Gray & Osborne, Inc.
CONSULTING ENGINEERS

TECHNICAL MEMORANDUM 20434-9

TO:	BILL HUNTER, P.E., ASSISTANT GENERAL MANAGER/DISTRICT ENGINEER
FROM:	KEITH STEWART, P.E. RUSSELL PORTER, P.E.
DATE:	FEBRUARY 18, 2022
SUBJECT:	SUDDEN VALLEY WTP EQUIPMENT RISK ASSESSMENT LAKE WHATCOM WATER & SEWER DISTRICT, WHATCOM COUNTY, WASHINGTON G&O #20434.00

INTRODUCTION

In 2019, the Lake Whatcom Water & Sewer District (District) contracted with Gray & Osborne to perform a condition assessment for their existing Sudden Valley Water Treatment Plant (WTP) as part of a larger effort to analyze the District's water treatment facilities in order to prioritize funds for rehabilitation, modification, and/or replacement projects. The goal of the assessment and subsequent analysis is to identify potential improvements for the existing structures and treatment processes in an attempt to maximize treatment efficiency and extend the operational life of these facilities. The reports and technical memoranda generated as part of this assessment project will be used to develop a strategy for prioritizing modifications to the WTP to ensure it can efficiently and cost effectively provide clean, potable water for the existing and projected service areas.

In conjunction with the reports and memos highlighted above, the District is interested in quantifying the risk associated with the treatment system components in order to prioritize their rehabilitation efforts and funds. This memorandum summarizes the findings of the treatment component risk assessment analysis.

BACKGROUND AND EXISTING FACILITIES

The District operates three Group A water systems – South Shore (DOH 95910), Eagleridge (DOH 08118), and Agate Heights (DOH 52957) – all of which are in and around the shores of Lake Whatcom, which lies southeast of Bellingham in Whatcom County, Washington. The District serves approximately 3,900 residential and

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commercial water system connections with a residential population of approximately 10,000 people.

The South Shore system is the largest of the three systems and is supplied wholly by water treated at its Sudden Valley WTP. In addition to the WTP, the District also owns and maintains surface water source, storage, and distribution system facilities that serve this system. The District's distribution system includes multiple pressure zones, four booster stations, and approximately 2.8 million gallons (MG) of storage in five reservoirs. The District also maintains a secondary intertie with the City of Bellingham Water System (DOH 50600) that is used only during emergency situations.

The existing WTP is a rapid-rate, direct filtration plant with a rated capacity of 2.0 million gallons per day (MGD) but currently operates at approximately 1.01 MGD (700 gpm). The WTP is housed in a partially below-grade concrete building located on Morning Beach Drive approximately 1 mile northeast of the intersection of Lake Whatcom Boulevard and Marigold Drive. The facility was constructed in 1972 and has undergone several minor improvements since that time, but was most recently upgraded in 1992. The WTP provides coagulation, flocculation, filtration, disinfection, and chlorine contact time before treated water is pumped to the distribution system and storage reservoirs.

PREVIOUS WORK

Phase 1 of the Sudden Valley WTP Assessment and Alternatives Analysis project included a condition assessment of the WTP and preparation of the WTP Condition Assessment Report (Assessment Report). This report highlighted the findings from the assessment and provided a listing of both high- and low-priority items that should be addressed in order to ensure long-term success of the WTP. The condition assessment was completed by Gray & Osborne, Inc. on February 12, 2020, and the accompanying report was finalized in July 2020 and includes structural, architectural, electrical, mechanical, and treatment process analysis.

Phase 2 of the Sudden Valley WTP Assessment and Alternatives Analysis project builds upon the condition assessment described above and includes alternatives analysis and recommendations for modifications to the WTP based on the condition of the existing equipment and the District's short- and long-term goals for treatment operations. To evaluate alternatives for the WTP, the treatment components were separated by treatment process and were analyzed individually in various technical memoranda. Each of the following technical memoranda includes a description of the existing components, a description of their condition, an analysis of alternatives for modifications, recommendations, and preliminary cost estimates for the proposed alternatives:

- Technical Memorandum 20434-1 – Pump Performance Testing
- Technical Memorandum 20434-2 – Chlorine Contact Basin Coating Investigation
- Technical Memorandum 20434-3 – Structure Seismic Analysis
- Technical Memorandum 20434-4 – Chemical Systems Analysis
- Technical Memorandum 20434-5 – Filtration Systems Analysis
- Technical Memorandum 20434-6 – Disinfection Systems Analysis
- Technical Memorandum 20434-7 – Backwash Systems Analysis
- Technical Memorandum 20434-8 – Structural and Architectural Component Analysis

The recommendations within each of these memoranda will then be compiled into a WTP Alternatives Analysis Report (Alternatives Analysis Report). This final Alternatives Analysis Report will then be used to guide decision making and planning processes for both short- and long-term WTP modifications.

This memorandum is the last memorandum of Phase 2. It provides a risk assessment for the entire water plant and incorporates the work from the previous memoranda.

RISK ASSESSMENT

In order to help the District prioritize modifications to WTP components, maximize the overall value of the improvements, and help ensure that the projects are incorporated in the most cost-effective manner possible, we have quantitatively and qualitatively assessed the risk associated with each treatment component. We have completed this assessment using two separate methods.

Method 1

The first method utilizes a likelihood and severity scale commonly used for water and wastewater treatment facilities (Falakh and Setiani, 2017). This method quantifies both the likelihood of an event occurring and the severity of the effect of the event on a numerical scale, multiplies these values together, and the resulting "score" can be used to quantify and compare risk of that component to other treatment components. While other similar methods quantify event frequency and value of losses (Loj-Pilch and Zakrzewska, 2019), or probability of occurrence and severity (Ali El-Quliti, et al., 2016), each of these permutations of likelihood and severity attempts to quantify the risk factor and associated effects of component failure. Using these methods, the higher the score, the more risk associated with a particular component. For example, a component that is likely to fail frequently and will negatively impact the District's ability to provide potable water will have a higher score than a component that is unlikely to fail and will not significantly impact the performance of the WTP. In order to reduce the overall level of risk for failure, modifications to the components with the highest scores should be prioritized over other, lower-scoring components.

Method 2

The second analysis method utilizes the District's Business Risk Exposure Index (BREI), which is similar to the likelihood versus severity ranking described above but utilizes more variables and scoring categories. This method utilizes the component's effective life, physical condition grade, consequence of failure, probability of failure, and renewal strategy to quantify the risk that a particular component presents to District operations. As with Method 1 described above, the higher the score, the more risk this component presents to the District and the sooner it should be modified/addressed.

Additional information and references for risk assessment at municipal treatment facilities is provided in Exhibits A and B.

RESULTS

For simplicity and to better identify which components present the highest level of risk to successful treatment operations, the WTP process treatment components were broken down as follows:

- Raw Water Intake
- Raw Water Pumps
- Raw Water Instrumentation
- Alum Delivery System
- Flocculation Tank
- Filters 1 and 2
- Filters 3 and 4
- Clearwell
- Clearwell Transfer Pumps
- Chlorine Disinfection System
- Soda Ash Delivery System
- Chlorine Contact Basin
- Finished Water Instrumentation
- Finished Water Pumps
- WTP Main Building Piping
- Finished Water Pump Building Piping
- WTP Main Building Electrical

- Finished Water Pump Building Electrical
- WTP Supervisory Control and Data Acquisition System (SCADA)
- WTP Security
- Auxiliary Generator

Method 1

Each of the components listed above was scored according to the two methods described above and then ranked according to their overall score. Additional information on the scoring rubric is provided in Exhibit B, and Table 1 below highlights the results of the scoring according to Method 1 described above. For this table, scores between 1 and 3 are considered minimal risk and colored green, scores between 4 and 6 are considered low risk and are colored yellow, scores between 8 and 12 are considered moderate risk and colored orange, and scores between 15 and 25 are considered high risk and colored red. Table 2 presents the same information but organizes the individual components according to their risk group based on the scoring listed in Table 1.

TABLE 1

Scoring Summary According to Analysis Method 1

Component	Impact(s) [(1)]	Confined Space/Health & Safety Hazard? [(2)]	Likelihood [(3)]	Severity [(4)]	Combined Score [(5)]	Rank
Raw Water Intake	Loss of production, no service.	Y	2	2	4	15
Raw Water Pumps	Loss of production, no service.	Y	3	3	9	6
Raw Water Instrumentation	DOH noncompliance, regulatory action.	N	2	1	2	17
Alum Delivery System	Decrease in water quality, increase in maintenance.	Y	4	4	16	1
Flocculation Tank	DOH noncompliance, decrease in water quality, increase in maintenance.	N	3	3	9	6
Filters 1 and 2	Loss of production, decrease in water quality, no service.	N	3	3	9	6
Filters 3 and 4	Loss of production, decrease in water quality, no service.	N	2	3	6	13
Clearwell	Loss of production, increase in maintenance.	Y	1	1	1	21
Clearwell Transfer Pumps	Loss of production, increase in maintenance.	N	3	3	9	6
Chlorine Disinfection System	Loss of production, DOH noncompliance, regulatory action, health hazard.	Y	3	4	12	3
Soda Ash Delivery System	Loss of production, increase in maintenance.	Y	3	4	12	3
Chlorine Contact Basin	Loss of production, DOH noncompliance, regulatory action, health hazard.	Y	4	4	16	1

TABLE 1 – (continued)

Scoring Summary According to Analysis Method 1

Component	Impact(s) [(1)]	Confined Space/Health & Safety Hazard? [(2)]	Likelihood [(3)]	Severity [(4)]	Combined Score [(5)]	Rank
Finished Water Instrumentation	DOH noncompliance, regulatory action.	N	2	1	2	17
Finished Water Pumps	Loss of production, increase in maintenance.	N	3	3	9	6
WTP Main Building Piping	Loss of production.	N	1	2	2	17
Finished Water Pump Building Piping	Loss of production.	N	1	2	2	17
WTP Main Building Electrical	Loss of production.	N	3	3	9	6
Finished Water Pump Building Electrical	Loss of production.	N	3	3	9	6
WTP SCADA	DOH noncompliance, regulatory action.	N	2	3	6	13
WTP Security	Loss of production, regulatory action, health hazard.	N	2	5	10	5
Auxiliary Generator	Loss of production, regulatory action.	N	1	3	3	16

(1) Impacts for qualitative purposes only and provide high-level effects if a catastrophic failure were to occur with the component in question.
(2) Indicates whether or not a particular component involves confined space entry or significant safety/health hazards. Components with confined space entry or significant safety/health hazards are assumed to be more difficult to remedy. For qualitative purposes only.
(3) Scored on a scale from 1 to 5. See Exhibit B for additional information.
(4) Scored on a scale from 1 to 5. See Exhibit B for additional information.
(5) Likelihood score multiplied by the Severity score.

