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**DEVELOPING A MAINTENANCE MANAGEMENT
SYSTEM FOR WATER TREATMENT PLANTS IN
NAJAF AL-ASHRAF (IRAQ)**

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Master's Thesis

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İstanbul, 2024

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Signature

DEDICATION

This study is addressed to my parents, brothers, sisters and close friends. My father, the late Jalal Habeeb, who supported and helped me throughout my life and inspired me with strength and self-reliance. I can't find enough words to describe it. He died at almost the same moment I was preparing to complete this study. My mother was a source of motivation, encouragement and strength in moments of despair and frustration. Special thanks to my supervisor for his support and assistance in completing this study.



ABSTRACT

DEVELOPING A MAINTENANCE MANAGEMENT SYSTEM FOR WATER TREATMENT PLANTS IN NAJAF AL-ASHRAF (IRAQ)

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Producing potable water is a fundamental task of infrastructure, primarily executed through potable water liquefaction units. Hence, maintaining these units is crucial to sustain their potable water production and extend their economic lifespan. Additionally, rejuvenating these units parallels comprehensive maintenance at the end of their economic cycle. Therefore, the focal point of this research is the preparation and advancement of a maintenance management system for these units, aligning its significance with the maintenance process and potable water production. This initiative represents the core objective of this research. The study delves into the principles of maintenance management and how to structure a system and its constituents. To provide a clear understanding of the research problem, it proceeds to explore the maintenance of drinking water liquefaction units. This exploration is substantiated by an in-depth analysis of the maintenance reality in water projects, encompassing the methods, frequency, and duration of maintenance activities, as well as administrative aspects tied to maintenance. The goal is to devise a modern, contextually fitting maintenance management system applicable to the water liquefaction units located in various regions around Najaf. Several deficiencies were identified within the existing system, the most significant being inadequate and inconsistent documentation and reporting of maintenance activities, along with the absence of an evaluation system for the maintenance process. This absence leads to an unstructured approach to planning, scheduling, and monitoring, devoid of standardized controls for

maintenance performance. The limited budget allocated to unit maintenance inevitably results in the neglect of certain less critical maintenance tasks, amplifying potential issues due to delays in completing essential activities. To address these criticisms and enhance the current maintenance management system, the researcher proposed multiple subsidiary systems that collectively form the primary system. This proposed system comprises five key components: a planning subsystem to optimize the total maintenance cost, a staff allocation subsystem determining the necessary staff numbers and types based on the unit's capacity, a budgeting system calculating the available funds, an evaluation subsystem suggesting criteria for maintenance performance assessment (the cost of producing one cubic meter of water and staff productivity), and a reporting subsystem supporting an improved documentation system. Furthermore, a computer program was recommended to implement the proposed planning system, and the project management program (Microsoft Project) was advocated for leveraging its capabilities, including monitoring and report generation.

Keywords: Maintenance, DOSD, Water Treatment Plants, CTA, Microsoft Project.

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ABBREVIATIONS

MTBF	:	Mean Time Between Failure
CMMS	:	Computerized Maintenance Management System
RCM	:	Reliability-Centered Maintenance
KPI	:	Key Performance Indicators
KSA	:	Kingdom of Saudi Arabia
QMS	:	Quality Management System
SCRB	:	State Commission of Road and Bridges
CTA	:	Certification of Training Achievement
ICC	:	Intermediate Construction Certificate
NVQ/SVQ	:	National Vocational Qualification/Scottish Vocational Qualification
US	:	United States
CCMUA	:	Camden County Municipal Authority
EMS	:	Environmental Management System
NEIC	:	National Enforcement Investigations Center
APUB	:	Akron Public Utilities Bureau
SDLC	:	System Development Life Cycle
IWAMS	:	Integrated Water Asset Management System
SCADA	:	Supervisory Control and Data Acquisition
USD	:	Union Sanitary District
BCEOD	:	Broward County Environmental Operations Divisions

IAS	:	Information Access System
EOMs	:	Maintenance Manuals
LCCA	:	Life Cycle Cost Analysis
O&M	:	Operations and Maintenance
LOS	:	Level of Service
CIP	:	Capital Improvement Program
R&R	:	Repair and Replacement
DOSD	:	Division of Sewerage and Drainage
RCM	:	Reliability-Centered Maintenance
NWA	:	Najaf Water Administration
SS	:	Start-to-Start
FF	:	Finish-to-Finish
SF	:	Start-to-Finish
FS	:	Finish-to-Start

1. INTRODUCTION

1.1 INTRODUCTION

Water management is crucial for human existence, economic development, and environmental preservation, but increasing urbanization and climate change make access to clean water increasingly challenging [1]. A water treatment facility is designed to produce and supply safe, reliable drinking water, prioritizing public health. The original facility was established in 1915, and over the years, various additions and modifications have enhanced its capabilities. The sedimentation basin and clear well are parts of the original construction that are still in use. Notable upgrades and modifications took place in 1941, 1944, 1957, 1961, 1965, 1972, 1977, 1986, 1988, 1989, 1991, and 1995.

The rapid development of computers and computational power over the past decade has encouraged researchers from various disciplines to show more interest in using numerical methods for data [2]. Maintaining the structural integrity of the buildings has always been a major focus, ensuring they remain in excellent condition. The dedicated plant personnel are committed to efficient operation, thorough maintenance, and cleanliness of the plant's processes, equipment, buildings, and surroundings. Historically, plant operators primarily managed the process control aspects, while maintenance mechanics handled maintenance tasks. In some cases, maintenance staff assisted operators in their duties. However, with the current trend towards utility privatization and automation, a Managed Maintenance Department was established. This department, supported by a computerized maintenance management system, is dedicated to preventive and predictive maintenance efforts. The Managed Maintenance Department oversees administrative tasks, planning, scheduling, and maintenance data management. The approach emphasizes teamwork and comprises multi-skilled work groups within the department [3].

Managing water treatment plants now is an important issue among modern systems of management. Therefore, maintenance management is a good approach to keep the main function of these plants. Groundwater, despite being essential for human survival, can cause significant damage to structures, particularly foundations and basements, necessitating the implementation of groundwater protection systems in buildings [4]. Assessing the value of project management as a tool and basis for development provides organizations with many advantages in the field of global competition [5]. Building life cycle analysis involves

selecting materials that significantly impact energy consumption and environmental damage, affecting sustainability [6].

1.2 MAINTENANCE DEFINITION

In order to explain the whole meaning of the word “maintenance”, many definitions are given at this scope and as [7]:

- a. The combination of any actions taken to safeguard an item with the goal of restoring it to a desirable condition. Then acceptable standard must be sought to meet the definition requirement. This standard set by the organization, which is carrying out the maintenance.
- b. Number of tasks that must be done for the aim of keeping the assets or repairing them and resuming these assets to the original situation or to an acceptable condition.
- c. Preventive process aims to avoid failures and damages at any structure, or repairing failures or damages, and removing defects from the structure returning to a condition that the structure can does its function without any danger.
- d. A try to keeping assets in use through economic life, such that maximize revenues and minimize costs.

From the definitions above it's clear that the term maintenance is dealing with any action being taken to the assets that gives these assets the ability to work safely and economically (and this represents the researcher opinion). Thus, the main objectives of maintenance can be clearly delineated as follows:

- a. Extending the lifespan of assets.
- b. Securing optimal availability of installed equipment for production or service to achieve the highest possible return on investment.
- c. Sustaining operational readiness of all equipment crucial for emergency use at all times.
- d. Ensuring the safety of personnel using facilities.

1.2.1 Types of Maintenance

Maintenance can be classified with many manners according to many purposes of the works to be executed; these manners are closely related to the development of the maintenance itself and the development of the methods of execution of this process. The first beginning of maintenance was with simple repairing for the failed part after it was happening. Then the concept of maintenance developed to be protecting and keeping the assets in work

economically. Classification also developed to be in parallel with development of maintenance of a number of these classifications as can be seen in the following.

a. Maintenance classification according to the size

With this type of maintenance classification, maintenance can be classified according to the size and the nature to major, minor and essential services, after assessment of the limitations of the majority or minority (e.g., major maintenance is any maintenance activity which has an expenditure greater than US\$2500 using cost factor). Time can be used for differentiating the major maintenance activities from minor, figure 1.1 shows this type of classification [8].

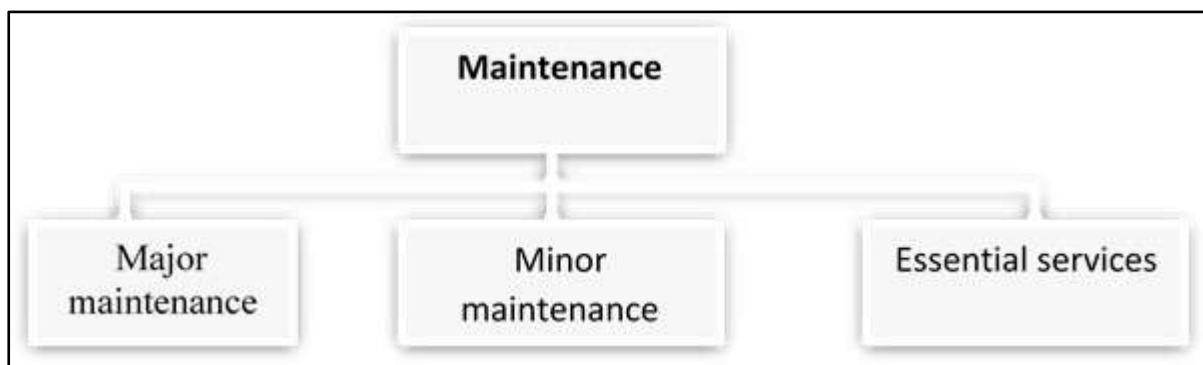


Figure 1.1: Maintenance Classification According to the Size .

b. Maintenance classification according to expenditure budget

Maintenance classification according to expenditure budget is divided to cyclical maintenance which includes items must be carried on routine basis and regularly, and occasional maintenance which includes items that will be carried out only when inspections reveal a serious damage or faults [9]. This type of classification can fall into many other types of classification. While the researcher believes that occasional and cyclical maintenance can depend on many factors in addition to expenditures as the expenditures related with the time in which expended.

c. Breakdown Maintenance classification

This old type of maintenance classified maintenance into two types: preventive corrective. Preventive maintenance is subdivided into scheduled maintenance and opportune maintenance, or this old type can also be divided into three major types: scheduled preventive maintenance, corrective maintenance, and unplanned maintenance. Adding unplanned maintenance will change the type of classification as in the next paragraph [10].

d. Planned and unplanned Maintenance classification

The widely used classification (and most common) is according the process of maintenance which classified maintenance to planned and unplanned where planned maintenance is also subdivided to corrective maintenance and preventive PM, figure 2.2 shows this classification [11].

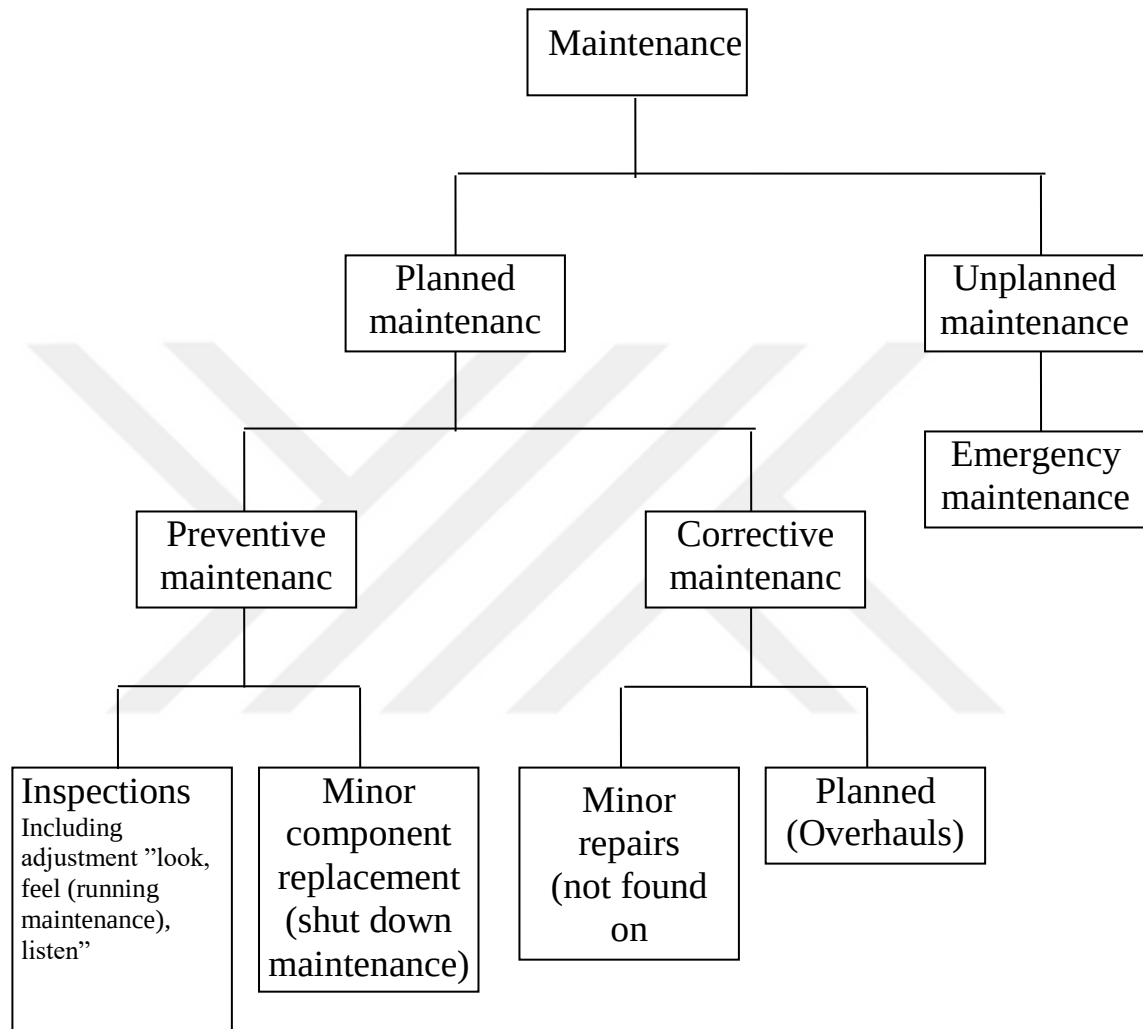


Figure 1.2: Maintenance Classification (Planned and Unplanned) .

The reason of because it's summing most of the ideas of the classification above is the reason that made it widely used. In this research this type of classification to be used and will be discussed in details in the next paragraphs as a preface for discussing maintenance.

i. Planned maintenance.

It embodies a systematic maintenance procedure meticulously planned, structured, and implemented with a focus on control and thorough documentation. This organized method encompasses routine inspections and servicing aimed at maintaining facilities in an optimal

condition. The primary goal is to establish a robust framework capable of identifying potential failures, making necessary adjustments or repairs to prevent such issues. This comprehensive strategy goes beyond the fundamental task of sustaining plant operations; it involves designing technical and human systems to ensure the production process operates within defined tolerance levels, facilitating effective system performance.[12] Failure rates may adhere to various statistical distributions. In the initial phases of production, a noticeable high failure rate, termed as infant mortality, is observed. Many companies conduct tests to identify "startup" issues before shipping. Once the production process stabilizes, an analysis of the MTBF (mean time between failure) distribution can be conducted. A minimal standard deviation in the distributions indicates a potential candidate for planned maintenance, even if the associated maintenance costs are high.

When assessing candidates for planned maintenance, it is crucial to evaluate the economic feasibility of such maintenance activities. Generally, as maintenance costs increase, the MTBF distribution must narrow. Additionally, if the cost of repairing the process when it malfunctions is no greater than the cost of planned maintenance, allowing the process to break down and then conducting the repair may be a prudent approach. At this stage, failures typically adhere to a normal distribution pattern. At the end of lifetime, the failure trend begins to be in increasing state as figure 1.3 shows.

Planned maintenance consists of two main activities: preventive and corrective. Preventive maintenance is scheduled at predetermined intervals or based on specific criteria to reduce the likelihood of an item dropping below an acceptable condition. The primary focus of preventive maintenance involves inspections conducted through the "look, feel, and listen" approach. It also includes minor adjustments at scheduled intervals and the replacement of minor components identified during these inspections. In the realm of preventive maintenance, each task is identified before any failure or deviation of the facility from acceptable standards occurs.

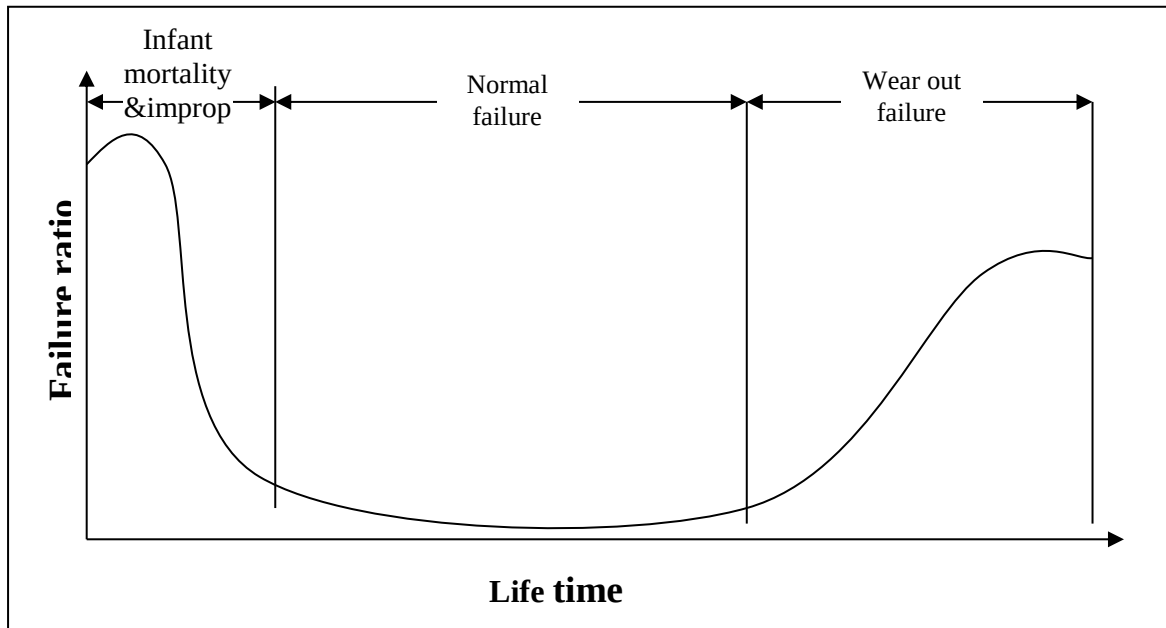


Figure 1.3: Life Time Failure Rates [12].

Major maintenance is feasible while the item is in service, whereas minor maintenance cannot be executed during service. Corrective maintenance is the category of maintenance performed to restore an item, involving adjustments and repairs, when it falls below acceptable conditions. Corrective maintenance covers minor repairs, frequently with short-term planning, which may arise between inspections. It also encompasses planned overhauls, like yearly overhauls, with details carefully planned on a long-term basis as a result of preventive inspections. Corrective maintenance stands out in its requirement for restoration to an acceptable standard and typically takes precedence in the allocation of available resources. The researcher believes that both preventive and corrective represent the two hands of planned maintenance, which is must work in parallel to keep all assets in a good condition [13].

ii. Unplanned maintenance

It's also called breakdown, so it has only one form that is the emergency maintenance. Heizer and Rounder defined it Maintenance demanding immediate attention to avert serious consequences, like loss of productivity, significant asset damage, or safety risks, is termed unplanned maintenance. Contingency maintenance serves as an alternative name for unplanned maintenance, defined by a policy of reacting only upon receiving a complaint from the user. In numerous developing countries, the contingency system stands as the predominant maintenance approach adopted by public authorities. The outcome of this

system is that critical tasks involving inspection and planned maintenance are assigned to untrained individuals [14].

1.2.2 Maintenance Cost

If someone inquires whether planned maintenance is constrained or disregarded, the response to this query is rooted in maintenance costs. Planned maintenance, encompassing expenses such as inspection and minor repairs, is associated with cost increments. Simultaneously, it results in diminished costs linked to failures and emergency maintenance. Therefore, maintenance costs cannot be escalated disproportionately, as this would be economically unsustainable and counterbalanced by the increased costs. Figure 1.4 visually depicts the correlation between maintenance costs [14].

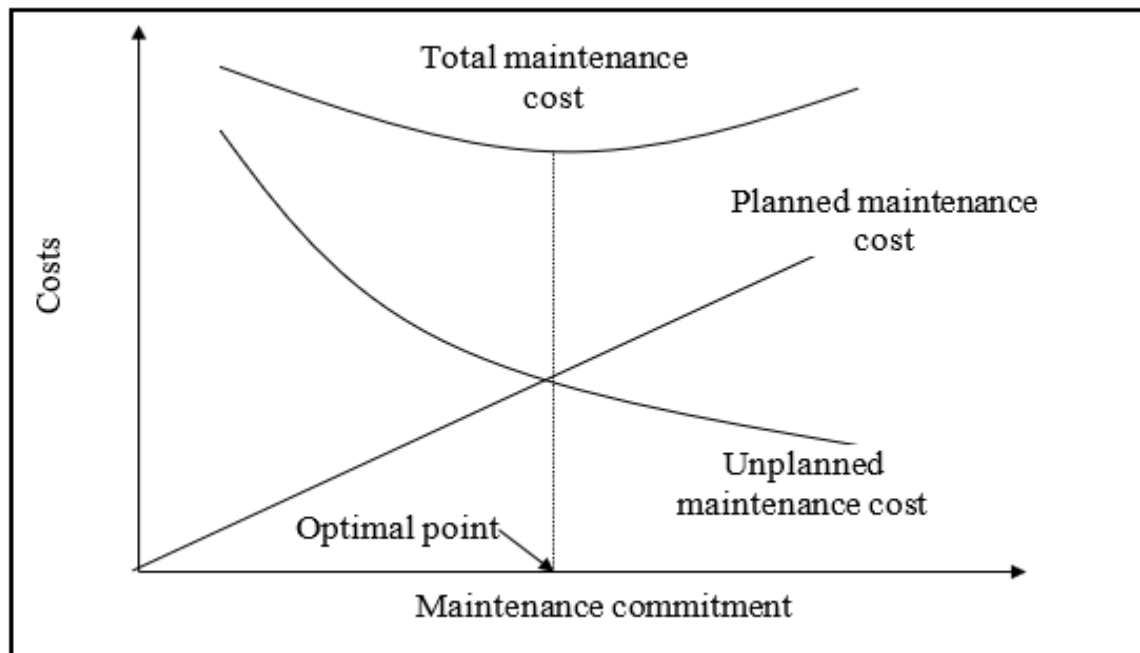


Figure 1.4: Maintenance Cost [14].

1.2.3 Maintenance Tools

In the present day, standard maintenance tools heavily rely on advanced strategies, as outlined by Oman [15], Paul, and colleagues in 1990. These tools encompass the following: Advanced CMMS Systems: The spectrum of maintenance management systems available today is extensive. Some systems even feature internet interfaces and electronic commerce functions. They have evolved to include Incorporated modules designed for effective administration of equipment maintenance strategies and optimization of inventory levels.

Preventative maintenance optimization techniques: Originating from the inception of Reliability-Centered Maintenance (RCM), this methodology has experienced rapid development. A plethora of companies and products now exist to optimize maintenance strategies across various industries. Numerous software applications are designed to provide assistance in this domain, extending to specialized areas like Root Cause Analysis, incorporating refined reliability engineering techniques.

Predictive Maintenance Technologies: Significant advancements have been made in this domain as well. A wide variety of techniques and applications for predictive technologies now exist, some of which were not even conceived of two decades ago.

Expanded Knowledge Base: Maintenance professionals today possess a broader range of knowledge compared to their counterparts twenty years ago. They have a comprehensive understanding of all realms of maintenance management, numerous advanced techniques and concepts have surfaced.

Even with these impressive technological advancements, a significant portion of maintenance departments continues to primarily practice reactive maintenance. The cause behind this is the inability of business processes to keep up with the changes with rapidly advancing technologies. Without a sharp focus on aligning business processes with technological advancements, the maintenance department remains trapped in a cycle of reactive spending. This progression of the maintenance department toward continually reducing costs and enhancing reliability unfolds through four distinct growth stages, each characterized by specific indicators. The first two stages involve the shift from a reactive approach to a planned state of maintenance.

Reactive State: This tool is represented by the measures below:

- a. Low Equipment Reliability
- b. Low Mean Time to Repair
- c. Inaccurate Inventory Planning
- d. Many Uncontrolled Stores
- e. Highly Reactive Workforce

vi. Planned State

- a. Management of Maintenance Resources: Effective maintenance planning and scheduling procedures result in significant shifts in the requirements for maintenance resources on a

weekly or even monthly basis. This transformation enhances resource management and planning over extended periods.

- b. Enhanced Inventory Control: Improved equipment reliability and efficient planning directly translate into better control over maintenance store throughputs, leading to streamlined inventory management.
- c. Reduction of Business Process Waste: Accurate planning and scheduling processes drastically reduce wastage in operations. Common forms of waste, such as Waiting times for materials, availability of equipment, and the provision of accurate information are significantly reduced.
- d. Accurate Maintenance Budgeting: Enhanced equipment reliability allows for substantial improvements in budget accuracy. Forecasting maintenance needs, be it by equipment or activity, becomes highly accurate once a planned maintenance stage is achieved.
- e. Decreased Maintenance Costs: A meticulously planned and scheduled task is at least 50% more efficient, both in terms of costs and time needed for completion. Implementing this efficiency standard across unplanned tasks leads to substantial cost savings. The subsequent phases in the evolution of maintenance management encompass optimization and achieving globally accepted world-class standards. However, the primary objective here is to chart the course from a reactive to a planned maintenance state.
- f. CMMS System: This step primarily refers to the system utilized to govern the complete maintenance function within the organization can be managed effectively. While adopting modern technology with a CMMS or EAM-style management system is ideal, achieving this objective is also feasible through a paper-based system. The meticulous selection and implementation of the system are essential to meet both current and future requirements.
- g. Definition of Work Processes: Clear delineation of all work processes to be employed throughout maintenance execution is essential. This includes establishing corporate business rules and integrating them with the chosen control system (CMMS). Critical components comprise systems for handling work requests, establishing standards for creating work orders, principles for backlog management, planning processes, data management for completed work orders, scheduling procedures, protocols for technical changes to equipment, processes for planning and executing shutdowns, analysis

procedures and policies, management of spare parts systems, mechanisms for inventory control, and processes for maintenance budgeting.

- h. Equipment Strategies: In the implementation phase, it is crucial to review and refine preventative and predictive maintenance strategies to improve equipment reliability. This involves careful selection, execution, and subsequent analysis using credible programs tailored to the plant's age, equipment types, and organizational goals.
- i. Exception and Functional Reports: This step involves establishing reporting hierarchies to control and facilitate business rules and processes effectively. Functional reporting aids in capacity scheduling, while exception reporting helps identify deviations from established rules and criteria.
- j. KPI Reports (Key Performance Indicators): Defining maintenance management goals and determining the KPIs necessary to monitor progress towards those goals is a critical step. KPIs can be structured hierarchically and interlinked to enable efficient root cause analysis of system failures.

