Internet Case Study #7:

Motherhood, Apple Pie, and Contaminant Source Reduction

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In the course of our work, we have encountered an interesting attitude that many people hold about concentrations in minesite drainage. The attitude is that a mining company should always strive to reduce concentrations in drainage from minesite components (see our Internet Case Study #5 for an explanation of minesite components).

Much like motherhood and apple pie, attempts at reducing contaminant concentrations at the source would seem to be unquestionably of great value. However, this is not necessarily so. This month's Internet Case Study will show how attempts to reduce drainage concentrations can lead to worse and longer-term problems. Mined-rock piles with fine-grained solid covers (clay, silt, etc.) will be used as examples.

To understand the conditions under which source reduction can lead to a worse problem, two basic concepts must be understood: (1) slowly vs. rapidly leachable metal and (2) equilibrium vs. kinetic reactions. The first is illustrated in Figure 1, based on the shrinking-core model which explains that metals at the surface of a particle will leach into water faster than metals further inside the particle. As a result, the amount of a metal in a particle can be simplistically separated into the "rapidly leachable" amount near the surface and the "slowly leachable" amount deeper inside. The finer the rock, the greater the proportion of a metal in the rapidly leachable category.

The second concept is illustrated in Figures 2 and 3. Concentrations responding to, or resembling, solid-liquid chemical equilibrium can remain generally constant in spite of changes in flow rate. However, the loading (mg/yr) increases linearly with flow, because each additional liter carries the same concentration. In our experience, roughly 80-90% of minesites and 80-90% of measured parameters respond to equilibrium, and thus these relationships among flow, concentration, and loading are common.

On the other hand, non-equilibrium kinetic reactions produce variable concentrations that depend on time and flow rate. Steady-rate kinetic reactions produce concentrations that decrease linearly with increasing flow (Figure 2) due to dilution; however, the resulting loading (mg/yr) remains relatively constant with changing flow. This is distinctly different from equilibrium trends, and only occurs at roughly 10-20% of minesites.

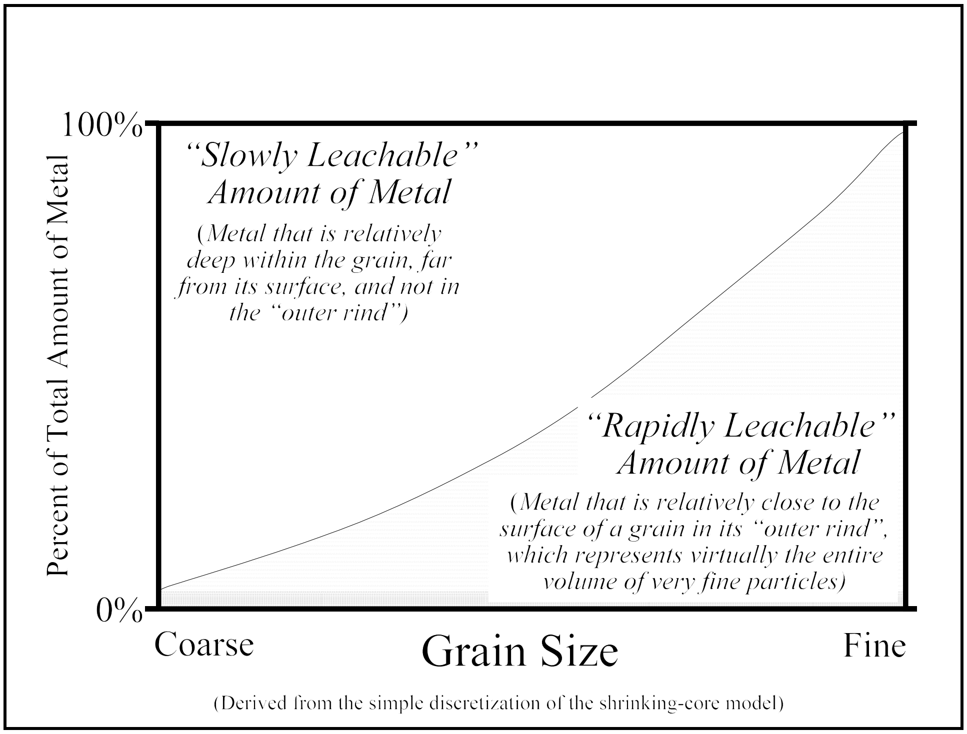

FIGURE 1. Slowly and Rapidly Leachable vs. Grain Size.

