Uncertainty and Risk Models for Decision-Making Processes

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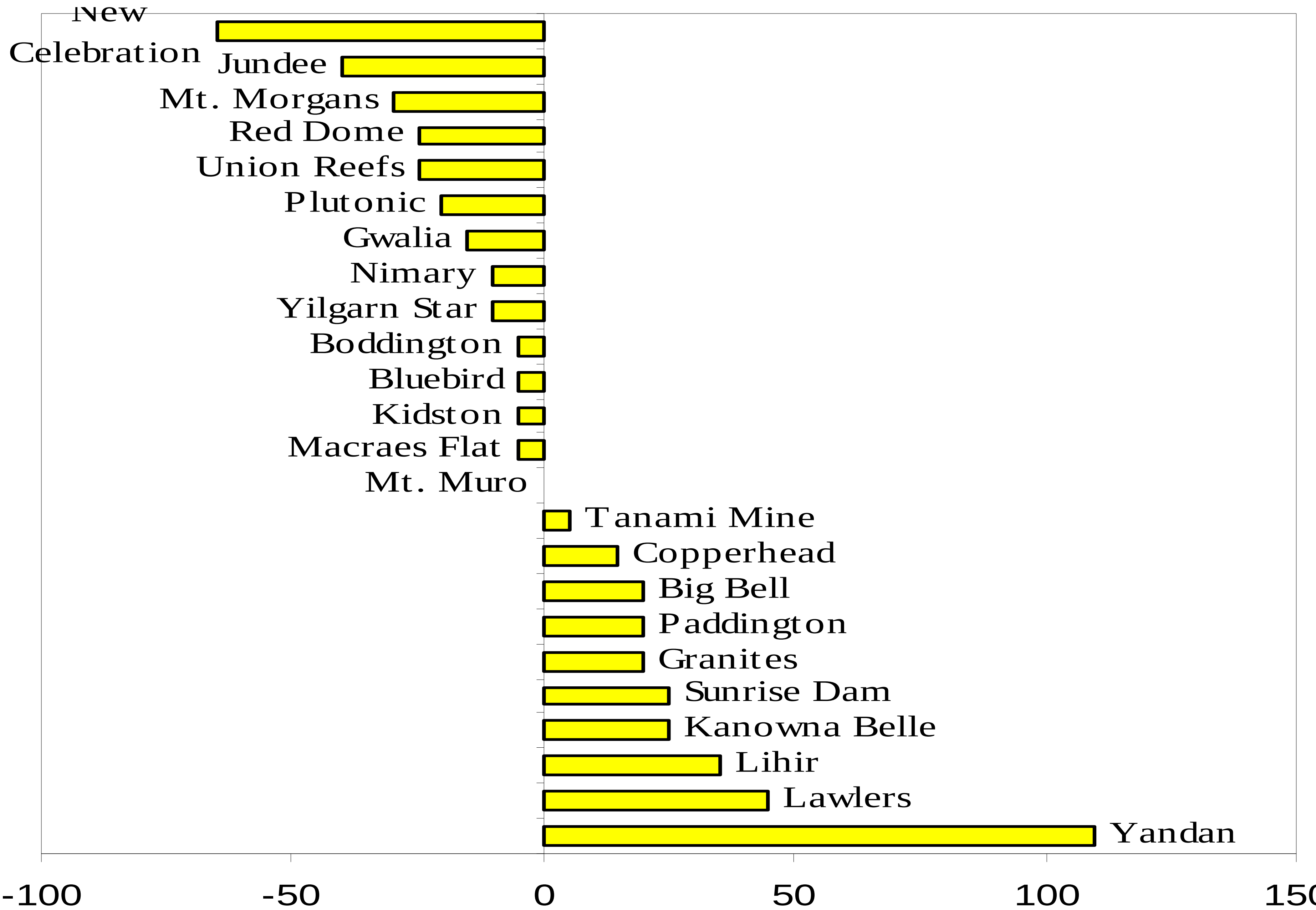
Introduction

- Most Feasibility Studies are not based on accurate Reserves calculations.
- Assessment of the uncertainty and risk associated with a specific Mine Plan.
- Are there enough reserves to support the Mine Plan ***on a monthly basis***?
- Results based on a production schedule, the expanded Production Rate.