The journey to genuine, long-term maintenance improvement is undoubtedly challenging. However, as the system stabilizes and continuous improvement gains momentum, it becomes more self-sustaining. By firmly establishing and disciplining these steps, organizations position themselves to progress towards optimization and achieving world-class standards in maintenance management, unlocking further bottom-line gains.

1.2.4 Maintenance Management System

Maintenance management can be succinctly defined as the efficient oversight of resources to achieve a specified service level. When all the elements of activities are executed in a prescribed sequence, it indicates the application of system concepts and compliance with the processes of performance budgeting [16].

Several fundamental aspects of a maintenance management system have been recognized, including:

- a. Inventory and Maintenance System Features
- b. Standards
- c. Planning, Budgeting, and Working Control Procedures
- d. Information Gathering and Reporting System
- e. Workforce

When appropriately aligned, these features create a cycle of planning, execution, and comparison—an approach adopted by most effective management systems. Supporting activities, like data collection, interpretation, and reporting, in conjunction Human intuition and experience act as the driving forces that facilitate the optimal completion of the cycle. Figure 3.6 illustrates the interconnectedness of these features.

1.2.4.1 Planning

The planning component involves the thorough process of assessing and choosing the optimal course of action. When it comes to planning a maintenance program, certain requirements need to be fulfilled:

- a. **Specific Goals and Objectives:** Clearly articulated objectives and goals are fundamental elements of the planning phase.
- b. **Estimation of Work Type and Volume:** Understanding the crucial aspect is determining the type and volume of work required to achieve the desired level of service. of maintenance program planning.
- c. **Timetable for Work Execution:** A well-structured timetable outlining when the work will be conducted is a vital part of the planning process.
- d. **Allocation of Budgeted Resources:** Adequate allocation of budgeted resources is essential to guarantee the successful implementation of the maintenance program.
- e. **Data Allocation and Feedback System:** Establishing an effective data allocation and feedback system is key to monitoring progress and making informed decisions.

The planning activities culminate in the creation of a maintenance work plan, serving as the groundwork for monthly operating plans, daily schedules, and performance evaluations is established on a clearly defined foundation. Nevertheless, before engaging in planning activities and program development, several preliminary steps must be taken:

Step 1: Define Maintenance Activities

Each significant maintenance work activity requires a precise definition to accurately identify the condition to be addressed and determine the appropriate actions. Maintenance work activities encompass various types of work performed, usually concentrating on tasks carried out frequently and in significant volumes. In the realm of maintenance management systems, three types of standards are utilized:

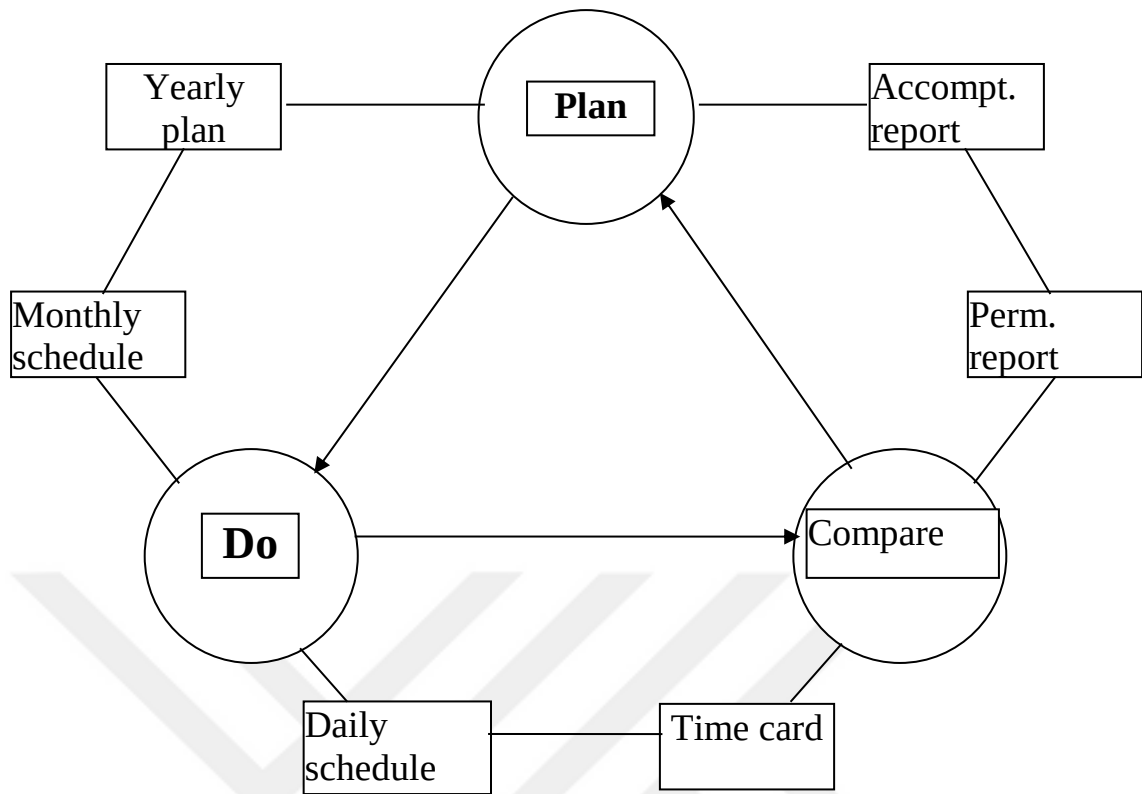


Figure 1.5: Maintenance Management System Cycle [16].

a. Quality Standards:

Quality standards establish precise criteria for how each completed maintenance activity should appear or function as a result of maintenance efforts. These standards take into account an agency's maintenance representation or level of service policy. Furthermore, quality standards delineate threshold or tolerance levels, indicating when work should commence. Essentially, they articulate the desired outcomes to be achieved.

b. Quantity Standards:

Quantity standards outline the necessary amount of work and resources to meet the quality standard or predetermined level of service. Additionally, they are employed to assess the labor, equipment, and material requirements for the maintenance work program.

c. Performance Standards:

Performance standards outline a general approach for task execution, detailing the necessary resources and the pace at which the work should proceed. These standards outline the specific personnel and equipment types and quantities, and materials required to complete a unit of work at an optimal rate or pace for the workers.

Activities should strike a balance, not being overly broad to encompass numerous alternative objectives, yet not overly restrictive to confine them to a single step within a completed operation is considered a work measurement unit. Work measurement units for work activities should be easily identifiable, and maintenance work activities should have a reasonable coding system that aligns with the organization's financial recording system.

Step 1 – Creating a Maintainable Features Inventory: Ideally, a maintainable features inventory should involve counting all maintainable features within a specified system area.

Step 2 – Establishing Priorities: Policy alterations, available funds, equipment, or personnel changes can influence the level of service provided by the maintenance organization.

Step 3 – Setting Standards: Standard values are essential for maintaining a consistent method to estimate resource requirements for maintenance programs and for evaluating individual or crew performance. The way these standards are employed determines the true effectiveness of the management system.

Step 4 – Compiling Cost Data: Compiling cost data is crucial as it assists in developing accurate mathematical models to predict various categories of maintenance cost requirements, creating a highly useful tool. Many management systems collect costs for each defined work activity, either internally or through periodic surveys of the local market. These costs typically encompass labor, equipment, and material expenses and are often stored in a computerized cost data file.

1.2.4.2 Budgeting

Developing budgets for ongoing operations and maintenance expenses is straightforward, as they can be derived from maintenance contractors' bids and historical cost records. However, creating capital replacement budgets requires specialized experience and knowledge that many property management firms may not possess. In accordance with most condominium association by-laws, the Board of Directors is required to establish and maintain capital replacement budgets and funding plans. Items such as roof systems, cooling towers, pool equipment, and exterior waterproofing systems have highly predictable life spans. Planning for their replacement, along with securing the necessary funds, is a task that can and should be undertaken years in advance [17].

A budget can be defined as an operational plan that consolidates cost estimates for a specific timeframe and outlines the intended methods of funding for the plan.

In the context of organizational activities, the responsibility for motioning a budget usually falls on the executive team. This involves aligning financial data (accounting records) with projected program requirements for various governmental functions and activities. The budgeting process involves three primary steps: preparation, adoption, and execution.

Discussing budgeting necessitates acknowledging the close interrelation between accounting and budgeting practices. For effective agency budgeting, both during the preparation and execution phases, accurate and appropriately categorized data from the organization's accounting system is indispensable.

1.2.4.3 Work scheduling

Scheduling involves the coordination of logistical aspects during the execution phase of work, often revealing areas of deficiency in the planning process that need to be addressed. Efficient scheduling typically adopts a capacity-scheduling approach, wherein the majority of the scheduling work takes place using modern systems that can output data to spreadsheets or similar tools [18].

a. Collecting Overhead Labor Hours: This includes safety meetings, toolbox meetings, break times, training periods, holidays, and categorizing them as standing work orders for future analysis.

b. Deducing PM Completion Hours: Based on data from the Computerized Maintenance Management System (CMMS), this focuses on ensuring optimal maintenance of equipment.

c. Implementing Corrective and Approved Improvement Measures: Determined by the prioritization system and operations plan, these constitute scheduled work orders. A metric for assessing the effectiveness of the priority system could be the age of work orders relative to their priority.

d. Balancing Planned Work Levels: The total hours allotted for corrective, preventative, and improvement work should match the planned/scheduled work levels. Initially, it's advisable to set a practical benchmark within the range of 70% to 80%, progressively working towards a more effective utilization of labor and resources.

For instance, planned work orders might be employed during opportune maintenance periods arising from major failures or operational reasons, underscoring the benefits of pre-planning. However, it is essential not to hasten equipment repairs solely because they have become available, especially if there is higher-priority work already in the plan.

Weekly reviews should focus on executed works, capturing re-scheduled works in hour terms by omission. Planned/scheduled work orders need to match the forecasted level, aiming for a planned/scheduled work order rate of 70%.

The majority of breakdown work orders typically involve tasks that are unplanned and unscheduled. However, modern systems include template work orders specifically crafted for corrective actions, effectively converting an unplanned breakdown into a "planned" one. These templates consolidate all relevant information, streamlining the planning process to highlight improvements. Moreover, these templates can integrate troubleshooting guides for specific symptoms or fault modes, derived from strategy review data. These improvements in work order templates significantly contribute to a more efficient and accurate scheduling and execution tool. Incorporating these changes into maintenance processes requires coordinated efforts through various initiatives, such as role-specific training, targeted reports for functional purposes, and the integration of KPI measurement into daily routines. It is crucial to consider the behaviors incentivized by these initiatives, often tied to salary expectations through bonus schemes. Work scheduling marks the initiation of the execution phase in the budget process. Field force managers typically commence by updating their annual work plan to accommodate unforeseen events that may render the initial plan impractical. This updating process is a collaborative effort between field or district organizations and a central office. Effective scheduling and organizing demand a thorough understanding at all management levels, ensuring alignment with the agency's goals. Annual plans document these goals and serve as the foundation for evaluating the maintenance program in the future.

1.2.4.4 Performance evaluation

Assessing the performance of individuals or crews is a vital component of an effective work control process. Work performance can be evaluated using one of two approaches: (a) comparing completed work to planned work or (b) comparing recorded time for completing work to a performance or production standard. Although these two methods are interconnected, they often serve distinct purposes. The first method provides valuable insights to agency administrators looking to monitor the overall performance of agency programs. On the other hand, the second method offers insights into how effectively individuals or crews carry out their daily tasks and meet predetermined quality benchmarks.

Both methods are valuable in identifying areas where additional attention or adjustments in work methods may be warranted [19].

1.2.4.5 Data reporting & recording

An effectively designed and programmed data processing system can efficiently convert a large volume turning data into actionable information necessitates a thorough understanding of the objectives of data processing and the management system it supports is essential for proper development and accurate evaluation of data processing. The standard steps in data processing have been identified as follows [20]:

- a. Data Capture: Involves recording data in a permanent and reusable format.
- b. Data Collection: Involves collecting individual data items and organizing them into processable groups.
- c. Data Conversion: Refers to transferring data from a human-readable format to a computer-readable form.
- d. Data Cleansing: Involves correcting and enhancing inaccurately recorded or converted data, as well as regenerating lost data.
- e. Data Transmission: Involves transmitting data to a computer site for processing.
- f. Data Processing: Involves processing the data into various formations or structures.

Information Display and Transmission: Pertains to presenting and sharing the processed information in a comprehensible format.

When completing maintenance management components, it's still a word on paper without the millstone of this process, directing process, but it depends on the component above of the system.

1.2.5 Cinques for Establishing Maintenance Techniques

Many techniques can be seen for planning of follow up maintenance activities (it's the same used in planning of following up project management) and this:

- a. Bar chart.
- b. CPM & PERT & Precedence.
- c. Expert System.
- d. Simulation techniques

One of these techniques or a combination of them can be used for maintenance planning and follow up.

1.3 RESEARCH JUSTIFICATION

Water treatment plants are one of the most important parts of infrastructures that are responsible for producing and supplying potable water to the community. Conversely, the elevated expenses of construction makes these plants and the process of operation and maintenance came as a task at the beginning to be studied by the researchers and which involves different aspects of operation and maintenance.

The importance of this research is due to many reasons, which can be described as follows:

- a. The issue of water treatment is highly related to life of anyone living in the world.
- b. The high investment in water treatment plants gives the operation and maintenance a special attention to keep the investment within the estimated revenues and life.
- c. Most of the water treatment plants in Najaf city are in bad state in both technical and managerial sides, that might cause terrific expenditures with low productivity, especially the old plants in which the cost of producing cubic meter of potable is higher than others, all these diagnoses are unknown without a system required. This bad state can be represented by many problems in planning, implementing, controlling, reporting, evaluation, and documentation for all steps of the process.

1.4 RESEARCH HYPOTHESIS

Several hypotheses need consideration to achieve the research objective, including: -

- a. This research is dealing with time and cost as the two sides of management triangle, which are quality, time, and cost. Supposing that quality is already within standard. This means that the quality is constant for purposes of this research. Practically this can be done by keeping the specifications of the produced water within standards. Quality of the work done is also to be within specification of activities implementation.
- b. The value of money is constant through the year of evaluation.
- c. The suggested system will be adjusted each year to comply with country circumstances and the state of the plant.

1.5 RESEARCH SCOPE AND FOCUS

This research is dealing with water treatment plants that are supplying potable water for Najaf City excluding all compact units that are sharing in this supplying because of the low capacity (as compared to water treatment plants) and the different ways of maintenance and management of compact units.

Also this research focuses on water treatment plants in Najaf City for many reasons; they are serving about 5.81 % of the whole population. , and it's representing a commercial, economical, political capital. In addition to that, most of the problems can vary from site to another. Finally there is a need for extensive efforts to study maintenance management for water treatment plants for Iraq.

Piping system is out of the scope of this study for aims of limitation of the problem of the research, and the failures and the problems of maintaining the piping systems differ from that of water treatment plants. Water treatment plants in this resaerch are limited from the intake to the piping system.

1.6 OBJECTIVE OF THE RESEARCH

The primary goal of this research is to formulate a new maintenance management system for water treatment plants that belong to Najaf water administration that supply about 94.75% of the total potable water supplied to Najaf [21], the developed system must overtake all or most of criticisms that are recorded to the current system . The objective of developing maintenance managemnet system optimize total maintenance cost in planning.

1.7 RESEARCH METHODOLOGY

The researcher followed the basis of engineering system design according to the following steps: -

- a. Defining the prpblem of the research which is poor system used for maintenance at the eight-water treatment plants at Najaf.
- b. Assessing the objectives of the research as they discussed at item **1.3**.
- c. Studying the literature review and the theoretical basis for both maintenance management (emphasizing that related to civil engineering) and water treatment plants (components, techniques, and maintenance activities).

- d. Studying the current state of maintenance which can't be considered as a maintenance management system because there is no real system to be seen or written, but there is a number of maintenance activities that were done in a sequence of engineering system. Therefore, this stage is concerned with data gathering about water treatment plants from all aspects of studying.
- e. Using theoretical components of maintenance management, principles of system design and analysis, and scientific research enhanced by the data collected from the water treatment plants; to develop a suggested maintenance management system for water treatment plants at Najaf city.

1.8 STRUCTURE OF THE THESIS

The structure of this thesis “Developing maintenance management system for water treatment plants in Najaf”, consists of seven chapters.

Chapter One serves as the introduction to the thesis, elucidating the scope, focus, objectives, methodology, and structure of the research. It delves into the principles of maintenance management, providing the foundation for maintenance and offering definitions of key terms in addition to all definitions of the issues branching from maintenance according to various classifications which were presented to select the suitable one in the thesis. Also the chapter shows the principles and components used for building any maintenance management or developing it, and the tools used for management.

Chapter two: is the literature review which consists of the studies, papers, theses that paid the attention to maintenance management at all sides of civil engineering emphasizing those regarding the managing water treatment plants, and precisely maintenance issues and their management.

Chapter three deals with water treatment plant maintenance, and the details of the units forming water treatment plants and the activities of the maintenance to be done in detail, gives an idea about the size of the maintenance required to be managed. In addition to various aspects of managing maintenance of water treatment plants. finally it describes some of the similar cases of managing maintenance for water treatment plants, and explores the existing maintenance system, giving a detailed description to all maintenance activities that were done in water treatment plants in Najaf City, in addition to the management of these water treatment plants from planning to scheduling, control, and evaluation and feedback.

Chapter four deals with the suggested system. This chapter sums up all information and field data to design a new developed maintenance management system which represents the main objective of the research.

Chapter five shows conclusions and recommendations, is assessing the conclusions extracted throughout the stages of study with the recommendations of the research and recommended future researches which are suggested by the research.



2. LITERATURE REVIEW

2.1 GENERAL

Iraq's construction movement faces delays, requiring optimization through leadership practices. Despite these challenges, the industry has generated significant profits in recent years [22, 23]. Many researchers wrote in various fields related to the issue of this research, but as a solution to the case of water treatment plants in Najaf City, no one of the researchers wrote to develop a maintenance management system for these plants.

Therefore, this chapter will classify the previous researches and studies according to the degree of relation to the research issue specifically, which divided into three section. The first one is the researches of maintenance management in civil engineering. The second is for researches that deal with maintenance of water treatment plants and managing sanitary engineering projects. The third one is for researching the management of water treatment plant maintenance.

2.2 MAINTENANCE MANAGEMENT RESEARCHES IN CIVIL ENGINEERING

Maintenance management is used for promoting an efficient use of resources within maintenance organization. Many of researchers have wrote about either designing or developing a maintenance management system for various cases of civil engineering.

Karaa established The growing public concern about infrastructure deterioration emphasizes the need for thoughtful solutions to address the effective oversight of critically failing water, wastewater, and transportation networks is a pressing concern. Specifically, the decisions related to maintenance, replacement, and rehabilitation planning necessitate robust methodologies and efficient data-collection practices. This research introduces maintenance management concepts, integrating preventive maintenance principles for crisis management. It delves into the information hierarchy and structure of a contemporary maintenance management system, closely examining its various functions. These functions encompass inventory and condition recording management, maintenance history, system failure analysis, maintenance management and control, capital improvement/maintenance planning, and the planning of maintenance resources. The case study provides valuable insights into the development of a maintenance management system for a water distribution network, outlining the requisite modules and their interfaces [24].

Al-Sultan highlighted the remarkable progress the Kingdom of Saudi Arabia (KSA) has made in comprehensive development over the last two decades. This progress encompassed nearly all sectors of the economy. The next phase involves further expansion within the constraints of financial resources, focusing on maintaining and solidifying the attained advancements. Achieving this necessitates a thorough maintenance program, addressing diverse maintenance-related issues specific to the Kingdom. The paper delves into the developmental plans concerning maintenance, analyzes the Saudi budget to identify expenditure trends aiding in predicting future maintenance requirements, and proposes strategies to enhance maintenance management [25].

Horner and colleagues pointed out the growing pressure to extend a building's useful life while preserving maintenance objectives, driving increased interest in integrated maintenance management approaches. They presented an innovative strategy selection method based on assessing failure consequences for each building component and determining an appropriate strategy for them. The study compared and contrasted corrective, preventive, and condition-based strategies, advocating a systematic approach to building maintenance management. The researchers suggested that this approach could assist maintenance engineers and managers in cost reduction while ensuring safety, health, and user satisfaction [26].

Sui Pheng and Omar suggested that the improvement of an established quality management system (QMS) by incorporating flexibility and innovation can raise the standard of product and service quality, aligning it with the business objectives of the organization. They examined the "segmentalist" and "integrative" concepts within the framework of construction firms. Drawing from their research findings, they proposed the elimination or integration of these concepts into the organization as required, with a particular emphasis on embracing an "integrative" approach that anticipates future challenges. The researchers stressed the need for a corporate renaissance within the organization to embrace change and innovation, highlighting the importance of humanistic factors and a participatory management environment alongside technical aspects as crucial elements for effective quality management system maintenance [27].

Shen underscored the increasing demand for research on maintenance prioritization methods, recognizing the challenge of budget limitations for maintaining public buildings adequately. In addressing this challenge, government maintenance authorities should

employ effective priority-setting methods to enhance the efficiency of maintenance programs. Maintenance plans should be guided by a thoughtful evaluation of priorities and up-to-date information on property conditions, aiming for the optimal utilization of resources. Shen conducted a comprehensive review of various maintenance priority-setting methods for public buildings in the UK and Hong Kong, providing maintenance managers with recommendations for selecting and implementing the most suitable method for their respective organizations [28].

Bejder and Kaklauskas conducted an analysis focusing on creating buildings with an efficient lifetime and emphasized maintenance considerations. They initially examined principles of complex analysis, functional aspects, cost-benefit optimization, interdisciplinary relationships, mathematical simulations, and more. This analysis enabled them to develop various decision-making systems. The paper provides a detailed description of one such system, "housing refurbishment decision making," and presents numerous strategies to enhance a building's lifetime efficiency, particularly regarding maintenance [29].

Larcher notes that in the past decade, there has been a growing global interest in harnessing private contractors to enhance efficiency and cut costs in the field of road maintenance. In many developing countries, the existing private contracting sector is inadequate for undertaking such tasks. Consequently, initiatives aimed at encouraging private sector involvement have been devised and executed with international technical assistance. These initiatives vary in focus, encompassing financial aid, training support, and other forms of assistance to establish a robust market. This paper investigates case studies from five diverse countries, each characterized by unique social, cultural, contractual, and organizational practices. While a construction development program involves various aspects, this paper specifically zeroes in on key issues such as international assistance, training programs, equipment provision, contracts and payments, program objectives, and the selection of contractors. Drawing insights from the experiences of previous projects, the paper distills valuable lessons to propose guidelines for future contractor development endeavors [30].

Hasan and others developed a maintenance management system for highways in Iraq. The researcher began to analyze the existing system that is used by State Commission of Road and Bridges (SCRB). And discovered that this system has many deficiencies the need to develop a new system, categorized based on management functions (planning, organizing,

directing, and control), has emerged. Consequently, the researcher has devised a system incorporating inventive elements such as a new highway inventory system, an enhanced performance evaluation procedure, a revamped estimating and budgeting system for maintenance works, a pioneering system for prioritized allocation of limited resources for maintaining highways, and an adjusted organizational structure for SCRB maintenance, and design of new modified control system [31].

Liu investigated the difficulties associated with infrastructure maintenance management, presenting significant challenges for civil engineers and government managers. The escalating number of deteriorated structures, complex spatial locations, increased service requirements, and constrained maintenance budgets contribute to these obstacles. As a result, maintenance management strategies have evolved for civil infrastructures such as bridges and roads in recent decades, with a primary focus on project-level maintenance management for individual structures. However, there is a growing demand and favorable conditions for network-level maintenance management in civil infrastructure systems. Researchers have explored this approach by integrating and applying modern information technologies, including database management systems, geographic information systems, genetic algorithms, and the Internet. The document explores various potential applications of each technology, discussing their crucial role in addressing real-world problems [32].

Cabahug and Edwards undertook an in-depth examination of the existing Certification of Training Achievement (CTA) scheme, offering a critical assessment of the significance of construction plant operatives in the UK construction industry. Their research brought to light a widespread discontent among practitioners regarding both the CTA scheme and the Intermediate Construction Certificate (ICC) route for achieving the National Vocational Qualification/Scottish Vocational Qualification (NVQ/SVQ) standard [33].

Alani and collaborators conducted a research study involving a comparative analysis of three established building maintenance forecasting models, incorporating a recently developed quantitative model. Providing succinct overviews of each approach, the researchers applied data collected from an extensive building survey to the four distinct methods. This facilitated a comparison of the maintenance priorities proposed by these models for future work. An evaluation was undertaken by analyzing responses from a questionnaire distributed to 100 companies and individuals involved in maintenance and facilities management, including organizations of quantity surveyors. The results indicated that all public sector organizations

use maintenance assessment methods to prioritize their maintenance management work. Additionally, 92 percent of the private sector and 95 percent of all organizations employ condition-based maintenance assessment methods for prioritizing maintenance operations. These questionnaire findings served as preliminary evidence highlighting the significance of this research initiative [34].

Shabha highlighted the circumstances that unfolded in the 1960s, marked by the construction of a significant number of high- and medium-rise single-sided corridor blocks using prefabricated concrete cladding systems. These structures often suffered from subpar quality materials, inadequate workmanship, insufficient supervision, and deficient environmental services. Over time, the buildings experienced deterioration due to issues like condensation, water ingress, and cold bridging, primarily attributed to low energy efficiency standards and inadequate thermal insulation. Initially, the plan aimed to address these issues at the end of the buildings' lifespan by incorporating high-tech components such as composite cladding and advanced environmental services, with the goal of improving operational efficiency, long-term durability, and cost-effectiveness. However, the associated costs surpassed what clients could afford. As a result, meeting the requirements of modern users and current building regulations required a reassessment of the entire process, leading to the development of alternative, cost-effective maintenance, and energy-efficient approaches. The paper critically assesses these approaches in the context of low-cost maintenance and refurbishment of high-rise buildings in parts of Birmingham, UK [35].

Dann and Wood's paper delves into a literature review centered on the maintenance management of historic buildings. The review commences with an exploration of literature pertaining to the philosophy and principles of conservation, followed by an analysis of the contemporary landscape of conservation management and its associated processes. A systematic comparison and contrast of the maintenance management requirements between heritage and non-heritage buildings is conducted. Throughout this examination, key themes are highlighted to emphasize best practices, encompassing aspects such as condition surveys. The paper concludes by pinpointing perceived gaps in knowledge within this field [36]. Researcher believes that the issue of this research can be integrated with the other researches depending on the major components of maintenance management.

2.3 MANAGING MAINTENANCE OF SANITARY PROJECTS STUDIES

Sanitary projects deal with water from the source to the consumers and then to be discharged. Many units and plants are there to build in the context of water processing along the cycle of the water. For that maintenance is very important to keep the plants and units in service by number of researches.

Walski. showed that in order to estimate the operation and maintenance cost of facilities, such as pumping stations, water and wastewater treatment plants, using some of O&M cost functions, it is necessary to know the actual flow rate handled by the facility. A major problem is to determine which flow rate to use as the average flow for the life of the project. This paper presents design aids to assist in determining the flow rate to enter into the cost function [37].

Smith suggested records keeping systems for scheduling and reporting on maintenance work pay dividends in terms of employee morale as well as reliable equipment [38].

