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Corroded rock support issues: implementation of an investigation and rehabilitation program

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Abstract

Raglan Mine site includes four underground mines extracting nickel (Katinniq, Kikialik, Qakimajurq and Mine 2). It is located at the extreme north of the province of Quebec. Due to freezing weather and the permafrost environment, the use of brine is mandatory. This brine is composed of about 10% calcium chloride and is corrosive to rock support systems. With mines extending deeper below the permafrost, brine flows more freely in the rock mass. The corrosion of support systems and the resulting loss of capacity can be a major safety and economic concern. Centred on rock support issues, this paper presents the mitigation measures implemented at Raglan Mine to ensure safety and the investigation program methodology to quantify and prioritise rehabilitation needs of long-term excavations. In corrosive environments, the selection and design of rock support should take the susceptibility of such systems to corrosion into consideration.

Keywords: *corrosion, brine, capacity, fall of ground, rehabilitation, inflatable bolt, pull test*

1 Introduction

The safety of workers is a primary goal in the mining industry. Ground control is a part of mining risk management and aims to reach zero occurrences of fall of ground. Despite the design and choice of material, ground control systems are subject to corrosion that leads to reduction in capacity. Inspection, quality control, and monitoring of aged rock supports are activities that can prevent a fall of ground. Restriction of access and rehabilitation are tools that can be used following inspection, quality control and monitoring. In many cases, corrosion is found to be the main contributing factor during an investigation into the mechanisms and cause of fall of ground failures (Hadjigeorgiou et al. 2012). This can have important safety and economic repercussions for underground mines. Figure 1 illustrates a fall of ground, the result of a loss of capacity attributed to corrosion. The corrosion of rock support in that case was caused by brine infiltration in the rock mass from a sump located in a level above.

Risk management associated with fall of ground is a concern at Glencore. At Raglan Mine, the goal is zero fall of ground incidents, and a detailed and specific program for managing this risk has been implemented. This program specified the causes of fall of ground (FOG), performance standards, and preventive controls (including critical controls). The inspection and rehabilitation of capital expenditure (CAPEX) excavations are critical controls. Figure 1 presents a FOG in a drawpoint attributed to corroded ground support. Figure 2 shows corroded inflatable rockbolt from that FOG.

This paper presents the investigation and rehabilitation program of long-term excavations conducted at Raglan Mine. The objective of this work is to qualify and quantify the loss of capacity of support systems based on several parameters, which include the presence of water, rock mass quality, condition of actual rock support, and corrosion state. This information is then used to determine appropriate support rehabilitation and the management of work priorities.

Raglan Mine is located in a permafrost environment, however the underground mines are not heated and the use of brine is needed for mining operations. Unfortunately, brine causes corrosion of metallic rock support. Another consideration is the warming of the rock mass with increasing depth. At a depth of roughly 500 m below surface, the permafrost zone ends. Below this depth, water and brine are thus free to infiltrate the rock mass and come into contact with rock support. Due to the aging of excavations, some locations need rehabilitation of rock support, and operational development such as main ramps and level accesses could be disruptive to mine production. At Katinniq mine, some historical excavations were supported according to old standards (ungalvanised rockbolts and rebar and no screen) and were a safety concern.

Figure 1 Fall of ground in a drawpoint caused by reduction of support system capacity related to corrosion

Figure 2 Heavily corroded inflatable bolts attributed to a fall of ground

2 Methodology

All infrastructures (garage, ventilation access etc.) and permanent excavations must be inspected on an annual basis to validate the integrity of their primary support and ensure that the excavations are still safe. The ultimate goal is to identify areas of potential risk, assess the level of risk, and plan rehabilitation according to their severity. CAPEX infrastructure includes, but is not limited to: refuge, lunchrooms, access ramps, service bays, and emergency exits. Approximately 18 km of main ramp alone are inspected annually.

A list of locations to inspect is maintained for each active mine. Depending on the progress of the operations, an evaluation of certain excavations is carried out to determine whether accessibility should be maintained. Mining engineering evaluates the future functions of the excavations and checks with underground operations which must remain open and which may be permanently closed.

An inspection protocol was developed to standardise the assessment of the underground sector. A rating of the quality of the rock mass, the integrity of the ground support, as well as an assessment of the level of corrosion of the ground support are undertaken. Rehabilitation priorities are then identified. Any high risk situation requiring immediate corrective action is identified as a priority and the corrective action is requested from the field supervisor. Non-destructive pull-tests are also performed on installed bolts. Following annual inspections, an action plan is established for the year. Rehabilitation plans are issued by a ground control engineer and work is planned according to the established precedence. Plans are presented every two weeks at a meeting between the mining engineering and underground mining operations departments.

The CAPEX excavation rehabilitation program is divided into several stages:

- Indication of the places to inspect on the mining plans.
- Inspection of underground areas and classification of the state of the support. The inspections are performed by walking through the various excavations.
- Identification of places where rehabilitation work is required.
- Establishment of priorities according to the risk level.
- Distribution of rehabilitation plans to underground operations.
- Follow-up and attestation of the quality of works.

The CAPEX inspections binder is located in the ground control office. The binder is divided by mine, with each division containing:

- Mine plans.
- A ‘Visual Assessment of Retaining Corrosion’ guide (Figures 3 and 4).
- A decision matrix for CAPEX Rehabilitation (Figure 5).
- A support state table.
- A ‘Summary of Rehabilitations’ table.

