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Performance Assessment Framework for Small to Medium Sized Water Utilities – A Case for Okanagan Basin

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Abstract: Similar to large water utilities (LWU), small and medium sized water utilities (SMWU) are also facing problems in managing their water infrastructure assets to achieve adequate performance. The first step towards affective asset management is evaluating the existing performance to identify the problematic components (both engineering and management) of a water utility. The participation of SMWU in National Water and Wastewater Benchmarking Initiative (NWWBI) is almost negligible in Canada due to overall less awareness, issues related to data availability, and technical and financial constraints. In present work, an effort is made with the aim of developing a performance assessment (PA) framework for SMWU in Okanagan Basin, British Columbia. The proposed framework includes the most suitable and easy to use performance indicators (PIs) for PA of all the organizational components of SMWU including water resources and environment, personnel, physical assets, quality of service, water quality and public health, and economics and finance. Due to nonparticipation of SMWU in benchmarking processes the calculated values of PIs are compared with the benchmarking relationships developed through literature, NWWBI reports and expert judgment (keeping in view the relatively low economies of scales in SMWU due to shortage of resources as compared to LWU). The framework can be used to estimate the performance level of individual PI between 10 and 100, and then aggregating them to develop the performance indices. The overall PA results are presented in the form of a web diagram with the purpose to demonstrate the utility's performance under each organizational component.

Keywords: Small and medium sized water utilities, Performance evaluation, Water supply System, Water utilities, Performance indicators, Performance assessment.

1 INTRODUCTION

Providing safe drinking water to the public is the main priority of any water utility. Water supply systems (WSSs) are one of the most important components of the Core Public Infrastructure systems. As per NRC (2010), the value of water infrastructure in Canada is approximately 64.5 $ billion. According to CWWA (1997), the estimated investment needs for water infrastructure were 27.3 $ billion for the period between 1997 and 2012. Both the existing conditions and long-term performances of the water infrastructure can be affected by a number of time-varying as well random events, e.g., lack of skilled personnel, aging and deterioration of pipe materials, financial constraints, increased load, population increase, climate change, tremendous rise in cost of the energy, etc. Consequently, the utilities are facing difficulties to meet their primary objectives including, public health and safety, environmental and financial sustainability, water security, customer's satisfaction, and useful remaining service life of the asset (NRC 2010).

In order to achieve the desired objectives, the first step is to evaluate the existing performance of all the organizational components (water resources and environment, personnel, physical assets, operations, water quality and public health, quality of service, and finance) of the water utility using suitable performance indicators (PIs). The general concept of evaluating the performance of a water utility is to compare its performance with established benchmarks (and standards) by the regulatory agencies and through cross-comparison with similar utilities (Alegre et al. 2000). Based on the results of performance assessment, rational decisions towards effective asset management can be taken.

In Canada, small and medium sized water utilities (SMWU) have not been participated in performance benchmarking process so far. This observation is highlighted from Public Report for 2012 of National Water & Wastewater Benchmarking Initiative (NWWBI) in Canada, where 41 LWU (50% of Canadian utilities covering more than 60% of the population) with population more than 50,000 participated in the benchmarking process; whereas, participation of the SMWU was almost negligible (AECOM 2012). The possible reason of SMWU for not being participated in NWWBI seems to be that there is no well-structured performance assessment framework available for SMWU which is simple to implement under given technical and financial constraints. Consequently, the performance benchmarking under such conditions is hard to conduct for SMWU. Therefore, SMWU in Canada are managing their systems (assets) without knowing (quantitatively) whether they are efficiently and effectively meeting their primary goals.

The objective of this paper is to develop a simple (with most relevant PIs) nevertheless comprehensive (covering all organizational components) framework for performance assessment of SMWU in Canada. The proposed framework has also been applied on a case study of a medium sized water utility in Okanagan Basin.

2 BACKGROUND AND METHODOLOGY

A conceptual framework for performance assessment of SMWU is presented in Figure 1. The performance of a water supply system (WSS) can be evaluated by selecting suitable PIs developed by various agencies around the world (Coelho 1997, Alegre et al. 2006, Berg and Danilenko 2011, NWC 2012, AWWA 2004, OFWAT 2012, NRC 2010, ADB 2012). Haider et al. (2013) carried out a state-of-the-art review of the PIs systems developed by these agencies and highlighted 114 potentially suitable PIs through initial screening process using checklist. These 114 indicators were grouped into 7 most commonly used organizational components of a water utility as stated above. Each organizational component corresponds to a certain category of PIs, such as operational, personnel, finance, etc.

