A B S T R A C T

HYDRAULIC PROPERTIES

OF

WELL SCREENS

Submitted by

Gilbert Lee Corey, Jr.

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ABSTRACT

Introduction

Pumping from wells has become a popular type of irrigation in the arid regions of the United States. Irrigation engineers and well drillers have long been faced with the problem of selecting the proper type of well screen to install in any particular well. They realize that the selection of a screen with proper slot openings is a very important factor in the construction of a well. Few scientific investigations have been made to determine the most efficient size and type of well screen to install. Much experience and a knowledge of previous wells in the region are relied on in the selection of a well screen.

The problem

The problem for which an answer is sought in this thesis may be stated as follows: What are the hydraulic properties of well screens when surrounded by gravel envelopes containing various sizes of gravel?

Problem analysis.--In analyzing the problem the following questions arise:

1. What is the loss of head through each well

screen operating in clear water with no gravel or sand surrounding the screen?

2. What effect does placing gravel envelopes around the screen have on the loss of head through the well screen?
3. What effect does size of particles in the gravel envelope have on the loss of head through the well screen?
4. What effect does size of particles in the gravel envelope have on the loss of head through the gravel envelope?
5. What effect does variation in discharge have on the above losses of head?
6. What effect does length of screen have on the loss of head through the screen?

Delimitations.--The well screens used in this investigation were limited to 12 inches in diameter and 2 feet in effective length.

The types of well screens used were as follows:

Well screen	Description	Width of slot	Material	C_s
A	Continuous slot	0.040 in.	Bronze	31.59%
B	Continuous slot	0.100 in.	Bronze	53.59%
C	Continuous slot	0.200 in.	Bronze	69.78%
D	Continuous slot	0.100 in.	Black iron	21.10%
E	Wire mesh	0.145 in.	Black iron	33.64%
F	Punched slot	1/16 in.	Galv. iron	2.54%
G	Punched slot	1/8 in.	Galv. iron	4.77%

The thickness of the gravel envelopes was 9 inches. The gravel used in them contained particles of approximately uniform size. The three sizes used in this investigation were 1 inch, 1/2 inch and 1/4 inch.

In this study only the losses of head that occurred through the well screens and the gravel envelopes were analyzed. No attempt was made to determine the effect of shape and type of screen perforations on the losses.

Definition of terms.--A gravel envelope is a layer of gravel which is placed around the well screen to retard the movement of sand and to allow free passage of water into the well.

Loss of head, as used in this thesis, is the loss of potential energy between any two points as measured by the difference in elevation of water surfaces in piezometers connected to these points.

Screen coefficient, C_s, is the ratio of the perforated area of a well screen to the total surface area of the screen, the quantity being expressed as a percentage.

A well screen is that portion of a well casing which contains openings through the wall for the passage of water into the well.

Methods and materials

The two foot well screens were sealed over an opening in the center of a large cylindrical tank which was 6 feet in depth and 7½ feet in diameter. The opening in the center of the tank was connected by means of a pipe to a weir box. Water was introduced into the tank, flowed through the well screen, and discharged into the weir box where the quantity was measured with a 90° V-notch weir. A valve in the entrance line and one in the line between the tank and the weir box controlled the discharge.

To obtain the loss of head through the well screen without a gravel envelope surrounding it the head inside and outside the screen was measured. These heads were measured by placing piezometers inside and outside the screen respectively. The piezometric heads were measured with hook gages placed in stilling wells connected to the piezometers. The difference in heads inside and outside the screen gave the loss of head through the well screen.

These losses were measured with various discharges going through the screen.

A similar arrangement was used to measure the head losses through the gravel envelope and through the well screen with the envelope surrounding it. Piezometers were installed to measure the heads both inside and outside the screen as well as the head outside the gravel envelope. These head losses were also measured at various discharges and with gravel envelopes containing the various sizes of gravel.

To determine the effect of length of screen on the head losses through it, four of the screens were tested with various lengths of screen exposed.

Analysis of data

A number of factors which affect the hydraulic efficiency of well screens were analyzed. From the mechanics of flow it seems evident that there is some relationship between screen coefficient, C_s, and the loss of head through the screen. Other factors which were analyzed included the effect of a gravel envelope surrounding the screen, the effect of length of screen, and the effect of gravel size.

It was found that when the screen coefficient was about 15% or greater it had little or no effect on the loss of head through the screen. For coefficients below

15% a sharp rise in the loss of head was encountered as the coefficient decreased. Evidently the loss of head due to a well screen is divided into two parts - one consisting of the loss of head in passing through the screen slots and the other consisting of the loss of head due to turbulence inside the well screen. If the screen has sufficient perforated area, above 15%, the former loss is quite insignificant and may be neglected. However, for screens whose perforated area is less than 15% the loss of head in passing through the slots becomes great enough to increase the total screen loss significantly.