Each plan corresponds to one sector (Figure 6). Segments are named sequentially from the top of the mine downwards. The notation is the following by mine: first four letters represent the mine and a sequential number. For example:

- KATI #1 (Katinniq sector 1).
- QAKI #4 (Qakimajurq sector 4).
- MINE 2 #3 (Mine 2 sector 3).
- KIKI #7 (Kikialik sector 7).

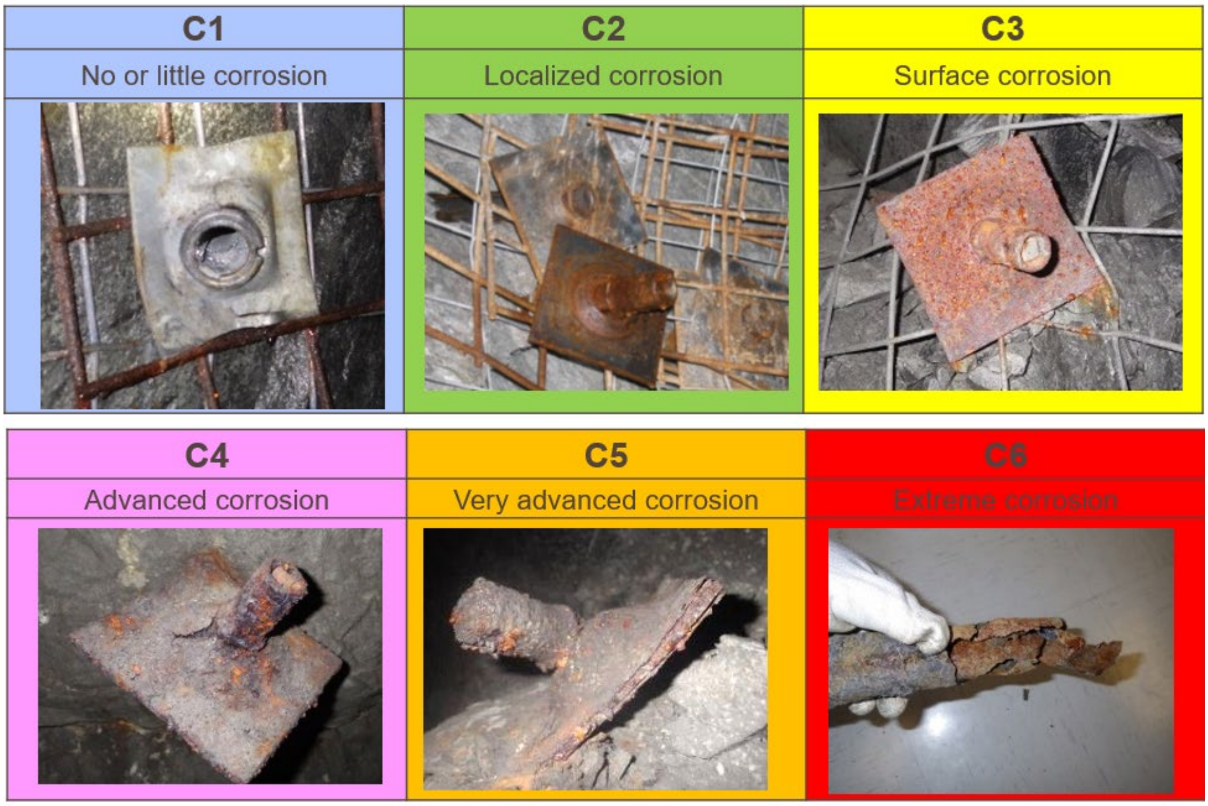


Figure 3 Level of corrosion of rock support

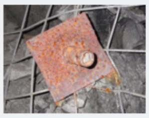
Corrosion Level	C1 No or little corrosion	C2 Localized corrosion	C3 Surface corrosion	C4 Advanced corrosion	C5 Very advanced corrosion	C6 Extreme corrosion
Description	<10% of spots on the surface	10% à 75% of surface corrosion	75% of surface corrosion. No crust	100% of the surface is corroded. Presence of a thin crust (<1mm)	100% of the surface is corroded. Presence of a thick flaky crust (>1mm)	Important degradation. Breakable. Presence of holes.
#6 mesh diameter	> 4,75mm	4,50 à 4,75mm	4,00 à 4,50 mm	3,50 à 4,00mm	2,50 à 3,50 mm	< 2,50mm
Typical corrosion rate (after 1 year of exposure)	< 0,02 mm/yr	0,02 to 0,04 mm/yr	0,04 to 0,15 mm/yr	0,15 to 0,30 mm/yr	0,30 to 0,60 mm/yr	> 0,60 mm/yr
Intervention required	None	None	None Follow up if installed during the last year	Close follow up Pull test	Rehabilitation to plan	Rehabilitation without any delay (closure)
Examples						

Figure 4 Chart of corrosion level and capacity of mesh #6 and corrosion rate (Dorion et al. 2015)

MINE RAGLAN
UNE COMPAGNIE GLENCORE

Contrôle de terrain - Inspection des galeries - Matrice décisionnelle pour réhabilitation CAPEX

Légende:

W = Cotation pour eau (water)	BP = Béton Projeté	P = Priorité
C = Cotation pour corrosion	VS = Vieux standard	**P1 = RÉHABILITATION**
GS = Cotation pour grillage et état massif (ground support)		

Section 1 - Présence d'eau ou d'humidité (W)