Deviation from Stated Reserve Grade (%), (from Baker and Giacomo 1998).

METHODOLOGY

- Based on the use of Conditional Simulations.
- Objective is to validate the predicted Mine Plan Grade, so the conditional simulation model should use the same information as the Block Model used to develop the Mine Plan.

SOURCES OF UNCERTAINTY (1)

- **Lack of Information.** Depends on the geology, and stage of the project.
- **Sampling.** Includes sampling itself, sample prep., sample assaying, sample and data handling, etc.
- **Geologic Model.** Includes logging, geologic data base handling, ore controls determination, interpretations, and computerized modeling.

SOURCES OF UNCERTAINTY (2)

- **Grade Estimation.** All aspects of block modeling.
- **Recoverable Reserves Estimation.** Usually the single most important factor of under- or overestimation.

The Case Study (1)

- Large Porphyry Copper Operation in northern Chile:
  - Originally about 150,000 tons cathode Cu/year production, Feasibility Study to expand a 250,000 tons cathode Cu/year.
  - Approximately 820 Mtons @ 0.54% Cu in Reserves and Resources.
  - Typical Porphyry Copper mineralization. Oxide mineralization intermixed with Leached material, structurally controlled.

The Case Study (2)

- Block Model based on 25x25x15m blocks, 15m bench composites, and a detailed Geologic Model describing Leached, Oxide, Mixed, Secondary Enriched (Strong and Weak), and Primary mineralization.
- Selective Mining Units (SMU) are considered to be the same 25x25x15m blocks.

The Case Study (3)

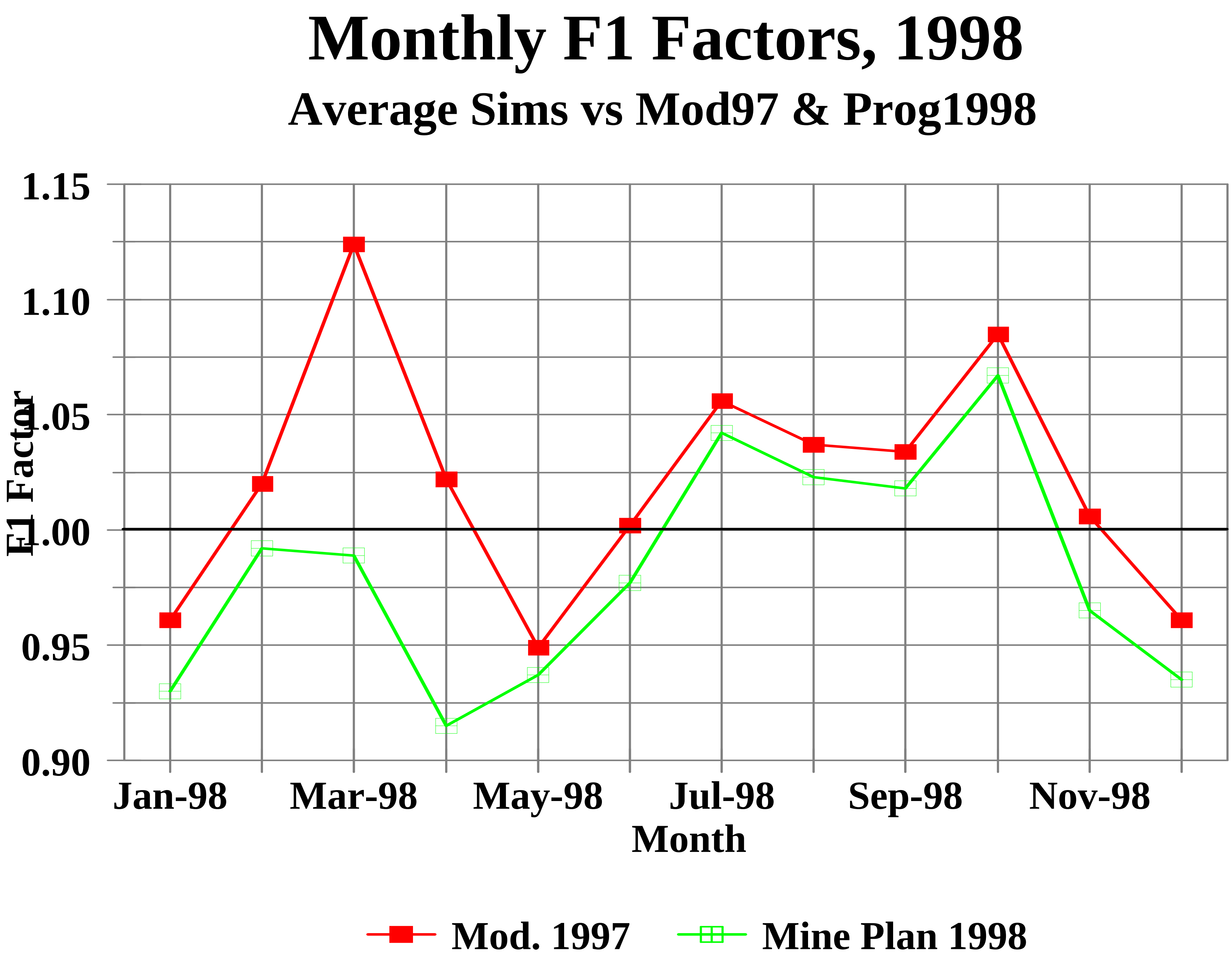
- Sequential Gaussian Simulation Model based on the same information, originally 5x5x15m nodes. Used same 15m bench composites, and same Geologic Model.
- Characterization of the Uncertainty related to Grade Estimation and Recoverable Reserves Estimation.

