APPENDIX L

GRADE CONTROL STRUCTURES

6.7.2 Types of Grade Control Structures

Grade control structures can range in complexity from simple rock riprap type drop structures to concrete structures with baffled aprons and stilling basins. For the range of discharges and velocities typically expected on a surface mine site, and considering the construction techniques typically employed, only the design of rock riprap structures is covered in this manual. Figure 6.9 illustrates a loose rock drop structure.

General guidelines for construction of loose rock drop structures constructed in mild slope channels are similar to stone check dams. The following specific recommendations are made:

1. Maximum drop height of three feet (guidelines for designing loose rock drop structures for drop heights greater than three feet are given in the Part 2.

2. Top width no less than five feet.

3. Downstream slope of 2 horizontal to 1 vertical.

4. 25 percent of the rock by volume will be 18 inches or larger. The remaining 75 percent shall be well graded material consisting of sufficient rock small enough to fill the voids between the larger rocks.

5. Energy dissipation should be provided at the downstream toe of a structure with a small plunge pool and large rocks.

6.7.3 Design Procedure Involving Grade Control Structures

Development of the graphical design procedure presented below is detailed in Appendix D. The design procedure is based on an application of Shields' relation (Equation 6.3) and the Manning equation (Equation 4.13). The primary design relationship is

$$S = \frac{0.047\ (G_s - 1)\ D_{50}}{R} \qquad (6.11)$$

where S is the static equilibrium slope, G_s is the specific gravity of the bed and bank material, often assumed to be 2.65, D_{50} is the median riprap size available or the armor particle size present in the natural alluvium, and R is the hydraulic radius.

The relationship defining R for a given combination of Manning's n, discharge Q and D_{50} is given in Figures 6.10a to 6.10c, where K is defined as

