Chapter 6
Well Design

6-1. Description of Well

While the specific materials used in the construction vary and the dimensions and methods of installations differ, relief wells are basically very similar. They consist of a drilled hole to facilitate the installation; a screen or slotted pipe section to allow entrance of ground water; a bottom plate; a filter to prevent entrance and ultimate loss of foundation material; a riser to conduct the water to the ground surface; a check valve to allow escape of water and prevent backflooding and entrance of foreign material; backfill to prevent recharge of the formation by surface water; and a cover and some type of barricade protection to prevent vandalism and damage to the top of the well by maintenance crews, livestock, etc. Figure 2-1 shows a typical relief well installation. The hole is drilled large enough to provide a minimum thickness of 4 to 6 in. depending on the gradation of the filter material as subsequently described. The hole is also overdrilled in depth to provide for the fact that initial placements of filter material may be segregated. The amount of overdrilling required is variable depending upon the size of tremie pipe used for filter placement, the total depth of the well, and most importantly on the tendency of the selected filter material to segregate. The backfill indicated as sand in Figure 2-1 normally consist of concrete sand or otherwise excess filter material. Its only function is to fill the annular space around the riser pipe to prevent collapse of the boring; these granular materials are easily placed and require a minimum of compaction. The backfill indicated as concrete in Figure 2-1 forms a seal to prevent inflow of surface water from rains and flooding.

6-2. Materials for Wells

Commercially available well screens and riser pipes are fabricated from a variety of materials such as black iron, galvanized iron, stainless steel, brass, bronze, fiberglass, polyvinyl chloride (PVC), and other materials. How well a material performs with time depends upon its strength, resistance to damage by servicing operations, and resistance to attack by the chemical constituents of the ground water. Wood has proven to be very stable in most environments in well installations, as long as it is continuously submerged in water; however wood well screens and risers are no longer commercially available. Stainless steel is apparently a very stable material in most environments; however it is relatively expensive. Type 304 stainless steel has excellent corrosion resistance; whereas Type 403 stainless steel has moderate corrosion resistance. Low-carbon or other-type steel wire-wrapped screen may be more economical in many instances; however it has no corrosion resistance. Brass and bronze are extremely expensive and are not completely stable in some acid environments. Fiberglass is a promising material; however its performance history is relatively short. PVC appears to be completely stable, and it is easy to handle and install; however it is a relatively weak material and easily damaged. The life of iron screens is extended by galvanizing, which may not provide permanent protection. Ferrous and nonferrous metals should never be placed in direct contact with each other, such as the case of a brass screen and a steel riser; the direct contact of these dissimilar metals may induce electrolysis and a resultant deterioration of the material.

6-3. Selection of Materials

Since pressure relief wells are designed and installed to protect the foundations of structures, selection of materials for the well should be based on costs and performance over the life of the structure which it protects. Generally, the choice of well screen material will depend on three factors: (a) water quality, (b) potential presence of iron bacteria, and (c) strength requirements. A water quality analysis will determine the chemical nature of the ground water and indicate whether it is corrosive and/or incrusting (see Table 3-1). Enlargement of screen openings due to corrosion can cause progressive movement of fines into the well, therefore it is essential that the well screen be fabricated from corrosion-resistant material where corrosive waters are expected. Similarly, if incrusting ground water is expected, future maintenance which may require acid treatments as described in Chapter 12 necessitates the use of material that can withstand the corrosive effect of the treatments. When the presence of iron bacteria is anticipated, the well screen should be selected which can withstand the damaging effects of the repeated chemical treatments described in Chapter 12. The strength of the well screen is usually not a major factor when commercial well screens designed for deeper well installations are employed. The screen sections should be able to withstand maximum compression and tensile forces during installation operations as well as horizontal forces which may develop during installation and possibly later because of lateral earth movements.