TABLE 2

Method 1 Analysis Risk Group Summary

High Risk **Score (15–25)**	**Moderate Risk** **Score (8–12)**	**Low Risk** **Score (4–6)**	**Minimal Risk** **Score (1–3)**
Alum Delivery System	Raw Water Pumps	Raw Water Intake	Raw Water Instrumentation
Chlorine Contact Basin	Filters 1 and 2	Filters 3 and 4	Clearwell
	Clearwell Transfer Pumps	WTP Main Building Electrical	Finished Water Instrumentation
	Finished Water Pumps	Finished Water Pump Building Electrical	WTP Main Building Piping
	Flocculation Tank		Finished Water Pump Building Piping
	Soda Ash Delivery System		Auxiliary Generator
	Chlorine Disinfection System		
	WTP SCADA		
	WTP Security		

The information in Tables 1 and 2 suggest that the alum delivery system and the chlorine contact basin present the greatest risk to successful WTP operations. For the alum components, this risk is largely due to the age of the tank, lack of system redundancy, and risk to adjacent electrical equipment should the tank rupture or leak. For the chlorine contact basin, the risk is largely due to the fact that the size of the tank limits the flow through the WTP, the condition of the exterior/interior coating systems, and the fact that there is no redundancy for providing chlorine contact time should the existing tank need to be removed from service.

The moderate risk category includes chemical delivery systems, disinfection systems, flocculation tank, pumping systems, SCADA, Filters 1 and 2, and WTP site security. The raw water, clearwell transfer, and finished water pumps are old and utilize aging and antiquated electrical components that are increasingly difficult to replace. The disinfection system utilizes gas chorine which carries some inherent safety and health risks and is subject to supply limitations. Filters 1 and 2 are old, have not been recently inspected, and show signs of corrosion and deterioration. The flocculation tank shows signs of deterioration and does not have any redundant systems. The SCADA system lacks redundancy and sophistication. Finally, the WTP utilizes limited security measures, is adjacent to a public park, and even shares a common wall with two public restrooms.

The remaining treatment components are considered low/minimal risk and while they should be maintained and possibly modernized as technology changes, these components should be addressed only after other, higher risk components are addressed.

Method 2

Each of the components listed above was also scored according to Method 2 described above, and then ranked according to their overall score. Additional information on the scoring rubric is provided in Exhibit C, and Table 3 below highlights the results of the scoring according to Method 1 described above. Table 4 provides the same results as Table 3 but organizes the components in order of their scoring/rank.

TABLE 3

Scoring Summary According to Analysis Method 2

Component	Effective Life (years)	Consequence of Failure (CoF)	Probability of Failure (PoF)	Reduction	Score	Rank
Raw Water Intake	60	7	5	0	35	9
Raw Water Pumps	40	9	7	0.5	31.5	13
Raw Water Instrumentation	10	2	2	0	4	20
Alum Delivery System	20	6	10	0	60	2
Flocculation Tank	20	6	5	0	30	14
Filters 1 and 2	50	9	6	0	54	3
Filters 3 and 4	50	9	5	0	45	4
Clearwell	100	9	4	0	36	5
Clearwell Transfer Pumps	40	8	8	0.5	32	11
Chlorine Disinfection System	15	9	5	0.5	22.5	15
Soda Ash Delivery System	10	6	6	0	36	5
Chlorine Contact Basin	25	9	8	0	72	1
Finished Water Instrumentation	10	2	2	0	4	20
Finished Water Pumps	40	8	8	0.5	32	11
WTP Main Building Piping	60	6	6	0	36	5
Finished Water Pump Building Piping	60	6	6	0	36	5
WTP Main Building Electrical	10	8	4	0.5	16	16
Finished Water Pump Building Electrical	20	8	4	0.5	16	16
WTP SCADA	30	2	4	0	8	19
WTP Security	30	7	5	0	35	9
Auxiliary Generator	40	8	2	0.5	16	16

TABLE 4

Summary of Rank for Method 2

Component	Rank
Chlorine Contact Basin	1
Alum Delivery System	2
Filters 1 and 2	3
Filters 3 and 4	4
Clearwell	5
Soda Ash Delivery System	5
WTP Main Building Piping	5
Finished Water Pump Building Piping	5
Raw Water Intake	9
WTP Security	9
Clearwell Transfer Pumps	11
Finished Water Pumps	11
Raw Water Pumps	13
Flocculation Tank	14
Chlorine Disinfection System	15
WTP Main Building Electrical	16
Finished Water Pump Building Electrical	16
Auxiliary Generator	16
WTP SCADA	19
Raw Water Instrumentation	20
Finished Water Instrumentation	20

The data in Tables 3 and 4 are consistent with the results from Tables 1 and 2. The components in the high and moderate risk categories in Method 1 all rank highly in Method 2.

SUMMARY AND CONCLUSIONS

The results in Tables 1 through 4 above provide a quantitative analysis for the risk associated with individual treatment components at the WTP. In general, the quantitative results match the qualitative analysis provided by both the District staff and the Assessment Report provided by Gray & Osborne in 2020 as documented in the Assessment Report.

Results from the quantitative risk analysis can be summarized as follows:

- The alum delivery system and chlorine contact basin represent the highest risk to WTP operations, and modifications to these systems should be prioritized over other treatment components.

- The items listed below present the next highest level of risk to WTP operations and should be addressed after other higher-priority items, or as feasible based on other revisions implemented at the WTP:

  - Raw Water Pumps
  - Filters 1 and 2
  - Clearwell Transfer Pumps
  - Finished Water Pumps
  - Chlorine Disinfection System
  - Soda Ash Delivery System
  - WTP SCADA
  - WTP Security
  - Flocculation Tank

- The remaining treatment components as noted below should be maintained to prolong their effective life, but a major replacement or rehabilitation is not necessary based on their risk to WTP operations. It may be advantageous to modify or replace some of these components, but this can be done as part of larger projects and as funding allows:

  - Raw Water Intake
  - Filters 3 and 4
  - WTP Main Building Electrical
  - WTP Finished Water Pump Building Electrical
  - Raw Water Instrumentation
  - Clearwell
  - Finished Water Instrumentation
  - WTP Main Building Piping
  - Finished Water Pump Building Piping
  - Auxiliary Generator

EXHIBIT A

ADDITIONAL RISK ASSESSMENT REFERENCES

Procedure for Hazard Identification and Risk Assessment in Waste-water Treatment Planting Saudi Arabia

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Abstract *: It is well known that wastewater treatment projects worldwide has become one of the most important, vital projects and linked to civilization. Since potable water and irrigation for agriculture water considered a very low resources in the Kingdom of Saudi Arabia - desert regions - soit is necessary to pay more attention to these projects, which already happened, where billions of Saudi Riyals have been invested in the sewage and industrial water treatment projects.*
Wastewater treatment industryin Saudi Arabiahas expanded to include a lot of units and departments, machines and hundreds of workers and has become a danger to staff and the areas surrounding these stations.
In this research we mention the steps and methods to be used and followed by workers in dealing with the various hazards. We start by identifying the hazards then point out how to analyze these hazards and classified into several degrees according totheir severity.
However it's necessary to specify the responsibilities and roles of employees in dealing with these risks.

I. INTRODUCTION

There are two kinds of wastewater treatment plants in Saudi Arabia,industrial wastewater treatment plant and sanitary wastewater treatment plant. The industrial wastewater treatment plant is designed to treat incoming industrial wastewater from industries like factories and plants. The sanitary wastewater treatment plant is designed to treat incoming sanitary wastewater from community area.
Hazard assessments and controls help build safe and healthy workplaces. They are at the core of every organization's occupationalhealth and safety management system. The hazard assessment and control process provides a consistent approach for employers and workers to identify and control hazards in the workplace. It allowseveryone to focus their efforts in the right areas, andto develop worker training, inspections, emergencyresponse [1].
This research aims to identify the OH&S hazards of (equipment, substances and / or movements) which may cause harms -in order to determine the level of risk associated with the hazard and its controls.
The procedurecan be implemented for:

- Routine and non-routine activities.
- Activities for all personnel having access to the work place
- Activities of contractors and/or subcontractors.
- Facilities at the workplace (Water Treatment Plant, Workshop, Buildings, electrical Substation, warehouses for Spares and Material, labs, etc.…..).