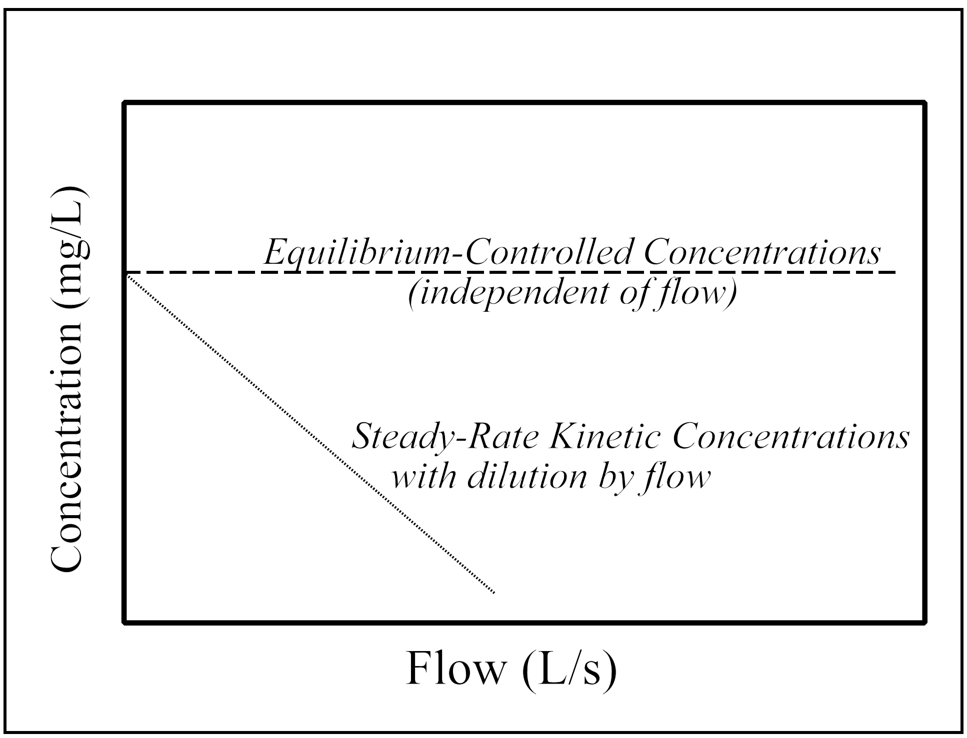

FIGURE 2. Equilibrium-Controlled and Kinetic Concentrations vs. Flow.