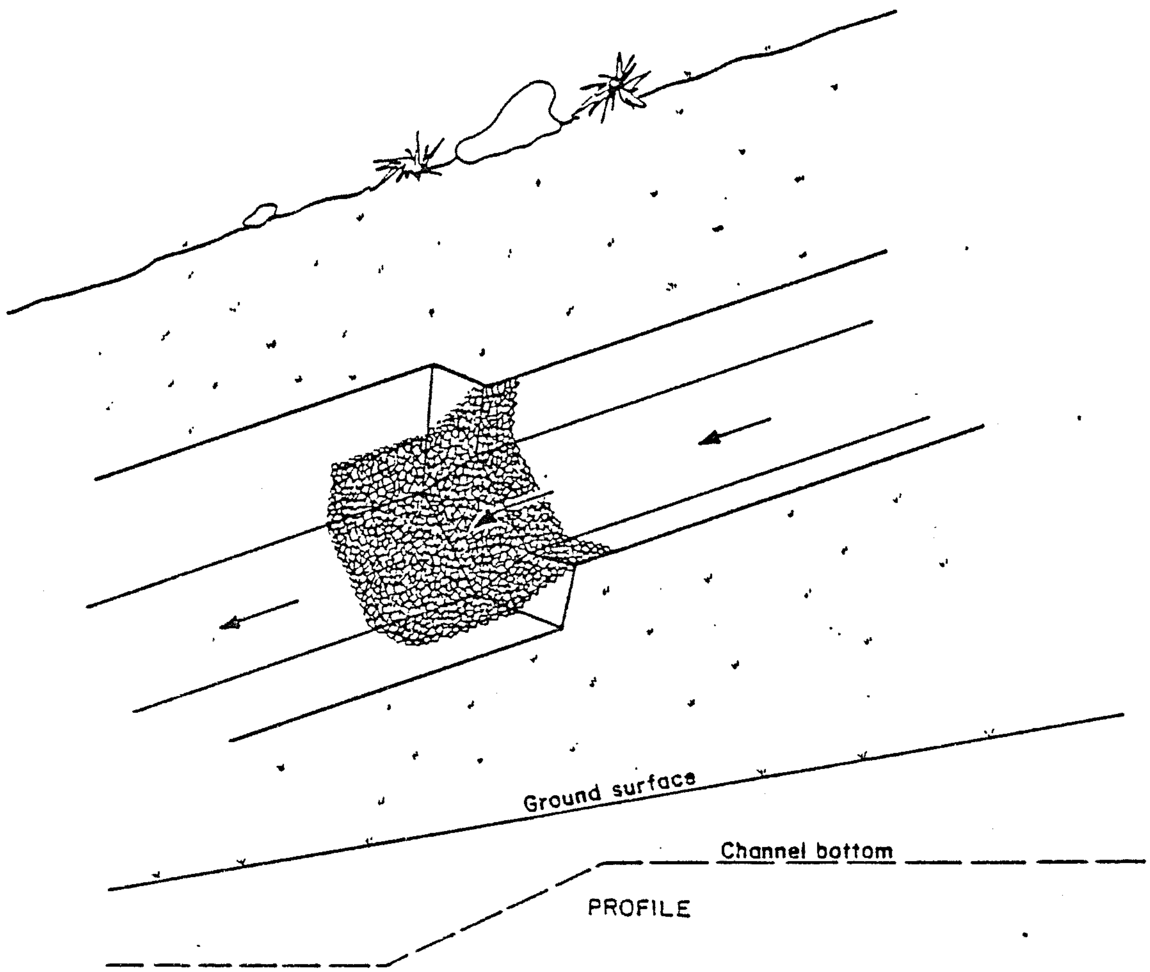

Figure 6.9. Definition sketch of a rock riprap drop structure (protection upstream and downstream according to Section 5.4).

$$K = \left(\frac{Qn}{0.323\sqrt{(G_s-1)}\ D_{50}}\right)^6 \qquad (6.12)$$

For values of K beyond the limits given in the figures, Equation D.9 in Appendix D must be solved.

The design procedure using these figures is simple to apply. After establishing the D_{50} of the available riprap, or the natural alluvium for development of an armor layer, the value of K is computed for the design flow Q and the representative Manning n. For gravel-cobble size rock Equation 4.18 gives a good estimate of the Manning n. With K established, the value of R is determined from the graphs. Equation 6.11 can then be solved for the static equilibrium slope required to maintain stability for the given D_{50} and flow conditions. If the natural terrain slope is less than the computed static equilibrium slope, the riprap will be stable without the need for drop structures. Otherwise, drop structures will be needed to establish the required slope.

6.7.4 Spacing of Grade Control Structures

If the above computation indicates grade control structures are required, the number and spacing of the structures must be determined. The vertical height that must be controlled for the given reach to achieve the required static equilibrium slope can be evaluated from

$$\Delta H = (S_o - S)\ \Delta X \qquad (6.13)$$

where ΔH is the total height requiring structural control, S_o is the original channel slope, S is the estimated static equilibrium slope, and ΔX is the length of channel to be controlled.

To prevent highly erosive velocities at the base of a rock riprap drop structure, the maximum allowable height of the structure is three feet. Therefore, the number of structures N required to control the total vertical height is