II. Basic Terminology:

- **HSEC**:Health, Safety and Environment Committee.
- **Hazard**:source, situation, or act with a potential for harm in terms of human injury or ill health, or a combination of these.
- **Hazard identification**: process of recognizing that a hazard exists and defining its characteristics.
- **Risk**: combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can because by the event or exposure(s).
- **Risk assessment**: process of evaluating the risk(s) arising from a hazard(s), taking into account the adequacy of any existing controls, and deciding whether or not the risk(s) is acceptable.
- **Acceptable risk**: risk that has been reduced to a level that can be tolerated by the organization having regard to its legal obligations and its own OH&S policy

- **Behavior Based Safety (BBS):** workplace behaviors are what one sees when observing people conducting tasks in their workplace.
- **OH&S:** occupational health & safety.
- **HSER:** Health, Safety&environmental Management Representative.
- **IMS Management representative:** A member appointed by the top management to be responsible for certain quality, safety and environmental tasks irrespective of his other responsibilities.

III. THEWASTE WATER TREATMENT PLANT: AN OVERVIEW

Water is one of the most significant sectors in the Kingdom the National Water Company (NWC) established in 2008, as a Saudi joint stock company fully owned by the government (namely the Public Investment Fund), aims to provide water and wastewater treatment services in accordance with the latest international standards. This is achieved by the concerted efforts of national cadres in partnership with carefully selected international operators through foreign PPP.

NWC specializes in providing the highest quality drinking water, ensuring the presence of water and wastewater connections in all households, preserving natural water resources and the environment, using the Treated Sewage Effluent (TSE) with maximum efficiency, and training qualified Saudi employees in accordance with the latest international standards.

Throughout its new phase, NWC is able to implement radical changes in the water sector's performance. This was achieved through raising the company's operational efficiency in line with international standards, establishing a solid infrastructure that can accommodate the evolving demands of a growing KSA population, providing high-quality services to clients and customers, and investing all essential efforts for preserving natural water resources, protecting the environment, and ensuring sustainability.Figure 1.

Figure 1. Wastewater Treatment Plant

3. PROCEDURE

3.1 Hazard Identification

There are many hazards that may cause injury, illness. Hazard Identification is the basis for the risk assessment process. (Table 1) contains questions that will lead to identifying commonly observed hazards [2] and [3].

Table 1: Hazard Identification Checklist

	HAZARD IDENTIFICATION	
A	**ENTANGLEMENT**	
A1	Can anyone's hair, clothing, gloves, neck-tie, jewellery, cleaning brushes, rags or other materials become entangled with moving parts of the plant, or materials in motion?	
B	**CRUSHING**	
B1	Can anyone be crushed due to:	
	a	Material falling off the plant?
	b	Uncontrolled or unexpected movement of the plant or its load?
	c	Lack of capacity for the plant to be slowed, stopped or immobilized?
	d	The plant tipping or rolling over?
	e	Parts of the plant collapsing
	f	Coming in contact with moving parts of the plant during testing, inspection, operation, maintenance, cleaning or repair?
	g	Being thrown off or under the plant?
	h	Being trapped between the plant and materials or fixed structures?
	i	Other factors not mentioned?
C		**CUTTING, STABBING & PUNCTURING**
C1		Can anyone be cut, stabbed or punctured due to:
	a	Coming in contact with sharp or flying objects?
	b	Coming into contact with moving parts of the plant during testing inspection, operation, maintenance, cleaning or repair of the plant?
	c	The plant, parts of the plant or working pieces disintegrating?
	d	Work pieces being ejected?
	e	The mobility of the plant?
	f	Uncontrolled or unexpected movement of the plant?
	g	Other factors not mentioned?
D.		**SHEARING**
1		Can anyone's body parts be sheared between two parts of the plant, or between two parts of the plant, or between a part of the plant and a work piece or structure?
E		**FRICTION**
E1		Can anyone be burnt due to contact with moving parts or surfaces of the plant?
F		**STRIKING**
F1		Can anyone be struck by moving objects due to:
	a	Uncontrolled or unexpected movement of the plant or material handled by the plant?
	b	The plant, parts of the plant or pieces disintegrating?
	c	Work pieces being ejected?
	d	Mobility of the plant
	e	Other factors not mentioned?
G	**HIGH PRESSURE FLUID**	
G1	Can anyone come into contact with fluids under high pressure, due to plant failure or misuse of the plant?	
H	**Working at height**	

H1	Guardrail systems	
H2	Scaffolding system inspection and maintenance	
H3	All required PPEs are in use (helmet , safety shoes , gloves , etc....)	
H4	Working at height permits	
I	**ELECTRICAL**	
I1	Can anyone be injured by electrical shock or burned due to:	
	a	The plant contacting live electrical conductors?
	b	The plant working in close proximity to electrical conductors?
	c	Overload of electrical circuits?
	d	Damaged or poorly maintained electrical leads & cables?
	e	Damaged electrical switches?
	f	Water near electrical equipment?
	g	Lack of isolation procedures?
	h	Other factors not mentioned?
J	**EXPLOSION**	
J1	Can anyone by injured by explosion of gases, vapours, liquids, dusts or other substances, triggered by the operation of the plant or by material handled by the plant?	
K	**Confined space**	
K1	Confined spaces Work permits	
K2	Confined space safety inspection	
K3	Using suitable PPEs for working at confined spaces (helmets , safety shoes, oxygen cylinders	
L	**SLIPPING, TRIPPING & FALLING**	
L1	Can anyone using the plant, or in the vicinity of the plant, slip, trip or fall due to:	
	a	Uneven or slippery work surfaces?
	b	Poor housekeeping.
	c	Obstacles being placed in the vicinity of the plant?
	d	Other factors not mentioned?
L2	Can anyone fall from a height due to:	
	a	Lack of proper work platform?
	b	Lack of proper stairs or ladders?
	c	Lack of guardrail or other suitable edge protection?
	d	Unprotected holes, penetrations or gaps?
	e	Poor floor or working surfaces, such as the lack of slip resistant surfaces?
	f	Steep walking surfaces?
	g	Collapse of the supporting structure?
	h	Other factors not mentioned?
M	**ERGONOMIC**	
M1	Can anyone be injured due to:	
	a	Poorly designed seating?
	b	Repetitive body movement?

	c	Constrained body posture or the need for excessive effort?
	d	Design deficiency causing mental or psychological stress?
	e	Inadequate or poorly placed lighting?
	f	Lack of consideration given to human error or human behaviour?
	g	Mismatch of the plant with human traits and natural limitations?
	h	Other factors not mentioned?
N	**SUFFOCATION**	
N1	Can anyone be suffocated due to the lack of oxygen, or atmospheric contamination?	
O	**HIGH TEMPERATURE OR FIRE**	
O1	Can anyone come into contact with objects at high temperatures?	
P	**TEMPERATURE (THERMAL COMFORT)**	
P1	Can anyone suffer ill health due to exposure to high or low temperature?	
Q	**OTHER HAZARDS**	
Q1	Can anyone be injured or suffer ill-health from exposure to:	
	a	Chemicals?
	b	Biological?
	c	Toxic gases, vapours or fumes?
	d	Dust?
R	**OTHER HAZARDS (Cont'd)**	
	e	Noise?
	f	Vibration?
	g	Radiation?
	h	Other factors not mentioned?
S	**ENTRAPMENT**	
S1	Can anyone be locked or trapped in an area of space?	

3.2 Risk Assessment Team

A team approach is adopted for the risk assessments where representatives from relevant work places make up the risk assessment team, and are actively involved in the risk assessments. Team members consist of (At least)

- One Safety department representative,
- One area Section Head or supervisor
- One of the HSERs members.

It should be noted that:

- Team members must be trained on this risk assessment method and procedure.
- TheHSEC will lead the team as the risk assessment advisor/moderator.
- Risk assessment team identifies the hazards using hazard identification, Risk assessment and observation record sheet form (HSE-HI/FR01) which reviewed by the process owner manager and approved by HSSE Manager.
- Team members can include others up to six persons if needed.

3.3 Risk Identification and Assessment

When the hazard identification is completed, the following questionsare asked:

- What is the severity or consequences of the hazard (e.g. injury, damage, spillage, business interruption, fire, explosion, etc.)? As a rule, the most severe consequence is considered.
- What is the probability of occurrence? The probability should be estimated from previous experiences or, if possible, with the help of statistics.
- Is the hazard related to any Legal Requirement? Any hazard related to legal requirement and not compiling with it; the severity should be 5.
  Using the severity and probability criteria defined below, the risk can be introduced into a Risk Matrix based on [4] and [5].

$$\text{RISK} = \text{SEVERITY} \times \text{PROBABILITY}$$

3.4 Acceptable Risks

Acceptable risks of potential and/or existing hazards will be determined per hazard after finalizing the preparing of risk assessment sheet and applying the necessary control, which has to comply with legal obligations, canbe tolerated by the organization & will be updated per risk assessment updating.

3.5 Behavior Based Safety (BBS)

Everybody who works to reduce accidents and improve safe performance is concerned with human behavior. “Behavior and accidents is what it’s all about,” is a commonly heard phrase[6].

Behavior is defined as “an observable act”; i.e. workplace behaviors are what one sees when observing people conducting tasks in their workplace. The behavior is assessed as dangerous action, dangerous condition or positive point.

The BBS objective is improving the safety at work by privileging constructive dialogs and eliminating hazardous working conditions and acts [7].

Since the risk assessment will include person's behaviors, which isthe base of culture change, the following steps will be followed whenassessing employee's behavior

Announce your visit to the person to be visited and to his Supervisor (at the latest 24 hours before the visit)

- Explain to him the objective of your visit
- Observe the person work (10-15 minutes)
- Identify: The positive points (PP) - The Dangerous Acts (DA) - The Dangerous Conditions (DC).