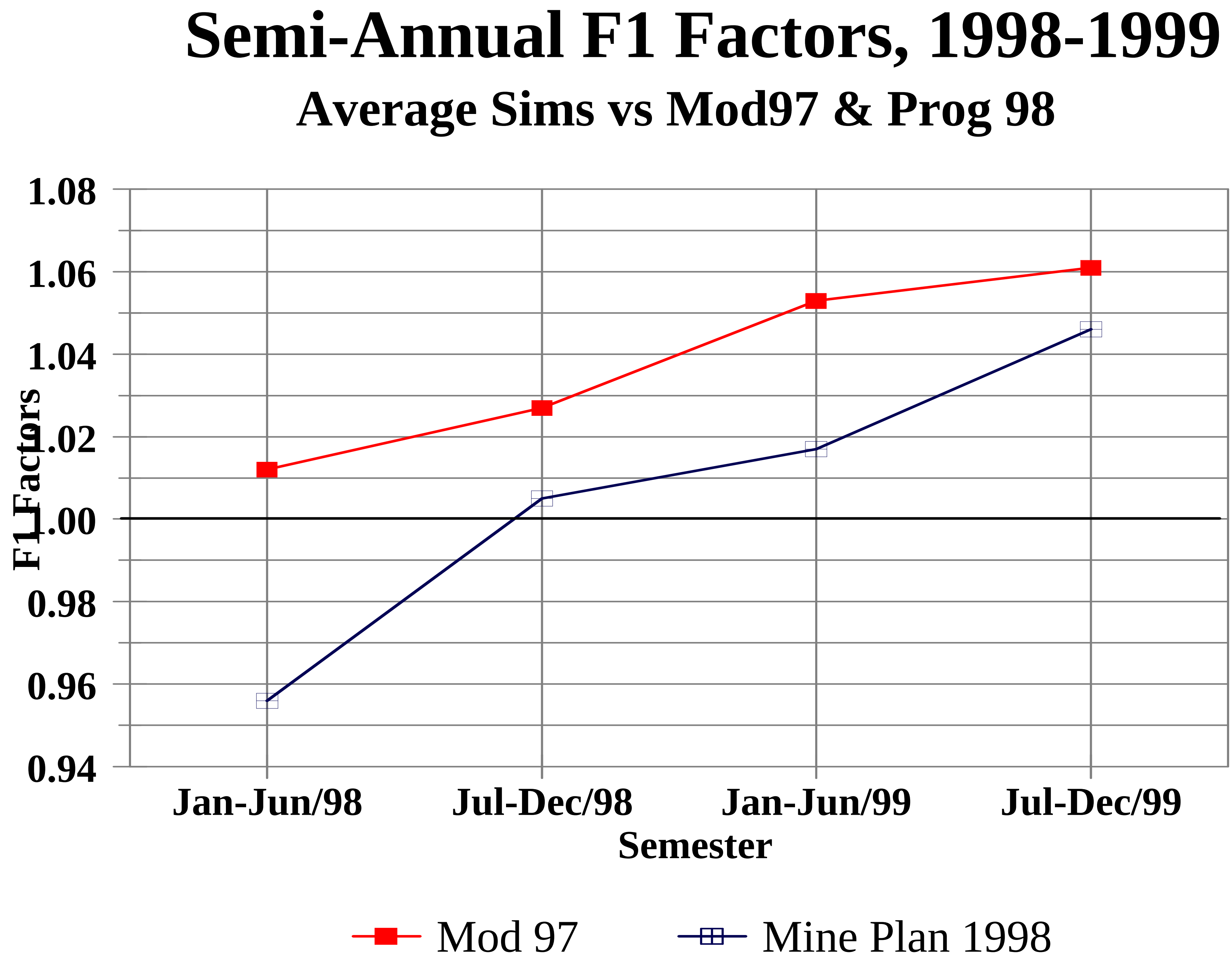
Results (1)

