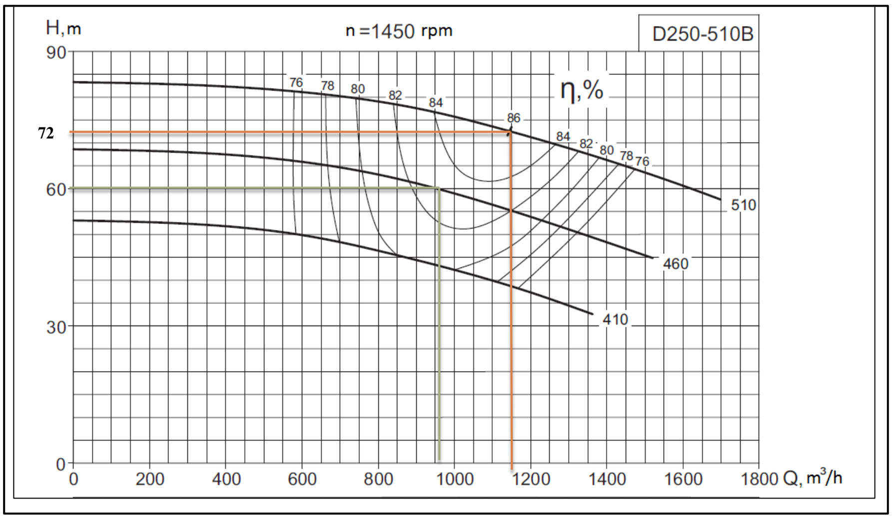



*Figure 7-2 Pump curve*

### 7.3.9. Changing old and Inefficient Pumps

Because of the anomalous degradation in the pump, it is occasionally seen that the pump efficiency can decrease by 15% to 20% over time and cannot be increased even after wearing rings are changed and the pump set is overhauled. To stop the massive energy wastage in this situation, the od and inefficient pump must be replaced. As a rule of thumb, when a pump's efficiency drops by more than 20% from its rated value, it is about time to change the pump set. In

Typical lifespans for different types of pumps are given below:

- 15 to 20 years for centrifugal pumps
- 15 years for Vertical Turbine Pumps

### 7.3.10. Replacement of defective Energy meters

Defective energy meters are a major source of excessive electricity bills. Concerned Distribution Power Company may be approached to replace defective energy meter as soon as it is identified because they charge average bills on all such meters.

### 7.3.11. Take reading of each connection personally and keep record

Coordinate with Energy Company to note reading of each energy meter jointly each month and compare the consumed units with calculated units as per operational hours and average power (KW) consumed of each Tube well. In this way you will be able to contest with Power Company about any incorrect electricity bill. For guidance various related terms are described below:

**(a) Units calculation**

In case of 40 HP motor, runs 12 hours per day. The calculation of units/month are as:

01 HP = 0.746 KW

40 HP = 40 x 0.746 = 30 KW

Per Day Units = Load x working hours

= 30 x 12 = 360 units (KWh)

These units are at full load, whereas actual units depend upon running load and working hours.

**(b) Tariff**

**D-1- Scarp Tariff/Agricultural**: - If applicable to any installation

- Rate of D-I tariff is less as compared to other tariffs.
- B-I, B-2 & B-3 – Industrial tariffs are applied on disposals stations, Lift stations and depend upon installed load.
- B-1 tariff is applied up to 40 KW load
- B-2 tariff is applied above 40 KW to 500 KW load
- B-3 tariff is applied above 500 KW to 5000 KW load

**(C) ELECTRIC LOADS**

There are three kinds of electric load and has major role in billing.

**i- Sanctioned Load:-**

- The load applied by Consumer and approved / sanctioned by Power Company is known as sanctioned load and its unit is KW.

**ii- Installed Load.**

- The load installed at site is known as the installed load e.g 40 BHP motor plus lights
- 40 BHP=40x0.746=111.9KW=30KW
- At disposal/lift station installed load is mostly more than the sanctioned load due to the reason that extra load is installed as a backup.
- At tube well installed load should not more than the sanctioned load.

**iii- Running Load.**

- The load actually runs the system is called the running load/ Shaft Load.

**Maximum Demand Indicator (MDI):**

- MDI stands for maximum demand indicator and it should not be more than the sanction load. MDI Meter noted that load, which runs half an hour continuously of that month.

**(d)Load Factor: -**

- load factor can be calculated by the following formula:
- Load Factor = <u>Actual units Billed*100</u>
- 730xload in KW
- where 730 = average working hours in a month
- In case of 30 KW (40 HP) motor and 12000 units/Month, the load factor will be as:

- Load factor = $\frac{12000 * 100}{730 * 30}$ = 55%

### 7.3.12. Avoid operating any pump on a low head or high head than designed for the pump

Operating pumps on low head than design results in excessive power consumed because mostly pumps run away from BEP at less efficiency.

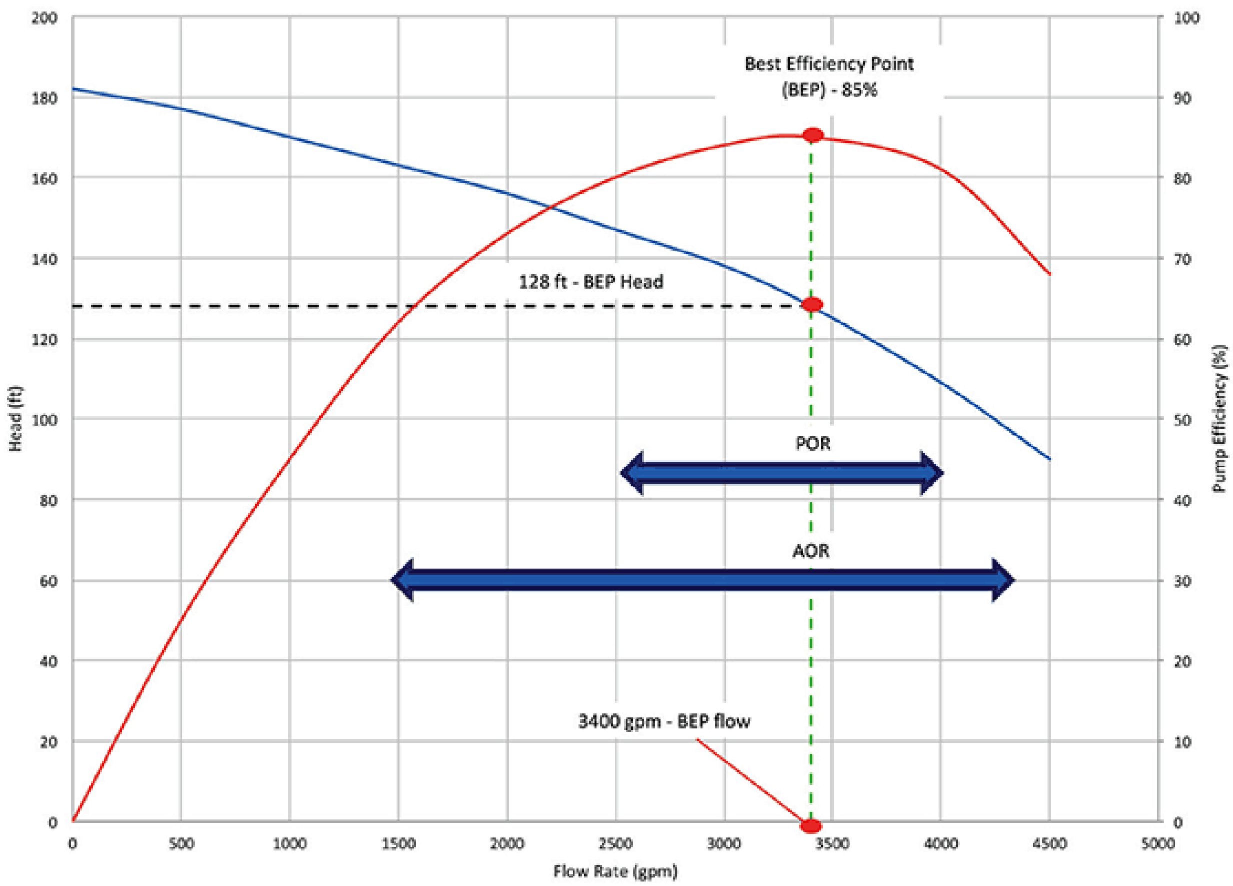



*Figure 7-3 Pump curve preferred operating region*

- A pump operating off the right of the curve (more than 120%) is cavitating.
- The shaft rattles; packing is worn; bearings are destroyed by hammering and shafts are bent. Pumps will get hot and cavitation will erode the impeller metal.
- This may be the case if you install high head pump on a very low head out of BEP
- When you operate pump more than 30% out of the BEP on left side meaning that now head is too much and flow is less. Consequently, efficiency is less and pump is cavitating.

## 7.4. ENERGY AUDIT EQUIPMENT

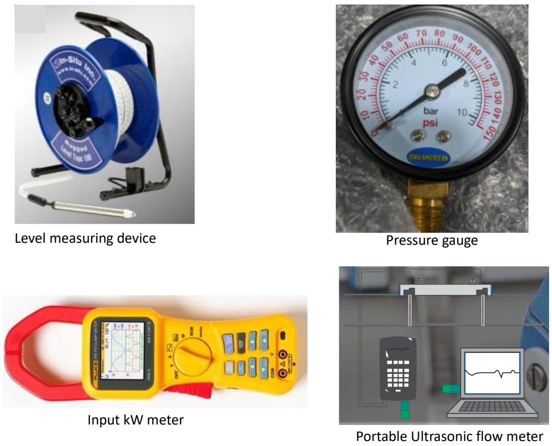



*Figure 7-4 Energy Audit equipment*

Energy analyzer is also very useful in measuring PF and power taken by the motor. May also be added if a MC can afford it.

# 8. REDUCTION OF UNACCOUNTED-FOR WATER

## 8.1. WHAT IS NRW?

Facing ever-increasing urban populations and expanding service areas, many water utilities in Asia and the Pacific continue to struggle with providing clean drinking water to their consumers. Common water supply problems in Asian cities are related to the sources and use of raw water, intermittent supply, and the quality of tap water at the consumer's end.

One of the major challenges facing water utilities is the high level of water loss in distribution networks. If a large proportion of water that is supplied is lost, meeting consumer demands is much more difficult. Since this water yields no revenue, heavy losses also make it harder to keep water tariffs at a reasonable and affordable level. This situation is common in many Asian cities. "Non-Revenue Water" (NRW)—defined as the difference between the amount of water put into the distribution system and the amount of water billed to consumers—averages 35% in the region's cities and can reach much higher levels.

NRW is a good indicator for water utility performance; high levels of NRW typically indicate a poorly managed water utility. In addition, published NRW data are often problematic, suspicious, inaccurate, or provide only partial information. Some utilities invent "creative" definitions of NRW, use wrong or misleading performance indicators, and fail to quote important information, such as average pressure and supply time.

Conversely, successful utilities actively address NRW by controlling physical losses, ensuring customer meter accuracy and making all efforts to keep the number of illegal connections within limits.

*Figure 8-1 Water Leakage*

Physical losses are the main problem

Taking these measures can boost revenue by increasing the amount of water that can be billed while reducing wastage of the product. This increases profitability and improves the return on investment. With larger profits, the utility can then reinvest retained earnings and improve its productivity.

While the benefits of reducing NRW are well known, decades of effort have not delivered much improvement in the developing world. While there are many explanations and excuses, much of the failure is due to underestimating the technical difficulties and complexity of NRW management, along with the potential benefits of taking action.

For many cities, reducing NRW should be the first option to pursue when addressing low service coverage levels and increased demand for piped water supply. Expanding water networks without addressing water losses will only lead to a cycle of waste and inefficiency. Also, a high rate of NRW is closely related to poor energy efficiency, since water transported in networks is "loaded" with energy through the distribution and treatment processes.

*Figure 8-2 Small leaks go undetected*

In most water utilities in Asia, the water loss levels are so excessively high that they should at least be reduced by 50% before any economic analysis is needed.

### 8.1.1. Non-Revenue Water and the Urban Poor

The urban poor are often blamed for high levels of NRW, especially due to illegal connections. On the other hand, the poor are significantly affected by high water losses. While theft of water in low-income communities is certainly a reality in many Asian cities, its impact must be put in the proper perspective.

The volume of water that is illegally consumed by a poor household is normally quite small, because of the lack of washing machines, flush toilets, garden irrigation, etc. Furthermore, this low level of consumption would nearly always be in the lowest tariff category (if such category exists). Therefore, the financial impact is even less than the volumetric impact. Experience in many countries shows that water theft by higher income households, and commercial and industrial users can be much more of a problem.

### 8.1.2. Benefits of Water Auditing and Leak Detection

Water audits and leak-detection programs can have a significant positive impact, such as the following:

**(a) Reduction in Water Losses**

A leak repair program must start with a water audit and leak identification. The utility will save money by fixing the leak because it will use less energy to distribute water and use fewer chemicals to purify it.

**(b) Financial Stability**

A water audit and leak detection program can raise revenues from undercharged consumers, cut the overall cost of wholesale supplies, and lower treatment and pumping costs.

**(c) Better Understanding of the Distribution System**

Distribution staff members become familiar with the distribution system, including where the main and valves are located, during a water audit. This comfort with the situation enables the utility to react to situations like main breakage.

**(d) Making Better Use of Existing Supplies**

Stretching already-existing supplies to meet rising demand is made easier by reducing water losses. Construction of additional water facilities, such as new sources, reservoirs, or treatment facilities, may be delayed as a result.

**(e) Protecting property and the public's health**

A water distribution system's upkeep can assist lower the risk of property damage and protect people's health and safety.

**(f) Strengthened Public Relations**

The public appreciates that the water supply system is maintained. Teams working in the field to audit water usage, find leaks, or perform repairs and maintenance give visual proof that the system is being maintained.

**(g) Reduced Legal Liability**

Water audits and leaks detection assist in shielding the MC from high-cost legal actions by safeguarding public health and property as well as by providing precise information about the distribution system.

### 8.1.3. Main components of NRW

NRW comprises three components as follows:

**Physical (or real) losses** comprise leakage from all parts of the system and overflows at the utility's reservoirs. They are caused by poor operations and maintenance, the lack of active leakage control, and poor quality of underground assets.

**Commercial (or apparent) losses** are caused by customer meter under- registration, data handling errors, and theft of water in various forms.

**Unbilled authorized consumption** includes water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups.

Most water utilities do not have adequate monitoring systems for assessing water losses, and many countries lack national reporting systems that collect and consolidate information on water utility performance. The result is that data on NRW is usually not readily available. Even when data is available, it is not always reliable, as some poorly performing utilities are known to practice "window dressing" in an attempt to conceal the extent of their own inefficiency.

## 8.2. NON-REVENUE WATER IMPACT ON WATER UTILITY EFFICIENCY

No business can survive for long if it loses a significant portion of its marketable product, but that is exactly what is happening with many water utilities. High levels of NRW lead to low levels of efficiency. When a utility's product (treated water) is lost, water collection, treatment and distribution costs increase, water sales decrease, and substantial capital expenditure programs are often promoted to meet the ever-increasing demand. In short, the utility enters into a vicious cycle that does not address the core problem.

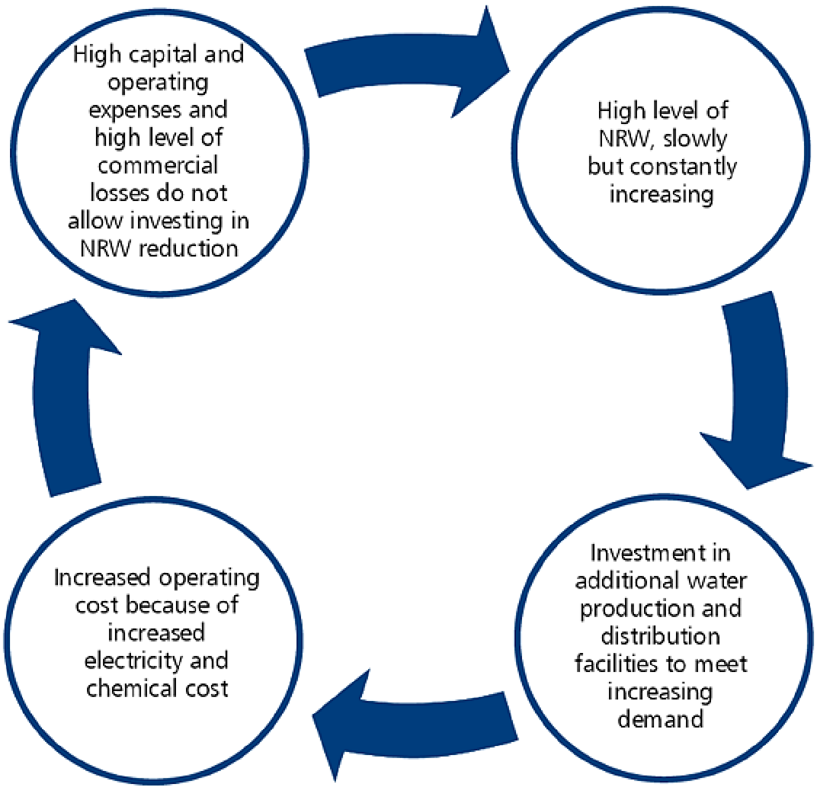



*Figure 8-3 The Vicious NRW Cycle*

## 8.3. THE IMPORTANCE OF ESTABLISHING A WATER BALANCE

The first step in reducing NRW is to establish current levels of water losses through a water audit.

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Commercial Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Physical Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Metering</td></tr>
</table>

Source: International Water Association.

*Figure 8-4 Water Balance*

The first step for any utility aiming to reduce water losses is to prepare a baseline to establish current levels of water losses. This is done by carrying out a water audit that leads to a water balance, which is a prerequisite for designing a NRW reduction strategy. This first step is critical, yet it is often overlooked in the development of many urban water supply projects.

### 8.3.1. Physical Losses

Real Losses refer to the volumes that are produced and not consumed such as leakage and tank overflow.

