Using meaningful reconciliation information to evaluate predictive models

M.E. Rossi and J. Camacho V.

Abstract

Reconciliation of production information is critical to evaluating the effectiveness of predictive models that would allow for the optimization of mining operations. Whether mining open pit or underground, mine-to-mill reconciliations can be one of management's better tools for the performance of proper accounting. Such reconciliations can also be a very useful tool in evaluation and optimization. This paper proposes a set of criteria and objectives for a typical reconciliation program. This paper also presents a stepwise, logical approach to performing reconciliations and discusses the benefits associated maintaining good information. It also highlights some of the potential pitfalls involved and the methods used to avoid collecting misleading information. These issues are illustrated with an example of a model-to-mine-to-mill reconciliation program that is being implemented at an operating mine. The program involves multiple predictive models (long-term and short-term block models), feed from three open pits and one underground mine, in addition to intermediate stockpiling, for a total of 23 mill streams. This paper presents a summarized version of this reconciliation program and its initial results as implemented at Minera Michilla S.A.

Figure 1 — Location map of the Michilla Mine.

Introduction

Minera Michilla S.A. owns and operates a mostly Cu oxide deposit in northern Chile, approximately 120 km (75 miles) north of the city of Antofagasta (Fig. 1). Minera Michilla S.A. is a fully owned subsidiary of Anaconda Chile, based in Santiago, Chile, which in turn is part of the Antofagasta Holdings group. The Michilla mine produces approximately 60,000 t/a (66,000 stpy) of cathode copper, in addition to smaller amounts of copper concentrates.

The deposit is located on the Coastal Cordillera at an elevation of about 900-m (3,000-ft) and in an area where Cu has been mined for decades. There are several small to medium-sized orebodies in the district, some of which are mined directly by Minera Michilla, while others are mined by smaller, contracted companies who sell the ore to Michilla for processing. Both underground and open pit deposits are mined in the Michilla district.

The geology of the area is characterized by a very thick, well-studied volcanic sequence, known as the La Negra Formation. The La Negra Formation is inclined N30°W and consists of a stratified series of andesites and volcanic breccias of various characteristics. The andesitic sequence varies from aphanitic to porphyritic, with intercalated volcanic breccias. The more porous strata (breccias and porphyric andesites) host most of the Cu mineralization.

Genetic models to date suggest that Cu mineralization occurs locally as high-grade bodies in higher porosity strata. A significant portion of the deposit presents oxide mineralization, typically atacamite, although there is also significant chrysocolla. Regionally, mineralization is hosted around smaller dioritic intrusives, themselves barren, but that are thought to have contributed to the mineralization of the host volcanic sequence.

In addition to the stratigraphic controls, mineralization is also strongly controlled by a series of important structures, mainly the Muelle fault, striking N45°E/N60°E, and also by a set of minor, roughly parallel, structures and its conjugate set.

The existing mineralized bodies ("mantos") are generally ellipsoidal in shape (concordant with stratification) and are of variable size and grade. In general, most bodies are 4- to 5-m- (13- to 16-ft) thick, but with widely varying widths and lengths, up to 40 or 50 m (130 to 160 ft). All grade ranges are found within these bodies, but typically they will vary between 1% and 5% Cu. Grades over 10% are commonly reported, with individual 1-m samples reaching as much as 25% total Cu and 15% soluble Cu. The open pits typically mine up to 5% total Cu "mantos", with a mill-feed grade averaging approximately 1.6% total Cu.

Objectives and requirements

The main objectives of any reconciliation program in a producing mine can be summarized as follows:

M.E. Rossi, member SME, is geostatistician with GeoSystems International, Milpitas, CA; **J. Camacho V** is geology superintendent with Minera Michilla S.A., Antofagasta, Chile. Preprint 99-020, presented at the SME Annual Meeting, March 1-3, 1999, Denver, CO. Revised manuscript accepted for publication February 2000. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME prior to Sept. 30, 2001.

