Mineral-deposit models are an integral part of quantitative mineral-resource assessment. As the focus of mineral-deposit modeling has moved from metals to industrial minerals, procedure has been modified and may be sufficient to model surficial sand and gravel deposits. Sand and gravel models are needed to assess resource-supply analyses for planning future development and renewal of infrastructure. Successful modeling of sand and gravel deposits must address (1) deposit volumes and geometries, (2) sizes of fragments within the deposits, (3) physical characteristics of the material, and (4) chemical composition and chemical reactivity of the material. Several models of sand and gravel volumes and geometries have been prepared and suggest the following: Sand and gravel deposits in alluvial fans have a median volume of 35 million m$^3$. Deposits in all other geologic settings have a median volume of 5.4 million m$^3$, a median area of 120 ha, and a median thickness of 4 m. The area of a sand and gravel deposit can be predicted from volume using a regression model ($\log$ [area (ha)] $= 1.47 + 0.79 \log$ [volume (million m$^3$)]). In similar fashion, the volume of a sand and gravel deposit can be predicted from area using the regression ($\log$ [volume (million m$^3$)] $= -1.45 + 1.07 \log$ [area (ha)]). Classifying deposits by fragment size can be done using models of the percentage of sand, gravel, and silt within deposits. A classification scheme based on fragment size is sufficiently general to be applied anywhere.

Key words:
Sand and gravel
Aggregate
Volume model
Area model
Frequency distribution
Mineral-resource assessment
Regression model
Quantitative models such as the type discussed here are used by government, industry, and academia in mineral-resource assessment and exploration. Models help supply reasonable answers to questions such as these:

What is the size of an undiscovered mineral deposit?  
What is the metal grade of an undiscovered mineral deposit?  
How many undiscovered mineral deposits are likely?

Answers to these questions form the basis for quantitative mineral resource assessment. Answers to these questions are valuable to local land managers considering land-use alternatives, as well as to those interested in how much metal (or material) is yet to be discovered in a region or even a country. Because the deposit(s) is undiscovered, exact answers (for example, the volume is 500,000 m³) are impossible. This is because "uncertainty is an integral part of the problem" (Singer, 1993, p. 70). We need to know how deposit volumes vary before attempting to forecast the volume of a single undiscovered deposit! Models do this. A volume model uses data from a representative sampling of all volumes reported for a certain type of deposit. The predicted volume in an undiscovered deposit is not a single value, rather it is a distribution of values.

Models are simple diagrams, and several examples are included in this article. Commodity grades, tonnages, and other variables are plotted on the horizontal axis. Cumulative proportion of deposits (the sample data) is plotted along the vertical axis. Construction is completed by plotting smoothed curves through the data points and the intercepts for the 90th, 50th, and 10th percentiles (Cox and Singer, 1986a). The curve commonly represents a lognormal distribution that has a mean and a standard deviation that fits the data.

Grade and tonnage models are commonly accompanied by descriptive models. In fact, the descriptive model is commonly prepared before the grade and tonnage model. The descriptive model gives concise details (that is, regional geology, local geology, mineralogy, alteration) about a natural grouping of mineral deposits, which collectively is called a mineral-deposit type. Member deposits share certain essential features that make them members of the deposit type. It is from these deposits or a sample thereof that we find the data on size, grade, and so forth, used to make quantitative models. About 100 descriptive and grade-tonnage deposit models are available. Most are in Cox and Singer (1986a) and Bliss (1992a). Initial modeling work focused on deposit types with metallic-deposit types. This is due, in part, to increased interest by federal land managers and others in industrial minerals. To meet this need, compilations of some descriptive models (Orris and Bliss, 1991) and grade, tonnage, and other models (Orris and Bliss, 1992) of industrial mineral-deposit types have been made. Models of industrial minerals may use grade and tonnage data as is done for metallic deposit types. However, many industrial minerals have other features related to end use that must be considered (Orris and Bliss, 1989). One example of this includes the content of impurities (for example, iron in glass sands). For others, unique deposit-type specific characteristics are involved (for example, percentage of stones of gem quality in diamond placers; Bliss, 1992c).

Sand and gravel production in the United States is large and economically important. Sand and gravel along with crushed stone are the principal sources of aggregate used in cement and asphalt (Langer, 1993). The estimated value of U.S. sand and gravel production was $2.9 billion in 1991 (U.S. Bureau of Mines, 1992) and ranked third among industrial minerals produced in the United States. Sand and gravel account for 15 to 17 percent of the total value of industrial-mineral production from 1986 to 1991, according to the U.S. Bureau of Mines. Building and maintaining national infrastructure requires a continuous supply of aggregate. We must know how much aggregate is available, both locally and nationally. Land managers also want guidance in making land decisions in which aggregate resources must be considered. A detailed evaluation of aggregate resources of the country as a whole will require considerable money, people, and time. Given that these resources are unlikely to be available, only a small part of the nation will ever be evaluated in detail. However, appropriate models and a quantitative assess-