Later, Haider et al. (2014) developed a framework used for the selection of most relevant PIs for SMWU. The initially identified 114 PIs were evaluated against a set of 4 criterions (applicability, measurability, understandability, and comparability) to evaluate the suitability of an indicator through multicriteria analysis using ELECTRE method (refer to Figure 1). In result, a set of 58 most relevant PIs covering all the organizational components of SMWU have been identified. The numbers of indicators under each category are shown in parenthesis in Figure 1.

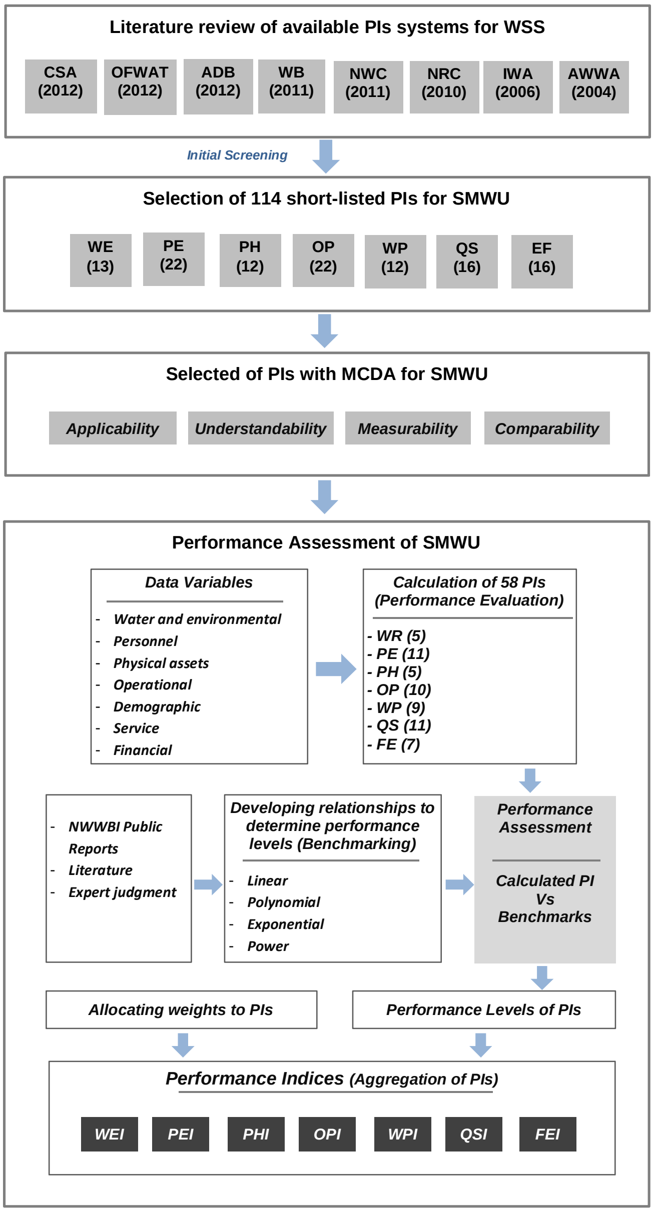


Figure 1: Proposed performance evaluation framework for SMWU

The selected (58) PIs were used to measure the performance of SMWU. The performance indicators are either commensurate or non-commensurate values (percentage or ratio). In order to calculate them, data variables are used either with their absolute values (e.g., average turbidity), or as numerators and denominators (e.g., number of field personnel/ 100km of pipe main). These calculate values of PIs are then compared with the performance benchmarks. How much the calculate value is away from the benchmark (standard) value shows the performance gap. This gap further guides about the decisions required to improve or maintain the existing performance of that particular component of the water utility.