6-4. Well Screen

a. Slot type. A variety of slot types are available in most types of well screens. PVC screens with open slots of varying dimensions consisting of a series of saw cuts are typically available. Metal and fiberglass screens are available with open slots, louvered or otherwise shielded slots, or "continuous slots." The "continuous slot" screens consist of a skeleton of vertical rods wrapped with a continuous spiral of wire. The wire can be a variety of cross-sectional shapes. The trapezoidal-shape wire provides a slot that is progressively larger toward the inside of the screen. This shape allows any filter gravel that enters the slot to fall into the well rather than clog the screen. The open-type slots are advantageous in developing the filter. They allow the successful use of water jets; whereas shielded slots deflect the water jet and reduce or destroy its effectiveness in the filter. Machine cut slots typically have jagged edges which facilitate the attachment of iron bacteria making screens difficult to treat later. Continuous slot screens are commercially fabricated of Type 304 and 316 stainless steel, monel, galvanized or ungalvanized low-carbon steel, and thermoplastic materials, mainly PVC and ABS or alloys of these materials. Couplings and the bottom plate for the well screen may be either glued, threaded, or welded and should be constructed of the same material as the well screen.

b. Dimensions. The size of the individual openings in a well screen is dictated by the grain size of the filter. The openings should be as wide as possible, yet sufficiently small to minimize entrance of filter materials. Criteria for selection of screen opening size are presented subsequently. The anticipated maximum flow of the well dictates both the minimum total open-slot area of the screen (the spacing and length of slots) and the minimum diameter of the well. The open area of a well screen should be sufficiently large to maintain a low entrance velocity of less than 0.1 ft per second (fps) at the design flow. Representative areas and maximum well capacities for various well diameters with different continuous slot sizes are shown in Table 6-1. Well screen manufacturers should be consulted for more specific information. The well diameter must be large enough to conduct the maximum anticipated flow to the ground surface and facilitate testing and servicing of the well after installation. Head loss in the well should also be taken into consideration in selecting a well diameter.

6-5. Filter

a. In order to prevent infiltration of foundation sands into the filter, the filter gradation must meet the stability requirement that the 15 percent size of the filter should be not greater than five times the 85 percent size of the foundation materials. As shown in Figure 6-1, the design should be based on the finest gradation of the foundation materials, excluding zones of unusually fine materials where blank screen sections should be provided. If the foundation consists of strata with different grain size bands, different filter gradations should be designed for each band. Each filter gradation must also meet the permeability criterion that the 15 percent size of the filter should be more than three to five times the 15 percent size of foundation sands. Either well graded or uniform filter materials may be used. A uniform filter material has a coefficient of uniformity, C_u, of less than 2.5 where C_u is defined as

$$C_u = \frac{D_{60}}{D_{10}} \qquad (6\text{-}1)$$

where

D_{60} = grain size at which 60 percent by weight is finer

D_{10} = grain size at which 10 percent by weight is finer

The C_u of well-graded filter materials should be greater than 2.5 and less than 6 to minimize segregation. The grain sizes should be reasonably well distributed over the specified range with no sizes missing. Well-graded filter materials used with proper well development procedures increase efficiency and permit the use of large screen openings; however they are subject to segregation during handling and placement. Well-graded filters should have an annular thickness of 6 to 8 in. Uniformly graded filters permit a lesser annular thickness of filter (4 to 6 in.) and are not subject to segregation, thereby reducing the amount of overdrilling.

b. The filter should consist of natural material made up of hard durable particles. It should contain no detrimental quantities of organic matter or soft, friable,

Table 6-1
Properties of Wire-wrapped Continuous Slot Screens
(Manufactured by Johnson Division, SES Inc.)