- Visible and invisible leaks in distribution networks
- Visible and invisible leaks in service connections
- Overflow of tanks and reservoirs
- Infiltration and discharge from tanks and reservoirs
- Reported leaks and unreported leaks

#### (a) Types of leaks

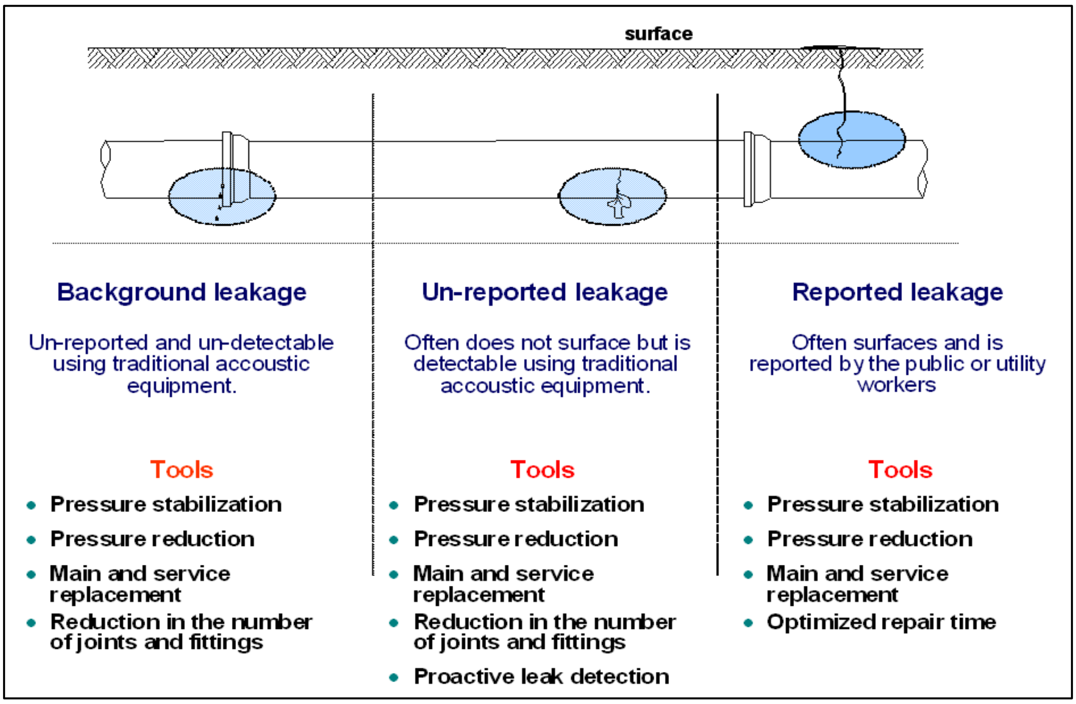



*Figure 8-5 Types of leaks*

### What You Should Know about Physical Losses?

Normally around 90% of water that is physically lost from leaks cannot be seen on the surface. These leaks might eventually become visible after many years, but until then, large volumes of water are lost every year. Sometimes, undetected leaks can be quite large, such as those that run directly into a sewer or a drain. Therefore, a water utility that does not practice a policy of efficient and intensive active leakage control will always have a high level of leakage, except if the infrastructure is new and/or in excellent condition.

In order to reduce the current level of physical losses, all four elements must be implemented as follows:

• Active leakage control must be introduced in order to detect all present and future leaks.

• Known leaks must be repaired as soon as possible to keep leak run times low, and good quality of the repairs will make the efforts sustainable (in poorly run water utilities, even visible leaks are often not repaired).

• In the long run, pipes must be rehabilitated or replaced using good quality materials and installation (asset management).

• Pressure management must be exercised, as explained below.

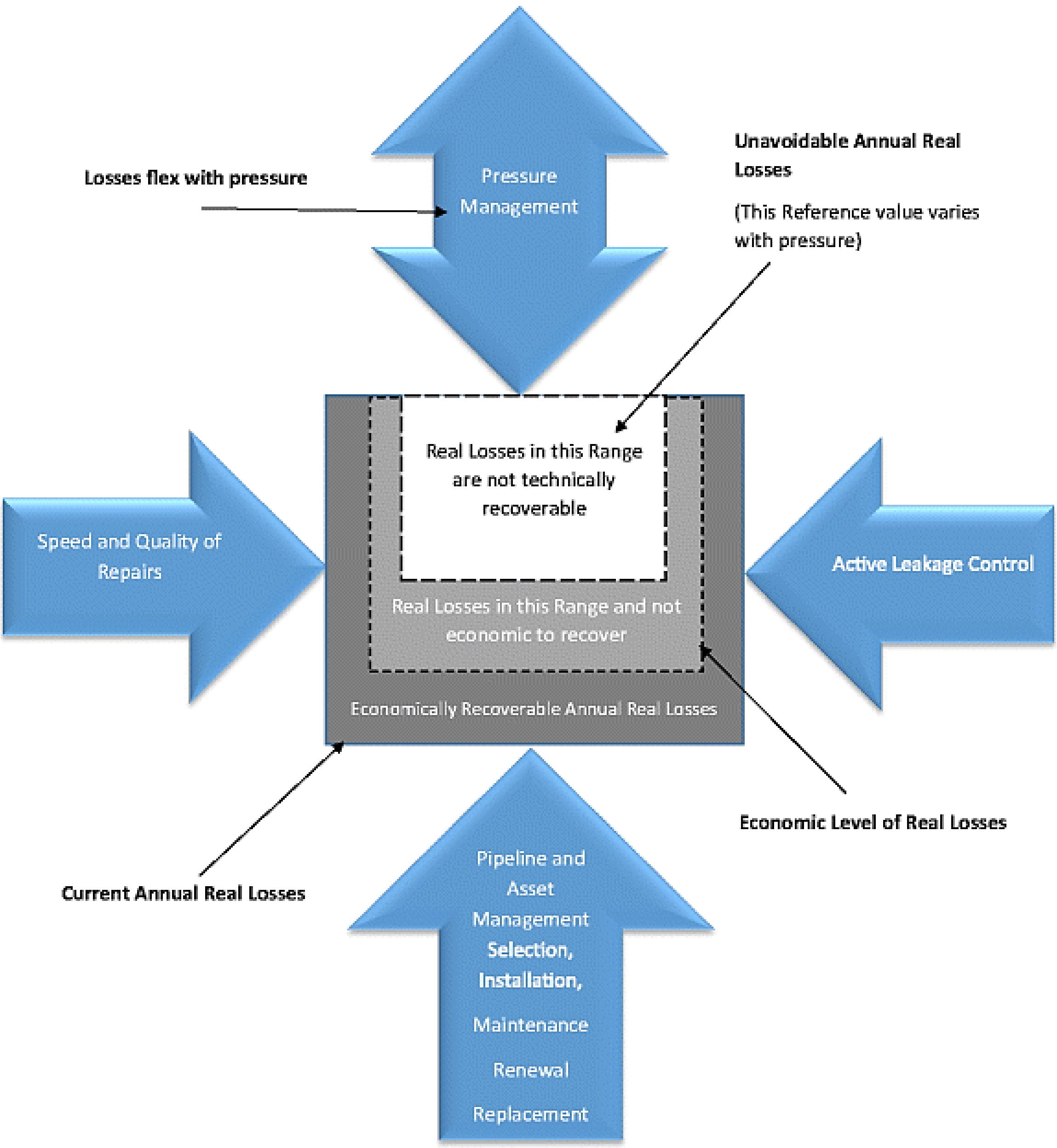



*Figure 8-6 The "Four Arrows Chart"*

While the first three elements are self-explanatory, the fourth (the only one represented by a bidirectional arrow) must be explained further. Leakage is directly related to pressure. The higher the pressure, the higher the volume of water lost from any given leak. Pressure leakage relationships are a complex issue, but a utility can assume a roughly linear relationship between the two. This means that when the pressure increases by 10%, the volume of leakage also increases by 10%. However, if pressure can be reduced, this will lead immediately to a leakage reduction—without repairing a single leak. Therefore, the arrow is bidirectional.

### 8.3.2. Leakage Monitoring and Detection

The following are the main tasks involved in distribution system leak detection:

#### Leak detection equipment

- Acoustic leak detector
- Metal pipe detector

- Flow meter
- Leak detection with helium gas

## (a) Acoustic method

*Figure 8-7 Acoustic method*

*Noise of water escaping, at pressure, from small orifices in a pipe*

Amplitude, frequency & attenuation depends upon:

- water pressure
- size and shape of orifice
- leak path
- pipe material
- pipe diameter

**Sounding valves and fittings**

Water leaks in underground, pressurized pipes may make many different sounds:

- "Hiss" or "Whoosh" from pipe vibration and orifice pressure reduction
- "Splashing" or "Babbling Brook" sounds from water flowing around the pipe
- Rapid "beating/thumping" sounds from water spray striking the wall of the soil cavity
- Small "clinking" sounds of stones and pebbles bouncing off the pipe

**What Factors Affect These Sounds?**

There are several factors that affect the loudness and the frequency range of the sounds made by water leaks transmitted on the pipes and transmitted to the surface of the ground:

- Water pressure in the pipe
- Pipe material and pipe diameter
- Soil type and soil compaction
- Depth of soil over the pipe
- Surface cover: grass, loose soil, asphalt, concrete slab, etc.

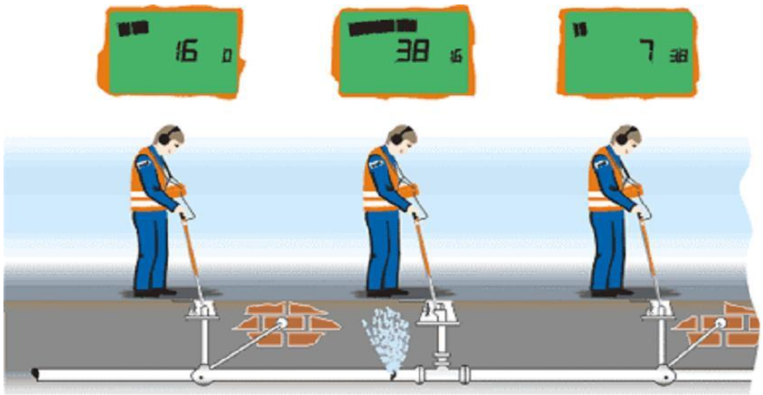



*Figure 8-8 Sounding valves*

### (B)Leak detection by helium gas

**Why use helium for leak testing?**

Being inert, helium is relatively safe to use (rather than hydrogen) and will not react with any of the materials within the part to be tested. In most helium leak testing applications, a mass spectrometer is used to detect helium. Although, it is also possible to use a residual gas analyzer. Helium leak testing can generally be between one thousand and one million times more sensitive than using pressure decay techniques.

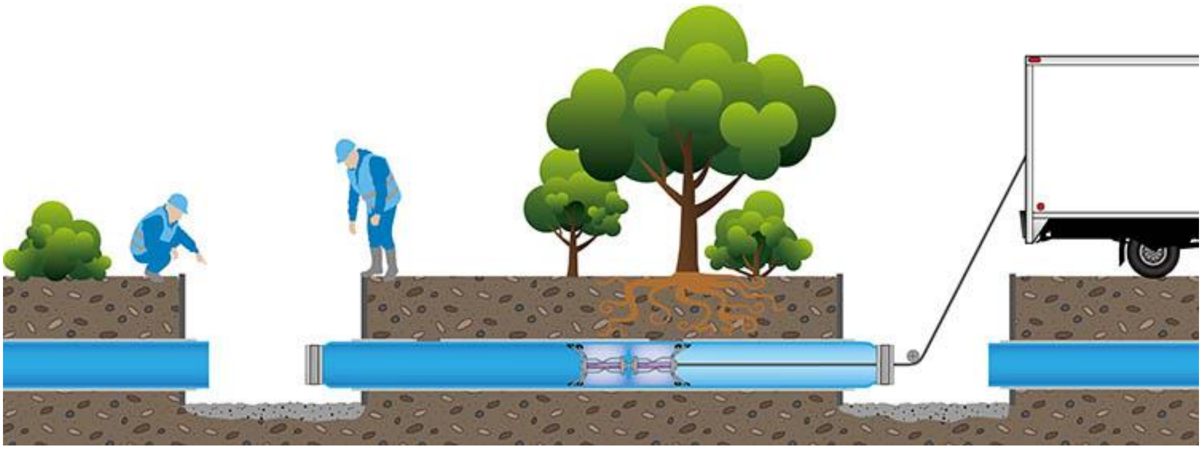


*Figure 8-9 Leak detection by helium gas*

Leak detection should be undertaken at night when the flow is minimum.

### What are the benefits of Helium Leak Testing?

Using this technique, you can leak test to find smaller leaks than with other test processes, using a largely temperature independent, dry technique. This should result in a longer product life.

Most tests use readily available Balloon Gas. On rare occasions, a certifiably pure gas can be used. On a safety note, please remember that bottled helium contains no oxygen and is therefore an asphyxiant. It is worth remembering that leakage is a flow of fluid from a higher pressure to a lower pressure through a fault in an assembly or manufactured part[14].

### 8.3.3. Planning and Gathering of Preliminary Data

The water distribution maps should be examined and revised. The quantity of service connections must be determined, and the precise positions of the connections must be marked on the road designs. The limits of the district and sub-district are appropriately set, taking into the quantity of service connections, the length of the mains, and the pressure points inside the main. In the designs, the precise locations and sizes of the valves and hydrants should be noted. The aforementioned actions will aid in planning the performance of leak detection work, fixing places for conducting pressure testing in intermittent water supply systems prior to beginning that work, or monitoring pressure and leak flow in the supply of water that is constant.

### 8.3.4. Commercial Losses

Commercial losses are nearly always less in volume than physical losses, but this does not mean that commercial loss reduction is any less important. Commercial loss reduction has the shortest possible payback time, as any action immediately results in an increase in billed volume and an increase in revenues.

Commercial losses consist of three main elements:

- customer meter under-registration;
- illegal connections and all other forms of water theft; and
- problems and errors in metering, data handling, and billing.

#### 8.3.4.1. Unbilled Authorized Consumption

It includes:

- Operational Use
- Cleaning of tanks and reservoirs
- Flushing of the distribution network
- Cleaning sanitation systems
- Fire fighting
- Analyzers and chlorinators
- Unbilled Free Consumption (example)
- Public fountains

#### 8.3.4.2. Apparent (Commercial) Losses

Apparent Losses refer to the volumes that are produced and consumed but not billed such as water meter under-registration or unauthorised consumption.

- Meter errors
- Error on estimated consumption
- Unauthorised consumption
- Data acquisition and transmittal errors

[14] https://www.tqc.co.uk/our-services/leak-testing/helium/guide-to-helium-leak-testing/

#### 8.3.4.3. Metering:

Minimizing customer meter under-registration requires substantial technical expertise, managerial skills, and upfront funding. Customer meter management should be undertaken holistically, best described by the term “integrated meter management.” In this effort, PMDFC has selected appropriate meter types and prepare tailored specifications.

Contributing to this problem is the lack of good quality meter testing facilities, especially when it comes to larger diameter meters, and the lack of experience in how to best utilize such facilities. This makes it easy for manufacturers to supply meters from second class quality manufacturing batches with little risk that the utility would ever find out.

Meters will help in controlling NRW:

- How much water is supplied and where does it go?
- How much water is consumed?
- How is consumption changing with time?
- A well-run integrated water meter management programme results in
- better decisions
- better planning
- better service

#### 8.3.4.4. Billing system issues:

The billing system is the only source of metered consumption data that can help determine the volume of NRW through an annual water audit. However, most billing systems are not designed to retain the integrity of consumption data. Rather, they are designed to deliver accurate bills to customers and correctly account for the bills. However, there are many day-to-day processes in operating a billing system that have the potential to corrupt the integrity of the consumption data, depending on the design of the particular system.

Issues that can affect consumption volumes include:

- meter reading practices
- handling of reversals of over-estimation
- processes used for dealing with complaints about high bills
- customer leaks
- estimation of consumption
- meter change-outs
- tracking inactive water accounts, and
- the processes for the identification and rectification of stuck meters.

## 8.4. WATER THEFT:

- While meter under-registration is more of a technical problem, water theft is a political and social issue. Reducing this part of commercial losses is neither technically difficult nor costly, but it requires making difficult and unpleasant managerial decisions that may be politically unpopular. The reason is that illegal connections are nearly always wrongly associated with only the urban poor and informal settlements. However, water theft by high-income households and commercial users, sometimes even large corporations, often accounts for sizable volumes of water lost and even higher losses of revenue.

In addition to illegal connections, other forms of water theft include:

- **meter tampering and meter bypasses,**
- **meter reader corruption, and**
- **illegal hydrant use**.
- Another common problem is "**inactive accounts**." In cases where a customer's contract has been terminated, the physical service connection, or at least the tapping point on the main, still exists and is easy to reconnect illegally. A stringent inactive account management and verification program can easily solve this problem.

## 8.5. ILLEGAL CONNECTIONS

- Efforts to address illegal connections by walk-through surveys and authorizing illegal connections by legitimizing them and adding them to the network may be a good solution. In Phnom Penh, the public utility was able to reduce NRW by 91% in 15 years through strong commitment and a comprehensive network replacement and physical loss reduction program. On top of that, simple but unique measures were taken to reduce commercial losses. For example, if a meter reader of an area did not, or could not, find an illegal connection, but one of his colleagues did, the colleague received a reward and the meter reader was penalized.
- The public may also be made aware of the problem of illegal connections. Those customers found to have illegal connections may be heavily penalized, and anyone who reports an illegal connection may be reward.
- Inspection teams may be set up to search for, find, and eliminate illegal connections. even one illegal connection[15].

## 8.6. INTERMITTENT SUPPLY

Intermittent supply of low-pressure water for few hours is a common problem in developing countries.

Meters and instruments for leak detection are useless at low pressure. In order to determine leak flow, pressure must be raised for a set period of time. The stop taps at the consumer's end and the boundary valves of the test areas are both closed in order to isolate the water mains that will be put through the test.

## 8.7. PRESSURE MANAGEMENT

It is also the only element that can shrink (or expand) the small box, which represents the minimum achievable volume of physical losses. In the past, pressure reduction was only considered in systems with excessively high pressures. Presently, pressure management is considered essential to sustain leakage reduction efforts, especially in deteriorated distribution networks with relatively low pressures. For example, in a system with an average pressure of only 15 m (not uncommon in Asia), a 3 m pressure increase (which will hardly be noticed) will increase the volume of leakage by 20%. In addition to having an immediate positive impact on the volume of water lost, pressure management will also dramatically reduce burst frequency and therefore extend the lifetime of assets and reduce repair and maintenance costs.

Pressure management in its simplest form requires zoning by elevation, but the trend is towards more sophisticated pressure management, where marginal pressure reductions and the avoidance of pressure fluctuations are the main objectives. This trend is relatively new and hence there is a substantial lack of understanding in water utilities

To be able to determine how much water is lost in specific parts of the network, the network must be split in hydraulically discrete zones and the inflow to these zones must then be measured. By computing the

[15] ADB: The Issues and Challenges of Reducing Non-Revenue Water

volume of leakage in each zone, leak detection specialists can better target their efforts. Clearly, the smaller the zone, the better the information and the efficiency of leak detection.

The smallest zones are called District Metered Areas (DMAs). A DMA is hydraulically discrete and ideally has only a single inflow point. The inflow and corresponding pressure are measured and monitored on a continuous basis. Ideally, when the entire distribution network is split into DMAs, the utility has several advantages. For instance:

- The volume of NRW (the difference between DMA inflow and billed volume) can be calculated on a monthly basis.
- The components of NRW (physical and commercial losses) can be quantified by analyzing flow and pressure data.
- Leak detection works can be prioritized.
- New pipe bursts can be identified immediately by monitoring the minimum night flow, and therefore awareness time will be reduced from several months to several days (or even less).
- When leakage is eliminated, utilities can better gauge the existence of illegal connections or other forms of water theft and can take action.

  Furthermore, DMAs can be helpful in managing pressure. 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 tradeoff. 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.

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 design irrespective of the size of the DMAs.

