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NRCC-43089

A version of this paper is published in / Une version de ce document se trouve dans : CSCE 1999 Annual Conference - 14th Canadian Hydrotechnical Conference, June 2-5, 1999, pp. 421-430

A Practical Measure to Prevent Frozen Water Service Lines – The Region of Ottawa-Carleton's Experience

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ABSTRACT

The problem of frozen water service lines in severe cold winter months can be costly to municipalities across Canada. During the 1993/1994 winter 2,745 water service lines were frozen in the Region of Ottawa-Carleton and the corresponding cost of thawing was approximately $2.2 million or $800 per service line. The Region has since implemented a procedure to minimize the number of frozen services and corresponding costs in the subsequent winters by sending alert notices to the residents advising them to let water run from a faucet. The procedure is based on frost depth prediction using Brown's formula and daily mean air temperature forecast. Moderate correlation between the number of frozen services and freezing index was found using the region's statistics of frozen services.

Keywords: frozen water service, frost depth, prediction, prevention

Le problème du gel des branchements de service durant les mois d'hiver rigoureux peut être couteux pour les municipalités canadiennes. Durant l'hiver de 1993/1994, 2745 branchements de service ont gelé dans la Région d'Ottawa-Carleton occasionnant des dépenses de 2.2 millions de dollars pour leur dégel ou l'équivalent de 800$ par branchement. Depuis ce temps, la région a établi une procédure afin de minimiser le nombre de gel de branchement et les coûts pour les hivers subséquents. Cette procédure consiste en l'envoi d'une note aux résidents les avisant de laisser l'eau couler d'un robinet. Cette procédure est basée sur l'équation de Brown pour prédire la profondeur du gel et sur la température moyenne journalière prévue de l'air. Une corrélation modérée a été observée en utilsant les données du nombre de gel de branchement de service pour la région.

Mots-clés: branchements de service gelé, profondeur du gel, prédiction, prévention

1.0 INTRODUCTION

Loss of vital water supply can be a reality to many residents in Canada at the worst time of the year because their water service pipes (also referred to as service lines or services) can freeze in winter. These pipes, usually made of small diameter copper tubing, connect the street mains to individual houses. Water flows in these service pipes only when the residents use water. A prolonged cold period in combination with infrequent use of water can cause the pipes to freeze. According to a national survey (McDonald et al. 1997), municipalities that are affected by the freezing problem in winter have a population ranging from less than 10,000 to more than 100,000. This widespread problem is associated with the climatic conditions in many parts of the country.

The Region of Ottawa-Carleton (ROC) serves 11 local municipalities with a total population of approximately 650,000. Underground utilities are buried in various types of native soils, ranging from rock to clay, and at different depths. Records show that the region has experienced the frozen water service pipes every winter (Fig. 1) (Tobalt and Scothorn, 1995). Cumulative winter freezing index (degree C-days) for the region is 1,010 on average. There were two recent peaks in the number of frozen services - 811 incidents in 1980/1981 winter and 2,745 incidents in 1993/1994 winter. During the 1993/1994 winter, the crisis reached such a state that 11 electric thawing machines running 16 hours a day could not keep up with the emergency calls. The total cost of this thawing operation was $2.2 million, or $800 per service line. The peak in the number of frozen services for the 1980/1981 and the 1993/1994 winters prompted ROC to take two remedial measures:

- Water Service Lowering/Insulation Program started in the summer of 1981, and
- Let-Run Program started in the winter of 1994/1995.

Implementation of these two measures has significantly reduced the freezing incidents to a manageable level in the region, which has resulted in considerable savings.

2.0 WATER SERVICE LOWERING/INSULATION PROGRAM

After the winter of 1980/1981, the second coldest in recent time, ROC began a water service lowering/insulation program. Some of the water service lines were installed at shallow depths due to various reasons, one of them being shallow bedrock. Without a computerized database, the program initially relied on manual records and the memory of the staff to locate problem areas. The corresponding rehabilitation also depended on the availability of surplus maintenance funds after all regular maintenance costs were covered. After the crisis winter of 1993/1994, an increased budget was approved to complete the program. Coordinated with road resurfacing and sewer upgrading, about 100 services were lowered and insulated as per the current ROC standards. The cost of implementing this program totaled at $550,000. A database was set up to maintain thawing records and a compilation of a prioritized list of problem locations.