McCann and Bill utilized the PILOTE software, specifically crafted to emulate the decision-making processes of adept operators responsible for scheduling outlet pumps at a water treatment plant near Paris, France. The program seamlessly integrates mathematical models and heuristics, representing the rules-of-thumb employed by operators in selecting configurations of outlet pumps. These models incorporate statistical procedures predicting hourly water consumption and hydraulic simulations estimating hour-by-hour elevation changes at regulating reservoirs and the elevated reservoir receiving the pumped flows. The heuristics within the program consider factors related to water quantity and quality, as well as operation and maintenance costs. An evaluation of the program demonstrated commendable performance in statistical forecasting procedures, although the simulation model consistently overestimated the volumes pumped. The heuristics accurately mirrored the rules used by expert operators, except for those associated with ranking alternative pumping strategies. The assessment outlined a research agenda aimed at refining PILOTE for seamless routine use.[39]

McKinney and Lin developed a groundwater management model utilizing a nonlinear programming algorithm to determine the minimum-cost design for both the pumping and treatment elements of a pump-and-treat remediation system. The model takes into account fixed costs related to system construction and installation, along with operation and

maintenance expenses. When tested on an aquifer with homogeneous hydraulic conductivity, the proposed model significantly influenced the design and cost of such systems. This impact led to cost reduction by utilizing fewer wells with lower flow rates in the combined well field and treatment process mode [40].

deMonsabert and Thornton's exploration delves into the issue of infiltration and inflow (I/I) affecting wastewater treatment plants, exerting a substantial influence on both the volume and cost of treating domestic wastewater. Various methods can be employed to address identified pipe or manhole defects, including chemical grouting, lining, burst lining, or excavation with subsequent repair or replacement. Each approach for eliminating infiltration or inflow comes with distinct costs and efficiencies. To address this, a comprehensive Benders decomposition model was crafted to optimize the strategy for repairing and replacing a sewer network. The model aims to identify the most cost-effective solution by minimizing both wastewater treatment and repair costs. The outcomes of a thorough analysis of an existing sewer are presented [41].

Gallagher provided an overview of the tender process and essential elements of an innovative contract for the construction of a new drinking water treatment facility with a daily capacity of 454 million liters. The facility, anticipated to be operational by 2000, is intended to supply potable water to the Seattle Metropolitan Area in the State of Washington, United States (US), and will be owned and funded by Seattle Public Utilities. CDM Philip Inc., a venture jointly owned by Camp Dresser & McKee Inc. and Philip Utilities Management Corporation, secured a singular contract encompassing permitting, design, construction, performance testing, and 25-year operation, maintenance, renewal, and replacement responsibilities for the facility. This unique contracting approach marks a departure from the conventional sequential model of design, construction, and operations in public water and wastewater facility projects. Inspired by US experience in solid waste-to-energy ventures, Seattle Public Utilities has introduced a novel approach to the public water sector, showcasing significant cost savings of approximately 40% and a substantial improvement in risk distribution compared to traditional estimates. The single-contract project delivery method proves to be a viable and advantageous alternative for this specific undertaking. Alongside recent alterations in municipal financing regulations, it has the potential to challenge traditional public works contracting methods in the US [42].

Salo provided a comprehensive overview of the financial challenges faced by the City of Atlanta, anticipating an 80% increase in sewer rates to support a Capital Improvement Program exceeding \$1 billion. In response, Mayor Bill Campbell mandated a thorough examination of cost-cutting options to address the impending rate hike. This led to a detailed assessment of the city's entire water and wastewater operations, exploring various internal and external management approaches. Subsequently, the Mayor introduced a comprehensive plan incorporating a combination of strategies: contracting the operation of the entire Water System, outsourcing the operation of the largest wastewater treatment plant, and reengineering other city wastewater and sewer operations. The ambitious reengineering and contract operations program were successfully implemented or initiated, with the contract operation of the Water System commencing on January 1, 1999. The Atlanta reengineering plan for the Sewer System was formulated in 1999, and a 5-year implementation plan is currently underway. Due to specific factors and events, the city transitioned from a plan for the contract operation of the largest wastewater treatment plant to implementing a design-build-operate contract for managing biosolids across all three of the city's wastewater treatment plants. This paper provides an update on the city's reengineering and contract operations program, four years after its initiation.[43]

Tom recounted another scenario involving the management of a sanitary plant, focusing on the Camden County Municipal Authority (CCMUA) overseeing an 80-million-gallon-per-day secondary wastewater treatment plant in Camden City, New Jersey. The CCMUA undertook a comprehensive initiative to optimize plant performance, improve odor control, and reduce operational costs. As part of this endeavor, the CCMUA adopted an Environmental Management System (EMS) following the guidelines of the National Enforcement Investigations Center (NEIC) Compliance-Focused Environmental Management System-Enforcement Agreement. The EMS provided a structured approach to overseeing environmental affairs, encompassing staff, processes, and principles aligned with CCMUA's business objectives and environmental mission. Key stages in EMS development included a gap analysis, team chartering, awareness training, EMS manual development, and sustained implementation. CCMUA's EMS aligns with the 12 key NEIC elements and is supported by an environmental policy expressing the organization's commitment to environmental compliance, continuous improvement, and overall environmental performance. Since the implementation of the EMS and other optimization efforts, CCMUA

has witnessed improvements in various areas, including operations and maintenance costs, wet weather bypass control, sludge removal, odor control, and community involvement. CCMUA's EMS serves as a framework for identifying innovative approaches to enhance performance, benefiting the environment, employees, ratepayers, and the local community [44].

Crotty discussed the progress of a project aimed at developing a limited set of high-level performance indicators for water and wastewater utilities, detailing the process of identifying these indicators and engaging utility representatives in a review for feedback. The workshop engaged managers and executives from 26 utilities and consultants, conducting sessions in Denver, Colorado, in December 2001 (Workshop I) and May 2002 (Workshop II). Workshop I involved a thorough review of outcomes from over 300 survey respondents in April 2002. The second workshop, held in May 2002 with the same participants, considered all received comments and made final recommendations regarding a suite of high-level indicators to assist utilities in evaluating their performance relative to others and tracking their performance over time. Outcomes of Workshop II were finalized in July 2002. This research, sponsored by Quality Programs and the American Water Works Research Foundation (AwwaRF), will contribute to the Benchmarking Clearinghouse's efforts to develop a database system for collecting, validating, and annually reporting these data [45]. Mary authored a case study on the Akron Public Utilities Bureau (APUB), which grappled with having the highest water and sewer rates among cities of its size in Ohio. Faced with escalating debt service, the Mayor encouraged APUB to streamline operations and address the rate issue. To address its financial crisis, APUB embarked on a transformation, fostering a new work environment and cultivating a cooperative relationship between management and labor. The initiative aimed to curtail costs while simultaneously boosting productivity and morale.

Two years into its Competitive Action Program, APUB has already saved nearly \$8 million, making substantial progress toward its five-year goal of \$10 million. The success is attributed to six key workforce strategies implemented to transform the utility:

- a. Establishing a labor-management partnership based on the belief that a positive work environment can be achieved through collaborative efforts toward the common goal of becoming a best-in-class utility.

- b. Developing a new participation model involving employees, unions, and management, with a target of engaging at least 70 percent of all APUB employees and management in redesigning new work practices.
- c. Mitigating resistance to change through an assertive communications program called Tool Box Talks, involving regular informal meetings to share information and facilitate two-way communication.
- d. Transitioning the organization from a hierarchy to teams, with teams trained and certified in multiple areas, empowered to make decisions such as scheduling work, setting goals, and evaluating performance.
- e. Providing extensive training for employees and team leaders, encompassing teamwork training for all teams and leadership training for Team Leaders.
- f. Piloting new work practices and implementing quick wins, testing designs and bringing employees closer to the work; quick wins, implemented in 30 days or less, have saved \$350,000 in the past two years.

APUB operates in water and wastewater treatment, water distribution, sewer maintenance, and billing and collection. The presentation underscores the stability of water and sewer rates, highlighting APUB's substantial improvement in customer service. With over half of all employees participating in the program, there is a goal to increase participation to 70-80 percent. The presentation delves into the six key steps in this transformation, illustrating their applicability to any utility, regardless of size.

Barran discussed the Toronto case, where the Works and Emergency Services Department introduced the Works Best Practices Program (WBPP). This program employed an integrated approach to enhance work practices, organizational processes, and the adoption of technology [46]. In the evolution of technology system deployment, the importance of a coordinated implementation approach becomes evident. In response to this need, WBPP Integrated Technology has adopted a System Development Life Cycle (SDLC) approach. This methodology involves breaking down work into a series of clearly defined, manageable, and cyclical development steps. A service model is employed, where external contractors provide well-defined services and solutions for the development and implementation of work within these steps. The primary objectives of the System Development Life Cycle include:

- a. Implementing all applications without compromising the technology architecture.

- b. Providing a formal mechanism for users to contribute input into future enhancements and upgrades.
- c. Establishing a manageable software development process.
- d. Developing a training program closely aligned with the system functionality defined by users.

Following the adoption of the SDLC model, WBPP has experienced notable enhancements, including increased user engagement and a more streamlined schedule for technology implementation. Aklog and Hosoi pursued a dual purpose: introducing an innovative reliability-based optimal design formulation and model, and investigating the impact of specifying minimum allowable pipe sizes during least-cost designs on system reliability. The system reliability estimation employs the minimum cut-set method, but instead of relying on the mechanical failure probabilities of pipes, weighted failure probabilities are calculated by considering the ratio of the actual supply to demand. A notable feature of this study, particularly the new reliability-based design model, involves using a pressure-driven network simulation model to determine the actual supply at each demand point when a component fails. To showcase the performance of the new model and explore the effect of specifying minimum allowable pipe sizes, a simplified two-loop network is employed. The results demonstrate that the new model preserves loops, resulting in a system with enhanced reliability. Moreover, if minimum allowable pipe sizes are appropriately specified in the least-cost design, the required reliability can be achieved at a reasonably low cost.[47]

Saegrov et al. presented a succinct summary of computer-based methods for water network rehabilitation planning currently utilized in Norway. The article highlights examples from different Norwegian cities using tools for estimating long-term rehabilitation needs, assessing network serviceability, and predicting water network failure frequency and distribution. These tools have proven significant in assisting the planning of future investments in water networks and the selection of rehabilitation candidates.[48] Johnson's project aimed to address the issue of water meters operating outside their performance specifications, contributing to non-physical water losses and financial losses for a water authority. The objective was to develop and test a computerized system providing a continuum of methods for selecting water meters. This selection process ranges from purely theoretical to semi-empirical and ultimately to a wholly empirical approach. The theoretical process relies on water demands derived from local and international design codes and

standards when selecting new water meters for buildings or water management areas. The initial estimate for water meter selection can be based on both records of billing data and theoretically determined peak and minimum water demands.[49]

Johnson emphasized that as data progresses through different levels of an organization, from its capture to its processing and refinement, it transforms into information relevant to a specific application. This conversion process can potentially impact the data, leading to sub-optimal decisions. Therefore, the collection and handling of information for a water authority must be well-organized. Asset management systems typically consist of three main components: inventory, programmed action, and optimization. In developing countries, the institutional capacity needs of water authorities often require greater emphasis on the first two components. To address this, a pragmatic and user-friendly Integrated Water Asset Management System (IWAMS) has been developed, encompassing modules for water meter management, leakage control, and incident management. The system also includes a water audit and water balance module to determine levels of unaccounted-for water and the unit cost of leakage. The prioritization of water mains rehabilitation can be established by representing various collected data in the form of a common severity rating, aiding decision-making.[50]

The project led by Johnson and Mjoli aimed to create computerized management systems for water utilities, targeting increased productivity and addressing shortages of middle and high-level manpower—common challenges in developing countries. Specifically designed for water services institutions, the project focused on enhancing knowledge through a computerized human resource planning system that incorporated human resource modeling techniques. The initial phase involved an extensive literature survey and the development of the first version of the software. Following limited exposure of the demonstration software to various stakeholders, an improved version 2 was developed based on feedback received from users through pilot studies and presentations. The resulting computerized Human Resource Planning and Management System (HRPMS) is designed to assist managers in conducting human resource planning for water services institutions.[51]

Yep underscores the importance of continually refining utility operations through strategic planning, annual business planning, organizational evaluation, and performance tracking. The Water Utility Operations Division is integrating principles from the Malcolm Baldrige National Quality Program and ISO. In particular, the Baldrige framework's categories,

encompassing Leadership, Strategic Planning, Customer and Market Focus, Measurement, Analysis, Knowledge Management, Human Resources Focus, Process Management, and Business Results, serve as a robust business framework. Yep is convinced that tailoring these processes to specific needs will guarantee dependable operations, bolster customer focus, and yield favorable business outcomes [52].

2.4 MAINTENANCE MANAGEMENT OF WATER TREATMENT PLANTS STUDIES

A number of researchers studied this issue, which are presented below to be as a guide or for comparison with other works of the researchers and this research.

In his presentation, Carlos aimed to establish a link the Commonwealth of Puerto Rico is actively pursuing sustainable water treatment technologies tailored for challenging conditions. Presently, improvements are underway at sixteen existing water treatment facilities, incorporating five distinct water treatment technologies and three novel water intake technologies. The selection of these technologies is driven by their effectiveness in treating high turbidity raw water while ensuring consistent operation in the face of challenging conditions and limited operational resources [53].

He described the predictive maintenance at the automated Mery-Sur-Oise Drinking Water Treatment Plant which is operated predicted maintenance information provided Syndicat des Eaux de l'Île de France provides an overview of their computerized control system. This includes an explanation of the functionality and operation of the Asset Management Solutions software.

Butt and Head discovered that most reported values on SCADA (supervisory control and data acquisition) systems used for water treatment are not examined or used until an alarm is generated. It therefore makes sense to develop a system that utilizes the data now accessible for proactive treatment plant management. This document outlines the creation of a prototype system featuring user-specified simulations, an instrument analyzer, alarm handling capabilities, and real-time simulations. The system serves not only as a training tool but also supports proactive operation, de-manning, risk reduction, lowered maintenance and chemical costs, among other benefits. Additionally, potential future development areas and factors influencing the implementation of such a system are discussed [54].

A balanced scorecard of performance measures, as described by Robert Kaplan and David Norton, is a versatile tool that adds value to a variety of organizational improvement strategies. Union Sanitary District (USD) in the cities of Eugene and Union City, California, Oregon have used the balanced scorecard to implement a variety of improvement strategies, including treatment plant competitiveness, reduction of sanitary sewer overflows and environmental management.

Donna described the balanced scorecard model, the strategies for which it has been used, and the reasons the balanced scorecard model was chosen by USD and Eugene. It will focus on how other organizations can leverage the balanced scorecard to increase their chances of successfully implementing improvement strategies, using Union Sanitary District and Eugene as case studies [56].

Eugene recognized that most prosperous companies have maintenance strategic planning as a fundamental component. This essay looks at the strategy that the Broward County Environmental Operations Division (BCEOD) used to create their plan. A maintenance strategy plan may be prepared using a variety of techniques. This document outlines [49]. The Water Services Department of the City of Phoenix is actively engaged in the development of the Information Access System (IAS) platform. This platform is designed to provide accessibility to Electronic Operations and Maintenance Manuals (EOMs) pertinent to the Department's water and wastewater treatment facilities, along with its water distribution and wastewater collection systems, for the Department staff. Maze, Ron, Ramon, Greg, Kopchynski, and Richard are involved in this initiative [57] clarified that the creation of this program is an essential aspect of the Department's aims, with the following priorities and goals in mind:

- a. Assist the Department's re-engineering efforts by giving users access to a tool that provides fast access to relevant data.
- b. Get accurate and useful information for the operations staff.
- c. Provide an IAS platform that Department employees can readily manage.
- d. In the end, support the Department's initiatives to "achieve more with less," using the IAS as an additional instrument to help achieve this goal.

This project's main goal is to provide the EOM for a vital aspect of the IAS platform is the inclusion of the Wastewater Collection System within the Water Service Department. The IAS platform encompasses water treatment facilities, wastewater treatment facilities, and the

water distribution system. This specific Electronic Operations and Maintenance Manual (EOM) will cover an extensive network, comprising 4,300 miles of pipeline, 333,000 service connections, 24 lift stations, 13 odor control stations, and inverted siphons. These components are distributed across approximately 500 geographic miles within the coverage region, with a workforce of 102 employees dedicated to the system.

The Wastewater Collection System's existing Operation and Maintenance (O&M) manuals date back to 1980. These manuals have not been updated to reflect changes and new advancements over time. Furthermore, fresh data on installations built after 1980 is dispersed, lacking, and available in a variety of formats, mostly in hard copy. To address this challenge, the Department has introduced a standardized format for electronic Operations and Maintenance manuals (EOMs). This consistent structure was established during the initial EOM project for the 23rd Avenue Wastewater Treatment Plant, boasting a rated capacity of 63 million gallons per day (mgd).

Bloomfield and colleagues provided in-depth insights into comprehensive asset management plans for water and wastewater treatment plants, emphasizing the importance of employing diverse engineering and commercial optimization techniques. One particularly effective approach highlighted is the optimization of capital and operations and maintenance (O&M) costs through a thorough life cycle cost analysis (LCCA), offering the agency an efficient means of cost savings. By contrasting capital expenses based on the life cycle with operating and maintenance costs, agencies can assess potential savings. This comprehensive awareness of expenses and potential savings enables agencies to minimize risks related to performance, failure, and finances while meeting their intended level of service (LOS) goals. The Department of Environmental Services in the City and County of Honolulu, Hawaii, oversees the majority of wastewater treatment plants on Oahu and numerous pump stations. Utilizing their seven-step Asset Management Program (Program), they have cataloged assets, assessed their condition, criticality, vulnerability, and risk, and conducted several financial appraisals. Integration and evaluation of capital projects and O&M operations using LCCAs have enhanced overall cost-effectiveness, supporting optimal decision-making. The Program provides a framework for optimizing Capital Improvement Program (CIP) projects and ongoing operations, maintenance, repair, and replacement (R&R) choices to achieve specified LOS objectives and operational performance. The Department aims to

achieve cost reductions in labor, chemicals/supplies, and power by comparing O&M costs to capital costs and maximizing these savings through management decisions.[58]

Donahue and collaborators focused on the Division of Sewerage and Drainage (DOSD) within the City of Columbus, Ohio, discussing how data-driven technologies offer valuable information for planning, decision-making, and training at wastewater treatment facilities. Recognizing the challenge of effectively storing, accessing, and utilizing this information, DOSD conducted pilot testing of web-based technology to develop an online operations and maintenance training program for two wastewater treatment plants. This initiative enabled staff to receive training specific to the equipment at their respective plants, fostering a more efficient and well-trained workforce. The interactive learning modules also allowed staff to assess their proficiency against standardized benchmarks, encouraging continuous development and preserving training knowledge in a reusable system. Moreover, online training empowered DOSD management to monitor staff progress and provide timely feedback, ensuring that training and development objectives were met [59].

The underlying essence of these studies emphasizes the importance of establishing a comprehensive database to assist maintenance supervisors in comprehending the maintenance requirements and behavior of water treatment plants effectively. Mahmood et al. study soil properties and content's impact on earthquake-induced soil liquefaction, finding moderate temperature increases and increased Euphrates River discharge affecting liquefaction [60]. Mohammed et al. study geogrids for soil improvement using PLAXIS 3D FE program. They found that reinforcement and stone columns improved soft clay soil behavior, with up to 50% improvement in the construction phase. The study highlights the importance of reinforcement in soil improvement [61]. Khaleel et al. study the use of BIM technology in estimating construction project costs, finding it more accurate and practical than manual methods. The study also found that BIM saves time, effort, and cost [62].

Amhaimedi et al. conducted a comparative study on Building Information Modelling (BIM) and Multi-Criteria Decision Maker (MCDM) decision-making limitations, revealing effective factors for intelligent building design and improved project tracking [63]. The study explores the benefits of project management in managing construction project costs and schedules, highlighting the importance of BIM technology and REVIT Software. It found that adopting project management principles can reduce costs, time, and effort, and prevent financial losses from cost overruns or delays [64]. Breakwater sections for stone-filled

breakwaters were prepared at different wave heights and water depths. Costs were calculated using the Hudson equation. Factors like structure slope, water depth, and wave height affected costs. Vertical part of breakwaters is more sensitive [65].

The study compares unit volumetric weight values in soil relationships and finds a low relationship between literature and experimental values. It proposes using seismic methods for faster and less expensive estimation of unit volume and weight [66]. The study assessed groundwater quality in three Basrah governorate regions, assessing its suitability for drinking and irrigation. Fifty specimens were analyzed using the Water Quality Index (WQI). The results showed good condition, but not suitable for human consumption [67].



3. MAINTENANCE OF WATER TREATMENT PLANT

3.1 GENERAL

This research deals with one of the important sanitary projects, which supplies potable water. The process of treatment from the source to the piping system will be discussed in this chapter, emphasizing the management of the maintenance activities for each unit of the plant and how it can be done practically.

The water treatment process flow chart is as shown in Figure 3.1.

3.2 INTAKE SCREENS

Intakes must be well maintained to ensure that there is sufficient water flow from the source to the users. If intakes do not function properly, the flow of the water could decrease or even stop completely. This would cause people to look for another water source, possibly a less suitable one.

The process of screening always can be done by intake screens these are installed at the river intakes to stop relatively big floating material from getting into the operation. Occasionally, screens are installed in duplicate frames so that one frame may be removed for maintenance and cleaning without allowing unscreened water to enter the plant. Then cleaning and repairing of screens are the major activities of maintenance to this unit. These activities are most commons in the world, in Iraq can be seen and can be a real problem causing fatal problems in the next steps of treatment [68].

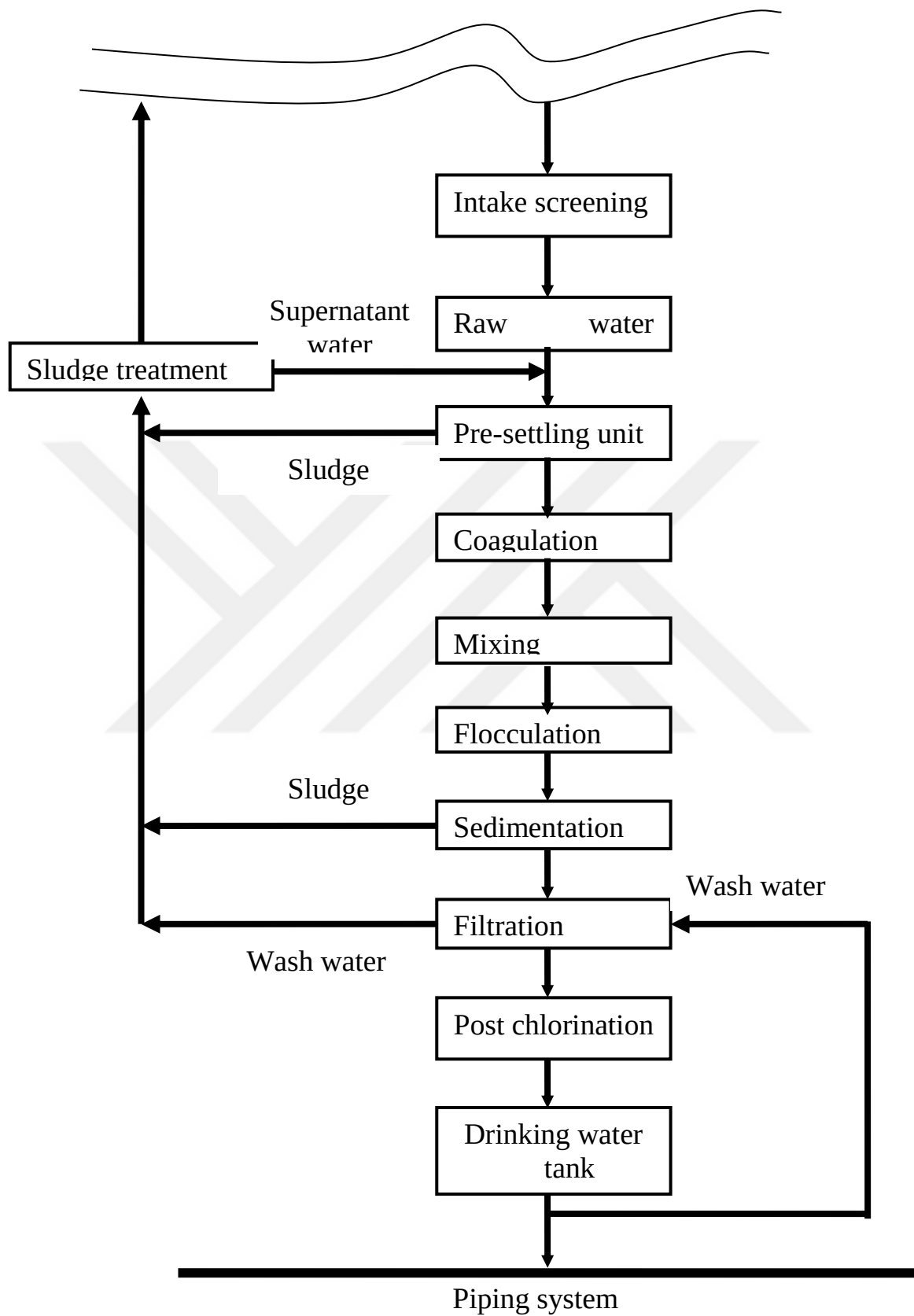


Figure 3.1: Flow Diagram Showing Treatment Stages.

The components and related elements constituting maintenance operations on intakes situated in rivers, lakes, and impounded reservoirs include [69]: -

- a. Periodic Structural examination: To find fractures or structural flaws, all structures should undergo routine examination.
- b. Suction Well Depth Measurement: Take a measurement of the suction well's depth to keep an eye on the buildup of sand and silt. Dredge these accumulations out as necessary.
- c. Ice-Related Precautions: Take precautions against icy conditions that can jeopardize the construction or block the intake aperture. To keep the water from freezing, place log booms there or introduce bubbles of compressed air into the water at key locations.
- d. Prevention of Ice Blockage: Address the formation of freezing ice that can occur in supercooled water, potentially causing complete blockage of intakes.
- e. Screen Maintenance and Equipment Repair: Remove any material on screens that cannot be cleared through regular operations. Furthermore, apply lubrication and conduct repairs on any supplementary equipment associated with movable screens.

3.2.1 Maintenance of Intake for Ponds and Lakes

The most important part of the intake is the screened section of perforated pipe, which is in the water. All water that enters the system must come through this perforated section. The smaller the opening in the screen, the more unwanted material is kept out of the system. However, smaller openings will cause the screen to clog more quickly. A screen with small openings needs to be cleaned more frequently but yields better quality water. Maintenance of the perforated pipe involves the steps listed below [70]:

- a. Checking at least once every three months, the intake to ensure it is not clogged with suspended matter or plant life. To maintain the intake, lifting the screened section of the pipe from the water and deciding if cleaning is necessary. If the screen is dirty, scrubbing it clean.
- b. Where the screened section of this pipe is fixed, then cannot be lifted from the water because the pipe does not bend. Waiting until the water is low enough that wading into the water is possible.

Then remove the screen from the pipe to check its condition. Be sure to shut the gate or globe valve before removing the screen from the pipe. all pumping equipment should be shut off during intake maintenance.