- Comparison is based on Schedule developed for the Expansion Case.
- Used 4 variables to compare:
  - » "Raw" Block Model Grade;
  - » "Planned" Block Model Grade;
  - » Average of 11 Conditional Simulations.
  - » Upper and Lower Probability Interval of Conditional Simulations, representing the 10th and 90th percentile.

Results (2)

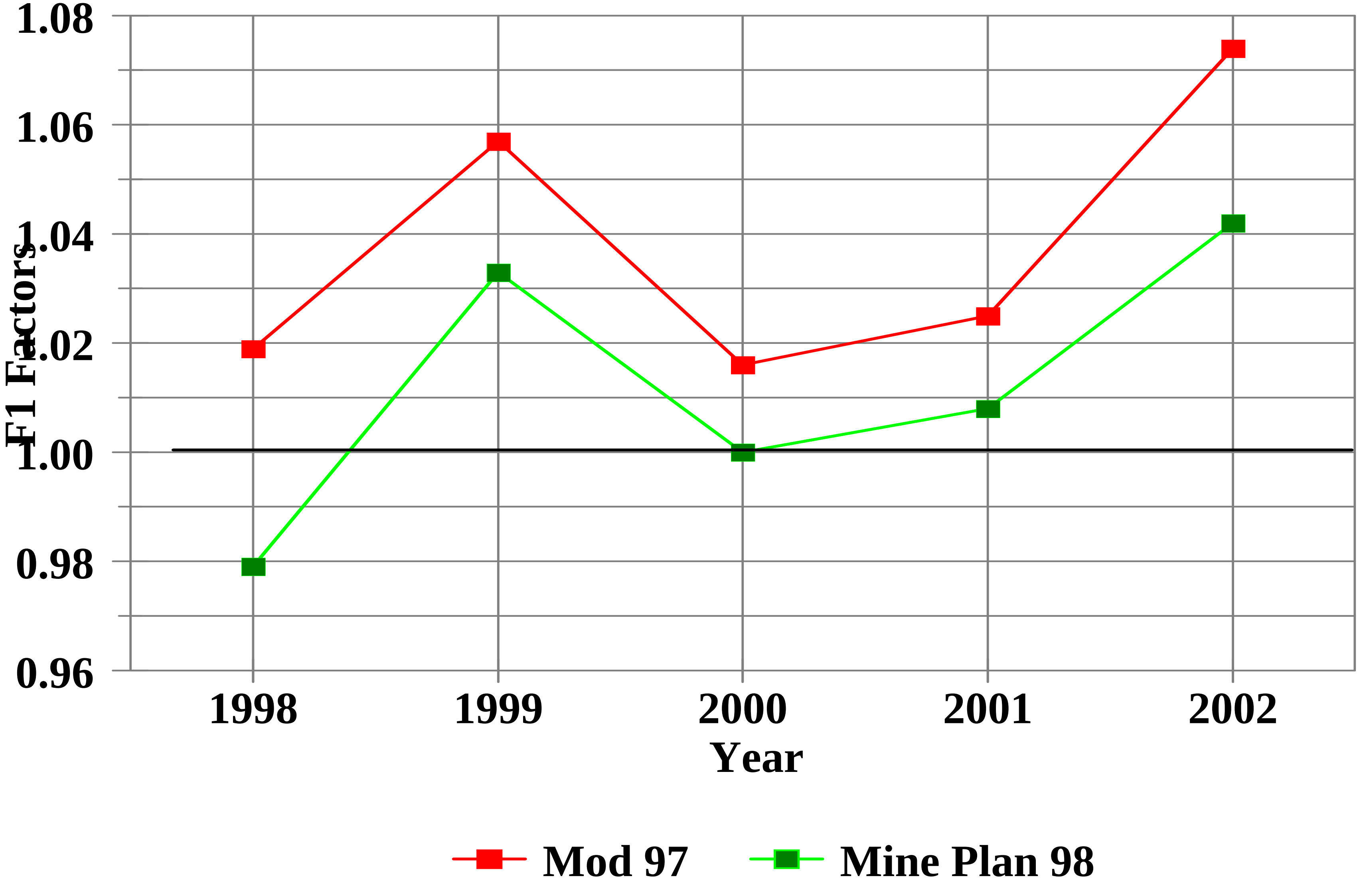
- Use of Factors for Comparison: The F_1 Factor is defined as Block Model/Grade Control.
- Factors are calculated for tonnage, grade, and metal content
- Mine Schedule developed monthly for 1998 (including individual blasts), semi-annually for 1999, and yearly for 2000-2004.