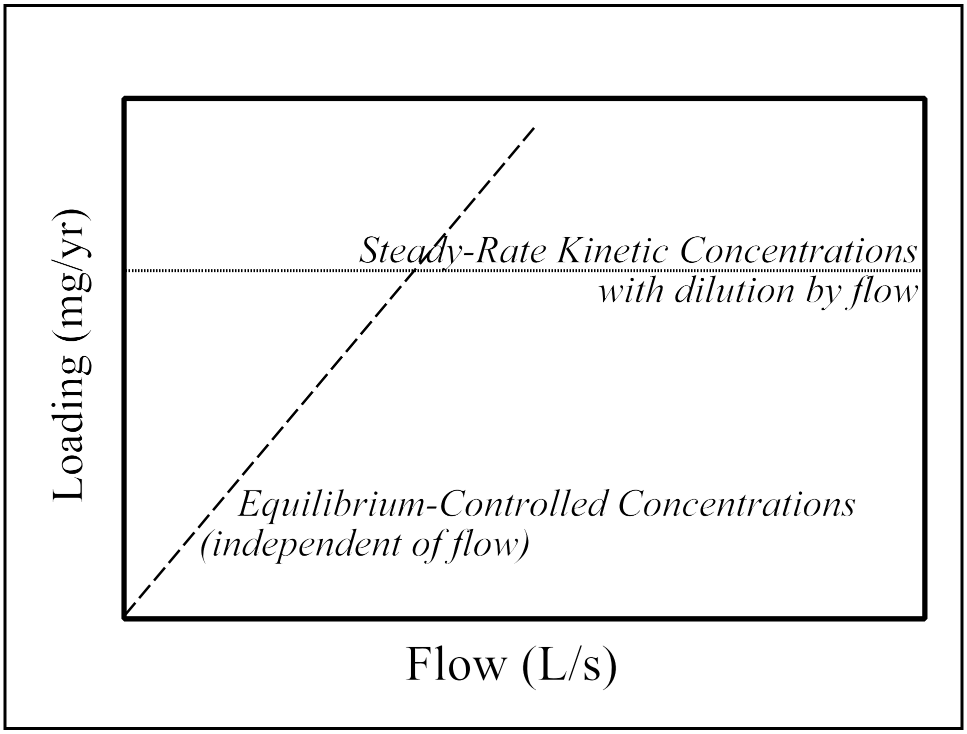

FIGURE 3. Equilibrium-Controlled and Kinetic Loadings vs. Flow.

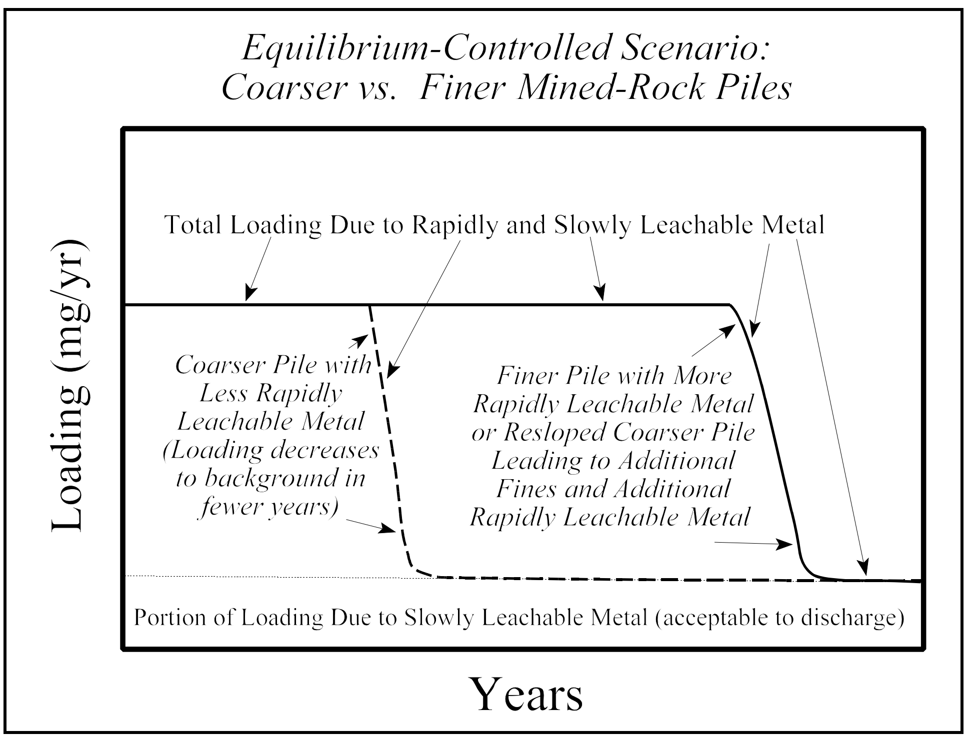

FIGURE 4. Equilibrium Scenario: Loading Through Time for Coarser and Finer Mined-Rock Piles (Same Flow).

With these two concepts in mind, the consequences of source reduction become more obvious, using mined-rock piles with solid covers as examples. Beginning with the more common equilibrium conditions, a coarser pile will have a shorter period of elevated loadings in the drainage than a finer-grained pile, under the assumption that flow is the same through both (Figure 4).

Interestingly, most piles require recontouring and resloping prior to placement of a cover. The vehicle traffic and grinding of one rock particle against others lead to smaller particles, which in turn leads to a greater amount of rapidly leachable metal (Figure 4). As a result, simply the basic activity of the disturbance can lead to longer times of elevated loadings.

The installation of a fine-grained cover can reduce infiltration into, and drainage from, a mined-rock pile. Under equilibrium conditions, the concentration in each liter may not change, but annual loadings will decrease (Figure 5). However, the elevated loadings would then persist for longer times, even more so if the pile is resloped.