- to properly account for the total material mined and processed;
- to evaluate the operation's performance for all departments managing the resource; and
- to assess the accuracy of the predictive models (resource and reserves models) and to allow for a more accurate cash-flow prediction and valuation of the mining property at all times.

These objectives are all interrelated, and their relative importance will vary from one operation to another depending on its characteristics. In addition, there are some basic requirements to be met for any reconciliation program to provide meaningful information. These include:

- top management involvement (typically the operations manager);
- coordination among the geology, mine-planning, operations and metallurgy departments;
- understanding of the different sources of information and their limitations; and
- clear delineation of responsibilities for each department to ensure proper information gathering and processing, including designated individual(s) responsible for preparing the corresponding monthly reports).

The first requirement is essential because production reconciliation can quickly become a cause of disagreement among the groups involved. As anyone familiar with this type of operation would all too easily recognize, metallurgists will tend to blame the mine for lower head grades (because almost always they are able to achieve the desired, constant recoveries and tail grades); the mining department will tend to blame the geology department for poor predictive models; and the geology department will eventually recognize that more in-fill drilling is required to solve the production vs. modeling discrepancies, which are often due to "support" issues, short-range variability and unplanned dilution. A better way to ensure a good-faith effort from all involved is for the operations manager to recognize the importance of the issue and to adequately distribute responsibilities and prioritize the tasks involved in a reconciliation program.

Another important aspect is to recognize the practical difficulties that invariably will appear when designing and implementing a reconciliation program. Many mines simply do not sample head grades, either because samplers are too "expensive" or because there are practical problems associated with sampling some of the streams. For example, run of mine material cannot be sampled, and, in general, leach operations that stack coarse material may not lend themselves to reliable sampling. Other operations may not sample blast holes or may not sample all the blast holes available. These problems can and should be addressed on an individual basis; if changes are required (for example, a new sampler for head grades) it is generally feasible to perform a cost-benefit analysis that would allow management to make informed decisions. The case study presented here illustrates some of the practical issues that normally arise in any reconciliation program.

Performance assessment criteria

The basis for the criteria presented here is common in the mining industry. Most of the operations that do perform production reconciliations do so utilizing some variant of comparison factors, also known as mine call factors. The explicit presentation here follows an expanded scheme from one proposed by H.M. Parker (personal communication).

The factors proposed are intended to separately evaluate the model estimates to daily grade-control estimates and to process head-grade estimates. Model estimates may include long-term models (reserve block models) and short-term models.[1] This should be done for tonnages and grades and should be based on a reasonable production period. Appropriately, the more commonly used production period is monthly, although there can be some exceptions to this.

The basic information to be compiled is as follows:

- Tons, grades and metal content of the long-term (block) model for the period. This implies obtaining the volumes corresponding to the advances for the period and to superimpose them on the reserves block model.
- In similar fashion, tons, grades and metal contents should be obtained for short-term models, if they exist.
- Tons, grades and metal contents should be obtained from the daily planning model (grade-control model). This information should be gathered daily but compiled into the proper reconciliation period (monthly). The reason for monthly reconciliations is that a sufficiently large statistical mass needs to be gathered before any definite conclusions can be reached. The grade-control model, with all its potential problems and pitfalls (generally due to sampling and sometimes due to inadequate modeling techniques), represents the best possible "in situ" information available, because the model is based on the greatest sample data density available.
- Tons, grades, and metal content *as reported by the mine* should also be compiled. The grade usually corresponds to the grade assigned to the extracted panel by the grade-control model (which often includes some downgrading to consider operational dilution). Reported tonnage may be from truck factors, direct topographic measurement of the extracted volumes or, sometimes, even the same tonnage reported by the grade-control model.
- Tons, grades and metal content informed as head grades and tons. This should be based on *direct sampling,* as opposed to back-calculated from tailings or discharge grades and assumed recoveries.