$$N = \frac{\Delta H}{3} \qquad (6.14)$$

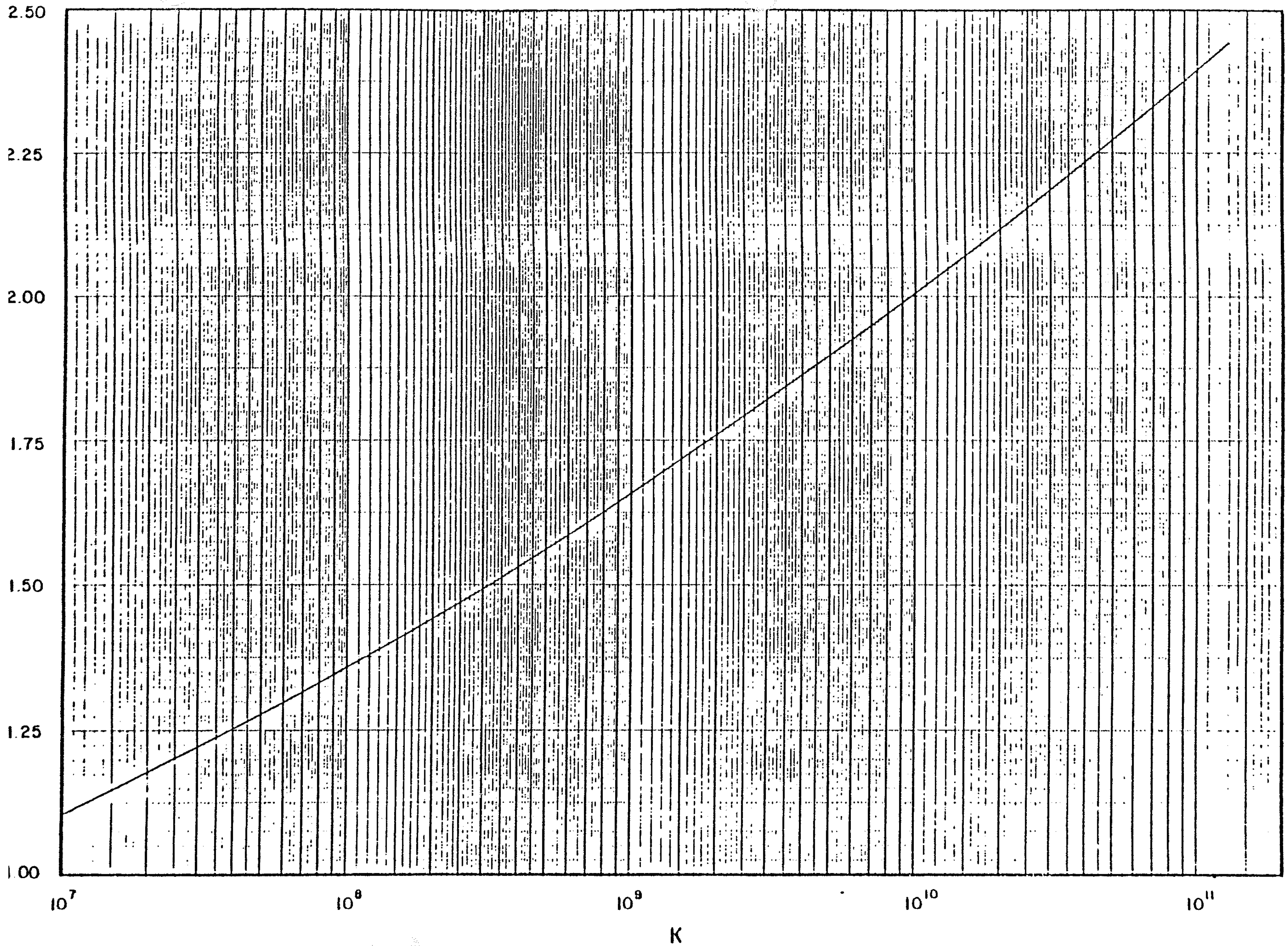

Figure 6.10a. Relationship between hydraulic radius R and K for trapezoidal channel with 2:1 side slopes and 6-foot base width.