After the observation, engage the dialog with the visited person, starting with the positive points (PP) that the visitors have observed.

Make him aware of the DC & DA and what are the improvements that could be done right now?

Each Process Owner is responsible for updating the hazard identification; risk assessment & observations register on annual basis.

If a major change in the process takes place the Head of Department is responsible for updating the hazard identification, risk assessment & observations Register and informing the department Health & Safety Coordinator. Changes could be the following and other pertinent information:

- Installation of new Equipment or new material
- Asset Transfers
- After Reported Accidents
- Machine Acceptance of Modified Equipment
- Chemical Approval Requests
- Operational Reviews
- Management Reviews.

Table 2: Criteria for evaluating the severity

Severity of Consequences					
Category/ Descriptive Word	**Personnel Illness/ Injury**	**Equipment Loss ($)**	**Down Time**	**Product Loss ($)**	**Environmental Effects**
5 CATASTROPHIC	Death	>1M	>1 Month	>1M	Long-term (>5yrs) environmental damage or requiring >$1M to correct and/or in penalties
4 CRITICAL	Severe injury or severe occupational illness >2 Week hospitalization	250K to 1M	1 Month to 1 week	250K to 1M	Medium-term (1-5 yrs) environmental damage or requiring $250K - $1M to correct and/or in penalties
3 SIGNIFICANT	Major injury or major occupational illness <2 Week hospitalization	50K to 250K	3 days to 1 week	50K to 250K	Short-term (3 mo-1 yr) environmental damage or requiring $50K - $250K to correct and/or in penalties.
2 MARGINAL	Minor injury or minor occupational illness No hospitalization Day case	1K to 50K	1 day to 3 days	1K to 50K	Brief-term (<3 mo) environmental damage or requiring $1K - $50K to correct and/or in penalties.
1 NEGLIGIBLE	First Aid No injury or illness	<1K	<1 day	<1K	Minor environmental damage, readily repaired and/or requiring <$1K to correct and/or in penalties

Table 3: Criteria for evaluating the probability

PROBABILITY		
Level	**Descriptive word**	**Definition**
5	**FREQUENT**	Expected to occur in all circumstances (Once per week)
4	**PROBABLE**	Expected to occur in most circumstances (Once per month)
3	**OCCASIONAL**	Will probably occur in most circumstances (Once per year)
2	**REMOTE**	Might occur at some time (Once per 10 years)
1	**IMPROBABLE**	Could occur at some time, but less possible (Once per 100 years)

Table 4: Risk Matrix

Probability	**5**	**5**	**10**	**15**	**20**	**25**
	4	**4**	**8**	**12**	**16**	**20**
	3	**3**	**6**	**9**	**12**	**15**
	2	**2**	**4**	**6**	**8**	**10**
	1	**1**	**2**	**3**	**4**	**5**
		1	**2**	**3**	**4**	**5**
			Severity			

Legend

≥20	E	Extreme risk - immediate action required (Red)
>10&<20	H	High risk - urgent management attention needed (Yellow)
>5 & ≤10	M	Medium risk - management attention as soon as possible (Green)
≤5	L	Low risk – non urgent management attention needed (White)

Table 5: Risk assessment procedure steps.

Step	Action	Explanations
1	Decide to perform a risk assessment	The risk assessment may be the result of: • New equipment being introduced or existing equipment or workplace being modified • Significant changes being introduced to the tasks performed in the workplace; • Safety control systems being modified; • Regulatory requirements • Equipment that is being used for another purpose • New information about the identified hazards being available • An incident investigations revealing new information regarding workplace hazards and/or the level of risk • An accident.
2	Establish a risk assessment team	A team of trained and appropriate people covering all domains of the projected assessment shall conduct the risk assessment. Team to be no more than 6 people.
3	Identify the hazards	Is there a hazard or issue (e.g. electricity, chemicals, thermal stress, moving equipment, human error, external event, etc.)? As an aid for assessors, Appendix A contains questions that will lead to identifying commonly observed hazards.
4	Assess the risk for all the hazards identified in Step 3 above	The Risk Assessment Team • Evaluates what is the likely severity (consequence) of such a hazard • Evaluates what is the probability of the hazard causing injury or loss.
5	Prioritize the risk	The severity and probability are introduced onto the Risk Matrix to prioritise the risks as: E: Extreme risk; immediate action required H: High risk; urgent management attention needed M: Medium risk; management attention as soon as possible L: Low risk; longer term action may be required
6	Develop action plans	Identified risks shall be prioritised for action and control measures. The following hierarchy will apply to reduce the risk as far as practicable: • Elimination; • Substitution; • Engineering controls; • Signage/warnings and/or administrative controls; • Personal protective equipment.
7	Communicate results and arrange training	The outcomes of risk assessments shall be communicated to all concerned people. Existing and new staff working in the assessed workplace must be made aware of the risks and trained on the mitigation and control measures.

3.6 Responsibility

3.6.1. The HSC in each department is responsible for maintainingthe hazard identification; risk assessment & observations register for each area.

3.6.2. OH&S Manager is responsible to review and update this procedure.

3.6.3. OH&S Manager is responsible to coordinate or establishing of hazard identification and risk assessment for subcontractors' activities and setting the need of controls with the concerned departments.

3.6.4. OH&S Manager is responsible for setting the need of controls for visitors as well as safety training & awareness of new employees.

IV. CONCLUSIONS

The employer's hazard assessment and management will determine, in large part which Standards and procedure shall be used in the workplace to provide safe and healthful working conditions. Therefore, it will be incumbent for the employer, and / or all persons involved in the hazard assessment to know which Standards will apply to any given situation.

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Hazard Identification and Risk Assessment in Water Treatment Plant considering Environmental Health and Safety Practice

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Abstract. Water Treatment Plant (WTP) is an important infrastructure to ensure human health and the environment. In its development, aspects of environmental safety and health are of concern. This paper case study was conducted at the Water Treatment Plant Company in Semarang, Central Java, Indonesia. Hazard identification and risk assessment is one part of the occupational safety and health program at the risk management stage. The purpose of this study was to identify potential hazards using hazard identification methods and risk assessment methods. Risk assessment is done using criteria of severity and probability of accident. The results obtained from this risk assessment are 22 potential hazards present in the water purification process. Extreme categories that exist in the risk assessment are leakage of chlorine and industrial fires. Chlorine and fire leakage gets the highest value because its impact threatens many things, such as industrial disasters that could endanger human life and the environment. Control measures undertaken to avoid potential hazards are to apply the use of personal protective equipment, but management will also be better managed in accordance with hazard control hazards, occupational safety and health programs such as issuing work permits, emergency response training is required, Very useful in overcoming potential hazards that have been determined.

1 Introduction

Occupational safety and health is heavily influenced by occupational hazards identified and managed in a competent risk assessment process. Hazards in the workplace can be physical, chemical or psychological and can lead to workplace incidents and work-related injuries, which have an impact on organizational productivity and profitability. [1]

Hazard Identification Risk Assessment (HIRA) is a method for determining and providing hazards based on their probability, frequency and severity and evaluating adverse consequences, including potential loss and injury. The work process in the industry must pay attention to aspects of environmental health and safety in order to support the effectiveness of the industry. The industry must identify hazards, assess the associated risks to tolerate continuous levels, risk assessments have been made using risk guidelines and standards. [2][3]

Water Treatment Plant (WTP) is an important infrastructure to guarantee human and environment health. As water supply, they have a key role in giving healthy clean water access to the society. In the progress of this, environmental and health safety aspect becomes things to be concerned about. [4] The high hazard impacts in workplace often become the cause of work accident and occupational disease.

Working in the field of water treatment is considered dangerous, especially as it can lead to frequent deaths in confined spaces. Occupational safety and health is not particularly noticed in this area, many decision makers consider it to be somewhat less dangerous at the moment, but processing workers are still experiencing the possibility of health problems and deaths, especially exposure to chemicals as materials for water purification. [4][5].

Water treatment companies use machines and equipment that are likely to cause injury to workers. Accidents that occur can be caused by negligence of workers when operating machinery and equipment or unsafe working environment conditions. Potential hazards that often occur are defects in operation, exposure to chemicals and work fatigue.

The study was conducted using the HIRA (Hazard Identification and Risk Assessment) method to identify potential hazards found in the workplace. By identifying potential hazards and work risks, it is expected to facilitate the company in the management and control of safety in the workplace and minimize the possibility of accidents.