Where the water is too deep for wading, a system can be installed. Affix an elbow joint to the pipe's end and attach to it a length of pipe extending to the surface of the pond or lake. The pipe should contain perforations at the desired water intake level. To screen the perforations, allow accessibility for maintenance, attach pieces of rubber tubing to the screen. The rubber tubing should fit the intake pipe. The screen can be lowered on the pipe to cover the perforations in the pipe. For maintenance, the screen is simply lifted from the pipe by someone in a boat, cleaned and slid onto the pipe once again.

- c. During long periods of dry weather, checking the level of the pond or lake to ensure that it is not lower than expected. If a floating intake drifts too close to the bottom of the pond or lake, clogging is likely. Suspended materials may enter the system causing sediment build – up in storage tanks. For fixed intakes it's important to be sure that the intake is always below water level. If the water level falls great deal, the intake pipe may have to be lowered. Water level must not be lowered so much that sediment from the bottom can be picked up. If drought, the amount of water used by the community must be decreased so the water source will not dry up.
- d. Checking the float, rope, and anchors of floating intakes to ensure that everything is in good condition. All parts should be securely tied to the float. If any wear or rot occurred, they must replace. Pipe intake also must be checked from leakage.

3.2.2 Maintenance of Intake for Rivers and Streams

Intakes and streams consist of infiltration systems, gravity flow and permanent direct pumping system. The maintenance of riverside wells and clear water wells is not difficult. The water in them should be analyzed every six months to ensure that the quality is acceptable. This analysis must be done carefully to detect any contamination. The biggest maintenance problem is the pump. Pumps must be maintained properly if they are to provide good service.

Collection pipes for infiltration gallery may need maintenance to ensure adequate flow into the water system. The steps below for maintaining collection pipes [71].

- a. Checking the flow of water into clear water well. Be sure that the flow from each side is good. If the water flow is low on either or both sides, suspect that the collection is clogged.
- b. Removing the obstruction from the pipe. The simplest way to unclog the pipes is to pour water into the clean-out system. Uncap the installed cleanout pipe and pour water into the system to break up any sediment. If a hose and water pressure are available, they should be used to thoroughly flush out the collection.

3.3 PUMPING STATIONS

There are two primary methods for water transportation: pumping and gravity flows. The design and features of Pumps and pumping facilities differ depending on their intended purpose. These uses can generally be categorized as follows:

3.3.1 Low-Lift Pump Stations

Low-lift pump stations are commonly employed to transfer water from a surface source to the intake of a non-pressure treatment facility. Within a treatment facility, these pumps can aid in directing water flow between various unit operations. Pumps designated as "low-lift" demonstrate efficiency in moving substantial water volumes against minimal head, typically less than fifty feet (15 meters [m]). They prove particularly advantageous for transporting surface water to a treatment facility, especially in cases where gravity flow is not feasible.

3.3.2 High Service Pump Stations

Potable water is conveyed directly from non-pressurized sources, such as storage reservoirs, to the distribution system using high-service pumps. For residential service, high-service pumps typically aim to sustain system pressures within the range of 50 to 75 pounds per square inch (psi), equivalent to approximately 3.5 to 5 kilograms per square centimeter (kg/sq. cm). Maintaining the system pressure above 20 psi is essential to prevent it from dropping to inadequate levels [72].

3.3.3 Pump Operation and Maintenance

Managing a water system requires the operation and upkeep of pumping machinery. One of the biggest reasons for system failure is improper maintenance, which includes repairing

little issues before they get bigger. For all varieties of pumping systems, operation and maintenance typically comprise the following tasks:[73]

- a. Ensuring cleanliness and applying regular paint to the equipment and pump house to prevent rust or weathering.
- b. Keeping equipment lubricated
- c. Recording system pressure and water use as well as preventive maintenance and repairs.
- d. Identifying possible mechanical issues and making adjustments before failure happens
- e. Replacing malfunctioning or broken equipment pieces.
- f. Maintaining the functionality of structures, including doors and windows.
- g. Keeping records, interpreting information recorded and making recommendations to management.
- h. Loading and storing chemicals, taking water samples, and performing tests of the water if water treatment equipment is located in pump house.

When these duties are performed regularly and correctly, major breakdowns can be avoided. The result is an overall lower cost of providing water.

3.3.4 Pumps Maintenance Scheduling

As no maintenance task is overlooked, a schedule is things that must be attended to on a daily, weekly, monthly, or other regular basis are developed. Examining the equipment manuals provided by the manufacturers, which ought to have come with every piece of equipment, is a good place to start when determining what routine maintenance is necessary. These handbooks and the pumping system's as-built blueprints have to be kept in a secure location that is easy to get to. Ordering the manuals from the manufacturer or provider is advised if they are not readily available. A typical maintenance schedule and record are displayed in Table 3.1.

It is crucial to find a quickly available supply source or to maintain supplies and replacement parts on hand for the goods that are most likely to be required. Grease and oil are included, along with fuses, repair clamps, and, in the event that they are hard to find, magnetic breakers. If at all feasible, spare motors, pumps, and bearings should be maintained on hand [74].

Table 3.1: Preventive Maintenance Schedule.

Frequency	Action
Daily	a. Turn pump on/off as required b. Check pump for excess heat in motor or bearing. c. Check controls for proper operation. d. Check water level in well. e. Check piping for leaks. f. Check condensation in pump house. g. Check chemical levels. h. Check oil level, pressure and fuel level if internal combustion engine. i. Record water and electric motor readings. j. Record system pressure. k. Record chemical residuals. l. Record unusual observations. m. Record fuel used, hours run, for internal combustion engine. n. Correct problems identified.
Monthly	• Lubricate pump. • Check amperage on electric motor. • Report on water use for month.
Semi-annually	• Lubricate pump house door hinges. • Test blow off is furnished.
Other	• Change oil, oil filters, fuel filters in accordance with manufacturers. • Each falls check heating system. • Do preventive maintenance as specified by manufacturer requirements.

3.3.5 Pumps Operation

One of the most important considerations in operating a pumping plant is to keep it clean and orderly. Oil and grease should be removed, dirt swept up, and tools and parts stored in their proper places at all times. Touch up the paint to prevent rust when repairs are made and repaint on a regular basis.

As common a mistake as not providing sufficient oil or grease is to use too much. Pumps must not be over oiled or greased, bearings run hotter if the grease is packed and these lubricants must be removed every 6-12 months and replaced by the recommended type by the manufacturer.

If noise or vibration occurs, find the cause. Centrifugal pumps and motor are meant to run smoothly even at high speeds. Noise or vibration probably means there is misalignment between pump and motor [75].

3.3.6 Trouble Shooting in Pumps

The system should be relatively trouble free if properly designed and installed and maintenance instructions from the manufacturer are followed. Unfortunately, there are no perfect pumps or pump controls. Problems will be encountered from time to time.

3.4 PRE-SETTLING UNIT

Rivers throughout the world exhibit wide fluctuation has significant turbidity brought on by the movement of silt during wet seasons. When pretreatment is done appropriately during times of high turbidity, it can lessen the strain on later treatment units and result in significant savings on total operating costs, particularly for chemicals.

So, pretreatment process can be done at pre-settling basins, these basins can allow for removal the suspended solids in raw water caused by spontaneous particle aggregation in a basin and gravity, without the need for coagulants. The size of the suspended particles and the settling rate have a major impact on the process' efficiency as determined by the reduction of turbidity. For the following reasons, plain sedimentation works extremely well in tropical developing nations [76]: -

- i. Soil erosion and silt settlement are the main causes of river turbidity.
- ii. These nations' warmer temperatures facilitate better sedimentation by reducing the water's viscosity. Then pre-settling tanks functions are: -
 - a. If using upward-flow basins on rivers that were previously thought to be very turbid makes sense for other reasons, then permit their use.
 - b. Will rescue existing upward –flow tanks prone to get into difficulties.
 - c. Might be constructed later in the event that circumstances on the collecting ground worsen (this is a frequent occurrence in developing nations when catchments covered in jungles are to be removed for development without prior notification or appropriate oversight).
 - d. May be utilized to preserve coagulants in horizontal flow basins.
 - e. Can be inserted to reduce the silt load on basins, which are difficult to clean.

Under condition of continuous treatment, at least two settling basins should be built to allow one to be shutdown periodically for cleaning. When possible, cleaning and sludge removal should do during periods of low turbidity. Sludge removal can be a manual process using labor, but normally is not necessary more than once a year, depending on basin size. Fire hoses or fixed nozzles can ease the cleaning process.

3.5 COAGULATION

When sedimentation alone cannot effectively remove suspended material that is too fine, coagulation and flocculation come into play. Coagulation and flocculation, often termed as "conventional" treatment along with filtration, involve clustering the suspended particles into settleable particles.

A coagulant refers to a chemical or substance that, when introduced into water, combines with naturally present or added chemicals to create a precipitate, known as a floc. This floc settles and facilitates the liquid's suspended matter being removed. Coagulation, which is accomplished by adding a chemical that creates a floc, is basically the instability and early aggregation of colloidal and finely split suspended materials [77]. A coagulant always is added as a solution after process of preparing this at the unit specialized for producing the solution with the provided concentration according to solution dose required for various conditions of water turbidity. The following are the top three coagulants [77]:

- i. Alum, or aluminum sulfate.
- ii. Ferric sulfate, or ferric acid.
- iii. Ferric chloride.

Solution –type feeders apply to coagulant solutions. Some general requirements for the design of these feeders are: -

- a. To ensure that feeding is not stopped while one unit is out of commission, a minimum of two chemical feeders (or a total of three if two chemicals are to be supplied) must be provided at each application site.
- b. The combined capacity of chemical feeder must be greater than maximum dosage required, but not so large as to be during periods of low flow.
- c. Concrete tanks must be adequately protected against corrosion by a layer of bit mastic enamel, plastic, rubber, or similar functioning substance.

- d. Adequately sized drains are needed to facilitate cleaning the tanks and flushing out accumulated sediments.
- e. The ability to mix chemical solutions with hand-operated or motor-driven peddles is a prerequisite.
- f. Rubber or plastic hose chemical feed lines that are easily cleaned are required. They should be supported periodically or positioned inside tile pipes for safety. Lime suspensions are best transported across open channels.
- g. Unless instructors are utilized, chemical feeders should be placed as close as possible to the chemical application site.

3.6 MIXING

The technique of quickly and evenly dispersing a coagulant throughout the water's bulk is known as mixing. Usually, this process takes place in the little basin that sits just in front of the "coagulation basin" or at its head end.[78]

Coagulants react almost instantly when they are put to water and well mixed. It is helpful to agitate the floc one more gently after it develops so that the floc particles may come together and enlarge. The two actions are comparable in that they both involve stirring the water. The second action, which comes after flock formation, should be kind, but the first action, which comes before flock formation, must be aggressive.

In each basin, both of these processes happen naturally at varying degrees. Turbulence causes mixing to occur when coagulants are supplied into an input pipe or channel. There will always be a rolling motion when the dosed water containing flock enters the settling basin through the input ports. This rolling motion can be enhanced by baffles in a basin with horizontal flow or by the sludge blanket in an upward flow basin. Hydraulic or mechanical methods can be used for mixing [78].

For example, even though it's usually thought of as too fast, a velocity of two feet per second could be the best option for coagulating extremely murky water in a particular basin. A variety of mechanical devices are included in mechanical mixing basins to agitate the water to be treated to the appropriate levels of violence.

Rapid mix requirements must satisfy the following:

- a. Unless the agency determines that other techniques, including baffling or injecting chemicals at a high velocity, would satisfy the other criteria of this section, basins must

be outfitted with mechanical mixing devices. It is advised to use driving equipment with variable speed.

- b. Depending on the velocity gradient the mixing devices supply, the detention time for mechanical mixing must be as brief as feasible.
- c. The flocculation basin and quick mix should be placed as near to one another as feasible. In order to guarantee adequate mixing of chemicals, the commissioner could need a quick mix device or chamber placed ahead of the solids contact unit.

3.7 FLOCCULATION

The process of flocculation involves mechanically causing the suspended particles to aggregate into dense, quickly settling flocks. Typically, this procedure takes place in a "mixing basin" or "flocculation basin." Flocks formed almost instantaneously but it may be fine and will probably require time to coalesce with neighboring particles to form bigger masses. Gentle stirring can accelerate this action. Then flocculation is the practice of gently stirring water where a flock has developed to encourage the particles to expand and consolidate. The flock settles more quickly when it is larger and denser [79].

3.7.1 Baffled Channel Flocculates

Mixing in baffled channel flocculation is achieved by turning around the water flow through the channels created by the end or over and baffles. Baffled channel flocculates are only effective in sizable treatment facilities ($>10000 \text{ m}^3/\text{day}$), when the flow velocity permits adequate head losses in the channels to facilitate gradual mixing without necessitating an excessively close spacing of the baffles (which would complicate cleaning). Such flocculates have the special benefit of operating under plug-flow circumstances, which spares them from short-circuiting issues. Because they are easier to drain and clean, horizontal flow flocculates with end baffles are occasionally favored over vertical flow flocculates. The main issue with vertical flocculates is the buildup of settled material on the chamber floors, which is difficult to remove. To address this issue, Brazilian designs have included weep holes, or tiny openings, in the base of the lower baffles that are equal to 5% of each chamber's flow area [80].

3.8 SEDIMENTATION

The natural process by which suspended matter transported by water or other liquids settles and deposits as a result of gravity is called sedimentation, sometimes referred to as settling. This mechanism causes subsidence and deposition by lowering the liquid's flow velocity below the point at which it can support the suspended material. Sedimentation is an essential phase in the traditional water treatment process that occurs between flocculation and filtration. Furthermore, a major part of the process of sedimentation, which is often called "clarification," is taking out large volumes of chemical precipitates that are created as lime softens [81]. Table 3.2 provides an overview of sedimentation basin maintenance techniques.

Proper maintenance of sedimentation basins is necessary to ensure that they work effectively. Unless properly cared for, sedimentation basins may not remove suspended matter from the water, causing filter systems or distribution systems to clog. The sediments or sludge that sink to the bottom of the sedimentation basin must be removed in order to keep it in good condition. The amount of sludge that accumulates at the bottom determines how frequently it must be removed. Usually, this takes six to eight weeks. The frequency of sludge removal should be increased in cases of highly turbid water. By raising the water's velocity in the tank, a thick coating of muck impedes the sedimentation process. Furthermore, accumulation of sludge can decompose and cause tastes and odors.

To remove the sludge, the sedimentation basin must be taken out of operation with these steps.

- a. Cutting off the flow of the water into sedimentation basin by closing the valve at the inlet to basin. Before cutting the water, being sure that the storage tank is filled so that people have access to water during the cleaning process. It is always a good policy advice user of a shut down in the water system so that they use less water. It is important to try to cut off the supply only during off-peak demand periods. This will usually be from mid-morning to mid –afternoon.
- b. Removing with shovels buckets pusher boards and wheelbarrow, the sludge from the tank by pushing it out through drain and carry it out from the site. Flushing the sludge off the bottom, if pump or hose are available. Sludge has higher water content and should flow easily from the tank. A board fastened to a pole is useful for scraping the bottom completely clean. Rinsing the tank completely before restarting operation.

- c. Operation as soon as the tank fills. This will be within 4-6 hours, depending on the volume of the tank. Cleaning and repairing a sedimentation basin are easier if the tank is designed with two separate sections, which can be used independently. This type of design allows for continuous flow of water into distribution system since one section can be cleaned while the other operates normally.
- d. Removing the sludge as quickly as possible that the basin is not out of operation for a long period of time. The water system should not be disrupted for more than one day. Since all sediment is removed. All drains must be closed, and valve must be opened to refill the tank.



Table 3.2: Maintenance Checklist.

Inspection	Action	Frequency
-Rapid-mix basins	-Draining, washing down walls, flushing sediment to waste line. -Repairing spalled spots on walls and bottom. - Checking valves or sluice gates, lubricating, and paint as necessary.	SA
-Baffled mixing chambers	-Cleaning baffles and repair as necessary.	SA
-Flocculator basins	-Checking paddle rotation to ascertain whether any flocculators are inoperative. -Cleaning and lubricating drive, bearings, gears, and other mechanical parts. -Checking underwater bearings for silt penetration. Replacing scored bearings.	M SA
-Rapid (or flash) mixers	-Checking paddles. Cleaning bearings and drive shaft. Lubricating and paint as necessary.	SA
-Revolving-sludge collector basins	-Draining tank. Checking submerged parts.	SA
-Operating parts	-Lubricating.	D or W
-Speed reducers and oil baths	-Removing water and grit. Replacing oil as necessary.	W
-Drive head	-Lubricating	D
-Worm gear	-Checking oil level. -Draining water from housing.	W M
-Turntable bearings	-Lubricating. -Changing oil.	M SA
-Chains	-Draining off water, adding oil as necessary. -Changing oil.	M SA
-Annular ball bearings	-Lubricating. -Inspecting condition.	D M
-Center bearings, shaft bearings, bushings, etc.	-According to manufacturer's instructions.	V
-Tank equipment	-Tightening bolts and nuts. Checking for excessive wear. Flushing and backing blow sludge line. Checking motors, couplings, and shear pins. Checking rakes. Cleaning and paint equipment. - Consulting manufacturer's instructions. - According to the above and manufacturer's instructions.	A V
-Conveyor-type-collector basins	- According to the manufacturer's instructions	V
-Up flow or solids-contact clarifier		V

(1) D-Daily; W-Weekly; M-Monthly; Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

3.9 FILTRATION

Water filtration is used to physically remove suspended particles, including microbiological pollutants. It is imperative that your drinking water treatment system include filtration if your water supply is surface water or groundwater that is directly impacted by surface water. To improve the removal of these particles from the water, coagulants—also known as chemicals—must frequently be added before filtering. The filtering process is made more efficient by these chemicals because they cause the particles in the water to cluster together [82].

Sand, spun cellulose, and other materials are used in mechanical filtering as medium to collect impurities. This process uses a variety of filters, including granular media, diatomaceous earth, cartridge, and bag filters. The following components of conventional (rapid sand) filtering are involved:

- a. consists of an under-drain system and a gravel layer supporting a granular material bed (such as sand or anthracite).
- b. A combination of positive head and bottom suction causes the water to descend through the filter medium.
- c. The complicated process of eliminating impurities takes place all across the filter bed.
- d. The filter bed needs to undergo backwashing (cleaning) to maintain ongoing effectiveness.
- e. This process demands intermediate operator skill levels.

3.9.1 Filters Maintenance

Different types of media are usually employed in the maintenance of conventional or fast filters, which were once referred to as "rapid sand filters." These consist of crushed anthracite, garnet or ilmenite, graded sand, and GAC (Granular Activated Carbon) Various media types can be employed either individually, such as in deep-bed monomedia filters and conventional sand filters, or in combination, as observed in dual, tri-, or mixed media filters. The subsequent maintenance methods are designed to supplement the specifications provided by the equipment manufacturers. Please refer to table 3.5 for a quick reference guide on gravity filter maintenance. Every month, the following actions need to be performed:

- a. Allow the filter to empty to the filter medium's surface.

- b. Examine the surface thoroughly, looking for cracks, unevenness, sinkholes, and any indications of slime, mud balls, or algae.
- c. In the presence of noticeable craters or depressions on the surface, extract the sand and gravel, and rectify any breaks in the under-drain system.
- d. Use high-pressure sprays to break up the mud balls or manually remove them.

3.9.2 Loss of Filter Media

The media in the filter can either travel through the gravel layer with the treated water or be taken away with the backwash water during backwashing. Regulating the backwash flow rate, maintaining proper height of backwash troughs above the media surface, and addressing hydraulic short-circuiting due to blocked media or gravel are essential measures to minimize media losses in backwash water. Furthermore, adjusting the mounding of filter gravel and introducing a layer of coarse garnet or limonite between the media and gravel contribute to limiting losses through the gravel. A little trap put in the effluent line from each filter can be used to monitor for material leaks. Sand leakage occurs sometimes with new filters, although it normally stops after a while. Although this leakage is typically not a major concern, an increase in sand leakage over time may indicate mounded gravel and should be addressed accordingly [83].

Table 3.3: Maintenance Checklist for Gravity Filtration Equipment.

Inspection	Action	Frequency
-Filter media	-Inspecting surface for unevenness, sinking holes, cracks, algae, mud balls or slime. -Digging out sand and gravel at craters of appreciable size. -Locating and repairing under drain system breaks. -Chlorinating to kill algae growths. -Probing for hard spots and uneven gravel layers; if present, treat filter with acid. -Checking wash water rise rate and sand expansion during backwashing. -Checking sand condition for grain size growth; sample sand, determining weight loss on acid digestion, and running sieve test; acid-treat if necessary, or replace sand, if necessary.	M V V Q SA SA A
-Gravel	-Checking elevation of gravel surface. -Examining gravel for encrustation, cementation, alum penetration, or mud balls; if necessary, removing, cleaning, and re-laying gravel.	M SA
-Under drain system	-Removing sand from an area 10 feet square (1 sq m) and inspecting an area of gravel 2 feet square (0.2 sq m) or larger. If underdrains are deteriorated, removing all sand and gravel must be removed, and repairing underdrains, and replacing gravel and sand.	A V
-Wash water troughs	-If underdrain is porous and clogged by alum floc, treating with 2 percent NaOH solution for 12 to 16 hours to be done. -Checking level and elevation; adjusting. -Checking for corrosion; if present, dry troughs, wire brush, and paint.	Q SA W V
-Operating tables	-Cleaning table (console or panel) inside and out.	V
-Cables	-Adjusting tension.	M
-Hydraulic lines (or pneumatic)	-Checking for leakage; repair as required.	M
- 4 way transfer valves	-Adjusting; tightening packing glands or adding new packing.	M
	-Lubricating with grease.	A
	-Adjusting valve position indicator, if necessary.	A
-Table	-Disassembling, cleaning, lubricating, and replacing worn parts.	W
Rate controllers	-Painting inside.	
Direct-acting		
-General		A or V
-Diaphragm pot	-Cleaning exterior, checking diaphragm leakage, tightening packing, and checking freedom of movement and zero differential.	Every 3 years
	Continued	W

Table 3.3: Maintenance Checklist for Gravity Filtration Equipment"Table Continued".

-Controller mechanism	-Disassembling, cleaning, and replacing. Continued	
Indirect-acting	-Disassembling and service; cleaning venturi; painting surfaces needing protection.	A
-General	-Cleaning outside; adjusting packing; lubricating and tightening fittings; checking knife-edges; checking piston travel; repacking as necessary.	Every 3 years M
-Pilot valves		M
-Controller mechanism	-Disassembling, cleaning, and lubricating; checking piston travel; cleaning piping and strainers; checking for leaks in diaphragm.	A
-Mechanically operated	-Disassembling and service; cleaning venturi; cleaning hydraulic cylinders; painting as necessary.	M
loss-of head gages	-Checking zero setting; adjusting stop collars or cable; releasing air from float chamber.	A
-Mud leg		SA
-Float chamber		M
-Diaphragm pendulum loss-of head gages	-Flushing out sediment.	SA
-Pipelines to diaphragm	-Removing float and cleaning; replacing mercury if necessary; checking pressure pipelines; painting interior and exterior.	A
-Diaphragm pendulum unit	-Checking zero setting; purging diaphragm cases of air; checking cable at segment; removing dirt from knife edges; tightening cam hubs on shafts; draining mud from mud leg.	M
-Mercury-float-type rate-of-flow gages	-Checking for free flow and absence of encrustation.	
-Pressure lines		
-Float chamber		
-Piping and valves		
	-Checking for leakage; disassembling unit, cleaning, and lubricating; checking working parts and cables; repacking stuffing box; checking knife edges.	
	-Checking at zero differential; adjusting indicator arm and recording pens; checking stop collars on cables.	
	-Checking accuracy and percent error; if greater than □3 percent, adjusting.	
	-Checking and cleaning as necessary.	
	-Cleaning float and check mercury; paint all parts requiring protection.	
	-Checking for joint leaks; checking pipe hangars and replacing, if necessary; painting as necessary.	

3.10 DISINFECTION

Disinfection is the process of neutralizing or deactivating organisms that could be problematic from a health or aesthetic standpoint. Given that the well-being of water consumers is a primary concern for water suppliers, the design and implementation of disinfection facilities must be meticulously executed [84]. The primary disinfectant utilized in treating drinking water is chlorine. Chlorine is a potent oxidizing agent known for its high corrosiveness. When administered correctly, chlorine

effectively combats bacteria, viruses, and Giardia (excluding Cryptosporidium). It allows for the maintenance of a residual chlorine level in the distribution system, preventing the re-growth of these microorganisms. Chlorination is a cost-effective option and is commonly available in forms like sodium hypochlorite and chlorine gas. However, chlorination does come with downsides - it can cause solid precipitation of iron (which necessitates filtration for removal). Additionally, chlorine's reaction with natural organic compounds in water can lead to the formation of disinfection by-products [84].

3.10.1 Chlorinators

In gas chlorination systems, it is essential for the operator to have a good understanding of the equipment for maintenance purposes. Every chlorinator comes with an instruction manual; it's crucial to refer to it for specific steps regarding servicing. In case of a lost manual, If the replacement request includes the model and serial numbers, the manufacturer will generate a duplicate. Adherence to the manufacturer's guidelines for operations and maintenance [85] is essential. The following paragraphs delineate general maintenance methods applicable to all gas chlorinators. Additionally, table 3.4 provides a troubleshooting chart for solution-feed, vacuum-operated gas chlorinators, and table 3.5 furnishes an overview of standard maintenance procedures for chlorination equipment

- a. **Checking for Leaks:** To find any water or chlorine leaks, check the chlorinator and all of the pipes every day. Every chlorine leak is dangerous and has the potential to quickly grow larger, resulting in significant corrosion and damage. Corrosive leaks are indicated at gas header connections by red staining. A bottle of ammonia and water can be used to find leaks of chlorine gas. If there is chlorine vapor present, a thick white cloud will develop when you waft the open bottle close to the suspected leak. Apply Teflon tape or lime and glycerine cement for all metal-threaded pipe connections; avoid the use of oil or grease.
- b. **Operating the Chlorine Valves:** Daily, ensure proper and complete operation by opening and closing all chlorine valves. Avoid using force to close a valve, and promptly repair or replace any faulty valves.
- c. **Inspecting the Water System:** Clean the water strainers and ensure the pressure-reducing valve operates correctly on a monthly basis. Annually, or as required, clean the injector nozzle and throat using muriatic acid to eliminate mineral deposits. Insufficient injector vacuum may indicate a need for cleaning.

d. Inspecting the Gas System: To ensure correct functioning, periodically inspect all pipelines and components that transport chlorine gas. Every time a valve or tube is attached, make sure to inspect the flexible connections at the gas-supply containers and apply a fresh lead gasket. Remove and clean gas filters on a regular basis. Make sure the heater is operating properly by checking it every day. Verify the functionality of metering devices, shutdown and pressure-reducing valves, hose lines, etc. When required, disassemble and clean to identify the source of any defects, replacing problematic components as soon as they begin to degrade.

e. Cleaning Cabinet and Important Operating Parts: Clean the chlorinator cabinet, glass components, flowmeter, rate valve, vacuum regulator valve, and any other component where dirt might obstruct functionality or appearance thoroughly. Cover unpainted metal prone to corrosion with an appropriate protective coating.

Table 3.4: Trouble Shooting of Chlorinators.