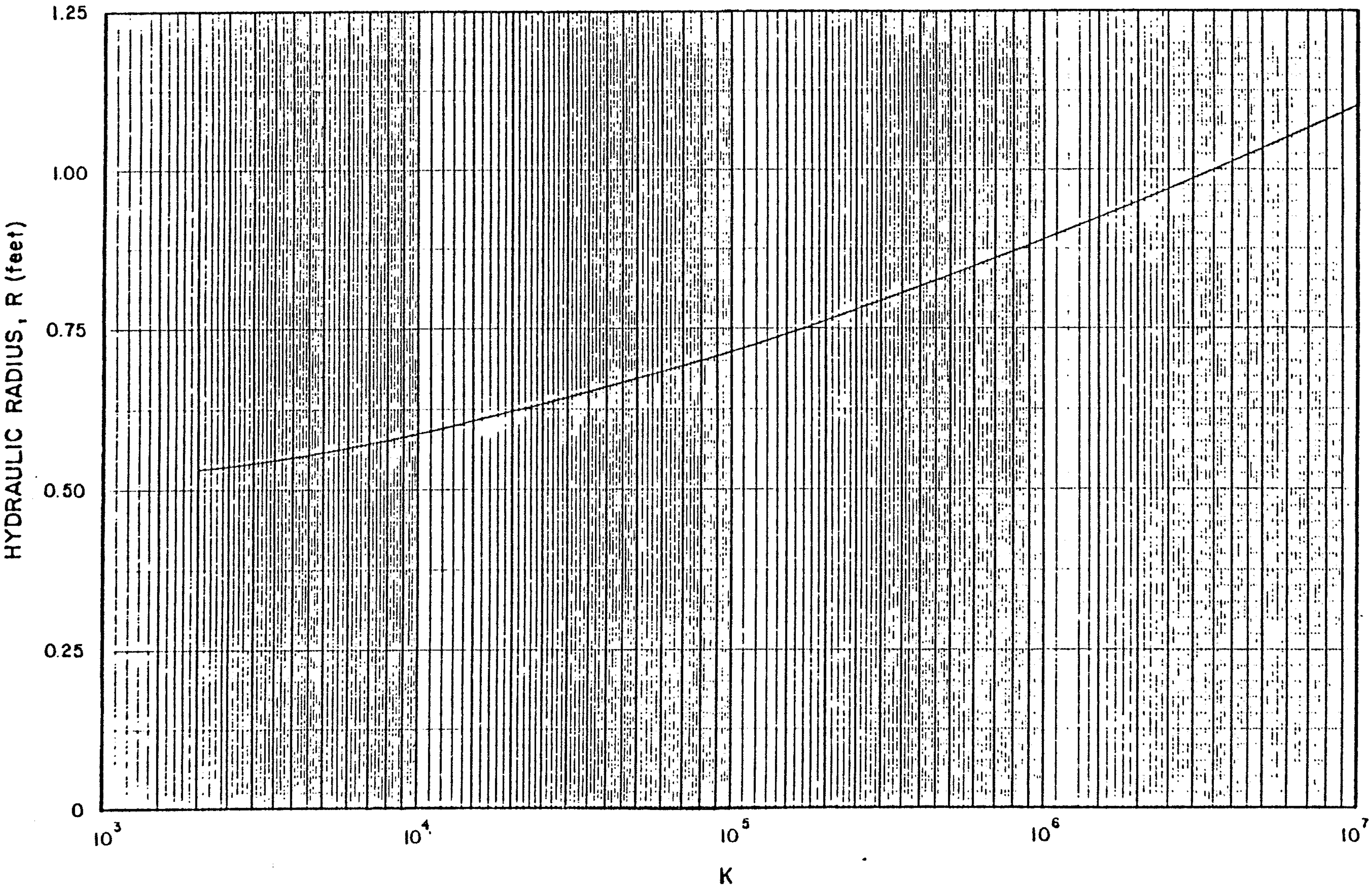

Figure 6.10a. Relationship between hydraulic radius R and K for trapezoidal channel with 2:1 side slopes and 6-foot base width. (continued).