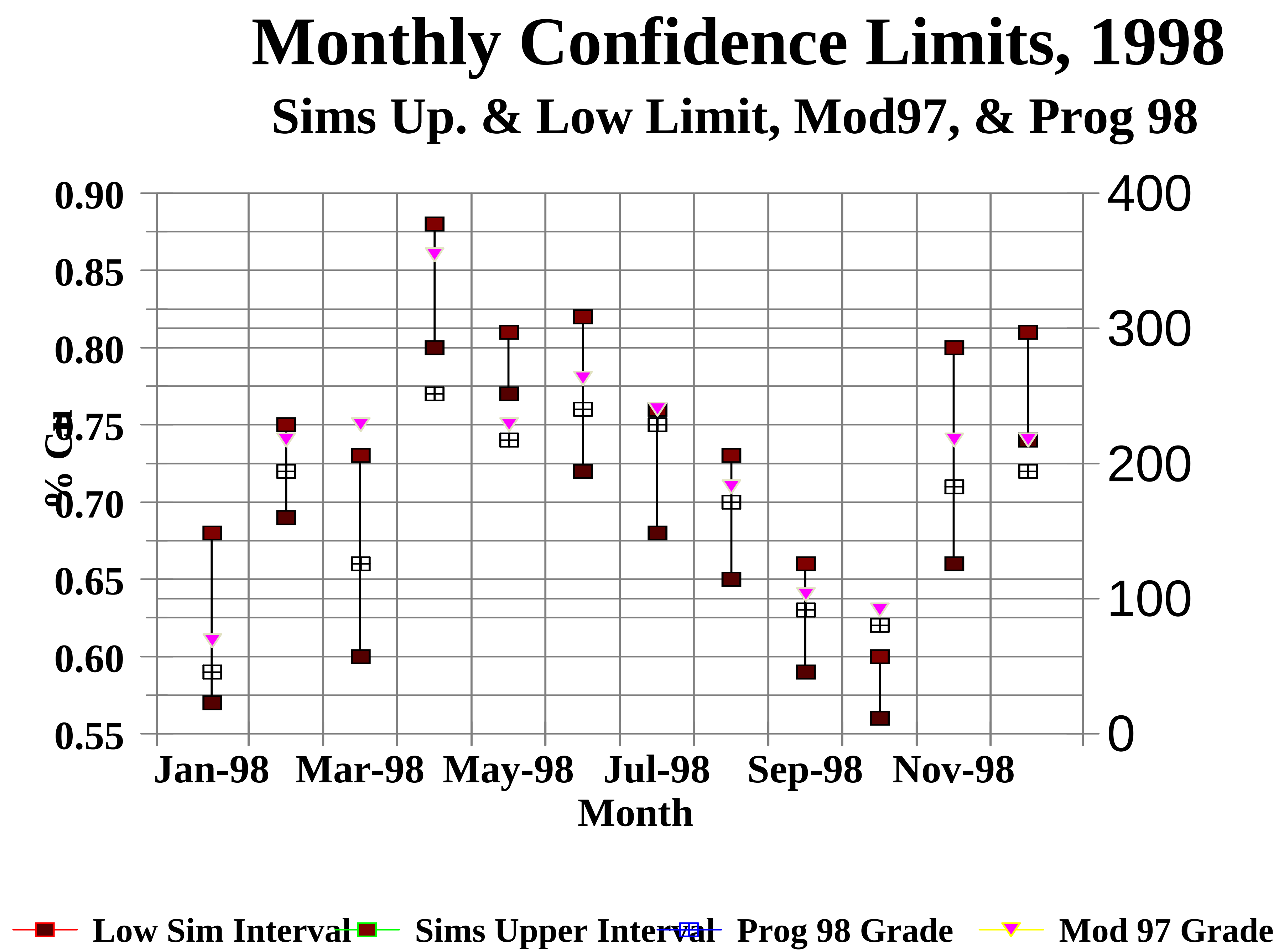

Monthly F1 Factors, 1998
Average Sims vs Mod97 & Prog1998
1.15
1.10
1.05
1.00
0.95
0.90
F1 Factor
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Month
Mod. 1997
Mine Plan 1998


Semi-Annual F1 Factors, 1998-1999
Average Sims vs Mod97 & Prog 98
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
F1 Factors
Jan-Jun/98
Jul-Dec/98
Jan-Jun/99
Jul-Dec/99
Semester
Mod 97
Mine Plan 1998