2. Literature review

Hazard Identification is a proactive process to identify hazards and eliminate or minimize/reduce the risk of injury/illness to workers and damage to property, equipment and the environment. It also allows us to show our commitment and due diligence to a healthy and

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safe workplace. We must identify hazards and potential hazards in the workplace in order to be able to take action to eliminate or control them. [8]

Table 1. Description of Likelihood Level

Level	Likelihood	Expected or actual frequency experienced
1	Rare	May only occur in exceptional circumstances; simple process; no previous incidence of non-compliance
2	Unlikely	Could occur at some time; less than 25% chance of occurring; non-complex process &/or existence of checks and balances
3	Possible	Might occur at some time; 25 – 50% chance of occurring; previous audits/reports indicate non-compliance; complex process with extensive checks & balances; impacting factors outside control of organisation
4	Likely	Will probably occur in most circumstances; 50-75% chance of occurring; complex process with some checks & balances; impacting factors outside control of organisation
5	Almost certain	Can be expected to occur in most circumstances; more than 75% chance of occurring; complex process with minimal checks & balances; impacting factors outside control of organisation

This is a step by step process to guide responsible persons to an effective hazard identification, assessment and controls system. The steps include:

- Hazard Assessment: identifying the hazards and potential hazards, determining the risks and the risk designation (rating) associated to the hazard based on: Likelihood and severity
- Hazard control - controlling the hazards and the risks associated with the hazard
- Providing information, education, training and supervision on the hazards, risks and controls for employees affected by the hazards
- Review of the hazard assessment and control process

Table 2. Risk Assessment Matrix

Likelihood	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
		Severity				

Extreme	: 15-25
High Risk	: 8-12
Medium Risk	: 4-6
Low Risk	: 1-3

Table 3. Description of Severity Level

Level	Description of Severity
1	• Minor onsite injuries (first aid and nondisabling, reportable injuries). • Property damage less than base level amount * • Minor environmental impact (no remediation). • Loss of production less than base level amount * • No offsite impact or damage. No public concern or media interest.
2	• Serious onsite injuries (temporary disabling worker injuries). • damage from 1 to 20 times base level. • Moderate environmental impact (cleanup or remediation in less than 1 week and no lasting impact on food chain, terrestrial or aquatic life). • Loss of production from 1 to 20 times base level • Minor offsite impact (public nuisance—noise, smoke, odor, traffic). • Potential adverse public reaction. Some media awareness.
3	• Permanent disabling onsite injuries or possible fatality. • Property damage from 20 to 50 times base level. • Significant environmental impact (cleanup or remediation less than 1 month and minor impact on food chain, terrestrial or aquatic life). • Loss of production from 20 to 50 times base level. • Moderate offsite impact limited to property damage, minor health effects to the public or first aid injuries. • Adverse public reaction. Local media concern.
4	• Onsite fatality or less than four permanent disabling worker injuries. • Property damage from 50 to 200 times base level. • Serious environmental impact (cleanup or remediation requires 3–6 months and moderate impact on food chain, terrestrial and/or aquatic life). • Loss of production from 50 to 200 times base level. • Significant offsite impact property damage, short-term health effects to the public or temporary disabling injuries. • Significant public concern or reaction. National media concern.
5	• Multiple onsite fatalities or four or more permanent disabling onsite injuries. • Property damage greater than 200 times base level.

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	• Extensive environmental impact (cleanup or remediation exceeding 6 months, significant loss of terrestrial and aquatic life or damage to food chain uncertain). • Loss of production greater than 200 times base level. • Severe offsite impact property damage, offsite fatality, long-term health effect, or disabling injuries. • Severe adverse public reaction threatening facility continued operations. International media concern

During the interview process, worker and safety officer is given a table containing the scale / category of likelihood and severity, so that the worker and the safety contractor can know and determine for themselves the category level of likelihood and severity. The value scale for likelihood is 1-5 ranging from an unlikely to almost certain level of probability.

While the value scale for severity is 1-5 ranging from insignificant to catastrophic severity. After the value of relative risk obtained then analyzed using Risk Assessment Matrix table. [7]

Risk is a measurement to analyze and evaluate the hazard. The measurement is made by identification on how severe and when likely of the hazard. In other words, the risk assessment is an in-depth look to specify situations, process and other harmful activities or hazard at workplace. [8]

Rating the hazard is one way to help determine which hazard is the most serious and thus which hazard to control first. Priority is usually established by taking into account the severity and Likelihood. By assigning a priority to the hazard, you are creating a rating or an action list.

The following factors play an important role:

- Severity of exposure - impact when exposed to the hazard.
- Likelihood - that an incident will occur when exposed to the hazard.

When the hazard is identified, determine the controls which are already in place to ensure this information is taken into account when assigning a risk designation.

Risk is presented in variety of ways to communicate the distribution of the risk throughout a plant and area in a workplace. The results of risk assessment that presented in a risk matrix are essential to make decision on risk control. Risk can be calculated using the following formula:

Risk (R) = Likelihood (L) x Severity (S). [7]

The phase of risk identification is essential, because it puts the bases of the risk analysis. Indeed, the data of risk identification will be the input of the evaluation, Therefore it is necessary to make an identification phase in an exhaustive way, to obtain the best results. [9]

4 Methodologies

The type and design of this research based on time research is cross sectional because the process of collecting data and observation of the variables done at once or at one particular time. While in terms of place, this research includes field research, because the research conducted and the way researchers in getting the data is directly plunged into the field by conducting interviews and observation

When viewed from the way of data collection, this study is observational because researchers obtain data through observations and interviews to workers and related parties in the company. In addition, the objects in this study were not treated during the course of the observational / observational study. Based on the nature of the problem and its data analysis, this research is included in descriptive research because this research does not make comparisons or connections between variables. This study describes a situation objectively.

Variables to be studied in this research are hazard identification, risk assessment, and risk level determination on water installation process. The data collected in this study there are two types of primary data and secondary data. Primary data obtained through observation and interview. These observations and interviews are used to determine the potential water hazard clearance process, the magnitude of occupational risks and the working environment.

While the secondary data collected is a general description of the company, the work procedure, the number of workers, tools and hazardous materials in the water treatment process and accident control efforts that have been done.

Processing techniques and data analysis conducted based on observation and interview data. Based on the results of observation and interviews are known potential hazard and value. Identification of potential risk hazards in the water treatment plant will be very effective if done on the basis of the factual conditions of the workplace and existing work processes, this is an effort that can be done so that industrial health and environmental health programs can be done well in accordance with policies and Regulations that have been set.

4. Result

Risk Assessment is performed using the Risk Matrix as described in the literature study, the results obtained from this risk assessment are the 22 potential hazards present in the water purification process, these findings are based on assessments of workshops and processing units at subsequent water treatment plants Described in detail in table 4. According the existing categories of extreme risk, high risk, medium risk and low risk then the findings are grouped into each risk category.

Extreme categories that exist in the risk assessment are chlorine leak and industrial fires. Leakage of chlorine and fires get the highest value because their impact threatens many things, such as industrial disasters that can harm human life and the environment.

Hazards Chlorine can be absorbed through the skin and cause burns ranging from mild to severe depending on the length of the contact In addition chlorine can also be absorbed through the eye, causing burning or discomfort, irregular blinking, unconscious closure of

eyelids, redness, and tearing. Large amounts of chlorine in the air can cause severe burns, pain, and blurred eyesight.
Therefore workers in storage must conduct a well-scheduled inspection so that the presence of chlorine can be safely maintained, besides that it is also necessary to have an emergency management control system that refers to leakage of chlorine and industrial fires, Prevention efforts from known potential hazards.

Table. 4 Hazard Identification Risk Assessment in Water Treatment Plant

No	Workshop or Treatment unit	Hazard / Hazardous Situation	Potential Risk	Consequence	Risk Assessment Matrix		
					L	S	Risk Value
1	Flow Meter Chamber	Possible entrance and entering the flow meter chamber	Chlorine inhalation by operator working inside the chamber	Lost-time accident up to fatality due to chlorine inhalation	3	2	6 (medium Risk)
2	Demolition in Chemical Building	Work at height (8m) for demolishing walls and floors	Falling from a height of approximate 8 meter to the ground	Permanent injury up to fatality	2	4	8 (High Risk)
3	Control Room	Electrical Hazard	Electric short circuit	fractures, Fatality, Disaster	3	5	15 (Extreme Risk)
4	Process of Treatment	Cleaning accumulation sludge in channel raw water inlet of accerator 1,2 at once a month	harmful atmosphere, difficulty of entry/exit access	Fatality accident more than 1 person	2	5	10 (High Risk)
5	Process of treatment	Cleaning once a month sludge extraction	All confined space risks, including fall, electrical shock	Fatality accident	2	4	8 (High Risk)
6	Process of treatment	Working at height for routine operating main drain valve, noise, smell	Falling, slippery	Fatality accident	1	4	4 (Medium Risk)
7	Process of treatment	Working/cleaning over compartment	Falling, drowning	Fatality accident	1	4	4 (Medium Risk)
8	Water treatment line	Working at height around sand filter	Drowning, Falling	Concussion, fracture	3	2	6 (Medium Risk)
9	Backwash pump room	Rotating part, noise, slippery at backwash pump	Injury at arm or hand in Projection of loose bolt, noise, fall	Arm amputation, fracture, hearing disorders, concussion	3	3	9 (High Risk)
10	Gear box of the turbine	Exposed rotating parts	Injury at arm or hand in Projection of loose bolt	Arm amputation, shut down machine, fracture	2	3	6 (Medium Risk)
11	Chlorine Facilities	Crash inside the site	Personnel crashed by chlorine vehicle	Fatality accident	3	4	12 (High Risk)
12	Chlorine Facilities	Chlorine Leakage	Inhalation of chlorine gas	Fatality accident, Disaster	3	5	12 (Extreme Risk)
13	Chlorine Facilities	Falling container when loading/unloading	Impacted by falling heavy objects (weight: +1.8 ton, height: 1.5 m)	Fracture/irreversible harm	2	2	4 (Medium Risk)
14	Purchasing	Wrong/miss specification when purchased devices, equipments, tools or materials and services	Use of improper devices, equipments, tools, materials	Stop production, fatality	5	1	5 (Medium Risk)
15	Filter gallery	Working at height	Falling at a height (6 M)	Fatality accident	2	4	8 (High Risk)