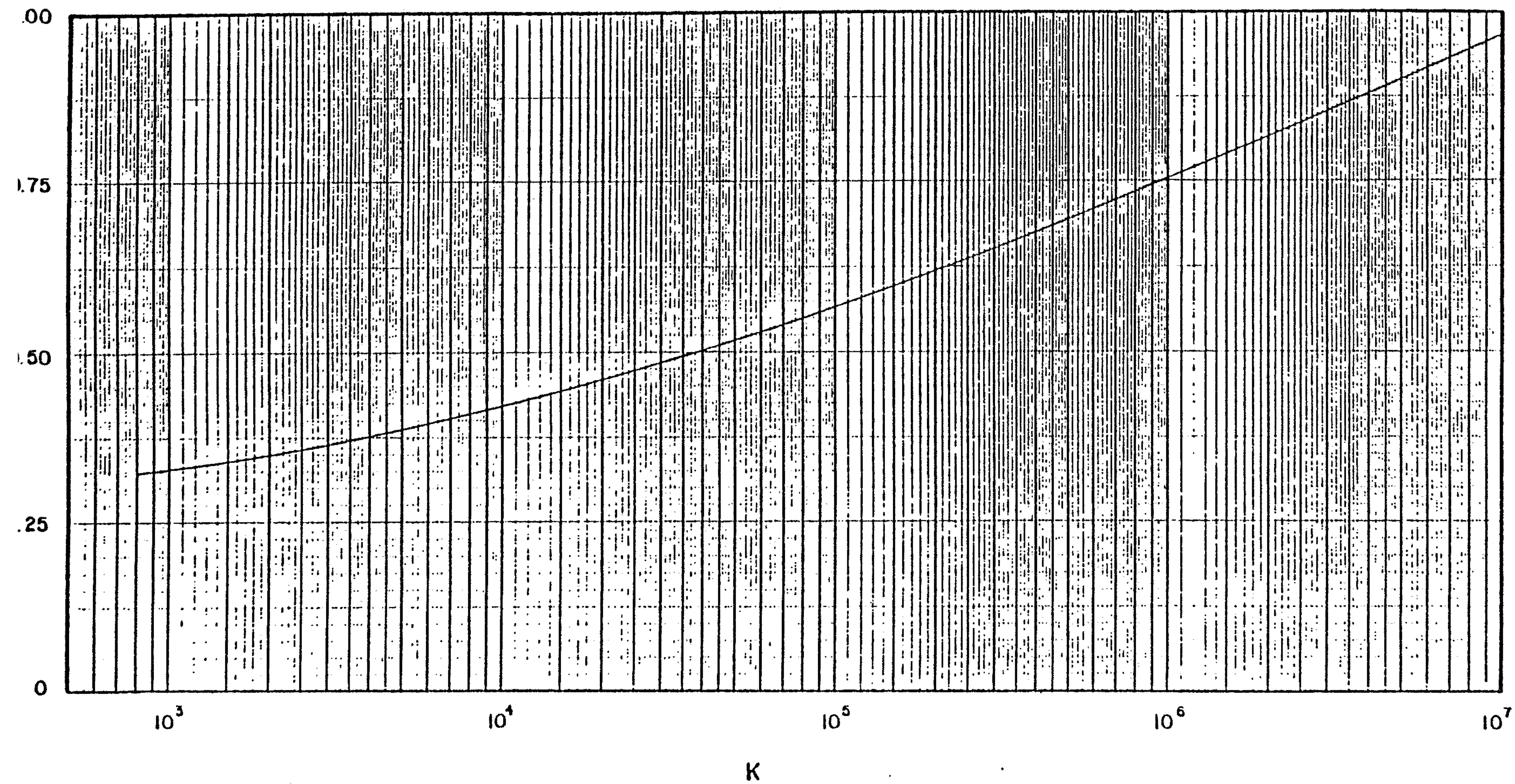

Figure 6.10b. Relationship between hydraulic radius R and K for trapezoidal channel with 2:1 side slopes and 10-foot base width.