There may be stockpiles to be considered between the mine and the mill. Also, there is sometimes material to be considered within the crushing and grinding streams themselves, prior to the head sampler. However, some or all of these stockpiles may not be relevant to the reconciliation program. If all stockpiles are completely turned over and replaced within the reporting period, they can be ignored for production reconciliation.

With the information described above, the performance factors can be calculated. It will be assumed that a monthly comparison period is chosen. Then the factors may be defined as:

- F_1 factors, defined for tons, grades and metal content (F_{1t}, F_{1l}, F_{1f}); they are based on the corresponding tons, grades and metal of the long-term model vs. the short-term model (if it exists) and are calculated as

$$F_1 = \frac{Short-term\ \ model}{Long-term\ \ model} \quad (1)$$

- F_2 factors, defined for tons, grades and metal content (F_{2t}, F_{2l}, F_{2f}); these are based on the corresponding tons,

[1] "Long term" here refers to models used in long-term mine planning (semiannually or annually minimum, up to life-of-mine); "short-term " refers typically to the one-to-six months planning horizon.

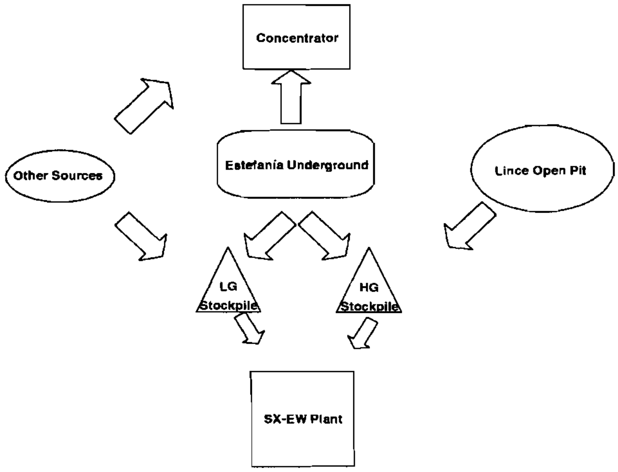

Figure 2 — Schematic flow of material at Michilla.

grades and metal content of the grade-control model vs. the short-term model (if it exists) and are calculated as

$$F_2 = \frac{Grade-control\ \ model}{Short-term\ \ model} \tag{2}$$

- F_3 factors, defined for tons, grades and metal content (F_{3t}, F_{3l}, F_{3f}); these are based on the corresponding tons, grades and metal content of the monthly mine report vs. the grade-control model. Sometimes mine reports for tonnage and grades are simply taken from the grade-control model and are informed as material sent to the mill. In other instances, they use the grade provided by the grade-control model (generally there is no other option), but the reported tonnage is based on truck counts or volumetric measurements of the advances. If applicable, the F_3 factors are calculated as:

$$F_3 = \frac{Mine\ \ reported}{Grade-control\ \ model} \tag{3}$$

- F_4 factors, defined for tons, grades, and metal content (F_{4t}, F_{4l}, F_{4f}); these are based on the corresponding tons, grades and metal content of the "received-at-mill" material vs. the mine reported material. The F_4 factors may be calculated as

$$F_4 = \frac{Received\ \ at\ \ mill}{Mine\ \ reported} \tag{4}$$

From these factors, several performance measures can be directly obtained. For example, to quantify, the accuracy of the long-term model in terms of tons and grades of ore delivered to the mill, an F_{LTM} factor for each of the variables can be obtained as

$$F_{LTM} = F_1 * F_2 * F_3 * F_4 = \frac{Received\ \ at\ \ mill}{Long-term\ \ model} \tag{5}$$

F_{LTM} measures how well the reserves block model predicts material delivered to the mill (the foundation of the prediction of future cash flows). Similarly, an F_{STM} can be defined to quantify the benefits achieved by, for example, in-fill drilling, assuming this is the difference between a long-term model and a short-term model

$$F_{STM} = F_2 * F_3 * F_4 = \frac{Received\ \ at\ \ mill}{Short-term\ \ model} \tag{6}$$