Symptom	Possible cause
-Flowmeter fails to indicate gas flow. -Ejector vacuum is insufficient. -Gas flow rate cannot be controlled -Maximum gas flow rate produces too low a residual in the treated process liquid. -Minimum gas flow rate produces too high a residual in the treated process liquid. -Flowmeter continues to indicate flow when ejector water supply valve is closed.	-Gas supply valve not open. -Gas supply cylinder(s) depleted. -Ejector vacuum insufficient. -Gas-inlet connection block filter clogged. -Flowmeter soiled. -Rate valve in closed position. -Rate valve contaminated. -Air leakage in the regulator stack. -Vacuum regulator valve plug jammed in the closed position. -Ejector water supply valve shut. -Solution line valve not open. -Strainer contaminated. -Ejector dirty. -Solution line partially or fully obstructed. -Ejector throat inadequately filled with water (relevant when the ejector is horizontally mounted, and back pressure is zero or less). -Inadequate water supply flow rate and pressure for prevailing back pressure conditions.. -Liquid chlorine (condensed gas vapor) in the chlorinator. -Vacuum regulator valve contaminated. -Air leakage in the regulator stack. -Ejector vacuum insufficient. -Chlorinator capacity too low. -Air leakage due to soiled sealing surfaces. -Chlorinator capacity range excessively high. -Liquid chemicals (condensed gas vapors) in the chlorinator. -Vacuum regulator valve stuck in the open position. -Solution line draining due to back pressure of zero or less. -Ball obstructing the flowmeter. - Diaphragm backflow check valve not sealing correctly.

Table 3.5: Maintenance Checklist for Chlorination Equipment.

Inspection	Action	Frequen cy
- Operation maintenance	- Installing a fresh lead gasket in chlorine valves or tubes connected to cylinders or equipment. - Airing out the area.	V
- Condensation on chlorine cylinders	- Employing an open bottle of aqua ammonia to detect leaks; promptly conduct repairs if any are found.	V
- Chlorine leak detection	- Dismantling, cleansing, and substituting faulty components in piping, meters, valves, and tubing. - Opening and shutting valves to ensure all are functioning; inspect stuffing boxes and repair or substitute malfunctioning valves or packing.	D
- Gas system	- Inspecting for potential leak sites and for the presence of iron and manganese deposits; if detected, address with a hexametaphosphate solution in makeup water.	D
- Chlorine valve	- Clearing water strainers and adjusting pressure-reducing valves; calibrate float valves and ejector capacity.	A
- Chlorine solution tubes	- Disassembling or operating; applying graphite grease to prevent freezing; hand-tightening only without utilizing tools.	
- Chlorine feeder water supply	- Removing any obstructions.	M
- Hard-rubber threads, valves and parts	- Thoroughly cleaning all parts where accumulation might impede proper functioning.	
- Vacuum relief	- Disassembling and extensively cleaning all components; painting the cabinet inside and out; scrutinize parts and undertake repairs or replacements as necessary; exercise caution in selecting cleaning agents and lubricants.	Q
- Cabinet and working parts	- Utilizing the same protocols as for a solution-feed machine where applicable.	D
- Overhaul		W
Direct-feed chlorinators		A

*D-daily, W-weekly, M-monthly, Q-quarterly, SA-semiannual, A-annual, V-variable as conditions may indicate

3.11 MAINTAINING STORAGE TANKS

Maintaining the quality of the water requires routine maintenance on water storage tanks. Two essential components of the maintenance are keeping the fresh water supply clean and preventing pollution. The maintenance protocols for raised tanks, ground-level storage tanks, and cisterns are described in this technical note. Ensuring the supply of high-quality water is dependent on following preventative measures and attending to repairs immediately.

3.11.1 General Maintenance

Tank storage water quality should be maintained. Every month, all storage tanks should be inspected to make sure that all required maintenance is carried out on time. It is not acceptable to ignore issues that come up for any length of time. When examining the tank, the following inspections are necessary [86]:

- a. Covers: Ensure that the cover fits snugly over the cistern or storage tank, leaving no gaps for dust or leaves to enter. The cover should provide a tight seal to prevent the ingress of light, which can promote algae growth within the tank.
- b. Possible Contamination Sources: Check the area surrounding the storage tank or cistern to be sure no pollutants have been added. Garbage sites and trash disposal should not be placed next to these facilities, particularly if they are subterranean. It is never a good idea to put animal pens or waste sites uphill from the cistern because pollutants might flow downhill and affect the quality of the water. Make sure to keep animals out of the drainage zone and create a drainage ditch to redirect surface water away from the cistern area.
- c. Screens: Check the integrity and quality of the screens that cover pipe ends on a regular basis. Small animals and insects can enter through damaged screens on overflow and outlet pipes. Replace any damaged or broken screens right away.
- d. Pipes: Make sure there are no leaks in the system by carefully inspecting every pipe connection. If any leaks are found, make the necessary adjustments or repairs to the pipes. Make sure all of the valves are functioning properly by giving them a thorough evaluation.
- e. Structure: Take care of any potential cistern or storage tank damage. Apply concrete where needed to fix cracks, chips, and damaged edges.

3.11.2 Tank Cleaning

No matter how much Although precautions are taken, routine cleaning and disinfection of a storage tank is essential. When the main water source is a cistern that gathers rainwater from a roof, it might be difficult to empty the tank for cleaning, particularly if the water supply is reliant on rainfall. Concerns about the cistern's water quality can be successfully resolved by using a pot chlorinator. In addition, employing a chlorinator in conjunction with the installation of a specific filter or a foul flush runoff mechanism can guarantee adequate water quality in the tank.

Ground-level and elevated storage tanks pose fewer challenges when it comes to emptying and cleaning. Given the constant flow from sources like springs, wells, or surface water, these tanks can be easily emptied, cleaned, and refilled. It's important to notify users of any decision to temporarily halt water flow. The cleaning process should ideally be completed within half a day, and it's recommended to clean the tank between peak demand periods. Here are steps to clean and disinfect the tank [87]:

- a. Empty the storage tank of all water. This is usually accomplished by letting the tank's water level drop naturally and then emptying the remaining volume.
- b. To get rid of all the debris and loose materials, give the tank a thorough brush and clean. After the tank has been emptied, select the best disinfection technique.
- c. Pour as much clean water into the tank as possible, then top it off with enough chlorine to get a 50 mg/l solution. To guarantee adequate mixing, add the chlorine as the tank is being filled. After filling, let the tank stand for at least six hours, but ideally longer. Once the allotted time has passed, empty the tank and let it fill up again for future usage.
- d. Directly apply a 200 mg/l strong chlorine solution to the inside surfaces of the tank. Before filling the tank again, for best effects, brush the walls with the solution and let the chlorine sit on them for at least half an hour. If you're short on time, you may utilize this faster technique.
- e. Another technique includes adding water to the tank that has been diluted with 50 mg/l of chlorine, but it does not entail cleaning the tank's upper walls. When the tank is full, this results in a chlorine concentration of 2 mg/l. Before adding fresh water, leave this chlorinated water in the tank for a full day. There's no need to empty the tank while using this procedure. Use of a tank with two compartments may help to lessen difficulties associated with tank cleaning. This allows for the uninterrupted supply of water by allowing one compartment to

be closed for cleaning while the other is still in use.

This method works well for storage tanks of various sizes. It is always important to notify users ahead of time when a system has to be temporarily closed for maintenance. This makes it possible to save more water and motivates people to utilize it wisely when the supply is interrupted. Cleaning should normally be done twice or three times a year.

3.12 MAINTENANCE INSPECTION

Personnel responsible for water supply systems prioritize three main categories of inspection and, to a certain extent, engage in overhaul and repair activities [88].

A preventive maintenance inspection involves cleaning, lubricating, adjusting, renewing, and replacing parts that don't require substantial overhauls or repairs. Additionally, it includes reporting any anomalous circumstances, such as appearance, leaks, strange noises, etc., to the relevant authorities. Employees who oversee specific inspection areas or who are in charge of a certain piece of equipment or system may conduct these inspections.

To determine their physical status, public utilities and works are subjected to scheduled testing and inspections. Control inspections are tests that are carried out by engineering and operational staff in tandem. Control inspection includes structural, mechanical, and electrical inspections as well.

3.13 WATER TREATMENT PLANT MAINTENANCE COST

Operation and maintenance (O&M) costs consist of several elements, including labor, energy, replacement, renewal, chemicals, and waste disposal. Additionally, there are other expenses such as taxes and insurance.

A table is included, providing a partial list of commonly used sources for gathering the data needed to generate the O&M cost estimate. The table also justifies the estimation of each of these components.

Factors impacting capital cost estimates are similar to those influencing operation and maintenance (O&M) cost estimates. Long-term factors that affect O&M cost projections include inflation, changes in interest rates, and competition for labor, energy, and chemicals. Annual cost predictions are usually not assigned a precise level of accuracy because of the inherent uncertainties related to these components. The major elements of water treatment plant maintenance costs are shown in Table 4.6 [89].

The annualized total maintenance cost is calculated considering several input parameters, including:

- a. Costs linked to actual failures or breakdowns.
- b. Costs associated with primary maintenance actions.
- c. Costs related to secondary maintenance actions (corrective repair triggered by observations or warning conditions identified during primary actions).
- d. Frequency of equipment failure based on its life characteristics.
- e. Probability of detecting and completing the secondary action within the warning time distribution.

As an example, the estimated annual operation and maintenance cost amount to US\$ 10 million, with a variable operation and maintenance cost of US\$ 0.007 per m³/year. These estimations are derived from historical values of similar facilities and are anticipated to remain relatively stable, not prone to significant variations, and are non-adjustable by the model user.

3.14 RELIABILITY OF WATER TREATMENT PLANTS

If the treatment plant cannot be shut down for maintenance and repair work, it's necessary to ensure redundancy for all critical components like pumps, settling basins, flocculators, filters, and chemical feeders. The significance of each component's redundancy needs to be assessed case by case, prioritizing the continuous supply of safe water at all times.

Table 3.6: Elements of Operation& Maintenance Cost.

Cost element	Basis of estimating	Data source
Labor	◆ Published cost curves for unit processes ◆ Estimates for overall staffing needs ◆ Prevailing local labor rates	◆ EPA Innovative and Alternative Technology manual ◆ Benjes Handbook of Biological Treatment ◆ Magazines and periodicals ◆ EPA State of the Art of Small Water treatment systems
Energy	◆ Published cost curves for unit processes ◆ Takeoff of horsepower totals from preliminary motor lists ◆ Calculations of heating /cooling requirements	◆ EPA manual on energy conservation in Municipal Wastewater Treatment ◆ EPA State of the Art of Small Water treatment systems ◆ Magazines and periodicals
Renwal and replacement	◆ Percentage of equipment cost ◆ Estimated dosage times design flow rates	◆ Equipment cost estimate ◆ Chemical Marketing ◆ Magazines and periodicals ◆ Chemical vendors
Waste disposal	◆ Estimated cost per unit of waste disposed	◆ Contract waste disposer

In case of anticipated prolonged power outages, it's advisable to consider installing emergency power generation facilities at the water treatment plant. Similarly, if the reliable delivery of essential chemical supplies is uncertain, it's prudent to maintain larger-than-usual reserves of these chemicals, requiring an expanded chemical storage area. The Reliability-Centered Maintenance (RCM) methodology offers a structured approach to develop a maintenance schedule that maximizes equipment reliability at an optimal cost.

The water corporation utilizes this methodology to craft its asset management strategy, with the primary aim of improving the synchronization of maintenance policies and plans with the corporation's needs. The overarching objective is to eliminate maintenance activities that do not add value while implementing practices that maximize business returns in a secure operating environment. Achieving this goal entails elevating standards by incorporating new techniques for monitoring, diagnosis, and systematic analysis, employing the structured decision support methodology embedded in the RCM Turbo approach [89].

3.15 MAINTENANCE STAFFING

The personnel needed for operating and maintaining water treatment plants typically depends on factors such as the design, layout, size, and complexity of the facility. For instance, a chlorinated groundwater supply facility may require just one person responsible for tasks like checking pumps and chlorinators. Rapid filtration plants with continuous operation require a minimum of four operators: one chief operator and three shift operators (assisted by maintenance mechanics and laborers). The manpower requirements are influenced by the following factors:

The nature of the water supply, whether it's surface or groundwater.

- a. The proximity of the supply source in relation to the treatment facility's location.
- b. The variability in raw water characteristics concerning both flow and quality.
- c. The type and complexity of equipment involved.
- d. The utilization of any specialized treatment methods.
- e. The need for pumping.

Determining the precise personnel needed to operate a treatment plant presents challenges due to the aforementioned variables. Additionally, the availability of central support services significantly influences both local plant requirements and the attention devoted to them. Furthermore, the personnel assignments are influenced by the history and social structure of the community and country. Table 3.7 [90] summarizes manpower requirements for various types of plants and population levels.

The plant maintenance supervisor should demonstrate skills in planning, organizing, assigning, directing, reviewing, and evaluating the work of plant maintenance staff. This encompasses planning and executing a comprehensive plant maintenance program, interpreting plans, specs, blueprints, and schematics, personally engaging in skilled

electrical, mechanical, and related trades work in water treatment plant maintenance, and maintaining accurate records and reports. Other essential skills include estimating, procuring necessary materials, tools, and equipment, understanding basic budgetary principles, exercising independent judgment within established guidelines, and establishing effective working relationships. Proficiency in computer operations for information retrieval is also vital.

In terms of experience, candidates should possess four years of progressively responsible journey-level experience in plant maintenance work across various trades, including process instrumentation maintenance experience in a water or wastewater treatment plant. Leadership or supervisory experience is considered desirable. Education-wise, a high school diploma or equivalent is a requirement, along with a minimum of two years of technical school or college-level coursework in a related field [90].

Table 3.7: Operation and Maintenance Manpower Requirements for Water Treatment Plants.

Treatment method	Size of community*	Manpower required		
		Unskilled	Skilled	Professional
Slow sand filtration (conventional, dynamic)	500 – 2500	1		
	2500 - 15000	2		
	15000 - 50000	5		
	50000 - 100000	8		
Conventional rapid filtration (conventional, dual-media, upflow-downflow)	500 – 2500	1	1	
	2500 - 15000	1	1	1
	15000 - 50000	8	2	1
	50000 - 100000	10	3	1
Advanced rapid filtration (multi-media, inclined – plate, or tube settling polyelectrolytes)	500 – 15000	1	1	1
	15000 – 50000	6	2	2
	50000 - 100000	10	5	2
Desinfection (chlorination)	500 – 2500	1		
	2500 - 15000	1	1	
	15000 - 50000	2	1	1
	50000 - 100000	4	1	1

Demand=275liter/day /capita.

3.16 SIMILAR CASES

Numerous companies have implemented maintenance systems or programs to achieve the essential objectives of an effective maintenance management system. These objectives comprise:

- a. Ensuring regular, timely, standardized, and comprehensive equipment maintenance.
- b. Minimizing excessive maintenance practices, such as over-greasing bearings.
- c. Improving system reliability by preventing or promptly detecting equipment malfunctions.
- d. Optimizing equipment operational efficiency.
- e. Extending equipment lifespan.
- f. Improving safety through the reduction of unexpected failures and the inclusion of safety guidelines within maintenance and service procedures.
- g. Decreasing overall maintenance costs.
- h. Implementing a thorough record system that encompasses equipment history, maintenance expenses, and workloads.

In a broader sense, the maintenance management system for water treatment plant components includes the following elements:

- a. Comprehensive equipment documentation and maintenance records.
- b. Strategizing for proactive maintenance measures.
- c. Documenting expenses related to corrective maintenance.
- d. Enforcing uniform preventive maintenance protocols.
- e. Creating managerial reports detailing maintenance costs, pending tasks, and employee assignments.

Two cases will be presented to illustrate the maintenance programs of these instances, acknowledging that the specifics of these programs fall within the domain of proprietary knowledge not disclosed by the program designers.

3.16.1 Brawley City Case

The operation and maintenance program will involve creating manuals for operation and maintenance, providing extensive training on equipment and processes, conducting annual refresher courses, holding seminars and workshops, and ensuring compliance with certification requirements. Prior to the initiation of plant operations, the operations and

maintenance personnel will undergo thorough equipment training, as detailed in the study by [91]. This training will address the following components:

- a. Instruction provided by a manufacturer's factory-trained operations and maintenance specialist for the Owner's maintenance and operations personnel. The training will cover the operation, disassembly, and assembly of major equipment items, start-up and shutdown procedures, safety protocols, troubleshooting techniques, installation methods, alignment procedures, and recommended corrective and preventative maintenance procedures for all specified equipment in the equipment schedule section.
- b. Engineer approval of the specialist's qualifications.
- c. Coordination of the training schedule by the Owner through the contractor, typically planned near the project's completion but before the equipment's start-up.
- d. Offering a combination of classroom and field training by the manufacturer.
- e. Recognition of the manufacturer's representative's training as a critical aspect of the project by the Owner. Failure to adhere to the required information submission schedule or delivering unsatisfactory training by unprepared or unqualified manufacturer's representatives may lead to withholding 10 percent of the progress payment for the respective equipment until satisfactory lead time and training are provided to the Owner's satisfaction.
- f. Specification of the training duration for each piece of equipment by the manufacturer.
- g. Preparation of final operations and maintenance manuals for use during training exercises.
- h. Commencement of training only after the manufacturer approves all individual systems and completes the necessary testing outlined in this section.

3.16.1.1 Instruction schedule

- a. Sixty days before the initiation of any training, the manufacturer will furnish the Owner with a preliminary training schedule and designate a contact person.
- b. Thirty days prior to the scheduled commencement of training, the manufacturer will present a proposed Lesson Plan for instruction, seeking approval.
- c. The manufacturer will seek approval for the credentials of their designated instructor, which will include a concise resume and specific details about the instructor's experience in training related to the maintenance and operation of the provided equipment.

3.16.1.2 Instruction lesson plan

- a. The manufacturer's proposed Lesson Plan will comprehensively address the elements outlined in the provided Instruction Lesson Plan, providing detailed specifics on various components and procedures.
- b. The manufacturer's proposed Lesson Plan will delve into specific instructional topics, referencing and attaching training aids where applicable. It will also outline any planned "hands-on" demonstrations for the instruction.
- c. The manufacturer will specify the expected duration for each segment within the training Lesson Plan.
- d. Outline of Instruction Lesson Plan:
 - Equipment Operation:
 - i. Clarify the equipment's operational (process) function.
 - ii. Explain the fundamental operating principles and dynamics of the equipment.
 - iii. Identify the mechanical, electrical, and electronic components and features of the equipment.
 - iv. Identify all support equipment associated with the operation of the subject equipment (e.g., air intake, filters, valve actuators, motors).

Detailed Component Description:

- i. Identify and provide detailed descriptions of each component's function.
- ii. Group related components into subsystems where applicable, describing subsystem functions and their interaction with other subsystems.
- iii. Identify and describe in detail equipment safeties and control interlocks.

Equipment Preventive Maintenance (PM):

- i. Describe PM inspection procedures required to:
- ii. Perform an inspection of the equipment in operation.
- iii. Identify potential trouble symptoms (anticipate breakdowns).
- iv. Forecast maintenance requirements (predictive maintenance).
- v. Define the recommended PM intervals for each component.
- vi. Provide lubricant and replacement part recommendations and limitations.
- vii. Describe appropriate cleaning practices and recommended intervals.

Equipment Troubleshooting:

- i. Define recommended systematic troubleshooting procedures.
- ii. Provide component-specific troubleshooting checklists.
- iii. Describe applicable equipment testing and diagnostic procedures to facilitate troubleshooting.

Equipment Corrective Maintenance:

- i. Describe recommended equipment preparation requirements.
- ii. Identify and describe the use of any special tools required for equipment maintenance.
- iii. Describe component removal/installation and disassembly/assembly procedures.
- iv. Conduct at least two "hands-on" demonstrations of common corrective maintenance repairs.
- v. Describe recommended measuring instruments and procedures, providing instruction on interpreting alignment measurements, as appropriate.
- vi. Define recommended torquing, mounting, calibration, and/or alignment procedures and settings, as appropriate.
- vii. Describe recommended procedures to check/test equipment following a corrective repair.

Training Aids: The manufacturer's instructor will incorporate training aids as appropriate to assist in the instruction. At a minimum, the training aids will include text and figure handouts. The manufacturer will provide the Owner with one complete set of all slides, transparencies, diagrams, and other written material used for training purposes. Other suitable training aids include:

- i. Audio-visual aids (e.g., films, slides, videotapes, overhead transparencies, posters, blueprints, and diagrams, catalog sheets).
- ii. Equipment cutaways and samples (e.g., spare parts, damaged equipment).
- iii. Tools (e.g., repair tools, customized tools, measuring and calibrating instruments).
- iv. The manufacturer's instructor will utilize descriptive class handouts during the instruction.

Hands-On Demonstration:

- i. The manufacturer's instructor will conduct at least one "hands-on" demonstration of common corrective maintenance repairs to allow key operations and maintenance personnel

to observe the demonstration. The manufacturer will provide the necessary tools and equipment for the demonstrations.

ii. In any hands-on training scenario where Owner's operations or maintenance personnel participate in the disassembly or assembly of equipment components, the manufacturer will be responsible for such actions and shall provide written certification of proper equipment operation to the Engineer. Adequate funds will be reserved in the project budget to ensure sufficient support for the operation and maintenance program. A preliminary estimate is as follows:

3.16.2 Operation and Maintenance for Expansion of the Jonathan Rogers Water Treatment Plant in El Paso, Texas

The facility expansion necessitates an increase in operation and maintenance personnel. To support the expansion, an additional 5 staff members will be required, constituting an approximately 23% increase over the current staffing levels. The projected annual cost of operation is estimated at \$6,022,000. It is expected that the unit cost of water production will closely match the current operational cost, which is approximately \$0.54 per 1,000 gallons of water produced [92].

3.16.2.1 Startup requirements

The startup procedures will be outlined in the contract documents, providing specific details regarding the schedule and correction of any deficiencies. Whenever feasible, critical startup procedures will be planned during periods of low water demand, such as early spring.

3.16.2.2 Operations training program

The training for operations personnel will begin following the successful startup and acceptance of the facilities.

3.16.2.3 Operations and maintenance manual

The Operations and Maintenance manual, originally created for the current plant, will be revised to incorporate the new facilities and any modifications to the existing facilities arising from the expansion.

From the above cases and the previous presentation of various elements of maintenance management of water treatment plants it's clear to give the importance to the following: items which shall be the keys to design the suggested maintenance management system:

- a. Planning of the maintenance activities reaching the optimum situation with determining the staff required for these activities and the method of procurement for these works and then according to this plan a budget must be put to go on to the next step.
- b. Implementation of the plan showing the proper reports that explain the real state of implementation of maintenance program with multi types of these reports that can be daily, monthly.... etc.
- c. According to the two steps above a comprehensive comparison must be done between the maintenance program and the actual situation in fact. To complete the cycle of maintenance management plan- do- compare concept.

3.17 EXISTING MAINTENANCE SYSTEM

The existing situation of the maintenance management system must be studied at this stage, as an evaluation stage in the sequence of developing maintenance management system for water treatment plants, using the systems described before and the details of both managerial side and the technical side. This chapter discusses all the current aspects of managing water treatment in Najaf, using components of maintenance management as a guide to evaluate the current system. Highly detailed information in this chapter is very necessary to assess the deviation between theoretical and actual state, and to what extent the actual state is close or far from the theory or other international cases.

3.17.1 Data Collection

The details were taken from the headquarter of Najaf Water Administration (NWA), in addition to water treatment plants themselves. These details were gotten from their original sources; internal documents of the headquarter of NWA, papers and studies done for the aim

of this research, data collection form (designed by the researcher), documents of the manufacturer.

Most of the details at this chapter are taken from the data collection form. Designing such form is a good source for field data and can represent the actual state of water treatment plants.

3.17.2 Maintenance Planning

NWA prepares the plans water treatment plants. But the real clear problem was the pressure of the bad economic circumstances of the country. For this reason, maintenance and rehabilitation plans for water treatment plants were set according to the human relief and UN organizations, that causes a incompatible view in planning according to UN organizations idea. NWA put a simple plan that depends firstly on dealing with emergency maintenance. Therefore, it's difficult to have clear plans for maintenance. The cause of this problem is seven that NWA forbid showing these plans that is elongate the task of the researcher, or it's unavailable for many reasons as no preceding planning, or the issue of maintenance planning became routine but undocumented or there are any other reasons that is unforeseen.

Maintenance activities are prioritized to align with the allocated budget, allowing less critical activities to be deferred or scheduled during periods of human relief and UN organization availability. The missed information can result that maintenance activities are not assessed, the prepared is far from actual state. Data collection form was a good source for summing these activities and the information related to them, and they shall be discussed in details in the next paragraphs as the description of the activity, frequency, the duration of the activities, and the plant in which these activities were done.

3.17.2.1 Intake maintenance

Intake maintenance activities at the water stations in Najaf governorate include several activities, the most important of which are:

- a. Cleaning and sediment removal: The intake is cleaned of dirt and sediment suspended in it periodically to avoid its accumulation and its impact on the water flow process.

- b. Examination of networks and pipes: Networks and pipes in the intake are examined and the necessary maintenance is carried out to avoid any damage or breakage in them, in order to ensure proper water flow.
- c. Cleaning and maintaining the machines: The machines in the intake, which are used in the water filtering and purification process, are cleaned and maintained to avoid any defect or damage.
- d. Damage repair: In the event of any damage or damage to the intake, it must be repaired immediately, in order to avoid its negative repercussions on water quality and flow.
- e. Maintaining the filtration system: The filtration and purification system in the intake is maintained through regular maintenance, to preserve water quality and prevent the impact of any detrimental substances on the system.

The teams responsible for maintaining the intake at the water stations in the Najaf Governorate must carry out these activities on a regular basis to maintain the quality of the water and ensure its proper flow.

3.17.2.2 Alum solution production unit maintenance

For the aim of coagulation and flocculation, alum solution must be prepared at the unit specified for this purpose then it will be carried to the mixers or flocculators. This unit is suffering from following problems:

- a. The major problem is the large quantity of impurities that came with alum powder that already clog the strainers and solution transformation network and solution pumps.
- b. Solution pumps need a special type of pumps because of chemical effect on them.

3.17.2.3 Flocculator maintenance

The process of flocculation is maintained by the activities (Lubrication greasing gearbox, Bearing replacing, Basin cleaning, Repairing mixer fan, and Repairing mixer (motor & gearbox)). A major problem of irregular turbidity affects this process, this might cause a fluctuation in performance of the unit.

3.17.2.4 Sedimentation basin maintenance

The activities of maintenance of sedimentation basin (Basin cleaning, Scraper maintenance, Sludge turning out, Electrical board & scraper motor maintenance, Basin maintenance

(leakage treatment), Sludge pit cleaning, Valve maintenance, Basin parasol maintenance, Repairing submersible pumps(for sludge pits), and Scraper lubrication). At sedimentation basin, there is a large problem of drainage of sludge to the river because if the turbidity of water is high, a large quantity of sludge shall result and there is an urgent need for sludge drainage. That might be so difficult to be drained when the sludge is cumulated.

3.17.2.5 Filters maintenance

Filtration has a number of activities for maintaining this unit these activities are (Back washing, Cleaning from algae , Cleaning filter walls, Lubrication & greasing pumps & air compressors, Valve repairing, Media replacing, Repairing air blowers, Air valves repairing, Air compressors repairing, Nozzle replacing, Scraping filter surface, Repairing submersible pumps, Repairing control system, and Repairing washing pumps). Where the problem of side effect of back washing represents the major part of these problems as losing filter media, valves, improper work, pumps failure, air blowers failure, and other effects.