Conventionally, either regression equations of PIs are used for benchmarking process (Sindhe et al. 2013); or a comparison of a particular utility's performance is made with the best and worst value of the indicator as (Stahre et al. 2008);

[1] $$Score"PI" = \left[\frac{(actualPI - value) - (worstPI - value)}{(bestPI - value) - (worstPI - value)} \times 90 + 10 \right]$$

A large data set is required for the first method (regression), which is only possible in case of a large number of participating utilities over long-time. In second method, the equation [1] will produce the performance score ranging between 10 and 100, where 10 for the worst performing utility to 100 for the best performing utility. The equation is suitable only for the cross-comparison, and does not include the even better or even worse performances out of the group of utilities participated in the cross-comparison process. Moreover, the equation [1] follows a straight line which can be misleading to calculate the PI score for average performing utilities. For example, in Figure 2 the performance score for the water utility with average performance (for a particular performance indicator) comes out to be 30 instead of 50 using equation [1].

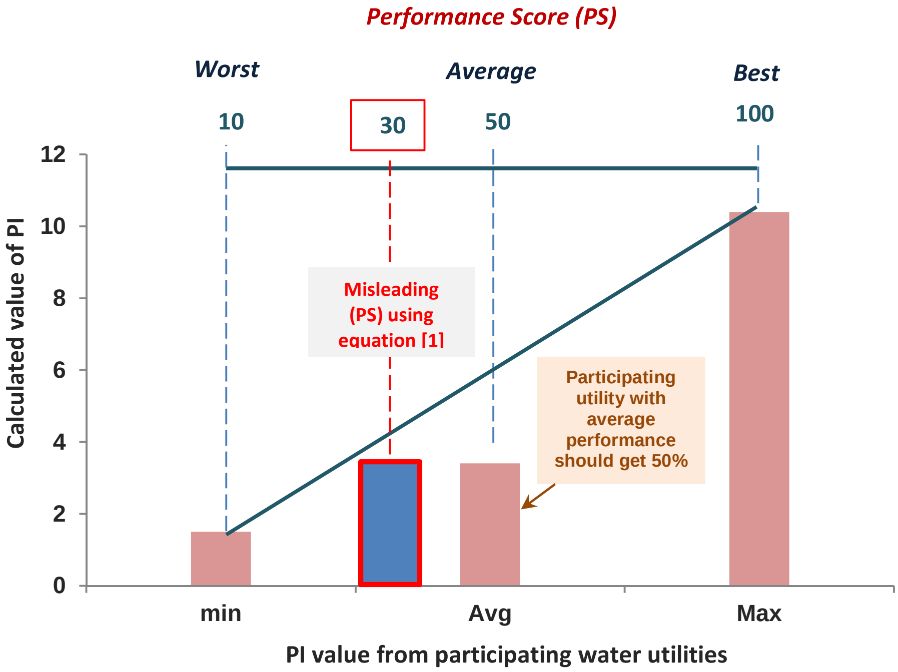


Figure 2: Graphical description of Equation [1]

As mentioned earlier, SMWU in Canada have not been participating in the annual benchmarking process; therefore, an effort has been made in this study to develop rational mathematical relationships (linear, polynomial, logarithmic, and exponential) for performance benchmarking through NWWBI public report for the year 2012, literature, and expert opinion (EO). After developing these relationships, the data of a medium sized water utility with population of less than 50,000 operating in Okanagan Basin, British Columbia has been used to evaluate the performance level (score) for each indicator as a case study.

Subsequently, the calculated performance scores are aggregated by multiplying them with their respective weights to develop performance indices for each organizational category, for example water resources and environmental sustainability index (WEI). The weights to PIs have been allocated using expert judgement and keeping in view the final ranking of the indicators established by Haider et al. (2014) through multicriteria analysis. In this connection, the indicator with higher rank (i.e., more relevant to SMWU) was given relatively higher weight. The sum of weights under each category was ‘1’, so that the value of index should range between 10 and 100.

3. RESULTS AND DISCUSSIONS

The framework presented in Figure 1 has been proposed for the performance assessment of SMWU in Canada. An excel based tool has been developed and also implemented to assess the performance of a medium sized water utility in Okanagan Basin, British Columbia. The overall performance assessment process consists of evaluating the score of each performance indicator using data variables. These values are then used to estimate the performance levels using the benchmarking relationship developed in this study. As these relationships have been developed based on NWWBI reports, literature and EO for initial assessment of SMWU, therefore should not be considered as absolute benchmarks. Moreover, these relationships need to be changed with additional data and a continuous benchmarking process. Finally the performance levels are aggregated to determine the performance indices for the case study. Details regarding development of these relationships, determination of weights and the case study are given in the following.