If a solid cover is not maintained through time, the annual flow passing through it may increase at a later time (Figure 6). This would, in turn, cause loadings to increase towards pre-cover levels. In exchange, the time of elevated loadings would decrease.

This leads to the main issue of this study. If the loading that is acceptable for discharge to the environment is just above the loading from the slowly leachable metal, then a fine-grained cover will lead to three problems. First, collection and treatment of the drainage will have to continue for a longer period of time. In a simplified example, if the cover reduces infiltration by 30%, then a treatment period of 100 years is extended to 130 years, although the cumulative loading and amount of treatment waste are similar. Second, since new rapidly leachable metal is created by disturbance, then the treatment period is extended even longer than 130 years, and the cumulative loading and amount of treatment waste are greater. Third, if a cover is not maintained well for the duration of elevated loadings, the loadings increase for awhile, total length of treatment will still be greater than 100 years with no cover, and the cumulative amount of treatment waste will be greater due to disturbance during cover installation.

Unlike the equilibrium-controlled scenario, steady-rate kinetics can actually lead to higher loadings in a finer-grained pile, under the assumption that flow is the same in both (Figure 7). If a coarse pile is recontoured and resloped, then additional rapidly leachable metal is created by the breakdown of disturbed rock particles. As a result, loadings can increase as also shown in Figure 7.

Interestingly, if there is no disturbance of a kinetics-limited mined-rock pile during cover installation, then there will be no change in annual loadings and duration of elevated loadings relative to uncovered conditions (Figure 8). This is because the infiltration and drainage are reduced, but concentrations in each liter increase due to less dilution. However, because piles are typically disturbed during cover installation, annual loadings can often be expected to increase, the duration of increased loadings is longer, and the cumulative amount of loading and treatment waste are higher. This is enhanced further by any soluble retained metals that are then exposed to water.

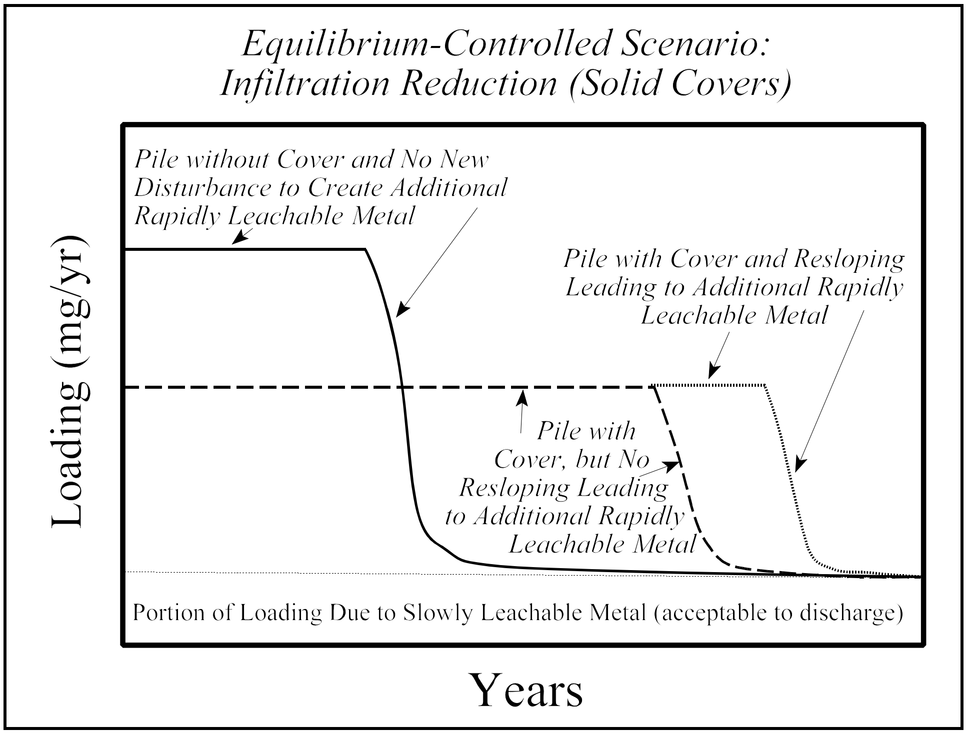

FIGURE 5. Equilibrium Scenario: Loading Through Time for Uncovered, Covered, and Resloped Piles.

