Optimization of the Red Lake Mine Ventilation System

Keith G. Wallace, Jr.
Mine Ventilation Services, Inc.

Mark Tessier
Goldcorp Inc.

Michael Pahkala
Goldcorp Inc.

Larry Sletmoen
Goldcorp Inc.

ABSTRACT: The Red Lake Mine is the richest gold mine in North America with over 5 million ounces of reserves and a 2004 production of over 550,000 ounces of gold at a cash cost of US$92 per ounce. Starting in 2003, Goldcorp initiated an expansion program at the mine. This expansion included a new 6.55 m (21.5 ft) diameter hoisting shaft currently under construction. The shaft will be driven to a length of approximately 2,000 m (6,500 ft). The shaft will be used as the primary intake to the mine. The original ventilation design was to have a "push/pull" ventilation system. In 2005, a detailed review of the mine expansion program was performed. This review resulted in a proposal for significant modifications to the mine ventilation system. This paper describes the proposed changes in the ventilation system designed to optimize this system.

1 INTRODUCTION

Figure 1 shows the location of the Goldcorp Inc. Red Lake Mine. The mine was started in 1945 with the first bar of gold poured in 1949. In the early years, the primary mining method was small open stopes mined using jacklegs and slushers. The principal access to the mine was through the No. 1 Shaft. This shaft extended to approximately 1,050 m (3,450 ft) below surface. At this depth, the original orebody was determined to continue, but was offset from the No. 1 shaft location by approximately 800 m (2,625 ft). A transfer drift was constructed and an internal No. 2 Shaft was driven from 23 Level to 37 Level. The mine total depth at this time was approximately 1,690 m (5,550 ft).

Both shafts are about 2.13 m x 7.62 m (7 ft x 25 ft). The No. 1 Shaft is equipped with two skips and one dedicated man and material conveyance. The No. 2 Shaft conveyance incorporates the two skips in combination with the man and material handling. The first diesel equipment, a small loader, was purchased in 1979. Around this time, the mining method changed to cut and fill with mobile diesel equipment. However, given the small material conveyance, it has always been a challenge to bring mechanical equipment and materials into the mine.

The original ventilation system consists of intake air passing through small raises connecting open stopes. This has the benefit of not requiring air heating during the cool winter months. Winter temperatures can be as cool as -40 ºC.

Figure 1. Location of Red Lake Mine.

The existing system also has challenges because many of the upper mine areas are inaccessible and any problems in these zones cannot be easily repaired. At the end of 1994, the Red Lake Mine was a marginal operation. In 1995, a $7 million exploration program was initiated that lead to the discovery of a High Grade Zone (HGZ) of gold mineralization. The HGZ was discovered at a depth and location previously thought to have no potential. The average reserve grade of this mineralization is presently 80.6 gpt (2.22 opt). This discovery made the Red Lake Mine the richest gold mine in the world and the largest gold mine in Canada. In April, 2005 Goldcorp Inc. performed a friendly takeover of Wheaton River Minerals Ltd.

Following the new HGZ discovery, and three years of production, Goldcorp began a major deepening program at the mine. This program consisted of constructing a new 6.55 m (21.5 ft) hoisting shaft (called the McEwen Shaft). In addition, a 3.66 m (12 ft) return shaft was proposed from surface to the 38-2 Level. In the summer of 2005, a complete review of the proposed mine and ventilation plan was performed. During this review several major changes to the design were analyzed and recommended for inclusion in the design. These changes included the removal of intake booster fans, increasing the size and number of exhaust airways, including the primary exhaust raise to surface, and modifying the mine plan to allow for a rapid completion of the new McEwen Shaft.

2 VENTILATION SURVEY

The Goldcorp Red Lake Mine ventilation system design is based on a ventilation survey performed in 2003. This survey included measurements of airflow, pressure differential, fan performance, and psychrometric properties. In addition, rock thermal properties of the virgin rock temperature, conductivity and thermal diffusivity were measured.