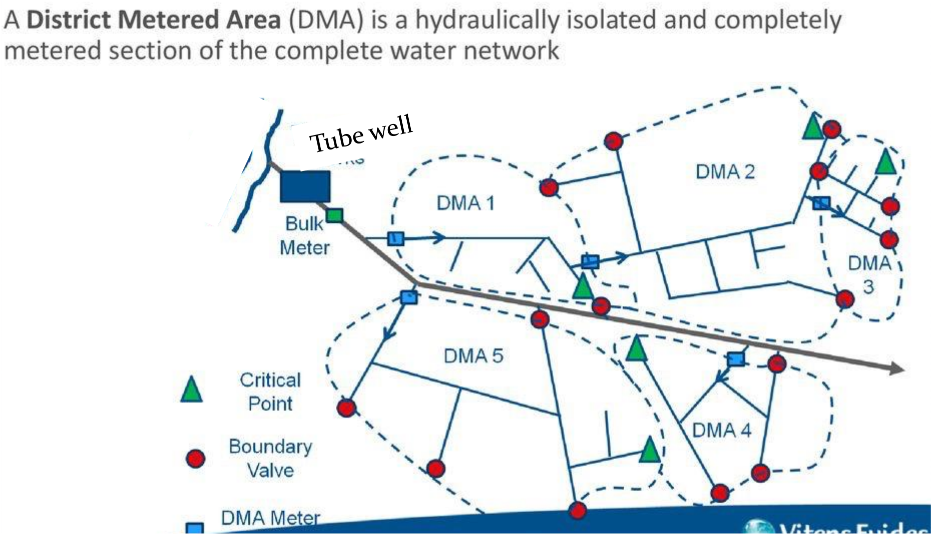



*Figure 8-10 DMA. Source IHE.Delft*

Water losses from larger diameter pipes can be quite significant, with predominantly low-pressure systems, where leaks will not come to the surface and remain unnoticed for many years. Leaks on large diameter pipes are always difficult to detect and often specialized equipment is required (e.g., inside pipe inspection and leak detection).

## 8.8. PREVENTION OF UFW IN CONSUMER CONNECTION

Galvanized iron pipes are typically used for domestic connections. These pipes eventually clog up from corrosion or tuberculation. Use of non-corrosive pipes for house service connections is recommended for this project which shall help in minimizing leakage.

## 8.9. PERFORMANCE INDICATORS

It is important to have standardized performance indicators, calculated according to a clearly defined methodology and using standard definitions.

Unfortunately, the most widely used performance indicator for water loss is still the percentage of NRW.[9] This is calculated by dividing the total volume of NRW by the total system input. Although this figure is important for a utility to measure, many practitioners tend to overlook its shortcomings in properly assessing water losses.

Published NRW data are in many cases problematic, suspicious, inaccurate, or provide only partial information. The percentage of NRW is completely unsuitable to compare water utilities with different consumption.

*Table 8-1 Recommended Performance Indicators for NRW*

| Performance Indicator | Measure | Notes |
|---|---|---|
| NRW | Liters/Service Connection/Day (w.s.p.)[16] | – A service connection is the small diameter pipe between the main pipe and location of water consumption (e.g., a building).<br>– The number of physical service connections is nearly always less than the number of customers, because one location can have multiple customers. |
| Physical Losses (basic) | Liters/Service Connection/Day (w.s.p.) | – Calculated by dividing the average daily volume of physical losses by the number of service connections and adjusting this value to the supply time.[17]<br>– For this indicator, it is important to take the supply time into account. |
| Physical Losses (advanced) | Infrastructure Leakage Index (ILI) | – ILI is the ratio between the current annual volume of physical losses (CARL)[18] and the minimum achievable annual volume of physical losses (UARL).[19]<br>As a truly meaningful inter-utility comparison, it indicates how well a distribution network is being managed and maintained at the current operating pressure. |
| Commercial Losses | Percentage of authorized consumption | – Both billed and unbilled should be measured. |

*Source: International Water Association.*

[16] w.s.p. stands for when the system is pressurized. This means that the indicator is adjusted as if the system would have continuous supply.

[17] For example, if the daily volume of physical losses divided by the number of service connections is 200/l/conn/d but the average supply time is 12 hours per day, the physical loss performance indicator is 400 l/conn/d (w.s.p) (400 = 200 / 12h × 24h). Only now it can be used for comparisons with a system with a different supply time.

[18] The corresponding IWA term is current annual volume of real losses (CARL).

[19] The corresponding IWA term is unavoidable annual volume of real losses (UARL).

# 9. CONSUMER WATER METERING

## 9.1. INTRODUCTION

- Water distribution system is an asset that has to be managed.
- Water meters are used to measure the movement of water and they cost money to install and maintain
- They also generate money through sales
- There is a legal imperative on municipalities to measure consumption in accordance with applicable standards

## 9.2. WHY WATER METERS?

- Equity
- Water efficiency and the environment
- Economic benefits
- System Management

### 9.2.1. Equity

- Consumers billed based on consumption
  Consumer can manage own consumption and thus cost of water
- Cross-subsidization done openly and fairly
- Free basic water

### 9.2.2. Water Efficiency and the Environment

- All water taken from the environment
- Natural water resources limited
- Meters reduce demand
- Meters required for loss management

### 9.2.3. Economic benefits

- Measured consumption is basis of water billing system
- Water meters are the cash registers of a municipality
- Better metering system = greater income

## 9.3. WATER METERING TECHNOLOGY SELECTED FOR THIS PROJECT

Multijet mechanical water meters have been recommended for this project.

Multiple jet (multijet) meters can be included in the group of velocity meters. They are mainly for domestic consumers, and sometimes in irrigation networks. Their operating principle is quite similar to the one featured in single jet meters. The difference lies in the fact that in multijet meters the water impacts the impeller in multiple points around its perimeter instead of doing it in a single point.

This method achieves a more balanced operation of the impeller, and in theory a greater durability of the meter. Additionally, multijet meters are supposed to behave better at low flowrates and have lower starting flowrates.

Just as with single jet meters, the impeller's angular velocity depends on the velocity of the water jets. Consequently, any modification affecting the flow or the entry velocity of water in the measuring chamber will alter the error curve.


*Figure 9-1 Parts of a multijet water meter*

The measuring chamber can be found inside the meter housing. However, contrary to what happens in single jet meters, the dimensions of the housing have no effect on the accuracy of the meter, allowing for more flexible tolerances in the manufacturing process.

In multiple jet meters, the adjustment of the error curve is carried out by means of a *regulating screw* which controls the amount of flow circulating through a by-pass circuit. The water can consequently go through the meter following two different paths, one through the impeller chamber and the other through the by-pass, which is regulated by the screw. The higher the by-pass flowrate, the smaller the volume that gets registered by the meter while the error curve is displaced towards negative errors (under-registration). When the by-pass is closed using the screw, the flowrate through the measuring chamber is increased and the error curve is displaced towards positive values. Quite often, multiple jet meters present a long *strainer*, and in some cases, another one covering the openings to the metering chamber. Obviously, a clogged entry strainer will not have any effect on the metrology of the meter.

*Figure 9-2 Water flow inside a multijet meter and an impeller*

### 9.3.1. Orientation:

- Multiple jet meters are usually designed to operate in a perfectly horizontal position. This set up reduces considerably the wear of the mobile parts.

  For Multi-jet dry type meter:

- The measuring impeller and register are magnetically coupled not directly connected. If the meter is installed vertically the distance between the two magnets will change therefore the connecting force of the two magnets will change and can possibly even intermittently lose total connection at higher velocities therefore causing a decrease in accuracy.

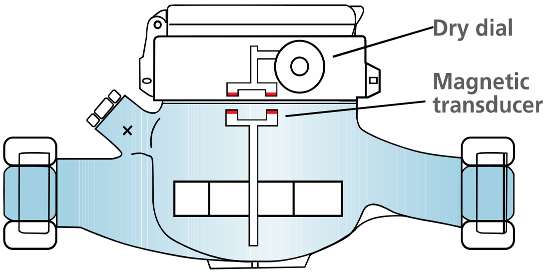



*Figure 9-3 Dry type water meter*

### 9.3.2. Governing International Metering Standards

These meters are manufactured as per OIML R-49-2013 and ISO-4064-2014 standards:

**(1) International Organization of Legal Metrology (OIML)**

OIML R49-1 (Metrological and technical requirements)

OIML R49-2 (Test methods)

OIML R49-3 (Test Report Format)

**(2) International Standards Organization (ISO)**

ISO 4064 Part 1 (Specifications)

ISO 4064 Part 2 (Installation Requirements)

ISO 4064 Part 3 (Test Methods and equipment)

### 9.3.3. Operating conditions of these water meters

- **Permanent flow rate-**$Q_3$
  Highest flow rate within the rated operating conditions at which the meter is to operate within the maximum permissible errors. For these meters, the Q3 is as below:

  *Size of meter: 15mm 20mm 25mm*

  *Q3 in m3/h: 2.5 4.0 6.3*

- **Overload flow rate-**$Q_4$
  Highest flow rate at which the meter is to operate for a short period of time within the maximum permissible errors, while maintaining its metrological performance when it is subsequently operating within the rated operating conditions. This should be 1.25 of the permanent flow rate.

- **transitional flow rate-**$Q_2$
  flow rate between the permanent flow rate and the minimum flow rate that divides the flow rate range into two zones, the upper flow rate zone and the lower flow rate zone, each characterized by its own maximum permissible errors

- **minimum flow rate-**$Q_1$
  lowest flow rate at which the meter is to operate within the maximum permissible errors .Q3/Q1=160 and Q1,the minimum flow is 15.6 liters/h for 15mm size.

- **maximum admissible temperature-MAT**
  maximum water temperature that a meter can withstand permanently, within its rated operating conditions, without deterioration of its metrological performance. It is $50^0$ C.

- **maximum admissible pressure-MAP**
  maximum internal pressure that a meter can withstand permanently, within its rated operating conditions, without deterioration of its metrological performance.It is 10 bar.

### 9.3.4. Accuracy class

- Accuracy class 1 designation shall be applied to all water meters with ***Q*3 ≥100 m3/h.**
- Accuracy class 2 designation shall be applied to all water meters with ***Q*3 < 100 m3/h**

### 9.3.5. Accuracy class 1 water meter

- The maximum permissible error for the upper flow rate zone (*Q*2 ≤ *Q* ≤ *Q*4) is ±1 %, for temperatures from 0.1 °C to 30 °C, and ±2 % for temperatures greater than 30 °C.
- The MPE for the lower flow rate zone (*Q*1 ≤ *Q* < *Q*2) is ±3 % regardless of the temperature range.
- This class is applicable for 1 cusec, 1.5 cusec and 2 cusec Tube wells.

### 9.3.6. Accuracy class 2 water meter

- The Multijet meters for this project have permanent flow less than 100 m3/h therefore, the maximum permissible error for the upper flow rate zone is ±3 % and lower flowrate zone is ±5 %. This is applicable for 0.5 cusec Tubewells flow and on all domestic water meters.

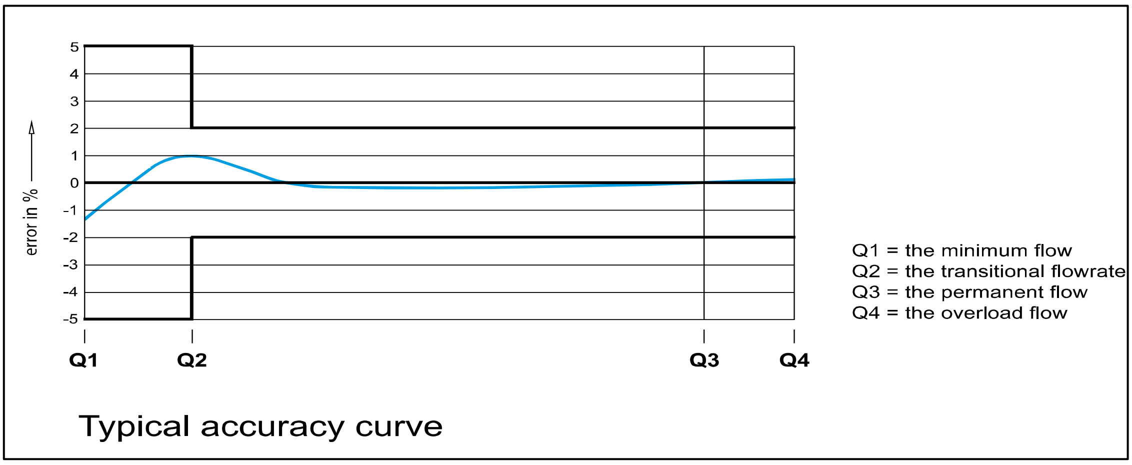



*Figure 9-4 Accuracy curve for a class 2, 50° C temperature class meter*

- For mechanical meters of half inch size we require minimum flow around 15-16 l/hr or even less and permanent flow around 2.5 M3/hr.

### 9.3.7. Marks and inscriptions

- A water meter shall be clearly and indelibly marked with the following information. These markings shall be visible without dismantling the water meter after the instrument has been placed on the market or put into use.
- a) Unit of measurement.
- b) Accuracy class, where it differs from accuracy class 2.
- c) Numerical value of *Q*3 and the ratio *Q*3/*Q*1: if the meter measures reverse flow and the values of *Q*3 and the ratios *Q*3/*Q*1 are different in the two directions, both values of *Q*3 and *Q*3/*Q*1 shall be inscribed;
- the direction of flow to which each pair of values refers shall be clear. The ratio *Q*3/*Q*1 may be expressed as R, e.g. “R160”.

- If the meter has different values of $Q3/Q1$ in horizontal and vertical positions, both values of $Q3/Q1$ shall be inscribed, and the orientation to which each value refers shall be clear.
- Type approval sign according to national regulations.
- e) Name or trademark of the manufacturer.
- f) Year of manufacture, the last two digits of the year of manufacture, or the month and year of manufacture.
- g) Serial number (as near as possible to the indicating device).
- h) Direction of flow, by means of an arrow (shown on both sides of the body or on one side only provided the direction of flow arrow is easily visible under all circumstances).
- i) Maximum admissible pressure (MAP)1) if it exceeds 1 MPa (10 bar) or 0.6 MPa (6 bar) for DN ≥ 500.
- j) Letter V or H, if the meter can only be operated in the vertical or horizontal position.

*Figure 9-5 Inscription on Multijet water meters*

### 9.3.8. The management of water meters

The management of water meters comprises several aspects which influence the overall performance of the metering system in a utility.

- Once the meter has been selected, the utility should make sure that the actual devices comply with the manufacturing specifications. Additionally, the appropriate steps should be taken to ensure that the installation of such meters is performed in such a way that their metrological characteristics are maintained.
- Once the meter is in place, management procedures should ensure that the evolution of the meters' performance is known, and the optimum renovation frequency is determined.

### 9.3.9. Maintenance of water meters

Maintenance of metering devices is often limited to:

- their periodic reading,
- cleaning of the filters and
- occasional replacement of certain elements (such as totalizers).

### 9.3.10. Maintaining Accuracy

- The accuracy of water and flow meters of all types depends on the actual flowrate circulating through them. In other words, the error of any water meter is not a constant, and it changes throughout the measuring range. For medium and high flowrates, the variations are minimum, but for low flowrates the error curve is steep until reaching the minimum flowrate. Consequently, it is impossible to determine the percentage of water that a meter will register correctly unless the circulating flowrates are also known. And for the same meter, depending on the characteristics of the end user, the consumption could be registered with a great accuracy or with a significant error.
- The wear of mobile components in the meter has a greater effect in the accuracy at low flowrates. Usually, this sort of consumption is originated in leaks and toilets inside the households or in intermediate storage tanks.
- Taking into account these facts, we can state that in order to assess the overall accuracy of all meters in a utility, it is necessary to have two sets of information. Firstly, the error curves of all types of installed meters, and secondly, the demand flowrates of all different types of users.
- The meters must be clustered according to their characteristics (model, technology, age, nominal diameter, nominal flowrate, accumulated volume, etc.). A distinction between domestic and non-domestic meters must also be made. While the first should be studied from a statistical point of view the second must be analyzed individually, especially for large diameters. In this project same type of water meters are being used.

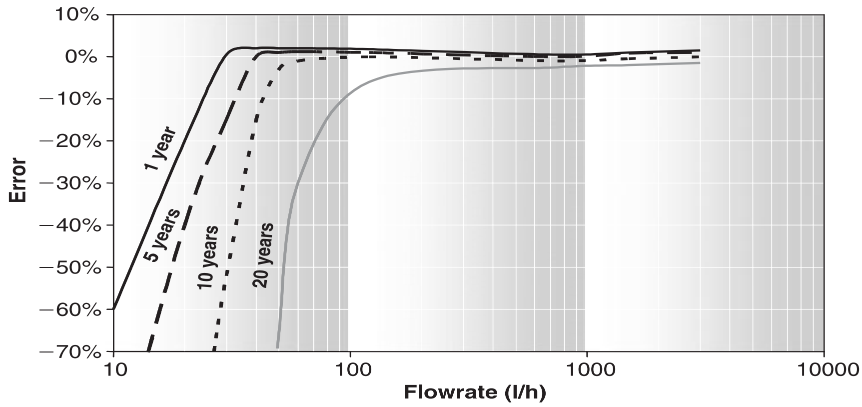



*Figure 9-6 typical decay of the error curve of a water meter*

## 9.3.11. Main factors affecting accuracy

### 9.3.11.1. Velocity profile distortions

- With a few notable exceptions, the metrological behaviour of all flow measuring devices is affected to some extent by the velocity distribution at the device inlet section, depending on the construction technology.
- Sensitivity to flow profile distortions of a Multijet meter is very low.

### 9.3.11.2. Suspended solids and limescale build-up

- The error curve of most meters, regardless of their technology, may be seriously affected by the quality of the water.
- Suspended particles can affect the filter of the meter therefore, cleaning after a reasonable time (1-2 years depending upon quality of water)
- In some other cases, an excessive build-up of limescale will influence the rotation of the impeller, even stopping it, leading to a significant under-registration

*Figure 9-7 partial clogging caused by suspended particles and Lime scale*

### 9.3.11.3. Installation position of the meter. Multi-jet dry type meter not suitable for vertical installation

- Quite often, the space available for the installation of a meter is minimal, leading to an incorrect position of the meter, making it almost impossible to read. This problem is not just limited to old households. Many new buildings lack the appropriate facilities to allow a proper installation of the meters. The problem can become worse when the meter is placed inside a reduced space (like a cabinet). Figure-9.7 shows the display of a meter at 45° angle.


*Figure 9-8 Display of a meter at 45° angle*

For Multi-jet dry type meter: The measuring impeller and register are magnetically coupled not directly connected.

*Figure 9-9 Meter for vertical installation*

If the meter is installed vertically the distance between the two magnets will change therefore the connecting force of the two magnets will change and can possibly even intermittently lose total connection at higher velocities therefore causing a decrease in accuracy.

- However, the problems from an inappropriate installation of a meter do not end with the difficulties to read. If the meter is installed on a certain inclination, the impeller will not rest appropriately and will increase the friction on the medium term. At low flowrates this greater friction will influence the measure.

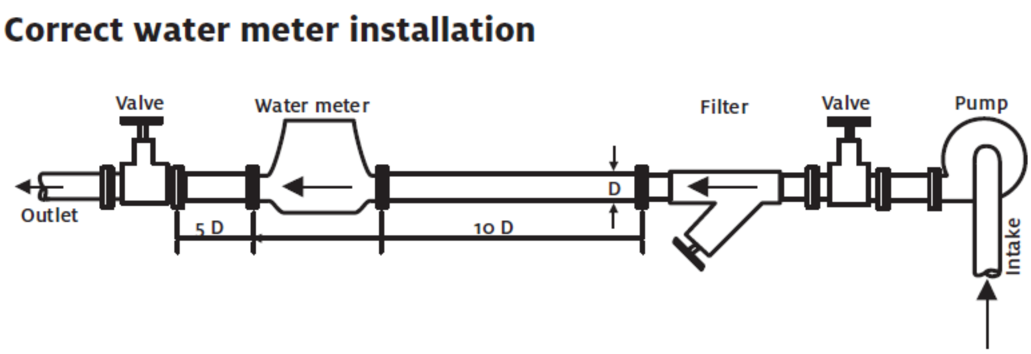



*Figure 9-10 Correct installation of a water meter*

## 9.4. FOGGING

Fogging of the totalizers display is a problem that usually occurs in humid areas when meters are installed outdoors at ground level. The accumulation of condensation in the display introduces additional difficulties in meter reading, and sometimes it even impedes it. Occasionally fogging will produce wrong readings and originate billing complaints from users.

