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PUMP STATIONS CONDITION ASSESSMENT AND REHABILITATION PLAN IN EDMONTON

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Abstract: The City of Edmonton Drainage Services Branch operates the Sanitary Utility (collection and transmission of wastewater) and the Land Drainage Utility (collection and transmission of stormwater). The sewer collection and conveyance systems are extensive, valuable, and complex systems that consist of pipelines, outfalls, pumping stations, forcemains, stormwater management facilities, and other facilities. Pump stations are important assets that provide conveyance service to city's neighbourhoods. The city of Edmonton currently has 88 pump stations including 64 sanitary pump stations, 3 combined stations, 13 storm stations and 4 dual stations (i.e. Both sanitary and storm stations are in the same building). More than 70% of pump stations are older than 20 years. Aging of the pump stations and growing risk for deterioration, leaking and odour issues is inevitable. Maintaining an acceptable level of environmental protection and service requires rehabilitation of the pump stations on an on-going basis. In order to meet the requirement, an assessment tool has been developed and used for condition assessment of pump stations. The tool is a risk-based approach considering both the likelihood and consequence of asset failure. 88 pump stations were assessed in this study. The results show that 93% of the pump stations are in good or fair condition. Based on the prioritization list, a rehabilitation plan has been developed for future years. The assessment provides the best information for determining and prioritizing pump stations rehabilitation needs.

1 BACKGROUND

1.1 Pump Station Inventory

Eighty-eight (88) pump stations were analyzed in this study. The following is a brief description of the pump stations based on the drainage database DRAINS (Drainage Inventory Network System).

1.1.1 Waste Type Distribution of Pump Stations

Table 1: Waste type distribution of pump stations

Waste Type	Numbers	Percentage
Combined	3	3.4%
Sanitary	68	77.3%
Storm	17	19.3%
Total	88	100.0%

As can be seen from table1, sanitary pump stations make up the majority of total numbers. Combined sewer pump stations are only about 3.4% of the total numbers even though the combined sewer area is about 20% of the total area in Edmonton.

1.1.2 Age Distribution of Pump Stations

Table 2: Age distribution of pump stations

Age Range (Years)	Numbers	Percentage
< 10 Years	16	18.2%
10 - 20 Years	22	25.0%
21- 34 Years	23	26.1%
35 -50 Years	19	21.6%
> 50 Years	8	9.1%
Total	88	100.0%

It can be seen from table 2 that more than 56.8% of the pump stations are older than 20 years. The average age of pump stations is 25.5 years.

1.1.3 Size Distribution of Pump Stations

Table 3: Size (horsepower) distribution of pump stations

Size Range	Horsepower	Numbers	Percentage
XS (Very small)	1 - 4.9	8	9.1%
S (Small)	5 - 24.9	38	43.2%
M (Medium)	25 - 49.9	26	29.5%
L (Large)	50 - 99.9	10	11.4%
XL (Very Large)	100 - 1000	6	6.8%
Total		88	100.0%

The table shows that small and medium size pump stations make up about 70 % of total pump stations. 6.8% of stations are very large size and 9.1% of stations are very small size stations.

2 CONDITION ASSESSMENT

2.1 Assessment Tool

A risk -based assessment tool has been developed in order to assess pump stations condition. Risk is expressed as:

Risk = Likelihood x Consequence

Pump stations are broken down into 6 major components:

- Site and Building (Fencing, building, hatches, etc.)
- Sub-Structure (Wet well, dry well, storage tank, etc.)
- Pipework & Valves
- Pumps & Motors
- Controls & Comms (panel/SCADA)
- Power

The likelihood of failure of each component is assessed through the use of 4 Condition Grades:

- Physical Condition (PC)
- Functional Condition (FC)

• Capacity Condition (CC)

• Safety Condition (SC)

Table 4 shows the likelihood matrix that is used for the assessment tool. The 5 point scale was used for the likelihood scores: A or 1=Very Good, B or 2=Good, C or 3=Fair, D or 4=Poor, F or 5=Very Poor.