The survey and rock property measurements are described in a paper given in the Eighth International Mine Ventilation Congress. In summary, the ventilation survey resulted in a basic model that was correlated against measured airflows with the percent error calculated to be 6%. The basic model was used extensively to determine future fan requirements, and ventilation system upgrades required to support the mining rates predicted for the Red Lake Mine. The thermal rock temperatures measured in the mine showed the interesting result that the rock is actually cooler than the air on the lower mining horizons measured during the survey. These results are shown graphically on Figure 2. Recent data collected on the deepest level of the mine confirm the geothermal gradient being used at the mine. Figure 3 shows the predicted temperature gradient in relation to depth. The data collected during the survey was used to predict the future ventilation options at the Red Lake Mine.

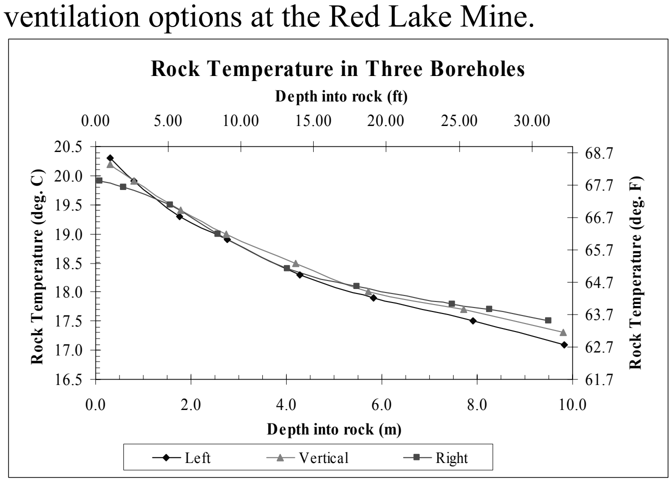

Figure 2. Rock temperature in borehole.

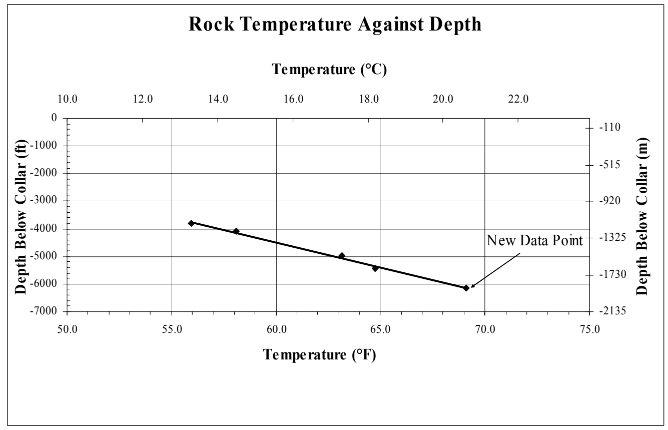

Figure 3. Rock temperature against depth.

3 ORIGINAL VENTILATION DESIGN

Figure 4 shows the original predicted ventilation design for the year 2012 for the Red Lake Mine. For ventilation purposes, the mine was divided into three Zones. Zone 1 is from 30 to 37 Level, Zone 2 is from 37 to 43 Level, and Zone 3 is from 43 to 47 Level. The year 2012 was used as the maximum ventilation requirements for the mine since each Zone was assumed to be in production at this time.