3.1 Benchmarking relationships for PA

The main purpose of the relationships proposed in Table 1, is to calculate the actual score of the PIs with the intention of avoiding the possibly wrong calculation by just comparing the PI value of the utility under study with the worst and best performing utilities in the benchmarking process (as shown in Figure 2). In most of the relationships presented in Table 1, it can be seen that the reference NWWBI (minimum, median and maximum) values are used after adjustment for expected less economies of scale (EOS) in SMWU. The performance levels are established between 10 and 100 for the development of these relationships.

Two examples of per capita water consumption (a water resources indicator) and service connection repairs (an operational indicator) are shown in Figure 3a&b respectively. In Figure 3a, the values reported in NWWBI public report correspond to large water utilities, where the maximum value of average per capita water consumption for residential consumers has been reported as ‘593’ which could be an average value in case of SMWU. The average daily demand of one person in Okanagan Basin can go up to 900lit/capita/day (AECOM 2012). Therefore, the values are extrapolated with an expert opinion to develop relationship for performance benchmarking of SMWU keeping in view the relatively lower rates and higher water consumptions (due to lower treatment levels, higher water availability, less population, etc.) (Figure 3a). In the other example of an operational indicator (i.e., percentage of service connection repairs annually), the minimum, median, and maximum values reported in NWWBI 2012 public report were found to be rational for SMWU. However, the relationship was found to be logarithmic, instead of a linear function.

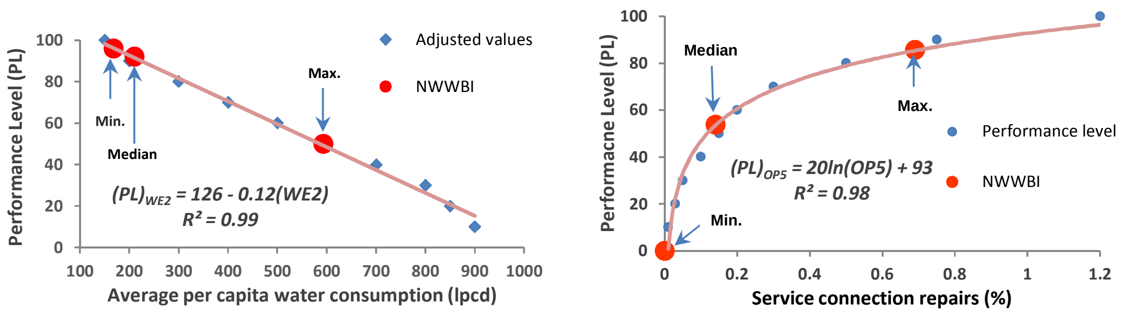
If the indicators performance levels were not found in NWWBI report and the indicators were found to be important for SMWU, the literature values were used to serve he purpose. For instance, water main breaks in a year is one of the most important indicator with respect to customers satisfaction and asset management but has not been considered in NWWBI annual reports.