Table 4: Likelihood matrix for pump stations

Rating	1	2	3	4	5
	Very Good	Good	Fair	Poor	Very Poor
Physical Condition	Excellent or "as new" physical condition. Only normal routine maintenance required to keep the asset operational	Good physical condition. Element shows only minor deterioration. Minor maintenance work or operational "prop up" actions required to keep the element operational.	Fair physical condition. Moderate deterioration evident. Significant ongoing maintenance and/or operational "prop up" actions required to keep element operational.	Poor condition. Major deterioration evident. Extensive ongoing maintenance and/or operational "prop up" actions are required to keep the element operational.	Very Poor condition. Element deteriorated to such an extent that it is generally inoperable or unsafe. History of failures. Immediate need to replace most or the entire element.
Functional Condition	Design and function are fully aligned with current purpose. Fully satisfies all current statutory and/or internal standards and requirements. Very high confidence that spares are readily available. All necessary O&M work can be undertaken with standard approaches.	Generally satisfies all current statutory and/or internal standards and requirements although there may be some minor non-compliances. High confidence that spares are readily available. Necessary O&M work may require some minor work arounds.	The asset satisfies current statutory and/or internal standards and requirements in most areas although there may be a few significant shortcomings. May have moderate efficiency shortcomings. Some doubts over spares availability. Necessary O&M work can involve significant work arounds but can be addressed through advanced planning.	Significant non compliance with current design standards and/or policies and requirements. Long lead times for spares or special sourcing requirements. Necessary O&M work involves tightly planned and controlled work arounds due to shortcomings.	Major non-compliances with current statutory and/or internal policies and standards and requirements. Unacceptable lead time for spares or spares now unavailable. Necessary O&M work presents serious increased risks and involves major/emergency planning and mobilization of significant additional resources.
Capacity Condition	The element is sized appropriately for all foreseen needs and/or has capacity to comfortably deal with demands expected over the next 20 years	The element is generally sized appropriately with only minor concerns/issues and/or has capacity to deal with demands over the next 10-15 years	The element has some moderate size related concerns/issues which can typically be worked around at extra cost/time and/or has capacity to deal with demand over the next 5-10 years	The element has major size related concerns/issues that require significant costs/time to work around and which introduce additional risks and/or has capacity to deal with demand over the next 2-3 years	The element has major size related concerns which are extremely problematic to work around, or has a history of causing major failures/costs and/or is already consistently operating at the limits or in excess of its design parameters and/or is incapable of meeting current demand
Safety Condition	A person who succumbed to this hazard would be very unlikely to be sustain serious injury or worse	A person who succumbed to this hazrard would be unlikely to sustain serious injury or worse	A person who succumbed to this hazrard would be as likely as not to sustain serious injury or worse	A person who succumbed to this hazrard would probably sustain serious injury or worse	A person who succumbed to this hazrard would be almost certain to sustain serious injury or worse

In the event of a pump station failure there are generally two possible negative outcomes:
a. Spill to a water body
b. Flooding to land/property

A consequence matrix was developed as shown in table 5. The 5 point scale was used for the consequence scores: 1=Very Low, 2=Low, 3=Moderate, 4=High, 5=Very High.

Table 5: Consequence matrix for pump stations

Rating			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
Service Consequences	Spills	Available Storage	>24 hours	12-24 hours	8-12 hours	4-8 hrs	< 4 hrs
		Spill Type	River downstream of City	In City downstream of WTP	In City upstream of WTP	Creek or ravine	Highly visible location
		Catchment Type	Residential		Commercial		Industrial and/or Animal Waste
	Flooding	Available Storage	>24 hours	12-24 hours	8-12 hours	4-8 hrs	< 4 hrs
		Flooding Type	Flooding of unused industrial areas	Local Road Flooding	External flooding to Residential areas	External flooding of Sensitive Customers	Internal / Basement Flooding
		Catchment Type	Predominantly Residential	Mixed Residential and Commercial	Predominantly Commercial	Mixed Commercial and Industrial	Predominantly Industrial and/or Animal Waste
		Safety	Negligible/Minor injury - requiring minor first aid only	Medical intervention and potential time loss	Serious - reportable accident e.g. requiring medical intervention or hospitalization and time loss	Major injury involving long term disability or illness	Single or Multiple fatalities

2.2 Risk Calculation

In order to calculate Pump Station Service Risk, inspections for each pump station were completed to determine PC, FC and CC scores. The PC, FC and CC scores then were combined into an overall Likelihood score. Table 6 shows the weighting factors for each component.

Table 6 Weighting the Components

Component	Weights			
	PC	FC	CC	Component
Site and Building	1	1	1	0.7
Sub-Structure	1	1	1	0.8
Pipework and Valves	1	1	1	1
Pumps and Motors	1	1	1	1
Communications	1	1	1	0.9
Power	1	1	1	1

For each component, there are 3 separate scores for PC, FC and CC. These 1-5 (Very Good to Very Poor) assessments are then mapped to a 1-10 score which reflects the non-linear nature of likelihood of failure (table 7).