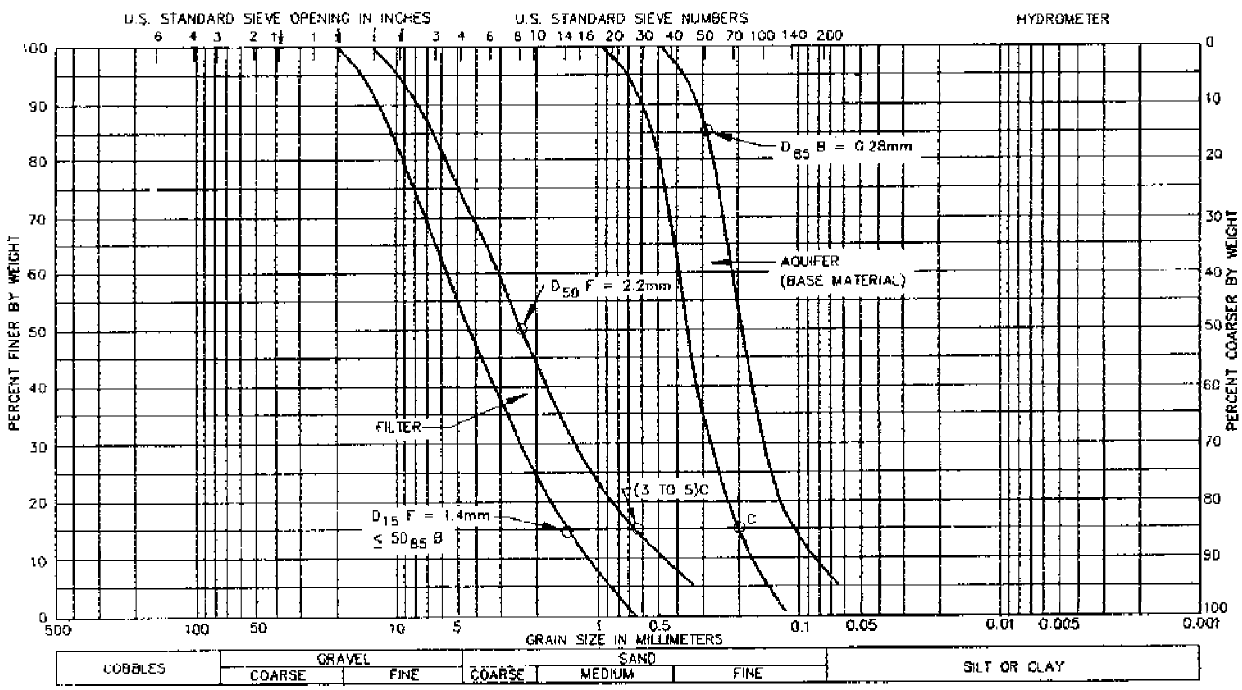
Shipping Weight		Intake Areas (square inches per foot of screen)							
		Slot Opening Size							
Lb/Ft	Nom. Diam.	10-slot	20-slot	40-slot	60-slot	80-slot	100-slot	150-slot	250-slot
4	3	15	26	41	52	59	65	73	82
5	3 1/2	18	31	49	61	70	77	88	99
6	4	20	35	57	71	81	88	101	115
6	4 1/2	23	40	64	80	92	100	114	129
7	5	26	45	72	90	102	112	112	132
8	5 5/8	28	49	79	99	113	123	141	159
10	6	30	53	85	106	100	112	132	156
15	8	28	51	87	113	133	149	160	194
19	10	36	65	108	141	166	186	200	243
22	12	42	77	130	143	171	195	237	265
35	14	37	68	97	132	161	185	232	292
41	16	42	60	108	148	180	208	261	327
47	18	36	69	124	169	206	237	298	375
57	20	41	77	139	189	229	264	280	366
71	24	61	113	131	182	226	265	343	449
72	26	63	118	138	191	237	278	360	471
81	30	75	138	161	224	278	325	422	552
91	36	84	157	184	255	317	371	481	629

Notes:
1. Open areas may differ somewhat from these figures. Extra-strong construction, for example, reduces open areas in some cases because heavier material is used to increase screen strength.
2. The maximum transmitting capacity of the screen can be derived from these figures. To determine gpm per ft of screen, multiply the intake area in square inches by 0.31. It must be remembered that this is the maximum capacity of the screen under ideal conditions with an entrance velocity of 0.1 fps.

thin, or elongated particles. Crushed carbonate aggregates should be avoided because they tend to break down with a loss in permeability. Furthermore, they will tend to dissolve if the wells require future acid treatment as part of future rehabilitation operations. It is often difficult to purchase material that meets the required gradation, and it may be necessary to have the material specially blended. The special blends are expensive and sometimes difficult to acquire, but essential to the installation of acceptable permanent relief wells.