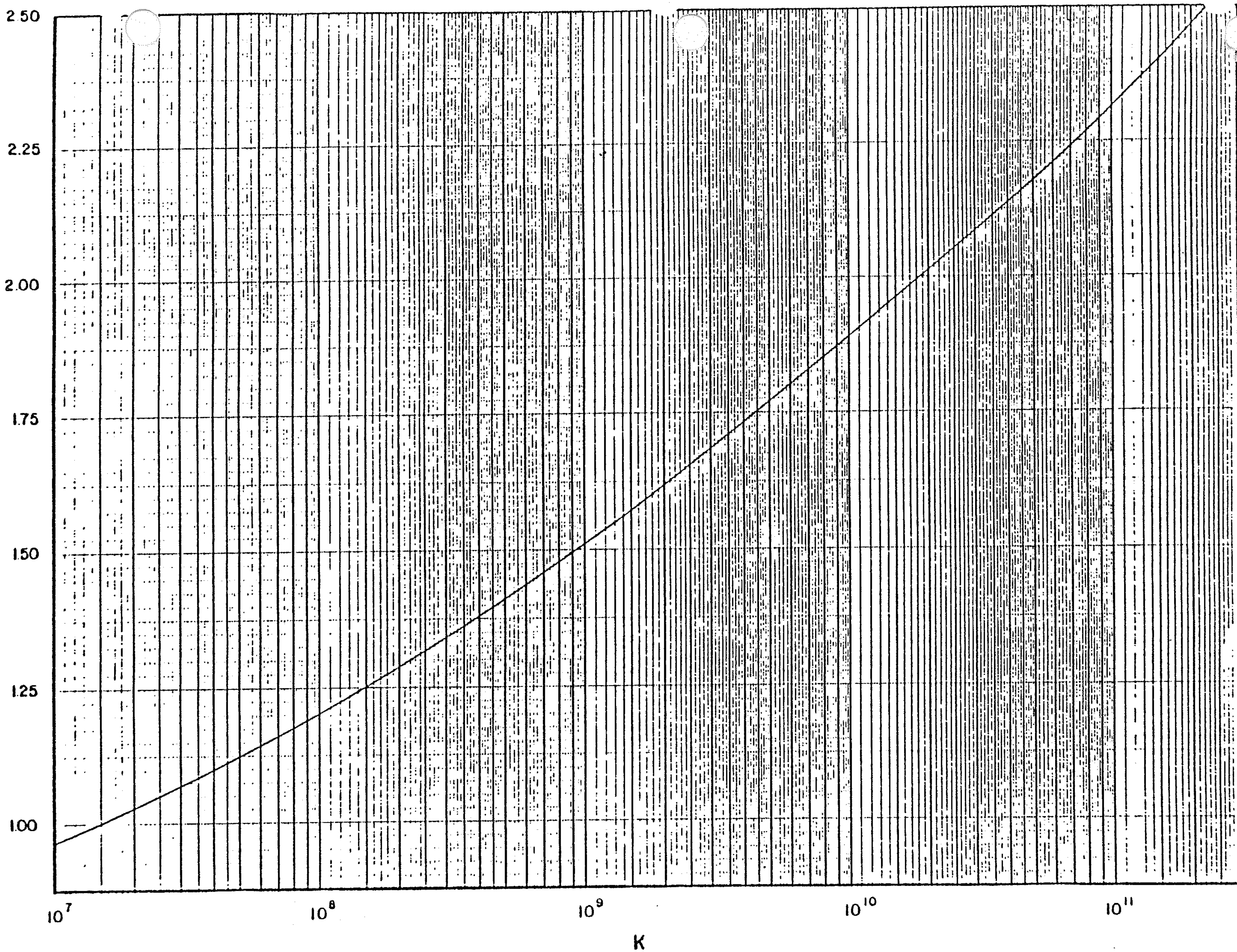

Figure 6.10b. Relationship between hydraulic radius R and K for trapezoidal channel with 2:1 side slopes and 10-foot base width (continued).