Table 7 Likelihood Scores

LH Scores	
1	1
2	2
3	4
4	7
5	10

The PC, FC and CC scores, combined with the above weightings then give an overall Component Service Likelihood score. All six component likelihood scores are then combined to give an overall Pump Station Service Failure Likelihood score. An example of calculations is shown in table 8.

Table 8 Worked example of Likelihood

Component	**PC**	**FC**	**CC**	**Base Score (excluding Component Wt)**	**Adjusted for Component Wt**
Site and Building	1	3	1	(1/10)+(4/10)+(1/10)/3 = 0.6/3 = 0.2	0.7 * 0.2 = 0.14
Sub-Structure	3	5	5	(4/10)+(10/10)+(10/10)/3 = 2.4/3 = 0.8	0.8 * 0.8 = 0.64
Pipework & Valves	3	3	3	(4/10)+(4/10)+(4/10)/3 = 1.2/3 = 0.4	0.4 * 1 = 0.4
Pumps & Motors	2	3	2	(2/10)+(4/10)+(2/10)/3 = 0.8/3 = 0.27	0.27 * 1 = 0.27
Controls & Comms	4	1	4	(7/10)+(1/10)+(7/10)/3 = 1.5/3 = 0.5	0.5 * 0.9 = 0.45
Power	5	5	5	(10/10)+(10/10)+(10/10) = 3/3 = 1	1 * 1 = 1
				Total	2.9/6 = 0.483

Each pump station was considered and determined as either a “spill” or “flood” consequence type. Each of the appropriate three consequence categories was then assessed to best represent the overall consequence of failure at that station. As per the Likelihood scoring, table 9 shows that the 1-5 assessment is mapped to a 1-10 consequence score. The relevant three scores (for spills or flooding) were then summed to give a total consequence out of a maximum of 30.

Table 9 Consequence Scores

		Consequence Scores				
		VL	L	M	H	VH
Spills	Available Storage	1	2	4	7	10
	Spill Type	1	2	4	7	10
	Catchment Type	1	2	4	7	10
Flooding	Available Storage	1	2	4	7	10
	Flooding Type	1	2	4	7	10
	Catchment Type	1	2	4	7	10

As an example, a station has “12-24 hours” storage, spills “in city upstream of WTP (Wastewater Treatment Plant)” and is a primarily an “Industrial” catchment. The total consequence score is 2+4+10 =16.

Strategic Importance Factors (SIFs) are used to reflect other factors that may significantly influence the consequence of failure but cannot generally be captured in standard consequence matrix. SIFs provide % uplift on the overall consequence. Table 10 shows the SIFs and associated % uplifts.

Table 10 Strategic Importance Factors

SIF		**Value**
No Temp Pumping	Temporary pumping is not possible in the event of failure	25%
End of Chain	Failure of this pump station will cause knock-on effects at others	10%
Odour	Station is/may be particularly susceptible to odour complaints	5%
High Opex	Station requires comparatively high O&M costs (i.e. it is propped up)	5%

If the example station had no temp pumping, the previously scored consequence (16) would receive an uplift of 25%. The Uplifted Service Failure Consequence is therefore 16*1.25 = 20.

Pump station size (horsepower) is also taken into account by factoring up the Uplifted Service Failure consequence on the basic logic that a larger spill is worse than a smaller spill. Size is based on the firm capacity expressed in Pump HP. Table 11 is used to categorize various firm capacities into five size bands and attribute an appropriate size band weighting.

Table 11 Pump Station Size Bands

	Firm Capacity			
Size Band	**Min**	**Max**	**Band**	**Weight**
Very Small	1	4.9	XS	0.8
Small	5	24.9	S	1
Medium	25	49.9	M	1.25
Large	50	99.9	L	1.5
Very Large	100	1000	XL	1.75

The Size Band Weighting is applied to the Uplifted Service Failure Consequence to give a Total Consequence score for the station. Continuing the previous example, if the station has total installed capacity of 80 HP and 2 pumps in standard duty/standby arrangement then firm capacity would be 40 HP. This 40 HP firm capacity would constitute a “medium” station and would therefore attract a weighting of 1.25. The Total Pump Station Service Failure Consequence is then 20*1.25 = 25.