This problem is addressed by choosing hermetically sealed extra- dry totalizer.

## 9.5. METER TAMPERING

The manipulation of meters by third parties in order to alter their accuracy will obvi- ously create problems in the measurement of consumption. There are many techniques used to tamper the meters. Quite obviously, as new fraud preventing systems are developed, new methods are created to neutralize them. **Some of the most common manipulation attempts are:**

- Introduction of a needle or similar object in the totalizer to block the motion of the gears. This element is periodically removed as the reading date approaches. Sometimes the foreign object is simply introduced before an important consumption is made (filling a pool, watering the garden).
- Introduction of foreign objects in the metering chamber to block the impeller. In order to perform this operation. the meter needs to be removed from the installation. If precincts are used at the time of installing the meter, the manipulation will be easily detected.
- Placement of powerful magnets to break the magnetic coupling of impeller and gears. New models incorporate protection rings which make this operation more difficult.
- Impacting strongly the meter at a certain point. Quite often, some models will significantly increase their error after such impact. Some models incorporate mechanisms to warn about this type of fraud.
- The reading mechanism is hermetically separated from the water flow chamber. The counter and indicator are placed in a sealed chamber.
- Dry dial meters often use magnetic transducers, and thus require special protection against magnetic fields that may interfere with the meter reading.

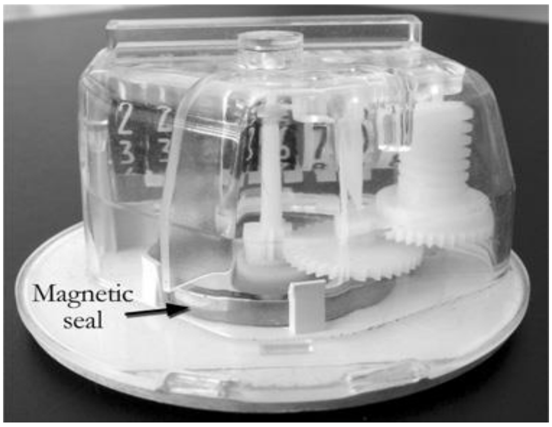



*Figure 9-11 Anti-fraud metallic seal of meter*

The picture also shows an anti-fraud metallic ring that prevents the manipulation by means of an external magnetic field.

- Temporary removal of the meter. Although it is quite easy to detect, often utilities will have problems proving that it was the user who altered the integrity of the meter.

**Prevention of Water Meter Tampering**

Modern meters are manufactured with certain protections to avoid magnetic tempering

- The register glass is made with a thick polymer glass, prohibiting any unauthorized stopping or tampering.
- Meters may have no magnetic coupling
- Protection rings may be incorporated to make this operation more difficult.
- Additional shroud is installed to prevent magnetic field

## 9.6. CALIBRATION, VERIFICATION, AND RE-CALIBRATION?

After water meters are manufactured, they need to be calibrated before they can be sold. Most flowmeter manufacturers have their own flowmeter calibration facilities to do this initial calibration.
All instrumentation, whether a flowmeter or another type of instrumentation, loses its accuracy over time due to wear and tear and other factors. To correct this loss in accuracy, instrumentation needs to be regularly tested or verified, and re-calibrated if necessary. The two most common methods of verifying a flowmeter are:

- Using a master meter
- Volumetric calibration.

### (a) Using a master meter

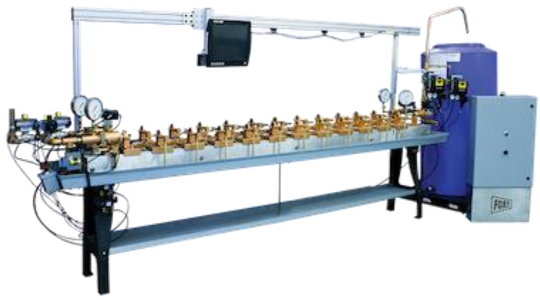


*Figure 9-12 Master meter test bench*

Calibrated master meter is installed in line with the meter being tested. The meter can be left in place for some time before comparing the volumes through the two meters. This is an accurate method. It is simply another meter, to verify and re-calibrate your flowmeter is a valid method, but only if the master meter itself has been recently calibrated, or verified and re-calibrated, through a process that can be traced back to some national or international standard.

**What are the most suitable master meters?**

Clamp-on ultrasonic water meters are considered in the industry as the most suitable and accurate master meters. There are two types: the “Doppler” type and the “transit time” type. Isobel van der Stoep recommends the “transit time” type for irrigation water. The Doppler type works best with very dirty water, with suspended solids, and is more suitable for the municipal environment.

- The pipe onto which the ultrasonic meter is clamped should be straight, without any valves or fittings that can cause disturbances, and with a constant diameter for a length of at least 10 times the pipe diameter upstream of the meter and at least 5 times the pipe diameter downstream of the meter.
- The pipe should not vibrate, because the vibration will interfere with the accuracy of the meter.

- The pipe should be preferably PVC or HDPE (high-density polyethylene) and not steel because steel pipes tend to rust, especially older ones. If there is rust, the ultrasonic meter will struggle to take a reading, because the air that gets trapped behind the rust layer in the pipe interrupts the ultrasonic signal.

**(b) Volumetric calibration**

*Figure 9-13 Volumetric type test bench*

It is an alternative method to calibrate a flowmeter. Volumetric calibration means that you push a known volume through your meter, test the meter readings against the known volume, and make the necessary adjustments. Volumetric calibration is the most accurate method, but it is time-consuming and difficult to do on-site. It is usually done in a laboratory.

It is recommended that permanent verification workshop or calibration lab may be set up.

When you buy a water meter, the manufacturer will recommend how often the meter must be verified, and re-calibrated if necessary.

For example, most manufacturers recommend that their meters be verified every 2-3 years because of the normal wear and tear of the pump impeller and the motor. If the water has a high sand content, it will be necessary to verify and re-calibrate every 1-2 years.

## 9.7. DETAILED METROLOGICAL SPECIFICATIONS

Their specs for multijet water meters for this project are given below:

*i. Size: 15mm to 25mm*

*ii. Accuracy: Class II*

*iii. Material: Brass / Non-ferrous Metal.*

*iv. Protection Class: IP-68*

*v. Ambient Temperature: +5$^{o}$ to 55$^{o}$ C*

*vi. Liquid Temperature: Up to 50$^{o}$ C*

*vii. working pressure: 1-10 bar*

*viii. Flow rate: Q3/Q1 = 160*

*ix. Maximum Flow rate (m3/hr) :*

*Q3 15mm 20mm 25mm*

*2.5 4.0 6.3*

*x. Installation:*

*a. Any direction*

## 9.8. TROUBLESHOOTING

*Table 9-1 Water Meter Troubleshooting*

| Sr. No. | Trouble | Cause | Remedy |
|---|---|---|---|
| 1. | Meter reads in reverse direction | Might have been installed in reverse direction | Check the arrow on the meterbody and install the meter properly, if necessary |
| 2. | Meter not recording | Impeller to register link broken | Remove the meter for servicingand repairs |
| 3. | Continuously moving pointer/digit rotates butno change in indicator | Pointer and drum link missing<br>Drum defect | Remove the meter for servicingand repairs<br>Remove the meter for servicing and repairs |
| 4. | Dial/glass foggy | Climatic condition | Wait for climate change, if it israiny season |
| 5. | Meter suspected to be slow or fast | Inlet flow disturbance, missing internally defective, deteriorated magnets in case of magnetic meter | Clean the external filter/dirt boxwere provided and the in-built strainer<br>Ensure full open condition of upstream valve. If doubt persists, remove meter for testing, servicing & repair |
| 6. | Bush/gland leakage | Gland deformity | Remove meter for testing and servicing |
| 7. | Regulator, head, body leakage | Regular washer damaged, loose screw | Remove the meter and repair |

# 10. SAFETY PRACTICES[20]

## 10.1. INTRODUCTION

There are risks involved in operating and maintaining a water supply system, just like there are in any utility or sector. As a result, safety procedures are required. Infections, wounds, bruises, and physical traumas are frequent. But, even if they don't happen as frequently, serious injuries that require extended recovery times, limb or eye loss, accidental death, or electrocution are also possible. The use of safety gear and the adoption of safe practices can significantly reduce work hazards.

It should be kept in mind that there is a cause behind every accident; they do not simply occur randomly.

## 10.2. IDENTIFICATION OF WATER SUPPLY RELATED ACCIDENTS

### 10.2.1. Source/Cause of Accidents

Knowing the cause of accidents is essential to creating a safety program. Then, preventative and corrective measures can be taken. Reviewing records or information about accidents at other MCs is helpful in addition to being aware of mishaps within the company itself.

The following, among others, are the principal hazards at a water supply system:

(a) Physical harm brought on by touching objects, dropping objects, lifting objects, falling, using tools, etc.

(b) Walking on or bumping into things

(c) Hazards related to operation and maintenance of Water Supply Machinery

(d) Infections

(e) Exposure to dangerous gases

(f) Chemicals spill over

(g) Fire hazard

(h) Electrical shock

(i) Excessive noise

(j) Trench collapses as water mains are being repaired.

### 10.2.2. Location

The aforementioned risks could be present throughout a water works system. They include, among others:

Storage facilities with chemical dangers, huge open filters, handling of materials, cleaning of internal sewage systems, septic tanks, etc., mechanical & electrical hazards. Intakes, Pumping stations, Transmission Mains, Distribution System, Water Treatment Plants.

The person in charge of the safety program should be continually on the lookout for any dangers that could hurt a worker.

### 10.2.3. Types of Injuries

Knowing the injury type most common in water supply systems is crucial for developing a safety program. The most frequent wounds seen in water delivery systems are injury to the eyes, shocks, irritation from gases, and other industrial ailments, as well as deaths, permanent disabilities, and temporary disabilities. Statistics on the major types of incidents that take place in Pakistan water supply sector are not available.

[20] https://openjicareport.jica.go.jp/pdf/12367207_04.pdf

### 10.2.4. Accidents Costs

The following are the cost components of accidents:

- Compensation given to employees or other affected parties.
- The cost of treating accident or injury victims' medical bills.
- The price of replacing or repairing the equipment.
- Production loss with ensuing overtime and damage payments.
- Fees for counsel.
- Workplace relations.
- A decline in reputation and goodwill.
- Waiting for an injured employee to resume work and/or additional hiring fees, which include training fees.

## 10.3. SAFETY PROGRAM

### 10.3.1. Introduction

Good management is necessary for safety procedures. Small wounds like scratches and bruises may occur from time to time, yet there may be a loss of limb, vision, or even death.

You can organize safety as you like. It could be a fully functional safety organization with a Safety Officer and the required staff. It might only be the facility manager, with a select few employees chosen for certain tasks. Everyone on the job is aware of what might occur in specific circumstances, yet they are all preoccupied with their own tasks and obligations. A safety officer, however, devotes their entire time to safety. Another option is to form a safety committee. Depending on the size of the organization, you may or may not need a full-time safety officer. But we must give safety our whole focus.

### 10.3.2. Program for Safety Practices

#### 10.3.2.1. First Step

A water supply system must have a safety program. It needs the management's complete support; else, it won't be successful. In a large organization, the program may be assigned to a safety officer who can dedicate part- or full-time to the position. That person might be the officer in charge of the plant in a smaller organization.

#### 10.3.2.2. Record Keeping

A safety program needs to keep injury records. Also, it is required under several laws, rules, and regulations that the government has created. Records provide the program direction and ensure its success.

Standard forms are offered for record maintenance. The forms could include things like:

a) Accident report
b) An accident's description
c) A medical report
d) Steps taken
e) Analysis of accidents

A summary of accident types and reasons should be generated every year; Table 18.1 provides a suggested format.

*Table 10-1 Summary of types and causes of accidents*

| **Type of injury** | **Primary cause of injury** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unsafe Act | Chemical | Falls | Handling Objects | Heat | Machinery | Falling Objects | Electrical | Striking | Misc. | Total |
| Fractures | | | | | | | | | | | |
| Sprains | | | | | | | | | | | |
| Eye Injuries | | | | | | | | | | | |
| Cuts | | | | | | | | | | | |
| Bruises | | | | | | | | | | | |
| Burns | | | | | | | | | | | |
| Miscellaneous | | | | | | | | | | | |

#### 10.3.2.3. Identifying Hazards

This requires:

- To search through records for circumstances and events that led to accidents. Remember the events that caused the accidents. Try to identify some of the problematic areas in your structure, your tools, or the negative habits that are being practiced.
- Examine the areas of the body that were hurt in the collisions. Personal Protective Equipment may be needed.
- Take a systematic look around and conduct an inspection. Use your supervisors as a resource. Look around for potential sources of fire, health, and personal injury
- Keep an eye out for risky behaviors and improper job performance.
- Minimize dangers associated with tools, materials, and the workplace. You can reduce the amount of time you spend handling tools and supplies yourself by using the supervisory staff. Purchasing power equipment might be more affordable.
- Ensure that the task is completed in a legal and secure manner.

#### 10.3.2.4. Training And Inspiration

Any training program designed for the safety of the water supply sector workers of MCs, and for the general health and safety of the residents/MC's clients should be based on provincial, national and international performance standards/regulations related to environmental, health, and safety of the workers. These may include but are not limited to:

- IFC Performance Standards on Environmental and Social Sustainability. Particular emphasis will be laid upon study of the following performance standards
    - Performance Standard 1: Assessment and Management of Environmental and Social Risks and Impacts

- Performance Standard 2: Labor and Working Conditions
- Performance Standard 3: Resource Efficiency and Pollution Prevention
- Performance Standard 4: Community Health, Safety, and Security

- Occupation Safety and Health Administration (OSHA) Guidelines
- National Standards for Drinking Water Quality
- National Environmental Quality Standards for Municipal and Liquid Industrial Effluents
- National Environmental Quality Standards for Ambient Air
- National Environmental Quality Standards for Noise
- Punjab Environmental Quality Standards for Drinking Water

Key points for the training and inspiration of the employees include:

- Everyone needs to be trained in safety precautions if we want to have a good safety record. The new operator who has been hired recently or who has been moved from another work location must begin a safety program. He needs to be made aware of the value of policies, correct reporting, and safety. Safety Procedures copies should be given to him. He can then receive more in-depth training after a few months. A person who has been transferred merely needs to be informed of the specific safety requirements for his new position.
- Instruction will cover job-specific skills. The people must get instruction from the plant supervisor on every area of plant safety. This will cover the risks associated with electrical hazards, fire hazards, tool handling, and correct tool maintenance to avoid accidents. It is necessary to provide special instructions for specific tasks in tight spaces like trenches, manholes, petrol, etc.
- The training must be ongoing and not just once. Case studies may be covered in a review course. Injury victims can provide their insights into how the accident occurred. A constant reminder and aid in continued education are safety posters strategically positioned throughout the factory.
- Appropriate instruction and equipment use must be provided. The proper use of tools must be continuously monitored by supervisors. They must confirm that the techniques used are appropriate and secure.
- Encourage employees to work safely even when no one is looking. Positive strategies, such as acknowledging a safety record or having competitive interests, etc., can be tried. The program of Safety Practices places a great priority on the value of positive interpersonal relationships, a high level of morale, and responsive management to the needs and interests of people.

## 10.4. OPERATOR PROTECTION

### 10.4.1. Personal Safety Gear

To start regulating a dangerous situation, the hazard must be mechanically removed. Giving the worker personal protective equipment is a supplementary form of safety. A review of the statistics revealed a significant number of injuries to various body parts. Personal safety gear is intended to help safeguard a person's body, hands, feet, ears, lungs, nose, face, and other vital organs. Such safety equipment is unable to shield the worker from risky situations or behaviors. It can only be used to support safe working practices.

#### 10.4.1.1. Head Safety

- Appropriate hard helmets must be worn at all times by workers in situations where there may be a risk of falling objects, flying tools, or other objects. Such headwear must adhere to the applicable BIS. When working near high voltage, special insulated hard helmets must be worn to prevent electrical shock.

- Detachable cradles and sweat bands are recommended for two reasons: (1) to facilitate simple replacement of cradles and sweat bands, and (2) to enable assignment of
- For hygienic reasons, one helmet was distributed to multiple workers, each with his own cradle and sweat band.
- A hard hat's crown cannot be effectively restored once it has been shattered. It has to be changed.

#### 10.4.1.2. Face and Eye Protection

Using impact goggles will protect you from flying items. These can be cup goggles or spectacles.

To hold lenses in place in front of the eyes, spectacles must have a strong frame. For ease of washing and disinfection, frames must resist corrosion and have a straightforward design.

Cup Goggles should have cups larger enough to cover a wide area of the facial bones and protect the eye socket.

- Acid Hoods and Chemical Goggles for defense against corrosive chemical splashes. A glass or plastic windowed hood treated with chemical resistant material provides effective protection. The material of the hood and the window should be joined securely.
- Facial shields can protect you from minor impacts. Polypropylene shields should nonflammable and be free of blemishes that cause distortions, such as scratches.
- To protect yourself from welding's radiation and splashes, wear a welding mask.
- Protective creams are applied to the skin to prevent contamination and penetration by substances such as oils, greases, paints, and dust.

#### 10.4.1.3. Hands and Lower Arms

- For a variety of occupations and risks, protective sleeves, gloves, and finger pads are employed.
- Safety gloves should be long enough to reach far above the wrist and not protrude past the sleeve of a shirt or garment.
- Never approach electrical equipment while wearing gloves or mittens reinforced with metal.
- Specially designed and tested rubber gloves are required for linemen and electricians working with energized or high voltage electrical equipment.

#### 10.4.1.4. Body Defense

For most vocations, dungarees are sufficient. When handling chemicals, rubber aprons should always be worn. Use utmost caution when working on ladders or scaffolding to avoid falls.

#### 10.4.1.5. Legs and Feet

- If leg protection is required, leggings are provided and fall into the same category as coats, frocks, and aprons. For jobs requiring kneeling, kneepads made of cotton, padding, rubber, or cork are utilized.
- For many jobs, everyday work shoes are suitable. To avoid slipping, they ought to feature nonskid soles. Where there is a chance of dropping equipment or materials onto the feet, safety shoes are a need. When using machines like air hammers, concrete breakers, etc., men are required to wear toe protection. Use the proper safety footwear when working on electrical equipment.

#### 10.4.1.6. Respiratory Equipment

Effective filter masks must be worn in all dusty regions to protect against the particular hazard.

Men entering tanks or pits where there may be harmful amounts of dust, mist, gases, or insufficient oxygen should wear a hose mask. A hose mask with blower and an airline respirator are used when there is an urgent danger, meaning that if the equipment fails, a rapid escape would be dangerous or impossible.