6-6. Selection of Screen Opening Size

In general, the slot width (or hole diameter) of the screen should be equal to or less than the 50 percent size of the finest gradation of filter. Application of this criterion is demonstrated in Figure 6-1. Use of the



General Procedures

1. Determine minimum $D_{85}B$ on band of grain size curves for aquifer.
2. Determine maximum $D_{15}F$ for filter material based on the stability criterion. $D_{15}F < 5\ D_{85}B$
3. Select a widely graded ($C_u > 2.5$) or uniform filter material meeting the above criteria.
4. Establish a reasonable band of grain sizes for the filter.
5. Check to ensure that permeability criterion is satisfied, i.e. the D_{15} size of the filter band is 3 to 5 times greater than the D_{15} size of the aquifer band.
6. Select a maximum screen slot size equal to the D_{50} size of the fine curve of the filter band.

Figure 6-1. Typical design of filter for relief well

50 percent size criterion for the selection of screen slot size appears to provide reasonable assurance against in-wash of filter materials during well development and surging and furthermore results in suitably large openings to minimize the effects of incrustations and blockages which may develop during the life of the well (Hadj-Hamou, Tavassoli, and Sherman 1990).

6-7. Well Losses

a. Head losses within the system consist of entrance head loss in the screen and filter (H_e) plus friction head losses arising from flow in the screen, riser, and connections (H_f) plus velocity head loss (H_v). The total hydraulic head loss in a well (H_w) is given by

$$H_w = H_e + H_f + H_v \tag{6-2}$$

b. The entrance losses in the screen and filter for a properly designed and developed screen and filter will generally be relatively small at the time of well installation. Installation techniques resulting in smear or undue disturbance of the drill hole walls, however, can result in relatively large initial entrance losses. Entrance losses can be expected to increase with time for a variety of reasons discussed in Chapter 11. For example, as shown in Figure 6-2, the entrance losses for 8-in.-ID slotted wood well screens, based on piezometer data at the time of installation, amounted only to about 0.10 to 0.25 ft for a flow through the screen of 10 gpm per foot of screen. However, as shown in Figure 6-2, entrance losses for the particular wells increased significantly with time. The initial entrance losses for wire-wrapped screens should be even less. Both field and laboratory tests indicate that the average entrance velocity of water moving into the screen should not exceed 0.1 fps. At this velocity, friction losses in the screen openings will be negligible and the rates of incrustation and corrosion will be minimal. The average entrance velocity is calculated by dividing estimated well yield by the total area of the screen openings. If the velocity is greater than 0.1 fps, the screen length and/or diameter should be increased accordingly. The long-term value of entrance loss is difficult to predict, and unless experience in a specific location is available, conservative values based on Figure 6-2 should be selected.

c. Friction losses in the screen and riser sections may be estimated from Figure 6-3. The head loss in the screen section should be computed for a distance of one-half the screen length. More accurately, friction losses can be calculated according to the Darcy-Weisbach formula as described in EM 1110-2-1602. The resistance coefficient in the formula is solved by the Colebrook-White equation also given in EM 1110-2-1602. This equation requires the input of an effective roughness parameter for the material comprising the well screen and riser pipe. A computer code for the solution of the Colebrook-White equation is given in USAEWES (1973).

d. Velocity head losses, H_v, should be computed by means of the equation

$$H_v = \frac{\upsilon^2}{2g} \qquad (6\text{-}3)$$

where

υ = the velocity of the water in the riser pipe

g = acceleration due to gravity = 32.2 ft/sec^2

Losses due to elbow connections should be included where applicable.

6-8. Effective Well Radius

The effective well radius to be used in design computations is calculated as the outside radius of the well screen plus one-half the thickness of the filter.