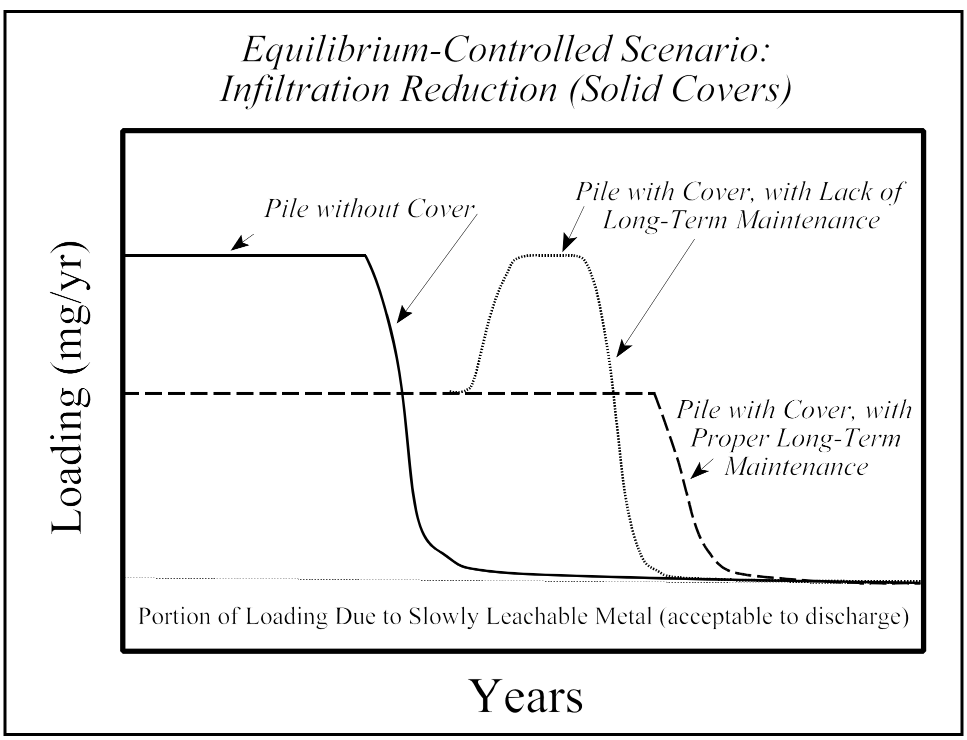

FIGURE 6. Equilibrium Scenario: Unmaintained, Covered Pile.