Table 1: Relationships developed for performance benchmarking for SMWU

PI #	Description of PI	Relationship type	Benchmarking relationship	R^2	Sources
1.	**WATER RESOURCES AND ENVIRONMENT**				
WE 1	No of days with water restrictions	Linear	$(PL)_{WE4} = 0.26(WE4)+10$	0.99	NWWBI <adj> EOS
WE 2	Per capita water consumption - domestic	Linear	$(PL)_{WE2} = 126 - 0.12(WE\ 2)$	0.99	NWWBI <adj> EOS
WE 3	Remaining annual water licence capacity	Linear	$(PL)_{WE1} = 100 -1.13\ (WE\ 1)$	0.99	NWWBI <adj> EOS
WE 4	Disposal of residuals from WTP	Polynomial	$(PL)_{WE3} = 0.11(WE3)^2 - 0.62(WE3)+100$	0.99	NWWBI <adj> EOS
WE 5	Impact of residual chlorine in flushing water on aquatic life	Polynomial	$(PL)_{WE5} = 5 +6.7(WE5) - 0.12(WE5)^2$	0.98	EO + Literature
2.	**PERSONNEL**				
PE 1	Field FTEs - Distribution	Polynomial	$(PL)_{PE2} = 21(PE2)-1.04(PE2)^2 - 8$	0.99	NWWBI
PE 2	Field FTEs - Metering	Linear	$(PL)_{PE4} = 954(PE4) + 10$	0.99	NWWBI
PE 3	Field accidents -Distribution	Polynomial	$(PL)_{PE6} = 0.073(PE6)^2 - 5(PE6)+100$	0.99	NWWBI <adj> EOS
PE 4	Sick days taken by FTEs - Distribution	Linear	$(PL)_{PE8} = 100- 5(PE8)$	0.99	NWWBI
PE 5	Field FTEs - Treatment	Polynomial	$(PL)_{PE3} =130(PE3) - 40(PE3)^2+5$	0.99	NWWBI <adj> EOS
PE 6	Field accidents - Treatment	Polynomial	$(PL)_{PE7} = 0.073(PE7)^2 - 5(PE7)+100$	0.99	NWWBI <adj> EOS
PE 7	Sick days taken by FTEs - Treatment	Linear	$(PL)_{PE9} = 100- 5(PE9)$	1	NWWBI <adj> EOS
PE 8	Water resources and catchment management employees	Linear	$(PL)_{PE1} = 862(PE1) + 10$	0.99	EO
PE 9	Overtime of FTEs - Distribution	Polynomial	$(PL)_{PE10} = 0.08(PE10)^2 – 5.3(PE10)+100$	0.99	NWWBI <adj> EOS
PE 10	Overtime of FTEs - Treatment	Polynomial	$(PL)_{PE11} = 0.08(PE11)^2 – 5.3(PE11)+100$	0.99	NWWBI <adj> EOS
PE 11	Personnel training hours	Linear	$(PL)_{PE5} =PE5$	1	EO
3.	**PHYSICAL ASSETS**				
PH1	Treatment plant capacity	Exponential	$(PL)_{PH1} = 100\ e^{-0.022(PH1)}$	0.99	NWWBI <adj> EOS
PH2	Raw water storage capacity	Linear	$(PL)_{PH2} = 0.3(PH2)+8$	0.99	EO
PH3	Treated water storage capacity	Polynomial	$(PL)_{PH3} = 10 - 0.011(PH3)^2+2(PH3)$	0.98	NWWBI
PH4	Metering level	Linear	$(PL)_{PH4} =0.97(PH4)+10$	0.99	EO
PH5	Degree of automation	Linear	$(PL)_{PH4} =0.97(PH4)+10$	0.99	EO
4.	**OPERATIONAL**				
OP1	Number of main breaks	Exponential	$(PL)_{OP8} = 100\ e^{-0.114(OP8)}$	0.99	NWWBI
OP2	Mains replacement	Polynomial	$(PL)_{OP4} =11 – 153(OP4)^2+260(OP4)$	0.99	EO + Literature
OP3	Mains rehabilitation/ renovation	Polynomial	$(PL)_{OP3} =11 – 153(OP3)^2+260(OP3)$	0.98	EO + Literature
OP4	Non-revenue water	Exponential	$(PL)_{OP7} = 100\ e^{-0.003(OP7)}$	0.99	NWWBI
OP5	Service connection rehabilitation	Logarithmic	$(PL)_{OP6} = 20\ ln\ (OP6) +93$	0.97	NWWBI
OP6	Inoperable or leaking hydrants	Exponential	$(PL)_{OP9} = 100\ e^{-1.14(OP9)}$	0.99	NWWBI <adj> EOS
OP7	Valves replacement	Polynomial	$(PL)_{OP5} = 8 – 587(OP5)^2+475(OP5)$	0.99	EO
OP8	Hydrant inspection	Polynomial	$(PL)_{OP2} =2 - 0.014(OP2)^2+2.3(OP2)$	0.95	NWWBI <adj> EOS