A gravel pack surrounding the screen has the effect of increasing the loss of head through the screen. The smaller gravel particles in the pack cause greater losses of head than the larger particles do.

Decreasing the length of the well screen has the effect of decreasing the head losses through it if the discharge per foot of screen is held constant.

The head losses through the gravel packs were found to be quite small when compared to the total loss through the well screen.

Discussion

The data obtained in answering all the problems stated in the problem analysis show that the loss of head through a well screen is divided into two parts. The greater part of the total loss is due to the turbulent loss that occurs inside the well screen. The water passes through the slot openings rather freely and little loss of head occurs, but in turning the jets of water through 90° and pulling the water up through the well screen a significant loss of head occurs. If a screen has sufficient perforated area this loss is practically the total loss for the well screen. If the perforated area is less than 15% the loss of head through the slots cannot be neglected.

Surrounding the well screen with a gravel pack caused an increased loss of head through the screen. This is due to the fact that the gravel, being adjacent to the perforations, causes a reduction in the perforated area. This reduction naturally causes an increased velocity through the remaining area which produces a greater loss.

In this study the maximum discharge per foot of screen used was much greater than could be expected in the field. However, using such discharges aided in analyzing the data. By using large discharges per foot of screen greater losses were obtained than are practical because the discharge is above the practical range. However, the length of screen was shorter than would naturally be expected in the field and it has been shown that for the same discharge per foot of screen the loss of head increases as the length of screen increases.

It must be remembered also that in this study only the loss of head through well screens has been considered. The loss of head is only one of the many problems to be answered in choosing the proper type of well screen to use in a well.

Suggestions for further study

In this study the total screen losses were measured. There was no attempt to separate the loss through the slot openings from the loss occurring inside the screen. A supplemental study to determine the loss of head through various slot sizes and shapes would make it possible to determine what portion of the total loss could be attributed to the screen slots.

It is suggested that the problem be extended further to include the effect of placing a sand formation outside the gravel pack. This study would provide much valuable data for, in addition to measuring the head losses, the amount of sand pumped through the gravel pack and screen could be measured.

In this study only one thickness of gravel pack was used. Perhaps other thicknesses should be investigated and especially so if a study is to be made with sand surrounding the gravel packs.

This thesis represents a study of only seven well screens. It would be interesting to extend the study to include many other types of well screens to see if the conclusions drawn hold true for them.

CONFIDENTIAL REPORT

(Nor for Publication)

This is a confidential report based on the thesis by Gilbert Corey, on one phase of a comprehensive study of well-screens sponsored by the Colorado Agricultural Experiment Station and the Division of Irrigation, of the Soil Conservation Service, with the cooperation of well screen manufacturers and well drilling companies. The distribution of this report is limited to the sponsoring and the cooperating agencies. The information contained herein has not been released for publication, but it may be used as a guide in designing well screens and for similar purposes. It should be kept in mind that this is a preliminary report on one phase of the study of well screens. When the study is completed it is entirely possible that the conclusions will have to be modified because of information obtained in subsequent studies involving other phases of the problem.

T H E S I S

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Chapter I

INTRODUCTION

The quantity of water available from streams and reservoirs in the arid regions of the world is frequently insufficient to supply the needs of land suitable for irrigation. In many of these areas a potential source of supply lies beneath the surface of the ground in layers of saturated sands and gravels. The most feasible means of recovering and using such water is by pumping from wells. This type of irrigation is centuries old and modern methods have made it quite popular in the arid regions of the United States.

Need for this study

Two general types of irrigation wells are in use today, the "developed well" and the "gravel-packed well". Where conditions are favorable the "developed well" is more effective in maintaining sufficient capacity without pumping excessive quantities of fine materials from the water-bearing formation. "Development" of a well removes the clay, silt, fine sand, and in some cases a portion of the coarse sand from the formation adjacent to the perforations in the well casing. This forms a filter of coarse and reasonably uniform particles which create a natural, well-graded, stabilized layer of highly permeable material entirely surrounding the well screen. To produce a properly developed well the water-bearing formation must contain sufficient coarse particles to insure the creation of a gravel filter. In formations consisting almost entirely of very fine uniform sand with insufficient coarse particles to permit successful development it is often advantageous to gravel pack the well artificially. The "gravel-packed well" accomplishes the same results as the "developed well". The difference between the two is that the gravel is artificially placed around the well screen in the former, whereas the envelope is naturally formed from the water-bearing formation in the latter.

In most formations a productive well, regardless of the type of construction, must have a perforated section or well screen which will allow free flow of water and a minimum passage of fine materials into the well. Careful consideration should be given the type of well screen used because the success or failure of the well may depend on this one item. Other things being equal, the well screen determines the amount of sand that will be pumped, the yield of the well, the yield per foot of drawdown, and the permanence of the well.

The "gravel-packed well" presents not only the problem of selecting the proper well screen, but also the problem of selecting the correct size of gravel to use in the envelope.