Pump Station Service Risk is the product of Pump Station Service Failure Likelihood and Total Pump Station Service Failure Consequence.

Based on the above example calculations: Pump Station Service Risk = 0.483 * 25 = 12.08.

2.3 Assessment Results

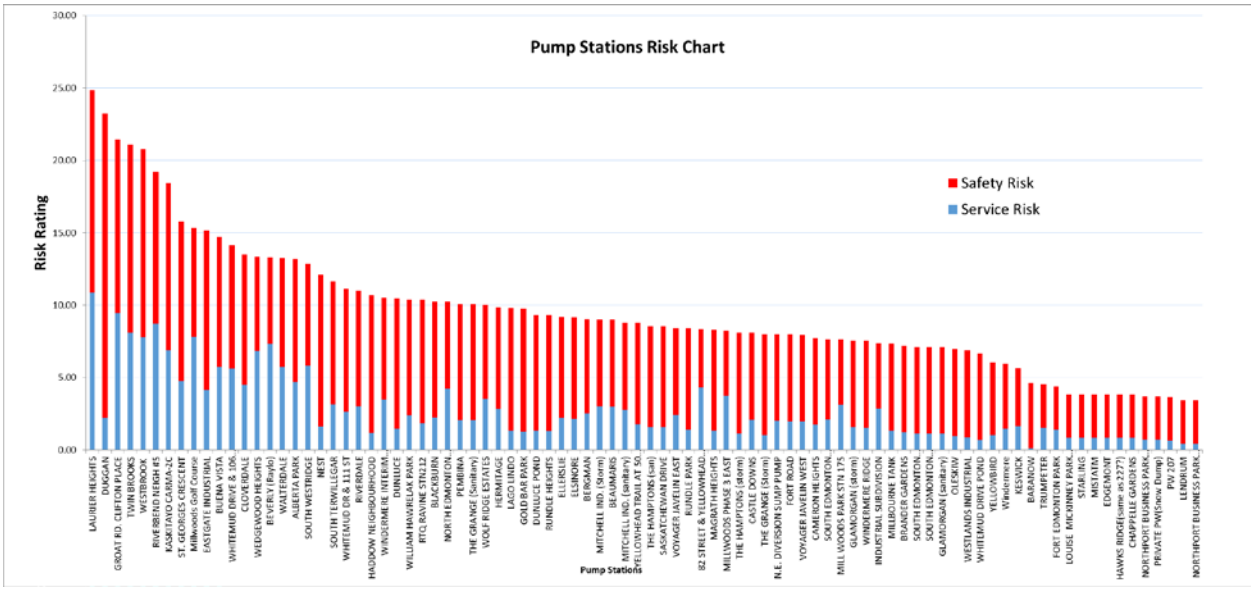

Figure 1: Risk of pump stations

Figure 1 shows the total risks of pump stations that are combined service and safety risks. The highest risk score is 24.87 and the lowest risk score is 5. This chart can be used to prioritize the pump station that need to be rehabbed or maintained.

3 REHABILITATION PLAN

3.1 Pump Stations Rehabilitation Scenarios Analysis

The Assessment tool (criticality model) is used as a short term capital (3-5 years) maintenance planning process. Scored Criticality parameters (PC, FC, CC and SC) together with the current Criticality Score and expected Criticality Score upon completion of the proposed works should be included in a business case which supports any request for expenditure. Currently Drainage Design and Construction manages the pump stations upgrade program. The purpose of the rehabilitation plan is to better predict and plan for expenditure aimed at maintaining current levels of service of existing pump stations. A 4-year rehabilitation plan is developed for this project.

The pump stations in the city of Edmonton should have a performance goal of achieving an overall 3 or lower (fair or good) condition rating of 90%. According to the current 88 pump stations condition assessments (figure 2, figure 3 and figure 4), 7% overall physical condition is in poor condition. 93% of overall physical condition is fair and good. In addition, 89% of overall functional condition is fair and good.

99% of overall capacity condition is fair and good. The overall functional condition is slightly lower than 90%. The physical and capacity overall conditions meet the goal but in the future years pump stations that are currently rated in the fair conditions (Rating is 3) will possibly drop into the poor condition category. Therefore, there is a need to have a rehabilitation plan for pump stations to reach the performance goal.