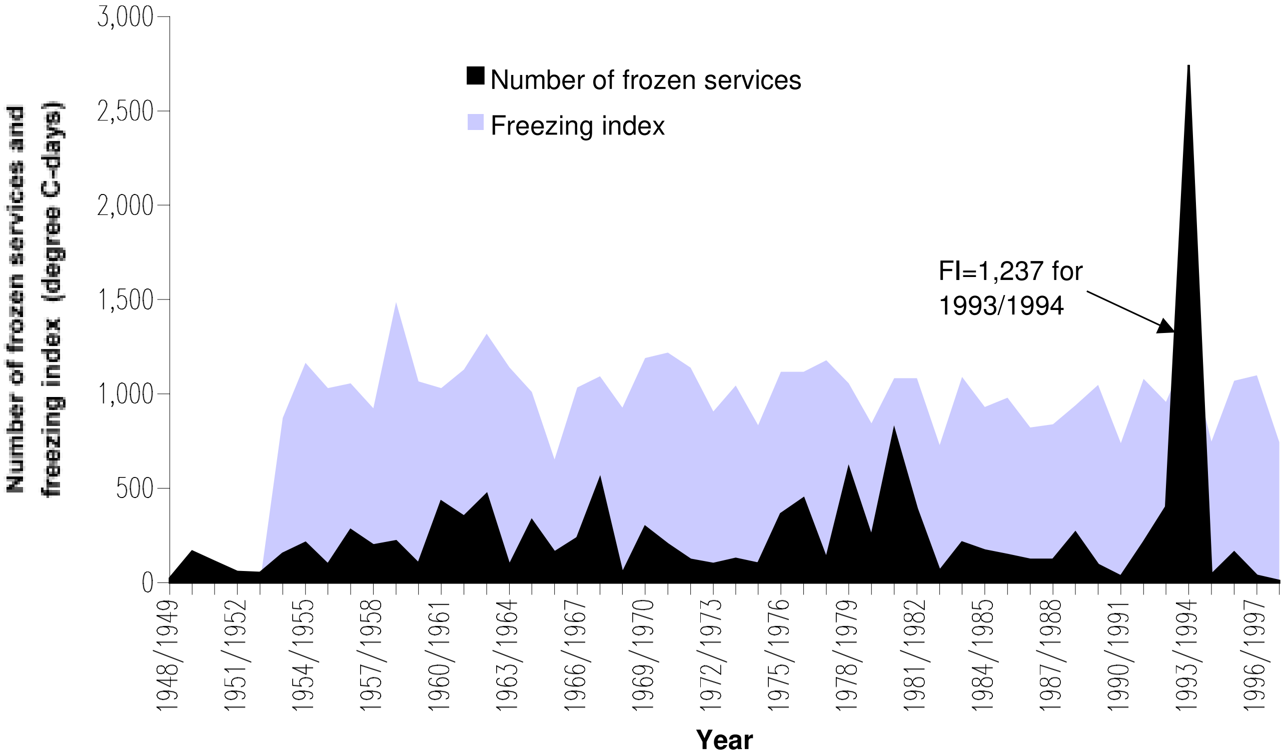

Figure 1. Total number of frozen services and winter freezing index

3.0 LET-RUN PROGRAM

Beginning in the winter of 1994/1995, ROC implemented another preventive measure – known as “Let-Run Program”. This program is based on the principle that flowing water in a pipe freezes slowly due to the constant supply of heat and change of water mass. With adequate flow rates, water in a pipe does not freeze. Implementation of the program involves predicting the frost depth, grouping problem locations and sending out notices to the affected residents to let water run continuously until April 15 at which time frost is expected to retreat from the ground in normal weather conditions, or until further notice.

3.1 Frost Depth Estimation

Accurate prediction of frost depth for a few simplified cases with semi-infinite soil domain can be made with the Neumann formula and Berggren equation (Johnston, 1981). However, the Berggren equation is in the complicated form of power and error functions that are not easily used. Alternatively, frost depth can be estimated using Brown's formula (Brown, 1964):

[Eq.1] $$d_{frost} = 0.0174(FI)^{0.67}$$

where d_{frost} = depth of frost for uncovered surface, m
FI = cumulative freezing index based on daily mean air temperature, degree C-days

Cumulative freezing index is a measure of coldness of a winter. It is calculated by summing up the daily mean air temperature values that are below 0 °C. Frost depth can be estimated in advance by Equation 1 based on long-range forecast on daily mean air temperature.