	Type d'écoulement		
Âge de l'excavation	Humide seulement ou traces mais maintenant sec	Suintement	**Écoulement (gouttes et/ou filets)**
	Cotation	Cotation	Cotation
<1an	W1 Suivi	W2 P3 - 2018	W3 P2 - 2018
>1 an	W4 P3 - 2018	W5 P2 - 2018	**W6 P1 - RÉHABILITATION**
Une des conditions présentes peu importe âge excavation: **Faille ou Wedge ou Corrosion ou Grillage Chargé**	W7 À évaluer selon état du soutènement (P2 - 2018)	**W8 P1 - RÉHABILITATION**	**W9 P1 - RÉHABILITATION**

Section 2 - Conditions particulières

Vieux standard de soutènement (pas de grillage, boulon mécanique, rebar, ...) **(VS)**	Sec - Très bon massif - niveau de corrosion <C4	VS - P2 ou P3
	Niveau corrosion ≥C4 ou eau ou faille	**VS - P1**
Endroit bétonné (shotcrete) **(BP)**	**Vérifier état du béton**	
Structure géologique majeure (faille) présente	**Est-ce que le soutènement est adéquat?**	
	Oui	**NON - P1 ajout soutènement**

Section 3 - Endroit sec - État du soutènement et du massif rocheux

COTATION GÉNÉRALE DU SOUTÈNEMENT				**État du grillage et du massif rocheux (GS)**			
Tableau pour : 1) donner une cotation générale de la section inspectée; 2) catégoriser un endroit spécifique. **Indiquer l'information sur le plan de mine**				**GS1**	**GS2**	**GS3**	**GS4**
Cotation du niveau de corrosion (C)				Aucune roche dans le grillage. Pas de "loose" ni de wedges. Le massif ne s'effrite pas - très bon état.	Quelques petites et moyennes roches dans le grillage. Grillage en bon état et soutient bien les roches. Le massif est en bon état.	Grillage avec plusieurs roches (assez chargé) ou gros blocs dans le grillage et/ou ou wedges. Grillage généralement en bon état mais signes de déformation.	**Grillage chargé : déformation du grillage ou bris des brins ou grillage ouvert. Gros "looses" ou wedges retenus par une partie du grillage.**
Niveau de corrosion	Corrosion localisée	C1 - C2	10% à 75% de la surface avec rouille superficielle	**C2-GS1**	**C2-GS2**	**C2-GS3**	**C2-GS4 P2**
	Corrosion en surface	C3	> 75% de la surface corrodée. Corrosion généralement superficielle (peu profonde). Pas de croûte.	**C3-GS1**	**C3-GS2**	**C3-GS3**	**C3-GS4 P1**
	Corrosion avancée	C4	100% de la surface corrodée. Il y a une couche de corrosion de <1mm d'épaisseur (début de feuillet)	**C4-GS1**	**C4-GS2**	**C4-GS3 P3**	**C4-GS4 P1**
	Corrosion très avancée	C5	Couche de corrosion >1mm. Structure feuilletée.	**C5-GS1 P3**	**C5-GS2 P3**	**C5-GS-3 P2**	**C5-GS4 P1**
	Corrosion extrême	C6	Détérioration importante. Perforation du métal. Structure très feuilletée. Grillage se brise aisément.	**C6-GS1 P2**	**C6-GS2 P1**	**C6-GS3 P1**	***C6-GS4 URGENT - BARRICADE***