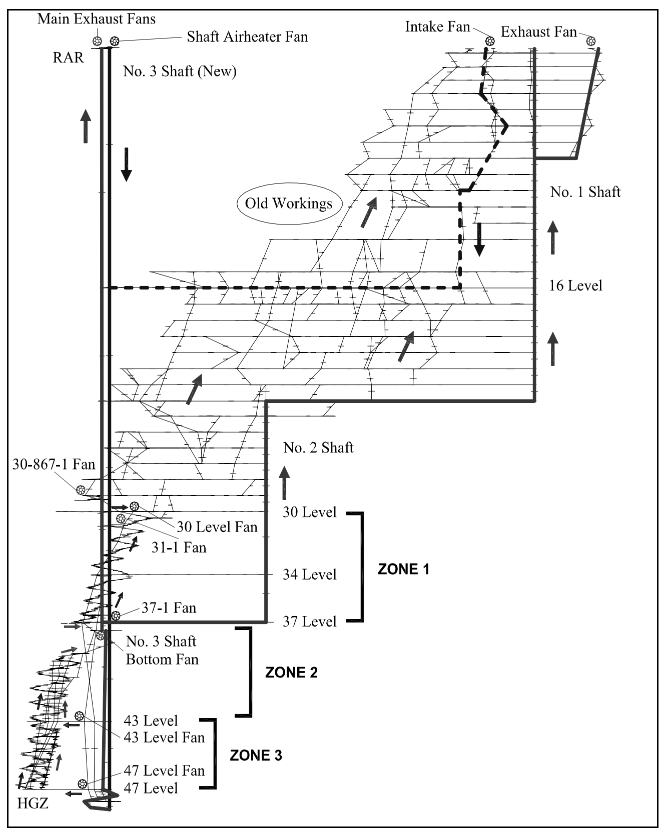

Figure 4. Original ventilation system design (predicted for 2012).

From the results of the various field tests and ventilation survey, and from data provided by the Red Lake Mine engineering team, a set of design criteria were established. This criteria included typical friction factors, resistance per length factors, shock losses associated with raises, rock thermal properties, and heat loads from existing stopes. Airflow requirements were based on providing sufficient airflow for the expected diesel equipment fleet, fixed facilities, leakage and travelways. Based on the original design, the airflow requirements were predicted to be 70.8 m^3/s (150,000 cfm) per Zone with each active sublevel ventilated with between 14.2 and 18.8 m^3/s (30,000 to 40,000 cfm).

Climatic simulations conducted for the original mine design showed that in primary airways the predicted environmental conditions should be below the design criteria of 26.6 ºC (80 ºF) wet bulb temperature. This is possible because of the low rock temperatures. Nevertheless, there may be areas in stopes that can exceed this criterion. However, the new design should have more airflow per stope which will help reduce temperatures in these areas.

A significant benefit is realized by bringing un-heated intake air in the existing, stopes in the upper portion of the mine. The stopes ice up in the winter months which results in heating the air in winter months and cooling the air in summer. For the ventilation analyses, two scenarios were analyzed. One was using the existing surface intake fan to push air into the mine to 16 Level where it would combine with intake air in the McEwen Shaft. This results in 66.1 to 70.8 m^3/s (140,000 to 150,000 cfm) entering the shaft on 16 Level. Since the intake air in the old mine workings could be affected by ground falls, a second intake scenario was analyzed where only 47.2 m^3/s (100,000 cfm) reached the McEwen Shaft on 16 Level.

4 PRELIMINARY MODIFICATIONS TO THE MINE VENTILATION SYSTEM

The original design required intake booster fans near the McEwen Shaft on the 43 and 47 Levels, respectively. These fans were required because of the limited return capacity in the proposed 3.66 m (12 ft) return raise. During the review of the overall mine plan in the summer of 2005, Goldcorp engineers decided that intake booster fans were undesirable from an operational and ventilation perspective. In addition, the mine plan was modified to not drive the McEwen Shaft to the 47 Level but, rather, to the 43 Level. By reducing the shaft length, the lower mining horizon could be brought on line sooner. Options will be maintained to sink the McEwen Shaft to below 47 Level after initiating production from Zones 2 and 3. Production from Zone 3 would be achieved by truck haulage up to 43 Level.

The airflow requirements for the new design were based on the following:

Zone 1: 70.8 to 84.9 m^3/s (150,000 to 180,000 cfm)
Zone 2: 70.8 m^3/s (150,000 cfm)
Zone 3: 70.8 m^3/s (150,000 cfm) plus 33.0 m^3/s (70,000 cfm) for shop and trackless haulage.