Yearly F1 Factors, 1998-2002

Average Sims vs Mod97 & Prog. 98

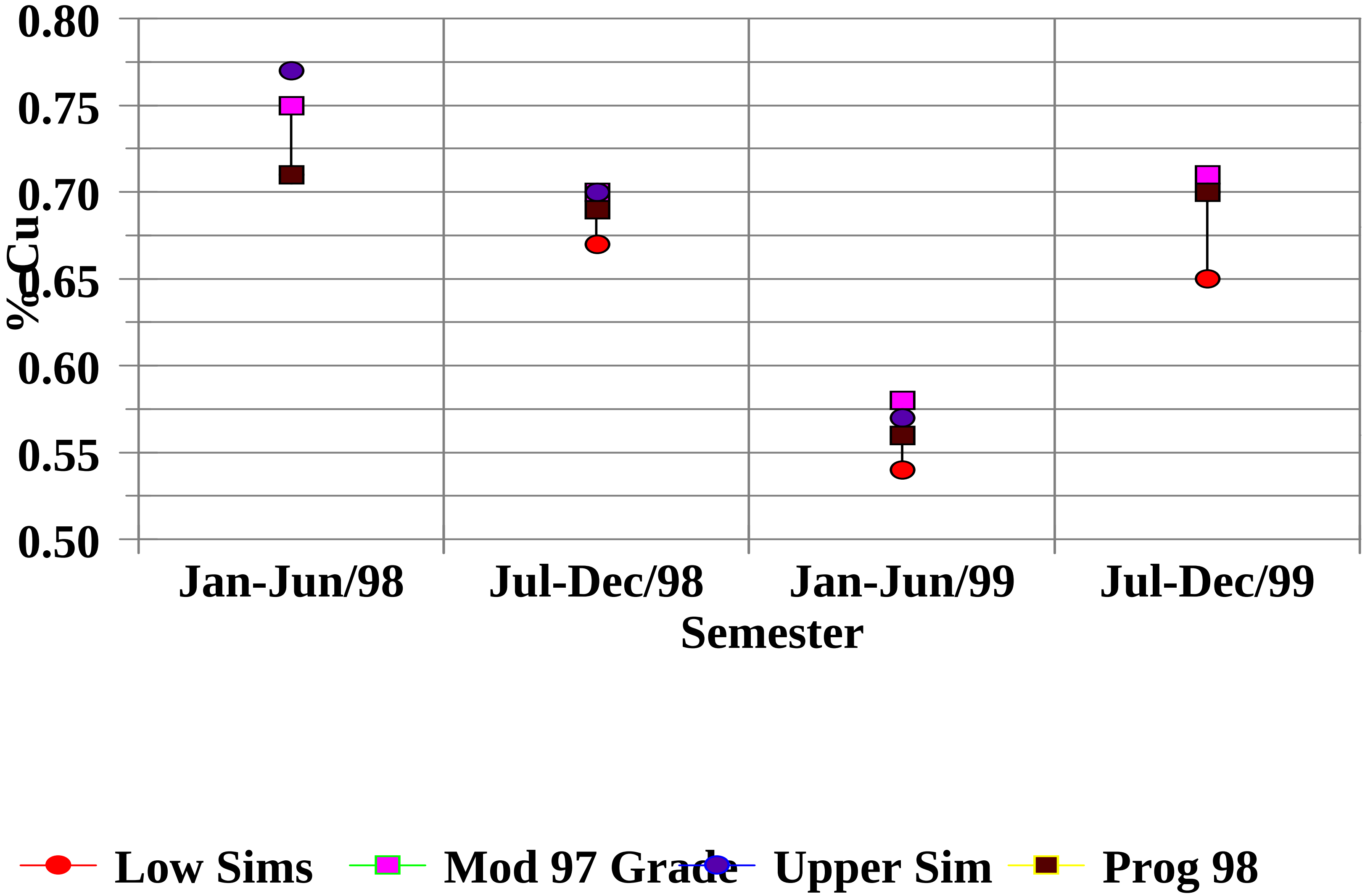




Monthly Confidence Limits, 1998
Sims Up. & Low Limit, Mod97, & Prog 98
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
% Cu
400
300
200
100
0
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Month
Low Sim Interval
Sims Upper Interval
Prog 98 Grade
Mod 97 Grade