Mise à jour : 8 avril 2017 — **Si urgent - Endroit à barricader**

Figure 5 Decision matrix for the management of rehabilitation priorities

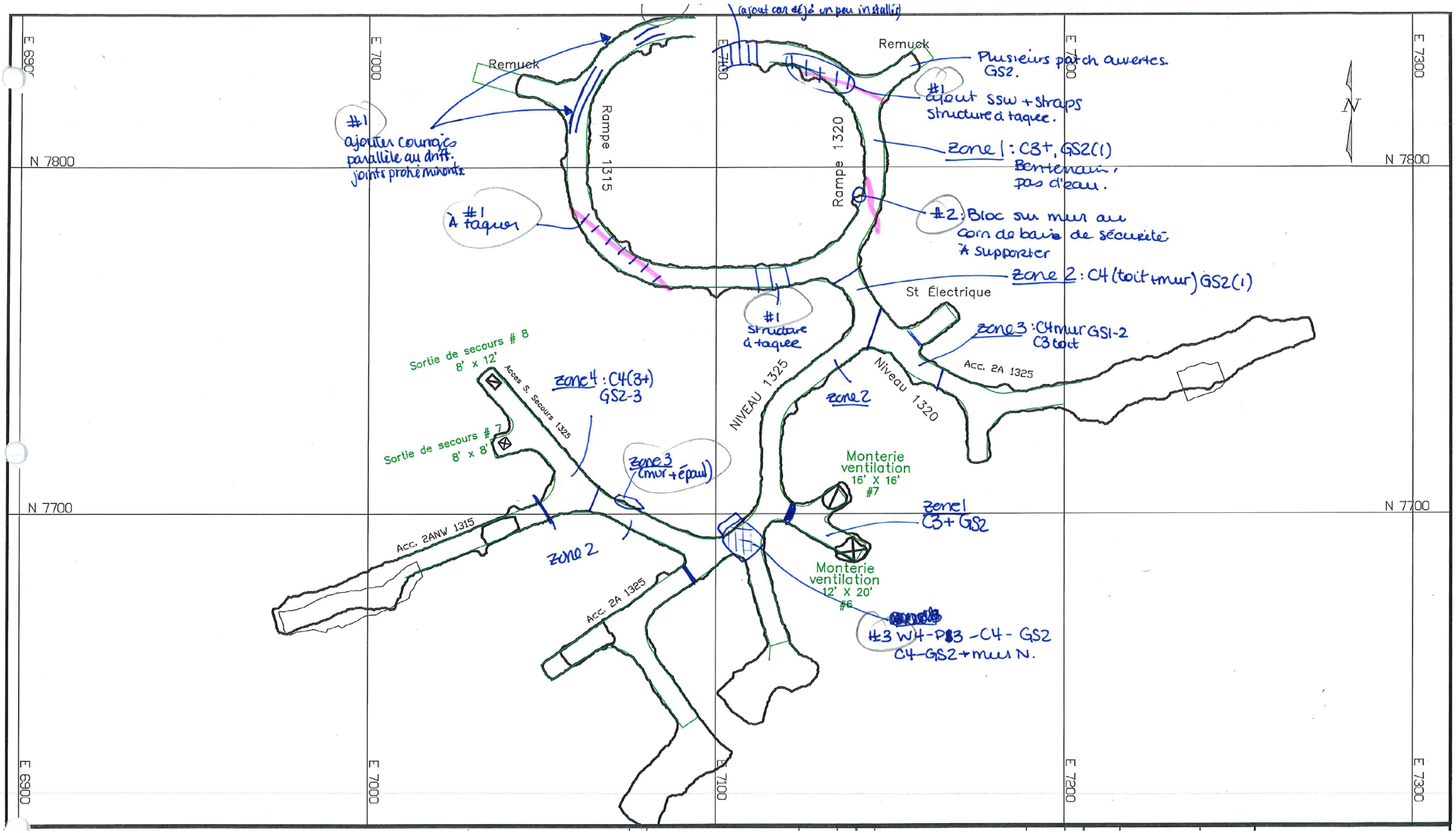


Figure 6 Example of inspection data collected on a mine plan

During inspections, several important aspects must be addressed; such as the major geological structures and water flows, as they can contain brine and cause corrosion of the support. Before inspections, four categories of items are identified on the mine plans:

- Purple: inspection not required for the current year (closed sector).
- Green: pay particular attention (sumps and underground drifts, emergency exits, ventilation, intersections etc.).
- Pink: presence of major geological structures.
- Blue: presence of water.

The inspection of CAPEX excavations is a visual inspection that must be done by walking to observe and note the state of the support and the rock mass. Each area should be inspected in more than one direction (for example, inspecting a ramp first from the top and then back up so as not to miss structures that would be visible from one direction).

When inspecting, the following information must be indicated on the aforementioned plans:

- Type of support (Swellex, split set, mesh etc.).
- Corrosion level (C1 to C6) for each type of support.
- Rating of the state of the grid and the rock mass (GS-1 to GS-4, according to the decision matrix).
- The presence of water.
- Quality of support where important geological structures are present.
- The presence of wedges, and an evaluation if the support is adequate.
- The places where rehabilitation is necessary are rated according to their condition and are named according to the name of the area.
- 'State of Support' and 'Summary of Rehabilitation' tables. If necessary, the plan is divided into smaller areas and the information for each area to be rehabilitated is indicated in the tables.
- Information previously indicated on the map during preparation is corrected, if necessary.
- Other relevant information is noted (barricades, gallery filled with 'muck' etc.).

A descriptive chart of corrosion levels is used. This one is divided into six categories. Figure 3 shows this chart of level of corrosion (Dorion 2013).

Figure 4 gives quantitative indications on the capabilities of the #6 mesh and corrosion rates. It helps to determine priorities for rehabilitation of mining support.

The document present in Figure 5 is used to identify needs and emergencies for rehabilitation work. This gives a certain uniformity to the work completed by the various people carrying out the inspections. This decision matrix is divided into three main sections.

Section one is for wet locations. As mentioned previously, generally the observed water flow is brine infiltration. The presence of brine promotes the corrosion of the mine support and special attention must be paid to these areas. In addition to checking the type of water flow, the age of the excavation and the quality of the state of the support and the rock mass are taken into account.

Section two is for special conditions; like places supported according to old standards, presence of shotcrete, or major geological structures (faults, shear). In the case of major geological structures, additional support may be required according to the support standard.

Section 3 is for dry excavations. In these situations, the level of support corrosion is considered (C1 to C6), as well as the general condition of the retaining wall and the rock mass (GS1 to GS4). The rating table of rehabilitation priorities is based on the tables used in risk management. This is easy to use and provides similar results from one person to another. The priorities (P) are indicated according to the combination of corrosion rating (C) and support state (GS).