3.2 Grouping of Problem Locations

The average depth of water services within the region is 1,625 mm (64 in.) with a variance of 305 mm (12 in.). Problem locations are grouped (Table 1) to allow staged actions to be taken. Depth of burial and the frozen service records for the winters of 1993/1994 and 1980/1981 were used to compile the group list.

3.3 Let-Run Notice

When frost depth calculated using a 5-day forecast, is about to reach 1,320 mm (52 in.), the residents in Group A are notified to let water run from one tap in the house. Similarly, the residents in Group B are notified when the frost depth is approaching 1,625 mm (64 in.). When the frost depth has reached 1,800 mm (70 in.) and/or the incidents of freeze-up are on the increase, 3,000 additional residents in Group C are notified. The residents in Group D on private property have experienced frozen services and typically receive the let-water-run notice on December 15 each year. The residents are advised to keep the water running at a "pencil thickness" or 6 mm (¼ in.) diameter stream until April 15 or further notice. To encourage compliance, ROC reimburses the resident the cost of the water consumption due to this continuous water bleeding.

Table 1 Let-Run Program summary

Group	# of residences	critical depth mm	remarks
A	27	1,320	3 areas under wide street surface, shallow depth
B	1,500	1,625	On public property, frozen during 1980/1981 or 1993/1993 winters, scattered around the region
C	3,000	1,800	Neighbors on the same streets as those in B
D	185	-	On private property, frozen record

4.0 RESULTS AND DISCUSSIONS

Available data on frozen water services in the Region of Ottawa-Carleton can be divided in to three time periods: (a) from the 1947/1948 winter to the 1981/1982 winter, (b) from the 1981/1982 winter to the 1993/1994 winter and (c) from the 1994/1995 winter to the 1997/1998 winter. The first, second and third period represent the time before Service Lowering/Insulation Program implementation, the time after the implementation of Service Lowering/Insulation Program but before that of Let-Run Program and the time after the implementation of Let-Run Program, respectively. The time periods allow the determination of the effectiveness of the two programs.

4.1 Trend in Number of Frozen Services

The data from the three periods are plotted in Fig. 2 except for the 1993/1994 winter. The unusually high number of frozen services during that winter is considered an exception and, if included in the graph, would skew the results. In general, the number of frozen services has declined since the implementation of ROC's Service Lowering/Insulation Program. This improvement would be more appreciated if the increase in total number of service lines within the region were taken into account. Unfortunately, records of the total number of service lines were not kept prior to 1991.