To compare the accuracy of the grade-control model vs. the material received at the mill, that is, to evaluate mine operating performance and unplanned dilution and ore loss, F_{GCM} can be calculated as

$$F_{GCM} = F_3 * F_4 = \frac{Received\ \ at\ \ mill}{Grade-control\ \ model} \tag{7}$$

Finally, note the F_4 factor measures directly the ore loss and dilution in the haulage and stockpiling system. This is assuming that the sampling points at the mill are deemed reliable for both tons and grades.

It is important to consider an appropriate time scale for these comparisons. For example, it is not likely that comparing the long-term model and the material delivered at the mill on a weekly, biweekly or even monthly basis is relevant. The purpose of the long-term model is to support long-term mine planning and scheduling, which is generally based on time units of six months, one year or more. Therefore, it is not appropriate to compare them at a smaller time unit, because the long-term model should not generally be used for small-scale estimation. This is because these models are based on widely spaced data, and it is generally difficult to predict the support (internal dilution) effect to be encountered at the time of mining. The reader is referred to Rossi and Parker (1993) for a more complete discussion of these and related issues. Similarly, and depending on whether stockpiles exist and how large they are, the F_3 and F_4 factors can be compared on a weekly or even daily basis, because it measures the mine reported material vs. the received at mill material.

Note that always a factor greater than 1.0 implies underestimation, while a factor smaller than 1.0 implies overestimation. Also, note that all the factors (for tons, grades and metal content) have no units.

The Michilla case study

The Michilla mine represents a complicated case for a thorough reconciliation program because of the numerous feed streams, multiple processing facilities and stockpiling practices. The main source of Cu is the Lince open pit, operated by Michilla, which produces only oxide ores. The other important source operated by Michilla is the underground mine Estefanía, which produces oxide, mixed and sulfide ore. In addition, there are several other sources of ore. These are smaller deposits that are operated by contractors and include Desierto Norte, Gambeta, Graebe, Polos Central, Polos Sur, Buena Vista, Falla Condell, Puerto Arturo, Urbina and Panizos Blancos. Most of these smaller deposits produce both oxide and mixed and sulfide ore. The processing facilities include a Cu oxide plant, where the ores are agglomerated, leached and the resulting solutions are treated in an SX-EW facility. From the SX-EW facility, approximately 60,000 t/a (66,000 stpy) of high-purity cathodes are produced. The mixed and sulfide ores are fed to a standard concentrator. Figure 2 shows a simplified scheme of the material movement at the mine.

For illustrative purposes, this paper deals with the reconciliation program for the oxide Cu plant only, fed from either the Lince open pit directly or from two intermediate stockpiles (high and low grade). This implies that all other feed to the cathode plant, coming from either the Estefanía underground mine or any of the other smaller deposits in the area will have to be discounted out. This is done by operating a separate crushing and grinding circuit for the feed from the smaller deposits in addition to not mixing the material coming from each one of these smaller deposits, i.e., batch-processing them.

The open pit mine operated at the time of comparison without a "formal" grade-control model. Blast holes were sampled only occasionally, and ore/waste selections were made by visual observations. This was deemed feasible because the main oxide minerals (atacamite and chrysocolla) are green or blue-green. However, this selection method proved later to be inadequate, because the visual observations can have as much as 100% difference compared to the corresponding laboratory results.

The SX-EW plant cutoff is 1% Cu, while the "low-grade" ore stockpile cutoff used is 0.5%. In part, this is because the plant has been designed for a 1.6%-Cu constant feed. Given that the ore out of the pit can vary from 0.5% to 6% Cu, Michilla utilizes two stockpiles for mixing ores. A large low-grade stockpile, 3 to 4 Mt (3.3 to 4.4 million st), which reportedly averages 0.7% Cu, and smaller high-grade stockpile, which usually turns over within a week.