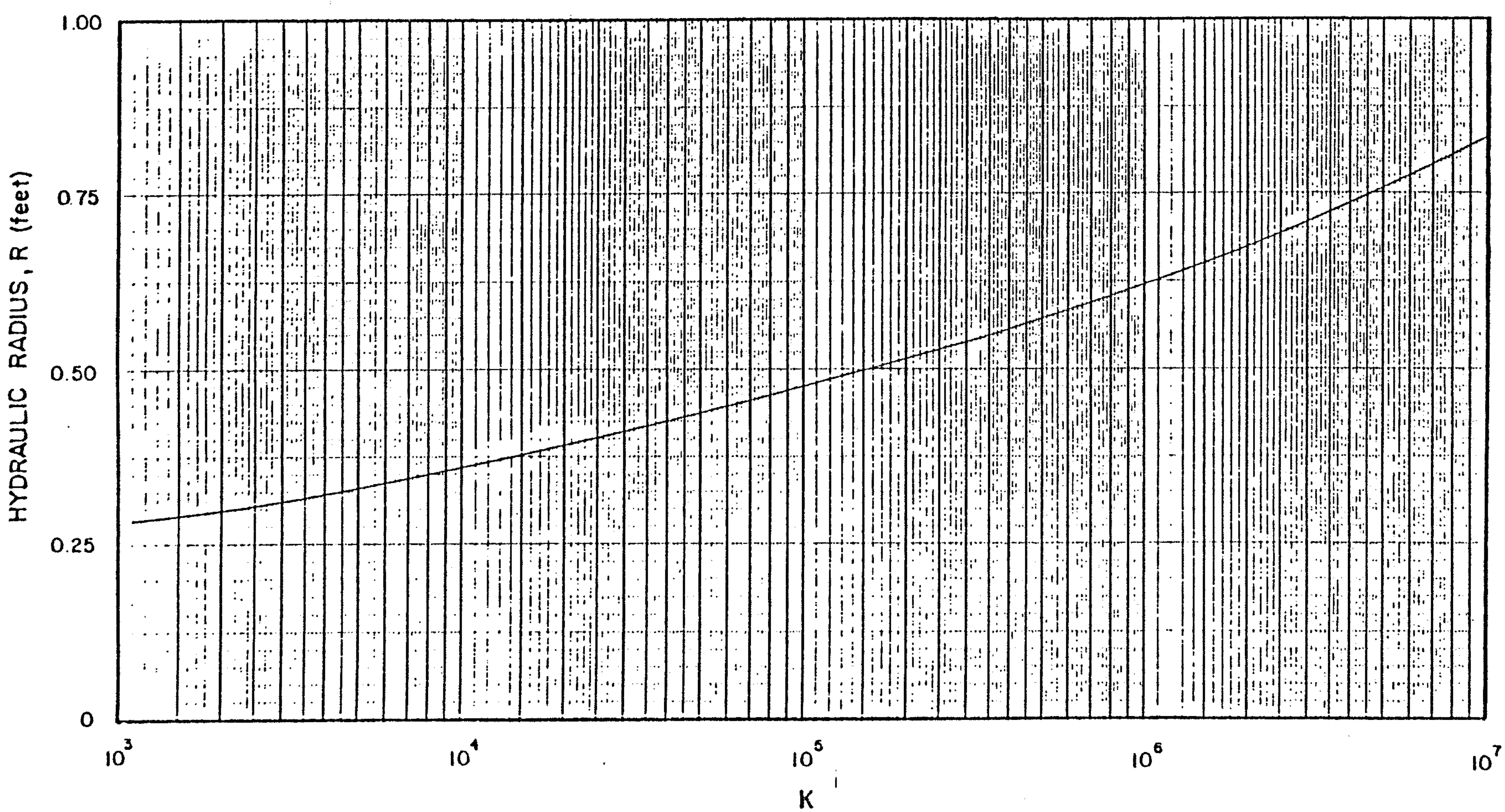

Figure 6.10c. Relationship between hydraulic radius R and K for trapezoidal channels with 2:1 side slopes and 14-foot base width.