Table 1(Cont'd): Relationships developed for performance benchmarking

PI #	Description of PI	Relationship type	Benchmarking relationship	R^2	Sources [a]
OP9	Cleaning of treated water storage tanks	Linear	$(PL)_{OP1} = 0.97(OP1)+10$	0.99	EO
OP10	Operational meters	Linear	$(PL)_{OP10} = OP10$	1	EO
5.	**WATER QUALITY AND PUBLIC HEALTH**				
WP1	Length of mains cleaned	Polynomial	$(PL)_{WP1} = -0.02(WP1)^2 + 2.7(WP1)+10$	0.99	NWWBI <adj> EOS
WP2	Days with boil water advisories	Linear	$(PL)_{WP2} = 100 - 9.7\ (WP2)^2$	0.99	NWWBI + EO
WP3	Average turbidity - Distribution	Polynomial	$(PL)_{WP3} = 2.5(WP3)^2 – 31(WP3)+100$	0.99	NWWBI <adj> EOS
WP4	Total coli occurrences - Distribution	Linear	$(PL)_{WP4} = 100 - 2.3\ (WP4)$	0.99	NWWBI + EO
WP5	Average THMs - Distribution	Exponential	$(PL)_{WP5} = 100\ e^{-6.8\ (WP5)}$	0.97	NWWBI + EO
WP6	Residual chlorine - Distribution	Exponential	$(PL)_{WP6} = 100\ e^{-0.53\ (WP6)}$	0.98	EO
WP7	Average turbidity - Treatment	Exponential	$(PL)_{WP7} = 100\ e^{-2.3\ (WP7)}$	0.99	NWWBI + EO
WP8	Total coli occurrences - Treatment	Linear	$(PL)_{WP8} = 100 - 10\ (WP8)$	0.99	NWWBI + EO
WP9	Nitrates - Treatment	Exponential	$(PL)_{WP9} = 100\ e^{-2.2\ (WP9)}$	0.98	NWWBI + EO
6.	**QUALITY OF SERVICE**				
QS1	Population coverage	Linear	$(PL)_{QS1} = 2.5(QS1) - 140$	1	EO + Literature
QS2	Unplanned interruptions	Exponential	$(PL)_{QS2} = 100\ e^{-0.053\ (QS2)}$	0.98	NWWBI
QS3	Unplanned maintenance hours	Exponential	$(PL)_{QS3} = 100\ e^{-0.023\ (QS3)}$	0.99	NWWBI
QS4	Billing complaints	Linear	$(PL)_{QS4} = 100 - 20\ (QS4)$	1	EO
QS5	Pressure complaints	Exponential	$(PL)_{QS5} = 100\ e^{-0.55\ (QS5)}$	0.95	NWWBI <adj> EOS
QS6	Water quality complaints	Linear	$(PL)_{QS6} = 100 - 20\ (QS6)$	1	NWWBI <adj> EOS
QS7	Service connection complaints	Linear	$(PL)_{QS7} = 100 - 20\ (QS7)$	1	EO
QS8	Total response to complaints	Polynomial	$(PL)_{QS8} = 2.4(QS8) –0.01(QS8)^2 - 53$	0.99	EO
QS9	Aesthetic tests compliance	Polynomial	$(PL)_{QS9} = 2.5(QS9) – 160$	0.99	EO
QS10	Microbiological tests compliance	Polynomial	$(PL)_{QS10} = 2.5(QS10) – 160$	0.99	EO
QS11	Physico-chemical tests compliance	polynomial	$(PL)_{QS11} = 2.5(QS11) – 160$	0.99	EO
7.	**ECONOMICS AND FINANCE**				
FE1	Revenue per unit of supplied water	Polynomial	$(PL)_{FE1} = 250(FE1) – 50$	0.99	EO
FE2	O&M cost – Distribution	Linear	$(PL)_{FE2} = 112 - 3\ (FE2)$	0.99	NWWBI <adj> EOS
FE3	O&M cost - Treatment	Exponential	$(PL)_{FE3} = 170\ e^{-0.007\ (FE3)}$	0.99	NWWBI
FE4	Water rates	Polynomial	$(PL)_{FE4} = 134 – 0.17(FE4)$	0.99	NWWBI <adj> EOS
FE5	Operating cost coverage ratio	Polynomial	$(PL)_{FE5} = 10 + 97(FE5)^2 –43(FE5)$	0.99	EO + Literature
FE6	Debt service ratio	Linear	$(PL)_{FE6} = 83 - 94\ (FE6)$	0.99	EO + Literature
FE7	NRW by volume	Linear	$(PL)_{FE7} = 100 – 2\ (FE7)$	0.99	EO + Literature



(a) (b)

Figure 3: Examples of performance benchmarking relationships (a) per capita water consumption of residential consumers *(WE2)*, a water resources indicator, (b) percentage of service connection repairs in a year *(OP5)*, an operational indicator

Theuretzbacher-Fritz et al. (2013) reported the annual rehabilitation rates as water mains as percentage of mains lengths for around 1300 water utilities of all sizes participated in Trans-National Water Supply Benchmarking Project in Austria and Germany. The value for this PI was found to be ranging from 0.1% to 2.0% for SMWU (with water supplied from less than $2Mm^3$ to $8.0Mm^3$). It is important to mention here that values higher than 1.0 were observed for privately owned smaller systems with amount of water intake less than $2Mm^3$. Such systems can afford higher rates of rehabilitation due to higher water rates in Europe. Consequently, literature values are used ranging from 0.1 to 1.0 (%/ year) against performance levels from 10 to 100 respectively. Similar approach of obtaining guidelines from literature has been adopted for other such PIs.