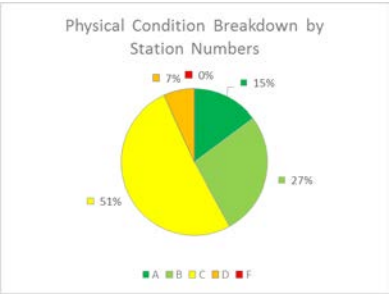

Figure 2: Physical condition

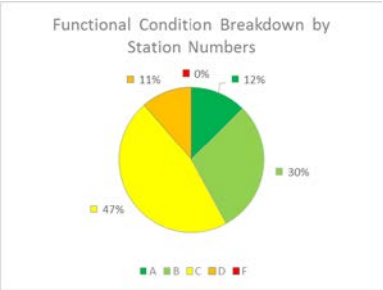

Figure 3: Functional condition

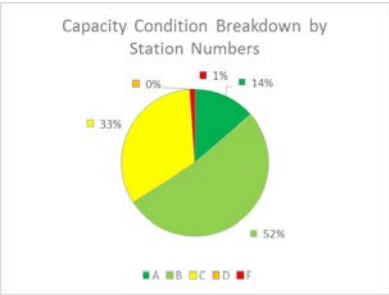

Figure 4: Capacity condition

Pump stations rehabilitation prioritization has been completed according to the risk ranking and condition ratings (in poor and very poor condition). Based on the risk analysis, the overall service and safety risk index(RI) for the top 50 pump stations is 11.71.The maximum risk index is 24.87. The number of pump station in each condition is shown in table 12.

Table 12: Risk index prior to rehabilitation

Risk index	RI: <10	RI: 10 - 14	RI:15-20	RI:21-25	RI: >25
Number of pump Stations	22	18	6	4	0

Two scenarios were used for the analysis for pump stations rehabilitation. Scenario one was done by upgrading condition rating from C, D, F to A (replacement) with cost equivalent to replacement cost; Scenario two was done by upgrading condition rating from C,D to B (rehabilitation) with cost equivalent to 60% of replacement cost and also from F to A with replacement cost.

3.1.1 Scenario one results:

Figure 5 shows the new service and safety risk index before and after replacement through scenario one.

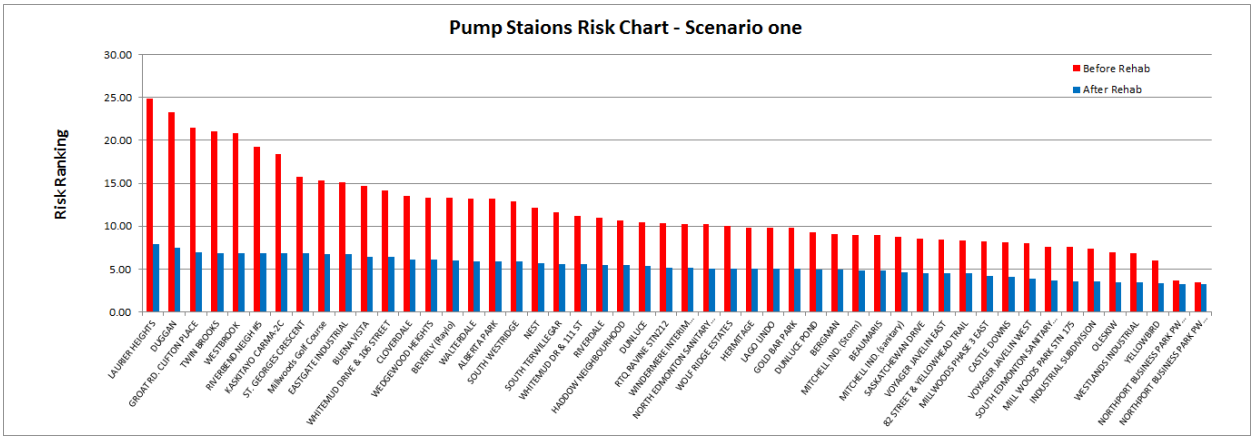

Figure 5 Pump station risk scenario one analysis

The number of pump station in each condition for scenario one is shown in table 13. The all pump stations risk will be below 10. There will be 19 stations that are less than risk index 5 and 31 stations risk index are between 5 and 10.