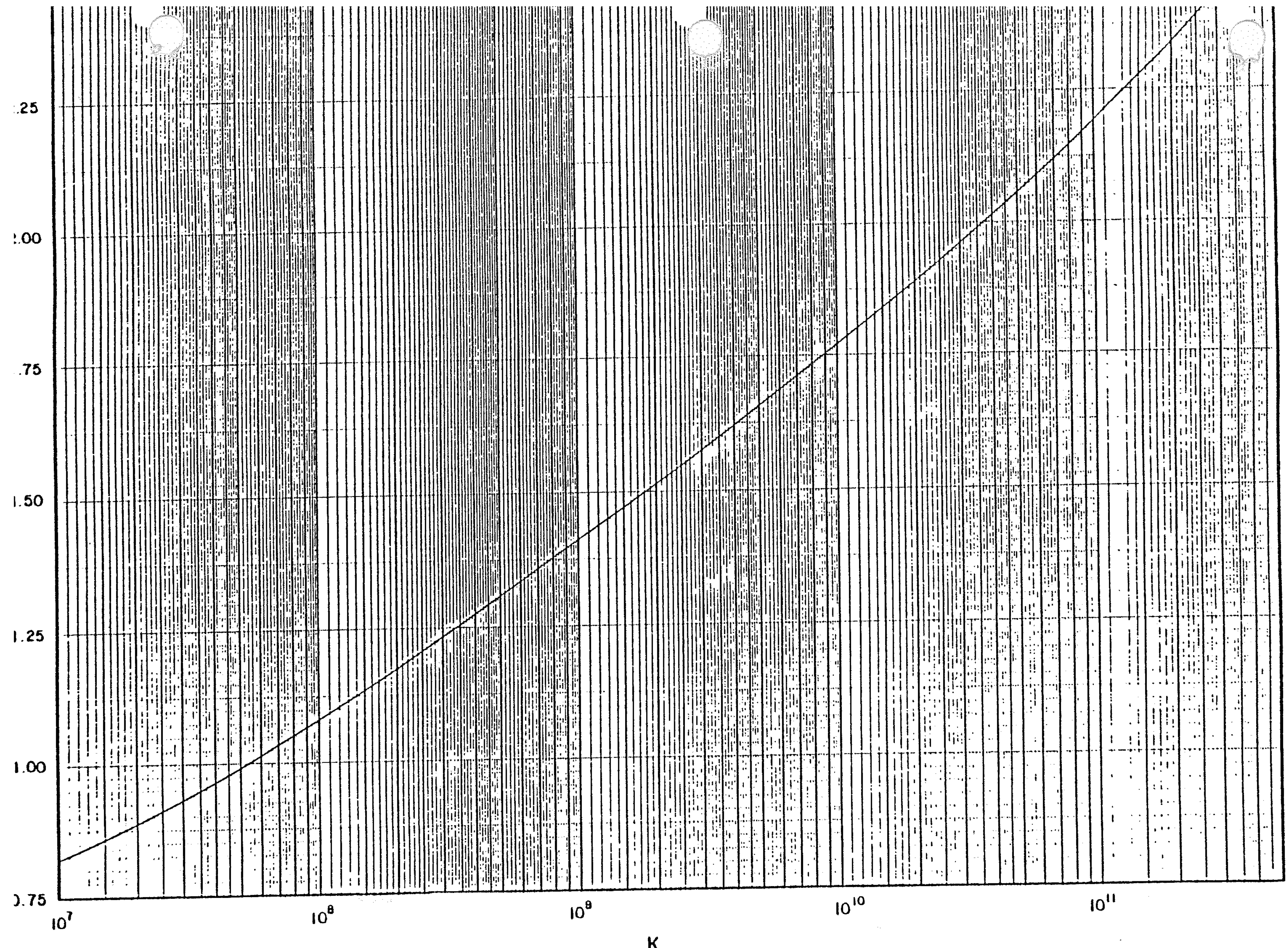

Figure 6.10c. Relationship between hydraulic radius R and K for trapezoidal channels with 2:1 side slopes and 14-foot base width (continued).

The spacing L of the drop structures is then

$$L = \frac{\Delta X}{N} \qquad (6.15)$$

6.7.5 Protection of Grade Control Structures

The velocity of flow on the downstream side of a drop structure can be quite high, creating the potential for local scour at the toe and possible undercutting of the structure. Therefore, a riprap transition between the toe and the downstream channel must be provided with adequate energy dissipation measures.

The method for determining the length of protection required below a grade control structure is identical to the procedure for protection below steep slopes presented in Section 5.4. A riprap layer should be extended below the structure for a distance equal five times the downstream depth of flow, but never less than 15 feet. Additionally a small plunge pool can be provided at the downstream toe to help dissipate energy.

6.8 Design Procedure Summary

1. Design channel based on maximum permissible velocity method according to steps 1-6, Section 6.4.1.
2. Evaluate the channel for reasonable shape using Equations 6.7-6.10, and engineering judgment.
3. If a more hydraulically efficient channel is desired, evaluate the use of linings (vegetation or riprap) or grade control structures. Table 6.6 will aid in this evaluation.
   a. Vegetation
      1) Determine maximum permissible velocity for given vegetation type from Table 6.2.
      2) To design for stability, assume vegetation is mowed and identify retardance class from Table 6.3.
      3) Enter Figures 6.5a-e for given velocity, retardance and design slope to establish R.
      4) Calculate A = Q/V.
      5) Determine d for given b such that