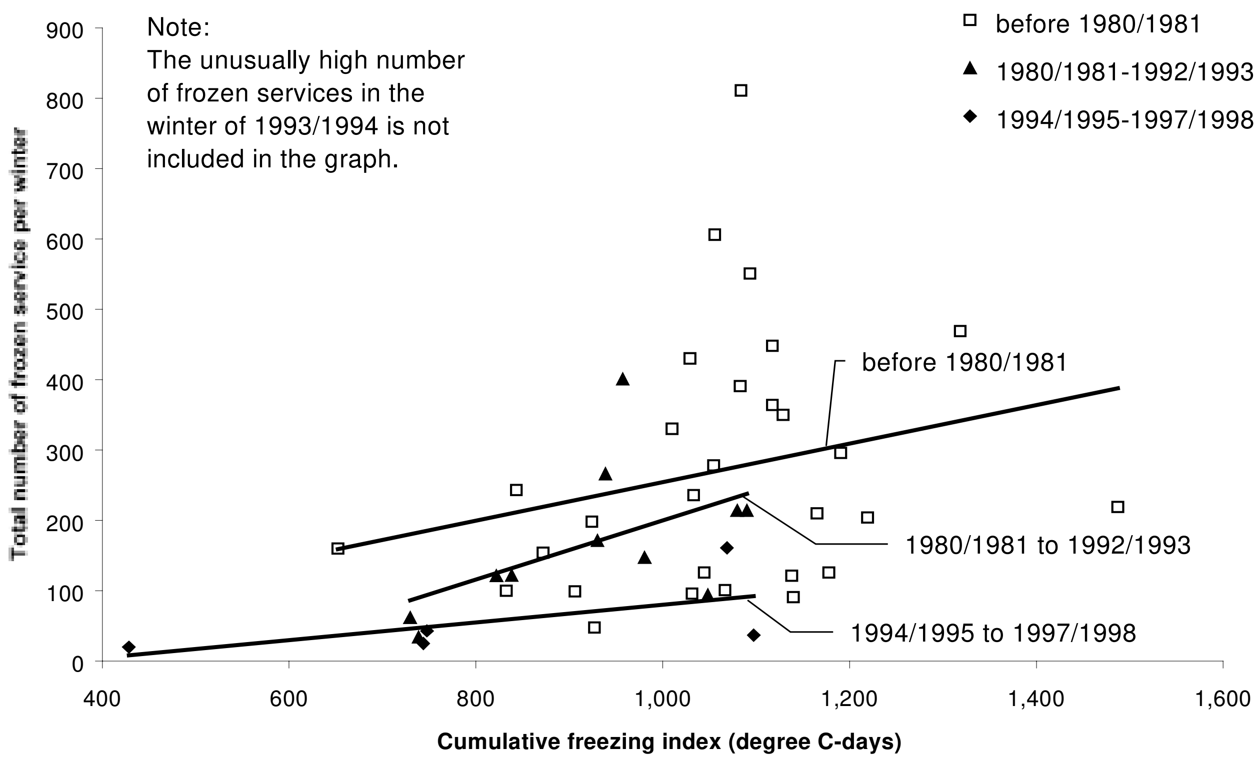

Figure 2. Comparison of number of frozen services for three time periods

4.2 Correlation between Frozen Services with Freezing Index

Fig. 3 shows the correlation between number of frozen services in percentage with freezing index, based on the available total number of service lines from 1991 to 1998. A power relationship shows the best correlation:

[Eq. 2] $$N = 6\times10^{-7} e^{0.0075(FI)}$$

where *N* is number of frozen services in percentage. An R-square value of 0.56 indicates moderate correlation between the variables. Although this relationship is based on a small data set and should not be used to predict the number of frozen services, it shows that the percentage of frozen services would increase sharply when the freezing index is over 1,200 degree C-days. Under these conditions, the frost will penetrate down to an estimated depth of 2,000 mm, which is deeper than the average depth of service pipes of 1,600 mm (63 in.) in the region. Therefore, a sharp increase in the number of frozen services may be expected. Taking the 1993/1994 winter as an example, the estimated maximum frost depth for was 2,100 mm (83 in.) for a freezing index of 1,237 degree C-days and the corresponding number of frozen services jumped to 2,745. The limited data confirms that the high freezing index (colder the winter) leads to an increase in the percentage of frozen services.

4.3 Predicted Frost Depth and Factors

Frost depths based on field temperature data at three typical sites within the region are plotted along with the predicted frost depth using Equation 1 for 1994/1995 winter (Fig. 4). The St. Andrew site represents a rock trench, the Richelieu site a fine-grained clay soil trench and the Dorchester site a till trench, all backfilled with granular materials. The predicted frost depth follows closely the trend of the measured frost depths, but is more conservative except for the Dorchester site. The measured frost depth for that site was consistently deeper than the predicted because there was a catch-basin near the installed sensors (one of the objectives of the field measurement project was to determine the influence of catch-basins).