Where necessary, self-contained oxygen breathing equipment using cylinders or bottles of compressed oxygen or air is employed, sometimes known as oxygen or air breathing apparatus. When the hosepipe's length for the oxygen delivery is larger than 45 meters, this is a need.

Gas masks with canisters have a facepiece that is connected to a canister by a tube. The canister's chemicals clean up polluted air. There isn't a single gas mask that can clean up all kind of gaseous pollutants. In short, a gas mask with canisters can be utilized in situations when there is enough oxygen but does not supply any.

#### 10.4.1.7. Protection for Ears

Effective ear-pads or earplugs must be worn when noise levels are excessive and exceed prescribed limits.

#### 10.4.1.8. Training

The issue cannot be resolved by giving the worker the proper equipment. The employee must be aware of the equipment's limitations as well as when, how, and where to utilize it. This necessitates training the men.

### 10.4.2. Personal Hygiene Practices

Every employee must maintain good hygiene to avoid getting sick. A clean plant is safer from contamination and physical mishaps. After working and before eating or smoking, hands must be cleansed with soap.

Utilize the first-aid kit to treat minor wounds, bruises, and scratches right away.

### 10.4.3. Guideline for Proper Use of Tools

A few fundamental tool guidelines are:

a) Always choose the appropriate tool for the task. Pry bars are not screwdrivers. Wrenches are not pliers

b) Regularly repair or replace tools that are worn out or broken

c) Avoid placing tools near or on moving machinery

d) Make sure you have enough space in case the tool slips

e) Watch out your steps to avoid slipping

f) Use well-fitting gloves, unless you're hammering

g) Avoid wearing jewellery or loose clothing near moving parts

h) When utilizing any impact tools, power grinders, or sharpeners, always use goggles.

i) Wipe, clean, and replace each tool in the carrier or work belt after use. A slick spanner might be harmful.

j) Avoid placing tools in areas where they could fall on workers below or on top of ladders.

k) When performing any task where explosive gases may be present, always use non-sparking instruments

## 10.5. SECURITY IN PLANT MAINTENANCE

### 10.5.1. Maintenance Hazards

Maintenance of the treatment plant, also known as housekeeping or cleaning, is crucial for the machinery of the facility. An operator performing maintenance must be able to use machinery, manual and power tools, fix electrical equipment, and enter trenches, sumps, manholes, among other places. All of these activities carry the risk of harm, fire, illness, or even death.

The structures are designed or constructed with fixed safety features. The maintenance engineer may, however, occasionally add to or modify the current structure. Many incidents can be avoided with prompt, effective maintenance.

### 10.5.2. Cleaning

It will be much better to work in a clean plant as a whole. The factory will become safer just by keeping tripping risks out of the working areas. When no one else is in danger or inconvenienced, cleaning should be done. Wet flooring is dangerously slick. Put up signs warning people.

To dispose of discarded greasy rags, provide and use trashcans. Acids, caustics, and hazardous trash need to be cleaned up right away.

To lessen fire and tripping risks, trash must be kept out of doorways, hallways, stairways, and work areas.

### 10.5.3. Painting

Nearly all plants routinely paint. The following factors need to be taken into account:

- Always wash your hands before handling food or eating when working with dangerous paints, such as those that contain lead, zinc, or organic materials.
- Try to avoid using substances like carbon tetrachloride and steer clear of exposing your skin to solvents and thinners.
- Use a respirator when spray painting to prevent fume inhalation.
- Any open flames or smoking should be prohibited near the area being painted.
- Avert using closed containers with heat when painting or cleaning the spraying equipment. Spray or vapors could catch fire or ignite at a temperature known as the flash point, burning the user. Always do spray equipment cleaning in a space with enough ventilation. While using ladders or scaffolding, exercise extreme caution. They must be sturdy and well-maintained.
- To prevent fires, rags containing paint or oil should be put in a closed container.

### 10.5.4. Access to Equipment

Safe access to equipment reduces risks of injuries from falls. The safest methods are ramps and step stairs to access the equipment which is placed on racks beyond your reach. Ramp slope and step increase shouldn't be too steep. Steps must have handrails and a minimum 9-inch tread (25 cms).

Vertical ladders ought to be avoided. Nonetheless, they are frequently used. A hoop cage should be included with a vertical ladder that is at least 10 feet (3 meters) long to allow the user to restore control in the event of a slip. Ladders with vertical rungs should not have vertical distances that are less than 30 cm (12 in) or greater than 40 cm (15 in). 25 cm (9 in) should be the minimum width, with 30 to 40 cm being preferred. Enough room must be provided around the equipment.

### 10.5.5. Guards, Rails, Fencing, Enclosures and Shields

They are intended to stop people from sliding, falling, or coming into contact with moving machinery. These should be fixed or replaced if they are missing. Protective equipment needs to be replaced right way when needed.

Railings or fencing must be installed around settling tanks, basins, manholes, sumps, and other subsurface structures. If necessary, safety belts must be worn.

### 10.5.6. Lighting

It is important to provide adequate, glare-free lighting, especially near stairs and other sensitive areas. For the complex's safety and security, flood lighting needs to be installed in the appropriate locations.

### 10.5.7. Ventilation

A key safety component of water supply systems is proper ventilation. This can be achieved by:

a) By opening the entrance louvres or exterior windows.

b) Using mechanical exhaust fans and fresh air intakes.

c) Using fans with a forced draught.

d) Using air blowers or portable air compressors.

### 10.5.8. Equipment Safety

The following safety measures ought to be followed when maintaining and using equipment:

- Never remove any guards until the machine has been stopped
- Turn off all power yourself before beginning any equipment maintenance. Attach a cautionary note and sticker to the lockout.
- To stop dead movement, block any counterbalance or weighted mechanism.
- To handle big equipment safely, have enough personnel and hoisting equipment on hand.
- Before beginning work, block up underneath any heavy machinery that is on jacks or hoists.
- Keep tools in a kit bag or on your person (not on the floor).
- Have safety glasses close at hand. Employ them as necessary.
- Don't rush things. Speed causes mistakes.
- Overhead travelling cranes should only be operated by authorized personnel. Check the hook and wire, limit switches, and circuit breakers. Only universally recognized hand signals should be utilized. Give a warning before moving loads and make sure everyone is positioned safely. Hard helmets are necessary.
- While utilizing portable power tools, wear safety protection gear when using equipment for grinding, chipping, polishing, or paving. Tripping hazards are presented by extension cords. Use rubber mats when working in damp or wet environments. Tools for electricity should be grounded. Use safety connectors and clamps for pneumatic tools. Air hoses and electrical cords should not be near chemicals, oils, or sharp items.
- The maximum voltage for portable electric lighting is 24 volts, and they must adhere to I. E. regulations.
- A trained operator is required for gas or electric welding. Practices for personal and fire safety must be observed. Gas cylinders must be stored in water supply systems with the same caution as other gases.
- The system's safety valves must all undergo routine inspections in accordance with the maintenance plan.
- When using forklifts, only the operator is allowed to ride on them. Verify that the warning signs are functioning. Inspect the brakes. Before lifting or moving the forklift cargo, be sure it is properly stacked.

### 10.5.9. Lubrication Safety

1. If possible, avoid lubricating moving parts. If you must, make sure the lubricating point is 30 cms away. Alternatively, the lubricant should be piped outside a guard and away from the moving component.
2. Immediately clean up any grease or oil spills.
3. Never aim a grease gun directly at someone. Avoid getting grease on your hands.

### 10.5.10. Safety in Confined Spaces

A confined space is any area without convenient access for removing a person where there is a risk of low oxygen levels or harmful airborne contaminants. Pits, manholes, basins, and tanks are a few examples of such locations. Explosive mixes can be created when gases and vapors gather in small areas.

When oxygen is taken away or replaced by another gas, oxygen deprivation results. When it is consumed by bacteria, oxidized by metals, burned, or replaced by inert or harmful gases, oxygen is eliminated from the air. Shortness of breath occurs when the oxygen content of the air drops below 17%, and additional drops cause unconsciousness. Around 10% of people die due to low oxygen. Toxic gases harm or kill people on their own. When operating in these areas, safety inspections must be done.

## 10.6. RISKS OF HANDLING CHEMICALS - GASES

### 10.6.1. Chlorine

In the water sector, chlorine is regarded as a risk. Humans are poisoned by chlorine gas. When in contact with water, it becomes exceedingly corrosive. While working with chlorine, extreme caution must be used to prevent operator damage. Even a small amount can result in severe coughing and lung, nose, and throat irritation.

### 10.6.2. Carbon Dioxide

As carbon dioxide is hazardous and makes people suffocate because it lacks oxygen, it is only occasionally used in water treatment facilities. Thus, be mindful of the safety standards when employing carbon dioxide. The petrol does not typically diffuse away quickly because it is a thick vapor. Anyone entering mines, manholes, wells, etc. must be cautious.

First aid is bringing the person to fresh air, performing CPR, and getting medical help.

## 10.7. DANGERS OF CHEMICAL HANDLING - ACID

Acids all have a remedy in the form of neutralization. Large amounts of water will typically suffice. If acid is ingested, milk of magnesia or lime water may be required. First aid for those who have breathed vapors typically include giving them access to clean air, artificially reviving their breathing, or giving them oxygen. Acid splashed into the skin can be neutralized with baking soda.

In the treatment of water, many acids are utilized. Nonetheless, sulfuric acid is most widely used

### 10.7.1. Sulphuric Acid

1. The most hazardous chemical to be handled is sulfuric acid. The primary risk comes from touch.
2. Always wear protective clothing and tools. Body tissue exposed to acid rapidly suffers severe burns. It's crucial to flood the area with water right away.
3. Immediately clean up the acid spill. Till it is clearly identified or guarded, do not move. Use soda ash to neutralize the acid before flushing it down the toilet.

The first line of defense is quick removal of sulfuric acid from the body. Continue irrigating with flowing water and light alkaline solutions in alternate days (bicarbonate of soda). Wash your eyes thoroughly with water. Avoid making the patient throw up if they have swallowed something instead of encouraging them to drink as much water as they can. Get emergency medical attention.

## 10.8. CHEMICAL HANDLING RISKS - BASES

Hydroxides are the names for the bases used to treat water. They're employed to increase ph. Strong bases include sodium, calcium, and ammonia compounds. Hypochlorite, carbonate, and silicate are weak bases.

### 10.8.1. Calcium Hydroxide, (Hydrated Lime)

1. Lime and water interact very well, and a lot of heat is produced as a result. A fire in surrounding flammable goods could result from storage in moist areas. Compared to calcium oxide, calcium hydroxide (hydrated lime) is less problematic (quicklime).
2. They ought to be kept in a cold, dry location. In wet areas, flammable materials close by may catch fire. Also, avoid combining dry quicklime with substances like alum or ammonium sulphate that contain water of crystallization.
3. Personal protection equipment must be worn by anyone exposed to lime dust. Long-term contact to lime dust produces dermatitis, particularly at sweat sites. Lime slakers inspection requires the use of face shields and chemical goggles.
4. First aid for lime burns is similar to that for any caustic burn: complete submersion in water.

### 10.8.2. Sodium Hydroxide, (Caustic Soda)

1. Liquid caustic should be kept in steel-covered tanks, while dry caustic soda should be kept in a dry location where it won't be exposed to moisture.
2. Splash and mist are hazards for workers. They must put on safety goggles, face shields, rubber gloves, aprons, boots, and cotton dungarees as well as other protective clothing.
3. With any caustic burn, first aid is the same. Water the soil thoroughly.

### 10.8.3. Sodium Silicate

1. Liquid sodium silicate exists. While not being poisonous, flammable, or explosive, it nonetheless poses the same risks to the skin and eyes as other base compounds.
2. Avoid making extended skin contact. Use a lot of warm water to wash. Rubber gloves and a face shield should be worn when handling the solution. Put on some eye protection.

## 10.9. CHEMICAL HANDLING DANGERS - SALTS

### 10.9.1. Ferrous Sulphate and Aluminium Sulphate (Alum)

1. These materials need to be kept dry and clean because moisture tends to cause the material to cake.
2. Because these chemicals can irritate the skin and mucous membranes and seriously harm the eyes, handlers should wear protective clothes and protective cream on exposed skin areas. For liquid solutions, take the same safety procedures, but make sure to protect your eyes as well.
3. Never clean dry feed machinery or equipment using compressed air. Maintain coverings on feeding apparatus.
4. Keep in mind that quicklime and dry alum mixes can explode. While wet, ferrous sulphate dust is a good conductor of electricity and highly damaging to machinery.

   Ferrous sulphate dryers, in the presence of dusty environment, can potentially damage crucial instruments or equipment. The area's electrical equipment needs to be dust-proof and should be cleaned often.

5. The same first aid procedures for acid burns should be used for skin irritants and minor burns. Shower as soon as you can after washing with lots of warm water and soap. Irrigate liberally with warm water if your mouth or nasal passages are itchy. If the substance is in the eyes, flush with a lot of warm water and see a doctor.

### 10.9.2. Ferric Chloride

1. Given how caustic it is, you should treat this substance the same way you would any acid.
2. The salt is quite soluble in water, but when exposed to light or moist air, it breaks down and releases hydrochloric acid, which could lead to other safety issues. Normal safety precautions should be used when handling liquid ferric chloride to prevent splashing can happen, especially if the liquid is hot. Put on a face shield to shield your eyes, and wear rubber aprons to shield your clothes.
3. The eyes must be immediately washed out with copious amounts of water for 15 minutes as the first aid for liquid-exposed eyes. Since prolonged contact will irritate the skin and discolor it, ferric chloride should also be rinsed off with water.

### 10.9.3. Ferric Sulphate

1. Operators employing this material should be given protection suitable for dry or liquid alum due to its acidic nature.
2. Put on safety gear and a respirator. The dry form's acidic response with moisture on the skin, eyes, and throat should be avoided for extended periods of time.
3. Immediately flushing the eyes with lots of water is the first line of treatment for ocular exposure. Large amounts of water should also be flushed over the skin. Contact that lasts a long time could irritate.

### 10.9.4. Sodium Aluminate

1. There are not many risks associated with this molecule, but as with other compounds, you should use caution.
2. To avoid breathing in dust when handling the dry compound, wear respiratory protection.

   Flushing exposed eyes with water and keeping the skin clean with water are the first aid measures.

## 10.10. CHEMICAL HANDLING SAFETY - POWDERS

### 10.10.1. Activated Carbon

1. The risk of fire in carbon storage is one of the biggest threats. Dry bulk carbon should be stored in fireproof containers that have water or carbon dioxide apparatus for fire suppression.
2. Bag storage should be done in a spotless, dry location with access aisles surrounding each stack to allow for regular fire inspections and the easy removal of any carbon that may be burning.
3. The areas used for processing and storing carbon should never allow smoking. Keep carbon away from any fire hazards, such as heated pipes or electric motors or wires.
4. Electrical equipment that is explosion-proof and can be kept dust-tight should have dust-proof motors. Since it conducts electricity, damp carbon dust has the potential to short circuit electronic devices.
5. While handling carbon, dust masks should be worn, and effective dust collection tools should be employed. The staff should also wear dust-proof goggles, a cap, and loose clothing fastened at the wrists and ankles while loading carbon bins or hoppers.

**(a) Putting out fires**

Like conventional charcoal, activated carbon burns with intense heat but no smoke or flame. Such flames can be hard to spot and even harder to put out once they are found. Before a fire in a huge storage bin or stack is discovered, some time may have passed. When the bags begin to smell like burned paper or the side of the hopper has scorched paint, a fire is present.

Never use a strong stream of water to put out a carbon fire since the resulting steam will distribute the carbon in all directions. It works considerably better with a fine spray or fog nozzle. Remember that carbon monoxide can be dangerous while working with a carbon fire in a small space; therefore, air-supplied hoods or self-generating oxygen masks should be accessible.

Most of the activated carbon has enough oxygen adsorbed within the substance for it to burn without the presence of air. Depending on the type of material and the degree of grinding, carbon will begin to burn at temperatures between 350- and 450-degrees Fahrenheit. The easiest technique to fight the fire is to flood the area with water from spray nozzles to lower the surrounding carbon below this ignition point.

## 10.11. FIRE SECURITY

Fires receive a very scant amount of attention. A fire is started by three components: fuel, oxygen, and an ignition source. There is no fire if any of these components is missing. Removing one of these components is the foundation of firefighting.

*Table 10-2 Classification of fires*[21]

| Class of Fire | Description | Extinguishing medium |
|---|---|---|
| A | Fires involving ordinary combustible materialslike wood, paper, textiles etc. where the (constant air pressure) cooling effect of wateris essential for the extinction of fires. | Water Soda acid type, Water type (gas pressure),Water type |
| B | Fire in flammable liquids such as oils, petroleum products, solvents, varnishes, paints etc. where a blanketing effect is essential. | Foam Carbon dioxideDry Powder |
| C | Fires involving gaseous substances under pressure where it is necessary to dilute the burning gas at a very fast rate with an inertgas or powder. | Carbondioxide Dry powder |
| D | Fires involving metals like blanketing aluminum,zinc, potassium etc. where the burning metals is reactive to water and which requires specialextinguishing media or technique. | Dry powder<br>Special dry powder formetal fire. |

[21] Supply/ Installation/ Annual Maintenance Contract/ Maintenance of Fire Extinguisher And Other Safety Equipments, Fire Involving Ordinary Combustible Materials Like Wood, Paper, Textile Etc. Where The Cooling Effect Of Water Is Essential To Extinguish Fire. (2021). MENA Report.

| Class of Fire | Description | Extinguishing medium |
|---|---|---|
| E | Fires involving electrical equipment where the electrical non-conductivity of the extinguishing media is of first equipment importance. | Carbon dioxide Dry Chemical powder when electrical is<br>de-energized, same as forClasses A and B. |

### 10.11.1. Fire Extinguishers

Understanding the type of fire, you are attempting to put out is crucial since no single extinguisher can put out every kind of blaze. The different kinds of extinguishers must be used properly, and the right kind should be placed close to the location where that class of fire may occur. The operator must devote a significant amount of effort to the preventive maintenance program for fire extinguishers, and a system of record keeping is necessary.

**Fire extinguisher types**

(a) Water Pump Tank, Cartridge Operated, Stored Pressure, and Soda-Acid

1. They can handle Class A fires. It is crucial to do proper maintenance, hence a timetable must be created.
2. A stored pressure extinguisher can be used by simply turning a valve or squeezing the handle. Checking the air pressure and recharging the extinguisher as necessary are all that is required for maintenance.
3. The maintenance for the cartridge type is as simple as weighing the gas cartridge and adding water as needed. Turn upside down and bump to operate.
4. Simply turn the pump handle to activate the water pump tank style of extinguisher. One simply needs to empty the contents and replenish with water once a year or as needed for maintenance.
5. The soda-acid kind needs to be turned upside down in order to work, and it also needs to be recharged once a year.

(b) Foam Type

Foam-based extinguishers work well to extinguish Class A and Class B flames. They require annual recharge and work by rotating upside down, much like soda-acid.

Foam and water extinguishers shouldn't be used to put out electrical equipment fires. However, they can be used to extinguish Class B fires brought on by combustible materials such as grease, oil, paint, and gasoline.