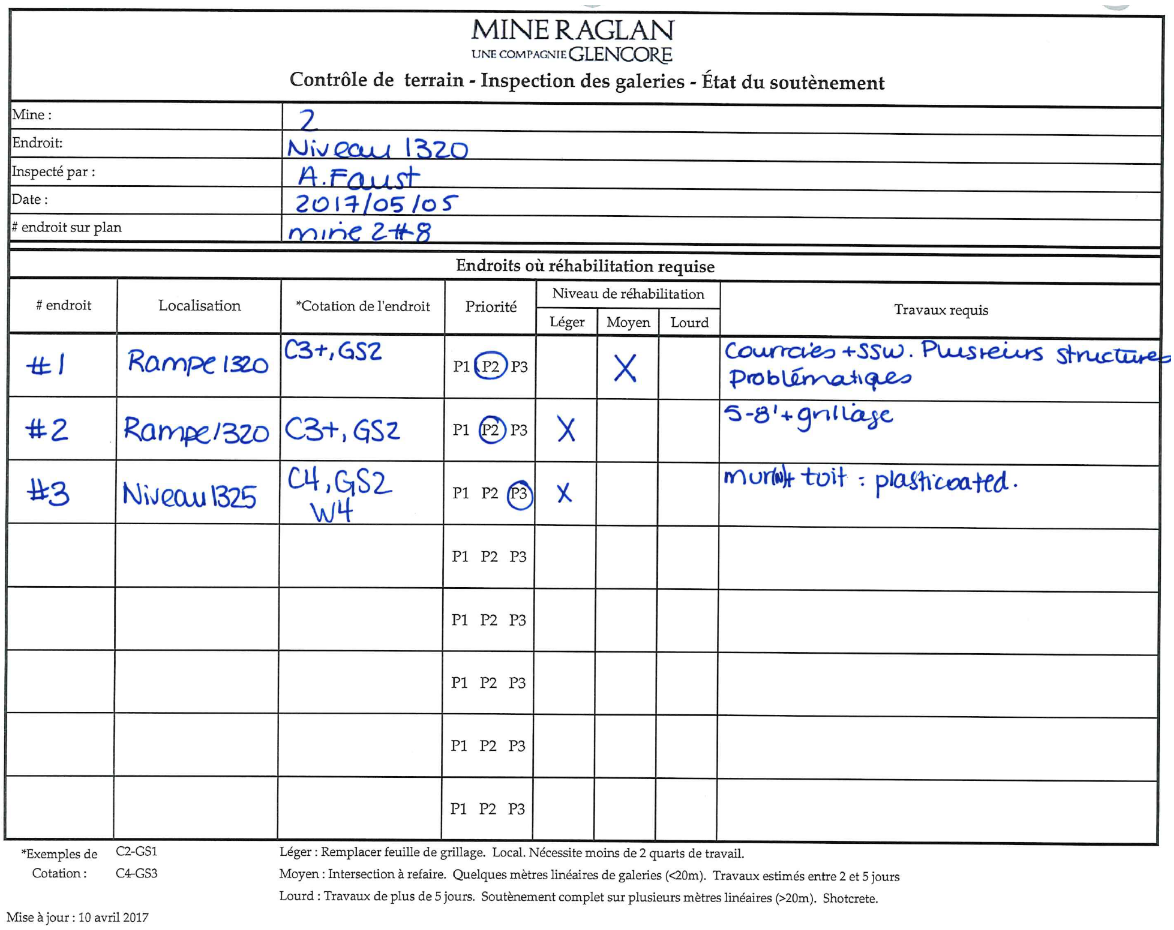
3 Data

During inspection, all information is collected and noted on plans and files. Pictures are taken and archived. Table 1 lists the number of metres of main ramps alone that were inspected in 2017.

Table 1 Length of main ramp

Mine	2017
Qakimajurq	3.6 km
Mine 2	5.6 km
Kikialik	3.6 km
Katinniq	4.0 km
Total	**16.8 km**

The following example presents a typical case of recorded information following an inspection. As can be seen, the excavations are divided into different sectors according to the state of the support. The level of corrosion, as well as the state of the support and rock mass is noted. Requests for rehabilitation work are indicated and entered in the form (Figure 7). In addition to information noted in forms and plans, an Excel file serves as a database.


MINE RAGLAN
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Contrôle de terrain - Inspection des galeries - État du soutènement

Mine :	2
Endroit:	Niveau 1320
Inspecté par :	A.Faust
Date :	2017/05/05
# endroit sur plan	mine 2#8

Endroits où réhabilitation requise

# endroit	Localisation	*Cotation de l'endroit	Priorité	Niveau de réhabilitation: Léger	Moyen	Lourd	Travaux requis
#1	Rampe 1320	C3+, GS2	P1 (P2) P3		X		Courroies + SSW. Plusieurs structures problématiques
#2	Rampe 1320	C3+, GS2	P1 (P2) P3	X			5-8' + grillage
#3	Niveau 1325	C4, GS2 W4	P1 P2 (P3)	X			mur + toit : plasticoated.
			P1 P2 P3				
			P1 P2 P3				
			P1 P2 P3				
			P1 P2 P3				
			P1 P2 P3				

*Exemples de Cotation : C2-GS1 C4-GS3

Léger : Remplacer feuille de grillage. Local. Nécessite moins de 2 quarts de travail.
Moyen : Intersection à refaire. Quelques mètres linéaires de galeries (<20m). Travaux estimés entre 2 et 5 jours
Lourd : Travaux de plus de 5 jours. Soutènement complet sur plusieurs mètres linéaires (>20m). Shotcrete.