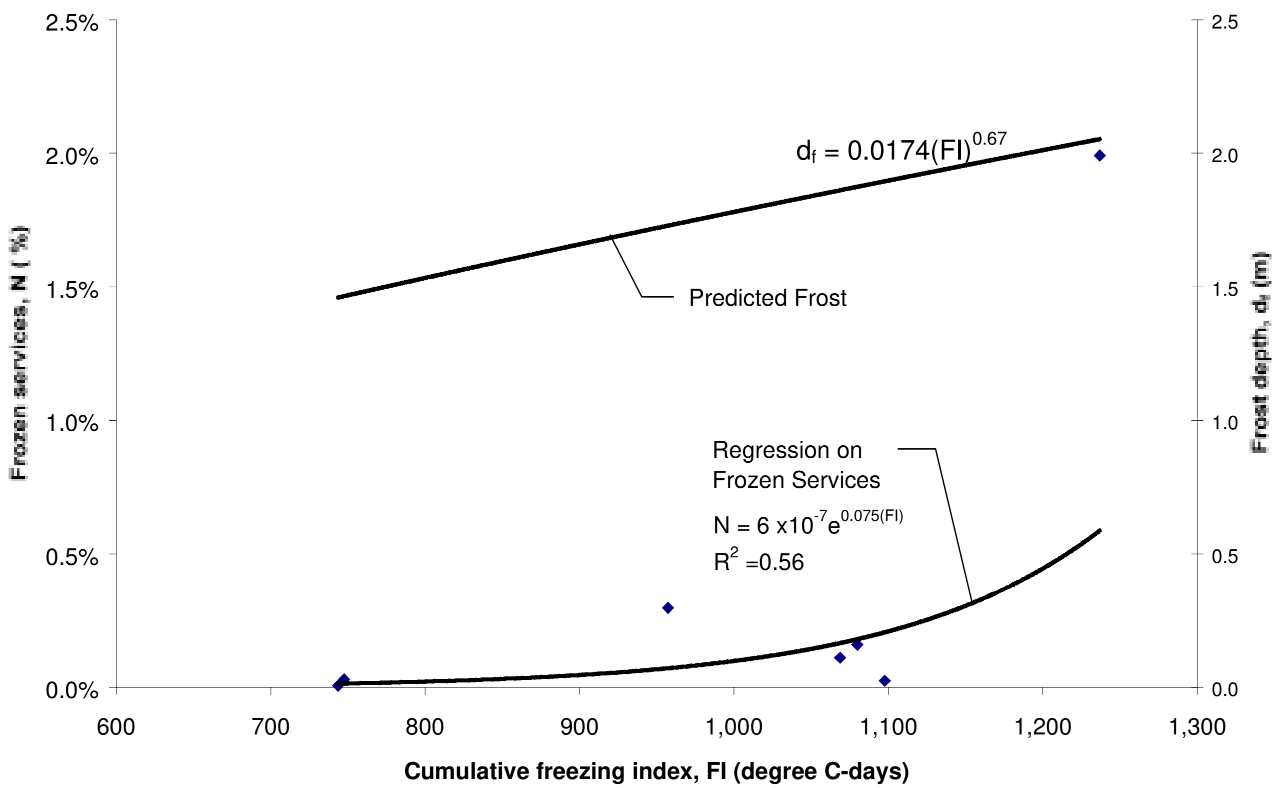

Figure 3. Correlation between % frozen services and freezing index

Brown's formula provides estimates that are sufficiently accurate for the intended use. Other factors which are not taken into account in the formula include soil and backfill type, soil moisture content (latent heat), snow cover thickness, nearby buried structures, and diameter of water service line. The simplified Stefan and Berggren equations (Smith, 1996) include the unfrozen thermal conductivity, volumetric latent heat and surface correction factor in addition to the freezing index. When these site-specific factors are known, these equations may be used.

In general, deep depths of cover, thick snow covers and large diameter water services will reduce the risk of frozen water service. The soils and backfill materials that have higher thermal conductivity and less water content will tend to promote deeper frost penetration (Daigle and Zhao, 1999). Nearby buried structures, such as maintenance holes (MH), catch basins, sewer and storm lines, also affect the penetration of frost into the ground. A service line under a city street or driveway is more susceptible to freezing than a line under snow and grass-covered areas. ROC has developed and relies on a database that contains these additional data and past records on frozen services to determine the problem areas.