The performance levels for some of the important PIs to develop benchmarking relationships were developed based on EO. For instance the indicator, 'water resources and catchment management employees', has not be considered in NWWBI, but it is an important PI for SMWU due to their smaller catchments in hilly or rolling terrains. In this case, the values between 0 and 0.1 ($No/10^6m^3$/year) were plotted against performance levels of 10 to 100.

3.2 Development of Performance Indices

After calculating the performance levels (between 10 and 100) of each indicator categories using benchmarking relationships, the next step is to aggregate the PIS to develop performance indices for each performance component;

- Water resources and environmental sustainability index *(WEI)*
- Personnel adequacy index *(PEI)*
- Physical assets functionality index *(PHI)*
- Operational efficiency index *(OPI)*
- Water quality and public health safety index *(WPI)*
- Quality of service efficacy index *(QSI)*
- Financial and economic viability index *(FEI)*

A conceptual cognitive map as an example to develop water resources and environmental sustainability is shows in Figure 4. It can be seen in the figure 4 that increase in some PIs has positive impact (WE1 number of days of water restrictions) on WEI, whereas some of the PIs need to be reduced or controlled (WE5 Impact of flushing on aquatic life) to improve the sustainability of WE category. The different types of data variables required to calculate the PIs are also in Figure 4. By limiting the PIs to the most essential ones in this study reduces the data collection efforts for SMWU. Subsequently, the WEI can be calculated using simple additive weighting (SAW) method as;

[2] $$WEI = (WE1 \times W_1) + (WE2 \times W_2) + (WE3 \times W_3) + (WE4 \times W_4) + (WE5 \times W_5)$$

where WE1 to WE6 are the performance scores of each calculated PI with values ranging from 10 to 100, and W1 to W6 are the allocated weights of the PIs with values ranging from 0 to 1. The sum of weights under each category should be '1' to have a final performance index value between 10 and 100. However, the assigning weights required great care, one important indicator with poor performance can significantly reduce the index value. On the other hand, if a relatively smaller weight is allocated to an important indicator and the resultant index is showing a higher value (acceptable performance), the results could be misleading. This situation should primarily be avoided in case of water quality indicators, where every indicator should meet water quality standards.

In this study, weights are allocated according to the ranks (importance) of the PIs established through multicriteria analysis by Haider et al. (2014). In this approach a weight of '1' is assigned to the most important indicator and n (the total number of PIs in each category) to the least important. The cardinal weights have been established using the following relationship (Stillwell et al. 1981);

[3] $$w_j = \frac{(n - r_j + 1)}{\sum_{k=1}^{n}(n - r_k + 1)}$$

where r_j is the rank of the j^{th} indicator, and n are the total number of PIs in each performance category (organizational component).

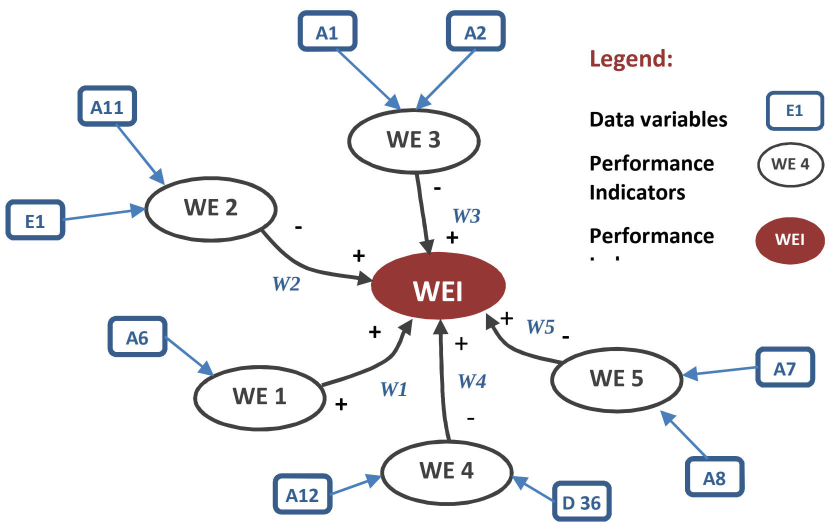


Figure 4: An example of cognitive map for water resources and environmental sustainability index (Source: Haider et al. 2014)