Mise à jour : 10 avril 2017

Figure 7 Form used to indicate rehabilitation works and priorities

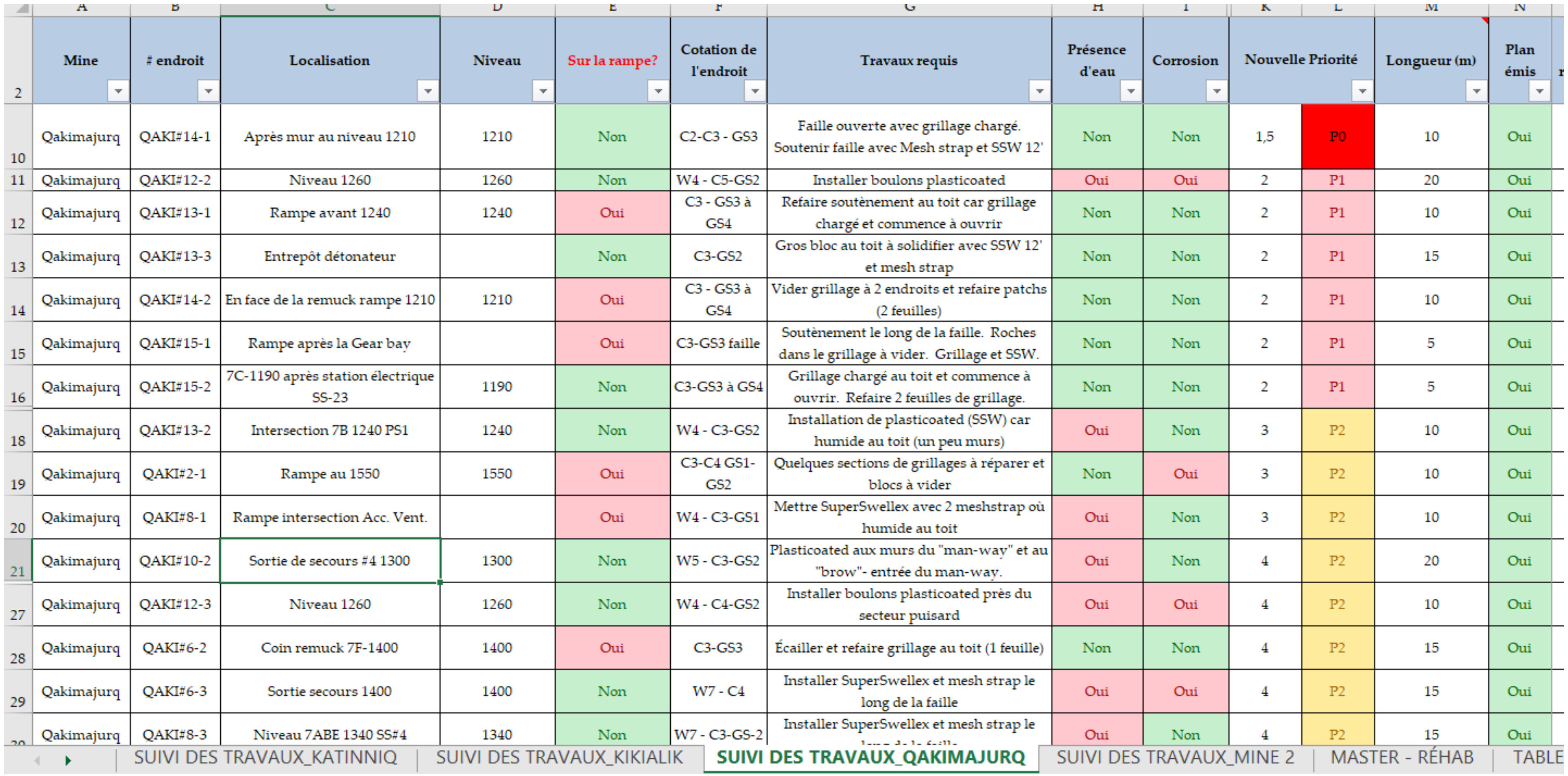
Depending on the inspection results, pull test on bolts may be performed. The type of bolt, its age and the corrosion level are noted. The pull test can be destructive or non-destructive. Because inflatable bolts are the main type of rock support at Raglan Mine, a camera is occasionally used to inspect the corrosion inside a given bolt after a destructive pull test. Figure 8 shows the inside of one such bolt.

Figure 8 Picture of the inside of an inflatable bolt

4 Results

The results of the inspections are all recorded in an Excel file (Figure 9). The priority management is established based on the rating of the location, but also on the risks related to the production in the event of a possible FOG. This means that the locations in the ramp would be a higher priority than similar locations in lower risk areas. The table also shows the details of the rehabilitation work to be carried out for each location. This table also makes it possible to follow if the plans are emitted as well as the progress of works for each of the working places.

According to established priorities, plans are distributed to underground operations (Figure 10). Each of the locations is indicated underground with a reference number. Priorities are also indicated on the plans. At each shift, a miner is given a work card with the plan indicating the work done, on which they describe any work completed. Thus, the field control team has the ability to follow the day-to-day rehabilitation work. As this work is carried out by a contractor, this system also facilitates the management of the budget.