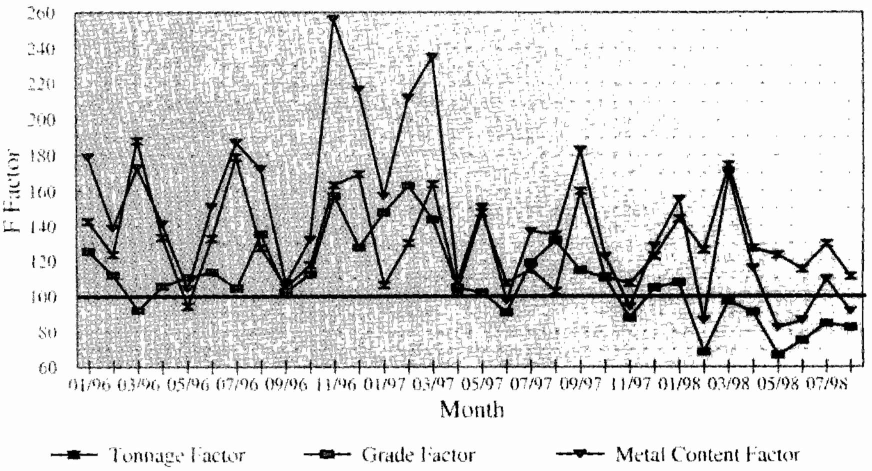

Figure 3 — Long-term model vs. mine reported factors.

Reconciliation program: January 1996 through August 1998. Given the information available at the time, the reconciliation program that was designed had two main objectives:

- to demonstrate to management the benefits derived from such a program in support of an integrated and ambitious operations optimization plan and
- to highlight the areas were basic information was deficient or lacking.

One such area of deficiency was the grade-control model for the Lince open pit, which was at the time virtually nonexistent. In addition, the practice of using truck factors was shown to be deficient, and, therefore, more frequent comparisons with random truck weighing programs was required, as well as calibrations of the belt weightometers at the crusher circuit.

The reconciliation practices incorporate better information as it becomes available. For the purposes of this paper, the reconciliation program as it stood for the period January 1996 through August 1998 is considered.

The initial comparison is to obtain the factors between the Long-term block model and the mine reports, here a combination of the F_1, F_2 and F_3 factors introduced above. As described before, the tons and grades from the long-term block model are obtained by passing the monthly advances through the model.

The mine reports take the tonnages obtained by using the surveyed advances and applying an appropriate density factor.[2] The grades used correspond to the grades informed by mine geology, which, for most of the months used here, are based on visual observations. Only in the latter months of 1998 do the grades correspond to the grade-control model now being implemented and tested. It is, therefore, not surprising to obtain the discrepancies observed.

The other set of factors presented here is the F_4 factors, i.e., received at mill vs. mine reported. Adequate tracking of the material movement between the open pit mine and the feed to the agglomeration plant is not trivial.

[2]Michilla has developed a detailed density model, by rock type and grade, which is updated every other year.

There are two crushing lines at the SX-EW plant before the material is sent to the agglomeration plant to heap leaching. In addition, material movement at the high- and low-grade stockpiles have to be considered, and, also, there should be proper discounting of the material sent to the SX-EW plant from other sources (including the Estefanía underground mine and the Graebe mine, another significant contributor). The intermediate tables and information on which the discounting of tons and grades are based are not presented here.

Finally, as part of the regular reconciliation program, there are several intermediate reconciliations that are performed on a regular basis. These include comparing truck factors vs. surveyed advances in the pit, which are the basis for the official mine reports, and, more recently, established random truck weighing practice against truck factors. In addition, several internal checks of belt weightometers among themselves are made on a routine basis, to assess the need for calibration beyond what is considered routine maintenance.