Table 13: Risk index after scenario one rehabilitation

Risk index	RI: <5	RI: 5 - 10	RI:11-20	RI:21-25	RI: >25
Number of pump Stations	19	31	0	0	0

3.1.2 Scenario two results:

Figure 6 shows the new service and safety risk index before and after replacement through scenario two. The number of pump station in each condition for scenario two is shown in table 14. There will be 9 stations that are less than risk index 5 and 41 stations risk index are between 5 and 10.

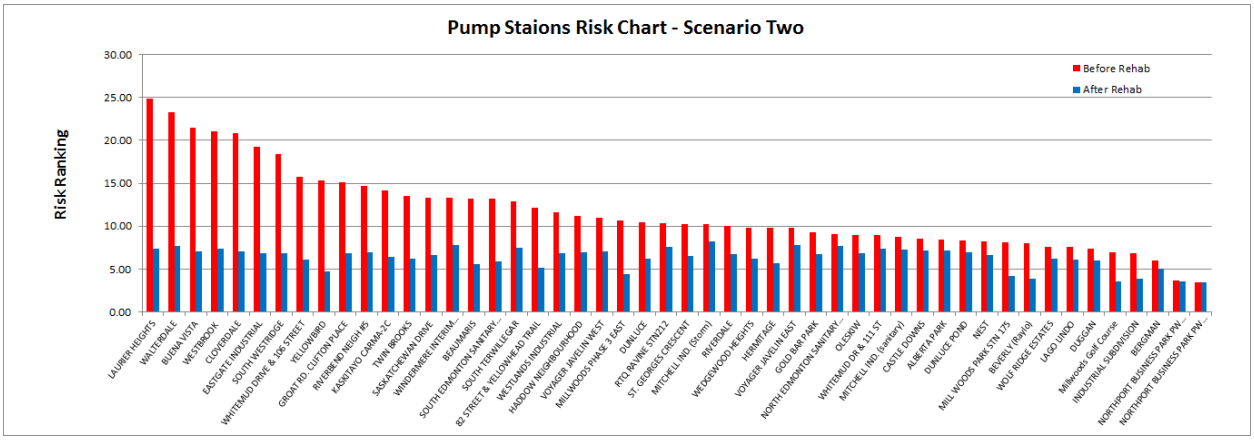

Figure 6 Pump station risk scenario two analysis

Table 14: Risk index after scenario two rehabilitation

Risk index	RI: <5	RI: 5 – 10	RI:11-20	RI:21-25	RI: >25
Number of pump Stations	9	41	0	0	0

3.2 Rehabilitation Plan

Based on the scenarios analysis, both scenarios meet the requirement of pump stations condition in the future years. Scenario two is used for rehabilitation plan in this study. Table 15 is the prioritization list for 4 years rehabilitation plan.

Table 15: Pump station rehabilitation plan

Station ID	Waste Water Type	Size Band	Risk	Risk After Rehab	Risk Reduction	Rehab Cost ($)
111	SANITARY	L	24.87	9.84	15.03	$2,249,100
105	SANITARY	L	23.23	7.03	16.20	$2,249,100
113	SANITARY	S	21.44	7.5	13.94	$559,980
163	SANITARY	L	21.09	7.39	13.70	$1,432,080
102	SANITARY	M	20.79	8.81	11.98	$1,255,824
140	SANITARY	M	19.22	8.25	10.97	$1,180,854
104	SANITARY	M	18.41	7.88	10.53	$1,255,824
112	SANITARY	XS	15.78	7.52	8.26	$499,025
172	SANITARY	S	15.33	5.1	10.23	$447,984
141	SANITARY	S	15.15	7.44	7.71	$901,017

4 CONCLUSION

Aging of the pump stations and growing risk for deterioration is an issue in Edmonton. An assessment tool has been developed and used for City of Edmonton's pump stations condition assessment. The study shows that the tool can provide good information for determining and prioritizing pump stations rehabilitation needs. According to the current 88 pump stations condition assessments, 7% of overall physical condition are in poor condition. In addition, 89% of overall functional condition is fair and good. 99% of overall capacity condition is fair and good.

Two scenarios of rehabilitation and replacement were analyzed and both of them meet the goal of achieving an overall 3 or lower (fair or good) condition rating of 90%. Scenario two is more cost effective and used for future rehabilitation plan.

Acknowledgements

Thanks CH2M HILL for the help in this project. The tool has been developed and used for the top 10 pump stations by the consultant. The rest of the pump stations were assessed by the city's staff, Drainage Services.

References

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Drainage Structures Rehabilitation Prioritization Project (SMA Consulting Ltd, 2014)

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