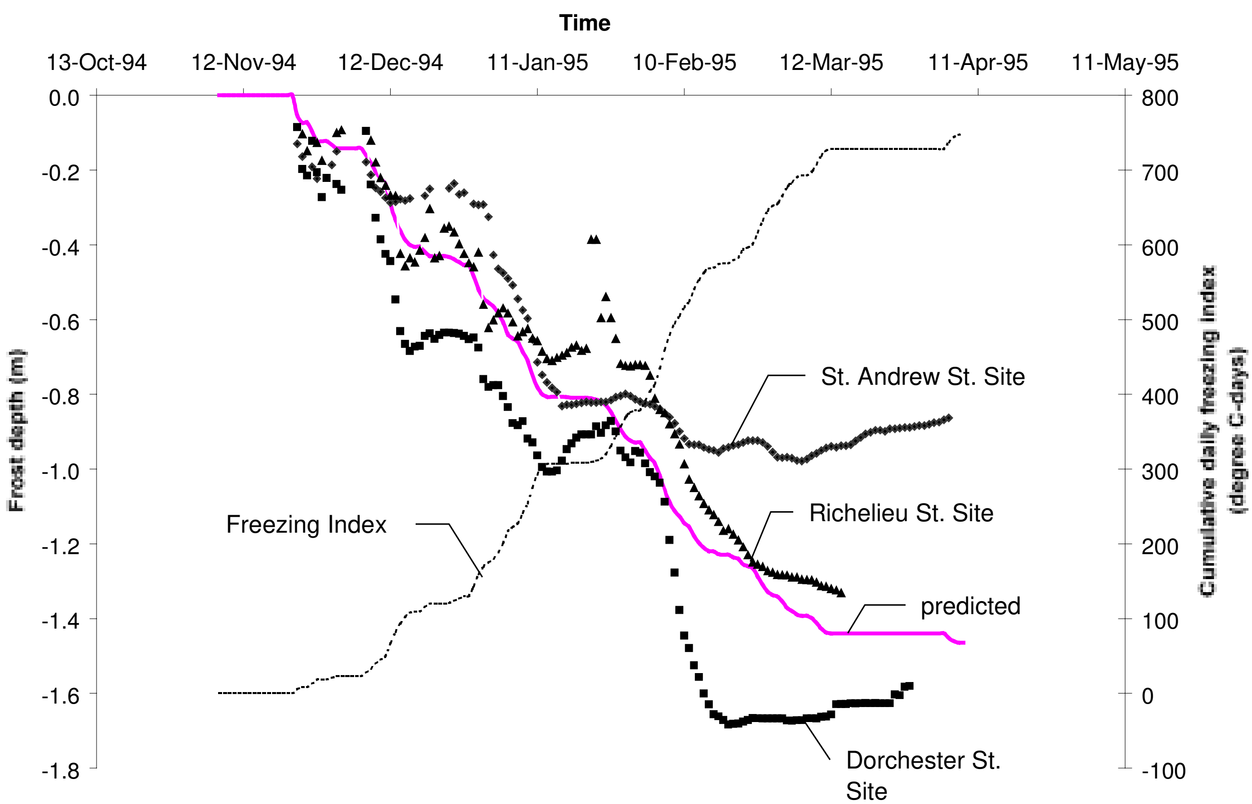

Figure 4. Frost depth and FI for 1994/1995 winter

4.4 Cost Comparison

Based on water pressures of 273 to 415 kPa (40 to 60 psi) and a 6 mm (¼ in.) diameter stream as the rate of let-run water from a tap, the total volume of water is calculated to range from 1,720 to 2,110 m^3/month. The corresponding cost of letting water run for a period of 4 months (December 15 to April 15) therefore ranges from \$270 to \$340. In comparison, the unit cost of thawing is about \$800 using the cost data from the winter of 1993/1994. It should also be noted that most of the service lines on the priority list can freeze repeatedly (e.g., the services of the 27 residences in Group A were frozen two or more times in the 1980/1981 and 1993/1994 winters) during the course of a winter. The cost benefit ratio for Let-Run Program is between 1:3 to 1:9 depending upon the number of repeated frozen service locations. Using the data from the winter of 1993/1994 as an example, the savings would be at least \$1.4 million.

5.0 SUMMARY

This paper presents the measures taken by the Region of Ottawa-Carleton in its effort to mitigate the frozen water service problem. These measures include lowering/insulating service pipes and intentional bleeding of water services to maintain sufficient water flow rates. Let-Run Program depends on the prediction of frost depth using a simple formula based on long-range weather forecast. Available data confirmed the validity of the formula for the intended purposes.

A power relationship with moderate correlation is observed between percent frozen services and cumulative winter freezing index. The relationship describes the effect of freezing index on number of frozen services. When cumulative freezing index in a winter exceeds 1,200 degree C-days, estimated frost depth will exceed the average depth of burial in the region. A crisis in frozen services would be expected if no pro-active measures were taken.

ROC's pro-active approaches have resulted in significant reductions in the number of frozen services. Let-Run Program can reduce the cost due to freezing service problems by a factor of at least 3. Experience of ROC has demonstrated that Let-Run Program is a simple and cost-effective measure to mitigate freeze of water service during cold winter months.

ACKNOWLEDGMENT

The field data was obtained from a research project that was jointly funded by ROC and The National Research Council Canada (NRC). The project was carried out by Harry Baker and James Crawford of NRC.

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