3.17.2.6 Chlorination unit maintenance

At the most of these plants' chlorine gas is used for disinfection stage. But many problems arise as the heater failure that is used for transforming chlorine gas to a liquid. In addition to problems of corrosion due to using chemicals as chlorine (especially when chlorine reacts with water) or impurities that might come with chlorine. Maintenance activities for chlorination unit are (Maintenance injector occultation, repairing network occultation, Dispenser repairing (from blockage), Repairing gas bottle crane, Electrical repairs, Chlorine valves replacing).

3.17.2.7 Low lift & high lift pump stations

There is a number of activities can be seen for maintaining low and high lift pumps these activities (Bearings replacing, Backings replacing, Lubrication, Electrical board repairing & maintenance, Transformer cleaning, Pumps painting, Overhaul pumps maintenance (bearings & so), Valves maintenance, Coupling replacing, Motor maintenance, Leakage treatment, Submersible pump maintenance , Replacing impeller cover, Motor lubrication, and Repairing broken shaft) bearing in mind that there are differences between them as the quality of water pumped through is different. Since low lift pumps are dealing with raw

water carrying silt and other impurities where high lift pumps are pumping potable with a dose of chlorine that might result corrosion for these pumps. Another problem is that intake affects low lift pumps when the process of cleaning and maintenance is absent.

3.17.3 Maintenance Scheduling

The major part of scheduling that is related to staffing water treatment plants is displayed in Table 3.8, this table illustrates the numerical values and types of staff required according to NWA to be compared with the numbers and types available in water treatment plants.

Staff training as another part of maintenance scheduling was too weak that the expenditures for training were 0.0322 %, 0.03053 %, 0.01838% from the total expenditures for the years 2019,2020,2022, respectively. These percentages reflect little attention to the overall training, which is part of the scheduling process.

Table 3.8: Required and Available Staff in Water Treatment Plants.

Job	Avail.	Req.	Avail.	Req.	Avail.	Req.	Avail.	Req.	Avail.	Req.	Avail.	Req.	Avail.	Req.	Avail.	Req.
Chief Eng. (Mechanic)	-	-	-	-	3	1	-	-	0	2	-	-	-	-	-	-
Chief Eng. (electric)	0	3	1	2	1	3	-	-	0	2	0	3	-	-	-	-
Senior Eng. (electrical)	1	4	1	1	-	-	-	-	-	-	-	-	-	-	0	1
Senior Eng. (mechanic)	-	-	0	2	-	-	-	-	-	-	-	-	-	-	-	-
Eng. (electrical)	-	-	-	-	0	1	0	1	-	-	1	1	1	0	-	-
Eng.(mechanic)	2	3	-	-	2	0	0	1	-	-	1	1	0	1	-	-
Eng.(chemical)	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Assistant Eng.	7	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chemist	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physicist	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrician	4	16	0	7	1	2	0	2	0	4	1	0	0	3	0	1
Mechanician	3	16	1	9	3	3	1	6	1	4	1	0	3	3	0	2
Technician (operation)	2	8	5	6	3	1	0	3	3	0	3	0	0	2	0	1
Technician assistant	2	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Repairer	6	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3.8: Required and Available Staff in Water Treatment Plants"Tables Continued".

Technical supervisor	1	0	-	-	3	0	-	-	0	1	-	-	-	-	-	-
Agricultural Eng.	1	0	1	0	-	-	-	-	-	-	-	-	-	-	-	-
Assistant lab.	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clerk	3	0	0	2	1	0	0	1			1	0				
Station operator	16	39	4	54	10	10	6	13	12	12	18	0	8	4	7	3
Pump station operator	12	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pump operator	2	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Driver	5	4	2	2	-	-	0	2	-	-	-	-	-	-	-	-
Gardener	1	19	0	8	0	10	-	-	-	-	-	-	0	2	0	1
Guard	2	38	-	-	0	10	1	2	0	6	8	0	0	2	-	-
Excavator driver	2	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Forklift driver	-	-	-	-	0	1	0	1	0	1	0	1	-	-	-	-
Shovel driver	2	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Service worker	23	10	2	18	0	10	1	7	2	8	6	0	-	-	0	4
Store secretary	1	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Cleaning worker	1	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-

3.17.4 Maintenance Budgeting

According to the balance sheet that shows the assigned budget for each item of the general budget of the NWA, it's clear that maintenance budget using the unified accounting system cannot give distribution of money assigned according to the plant or whether the maintenance activity was periodic or emergency, in addition that the classification according the unified accounting system didn't describe the details of the sums assigned for maintenance for example. But there are a number of figures that can be used as indicators for maintenance budget.

On the other hand, the revenues of NWA is highly depend on the revenues of selling potable and raw water to the people. The price of this water is too cheap to fulfill the needs for operation and maintenance of these plants and their supplementary plants as pump stations and major storage tanks , in addition to the project of the administration that certainly it must be covered from the general budget of the government.

No other data related to the budgeting are available for the purpose of this research or they are dispersed among the other archive documents. No sorting, no cost accounting document that might lead to good conclusions and suggestions.

3.17.5 Maintenance Evaluation and Reporting

Planning and following up department of NWA is responsible for evaluation and partially for reports. The reports prepared by this department shows the activities. At maximum evaluation process can be done by a comparison between previous years, without any consideration to the standards required for evaluation. Therefore, the presentation of activities done was the major part of all reports in addition to percentages of achievement, without showing the deviation between actual time schedule and cost with the planned.

The role of the plants reporting is too limited because of the limited authorities given to plants' management, so, it is difficult to the plant to know whether it is going in the right way or not. The real problem is cumulated by unavailability of the required standard for performance evaluation.

Following up the expenditures as compared with the budget was for aims of accounting only and the benefits of this comparison is limited to the top management. That might give good feedback for the plants themselves to adjust the performance and even the strategy of the plants.

As one of the standards used for evaluation the cost of producing a cubic meter of potable water, it's found that the cost is 3761 ID (about 1.88\$). This cost is compared with other countries such as Brazil was 4.783 U.S.\$ per cubic meter, which about 2.5 times that in Najaf.

3.17.6 Challenges of the Current Maintenance System

According to the previous presentation of the existing state to the maintenance system for water treatment plant in Najaf, it's clear that the system does not fulfilling the requirements of supplying potable water for Najaf city. For this aim a number of criticisms according to the management stage, taking to account the data collected and presented before. Handling the adaptive construction project for the facade is perceived as a notable challenge within construction project management. The incorporation of sustainable concepts presents an

economic challenge. This facet of building construction in Iraq has faced various difficulties [93].

3.17.6.1 General challenges

The major criticism for the system is that there's no real system. Therefore, all or most of the activities were done without using management rules for directing and organizing these activities in order to achieve good maintenance.

The first point is that all Najaf city consume $10,005\text{m}^3/\text{day}$. This demand is not only for residential use but also for industrial, agricultural, and other demands. After subtraction the losses and other demands the residential demand expected to be 94.75% then it will equal to 200.32. The average consumption will be $0.14\text{ m}^3/\text{capita}/\text{day}$ which is considered little. Then all the plants must be operated at all times with full capacity without any shutdown and that must need further maintenance, which is the first problem. A number of small plants can supply a little quantity of water as compared with large plants.

3.17.6.2 Planning challenges

There is a deficiency in maintenance planning for both major types, periodic and emergency. Even when planning is attempted, it lacks a thorough study. Emergency maintenance tends to be the most common plan across the eight plants, though this choice lacks substantial scientific validation.

The absence of well-grounded scientific planning has led to several problems in subsequent functions of maintenance management, including:

- a. Insufficient assessment of activities, lacking in evaluating their quality, quantity, and adherence to standards, which are crucial for plant preservation.
- b. Due to the inadequacy mentioned in (1), there is a lack of prioritization for the aforementioned activities.
- c. Significant discrepancies exist among plants regarding the implementation of maintenance activities. These disparities encompass the frequency of activities and the time required for each activity.
- d. The allocated time for these activities lacks specificity and has a broad range, resulting in inconsistencies during the execution of maintenance tasks.

e. Unavailability of the data that might be used, as reference for the maintenance, which is can be useful for planning to the future.

3.17.6.3 Budgeting challenges

From the data collected of the budget issue a number of criticisms are made on the budgeting side of maintenance management system as follows:

- a. Poor documentation led to a confused picture about the budgeting of maintenance.
- b. Planning of expenditures that represents the budget assigned for maintenance is not suitable for managing water treatment plants and does not covering all types of problems.
- c. Available budgeting data of the previous years do not show a clear pattern of developing the sums assigned at these budgets to develop water treatment plants.
- d. The budget is depending on the ammounts of money from the general budget of Ammanat Najaf that the body authorized of Najaf water administration, and the revenues of sold water to the consumers. In spite the ability to find new sources of revenues such as selling treated sludge that can be used as fertilizers, reusing of alum from settled sludge, and self-service revenues.
- e. Maintenance and rehabilitation of the plants that is done by humanitarian and UN organizations are not mentioned in the budget, and the activities that are done are not assessed at any documents of budgets.

3.17.6.4 Organization structure challenges

The organization structure of Najaf water administration is directing the department of operation and maintenance that is responsible of operation and maintenance of water treatment plants at Najaf City. This department directs all water treatment plants of Najaf, then there is a need for a high degree of cooperation with the other departments to achieve the their work.

The problem of organization structure of operation and maintenance department is that geographic departmentation for the plants is not suitable for managing these plants because of the limited region for Najaf city. Neither cost accounting section belong to operation and maintenance nor belong to administration and financing department that is available to explain the causes and locations of failures and can give good conclusions for managing water treatment plants, and especially for maintenance.

3.17.6.5 Staffing challenges

Staffing all plants is not stable and differs from plant to another such as the over availability state of job in plant and deficiency state in another. Then, the available staff of NWA need redistribution and to be reviewed by studying the actual need of staff and the jobs and their description. Also there is an urgent need to adjust the staff of the plant for both type and number of the staff required and must be studied scientifically.

3.17.6.6 Evaluation challenges

Evaluation of water treatment plants is confined to the comparison between design and actual capacity, and the comparison between planned and actual maintenance activities regardless to the achievement percentages or cost deviation. This can interpret the failures at the evaluated fields.

Standards and criteria for evaluation are not available to give a conclusion about any aspect such as performance, managerial, technical, and so. Therefore, many failures couldn't be proven, because of lack of these standards.

Cost accounting did not appear to be a reference for planning, scheduling, and controlling these plants and their developing. The lack of cost accounting department, which can show the weak points of maintenance and the ability to develop maintenance.

3.17.6.7 Reporting and feedback

As a result of the challenges explained above, the reporting was just formal report for saving at the main office at either operation and maintenance department or other departments of Najaf water administration. Even these reports are dispersed at many sides of N.W.A. Then all data that can be a good reference to the top management about the required behavior for treating crisis that NWA is not available. Certainly, there is too little feedback, which is the solution of the similar problems of water treatment plants. Feedback absence makes the review of management activities difficult, which can be a fatal mistake. At the end of the chapters, we notice in the appendices section the clarification of the tables for the allocated data.

4. DEVELOPED SYSTEM

4.1 GENERAL

According to the chapters discussed before, a maintenance management system was developed to overcome the problems and criticisms of maintenance management system in the existing situation. The main problem is poor documentation of all activities and other important data required for all components of maintenance management system as feedback data used for planning evaluation and increasing performance of the administration and individuals.

4.2 SYSTEM DESCRIPTION

The main goal of the proposed system is to attain the most cost-effective maintenance by striking a balance between periodic maintenance, encompassing all planned maintenance types, and emergency maintenance.

A significant benefit of this system is its adaptability, allowing for adjustments in plans and budgets in response to changes in economic circumstances, administrative conditions, and the plant's lifecycle during its operational phase. The system dynamically incorporates these alterations, effectively utilizing the new data stored in its database accumulated over a year of maintenance. This advantage is demonstrated through updates to activities and their frequencies, the time needed for these activities, and a thorough assessment of the justification for these changes, assessing their reasonableness and necessity.

The system is based on the principles of maintenance management that is discussed in chapter three with main components of planning, budgeting, scheduling, evaluation, and data recording and feedback.

4.3 SYSTEM REQUIREMENTS

Many requirements must be available to permit the suggested system to work in a good performance. These requirements give the system all enhancements for self-maintainability, otherwise most of the results such as plans, budget, evaluation, and reports will lead to wrong decisions. Coding system and documentation system are the requirements of the suggested system.

4.3.1 Documentation System

The criticisms of poor documentation concerning of managing water treatment plants and especially, the maintenance of these plants. Therefore, the first system is set to solve this problem. This system deals with scheduling all data required to be put in two suitable forms, which are designed by the researcher according to needs and demands of the suggested system of maintenance management components. These forms depend on the daily following up of all maintenance activities and all data concerned with these activities. And can be filled by the person responsible for maintenance for example, maintenance engineers, who must be familiar with all details of the maintenance activities for all units.

The first form represents the daily report as shown in tables 4.1, 4.2 , 4.3 , this forms is a review of the activities in different level of achievement such as the activities that are just started at that day and the activities that are in work now with any percentage of achievement and finally the activities that are finished at that day. the code, the method of implementation in addition to other remarks about each activity must be mentioned in the report. Daily report reflects the daily state of maintenance at the water treatment plant and accordingly, to be compared to the plan. The second form is assigned for each finished activity, though the activity is repeated.

Daily maintenance Report

Plant: Total water produced this day m³/day:Date:

No. Of work groups:No. Of staff for all groups:

Table 4.1: Activities Just Started:

	Code	Activity	Method of implementat ion	Remark s
1				
2				
3				
4				
5				

Table 4.2: Activities in Work.

	Code	Activity	Method of implementati on	Achieve ment %	Remarks
1					
2					
3					
4					
5					

Table 4.3: Finished Activities (Maintenance Sheet I or II Must be Prepared for Each Activity).

	Code	Activity	Method of implementation	Remarks
1				
2				
3				

These forms provide the system with the required data mainly for building a data base for maintenance of water treatment plants, in order to achieve self-maintainability in the future in conditions of changing the state of the plant and management or even economic situation changing of the country. The details gained from these forms are very important for continuation of the suggested system components. From these form frequencies can be calculated as the activity executed for more than once, the difference between the date of the form editing (which must be done immediately after the activity finishing). Also, the time required for the activity, method of implementation, cost of the activity, and other data required for planning and all pre-execution components.

A new form can be designed for any other method of implementation to combine the two maintenance sheets with the adequate heading for the details corresponding to the data of the previous sheets.

4.4 SUGGESTED MAINTENANCE MANAGEMENT SYSTEM COMPONENTS

The style of dealing with the case of the research (water treatment plants) is according to the theoretical components of maintenance management systems, then an evaluation for the

existing maintenance management system will be made. The component of the suggested system shall be explained in the next paragraphs.

4.4.1 Planning

Suggested maintenance management system gives high attention to the planning side that is depending on the constant situation of the plant design and variable field data, taking into consideration what might affect the total maintenance cost. The proposed system presents a strategy that can result in a fully optimized maintenance cost. This concept is notably original, particularly in Iraq, and it underscores the thesis's uniqueness in presenting an approach to achieving the optimal maintenance cost and constructing an efficient maintenance management system with an ideal total maintenance cost.

Several instances showcased an attempt to attain an optimized total maintenance cost. One notable instance occurred in Morocco, Marrakech, where the national office for drinking water branch recognized that the current maintenance system, developed by DEGREMONT Co., initially maintained a balance between periodic and emergency maintenance at 60% and 40%, respectively. Following an in-depth cost analysis, they modified this strategy, embracing a new allocation of 20% to periodic and 80% to emergency maintenance. This adjustment led to a notable decrease in the overall maintenance cost. In another instance, at Kununerra Dam, an analysis revealed a 70% reduction in the overall maintenance cost when compared to the manufacturer's initially recommended schedules. They achieved this by employing the RCM approach to determine the point that represented optimal maintenance cost.

When applying this approach to the specific research case, numerous challenges emerged. The first obstacle involved the extensive number of maintenance activities, both periodic and emergency. The second challenge stemmed from the wide-ranging differences among the plants in terms of capacity, streamline, plant lifespan, mixing methods, sedimentation methods, filter types, unit numbers, and other variables.

The proposed system heavily relies on the data needed for each plant, particularly maintenance-related information, to assist system users in devising a cost-optimized plan. To achieve this, the following steps outline the details of the suggested planning subsystem:

Step 1: Activity Assessment and Data Collection

This initial step involves assessing each activity's description, time required, frequency, cost, and other relevant data. The minimum frequency for each activity is determined to initiate the total maintenance cost curve for optimization. These data can be sourced from previous data or gathered through experiences from individuals involved in water treatment plant maintenance for the system's initial application. In subsequent applications, activities are saved in the system's documents and reports, allowing for necessary adjustments facilitated by the system. Manual data updating is beneficial when circumstances warrant changes, especially additions or omissions of activities.

Step 2: Preparation of Periodic and Emergency Plans.

Once the data from step 1 is complete, both periodic and emergency maintenance plans are developed. These plans serve as the initial trial in the optimization process, with the total maintenance cost calculated by summing the periodic and emergency maintenance costs.

Step 3: Adjusting Activity Frequencies

Starting with the minimum frequency for periodic maintenance, the frequency of each activity is increased. This involves altering weekly activities to daily, monthly to weekly, seasonal to monthly, semi-annual to seasonal, annual to biennial, and so forth. Concurrently, emergency maintenance is influenced by this frequency increase, leading to a decrease in the expected average frequency of emergency activities.

Step 4: Preparation of New Plans Based on Adjusted Frequencies

New plans are formulated to align with the updated frequency of periodic maintenance and its impact on emergency maintenance.

Step 5: Cost Comparison

A comparison is made between the initial total maintenance cost (referred to as "old cost") calculated in step 2 and the revised total maintenance cost (referred to as "new cost") calculated in step 4. If the old cost exceeds the new cost, there is an opportunity to reduce the total maintenance cost, prompting further trials.

Step 6: Iterative Optimization

Steps 3 to 5 are reiterated until the old cost becomes less than the new cost. The trial just before the final iteration represents the optimal total maintenance cost

Step 7: Embracing the Optimal Total Maintenance Cost.

The optimal total maintenance cost acquired in step 6 serves as the cornerstone for the planning process. All plans are presented using techniques like bar charts in Microsoft

Project software (or any suitable software), showcasing periodic maintenance activities based on their respective frequencies (daily, weekly, monthly, etc.).

4.4.2 Organization Structure

The suggested system presents an organization structure as a support system for the suggested system to help in keeping the system within the standards that are required for system maintainability.

One of the major criticisms presented was lack of cost accounting at the organization structure of operation and maintenance department that is responsible of all maintenance aspects for all water treatment plants at Najaf city, cost accounting can be also with a good benefit for NWA and especially for maintenance. The plants itself does not have any accounting unit that can deal with cash in and cash out and the related book keeping by any accountant. Therefore, cost accounting section must be added for helping in cost estimate, cost check, and cost details recording. Cost accounting can be also a section at the operation and maintenance department but the services of this section will be for this department only, then it must be a part of accounting department.

Cost accounting section will be responsible for sorting cost data from its origins according to the suggested system and a cross matching will be helpful to compare the results gained from the suggested system and cost accounting results. There will be double checked data resulted, and matching of these data will be helpful for evaluation of the standards that are used for planning and scheduling stages.

Data required for this section shall be supplied by the accounting department. Standard forms can be designed for this aim and sent to the plants and other production units, to use the raw data from these forms to reach the figures required for all purposes of managing water treatment plants, compact units, pumping station, and storage tanks.

The sub structure of operation and maintenance department is to be changed to comply with the suggested system. Functional structure will be suitable for the department. Figure 4.1 shows the suggested structure.

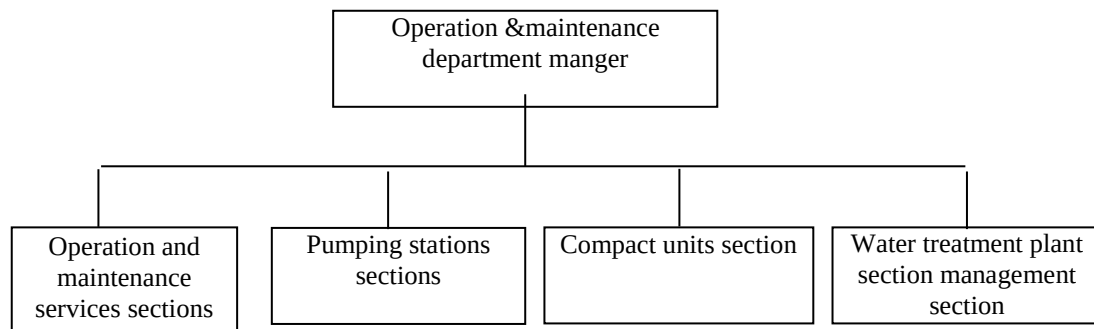


Figure 4.1: Suggested Operation and Maintenance Department Structure.

Plant organization structure can be done by assessing the authorities and responsibilities and giving a wide range for them, making the management more decentralized.

The plant management team beside the technical staff, administration and accounting staff is an important factor for the increasing of the authorities of plant manager. Maintenance will be a section of water treatment plant sections that is shown in figure 4.2.

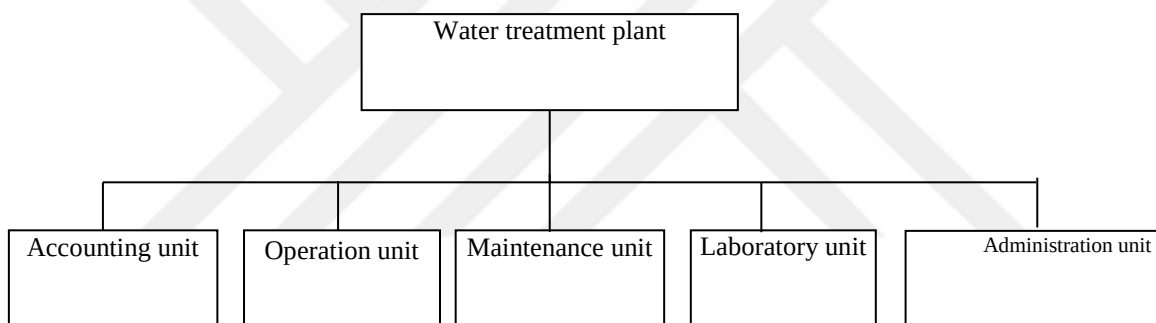


Figure 4.2: Suggested Water Treatment Plant Structure.

4.4.3 Operation and Maintenance Staff

Operation processes must be compatible with maintenance and there is a lot of overlap between them. For better management of water treatment plants, the staff must have two features; the first is providing the required number of staff and the second is the qualification and the training of these staff.

Each plant of water treatment plants must satisfy the number and the type of staff required for managing water treatment plants. The details of the staff are determined in table 4.4 such as the unskilled, skilled, and professional personnel for line staff who are responsible for the production of potable water. There is a number of personnel shall be joined to the production personnel as administrative, accounting, service, store secretary, guards, drivers, and so.

Professionals are the engineers of different specialties as electric, mechanical, sanitary, and civil. While the skilled personnel are represented by a number of technicians and foremen for directing unskilled personnel.

Table 4.4: Suggested Staff for Water Treatment Plants.

Capacity (1000m³/day)	Staffs required		
	Professional	Skilled	Unskilled
0.6875 – 4.125	1	2	8
4.125 –13.75	1	3	10
13.75 - 40	2	4	12
40 -120	3	5	14
120 - 400	4	6	16
400 - 1200	6	7	18

The number of staffs in table 4.4 can be multiplied factor about 30-40% for efficiency. Increasing streamline for the same capacity must increase the staff required with 50% for each additional streamline.

Training of these staff as an international standard must be at least 3% of total budget, and each skilled and professional staff must take about 30 hours of training.

4.4.4 Data Reporting

For purposes of maintenance control, data can express the state of the maintenance with various forms of reports, tables, and charts. The suggested documentation system in this research is the first step for this component. There is a number of reports which are useful for describing the state of the maintenance in water treatment plants, time basis reports shall periodically show the change and development in maintenance works and the deviations in time schedules and cost.

Microsoft project software is suitable for reporting as actual data is entered to this software reports and another project management aspect using the advantages of the software. This software can continue the planning according to the optimum maintenance cost, making full use of software facilities as resource allocation and any type of reports required as the researcher suggests in this paragraph.

4.5 PROPOSED SYSTEM

To clarify the proposed system, Utilized Microsoft Office Project, a project management software created by Microsoft and integrated into the Microsoft Office suite. It is commonly known as "Microsoft Project" or simply "Project." Microsoft Project is designed to assist project managers in planning, tracking, and managing projects of varying complexities. It provides tools to create project plans, allocate resources, set timelines, track progress, and analyze project performance. The software is widely used in industries such as construction, engineering, information technology, marketing, and many others. Key functionalities of Microsoft Project usually encompass:

- a. Project Planning: Users can formulate a comprehensive project plan detailing tasks, dependencies, durations, and milestones.
- b. Resource Management: The software enables project managers to assign resources (including people, equipment, and materials) to specific tasks and monitor their availability and workload.
- c. Timeline and Gantt Charts: Projects can be visualized using Gantt charts, which show the timeline of tasks and their interdependencies.
- d. Task Tracking: Project managers can monitor task progress, update statuses, and view real-time data on how the project is progressing.
- e. Budgeting and Cost Management: Users can estimate project costs, set budgets, and track expenses throughout the project's lifecycle.
- f. . Reporting and Analytics: Microsoft Project offers diverse reporting and analytical tools to assist project managers in evaluating project performance and making data-driven decisions.
- g. . Integration: It seamlessly integrates with other Microsoft Office applications, such as Excel and SharePoint, fostering collaboration and facilitating data sharing.

4.5.1 Steps of building Proposed System

Step 1: The main interface when opening a new project, as shown in figure 4.3, where we notice in the middle of the upper part the time line is specifying the start and end of the project, the timeline A timeline serves as a visual depiction of the project schedule, offering a broad overview of essential tasks and milestones. This enables stakeholders to grasp the

project's progress and significant events quickly. The timeline functions as a valuable communication tool that can be shared with team members, management, and other project stakeholders to provide a quick summary of the project's status and upcoming activities.