3.3 Application of proposed framework – Case Study of a medium sized water utility in Okanagan Basin, British Columbia, Canada

The above stated performance assessment framework has been applied on a medium sized water utility with 35,000 population in Okanagan Basin, British Columbia. The utility consists of five water supply systems with a total number of about 11,000 water connections and a total main length of approximately 280Km. The topography of the area is rolling and hilly with medium to steep grades. The primary source of water is surface water collected through dams, direct intakes from lakes, and natural creeks. In four of the water supply systems, the primary treatment is chlorination, whereas, in one of the system full conventional water treated facility including filtration system is being operated. The results of the performance assessment for all the organizational components of this utility during the year 2012 (assessment period) are shown in Figure 5. The details of data variables are out of scope of this paper. The description of proposed actions for an estimated performance level is presented in Table 2. It can be seen that except operational category, the utility understudy performed either good or very-good with the overall values of performance indices higher than 70. Although, the performance of operational efficiency index was found to be 'average', nonetheless its value is close to 60 (i.e., good). Such values of indices needs more detailed analysis of the respective category to identify the low performing PIs (i.e., the problem areas) within a water utility.

Performance indexes using the above approach can describe the condition and efficiency of each organizational component of the water utility. Based on the existing efficiency the utility managers and operators can take the decisions about the essential improvements, e.g., hiring additional personnel, increase main replacement rate, increase coverage, improve metering level, implement water conservation plan, etc.

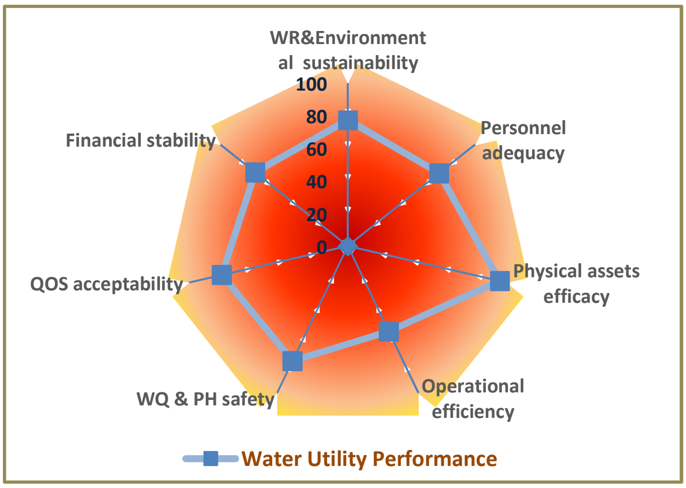


Figure 5: Performance assessment results of a medium sized water utility in Okanagan Basin, British Columbia, Canada

Table 2: Description of Performance levels with proposed actions

Index	Performance	Action proposed
0 - 20	Very poor	Urgent and detailed improvements required
20 - 40	Poor	Emergency measures required
40 - 60	Average	Detailed investigations required
60 - 80	Good	Satisfactory performance but further improvements would be useful
80 - 100	Very Good	Consistency required to obtain similar results

4. CONCLUSIONS AND RECOMMENDATIONS

Small and medium sized water utilities in Canada have not been participating in the performance benchmarking process neither at national nor at local (regional) level. In this connection, an effort is made in this study to develop performance benchmarking framework (using suitable PIs for SMWU) based on the results of NWWBI for large water utilities, literature values, and expert opinion. Certainly, the benchmarking relationships proposed in this work can never be the replacement of actual performance benchmarking processes involving similar sized utilities in the same region. However, the framework provides an opportunity to the utility managers and decision makers to assess the performance of all the organizational components of their utility for effective decision making. Moreover, the guidelines established in this work will provide a baseline analysis to initiate and organize actual benchmarking process. The framework does not cater for the data uncertainties, which can be further investigated with the help of probabilistic or fuzzy based approaches.

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