(c) Carbon Dioxide ($CO_2$)

Extinguishers that release carbon dioxide are frequently employed. To use them, just pull the pin and squeeze the lever. For maintenance, they must be weighed at least twice a year. Many of these extinguishers will eventually discharge. They work well to put out Class C (electrical) fires. If at all feasible, all electrical circuits should be shut off before attempting to put out this kind of fire. Both Class A surface fires and Class B fires brought on by substances like paint, oil, and gasoline can be extinguished using a carbon dioxide extinguisher.

(d) Chemical Extinguishers

Chemical extinguishers can either be operated using a cartridge or stored pressure. These are advised for Class B and C fires and might be effective for Class A surface fires as well.

1. With cartridge-operated extinguishers, all you have to do is squeeze the lever to burst the cartridge. The maintenance is a little more challenging because it calls for weighing the gas cartridge and examining the state of the dry chemical.
2. The action of the stored-pressure extinguishers is identical to that of the $CO_2$ extinguisher. Just release the lever and pull the pin. The maintenance calls for an examination of the dry chemical's condition and the pressure gauges.

### 10.11.2. Danger Points

The risk factors are:

- Unattended storage spaces with flammable materials
- Workshops using oil, cleaning agents, and soaked rags
- Labs with heaters, burners, and chemicals
- Workplaces with a lot of paper.

### 10.11.3. Prevention

1. Priority should be given to housekeeping. In a clean environment, morale is higher and sloppiness and carelessness are less likely to occur.
2. The biggest fire hazard is trash and waste that are not properly disposed of.
3. Oil-soaked trash or rags should be kept covered and in metal cans.
4. Changes and additions must be made with non-combustible materials.
5. Combustibles need to be kept away from heaters and places with flames.
6. Electrical wiring and equipment need to be checked and maintained properly.
7. In locations that are prone to fire, automatic fire alarm systems should be implemented.
8. Installation and routine maintenance are required for fire extinguishers and other firefighting supplies.
9. Use caution while using Bunsen burners, blowtorches, matches, or smoking.

### 10.11.4. Fire Caused by Chemicals

1. Sodium chlorite, a substance used in waterworks to regulate odors, turns explosive and becomes a fire hazard when organic waste is present. Even a spark or some sunlight can start it. A spilled liquid on a wooden floor is ignited by the scuff of a shoe. Spills on garments have resulted in locker fires. Fires can be extinguished with sand or soda ash; water should never be used. It needs to be maintained separate and kept far away from acids, sulphur, and organic compounds.
2. Another fire risk is activated carbon, which has been covered in 18.11- Safety in Chemical Handling - Powders.

## 10.12. PROTECTION AGAINST ELECTRICAL HAZARDS

### 10.12.1. General Requirements

1. Electrical equipment should only be maintained and operated by trained and competent individuals.
2. Kill, lockout, and tag any power going to any electrical appliance when performing maintenance on it.

3. Make sure you have solid footing to avoid falling onto a live wire. Always check to see if the wire is active. Use a pencil type tester
4. Insulated handles are required for hand tools. Electrical controls must come before insulated mats.
5. Be sure that all electrical devices, systems, and other items are securely grounded.
6. Remove all metallic jewelry, watches, and eyewear. Use wooden ladders instead of metal ones.
7. To stop people from stumbling over wires and cables, always mount and shield them.
8. Electrical controls ought to be functionally sound, accessible, and well labelled.
9. Make sure there is someone available to assist in an emergency. Avoid becoming sloppy or cocky.

### 10.12.2. Electrical First Aid

1. Use a dry wooden stick (such a broom handle or shovel handle), a section of rubber hose or plastic tubing, or another nonconductor to quickly extricate the sufferer from the live conductor. Never use your bare hands to grab the victim or the wire; doing so will result in the identical outcomes.
2. When someone is unconscious or not breathing, artificial respiration should be initiated right away and kept up until a medical practitioner or doctor relieves it.
3. By keeping the person warm and quiet, you can prevent shock.

## 10.13. SECURITY IN THE LABORATORY

The safety of handling and storing chemicals has already been covered above. Operators do not frequently work in dangerous laboratory environments. To prevent mishaps, nevertheless, best practices must be followed.

### 10.13.1. Sampling Safety

- Never collect field samples with your hands-only. gloves are a must.
- Avoid scaling or entering guardrails. Utilize long distance samplers such as poles, ropes, dippers, or other.
- Don't totally remove the tank cap when taking petrol samples. If necessary, install a sampling port.
- When taking gas samples, wear a reliable gas mask.

### 10.13.2. Housekeeping

For accuracy and safety in the lab, general sanitation and proper storage of chemicals and equipment are crucial. Basic rules are:

1. Maintain a daily routine for general cleaning the lab. Glassware or clothing that is filthy can spread infection. Glass that has been cracked, chipped, or shattered should be placed in containers labelled "Broken Glass only."
2. Give each piece of equipment its own location to be stored. Clean, sanitize, and put the item back on the rack after each usage.
3. Never perform any type of job in a stuffy place. Make sure the lab is well-lit. Do not overcrowd the lab. Have a lot of space.
4. Never wait to clean up and throw away spills.
5. All workbenches and tables should have tops that are chemically resistant or frequently painted with paint that is chemically resistant.
6. Do not keep any additional equipment in the lab.

### 10.13.3. Safety with Chemicals

- Reduce the number of working chemicals that are kept in the lab's outdoor storage.
- All bulk chemicals ought to be kept in their original packaging in a separate fire-resistant storage area. Always place larger bulk containers on the ground.
- To move chemicals from bulk storage to working stock bottles, you should have individual bulk syphons.
- To avoid mistakenly being dragged or jarred off, all chemical storage jars should be placed on broad shelves with holding rails.
- Strong and/or very corrosive acid and base storage jars ought to be placed in deep enough separate trays made of ceramic, plastic, lead, or both to retain the contents in the event of a jar break.
- Chemicals should always be stored as low as possible, never rising above shoulder height.
- All compounds should be labelled with their common and chemical names, formula, strength, and the date they were made or received. To maintain their legibility, change these labels as needed.
- All harmful chemical containers should have red "Skull and Cross bones" labels applied to them.
- Waste chemicals must be disposed of carefully by workers who are knowledgeable with their qualities. They must be properly considered for their impact on the sewer system before being flushed down the drain.
- Store highly reactive substances far apart
- Use a hood for any work with volatile bases, acids, or solvents. Use nitric acid with extreme caution. To chemicals that are quickly oxidized or nitrated, do not add it. An explosion or fire may result from this. Nitric acid combined with acetone, benzene, and toluene, as well as acetic acid, are further instances.

### 10.13.4. Equipment Safety

1. Equipment for laboratories, notably pressure units, should only be operated by professional, experienced technicians.
2. For autoclaves, water stills, and any other specific pressure equipment, precise, clear operating instructions shall be placed nearby permanently.
3. On such equipment, switches and valves must be numbered explicitly according to their order of operation. The grounding of any electrical equipment must be strong. Examine the insulation on all electrical cords for wear or cracks and replace as necessary.
4. Instructions from the manufacturer regarding operations, warranties, services, and safety must be retained in a permanent file.
5. All equipment must be placed away from service switches or valves for gas and electricity.

### 10.13.5. Safety with Glass

1. When handling glass, always wear gloves.
2. Twist the rod or tube into the stopper while maintaining contact.
3. While working with glass, put on full or wraparound goggles or a face shield.
4. Always use a number of cushioned clamps that are firmly fastened to support glass units.
5. All broken or cracked glass should be properly broken and discarded.

### 10.13.6. Safety in Laboratory Procedures

1. Never pipette by mouth. Use a bulb at all times.
2. Know your protocol and adhere to a checklist.
3. Always use safety glasses or goggles in the lab.
4. Never wear contact lenses in the lab
5. Create a viewing window to prevent people from entering the lab.
6. While working with chemicals or running any reaction, always wear a rubber apron.

### 10.13.7. Laboratory First Aid and Fire Prevention

1. Always keep a sufficient quantity of a quality eyewash on hand.
2. Have multiple fire blankets in a place that are easy to get to.
3. Specific fire extinguishers for chemical and electrical use should be openly mounted, properly marked, and regularly charged.
4. The numbers for the fire department and the ambulance service should be prominently displayed over each phone.
5. All staff, especially lab technicians, should receive thorough, ongoing first-aid instruction.

## 10.14. SAFETY PRACTICES FOR WATER MAINS REPAIR AND OPERATION

### 10.14.1. Planning

There are two essential components to a safety practice while building and maintaining a water distribution system: preparation and planning, and operation. In most cases, previous methods are used and then modified in light of experience. But planning is necessary if we are to successfully execute routine or unique tasks. This will get rid of all risks.

System maps must be kept up to date and regularly reviewed. A review of the environment in which the task will be done is a key step in accident prevention.

### 10.14.2. Control Of Traffic

1. A good distance before the work area must have warning signs; you can use signs, barricades, and old tires.
2. Utilize flashers or red caution lights at night.
3. For a one-way activity, use a flagman.

### 10.14.3. Safety Practices for Pipes Laying and Repair

1. Excavations need to be monitored carefully. To provide suitable side slopes or to shore up the trench, the kind of soil must be investigated, and the necessary precautions must be taken. Buildings and poles should be considered in relation to one another.
2. The trench's edge must be at least three feet apart from every pile of soil.
3. Fixing damaged mains requires manual labor. Typically, the ground gets soaked or swept away. Other utilities, especially potentially harmful electric cables, must be protected. Dry circumstances must be used for welding.
4. Safety helmets and other protection gear are required for the workers.
5. A crane operator should only receive signals from one trained and experienced guy.

6. Before it is delivered to the site, the equipment that will be utilized needs to be inspected. The advance crew should have maps showing where the valves need to be closed, barricading supplies, warning signs, valve and chamber keys, etc. in case a main burst. Also, portable pumps for draining the water should be sent.
7. The pipe that needs to be replaced needs to be halted in order to prevent it from rolling. The right tools should be used when lowering it into the trench. And there ought to be sufficient manpower involved
8. To avoid posing a risk to others, cleanup must be done after the task is over.

## 10.15. SAFETY WHILE USING A VEHICLE

Check that the car's brakes and other systems are working properly.

1. Vehicle operation should only be performed by licensed drivers. Preferably, just one or two drivers should operate each vehicle.
2. The driver should use simple forms to report any hazardous conditions

## 10.16. FIRST AID

1. Every person should be trained in first aid and cardiopulmonary resuscitation (CPR), though it is more feasible to train two persons per crew and shift. This training might be provided by the Red Cross, fire departments, or other organizations
2. All first-aid kits can be kept filled with supplies by these crew medics. They could act as mentors for the remaining coworkers.
3. First-aid kits must be conspicuously displayed in the vehicles and at various locations throughout the factory. The most dangerous sectors, such as laboratories, workshops, chemical handling facilities, etc., require special monitoring.

## 10.17. CONCLUSION

We must always remember that each person is responsible for their own safety. A safety program is necessary for the management. Many accidents have a significant human element. Although management could have the final say, the operator is nonetheless accountable. The operator's decision-making abilities and general attitude (response time, sense of alert, etc.) are critical. Watch out for anything that can prevent the user from using the tools and equipment with their natural perceptions and actions.

The interaction between them and the machine is something the operator is better familiar with. The best person to determine how the human factor contributed to an accident's cause is the operator.

# 11. IMPROVEMENT OF THE SERVICE EFFICIENCY AND SERVICE DELIVERY LEVEL

## 11.1. THE NEED FOR A TURNAROUND FRAMEWORK

### 11.1.1. Introduction:

What does the public want from its water utilities? The answer is simple: sufficient, reliable, convenient, and safe water services. Water provision should be transparent, financially sustainable, and responsive to citizens. Wastewater should be collected, treated and discharged properly. The measures needed to improve the operational and managerial capacity of water utilities are generally straightforward—for instance, information is readily available on how to efficiently procure and build water treatment plants, and how to install meters.

Yet, although many utilities are performing well, over half a billion people around the world still lack access to safe drinking water. The SDGs go beyond access to safe drinking water and require equitable access to safely managed and affordable drinking water for all. The success pyramid illustrates the interdependencies and complexities for water utilities trying to achieve sustained high levels of performance.

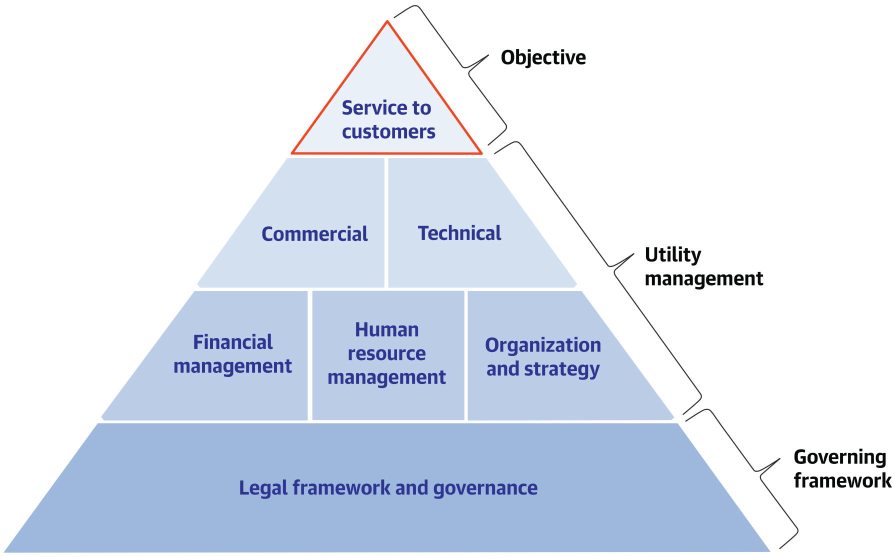



*Figure 11-1 The success pyramid*

Service to customers clearly depends on technical and commercial operations, but not exclusively so. Other elements of sound utility management are organization and strategy, human resource management (HRM), and financial management. Together, these promote effective and efficient commercial and technical operations—for instance, by increasing staff productivity and reducing water losses. The legal framework and governance in which the utility operates shapes its governing environment. Understanding the interactions and relations between the layers of the pyramid is important for developing and implementing a successful turnaround.

Performance will not improve unless the vicious cycles in which water utilities operate are broken. The challenge is to coordinate turnaround actions so that utilities can deliver better services, sustainably and at an affordable cost. To accomplish this, water utilities need a systematic, coordinated, and prioritized approach to improve their operational and management capacities.

Many water utilities have continued to perform poorly despite countless interventions. Donors have invested billions to improve water utility performance in developing countries. Donor funds support lending (and some grants) for capital investments, institutional reform, and technical assistance.

While past interventions incidentally did help improve governing environments and utility management, many water utilities continue struggling to improve service sustainably.

Turning around a utility's performance rarely is a linear process. Considerable tactical acumen is needed to mobilize political leadership, motivate staff, and overcome entrenched negative behavior and incentives, while gradually building public support and credibility among customers. To start undertaking actions that improve performance, utility managers must maneuver within their space for change. Because credibility at this point is generally low, the initial space for change is usually limited, as is the manager's autonomy.

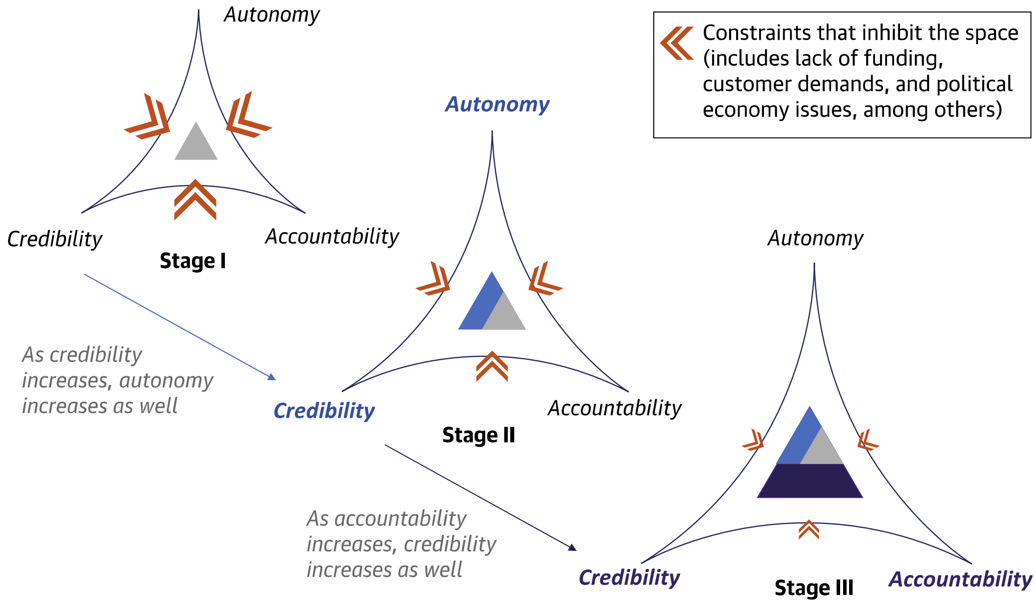



*Figure 11-2 Increasing the Space for Change*

**Stage I** represents the beginning of a turnaround, when managers have minimal autonomy, and little to no credibility and accountability. Having a minimum of autonomy is import- ant because it allows the utility manager to make decisions and use resources to improve performance. To begin expanding the space for change, managers need to increase shareholder, government, and customer confidence in the water utility's ability to perform. Managers accomplish this by making clear commitments—for example, to reduce accounts receivables in a short period—and consistently delivering on them.

As credibility grows, managers gain more autonomy to make decisions, and often also access to the capital needed for infrastructure investments. **At stage II**, managers have built so much credibility that stakeholders are willing to provide resources, provided they can hold managers accountable. As managers deliver on commitments tied to funding, accountability grows and with it, the space for change. At stage III, managers have delivered on enough commitments to secure significant credibility, accountability, and autonomy from stakeholders.

### 11.1.2. Inappropriate Model for Funding Water Utilities

Many water utilities operate in a political economy disequilibrium that contributes to the inefficient use of the funds available to the sector and aggravates the lack of access to commercial finance. In fact, current funding models will be unable to provide the money needed for investments to meet the water-related SDGs.

Poorly performing water utilities waste much of their available funding on inefficient operations and poorly planned and executed capital investments. As a result, providers of capital are reluctant to commit resources.

Once water utilities start using existing resources more effectively, their operating efficiency and credibility will increase. By combining increased operational efficiency with an improved governing environment, utilities gain greater accountability and autonomy. Over time, water utilities will achieve enough credibility and accountability to access *commercial* finance. The latter reinforces the sustainability of water utilities by instilling greater discipline, thereby ensuring better financial planning and more effective capital investment plans.

### 11.1.3. Insufficient Operational and Managerial Capacity

For a turnaround to succeed, it is critical to sequence and coordinate the steps taken to improve the operational and managerial capacity of water utilities, while remaining flexible enough to deal with unpredictable events. The actions required at different maturity levels of a utility are generally well known. For example, installing water meters, updating the customer database, implementing a new billing and collection system, and using a geographic information system (GIS) to map underground water pipes are all actions that will improve technical and commercial performance. However, if these actions are not properly sequenced and coordinated—as part of an overarching strategy—they won't improve a water utility's operational and managerial capacity.

The operational and managerial capacity of a water utility depends on the degree to which the areas of human resources, finances, and organization and strategy, are integrated with technical and commercial operations. The degree of integration is in turn linked to the maturity level of each performance area.[4] A minimal level of coordination would ensure that the customer database is linked to the billing and collection system, and that the GIS not only maps the pipes but also the location of every customer and every meter. The three systems would then reinforce each other to optimize commercial and technical operations. Unfortunately, integration and coordination are often absent in poorly performing water utilities.