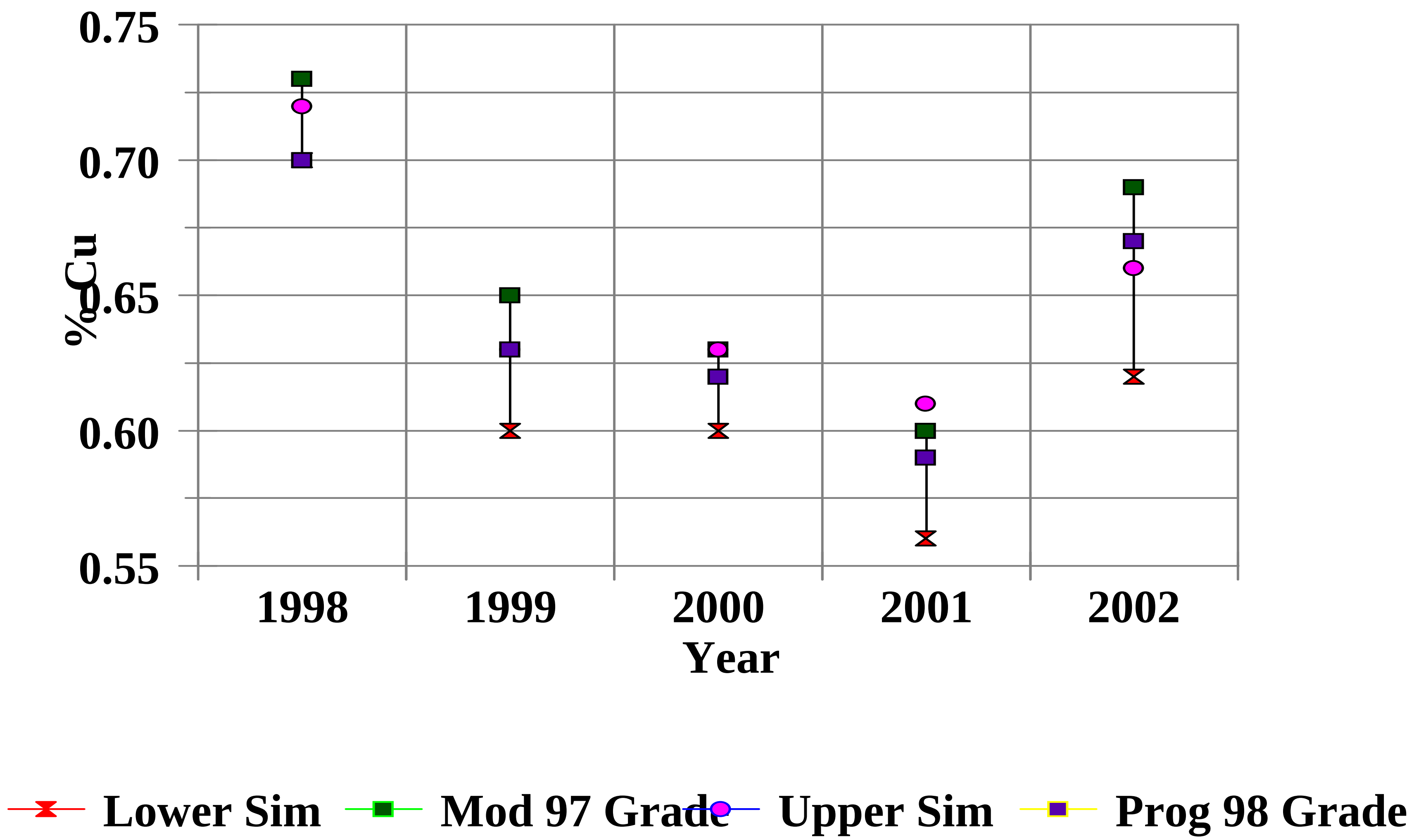
Semi-Annual Conf. Limits, 98-99

Upper/Lower Limits, Mod97 & Prog98



Annual Confidence Limits, 1998-2002

Sims Up. & Low Limit, Mod97, & Prog98



Conclusions (1)

- Conditional Simulations are becoming standard tools for analyzing uncertainty, risks analysis, and sensitivity analysis.
- The benefits of detailed (local), geology-based risk analysis outweighs the additional costs involved in a CS study.

Conclusions (2)

- CS allows for an increased confidence in Mine Plans and corresponding predicted cash-flows, so that arbitrary recovery and correction factors are not required.

- The planned expansion was approved, and, recently, its construction awarded.

Conclusions (3)

- The Probability Intervals that the CS model provided allowed for detailed planning of future in-fill campaigns.

- The planned expansion was approved, and, recently, its construction awarded.