	Mine	# endroit	Localisation	Niveau	Sur la rampe?	Cotation de l'endroit	Travaux requis	Présence d'eau	Corrosion	Nouvelle Priorité		Longueur (m)	Plan émis
10	Qakimajurq	QAKI#14-1	Après mur au niveau 1210	1210	Non	C2-C3 - GS3	Faille ouverte avec grillage chargé. Soutenir faille avec Mesh strap et SSW 12'	Non	Non	1,5	P0	10	Oui
11	Qakimajurq	QAKI#12-2	Niveau 1260	1260	Non	W4 - C5-GS2	Installer boulons plasticoated	Oui	Oui	2	P1	20	Oui
12	Qakimajurq	QAKI#13-1	Rampe avant 1240	1240	Oui	C3 - GS3 à GS4	Refaire soutènement au toit car grillage chargé et commence à ouvrir	Non	Non	2	P1	10	Oui
13	Qakimajurq	QAKI#13-3	Entrepôt détonateur		Non	C3-GS2	Gros bloc au toit à solidifier avec SSW 12' et mesh strap	Non	Non	2	P1	15	Oui
14	Qakimajurq	QAKI#14-2	En face de la remuck rampe 1210	1210	Oui	C3 - GS3 à GS4	Vider grillage à 2 endroits et refaire patchs (2 feuilles)	Non	Non	2	P1	10	Oui
15	Qakimajurq	QAKI#15-1	Rampe après la Gear bay		Oui	C3-GS3 faille	Soutènement le long de la faille. Roches dans le grillage à vider. Grillage et SSW.	Non	Non	2	P1	5	Oui
16	Qakimajurq	QAKI#15-2	7C-1190 après station électrique SS-23	1190	Non	C3-GS3 à GS4	Grillage chargé au toit et commence à ouvrir. Refaire 2 feuilles de grillage.	Non	Non	2	P1	5	Oui
18	Qakimajurq	QAKI#13-2	Intersection 7B 1240 PS1	1240	Non	W4 - C3-GS2	Installation de plasticoated (SSW) car humide au toit (un peu murs)	Oui	Non	3	P2	10	Oui
19	Qakimajurq	QAKI#2-1	Rampe au 1550	1550	Oui	C3-C4 GS1-GS2	Quelques sections de grillages à réparer et blocs à vider	Non	Oui	3	P2	10	Oui
20	Qakimajurq	QAKI#8-1	Rampe intersection Acc. Vent.		Oui	W4 - C3-GS1	Mettre SuperSwellex avec 2 meshstrap où humide au toit	Oui	Non	3	P2	10	Oui
21	Qakimajurq	QAKI#10-2	Sortie de secours #4 1300	1300	Non	W5 - C3-GS2	Plasticoated aux murs du "man-way" et au "brow"- entrée du man-way.	Oui	Non	4	P2	20	Oui
27	Qakimajurq	QAKI#12-3	Niveau 1260	1260	Non	W4 - C4-GS2	Installer boulons plasticoated près du secteur puisard	Oui	Oui	4	P2	10	Oui
28	Qakimajurq	QAKI#6-2	Coin remuck 7F-1400	1400	Oui	C3-GS3	Écailler et refaire grillage au toit (1 feuille)	Non	Non	4	P2	15	Oui
29	Qakimajurq	QAKI#6-3	Sortie secours 1400	1400	Non	W7 - C4	Installer SuperSwellex et mesh strap le long de la faille	Oui	Oui	4	P2	15	Oui
	Qakimajurq	QAKI#8-3	Niveau 7ABE 1340 SS#4	1340	Non	W7 - C3-GS-2	Installer SuperSwellex et mesh strap le	Oui	Non	4	P2	15	Oui

Figure 9 Inspection data compilation in Excel

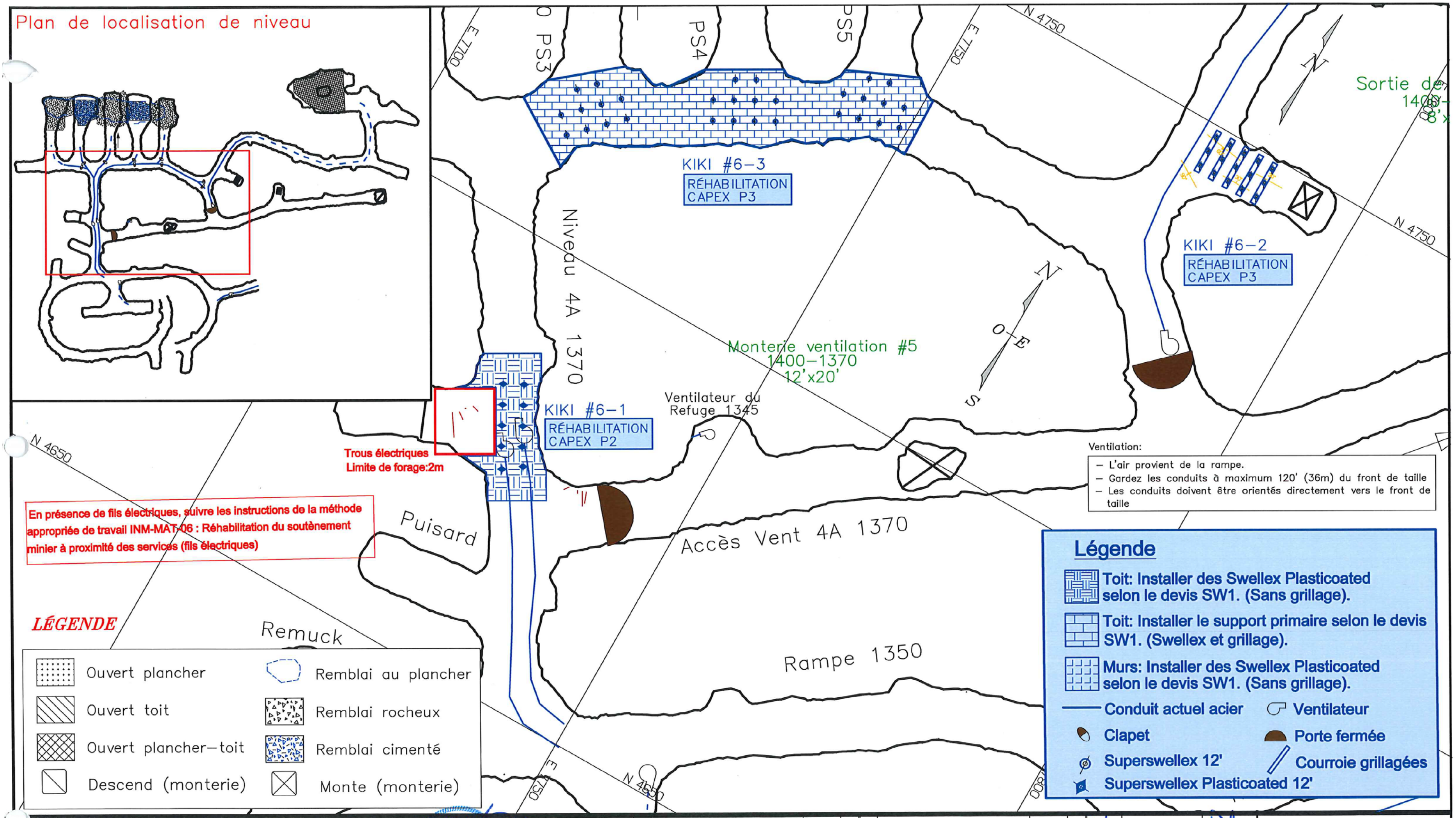


Figure 10 Example of a work plan for underground operations

Table 2 is the summary of the percentages based on priorities for work requested during 2018.