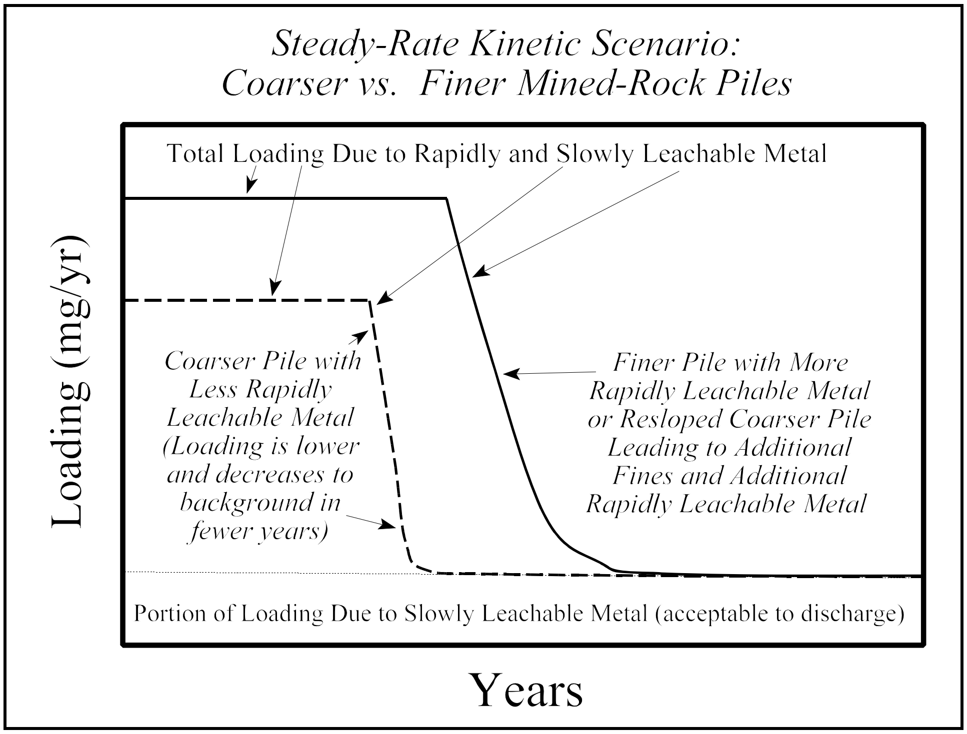

FIGURE 7. Kinetic Scenario: Loading Through Time for Coarser and Finer Mined-Rock Piles (Same Flow).

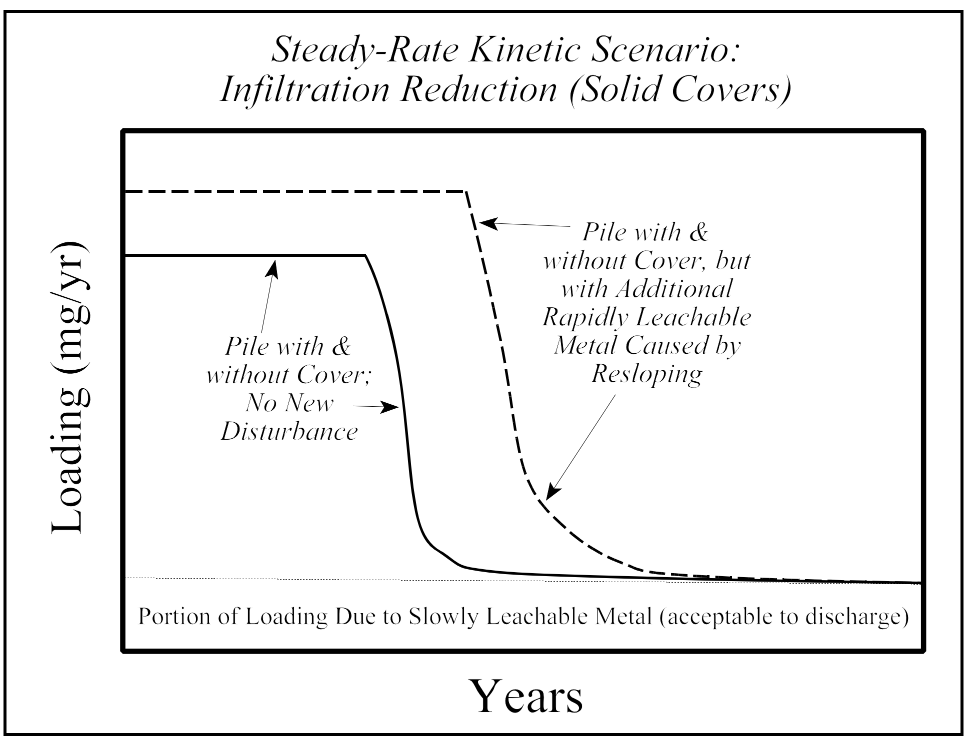

FIGURE 8. Kinetic Scenario: Loading Through Time for Uncovered, Covered, and Resloped Piles.

An important lesson to be learned from this is: unless a solid cover or other method of source reduction can reduce concentrations or loadings to the level where no collection and treatment are required, then the consequences could be (1) longer times for collection and treatment, which is an unnecessary burden for additional generations and (2) additional loadings and treatment waste, leading to additional costs for the mining company or society, and additional waste to handle.

On the other hand, there are scenarios where solid covers will be helpful, or of no consequence at all. For example, if the acceptable loading for discharge is below that solely from the slowly leachable metal, then collection and treatment will continue for a very long period of time, and the length of time and the amount of treatment waste will be virtually independent of whether a cover is ever installed. An example of a helpful solid cover is an equilibrium-controlled pile where loadings are lowered (concentrations are not changed) to a point where the water can be discharged without treatment, although this effect is unlikely or unimportant in many cases. Another example of a helpful solid cover is where financial security is required in advance for collection and treatment. Due to accumulating monetary interest, the cost of the security is mostly dependent on the annual loadings for the first 50-100 years. As a result, lower initial loadings caused by a solid cover will lessen the amount of required security.