# 12. NECESSARY CONDITIONS BEFORE STARTING A TURNAROUND

The empirical evidence from the case studies indicates that specific factors need to be present before starting a utility turnaround. These factors include catalysts that provide space for change, government leaders who champion the required reforms, and a competent manager with sufficient managerial autonomy to implement change. The first two conditions are exogenous and provide an opportunity to start a turnaround. However, these conditions alone do not ensure the success of a utility turnaround.

## 12.1. CONDITIONS

### 12.1.1. Catalysts:

ranged from an acute or chronic crisis to a purposely designed intervention to create space for change. Typical circumstances that created room for change were chronic water shortages (as in the case of ONEA).

### 12.1.2. Credible threat to the livelihood of the utility's staff.:

For example, a threat to privatize the utility. This was the case of CESAN, where the staff were under threat of privatization and made a commitment to improve performance.

### 12.1.3. Loss of funding:

For example, the government decides to stop transferring funds on an ad hoc basis, as the utility needs them. This happened to DAWACO when the government of Vietnam implemented reforms for SOEs that eliminated all subsidies.

### 12.1.4. Change in or application/enforcement of regulatory framework.

For example, a new regulator introduces regulation to enforce a previously unobserved law. In the case of SEDAPAR, Peru's water regulator pushed the utility to finally adopt a multiyear strategic plan that linked performance targets to tariff adjustments.

### 12.1.5. A government champion

committed to reform is a politician who assumes a direct leadership role in championing reforms in the sector. All utilities in the turnaround case studies had a government champion who gave the utility sufficient autonomy to deepen reforms without interference or predation from other parts of government.

#### 12.1.5.1. Competent manager:

In addition to these exogenous factors, evidence suggests that capable and entrepreneurial utility managers play a critical role in utility reforms. Every successful turnaround case had a **competent manager**, thereby raising the confidence of government authorities in the utility. A competent manager should guide the utility's staff in making critical changes from the very start of the turnaround process. That manager will identify early gains that will build credibility and instill confidence in the utility's staff that a turnaround is possible. Therefore, governance arrangements—whether established by law or through a political scheme—must give the relevant body the freedom to appoint a competent general manager for the utility.

#### 12.1.5.2. Managerial autonomy:

The manager must have a minimal level of **managerial autonomy** to make decisions and take action to begin the turnaround. In fact, the successful cases had governance arrangements giving the general manager the necessary level of autonomy and incentives to ensure good performance. At PPWSA, the general manager had the trust of both the prime minister and the city mayor, who gave him sufficient autonomy to enact deep reforms before the utility was granted formal autonomy. A manager must generally be responsible for the most important decisions—staffing, prioritizing areas of improvement, allocating existing resources, and leading interactions with government and other leaders. Having the freedom to carry out at least some of these actions is crucial to building credibility and improving performance.

## 12.2. ACTIONS THAT BUILD THE OPERATIONAL AND MANAGERIAL CAPACITY OF SUCCESSFUL UTILITIES

Building a water utility's operational and managerial capacity requires improving the five elements of the success pyramid: organization and strategy, human resources, and financial management, as well as commercial and technical operations. These elements thrive in an enabling governing environment, comprising the legal framework and governance in which the utility operates. For each area to be improved, specific actions contribute to performance.

### 12.2.1. Organization and Strategy

A well-developed strategy based on a **detailed baseline** assessment is necessary to complete and sustain turnarounds. Establishing a baseline that accurately diagnoses the utility's financial, operational, and commercial situation is necessary to make informed decisions in the early stages of a turnaround. In fact, every successful turnaround case study had developed a baseline. The baseline provides the most accurate picture possible for setting yearly targets to monitor improvements. As the utility improves its performance, the information it has avail- able will increase and become more precise.

Once the baseline has been established, a utility should define a multiyear plan based on the current situation and desired performance. The plan should clearly define **multiyear targets**, the actions required to meet those targets, and the resources needed to finance those actions.

Implementing an actionable **multiyear business plan** is necessary to create a clear development path. Improving a water utility requires coordinating many different aspects over several years—for example, obtaining reliable information, creating a competent and incentivized team, designing and developing new distribution networks and water treatment plants, and increasing collections from customers. The successful turnaround utilities had prepared and implemented business plans that integrated these actions, identified the resources required, and set clear targets. Utilities from previous studies, including AQUA, had done this as well. The capacity to design and implement such plans differentiate water utilities that were able to sustain good performance from those that were not.

Having comprehensive **management information systems (MISs**) in place is crucial to monitor performance and adjust plans. Successful water utilities rely on accurate, detailed, and up-to- date information for their operations and capital investments. For turnaround utilities such as CESAN and DAWACO, MISs provide live data to support daily decision-making. MISs were considered central to successful utilities. They optimize operations that are core to the business—including human resource management (HRM), network operations, metering, billing, and collecting.

### 12.2.2. Human Resource Management

Developing and managing human resources effectively is an essential element of a turn- around. An important first step is to develop and implement a staffing plan that is consistent with the utility's multiyear strategy. A **staffing plan** identifies the necessary composition, size, and structure of a water utility's staff. A good staffing plan considers outsourcing initiatives, the introduction of new technologies, and the expected gains in labor productivity through training and development.

All successful utilities had developed staffing plans early in the turnaround process. Staffing plan identified which staff should be trained and which jobs should be outsourced to carry out its strategic plan.

### 12.2.3. Staff evaluations and training

Successful water utilities have highly motivated and qualified staff, and successful performance management contributes to developing and retaining this staff. At SONEB, staff members were enrolled in 3-year training programs. In addition, employees' performance was evaluated annually, based on a performance objective contract cosigned by employees and their manager.

Getting compensation right is important for effective HRM. **Performance-based compensation** seems to be necessary for sustaining a turnaround. Tying compensation to performance is an important incentive that raises staff productivity and efficiency.

Offering **competitive compensation** is another important aspect of HRM. Successful water utilities offer competitive compensation to ensure they can attract and retain well-qualified employees. However, in some jurisdictions, public water utilities face legal constraints on the compensation they can offer. Under these circumstances, utilities find other ways to retain well-qualified employees.

### 12.2.4. Financial Management

Successful water utilities are financially sustainable. For instance, all the case study utilities that successfully turned around had also become financially sustainable by the end of the process. A **financially sustainable** utility covers its reasonable costs with a relatively predictable income stream, primarily derived from tariffs charged to its customers. It uses that income stream efficiently by **controlling expenses** and **managing cash flow**.

Ideally, **tariffs** cover at least operating expenditures (OPEX), and the utility should aim to recover all costs through tariffs in the long run. However, utilities may not have the credibility to increase tariffs to cost-recovery levels until they demonstrate efficiency and effectiveness. In that case, utility managers may find it more effective to first reduce costs and increase the reliability of government financial support—via **subsidies** or **transfers**—at the start of the turn- around. Previous studies have also shown that improving operational efficiency translates into greater financial stability because operational and management costs are controlled.

Achieving financial sustainability by **increasing cash flow from operations** demonstrates a commitment to improving performance. In all turnaround case studies, utilities made initial commitments and followed through on them, which allowed them to garner support and access funding from stakeholders to begin improvements. CESAN, for example, adopted a dual approach that cut costs, by reducing wasteful spending, and increased revenue, by raising the number of connections. This approach was so successful that CESAN persuaded the World Bank to reinstate previously canceled loans.

Having predictable sources of funding allows management to plan the operating and capital expenditures required to meet performance targets. During this process, capital expenditures (CAPEX) should not compromise the financial sustainability of the water utility. While CAPEX is necessary and important for water utilities, the utility's processes and systems must be improved before making large-scale infrastructure investments.

### 12.2.5. Technical and Commercial Operations

In a poorly performing utility, the **nonrevenue water** (NRW) ratio is likely to be high and needs to be lowered to improve service levels. To sustain good-quality services, a strategy for reducing NRW to its *economic* level must be developed. NRW has a direct and adverse effect on a water utility's service to customers and its financial performance. This was the case of DAWACO, which had an NRW level of about 39 percent, which it lowered to 19 percent during its turnaround. HPWSC also focused on lowering NRW and implemented a program that reduced NRW from 70 to 32 percent in 6 years. While most poorly performing water utilities have NRW levels that should be substantially reduced, the fact that NRW levels cannot be measured accurately due to the lack of data makes it particularly challenging.

Using the same logic, clear **metering** policies and a strategy to meter all connections must be in place to complete a turnaround. In all turnaround case studies, metering was recognized as a key component of successful operations—every utility experienced an absolute increase in metering throughout its turnaround. Producing and distributing water is at the core of a water utility's business. Meters are essential to giving utilities accurate information about the volumes of water produced, distributed, and consumed by customers. Some of the utilities analyzed in earlier studies, installed meters to help lower corruption and improve transparency. In addition, customer meters create incentives to use water efficiently, and are indispensable for keeping commercial losses in check. New technologies, such as prepaid meters and pay-by-phone platforms, can help utilities further improve in this area.

Metering consumption is also important for accurate customer billing. To complete and sustain a turnaround, **billing and collection systems** must be linked to a comprehensive customer database and be integrated with MIS. Successful turnaround utilities invested in information systems that digitalized commercial functions and improved integration between billing and collections. The turnaround case studies put in place systems that helped keep collection rates above 85 percent—doing so ensured the utilities had sufficient cash to operate and continue investing in improvements.

An effective **customer service strategy** also requires a comprehensive customer database. The case studies showed that successful utilities interact efficiently with their customers on every- day affairs—providing water and accurately billing them for it, responding to their complaints, connecting (and disconnecting) them, and settling accounts with them.

### 12.2.6. Legal Framework and Governance

While a competent utility manager with sufficient autonomy is needed to start a turnaround, robust legal frameworks and governance, including **formal rules and structures**, should be developed to sustain the improvements achieved—by preventing predation and political interference. This in turn ensures success in the long run. By the end of their turnaround, all successful utilities had established formal rules.

## 12.3. FACTORS TO CONSIDER FOR SEQUENCING A TURNAROUND

Utilities that successfully turned around carried out similar actions in roughly the same order, be it in different contexts and of varying duration. These actions include establishing a baseline, cleaning up finances, setting objectives and targets (in a business plan), updating MISs, and improving human resources.

In most cases, utilities established a baseline in the early stages of the turnaround as a key input for their business plan. As a result, utilities experiencing significant financial distress focused first on achieving financial sustainability by increasing revenues and/or decreasing costs. Utilities next focused on setting multiyear targets and developing sustainable business plans. For example, SDE developed a comprehensive long-term plan that first aimed to rapidly increase water production and expand service to the poor.

Almost invariably, the first actions aimed to improve human resources and MIS. At NWSC, for instance, management quickly invested in a corporate training facility to enhance staff capacity after clearly defining the company's vision, mission, and objectives.

At NYEWASCO, management adopted modern MISs to build internal capacity and a culture of transparency. Once improvements were under way, some utilities switched their focus to the sizable capital investments needed to meet ambitious goals.

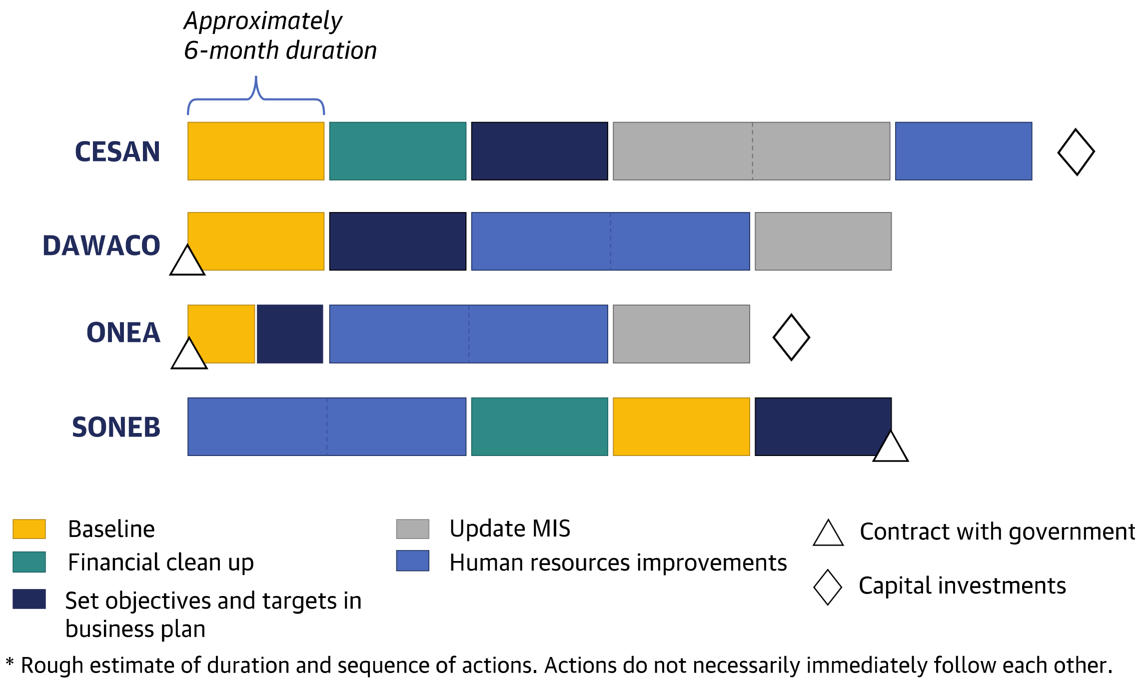



*Figure 12-1 Turnaround Sequences*

*Note:* MIS = management information system.

Three of the utilities reviewed—NWSC, SONEDE, and APA Vital—entered into contracts with the government at some point during their turnaround. This resulted in formal structures that defined the utility's expected performance, as well as the government's financial support to meet those performance targets. Other utilities used incentivized contracts for the same purpose, with senior management teams

### 12.3.1. Phase 1: Create Space for Change and Virtuous Cycles

This phase aims to develop the credibility, accountability, and autonomy needed to prepare and carry out an action plan. It is meant to create the necessary space for reform. At the end of this phase, the utility should have used the initial space for reform to open a path for *broader* reforms. The four steps of phase 1 are outlined below.

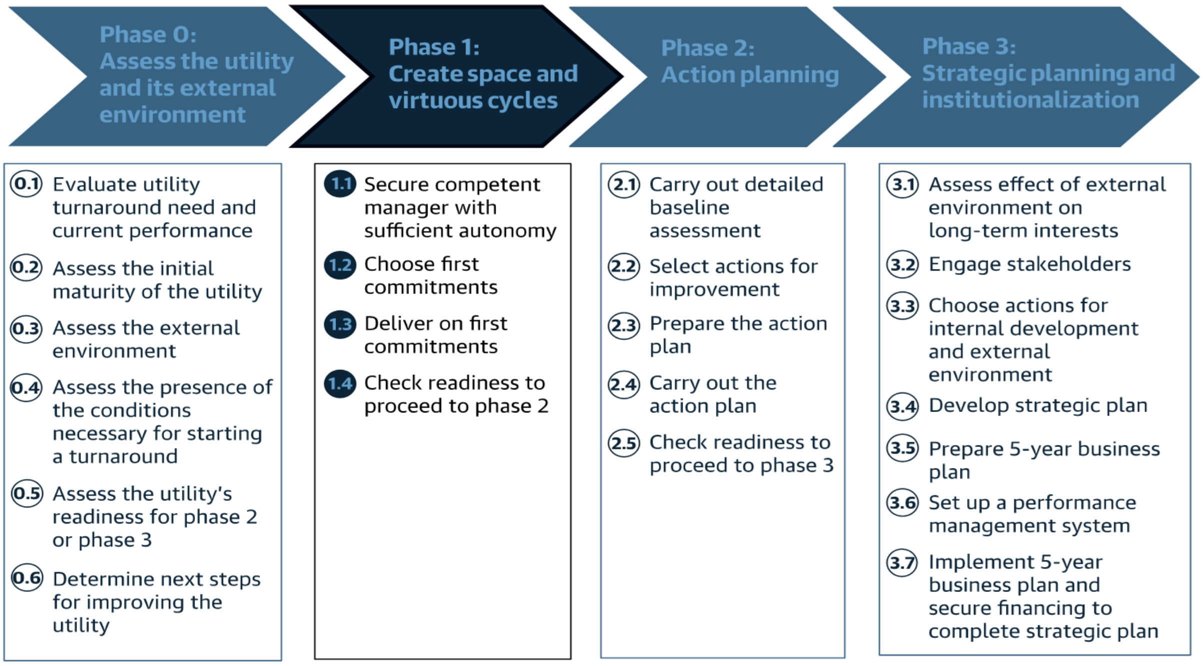



*Figure 12-2 Four steps for change*

*The timeline for completing phase 1 will vary, depending on the commitments chosen. Ideally, the four steps of phase 1 are completed in 6 months to a year. At the end of this phase, the manager can assess whether the utility is ready for phase 2. If the utility is not ready, phase 1 may have to be repeated several times. Each time it goes through phase 1, the space for change may expand enough to further build credibility.*

From the phase 0 assessment, the manager will have the information required to start the turnaround—through relatively small but high-impact interventions—to increase credibility, accountability, and autonomy. These carefully targeted interventions will increase the space for change, based on the results of the performance table and the initial maturity matrix from the phase 0 assessment. The phase 2 checklist helps the manager determine when enough space (for reform) has been created to move on to phase 2.

### 12.3.2. Secure Competent Manager with Sufficient Autonomy

If the utility does not have a competent manager with a minimum level of autonomy, the first step of phase 1 is to secure one. The government champion would be best placed to help appoint a competent manager and put in place a governance arrangement that grants the manager at least the minimum level of autonomy required to begin the turnaround. If the existing manager is competent, the government champion would only need to grant the minimum level of autonomy required to begin the turnaround.

The manager should be a strong leader, have a clear vision of the change required, and be self- driven. Moreover, the manager should have the autonomy to make the necessary decisions to start opening up the space for reform—such as reducing operating expenses and achieving basic improvements in human resources—and incentives to perform well. External incentives can be created by the government champion who took on the competent manager, or by more formal arrangements, such as a performance-based compensation scheme.

### 12.3.3. Choose First Commitments

#### Identify Root Causes

The second step involves choosing the first commitments to help break vicious cycles. The manager should make strategic decisions about feasible actions, considering the utility’s current level of autonomy.

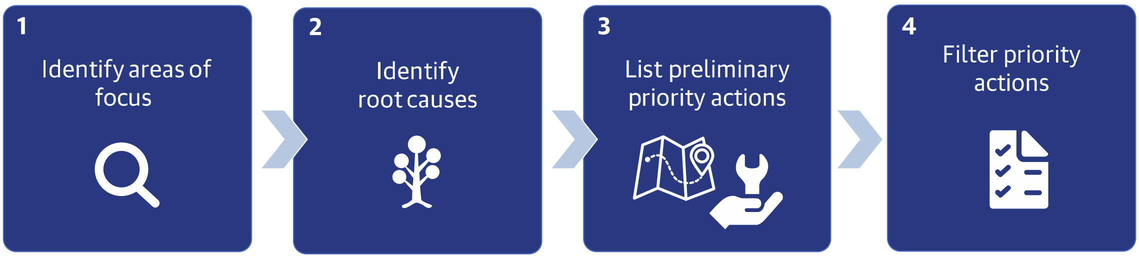



*Figure 12-3 1st commitments*

The second task involves identifying the possible root causes behind poor performance or initial maturity. Utility managers can use logic trees to this end. The problem can be dissected into probable causes visualized as branches. Probable causes are identified by asking "why" and considering the assessment of performance and initial maturity. The branches of probable causes come from primary branches until arriving at the final possible causes, given the information available.