Figure 3 shows the $F_{LTM/MR}$ (long-term block model vs. mine reported) factors for tonnages, grades and metal content for the 32-month period. It is quite evident that the long-term model fails to predict the material reported by the mine; however, it is also clear that at least the grades that the mine reports are highly suspect. In addition, it is interesting to note that in the more recent months in the chart all factors tend to stabilize lower and closer to 1.0. This is, in part, due to the establishment of sampling and the use of a grade-control model in the pit.

Figure 4 shows the F_4 factors for tonnages, grades and metal content. As defined above, the comparison is made between the received at mill and mine reported. It is again evident that there are significant differences in the behavior of the factors in 1998. Tonnage falls better in line with expectation, while the grade-control model achieves significantly better selection.

Finally, Fig. 5 shows the F_{LTM} factor, that is, the factor that measure how well the long-term reserves model predicts material sent to the mill. This factor was obtained by multiplying the two previous factors. Note that, regardless of the time-scale factor used, there is a clear need to revise the long-term model, given the discrepancies observed.

Finally, if the information presented in Fig. 5 is averaged to four-month periods, then a better reading of the underlying long-term trend is observed. Figure 6 shows the resulting trend, which clearly justifies revising the long-term block model and the resulting mine plan.

Conclusions

Some of the more obvious benefits of reconciliation programs have been demonstrated. If designed correctly, it can assess several important aspects of the operations, including:

- An analysis of the performance of the long-term reserves model and, therefore, the adequacy of the long-term mine plan.
- The need (or not) for developing short-term models, for short-term mine planning.
- An assessment of the adequacy of the sampling program at the time of ore/waste selection and the grade-control model implemented.
- An assessment of the unplanned dilution and ore losses (actually achieved) vs. the projected dilution and ore losses.
- An assessment of the need for stockpiling, according to plant requirements and material available for mining at any given time.

The immediate benefits derived for the particular case study presented here were:

- Development of a computerized grade-control model, which led to a significant decrease in dilution and ore loss.
- Revision of the long-term reserves model, including changes to the estimation procedures, to better reflect the material received at the mill, i.e., *recoverable reserves.*
- Support for several optimization and cost-cutting programs.
- Informed decisions with respect to several mining contracts between Minera Michilla and third parties.
- A recognition of the uncertainties involved in developing the reconciliation program as presented here; therefore, recognition of the need for collecting better information in certain areas of the operation.

Maintenance and future updates of the reconciliation program presented here, along with adaptations according to the new information being developed, will allow to demonstrate and quantify the progress achieved in all these areas.

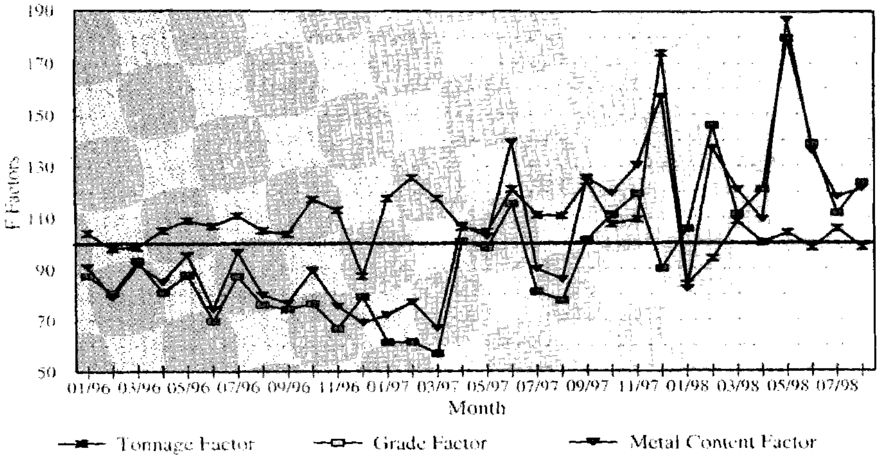

Figure 4 — Received at mill vs. mine reported factors.