Table 2 Metres of rehabilitation work in every mine and per priority

CAPEX rehabilitation priorities	Metres	% completed (Dec 2018)
P0 and P1	2,207	100%
P0 and P1 – Katinniq	1,369	100%
P0 and P1 – Kikialik	290	98%
P0 and P1 – Qakimajurq	215	100%
P0 and P1 – Mine 2	333	100%
P2 and P3	2,230	35%
P2 and P3 – Katinniq	1,539	17%
P2 and P3 – Kikialik	175	79%
P2 and P3 – Qakimajurq	185	66%
P2 and P3 – Mine 2	331	76%
Total P0, P1, P2 and P3	4,437	67%
Total P0, P1, P2 and P3 – Katinniq	2,908	56%
Total P0, P1, P2 and P3 – Kikialik	465	91%
Total P0, P1, P2 and P3 – Qakimajurq	400	84%
Total P0, P1, P2 and P3 – Mine 2	664	88%
Extra work Katinniq P0 and P1	2,265	60%
Rehabilitation at CV02	458	100%

Figure 11 shows the progress of work on a monthly basis. It is possible to follow the metres of rehabilitation carried out compared to the planned budget. The cost overrun is associated with additional requests added during 2018.

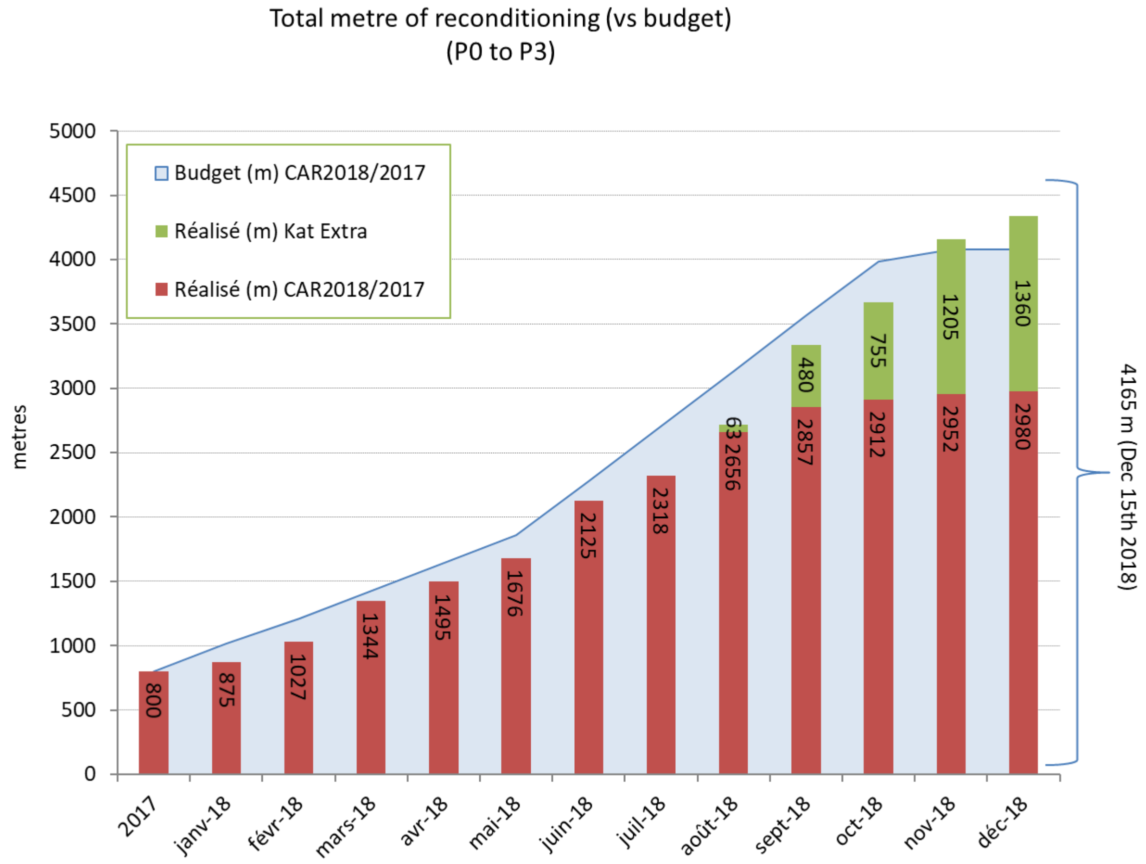


Figure 11 Graph of total rehabilitation metres compiled

5 Conclusion

This paper demonstrates the need for a well-structured inspection program to reduce the risks associated with deterioration of the ground support. The Raglan Mine's CAPEX inspection program includes the characterisation of corrosion levels of ground support and a destructive pull test program on corroded bolts which helps to quantify loss of capacity. This information allows the technical department to design a rehabilitation program based on objective criteria. This in turn can be used in mine planning to improve strategies for choosing support in the future excavation. In 2018 more than 4 km of mining excavation were reconditioned. Different support materials may be used depending upon whether an area is designated for short or long-term access.

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