16	Laboratory	Exposure to UV radiation (The device has a UV germicidal lamp with a wavelength of 257.7 nm, including UV-C type)	Erythema (damage / disorder) on the skin and damage the cornea of the eye	Skin disorders or skin and cataracts in the eyes for the long term	4	2	8 (High Risk)
17	Reservoir	Confined space hazard	Inadequate O2 content, high toxic gas content, leakage current on electrical	Fainting, poisoning, death	2	4	8 (High Risk)
18	Acid material	Strong acid vapor in the laboratory	Inhalation, skin contact	Respiratory disorders, Skin sores	3	1	3 (Low Risk)
19	Storrage & dosing system H2SO4	Exposure to H2SO4	Steam H2SO4 strong acid operation of H2SO4 dosing pump for water neutralization	Blind, burns, irritation	2	4	8 (High Risk)
20	Submersible Pump	Electrical	Electric caution, Fire	Disaster, Injury	1	5	5 (Medium Risk)
21	Storage of hazardous chemical waste	Waste spills	Hazardous chemical waste spills at the time of pouring, the occurrence of waste leakage	Environmental pollution, poisoning, fainting	3	2	6 (Medium Risk)
22	Storage Poly Aluminum Chloride	Poly Aluminum Chloride	Leaks on pipe connections and ball valves	Irritation, impaired vision, indigestion	3	2	6 (Medium Risk)

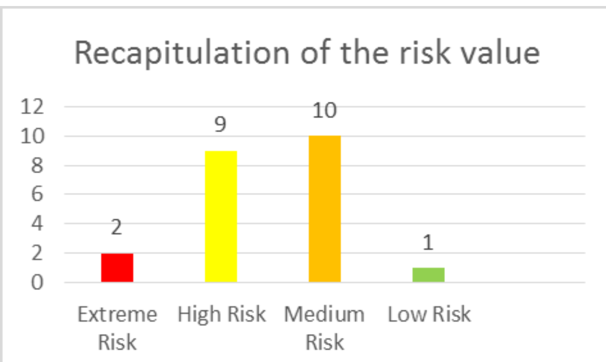

Fig 1. Recapitulation of the risk value

4. Conclusion

Potential occupational hazards in the water treatment industry are exposed to chemicals to workers, the potential danger of leaking chlorine gas can also greatly affect the safety and health of the industrial environment. Control measures undertaken to avoid potential hazards are to apply the use of personal protective equipment, but management will also be better managed in accordance with hazard control hazards, occupational safety and health programs such as issuing work permits, emergency response training is required, Very useful in overcoming potential hazards that have been determined.

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Article

Analysis of Risk Assessment in a Municipal Wastewater Treatment Plant Located in Upper Silesia

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Abstract: Nowadays, risk management applies to every technical facility, branch of the economy, and industry. Due to the characteristics of the analyzed wastewater treatment plant and the specificity of the used processes, one must approach different areas individually. Municipal sewage treatment plants are technical facilities; they function as enterprises and are elements of larger systems—water distribution and sewage disposal. Due to their strategic importance for the environment and human beings, it is essential that they are covered by risk management systems. The basic stage of risk management is its assessment. On its basis, strategic decisions are made and new solutions are introduced. Constant monitoring of the operation of a treatment plant allows for assessment of whether actions taken are correct and whether they cause deterioration of the quality of sewage. In our work, we present a method of risk assessment based on historical data for an existing facility and obtained results.

Keywords: municipal wastewater treatment plant; risk management; risk assessment; risk analysis; biological treatment; chemical treatment

1. Introduction

Municipal sewage treatment plants are strategic elements of infrastructure and special technical facilities, whose proper functioning determines environmental cleanliness, as well as, people's health. The individual stages of wastewater treatment use physical, biological, and chemical processes that are interrelated and dependent on each other. The effectiveness of each stage is affected by various negative factors, such as the variable composition of incoming sewage and atmospheric conditions. Operators need to limit the effects of events caused by these factors and even prevent their occurrence [1–3]. Therefore, the proper functioning municipal sewage treatment plant should be supported by a risk management system.

The risk of municipal sewage treatment plants can be examined and analyzed at various stages of the treatment plant operation. Considering the potential risk as early as the design stage of the facility allows for choice of the most appropriate trade-off between costs of measures and risks [4,5]. Currently, in Poland, modernization of existing obsolete objects is more common than emergence of new ones. Correctly carried out modernization should be based on risk analysis [6]. Modernization may involve repairs of existing equipment and improvement of technological conditions, or it may be considered as an extension of the technological line with modern devices, e.g., membranes. In particular, the second case should be preceded by a thorough analysis of costs, losses, and risks [7]. In addition, the risks should be monitored throughout the operation of the treatment plant, and the risk management system should be used effectively [8].

This paper discusses the application of risk assessment procedures for the management of municipal wastewater treatment plants, using a facility in Poland as a case study. The method of risk assessment is presented based on historical data.

Current research concerns individual chemical compounds: pharmaceuticals [9], antibiotics [10], individual devices of a treatment plant's technological line, and assessment of ecological risk of receiver after discharge from a sewage treatment plant [11–13]. In contrast to the cited papers (which are examples of research conducted thus far), we assess the risk associated with the entire wastewater treatment plant, which is a novelty in the scientific literature.

2. Theory of Risk Management

Defining the risk management process is difficult due to the multitude of various scientific and economic areas in which it is used. It can be defined as a way to find the most optimal methods for conscious, uninterrupted diagnosis and risk control [14]. Risk management should lead to risk setting at an acceptable level [15]. With regard to municipal wastewater treatment plants, risk management can be defined as preventing an occurrence of undesirable events and reducing the size of resulting damage after such events occur [16]. These actions should be carried out on the basis of continuous monitoring of the treatment plant operation, staff training, maintenance of technological process equipment, and maintenance of technical services.

The risk management process can be divided into two basic stages: risk assessment and risk control [17]. The components of risk assessment are identification, estimation, and determination of its acceptability [16]. Risk control involves the monitoring of sewage treatment plant operation and observation of introduced changes.

2.1. Risk Identification

The basic method of risk identification of a municipal sewage treatment plant is analysis of historical data, during which attention should be paid to all events causing damage. Due to the nature of the sewage treatment plant, risk identification should be an ongoing process in order to identify new threats and verify those already recognized [18,19]. The process of risk identification is the basis for risk management, and its correct functioning determines the success of the entire risk management process [20].

2.2. Risk Estimation

Risk estimation consists of determining its measure, which is dependent on the availability of data, reliability, and expected results [16,21]. In general, risk estimation methods can be divided into three groups [22]:

- Quantitative methods consist of two defining parameters: frequency of occurrence and value of losses; the results are objective and comparable.
- Qualitative methods include a subjective assessment based on knowledge and experience; the results are presented in a descriptive form.
- Mixed methods are the most commonly used type of strategy, involving the simultaneous use of quantitative and qualitative methods.

In the case of sewage treatment plants, the specificity of the collected data allows only the mixed method to be used. The qualitative method is used to identify risk, while the quantitative method is used in risk assessment, assigning specific values to described events.

The result of the mixed method is the so-called risk map (Figure 1). The risk map gives the possibility of a comprehensive presentation of the identified and quantified risk, but it is also a tool helpful in indicating which methods of risk control will work best for a given risk [23]. The risk map presented in this paper is the simplest type of possible risk matrix, determined by the size of losses and the frequency of their occurrence.

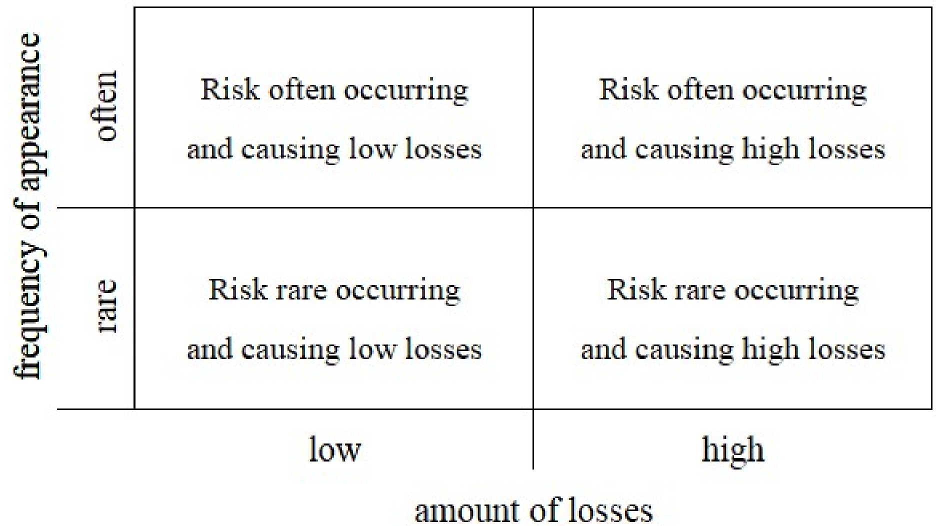

Figure 1. Sample scheme of a very simple risk map [19].

2.3. Risk Admissibility

In the literature [16,24] and practice, three basic degrees of risk acceptability are distinguished as follows:

- Acceptable risk—an event irrelevant to the general operation of the facility as a "daily risk"; it does not require special security measures.
- Tolerable risk—medium risk, requires intervention, provided that the cost of reducing the risk is reasonable for the damage caused.
- Unacceptable risk—high risk, means an immediate threat to the environment and people and requires immediate steps to limit it.

The degree of admissibility is determined on the basis of legal acts, applicable norms and standards. The Polish legal act for municipal sewage treatment plants is the Regulation of the Minister of Environment from 18 November 2014 [25]. The regulation defines the conditions for discharge of sewage to the receiver. When analyzing a single object, you should also permit considerations for specific water treatment. Graphical interpretations of risk hierarchization (Figure 2) are obtained by applying the acceptability of risk to the risk map (Figure 1) based on the aforementioned documents.