The Zone 2 and 3 requirements combined to give a total volume across 43 Level of 174.6 m^3/s (370,000 cfm). The total predicted mine volume was calculated to be 264.2 m^3/s (560,000 cfm) which is an increase of 47.2 m^3/s (100,000 cfm) over the original ventilation modeling scenarios. To achieve this airflow distribution and to remove the intake booster fans from the system, the *preliminary* ventilation modeling showed that the mine required a number of changes. These changes included:

1. 5.5 m (18 ft) diameter return air raise (RAR) is constructed from surface to the 23 Level.
2. From 37 to 23 Level two 4.0 m (13 ft) RARs are driven in parallel and connect to the 5.5 m (18 ft) RAR on 23 Level.
3. 43 Level mined at 5.5 m x 5.5 m (18 ft x 18 ft) dimension (to achieve the total flow requirements for Zones 2 and 3).
4. New return air raise (RAR) internal to Zones 2 and 3 at bored 4.0 m (13 ft) diameter. This raise is in parallel with a 2.7 m (9 ft) Alimak RAR raise in Zone 2.
5. Both Zones 2 and 3 have a 2.7 m (9 ft) Alimak fresh air raise (FAR). The FAR in Zone 3 will be used as a second egress route.
6. 38-2 Level slashed to 5.5 x 5.5 m (18 x 18 ft).
7. Adjust Zone 1 area fans to achieve 42.5 m^3/s (90,000 cfm) from 37-1 to 34 Level and 70.8 m^3/s (150,000 cfm) from 34 to 30 Levels.
8. 2.7 m (9 ft) raised borehole from shaft bottom to 38-2 Level.

Figure 5 is a sketch of the bottom levels of the mine showing this infrastructure.

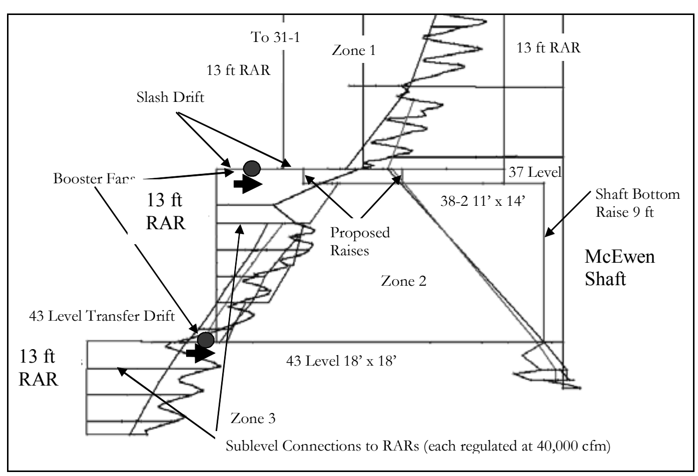

Figure 5. Preliminary modifications to lower mine.

5 OPTIMIZED VENTILATION SYSTEM

From the initial mine plan, further optimizations were performed. Many of these changes were designed to expedite development schedules, to better utilize existing mine infrastructure for ventilation purposes, or for geotechnical reasons. The changes include:

1. A 3.05 m x 3.05 m (10 ft x 10 ft) track drift will be driven from the base of the ramp in the HGZ at 42 Level across to the McEwen Shaft. This drift will be used to assist in the development of the shaft and the infrastructure around the shaft location (shop, loading pocket, etc.) Once the shaft and ramp are in, the track will be pulled for greater ventilation area.
2. A 4.6 m x 4.9 m (15 ft x 16 ft) ramp will be driven at a slight down grade from the 42 Level near the McEwen Shaft to the 43 Level at the HGZ ramp.
3. Below 43 Level (Zone 3) in the HGZ, the ramp will be driven at 4.3 m x 4.3 m (14 ft x 14 ft) to accommodate the truck haulage system below the 43 Level. Exhaust from this area will be through a 4.0 m x 4.0 m (13 ft x 13 ft) raise.
4. Above 43 Level to 38-2 Level (Zone 2), the intake air will be provided in the ramp and in the FAR parallel to the ramp. Twin 3.05 m (10 ft) diameter exhaust raises will be driven to return air from Zones 2 and 3.
5. Booster fans will be required on the return on level 43 to pull air up from Zone 3. In addition, a booster fan is required on the top of the two 3.05 m (10 ft) raises on 37 Level. For this time phase, each sublevel connection to the RARs is regulated with the exception of the lowest level. For this scenario, the lowest level was taken as 47 Level. The mine is expected to go deeper, but at this time, it was assumed that mining would be nearing completion in the upper part of Zone 2 allowing greater airflow to Zone 3.
6. The return raise system comprises of one 4.0 m (13 ft) diameter raise from 37 Level to 31-1 Level. On 31-1 the air transfers across existing drifts to the base of another 4.0 m (13 ft) diameter return raise up to 23 Level. A second 4.0 m (13 ft) diameter raise connects 37-1 Level to 23 Level. From 37-1 to 38-2 Level a 4.0 m x 4.0 m (13 ft x 13 ft) drop raise is driven to exhaust air from these two levels.
7. On 38-2 a 1.83 m (6 ft) diameter raise connects from the shaft bottom area (42 Level). This raise was initially designed to take air from the conveyor drift and shop. This design may change as it may not be possible to place the raise near the conveyor level.
8. The top of the 5.5 m (18 ft) RAR from 23 Level to Surface is reduced to 4.4 m (14.5 ft) in diameter for the last 15 m (50 ft). This reduction was necessary to accommodate construction limitations caused by an existing reinforced concrete pad.
9. Trucks will be used to haul ore and waste from the base of Zone 2 and from each sublevel in Zone 3. To meet existing production requirements, only two trucks were calculated to be in operation at any one time.
10. A conveyor drift will be installed near the McEwen Shaft. A flow of about 9.4 m^3/s (20,000 cfm) is designed to exhaust directly to the shaft bottom RAR.
11. The shop/fuel bay is moved to near the McEwen Shaft. The facility is designed for an airflow of about 14.2 m^3/s (30,000 cfm) exhausted to the shaft bottom RAR.

Two future time phases were considered for this study. The first time phase was at the end of 2007. At this time, Zone 2 is in full operation, but only one 3.05 m (10 ft) RAR is in place to 37 Level. The complete return system above 37 Level is assumed to be in place. Zone 3 was ventilated with 35.4 m^3/s (75,000 cfm). This air is required for driving the ramp and initial sublevel development.

The maximum airflow scenario was assumed to be around 2009 (and for several years after) when Zone 3 is in full production in addition to Zones 1 and 2. At this time, all ventilation infrastructure is in place. Only the 2009 model was run with a limited 47.2 m^3/s (100,000 cfm) entering the McEwen Shaft at 16 Level.

5.1 *Model Results*

The 2007 model showed that the primary surface exhaust fan should be capable of pulling air through the shop raise and across 37 Level without the need of booster fans. Zone 1 is ventilated with the existing 30 Level booster fan, the 37-1 Level intake booster fans, one exhaust fan on the 31-826 ramp at the 30 Level exhaust and a second exhaust fan on the 30-867-1 Ramp. The surface intake and exhaust fans are also operating at this time. The existing 22 Level booster fans are removed at this time. The predicted results of the modeling for 2007 are shown on Figure 6 (in Imperial Units).