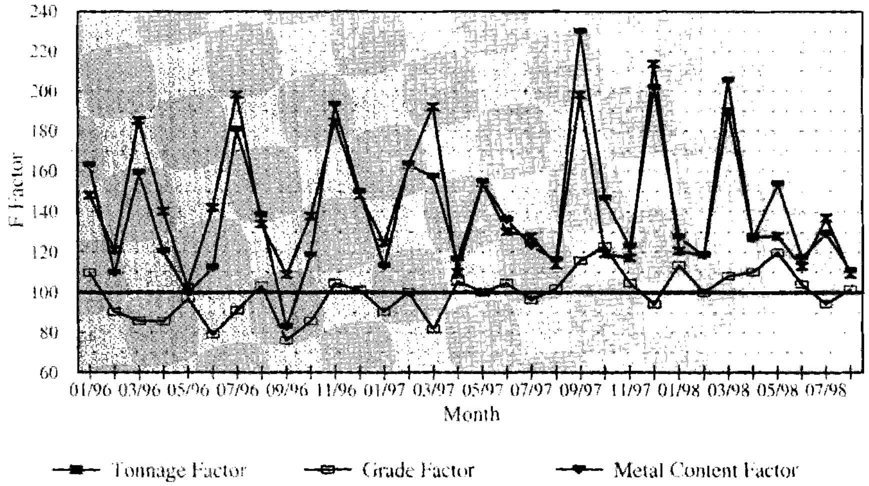

Figure 5 — Long-term model vs. received at mill factors.

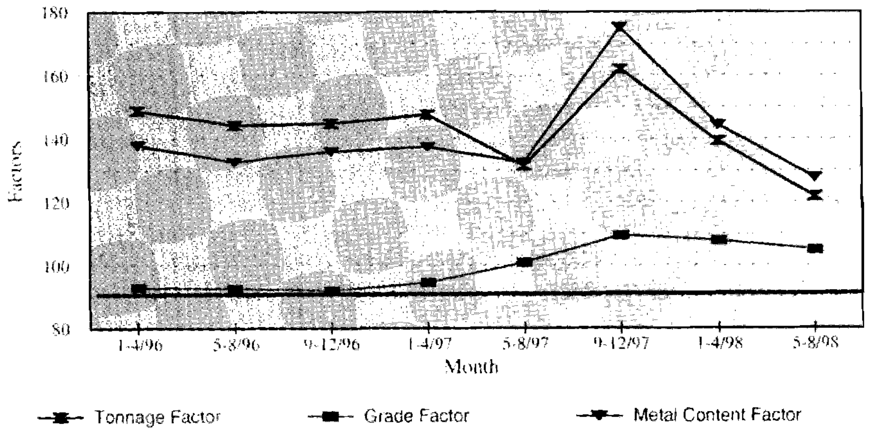

Figure 6 — Long-term model vs. received at mill factors, four-month averages.

Acknowledgments

The management at Minera Michilla is gratefully acknowledged for their permission to publish this information. In particular, Mr. Horacio Bruna, general manager, is acknowledged for supporting the reconciliation program. In addition, Mr. Vedran Tomicic A-L is gratefully acknowledged for compiling the information presented here, and the staffs of the Geology, Mining and Metallurgical Departments are acknowledged for their cooperation.

References

GeoSystems International, 1997a, "Informe Diagnóstico de la Operación Rajo Lince," Cía Minera Michilla S.A., unpublished Internal Report, May 1997, 17p.

GeoSystems International, 1997b, "Informe Visita No. 2, Operación Rajo Lince," Cía Minera Michilla S.A., unpublished Internal Report, July 1997, 51 p.

Rossi, M.E., and Parker, H.M., 1993, "Estimating recoverable reserves: Is it hopeless?" presented at the Forum "Geostatistics for the Next Century," Montreal, Quebec, Canada, June 3-5.