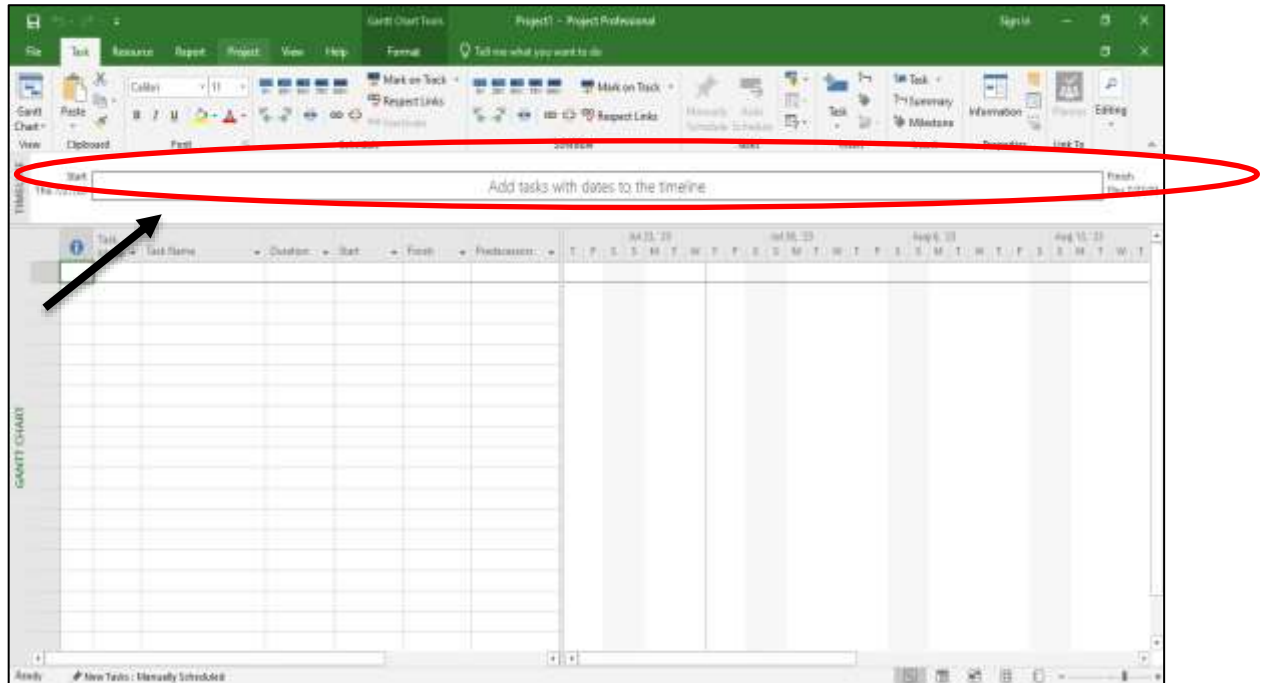


Figure 4.3: The Main Interface of Time line.

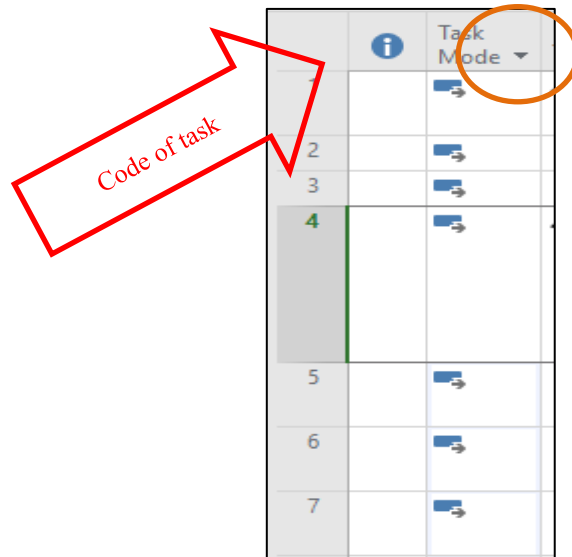
Step 2: Task Name, in Microsoft Project, the "Task Name" refers to the name or title given to individual tasks within a project. Every task signifies a distinct activity or work item integral to the overall project plan. Task names play a crucial role in identifying and distinguishing various tasks, facilitating project managers and team members in comprehending the project's structure and progress, as depicted in Figure 4.4.



Figure 4.4: Task Name Management.

The arrow, as shown in figure 4.4, indicates a drop-down list, that is, it is a summary of the main task, and it includes subtasks. This summary can be chosen from the summary task. In Microsoft Project, a "Summary Task" is a special type of task that serves as a container for a group of related subtasks. It allows users to create a hierarchical structure for organizing and managing complex projects more effectively. The summary task represents a higher-level activity or deliverable, while the subtasks are the detailed activities required to complete that higher-level task.

Step 3: task mode In Microsoft Project, "Task Mode" refers to how a task is scheduled and how its duration is determined. There are 2 task modes available in MS Project: auto and manually scheduling but most of the time, auto is chosen to take advantage of the program's features and ease of scheduling as shown in figure 4.5. As for the numbers that appear on the side, they represent the code for the task, which is a non-recurring code, meaning that each task has a unique special code.



	i	Task Mode ▾
1		→
2		→
3		→
4		→
5		→
6		→
7		→

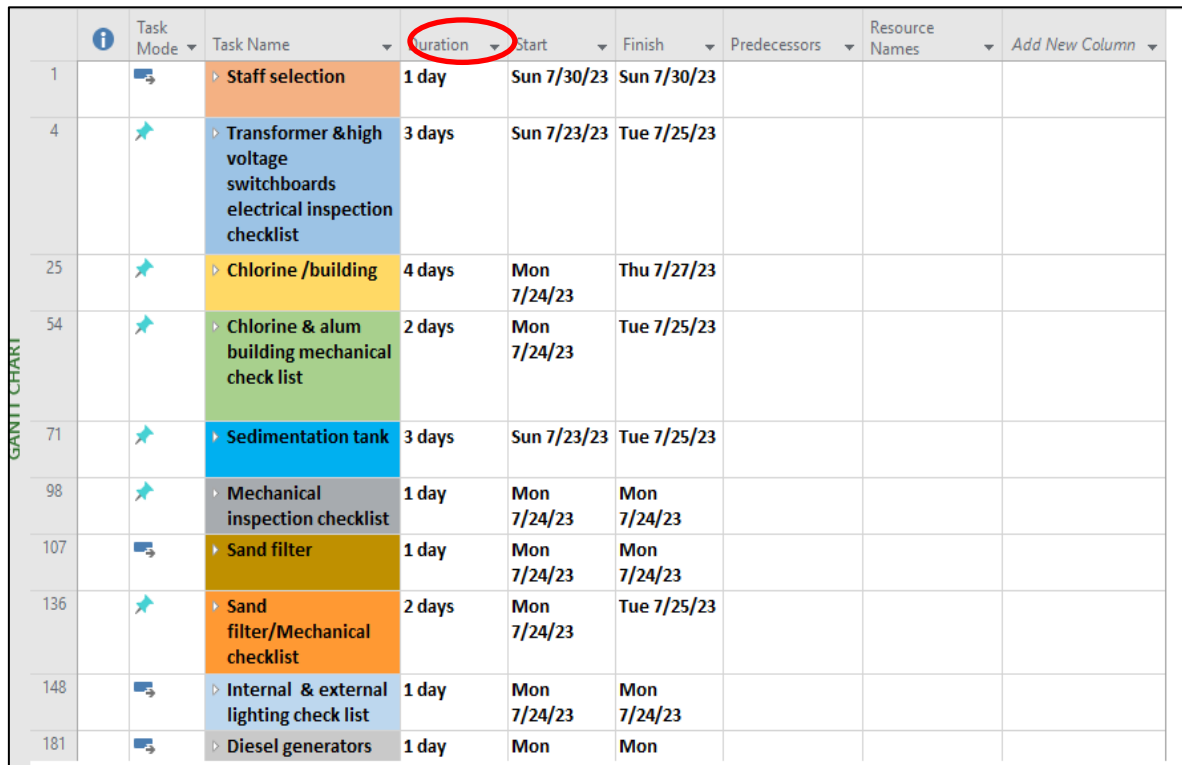
Figure 4.5: Task Mode Scheduling.

Step 4: Duration, in Microsoft Project, "Duration" refers to the total amount of time it takes to complete a task. It is typically measured in work hours, workdays, or calendar days, depending on the settings and calendar used in your project. Here's a brief explanation of the different types of duration in Microsoft Project:

- a. Duration in Work Hours: This type of duration is based on the number of work hours required to complete a task. If you work with a specific resource calendar, it will consider the working hours of that calendar and exclude non-working hours such as weekends and holidays.
- b. Duration in Workdays: Workdays are the days when work can be performed, excluding weekends and any non-working days defined in the project calendar. This duration represents the number of workdays required to complete the task.
- c. Duration in Calendar Days: This type of duration represents the total number of calendar days required to complete the task, including weekends and any non-working days defined in the project calendar.

When you enter a task in Microsoft Project, you can specify the duration in any of these formats, depending on how you want to plan and track the task. The software will use this information, along with resource assignments and dependencies, to schedule the task and calculate its start and finish dates. For example, if you have a task with a duration of 5 days, and it starts on a Monday, then its finish date will be the following Friday (assuming a

standard Monday to Friday workweek). However, if you have resource constraints or dependencies, the actual start and finish dates may vary as shown in figure 4.6.



	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Add New Column
1		Staff selection	1 day	Sun 7/30/23	Sun 7/30/23			
4		Transformer & high voltage switchboards electrical inspection checklist	3 days	Sun 7/23/23	Tue 7/25/23			
25		Chlorine /building	4 days	Mon 7/24/23	Thu 7/27/23			
54		Chlorine & alum building mechanical check list	2 days	Mon 7/24/23	Tue 7/25/23			
71		Sedimentation tank	3 days	Sun 7/23/23	Tue 7/25/23			
98		Mechanical inspection checklist	1 day	Mon 7/24/23	Mon 7/24/23			
107		Sand filter	1 day	Mon 7/24/23	Mon 7/24/23			
136		Sand filter/Mechanical checklist	2 days	Mon 7/24/23	Tue 7/25/23			
148		Internal & external lighting check list	1 day	Mon 7/24/23	Mon 7/24/23			
181		Diesel generators	1 day	Mon	Mon			

Figure 4.6: Duration of Total Time Task.

Step 5: Predecessor, in Microsoft Project, a "predecessor" refers to a task that comes before another task and establishes a dependency between the two tasks. The task that comes after the predecessor is known as a "successor." Dependencies help to define the sequence and order in which tasks need to be performed in a project. When you establish a predecessor-successor relationship between tasks, it signifies that the successor task is dependent on the completion of the predecessor task before it can commence. Various types of task dependencies can be configured in Microsoft Project:

- Finish-to-Start (FS):** This is the predominant type of dependency, indicating that the successor task cannot start until the predecessor task is completed.
- Start-to-Start (SS):** In this dependency type, the successor task cannot begin until the predecessor task starts.
- Finish-to-Finish (FF):** With this dependency type, the successor task cannot finish until the predecessor task is completed.

d. Start-to-Finish (SF): This is the less common type of dependency, where the successor task cannot finish until the predecessor task starts, as illustrated in Figure 4.7.

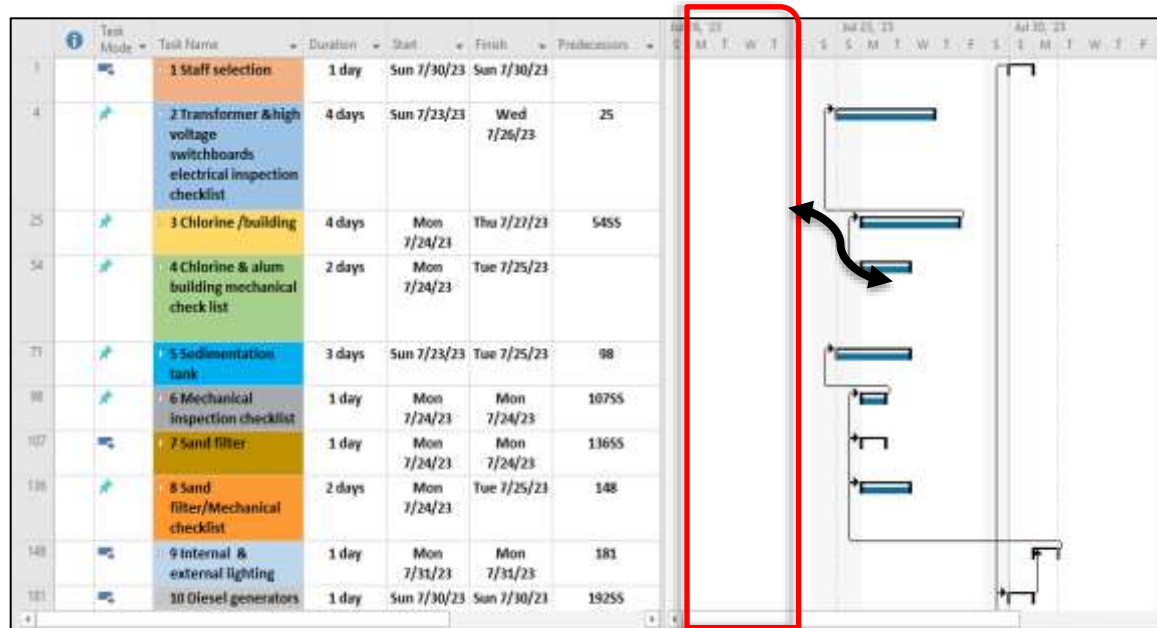


Figure 4.7: Predecessor in Project Task.

Step 6: Resource sheet, in Microsoft Project, the "Resource Sheet" is a view that allows you to manage and organize the list of resources that are required for your project. It provides a table-based layout where you can enter and edit various details about each resource. The Resource Sheet is an essential part of project planning and resource management. To access the Resource Sheet in Microsoft Project:

- Open your Microsoft Project file.
- Go to the "View" tab on the Ribbon.
- In the "Resource Views" group, click on "Resource Sheet."

Alternatively, you can also access the Resource Sheet by clicking on "View" in the top menu, selecting "Resource Sheet" from the drop-down list. Once you are in the Resource Sheet view, you will see a table with columns representing different resource-related information. The typical columns you might find in the Resource Sheet include:

- Resource Name:** This is where you enter the names of the resources. Each resource should have a unique name to identify them in the project.
- Type:** This column indicates the type of resource, such as Work, Material, or Cost.
- Initials:** You can assign initials to resources to help with visual identification in other views.

- d. Max Units: For work resources (people or equipment), this column represents their maximum capacity in terms of work hours or units.
- e. Standard Rate: If a resource is a work resource with an associated cost, this column shows the standard rate or cost per unit of time.
- f. Overtime Rate: If a resource has an overtime rate, it can be specified in this column.
- g. Cost/Use: For cost resources, this column indicates the cost associated with each use of the resource.
- h. Accrue At: This column specifies how costs are accrued over time for a resource.

You can add new resources to the list by simply entering their details in the appropriate columns. You can also edit existing resource information directly in the table. The Resource Sheet is crucial for resource management as it provides an overview of all resources, their types, availability, and associated costs. It is also the starting point for assigning resources to tasks in your project, which helps in creating a realistic schedule and tracking resource usage throughout the project's execution. As shown in figure 4.8.

	Resource Name	Type	Material	Initials	Group	Max.	Std. Rate	Ovt.	Cost/Use	Accrue	Base	Code	Add New Column
1	Capacity (1000)	Material		C			\$1,000.00		\$1,000.00	Prorated			
2	Professional	Work		P		100%	\$200.00/hr	\$250.00/hr	\$250.00	Prorated	Standard		
3	Skilled	Work		S		100%	\$200.00/hr	\$210.00/hr	\$210.00	Prorated	Standard		
4	Unskilled	Work		U		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
5	Chief Eng. (Mechanic)	Work		C		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
6	Chief Eng. (elect)	Work		C		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
7	Senior Eng. (elec)	Work		S		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
8	Senior Eng. (mec)	Work		S		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
9	Eng. (electrical)	Work		E		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
10	Eng. (mechanic)	Work		E		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
11	Eng. (chemical)	Work		E		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
12	Assistant Eng.	Work		A		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
13	Chemist	Work		C		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
14	Physicist	Work		P		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
15	Electrician	Work		E		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
16	Mechanic	Work		M		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
17	Technician (operation)	Work		T		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
18	Technician assistant	Work		T		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		
19	Repairer	Work		R		100%	\$100.00/hr	\$110.00/hr	\$110.00	Prorated	Standard		

Figure 4.8: Resource Sheet Management.

When you return to the main page and click on the resource name, multiple options will appear, so we select what is required and what is not required of the work staff, and so on for the rest of the task, as shown in Figure 4.9:

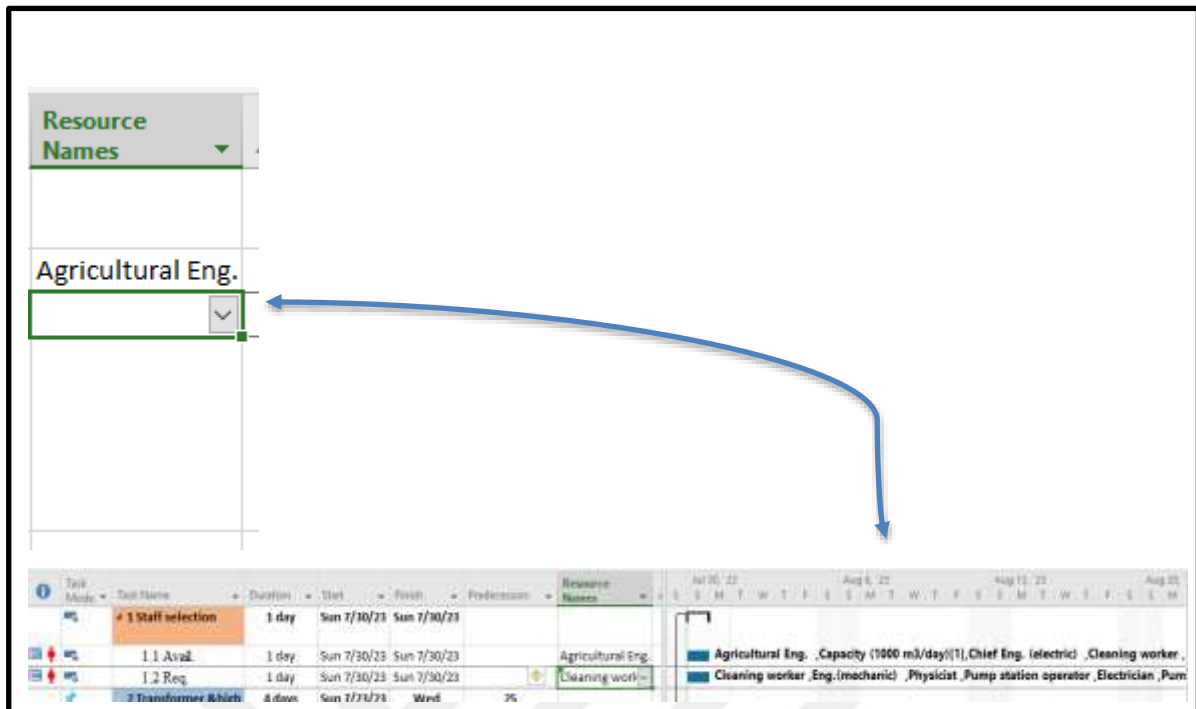
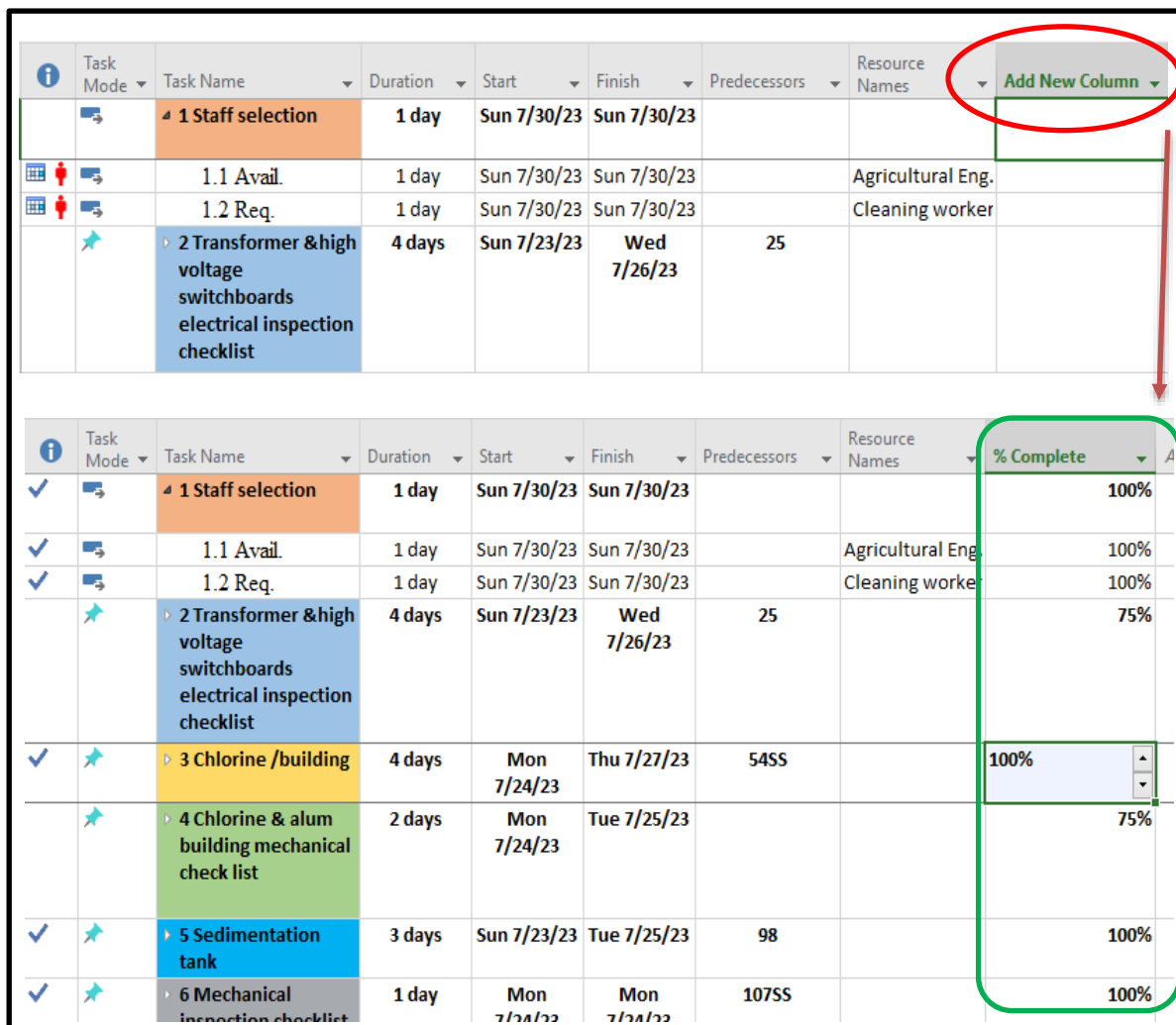


Figure 4.9: Resource Names Management.

Step 7: Add the new Colom name complete.

In Microsoft Project, the "Complete %" (Percentage Complete) refers to the progress made on a task or the percentage of work that has been completed up to a specific point in time. It is a way to track the actual progress of a task against its planned duration, as shown in figure 4.10.



Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	
	1 Staff selection	1 day	Sun 7/30/23	Sun 7/30/23			
	1.1 Avail.	1 day	Sun 7/30/23	Sun 7/30/23		Agricultural Eng.	
	1.2 Req.	1 day	Sun 7/30/23	Sun 7/30/23		Cleaning worker	
	2 Transformer & high voltage switchboards electrical inspection checklist	4 days	Sun 7/23/23	Wed 7/26/23	25		

Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
✓	1 Staff selection	1 day	Sun 7/30/23	Sun 7/30/23			100%
✓	1.1 Avail.	1 day	Sun 7/30/23	Sun 7/30/23		Agricultural Eng.	100%
✓	1.2 Req.	1 day	Sun 7/30/23	Sun 7/30/23		Cleaning worker	100%
	2 Transformer & high voltage switchboards electrical inspection checklist	4 days	Sun 7/23/23	Wed 7/26/23	25		75%
✓	3 Chlorine /building	4 days	Mon 7/24/23	Thu 7/27/23	54SS		100%
	4 Chlorine & alum building mechanical check list	2 days	Mon 7/24/23	Tue 7/25/23			75%
✓	5 Sedimentation tank	3 days	Sun 7/23/23	Tue 7/25/23	98		100%
✓	6 Mechanical inspection checklist	1 day	Mon 7/24/23	Mon 7/24/23	107SS		100%

Figure 4.10: Complete % Real Time.

Step 8: Project information

Within Microsoft Project, the dialog box named "Project Information" facilitate you to view and modify various settings and properties related to your project. It contains essential details about the project, such as project start date, end date, project title, working time, project calendar, and other general project settings. Figure 4.11 shown information about the project such as start and end date, schedule, time, etc.

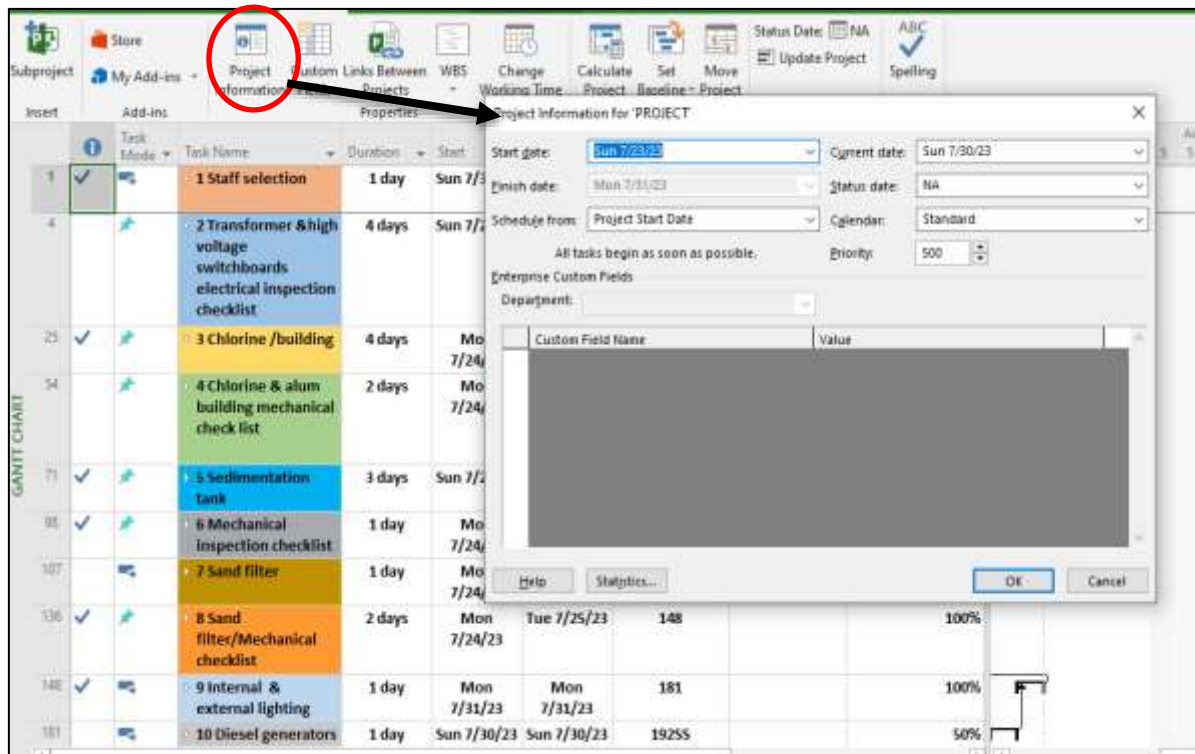


Figure 4.11: Project Information About the Project.

Step 9: Change working time.

Within Microsoft Project, you have the capability to modify the working time for your project by making adjustments to the working hours , non-working days, and exceptions in the project calendar. The project calendar defines when work can and cannot occur, and it affects how tasks are scheduled and resources are allocated. Here's how you can change the working time in Microsoft Project:

Accessing Project Calendar:

- Open your Microsoft Project file.
- In the top menu, click on the "Project" tab.
- In the "Properties" group, click on the "Change Working Time" button.
- Alternatively, you can quickly access the Project Calendar dialog box by using the keyboard shortcut: Alt + F9.