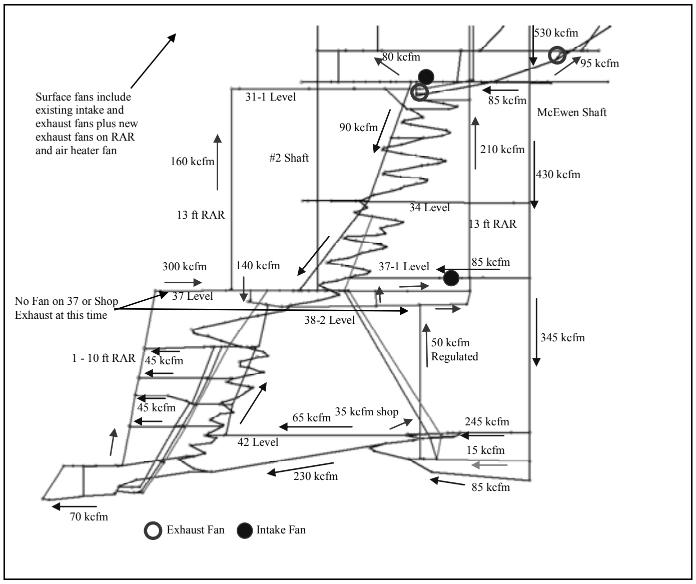

Figure 6. Predicted airflow distribution and fan locations for ventilation system at the end of 2007.

By 2009 it is assumed that the ventilation system is near full capacity. All Zones are fully ventilated with the deepest point in the mine development being to 47 Level. At this time, each sublevel in Zones 2 and 3 are ventilated with 21.2 m^3/s (45,000 cfm). Booster fans are required on the exhaust on 43 Level and 37 Level to help pull the air through the sublevels. An exhaust fan is also required on the shop exhaust raise. Zone 1 is ventilated as described in the 2007 model. Figure 7 depicts the predicted airflow distribution at this time (in Imperial Units).

The 2007 airflow distribution was developed assuming the maximum airflow available with the existing surface intake fan pushing air to 16 Level. Two additional models were developed which showed the impact on main fans if only 47.2 m^3/s (100,000 cfm) were available to 16 Level and if no air was available to 16 Level. These models did not change the airflow distribution significantly, but did impact the fan duties.

5.2 *Fan Requirements*

Table 1 shows the predicted air heating and fan operating costs for the models developed for this study. The model reflecting a complete loss of 16 Level intake was included in this table. For this analysis, it was assumed that the power cost is 8.1 cents per kWhr and that the propane cost is $0.58 per liquid liter. The results indicate that using the 16 Level as an intake saves significant air heating costs, however, limiting the intake to only 100,000 cfm does not have a large impact on the operating costs.

Fan duties were determined for each scenario modeled. These results are shown on Table 2. It is

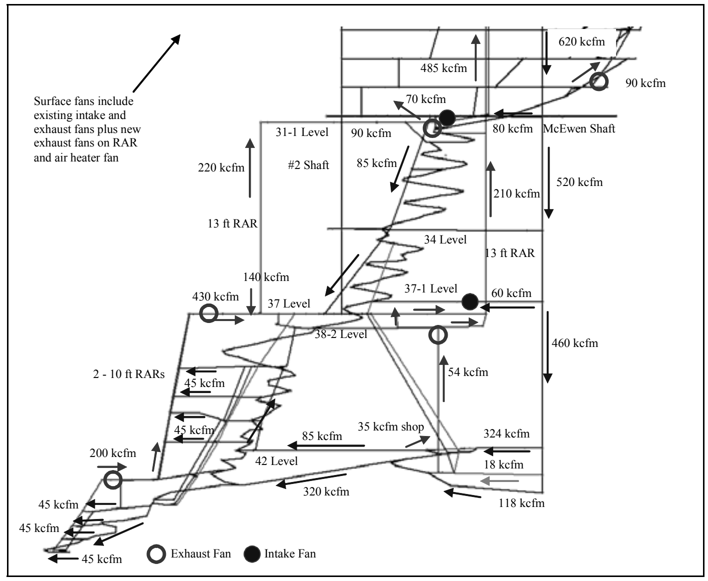

Figure 7. Predicted airflow distribution and fan locations for ventilation system at the end of 2009.

Table 1. Summary of analyses.