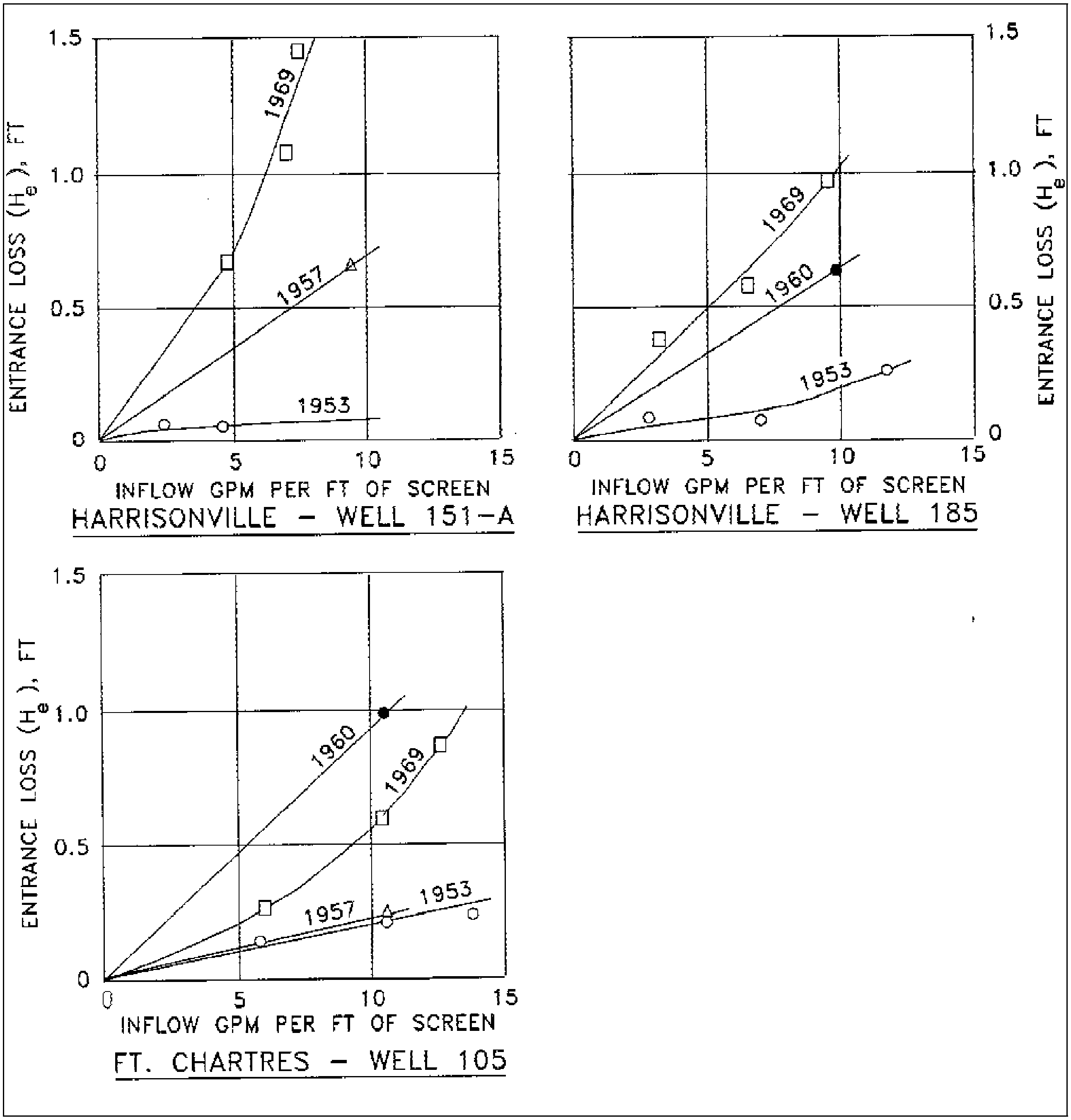


Figure 6-2. Entrance losses versus inflow for 8-in.-ID slotted wood well screens in St. Louis District (after Montgomery 1972)