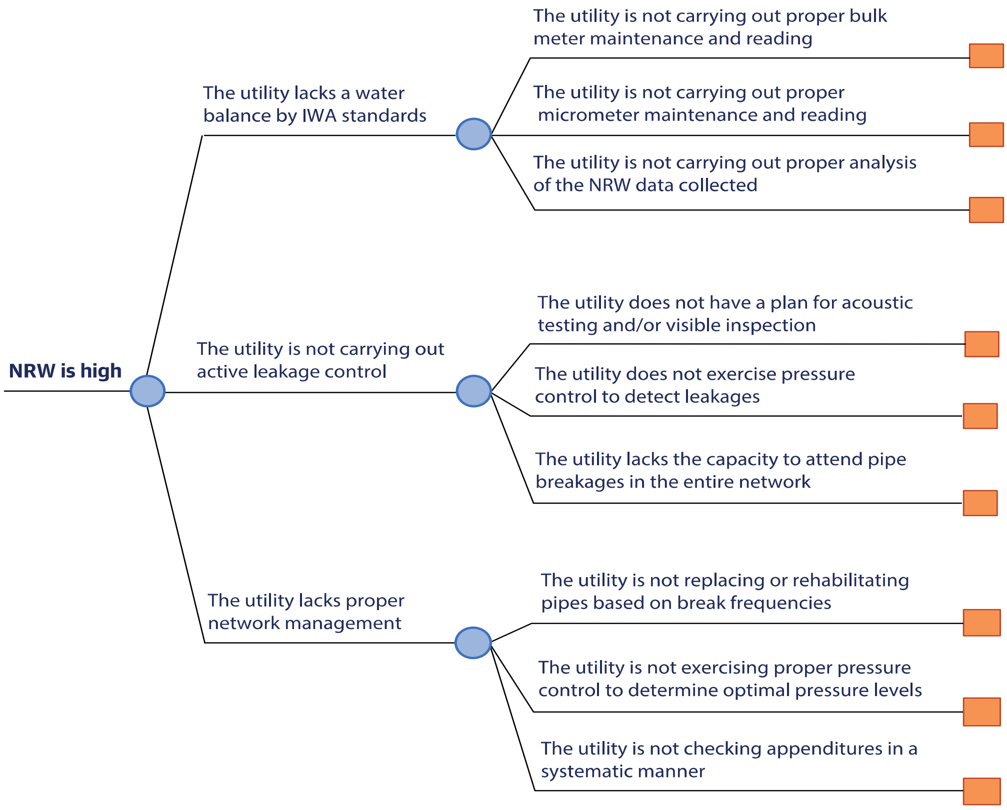



*Figure 12-4 Logic Tree for High NRW*

### 12.3.4. Phase 2: Action Planning

The purpose of this phase is to formulate and implement an action plan based on systematic, coordinated, and prioritized actions that will set the utility on a turnaround path. The action plan should be fully funded and include multiyear targets, allowing the utility to carry out the more costly and complex actions needed to continue its turnaround process. The manager will be using the tools and outputs shown to the right.

Unlike phase 1, phase 2 requires greater "depth" of management expertise, with the middle management of the utility participating fully. At the end of phase 2, the utility should be ready to transition to *continuous* performance improvements. If the initial action plan cannot deliver this (because it still suffers from systemic failures that put it at risk of backsliding to a vicious cycle), the utility should revise the action plan and take steps until it achieves the required performance and maturity level.

#### 12.3.4.1. Step 2.1: Carry Out Detailed Baseline Assessment

The first step of phase 2 is for the utility's management to prepare a detailed baseline assessment. This assessment is the backbone of a business planning process: it provides an accurate, detailed, and comprehensive snapshot of the utility's condition and performance. This snapshot will allow the utility to set performance targets and estimate the cost of achieving those targets. It will also provide a reference point for comparison as the utility proceeds on its turnaround path.

This baseline assessment will require significant time, expertise, and resources. It generally takes 6–12 months and typically requires a multidisciplinary team. The utility may need technical and financial assistance from the government and/or donors for this assessment. Once it has been completed, management can use all the data generated to identify the areas needing improvement.

Some key outputs of the baseline assessment are the following:

- **Underlying data for the utility's financial model.** The detailed baseline will yield all the data required for building the financial model, which is essential for preparing the action plan. The model will have detailed historical values and multiyear projections of the utility's financial figures, fixed assets by type, staff, customers, demand, water balance, and key performance indicators. It will thus allow management to establish current conditions, targets for improvements, and the cost of achieving those targets.
- **Detailed and accurate water balance.** NRW has a significant impact on the utility's financial position and its capacity to deliver quality service. The detailed baseline should produce the most accurate water balance possible—that is, a top-down audit of the losses of the whole system, starting with the total system input.
- **Qualitative data for completing the detailed maturity matrices.** These matrices will provide a comprehensive understanding of each element's maturity.

  With these outputs, the utility's management will have the inputs needed to develop the action plan. In addition to producing the above outputs, a baseline assessment will generally also include the following data-yielding activities:

- **Data collection.** An assessment starts by gathering available data on WSS infrastructure, ser- vice levels, income, and other demographic indicators, and researching relevant legislation, policies, and government strategies and documents.
- **Field surveys.** Field survey trips include interviews with all bodies that have responsibilities in the sector, directly observing processes at WSS facilities, mapping infrastructure, assessing O&M arrangements, and sketching water treatment and sanitation facilities and processes.
- **GIS mapping.** For utilities with the necessary technology, all WSS infrastructure should be mapped in GIS and include the best-available information from existing sources, as well as the results from field survey sketches.
- **Household surveys.** Customer enumeration surveys are conducted using GIS maps and should include all households, businesses, and organizations in the service area. Surveys should collect at least the usual number of people in each household, disaggregated by gender and age; the status of WSS coverage; reliability, quantity, and quality of service; and the status of the household meter.
- **Water quality testing.** Water quality should be tested in at least 5 percent of households in the service area by taking a sample at the point of delivery and another at the point of use.

### 12.3.4.2. Step 2.2: Select Actions for Improvement

- The second step of phase 2 is to select the actions targeting improvement for the action plan by applying a set of guiding principles and using the action matrices. In this step, it is best to use a highly participatory approach with the utility's staff to increase corporate ownership of the action plan. Management should select the priority actions by sequentially applying the five guiding principles shown in figure below:

  Figure shows the initial maturity cobweb for a hypothetical utility. In this hypothetical example, the initial maturity assessment suggests that the systems, processes, and procedures in human resources, financial management, and technical operations need to be improved.


| Items | Actions |
|---|---|
| Select balance in maturity cobweb | Identify priority areas<br>For example HR,financial and technical |
| Emphasize staff capacity | If HR is a priority area,focus on HR first<br>Develop Management team |
| Choose low-cost high impact avtions first | Collect account receivables |
| Do what is important for stakeholders | Connect the poor |
| Institutionalize reform to sustain success after achieving success | Create multistakeholder committees to monitor performance |

*Figure 12-5 Guiding Principles for Identifying Priority Actions*

### 12.3.4.3. Step 2.3: Prepare an Action Plan

The third step of phase 2 is to prepare the action plan, using the detailed baseline developed in step 2.1 and the actions selected in step 2.2. The expected duration of the action plan will vary depending on the utility's maturity, current performance, and availability of funding. In most cases, implementation of the action plan will take about 3 years, which allows enough time to carry out significant improvements. The action plan should include these key items:

- **Targets to be met.** Management identifies the specific annual targets to be achieved. These targets should be measurable, precise, time-bound, and assigned to specific units or departments of the utility.
- **Estimated cost.** Management estimates the cost of meeting the targets by building a financial model with inputs from the baseline assessment carried out in step 2.1. The financial model should accurately capture the baseline, and project the operating and capital costs for the utility, using a set of assumptions about the desired performance targets.

  • **Financing plan.** The action plan cannot be carried out without securing the total funding required to meet the targets. Insufficient funding would compromise efforts to increase credibility, autonomy, and accountability. The utility's management is responsible for securing the required funding.

### 12.3.4.4. Step 2.4: Carry Out the Action Plan

After securing funding, management should begin making the improvements set out in the plan. It should designate departments responsible for achieving each target and allocate resources accordingly.

Department managers and staff should be committed to meeting their targets. Staff performance should be closely monitored, preferably through a performance evaluation system. If compensation is not yet performance-based, staff can be incentivized in other ways to perform—for example, through bonuses, specialized training, or a collective reward.

As soon as actions begin, they should be closely monitored. Each department should have a clear mechanism to monitor performance, and actual performance should be regularly com- pared against targets. Ideally, management meets quarterly to review performance against targets and adjust resources accordingly (see box 4.8 for an example of this in a utility that achieved a successful turnaround). When performance is below target, management must adjust resources or responsibilities.

How effectively the plan is carried out will depend on management's ability to adjust resources and ensure that actual performance meets projected targets.

#### 12.3.4.5. 11.4.4.5. Step 2.5: Check Readiness to Proceed to Phase 3

The fifth step of phase 2 is to determine whether the utility is ready to proceed to the next challenge: to institutionalize practices that sustain performance. As the end of the action plan approaches—say, 3 to 6 months before the end—the utility's management should check whether it is ready to proceed to phase 3.

The utility is likely to have sufficient credibility, accountability, and autonomy for phase 3 once it has achieved level 3 or above in the performance and maturity cobwebs. At that point, it will have implemented enough low-cost, high-impact actions to achieve institutionalized levels of performance and maturity.

### 12.3.5. Phase 3: Strategic Planning and Institutionalization

This final phase aims to move from initial actions for improvement to a strategic plan that institutionalizes and sustains the improvements realized. It should facilitate the switch away from focusing on *short-term* measures to fix the most glaring problems toward institutionalizing improvements that sustain successful performance. The manager should carry out this phase using the tools and outputs shown to the right. Phase 3 consists of seven steps (figure below).

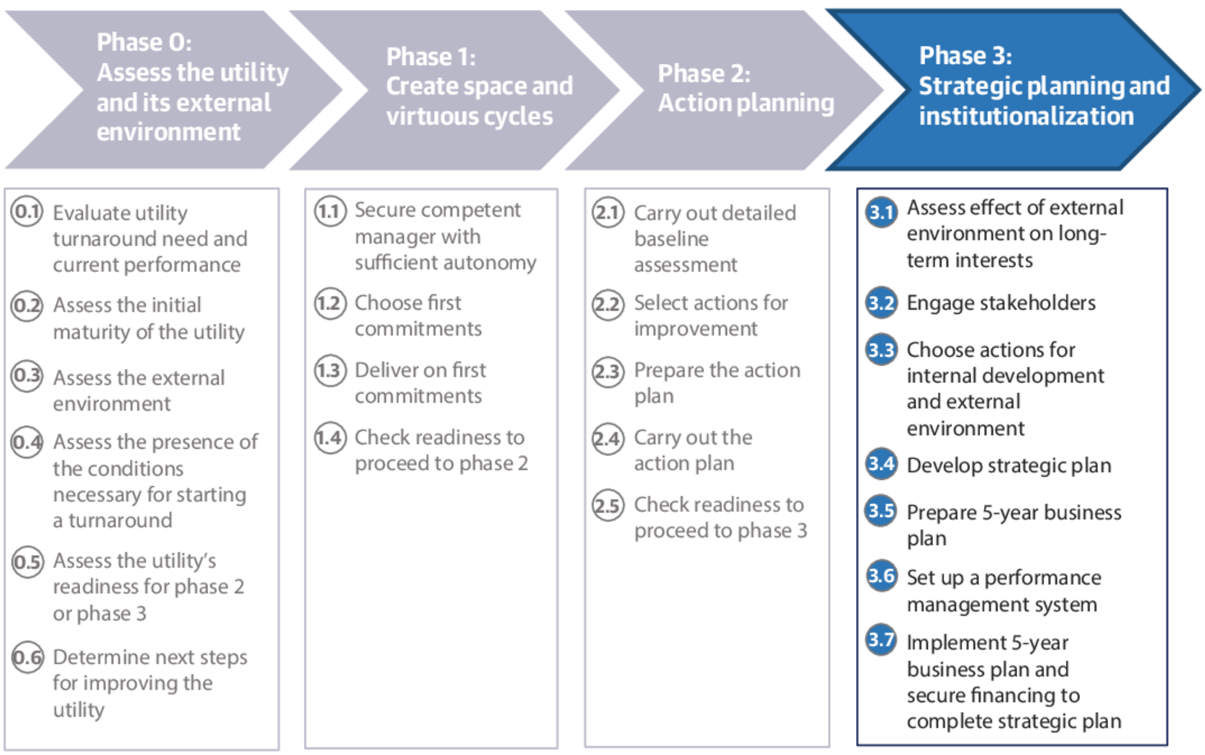



*Figure 12-6 Steps to Design and Implement a Strategic Plan*

To become a world-class performer, the utility should design a two-track strategic planning approach—the first track focusing on improvements that solidify internal development, and the second track focusing on engaging and cooperating with stakeholders who may affect the utility's long-term interests. Moreover, the approach should establish a *long-term* strategic vision (looking at least 15 years ahead), supported by a strategic plan.

Most utilities starting in phase 3 will require significant time and resources to achieve ambitious objectives such as meeting the SDG for drinking water and sanitation. To ensure that the long-term strategy is implemented, the utility should prepare 5-year business plans that segment the strategic plan.

Sustaining improvements to reach world-class performance will require longer-term, higher-cost capital investments, and dedicating resources to proactively influence the external environment. In addition, the utility should have discernible levels of good maturity and performance at the beginning of this phase—have the vision and ambition to aim for excellence.

To ensure that the external environment fosters successful performance, the utility should start advocating its long-term interests:

**Regulatory stability**. The utility should make sure that the regulatory framework in place allows it, for the foreseeable future, to cover all costs of providing the expected service, with a revenue stream that can be predicted accurately and reliably. To meet this objective, the regulatory framework will need to have a robust mechanism for setting and adjusting tariffs, clearly defined performance standards that are not subject to frequent or arbitrary changes, and transparent accountability mechanisms for enforcing standards.

**Labor stability.** The utility should make sure that it can rely on a pool of competent, capable staff subject to high performance standards. To meet this objective, the labor market should supply qualified individuals, and labor regulations should incentivize good performance.

- **Financial sustainability**. The utility should make sure that it can readily access the financing required for the capital investments needed to maintain high levels of access to WSS, quality of service, and operational efficiency. It can achieve this objective with strong financial performance, transparent financial reporting, and by ensuring that it uses financing efficiently and effectively. Ultimately, if a utility can pay the cost of capital, it will have access to the capital it requires.
- **Deep and broad customer satisfaction**. The utility needs to ensure that customers consistently find that it is the best and least-cost source for providing WSS services. This will generate strong customer support and ensure that its fixed asset base remains productive. The utility's customers will be satisfied if it prioritizes a customer focus, maintains a high level of service quality, and communicates directly and frequently with them.

#### 12.3.5.1. Typical Stakeholders Affecting Long-Term Interests

Following figure indicates typical stakeholders affecting long term interest

| Long-Term Interest | Typical Stakeholder |
|---|---|
| Regulatory stability | Government<br>Regulator<br>Labor stability |
| Labor unions | Labor department<br>Licensing agencies<br>Education department |
| Integrated water resources management | Government<br>Water management authorities<br>Municipal government<br>Urban planning department<br>Environmental agency |
| Financial sustainability | Government<br>Regulator<br>Commercial banks<br>Credit rating agencies<br>Institutional investors<br>Development banks |
| Deep and broad customer satisfaction | Consumer associations<br>Large customers<br>Customer committees |

*Figure 12-7 Typical Stakeholders Affecting Long-Term Interests*

#### 12.3.5.2. Develop a Strategic Plan

The fourth step is to develop a strategic plan, based on the outputs of the previous steps in phase 3. The strategic plan typically covers 15–20 years and should explicitly describe all the utility's long-term objectives. Utilities aspiring to world-class performance aim for universal coverage, excellent operational efficiency, and financial sustainability.

#### 12.3.5.3. Prepare 5-Year Business Plans

Once the strategic plan is ready, the utility should segment it into 5-year business plans for implementation. For example, a 20-year strategic plan should be developed into four 5-year business plans. The specific actions included in the first business plan should be selected based on the relevant guiding principles for internal and external development. This will allow the utility to prioritize correctly the actions included in its first 5-year business plan.

#### 12.3.5.4. Set Up a Performance Management System

Every utility has to incorporate continuous improvement and learning curves as it develops.[22] To this end, in this step of phase 3, the utility's management should develop a performance management system to ensure that the utility can monitor, review, and (if necessary) adjust the strategic plan during its implementation. The proposed performance management system is an iterative process with the following key components.

[22] Water-Utility-Turnaround-Framework-A-Guide-for-Improving-Performance.pdf by World Bank Group

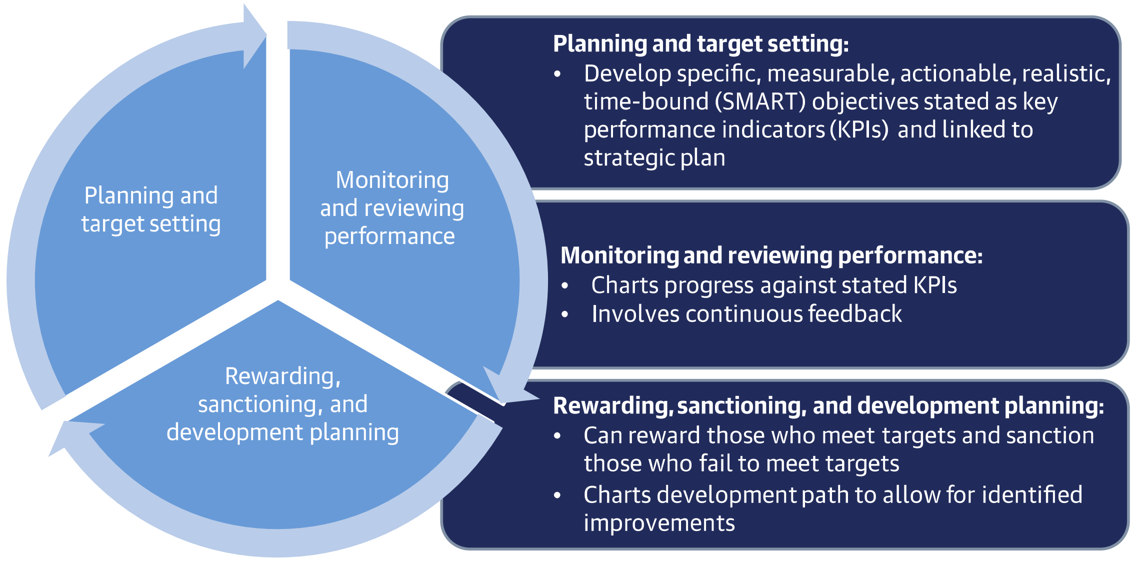



*Figure 12-8 Three Stages in the Performance Management Process*