Project Calendar Dialog Box: Once you open the Project Calendar dialog box, you will see a calendar view with the working and non-working time indicated. The dialog box will display the default "Standard" calendar, which represents the default working hours and days for the project.

Adjusting Working Time: To change the working hours for a specific day, select the day on the calendar, and then specify the working hours in the "Working times" section below the calendar. To add an exception (e.g., holidays or non-working days), click on the "Exceptions" tab, and then click "Add Exception." Enter the exception name, start date, and finish date, and define the working or non-working hours for that exception.

Creating New Calendars: If you need different working hours for various phases or resources in your project, you can create additional calendars. Click on the "Create New Calendar" button, give it a name, and then adjust the working and non-working time as needed.

Assigning Calendars to Tasks and Resources: After creating custom calendars, you can assign them to specific tasks or resources. For example, you can assign a resource-specific calendar to a part-time employee with different working hours.

Applying Changes: Once you have made the necessary changes to the working time and calendars, click "O-K" to apply the modifications and close the Project Calendar dialog box.

Changing the working time in Microsoft Project allows you to accurately reflect the actual working hours and non-working days of your project, which, in turn, affects how tasks are scheduled and resources are allocated. As shown in figure 4.12.

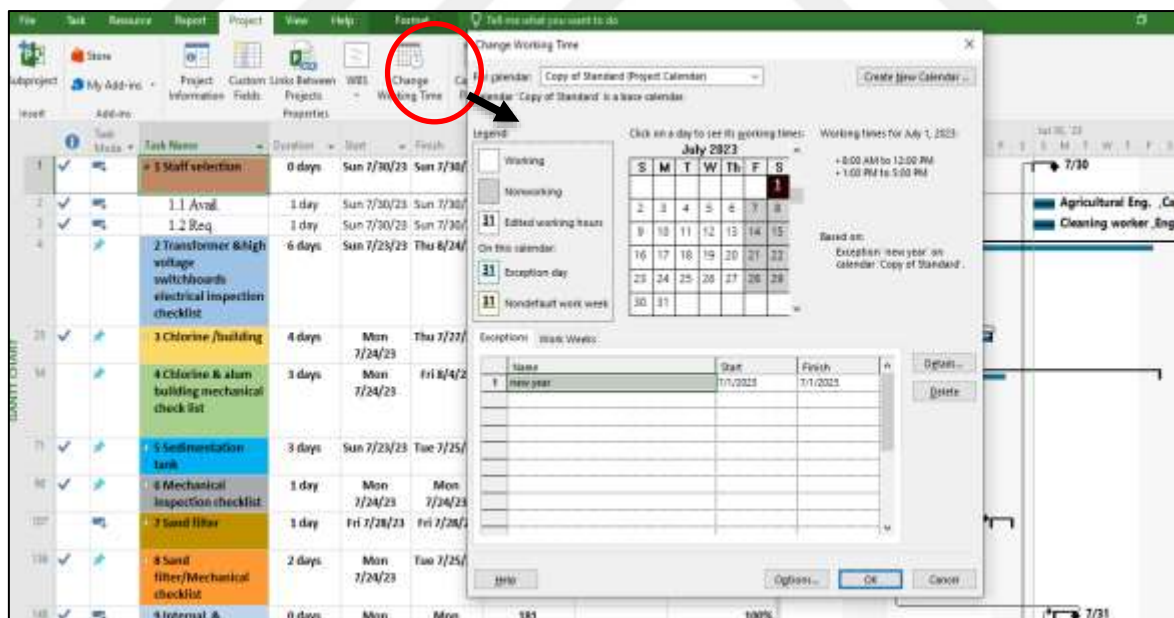


Figure 4.12: Change Working Time Scheduled.

4.6 RESULT

a. Dashboards ->project overview

figure 4.13 shows the project overview, where we note the start and end dates of the project, as well as the percentage, and on the second side, we note the percentage for completing the tasks.

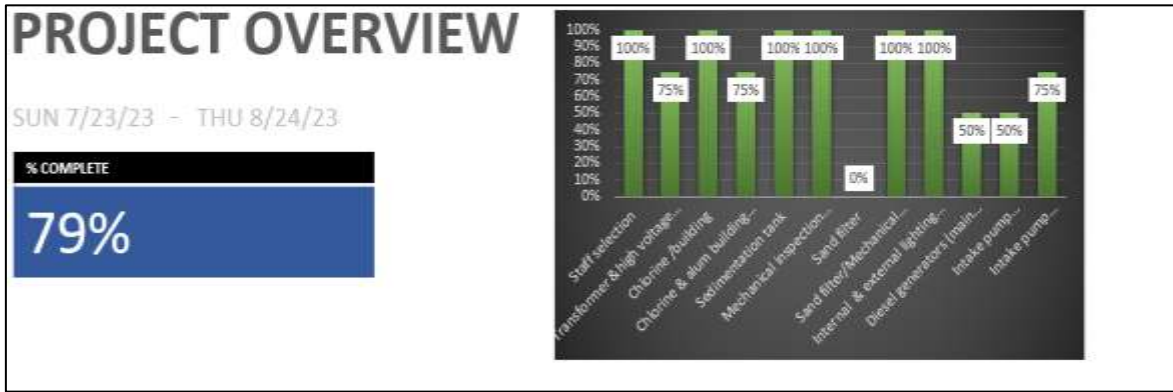


Figure 4.13: Result of Project Overview.

b. Cost Overruns



Figure 4.14: Cost Overruns.

5. CONCLUSIONS AND RECOMMENDATION

5.1 GENERAL

The steps to reach the objective of this research, were convincing. Many conclusions that reached give a new approach or new data for the persons responsible for managing maintenance of water treatment plants. Conclusions, recommendations, and the suggested future work are presented in this chapter.

5.2 CONCLUSIONS

There are many conclusions have been reached suggested maintenance management system for water treatment plants in Najaf City.

The conclusions of overall state of water treatment plants, and which can also affect maintenance significantly. These conclusions are as follow: -

- a. The percentage of losses in the piping system is 48%, which caused the plants must work in full capacity, and maintenance will definitely be affected.
- b. There is a chance to increase the revenues of data and NWA used to increase the assigned budget and especially for maintenance, this can be done by making full use of the sludge that is can be used as a fertilizer, and other ideas too.
- c. Automated control is little because that system of treatment is old and without updating. While water treatment plants in the world are automated using computers.
- d. Most of maintenance management components are far from the scientific approach and depend only on the experience of management team.
- e. The limited budget assigned for maintenance affects the strategy of managing maintenance and doesn't give the chance to deal with another strategy, and leads to a high level of failures due to the delay in some activities.
- f. Staffing water treatment plants is according to the available staff rather than the required staff (specialization).
- g. There is a need for reviewing job specification of the staff of Najaf water administration in general and especially water treatment plants.
- h. Organization structure for NWA, operation and maintenance department, and even the plant self, needs a review because of many weak points as indicated in the previous and new trends in management.

- i. Unified accounting system used in NWA is not enough to give a clear picture about the performance of this administration.
- j. Most data suffer under the mercy of emergency maintenance due to limited budget during the last few years. It might be the optimum especially in circumstances of low wages in Iraq but that needs scientific evidence.
- k. Evaluation of maintenance and managing water treatment plant is without any criteria or standards to give conclusions whether the process is in the right way or not. The suggested cost accounting section can give a good data for evaluation.
- l. Reports are almost interim and not periodic, and if so, they are according to the requirements of the body that need these reports. These must be gathered and unified in such manner that help the management with the required information in decision making.
- m. Based on the previous points, the feedback process is rare that may change the assumptions and standards of the planning and budgeting.

5.3 RECOMMENDATIONS

According to the conclusions of this research, the researcher reaches the following recommendations through developing a maintenance management system for water treatment plants in Najaf.

Adopting the suggested system with its requirements that is very important to keep the system working.

- a. All components of the suggested system have the same importance because they represent one unit and any problem in any components, certainly, will lead to other problems at many locations of the system.
- b. Reviewing the organization structure of NWA, operation and maintenance department, and the plant itself with a manner compatible with the suggested system.
- c. Make annual preparations for changes that might happen due to circumstances such as strategy changing, budget increasing, and so on.
- d. Continuous updating for the data required to the suggested system.

Recommended future works:

- a. To complete the efforts of this research, a number of works and studies are recommended and to be integrated with this research. These works are as follows: -

- a. Studying the effect of increasing frequency of periodic maintenance activities accurately on emergency maintenance activities in time and cost.
- b. Studying the feasibility of construction sludge packing unit to increase plant revenues.
- c. Building a new evaluation system with required criteria for both water treatment plants and NWA, to prove whether they are in the right way or not.
- d. Studying the ability of automation water treatment plants and the feasibility of such work.
- e. Studying the importance of the activities and the independent variable that is affecting this importance reaching the right priorities for all maintenance activities, to building a model that represents these priorities.



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APPENDIX A

Energy station/ Transformer & high voltage switchboards electrical inspection checklist

		Operation	No visual damage	No noise/sparks/overheat	Terminal/junction box		Cable/drum/gland	Signal lamp	Overall cleanliness	Function check	Mugger test	Oil leakage	gauges	relays
Daily	33kV switch board NO.1	Off/on	/	/	/		/	/	/	/			/	/
	33kV switch board NO.2	On	/	/	/		/	/	/	/			/	/
	33kV tap changer board 1	Off/on	/	/	/		/	/	/	/			/	/
	33kV tap changer board 2	Off/on	X1	/	/		/	/	/	/			/	/
	11kV switch board N0.1	Off/on	X2	/	/		/	X3	/	/			/	/
	11kV switch board N0.2	On	X2	/	/		/	X3	/	/			X4	/
	11kV switch board N0.3	Off	X2	/	/		/	X3	/	/			X5	/
	11kV switch board N0.4	Off	X2	/	/		/	X3	/	/			/	/
	11kV switch board N0.5	On	X2	/	/		/	X3	/	/			/	/
	11kV switch board N0.6	On	X2	/	/		/	X3	/	/			/	/
	11kV switch board N0.7	On	X2	/	/		/	X3	/	/			/	/
	11kV switch board N0.8	Off	X2	/	/		/	X3	/	/			/	/

110Kv dc charger and batteries	On	/	/	/	/	/	/	/	/	/	/	/	/
Transformers #1 (33kV//11kV,5MVA)	Off/on	X6	/	/	/	/	/	/	/	/	/	/	/
Transformers #2 (33kV//11kV,5MVA)	On	/	/	/	/	/	/	/	/	/	X7	/	/
Earth resistor	on	/	/	/	/	/	/	/	/	/	/	/	/
Transformers #3 (0.4kV//11kV,1.5MVA)	Off	/	/	/	/	/	/	/	/	/	/	/	/
Transformers #4 (0.4kV//11kV,1.5MVA)	Off	/	/	/	/	/	/	/	/	/	/	/	/
Generator synchronizing board	Off	/	/	/	/	/	/	/	/	/	/	/	/
Distribution board 400V, 5000Amp	off	/	/	/	/	/	/	/	/	/	/	/	/

APPENDIX B

Chlorine building/ Electrical inspection checklist

		Operation	No visual damage	Speed normal	No noise/sparks/overheat	Terminal/junction box	Cooling fan	Cable/drum/gland	Signal lamp	Overall cleanliness	Function check	Mugger test	Calibration
Daily & weekly	Main MCC	On	/		/	/		/	/	/	/		
	Mixer motore-1	Off	/	/	/	/	/	/		/	/		
	Mixer motore-2	Off	/	/	/	/	/	/		/	/		
	Mixer motore-3	On	/	/	/	/	/	/		/	/		
	Dosing pump-1	On	/	/	/	/	/	/		/	/		
	Dosing pump-2	On	/	/	/	/	/	/		/	/		
	Dosing pump-3	On	/	/	/	/	/	/		/	/		
	Dosing pump-4	On	/	/	/	/	/	/		/	/		
	Dosing pump-5	On	/	/	/	/	/	/		/	/		
	Dosing pump-6	On	/	/	/	/	/	/		/	/		
	Dosing pump-7	On	/	/	/	/	/	/		/	/		
	Dosing pump-8	On	/	/	/	/	/	/		/	/		
	Over hard crane of	On	/	/	/	/		/		/	/		

Chlorine room													
Over hard crane of Alum. room	On	/	/	/	/	/	/	/	/	/	/	X2	
ventilation fans	On	X1	X1	/	/	/	/			X1			
New chlorine system													
Main mcc#1	On	/		/	/	/	/	/	/	/		/	
dosing controller A	Off	/	/	/	/	/	/			X2		/	
dosing controller B	On	/	/	/	/	/	/			/			
Chlorine controller	On	/	/	/	/		/			/			
Solenoid valve of measuring cell	On	/	/	/	/		/		/	/			
Solenoid valve A	Off	/		/	/		/		/	/			
Solenoid valve B	On	/		/	/		/		/	/			
Gas detector	On	/		/	/		/		/	/		/	
Gas sensor #1	On	/		/	/		/		/	/			
Gas sensor #2	On	/		/	/		/		/	/			
MCC#2	On	/		/	/		/	/	/	/		/	
Change over	On	/	/	/	/		/		/	/		/	
Pressure gage	On	/		/	/		/		/	/		/	

APPENDIX C

Chlorine & alum building mechanical check list

		Operation	No visual damage	Speed normal	No noise/oil leaks /overheat	Bearing working smooth	caming rod check/change	Oil Lub. Check level /change	Safety requirements	Greasing	Bearing check replace	Gasket, o-ring &oil seal	pipeline & valves leakage	Maintenance ,check/change	Adjustment , setting&	Discharge gauge	Cleaning strainers
Daily	Insp.Alum. Dosing Pump#1	Off	X 1	/	/	/		/						/			
	Insp.Alum. Dosing Pump#2	Off	X 2	/	/	/		/						/			
	Insp.Alum. Dosing Pump#3	Off	/	/	/	/		/						/			
	Insp.Alum. Dosing Pump#4	Off	X 1	/	/	/		/						/			
	Insp.Alum. Dosing Pump#5	Off	/	/	X 7	/		/						/			
	Insp.Alum. Dosing Pump#6	Off	X 2	/	X 7	/		/						/			
	Insp.Alum. Dosing Pump#7	Off	/	/	X 7	/		/						/			
	Insp.Alum. Dosing Pump#8	Off/ on	X 3	X 3	X 3	/		X 3						/			
	Insp.Mixer of	Off/ on	/	X 6	X 6	/		X 6				/		/			

Alum.Tank #1																	
Insp.Mixer of Alum.Tank #2	Off	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Insp.Mixer of Alum.Tank #3	Off	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Insp.warmt h of heaters around filters	Off	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Insp.Vacuu m Chlorine pipline		/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Intet.&Outi et pipes (flex+PVC)		X 4	/	/	/	/	/	/	/	/	/	/	X 8	/	/	/	/
Incp. Overhead crane of chlorine room	On	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Incp. Overhead crane of Alum room	Off	X 5	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

APPENDIX D

Sedimentation tank/ Electrical inspection checklist

		Operation	No visual	Speed normal	No	Terminal/junct	Cooling fan	Cable/drum/gl	Signal lamp	Overall	Function check	Mugger lest
Daily & Weekly	1. Aux.Agitator Motor (A-1)	On	/	/	/	/	/	/			/	
	2. Aux.Agitator Motor (B-1)	On	/	/	/	/	/	/			/	
	3. Aux.Agitator Motor (A-2)	On	/	/	/	/	/	/			/	
	4. Aux.Agitator Motor (B-2)	On	/	/	/	/	/	/			/	
	5. Aux.Agitator Motor (A-3)	On	/	/	/	/	/	/			/	
	6. Aux.Agitator Motor (B-3)	On	/	/	/	/	/	/			/	
	7. Aux.Agitator Motor (A-4)	On	/	/	/	/	/	/			/	
	8. Aux.Agitator Motor (B-4)	On	/	/	/	/	/	/			/	
	9. MCC-1	On	/		/	/		/	/	/	/	
	10. Bridge motor-1	On	/	/	/	/	/	/			/	
	11. Bridge motor-2	On	/	/	/	/	/	/			/	

12. Bridge motor-3	On	/	/	/	/	/	/			/	
13. Bridge motor-4	On	/	/	/	/	/	/			/	
14. Aux.Agitator Motor (A-5)	On	/	/	/	/	/	/			/	
15. Aux.Agitator Motor (B-5)	On	/	/	/	/	/	/			/	
16. Aux.Agitator Motor (A-6)	On	/	/	/	/	/	/			/	
17. Aux.Agitator Motor (B-6)	On	/	/	/	/	/	/			/	
18. Aux.Agitator Motor (A-7)	On	/	/	/	/	/	/			/	
19. Aux.Agitator Motor (B-7)	Off/on	X1	X1	X1	/	/	/	/	/	/	
20. Aux.Agitator Motor (A-8)	On	/	/	/	/	/	/	/	/	/	
21. Aux.Agitator Motor (B-8)	On	/	/	/	/	/	/	/	/	/	
22. MCC-2	On	/	/	/	/	/	/			/	
23. Bridge motor-5	On	/	/	X2	/	/	/			/	
24. Bridge motor-6	On	/	/	/	/	/	/			/	
25. Bridge motor-7	On	/	/	/	/	/	/			/	
26. Bridge motor-8	On	/	/	/	/	/	/			/	

APPENDIX E

Mechanical inspection checklist

		Operation	No visual damage	Good normal	No noise/oil leaks/overheat	Complementary parts of tank	Bridge structure	Bearing working	Repair /replace damage	Bridge front & rear	Bearing check/replace	Change oil	Creasing	Central bearing check	Adjustment lifting lever	blochage removal	Valves,pipline & nenstocks check /change
Dally	Sed .Tank# 1	On	/	/	X1	/		/									
	Sed .Tank# 2	On	X2	X3	/	/		/									
	Sed .Tank# 3	On	X2	/	/	/		/									
	Sed .Tank# 4	On	/	/	/	/		/									
	Sed .Tank# 5	On	X2	/	/	/		/									
	Sed .Tank# 6	On	/	/	/	/		/									

	Sed .Ta nk# 7	Off/on	X2	X 3	/	/		/										
	Sed .Ta nk# 8	On	X2	/	/	/		/										



APPENDIX F

Sand filter/ Electrical inspection checklist

		Operation	No visual damage	Speed normal	No noise/sparks/overheat	Terminal/junction box	Cooling fan	Cable/drum/gland	Signal lamp		Overall cleanliness	Function check
Daily & Weekly	Compressor motor -1											
	Motor	Off	/	/	/	/	/	/			/	
	MCC panel	On	/		/	/		/	/	/	/	
	Compressor motor-2											
	Motor	On	/		/	/		/			/	
	MCC panel	On	/	/	/	/	/	/	/	/	/	
	Compressor motor-3											
	Motor	On	/	/	/	/	/	/			/	
	MCC panel	On	/		/	/		/	/	/	/	
	Washing motor-1											
	Motor	Off	/	/	/	/	/	/			/	
	MCC panel	On	/		/	/		/	/	/	/	
	Washing motor-2											
	Motor	On	/	/	/	/	/	/			/	
	MCC panel	On	/		/	/		/	/	/	/	
	Washing motor-3											
	Motor	On	/	/	/	/	/	/			/	
	MCC panel	On	/		/	/		/	/	/	/	
	Submersible											
	Submersible#1	Off /On	X1	X1	X1	X1		X1	X1	X1	X1	
	Submersible#2	Off /On	X1	X1	X1	X1		X1	X1	X1	X1	
	Submersible#3	On	/	/	/	/		/			/	
	Submersible#4	Off /On	X1	X1	X1	X1		X1	X1	X1	X1	

	MCC panel	On	/		/	/		/	/		/	/	
	Priming panel #1	On	/	/	/	/		/	/		/	/	
	MCC panel #1	On	/		/	/		/	/		/	/	
	Priming panel #2	On	/	/	/	/		/	/		/	/	
	MCC panel #2	On	/		/	/		/	/		/	/	



APPENDIX G

Sand filter/ Mechanical checklist

		Operation	No visual damage	Speed normal	No noise/oil leaks/overheat	Bearing working smooth
Daily	Cent fugal pump #1 insp.	/	/	/	/	/
	Cent fugal pump #2 insp.	/	/	/	/	/
	Cent fugal pump #3 insp.	/	/	/	/	/
	Air compressor #1 insp.	/	/	/	X	/
	Air compressor #2 insp.	/	/	/	X	/
	Air compressor #3 insp.	/	/	/	x	/
	Filtration valves		/		/	
	Backwash valves		/		/	
	Air valves & pipes		/		/	
	Drainage valves		x		X	
	Outlet penstocks		X		X	

APPENDIX H

Internal & external lighting check list

		Inspection	Replace florescent	Replace chuck	Replace starter	Replace project	Transformer check /change	Fitting check/change	Cleaning	Cable check/replace	Cables meggering
Dally	fluorescent AI 1 st floor of administration building	/	/	/	/						
	fluorescent AI 2 nd floor of administration building	/	/	/	/						
	Distribution board 1 st floor of admin building insp.	/		X							
	Distribution board 2 nd floor of admin building insp.	/		X							
	External projectors of admin building	/		X	X	x	x				
	Distribution board of admin building	/		X	X						
	Cable of admin building insp.	/									
	fluorescent AI 1 st floor of	/	/	/	/						

administration building house											
fluorescent AI 2 nd floor of administration building house	/	/	/	/							
Distribution board 1 st floor of send filter house	/		X	X							
External projectors of send filter house	/		X	X	X						
Internal projectors of send filter house	/		X	X	x						
Distribution board of External projectors of send filter house	/		X	X							
Distribution board of Internal projectors of send filter house	/		X	X		X					
External lighting poles of sed.tanks	/	X	X	X	x	X					
Distribution board of internal & external sludge pump station	/	/	X	/		x					
Internal lighting of sludge pump station	/		/		/						
External lighting of	/		X		/						

sludge pump station												
Distribution board of internal & external sludge pump station insp.	/	/	X	/								
Internal lighting of chlorine & alum building	/	X										
External lighting of chlorine & alum building	/	X	/									
Distribution board of External lighting of chlorine & alum building insp.	/	/	x	/								
Internal lighting of main lift pump station	/	X			/							
External lighting of main lift pump station	/	/			x	x						
Distribution board of internal & external main lift pump station insp.	/		x	/								
Internal lighting of diesel generators & H.T transformers	/	/	/									
External lighting of diesel	/	X	X		x	x						

	generators & H.T transformers										
	Distribution board of internal & external lighting of diesel generators & H.T transformers insp.	/		X	/						
	Internal lighting poles of land scape	/		X		X	X				
	External lighting poles of land scape	/	/	/		X	X				
	External lighting poles intake pump station	/		X		X	X				
	External lighting poles across intake station	/		X		/	X				

APPENDIX I

Plan for improve lighting Schedule 1/ The spent material

No.	Location	Projector	Fluorescent	Chuck	Starter	Dual fluore scent	Plug
1	1 st and 2 nd floor of sand filter	40 (250W) (internal lighting)	47 for 2 nd floor +39 for 1 st floor	16	46	13	--
2	Sand filter house external lighting	20(40W) (external lighting)	--	--	--	--	--
3	1 st and 2 nd floor of administration	4(400W)	41	22	35	4	6
4	Warehouse	--	12	--	35	4	2
5	Chlorine	--	29	8	10	15	2
6	Intake pump station	--	30	5	35	12	--
7	Main lift pump station	--	31	2	5	10	--
8	Information building	--	2	--	10	--	--
9	Substation & diesel generators	--	28	--	--	10	4
10	Sludge pump station	--	--	--	--	6	--
Total		64	159	53	150	74	14

Plan for improve lighting

Schedule 2/ The fault material

No.	Location	Projector	Fluorescent	Plug switch	Switch (on-off)	Mcb
1	Sand filter house 1 st floor	2(125W)	60	--	4(45)A	2(125W)
2	Administration	3	3	6	2	3
3	Chlorine	9	10	2	--	9
4	Main lift station	2	2	11	2	2
5	Substation & diesel generators	1	--	--	--	1
6	-sludge pump station	4	--	--	--	4
7	-warehouse	--	--	--	1	--
8	-sedimentation tanks	4	--	--	--	4
9	Main plan street	8	--	--	--	8
10	Intake street	31	--	--	--	31
11	Intake station	4	5		2	4
Total		68	80	19	11	68

APPEDIX J

Diesel generators (main site) check list

		Operation	Test loaded /unloaded	Cleaning check/replace		Creasing	Adjust /setting	Calibration	Coolant check level/change	Oil check level	Tighten bolts	meggering	Alignment tenttion belts lest
Daily	Generator #1 overall visual check	Off /ON											
	Generator #2 overall visual check	Off											
	Generator #3 overall visual check	Off											
	Alternator cooling screen			/									
	Fuel, coolant & oil level								/	/			
	Batteries (electrolyte & terminals)	On											
	Fuel water separator & drain the water												

	Engine #1 (1000KVA)	OFF/On		/		/			/	/			
	Engine #2 (1000KVA)	Off		/		/			X1	X2			
	Engine #3 (1000KVA)	Off		/		/			/	/			



APPEDIX K

Intake pump station

Electrical inspection checklist

		Operation	No visual damage	Speed normal	No noise/sparks/overheat	Terminal/junction box	Cooling fan	Cable/drum/gland	No fault indication	Overall cleanliness	Function check	Mugger lest
Daily & weekly	MOTOR-1	/	/	/	/	/	/	/			/	
	MOTOR-2	/	/	/	/	/	/	/			/	
	MOTOR-3	/	/	/	/	X	/	x			/	
	MOTOR-5	/	/	/	/	/	/	/			/	
	MOTOR-6	/	/	/	/	/	/	/			/	
	MOTOR-7	/	/	/	/	/	/	/			/	
	MOTOR-8	/	/	/	/	/	/	/			/	
	MCC-1	/	/	/	/	/	/	/			/	
	MCC-2	/	/		/	/		/	/	/	/	
	MCC-3	/	/		/	x		x	/	/	/	
	MCC-4	/	/		/	/		/	/	/	/	
	MCC-5	/	/		/	/		/	/	/	/	
	MCC-6	/	/		/	/		/	/	/	/	
	MCC-7	/	/		/	/		/	/	/	/	
	MCC-8	/	/		/	/		/	/	/	/	
	Service MCC	/	/		/	/		/	/	/	/	

APPEDIX L

Intake pump station/ Electrical inspection checklist

		Operation	No visual damage	Speed normal	No noise/oil leaks/overheat Bearing working smooth	Oil Lub.level/change	Mechanical (seal)/packing not leaking Check /change bearing	Check change water grease sealing Pipeline & valve leakage	Alignm .coupling	Discharge gauge	Strainers /cleaning
Daily	Centrifugal pump #1 insp.	On	/	/	/	/					
	Centrifugal pump #2 insp.	On	/	/	/	/					
	Centrifugal pump #3 insp.	On	/	/	/	/					
	Centrifugal pump #4 insp.	Off	/	/	X1	/					
	Centrifugal pump #5 insp.	On	/	/	/	/					
	Centrifugal pump #6 insp.	On	/	/	/	/					
	Centrifugal pump #7 insp.	On		/	/	/					
	Centrifugal pump #8 insp.	On	/	/	/	/					

	Sub.pump #1													
	Sub.pump #2	On	/											