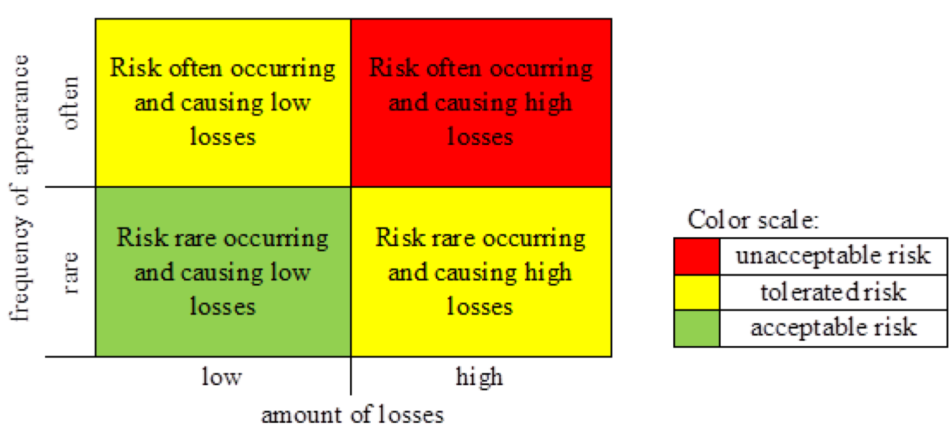

Figure 2. Risk hierarchy for the sample scheme presented in Figure 1 [21,22,26,27].

3. Obtained Results and Discussion

We analyzed the work of a sewage treatment plant located in Upper Silesia that uses activated sludge technology. The municipal wastewater treatment plant serves 62,000 inhabitants. Based on historical data collected by the operator of the sewage treatment plant from 2014 to 2016, risk identification and assessment were carried out. Our previous work [28] presents the risk identification that is assessed in the present paper (Table 1). The occurring risk factors (inside, outside, internal, external, latent, explicit) were identified, and the type of risk event (qualitative, operational, ecological, financial) was recognized according to the classification by Iwanejko and Rybicki [16].

Table 1. Examples of events together with the incidence rate (I) and the number of losses (L).

Device	Event	Type of Risk *	Risk Identification [16]			Risk Assessment		
			Factor **	Effect	Action Taken/Proposed	Number of Losses(L)	Frequency of Appearance (1/year)	Frequency of Appearance (F)
sifters	sifter scraper failure	Q	O	clogging of sifter	repair of scrapper	1	0.67	1
grit chamber	large dump of greasy sewage	Q	E	clogging of grease chamber outflow	unclogging the outflow	1	0.33	1
activated sludge chamber	emergence of filamentous bacteria	Q, OP	I	formation of scum layer	breaking the scum layer and actions aimed at stopping bacteria development	2	13.67	3
secondary settling tank	auxiliary devices failure	Q, OP	O	minor disturbance in the settling tank operation	repair of auxiliary devices	2	4.67	2
all devises of sewage treatment	electrical power outage	Q, OP, EC, Fi	E	no power for electrical powered devices	connection to emergency power supply	4	0.33	1

* Q—qualitative, OP—operational, EC—ecological, Fi—financial. ** O—Ordinary, E—external, I—internal.

In the process of risk identification [28], 32 different threats were identified, which occurred 114 times at different frequencies. All of these events were divided according to the frequency of their occurrence, as seen in Table 2, and on the basis of their specific type of risk, a quantitative loss value was assigned to them (Table 3). Results obtained in this way are presented in Table 1. Based on Table 2, a risk map was prepared with the admissibility hierarchy indicated. In order to accurately analyze these events, a risk map was divided into individual devices of the technological line (Figure 3).

Table 2. Frequency of appearance (F).

Occuring Events:	Frequency of Appearance	
	(1/year)	(F)
rarely	≤4 or 5	0–1
often	4 or 5–9	1–2
very often	≥9	2–3

Table 3. Number of losses (L).

Type of Risk	Amount of Losses (L)
qualitative	1
qualitative, operational	2
qualitative, operational, financial	3
qualitative, operational, ecological, financial	4

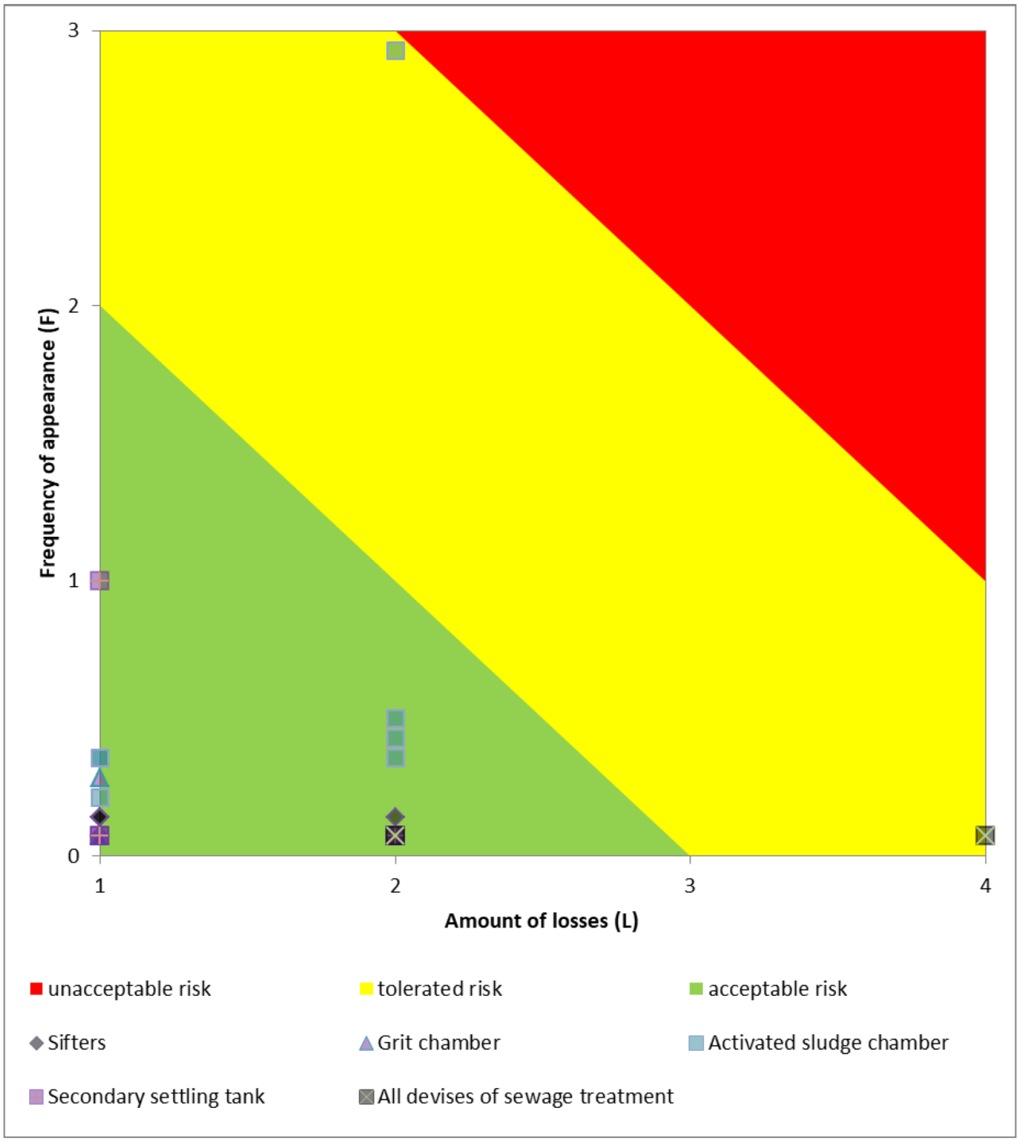

Figure 3. The risk map divided into technological line devices, taking into account the risk hierarchy.

The green color in Figure 3 is an acceptable risk area—these are events that do not require a reaction from the operator, and their effects are removed during the normal work of the personnel. The area of tolerated risk is marked in yellow; these events require a response from the staff, but those actions do not have to be taken immediately. The unacceptable risk area is represented by the red color, corresponding to the events that require immediate response from staff and relevant services, regardless of cost. Figure 3 presents 32 events that occurred 114 times. Almost all of the identified hazards are in the area of acceptable risk (30 events that occurred 72 times [28]), which proves the proper functioning of the municipal wastewater treatment plant. Only two events (emergence of filamentous bacteria in an activated sludge chamber, which occurred 41 times, and electrical power outage, which occurred once [28]), posed a greater threat to operation of the treatment plant, and therefore, they are in the area of tolerated risk.

The activated sludge chamber, where a tolerated risk event occurred, is a technological device, responsible for biological wastewater treatment. It works under variable loads of pollutant and under conditions of variable hydraulic loads. This device should be under strict control and supervision. The identified disruption of work in the activated sludge chamber was caused by the emergence of filamentous bacteria. The bacteria, analyzed in 2015, often appeared due to attempts to improve working conditions in the chamber and the testing of new technological solutions. This is an example of an attempt to modernize, which was not preceded by a risk analysis and gave the operator more problems than benefits.

Another event where the risk was tolerated was for the whole treatment plant. The recorded event concluded in a power failure to the entire facility. Such an event causes a great threat to the proper functioning of the treatment plant and may led to environmental contamination. In the case of the analyzed treatment plant, this did not occur because the facility was equipped with a power generator, and during the failure, strategic devices of the process line were working.