Scenario	Year	Number of fans in mine	Total fan horsepower*	Fan op. cost ($/yr)*	Heating op. cost ($/yr)*	Total Cost ($/yr)
Single intake for mine through McEwen Shaft (assumes dual intake will be available through 2007)	2006	n/a	n/a	n/a	n/a	n/a
	2007	n/a	n/a	n/a	n/a	n/a
	2009	13	3759	$1,929,952	$2,688,550	$4,618,502
Dual intake to 16 Level then through McEwen Shaft	2006	7	1021	$540,425	$0	$540,425
	2007	10	2091	$1,088,282	$1,827,783	$2,916,066
	2009	14	3656	$1,899,886	$2,148,729	$4,048,615
	2009*	14	3331	$1,737,134	$2,292,334	$4,029,468

* Assumes 100 kcfm through 16 Level to McEwen Shaft. Electrical power assumed at 8.1 cents/kWhr and propane at 0.58 $/liquid liter

Difference Between Dual Intake System and no airflow to 16 Level.

Year	Number of fans in mine	Total fan horsepower	Fan op. cost ($/yr)*	Heating op. cost ($/yr)*	Total Cost ($/yr)
2009	1	-428	-$30,066	-$396,216	-$426,282

Results indicate that fan operating costs are similar for the dual system, but that air heating costs are lower. Net result is total cost is less for the dual intake system.

important to note that the fan pressures shown for new fans does not include internal fan losses, duct work, etc. The cited pressures are the static pressure across the fan bulkhead or to the shaft collar. Any additional losses associated with the fan and duct need to be added to these duties.

6 SUMMARY

The Goldcorp Red Lake Mine is undergoing a major expansion project. Two new shafts are presently under construction. As part of this project, a significant ventilation study was initiated. This study consisted of surveying the existing mine system, measuring in-situ rock properties, establishing a basic ventilation model of the mine, and using the model to evaluate future ventilation requirements. In addition to ventilation analyses, climatic simulations were performed to predict the working environment in the major access airways in the mine. Throughout the study, a major consideration was utilizing the existing infrastructure as much as possible. The new ventilation system reflects this by using the existing airways on 31-1, 37, and 38-2 Levels.

The key results of this study show that by allowing about 30% of the summer intake air to course through the existing old workings, the temperature in the shaft is predicted to be reduced by 4 ºC when compared to having all the air entering the McEwen Shaft. This is a significant reduction and translates to a reduced temperature throughout the mine.

Goldcorp's Red Lake Mine is a world class operation. A state of the art ventilation system is presently being incorporated to provide a safe and reliable environment for the mine's workforce. The initial system components should be operational in late 2006.

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8 ACKNOWLEDGEMENTS

The authors wish to thank the management of Goldcorp Inc. for permission in publishing this paper.

Table 2. Summary of predicted fan duties.

Shop Conveyor Fan on 6 ft RAR		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	n/a	n/a
2009A	4.8	53.6
2009B	4.6	49.4

37-1 Intake Boosters (2 fans)		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	7.3	87.8
2009A	9.0	75.2
2009B	9.1	66.0

Primary Surface Exhaust Fans		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	14.5	398.3
2009A	14.5	522.7
2009B	15.0	526.2

30-867-1 Ramp Fan (1 fan)		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	8.0	105.8
2009A	8.5	104.7
2009B	9.5	101.9

43 Level Booster		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	n/a	n/a
2009A	0.5	246.4
2009B	0.5	253.0

30 Level Raise Fan (1 fan)		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	8.0	75.3
2009A	8.5	74.7
2009B	9.5	83.8

37 Level Booster (2 fans)		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	n/a	n/a
2009A	6.8	426.4
2009B	6.8	433.0

#3 Shaft Air Heater		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	n/a	n/a
2007	0.8	424.2
2009A	0.8	498.7
2009B	0.9	532.0

Note: "*A*" indicates dual intake system to 16 Level and "*B*" indicates 100 kcfm to 16 Level with the remaining intake air through the McEwen Shaft. Fan pressures shown above indicate delivered static pressure across fan bulkhead or to the collar of the exhaust shaft. It does not include internal fan velocity losses, silencers, duct losses, etc.

Temp Booster 31-1		
Year	Pressure (in. w.g.)	Quantity (kcfm)
2006	5.4	150.02