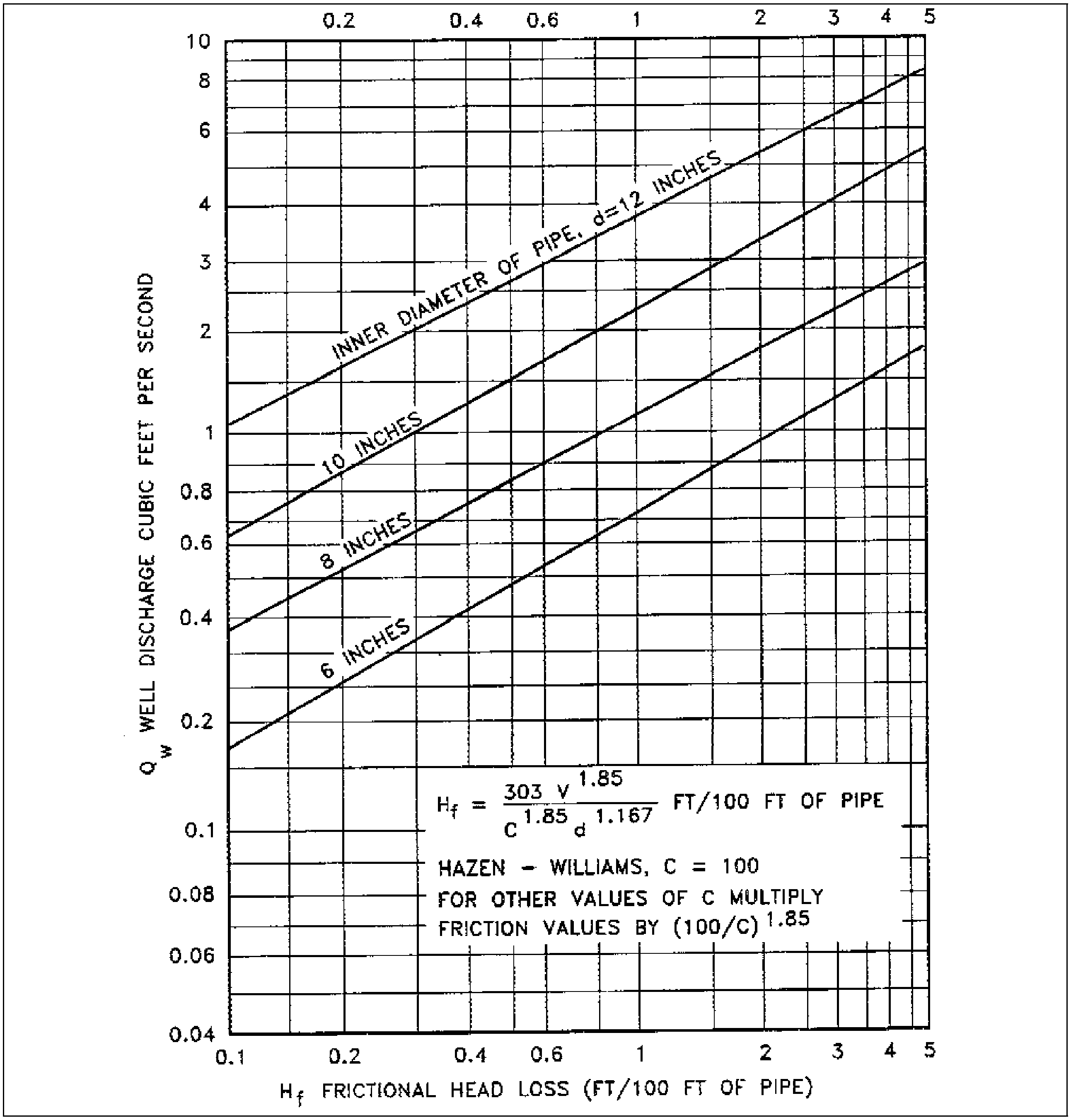


Figure 6-3. Friction head losses in screen and riser sections