We conducted a similar study for another sewage treatment plant [27] (SWT-2). In comparison with the treatment plant presented in this paper (SWT-1), there were bar screens instead of sifters, and SWT-2 carried out a chemical dephosphatation process that does not occur at SWT-1. No events for sifters were classified as a tolerated risk for bar screens; there were two such events that occurred 14 times (large fat and meat dump that occurred once and clogging of bars that occurred 13 times [27,28]). In both cases, one event in the activated sludge chamber was classified as a tolerated risk. In SWT-1, it was the emergence of filamentous bacteria that occurred frequently (41 times) with a small number of losses (2). While in SWT-2, it was a problem with the agitators and aeration rotors that occurred once but with a very high number of losses (4) [27]. Thus, events with very different frequencies and different numbers of losses may have a similar level of risk.

For the process of chemical dephosphatation in SWT-2, one event occurred 14 times: sludge floated on the surface of the dephosphatation chamber [27,28]. This did not happen in SWT-1 because there was no dephosphatation chamber in the technological line.

In the case of SWT-2, there were also two events classified as tolerated risk—the dump of greasy wastewater in the grit chamber and auxiliary device failure of the clarifier [27,28]. The dumping of greasy wastewater into the grit chamber was also reported in SWT-1, but in this case, it was classified as an acceptable risk because it occurred more frequently (once in SWT-1 but eight times in SWT-2 [27,28]). The auxiliary device failure of the clarifier did not occur in SWT-1. Based on these analyses, it can be concluded that SWT-1 is more reliable than SWT-2.

4. Conclusions

The analyzed municipal sewage treatment plant functions properly—none of the identified threats were classified as an unacceptable risk area. In addition, only two events were in the area of tolerated risk. The remaining 112 irregularities that occurred in the three-year period analyzed were events of acceptable risk—everyday risk. These are minor irregularities in the operation of individual devices that a well-trained crew can easily handle in the course of normal operations.

The proposed risk assessment method is only adequate for sites that have complete and good-quality historical data (detailed, consistently described, regularly collected), because it is based on risk identification. Assigned, on the basis of previously performed identification, weights for individual frequency of occurrence and the start size, determined on the basis of the type of risk, were correctly selected, which we concluded after identifying an adequate events distribution on the risk map (Figure 3).

Research to date has focused on risks associated with environmental pollution with chemicals and their impact on the functioning biological part of a sewage treatment plant and on the effects of discharge of such treated wastewater to receivers (rivers) [9–13]. In the framework of a larger project, this article presents only a fragment of research, the purpose of which is to look at sewage treatment plants as one organism. Based on the results obtained, the next stage of research is to develop appropriate weights for individual technological line devices. They will be assigned to individual devices based on their impact on the quality of treatment plant operations. These weights are necessary to define strategies to minimize risks and to prepare the risk management procedures in sewage treatment plants. The introduction of procedures, which are going to be developed, will facilitate the management of municipal wastewater treatment plants. Currently, there is a lack of unified procedures for managing risk at sewage treatment plants.

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EXHIBIT B

RISK ASSESSMENT SCORING RUBRIC – METHOD 1

Each treatment component was provided with a likelihood score. The modes of failure and frequency of failure were assessed qualitatively, then the results of this qualitative assessment were matched with the information in Table B-1, and the corresponding likelihood score was tabulated and included in the final scoring equation.

TABLE B-1

Method 1 Likelihood Scoring Rubric

Frequency Scoring		
Score	**Likelihood**	**Expected Frequency**
1	Rare	May only occur in exceptional circumstances.
		Simple process.
		No previous incidence of noncompliance or poor performance.
2	Unlikely	Could occur at some time (<25%).
		Noncomplex process.
		Existing system of checks and balances.
3	Possible	Might occur at some time (25%–50%).
		Previous issues with noncompliance and poor performance.
		Complex process with extensive checks and balances.
		Impacting factors outside of owner control.
4	Likely	Will probably occur in most circumstances (50%–75%).
		Complex process with some checks and balances.
		Impacting factors outside of owner control.
5	Almost Certain	Can be expected to occur in most circumstances (>75%).
		Complex process with minimal checks and balances.
		Impacting factors outside of owner control.

Each treatment component was provided with a severity score. The impacts of a potential failure were assessed qualitatively, then the results of this qualitative assessment were matched with the information in Table B-2, and the corresponding severity score was tabulated and included in the final scoring equation.

TABLE B-2

Method 1 Severity Scoring Rubric

Severity Scoring				
Score	**Personnel Injury/Illness**	**Equipment Loss**	**Down Time**	**Environmental Effects**
1	Minor First Aid	<$1K	1 day	Immediate term (<1 month). Minimal damage. Insignificant public image damage.
2	Minor Injury (<1 week)	$1K–$50K	2–3 days	Brief term (1–6 months). Minor damage. Minor public image damage.
3	Major Injury (1–2 weeks)	$50K–$250K	4–7 days	Short term (6–12 months). Some damage. Moderate public image damage.
4	Severe Injury (>2 weeks)	$250K–$1M	8–30 days	Medium term (1–5 years). Moderate damage. Significant public image damage.
5	Long-Term Injury or Death	>$1M	>30 days	Long term (>5 years). Significant damage. Severe public image damage.

The likelihood and severity scores were multiplied to achieve a final score. This final score was then color coded for the risk level (high, moderate, low, minimal) based on the range of scores shown in Table B-3.

TABLE B-3

Method 1 Combined Risk Assessment Scoring Rubric

Scoring Template						
Frequency	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
		Severity				

EXHIBIT C

RISK ASSESSMENT SCORING RUBRIC – METHOD 2

The effective life for various components is assigned. This effective life plays a role in scoring the Probability of Failure described below.

TABLE C-1

Method 2 Effective Life Scoring Rubric

Effective Life (years)	Asset Type
100	Sewers
75	Civil
60	Pressure Pipe
40	Pumps
35	Motors
30	Buildings
30	Valves
30	Electrical
25	Controls

Each treatment component was provided with a physical condition grade. The component's physical condition qualitatively, based on their current condition as well as the condition listed in the Assessment Report, then the results of this qualitative assessment were matched with the information in Table C-2, and the corresponding physical condition grade was tallied.

TABLE C-2

Method 2 Physical Condition Scoring Rubric

Grade	Condition	Remaining Life	Definition
1	Excellent	90%	Asset is like new, fully operable, well maintained, and performs consistently at or above current standards. Little wear shown and no further action required.
3	Good	75%	Asset is sound and well maintained but may be showing some signs of wear. Delivering full efficiency with little or no performance deterioration. Virtually all maintenance is planned preventive in nature. At worst, only minor repair might be needed in near term.
5	Moderate	50%	Asset is functionally sound, showing normal signs of wear relative to use and age. May have minor failures or diminished efficiency and some performance deterioration. Likely showing modest increased maintenance and/or operations costs. Minor to moderate refurbishment may be needed in the near term.
7	Poor	25%	Asset functions but requires a sustained high level of maintenance to remain operational. Shows substantial wear and is likely to cause significant performance deterioration in the near term. Near term scheduled rehabilitation or replacement needed.
9	Very Poor	10%	Very near end of physical life. Substantial ongoing maintenance with short, recurrent maintenance intervals required to keep the asset operational. Unplanned corrective maintenance is common. Renewal (refurbish or replacement) is expected in near term.
10	Failing	0%	Effective life exceeded and/or excessive maintenance cost incurred. A high risk of breakdown or imminent failure with serious impact on performance. No additional life expectancy; immediate replacement or rehabilitation needed.

Each treatment component was provided with a Consequence of Failure (CoF) score. The impacts of a potential failure were assessed qualitatively, then the results of this qualitative assessment were matched with the information in Table C-3, and the corresponding CoF score was tabulated and included in the final scoring equation.

TABLE C-3

Method 2 CoF Scoring Rubric

Rating	Description	Level Affected	Percent Affected
1	Minor Component Failure	Asset	0%–25%
2	Major Component Failure	Asset	25%–50%
3	Major Asset	Asset	0%–25%
4	Multiple Asset Failure	Facility/Subsystem	25%–50%
5	Major Facility Failure	Facility	50%–100%
6	Minor System Failure	Total System	20%–40%
7	Medium System Failure	Total System	40%–60%
8	Intermediate System Failure	Total System	60%–80%
9	Significant System Failure	Total System	80%–90%
10	Total System Failure	Total System	90%–100%

Each treatment component was provided with a Probability of Failure (PoF) score. The potential for failure were assessed qualitatively, then the results of this qualitative assessment were matched with the information in Table C-4, and the corresponding PoF score was tabulated and included in the final scoring equation.

TABLE C-4

Method 2 CoF Scoring Rubric

Rating	% of Effective Life Consumed
1	0%
2	10%
3	20%
4	30%
5	40%
6	50%
7	60%
8	70%
9	80%
10	90%

The reduction factor accounts for any redundancy already in place. For example, if two pumps are present, then failure of a single pump does not prevent the WTP from providing water service. If redundancy exists for a particular treatment component, then the PoF score described above is reduced by the factors listed in Table C-5.

TABLE C-5

Method 2 PoF Reduction Factor Scoring Rubric

Reduce PoF by	Level of Redundancy
50%	50% Backup
90%	100% Backup
98%	200% Backup

The renewal strategy is a qualitative assessment for the overall risk score of a particular asset. T covers a range from no action to complete replacement and provides a qualitative recommendation for additional methods to addressed shortcomings or issues associated with a particular treatment component. These strategies are summarized in Table C-6.

TABLE C-6

Method 2 Renewal Strategies Scoring Rubric

Option	Description	Type
1	Do Nothing	Non-Capital
2	Continue with Status Quo	Non-Capital
3	Maintain Differently	Non-Capital
4	Operate Differently	Non-Capital
5	Repair	Capital
6	Refurbish	Capital
7	Replace with Similar Asset	Capital
8	Replace with Improved Asset	Capital
9	Reduce Levels of Service	Non-Asset