Problem

The problem for which an answer is sought in this thesis may be stated as follows: What are the hydraulic properties of well screens when surrounded by gravel envelopes containing various sizes of gravel?

<u>Problem analysis</u>.--1. What is the loss of head through each well screen operating in clear water with no gravel or sand surrounding the screen?

2. What effect does placing gravel envelopes around the screen have on the loss of head through the well screen?

3. What effect does size of particles in the gravel envelope have on the loss of head through the well screen?

4. What effect does size of particles in the gravel envelope have on the loss of head through the gravel envelope?

5. What effect does variation in discharge have on the above losses of head?

6. What effect does length of screen have on the loss of head through the screen?

<u>Delimitations</u>.--The well screens used in this investigation were limited to 12 inches in diameter and 2 feet in effective length. The types of well screens were as follows:

Well screen	Description	Width of slot	Material
A	Continuous slot	0.040 in.	Bronze
B	Continuous slot	0.100 in.	Bronze
C	Continuous slot	0.200 in.	Bronze
D	Continuous slot	0.100 in.	Black iron
E	Wire mesh	0.145 in.	Black iron
F	Punched slot	1/16 in.	Galv. iron
G	Punched slot	1/8 in.	Galv. iron

These screens will be described in detail in Chapter III.

The thickness of the gravel envelopes was 9 inches. The gravel used in them contained particles of approximately uniform size. The three sizes used in this investigation were 1 inch, 1/2 inch, and 1/4 inch.

In this study only the losses of head that occurred through the well screens and the gravel envelopes were analyzed. No attempt was made to determine the effect of shape and type of screen perforations on the losses.

Definition of terms.--A gravel envelope or gravel pack is a layer of gravel which is placed around the well screen to retard the movement of sand and to allow free passage of water into the well.

Loss of head, as used in this thesis, is the loss of potential energy between any two points as measured by the difference in elevation of water surfaces in piezometers connected to these points.

Screen coefficient, C_s, is the ratio of the perforated area of a well screen to the total surface area of the screen, the quantity being expressed as a percentage.

A well screen is that portion of a well casing which contains openings through the wall for the passage of water into the well.

Chapter II

REVIEW OF LITERATURE

The yield or transmitting capacity of a well is governed by many factors. The velocity of flow (a function of the water table slope), ground water temperature, interference from other wells, and size of well all are factors to be considered in determining the well yield. For many years a very important factor in the transmitting capacity of a well was neglected. Only in the last 50 years have the hydraulic properties of well screens been given any consideration. Many irrigation engineers and well drillers now realize that the selection of a proper size of gravel and screen slot opening is the most important factor in the construction of a gravel-packed well. In spite of this realization, entirely too few scientific investigations have been made on the performance of well screens under various conditions. The yield of a well is further controlled by the number, size and shape of the screen openings. Therefore, all factors affecting the life and performance of a well screen must be given consideration before the best method of constructing a well can be decided definitely.

G. J. Lehr (4), in a study reported in 1926, pointed out that the loss of head through a well screen consists of two distinct and separate parts. There is a loss of head through the screen openings due to their size and shape and there is another loss of head attributed to the turbulence of the water in passing upward through the inside of the well screen. The sum of these two losses is the loss of head in bringing the water from outside the well screen to the pump. The author states that the loss of head due to the screen is relatively small and may be neglected where new screens are used. This loss can be stated theoretically in the form of a velocity head loss

$$h_2 = C_2 \frac{V_2^2 - V^2}{2\,g} \qquad (1)$$

where h_2 = the loss of head through the screen perforations in feet

V_2 = the velocity of the water at exit through the perforations

= Q/A where Q is the discharge in cfs and A is the area of the perforations in sq. ft.

V = the velocity of the water at entrance to the perforations

= Q/A_o where Q is the discharge and A_o is the outside area of the well screen in sq. ft.

C_2 = a coefficient varying with the roughness of the screen and the temperature of the water

g = acceleration due to gravity

The loss of head due to turbulence and friction inside the screen may be written in a form similar to the equation for the loss in a pipe.

$$h_1 = C_1 \frac{V_1^2\,L}{2\,g\,D} \qquad (2)$$

where h_1 = the loss of head in the pipe in feet

V_1 = the velocity of flow in the pipe in feet per second

L = the length of the pipe in feet

D = the diameter of the pipe in feet

g = acceleration due to gravity

C_1 = a coefficient varying with the roughness of the pipe

Mr. Lehr neglected the loss through the screen and worked with the turbulent loss only. He computed the loss theoretically for a well screen 45 meters long and 0.25 meters in diameter. The constant, C_1, he used for his computations may be stated as follows:

$$C_1 = 0.0149 + \frac{0.0094711}{\sqrt{V_1}} \qquad (2a)$$

He also measured the loss of head in a well of the same size and found that the measured loss was 2.55 times greater than the computed loss. The author applied this correction to Eq. 2 and substituted discharges divided by cross section area for V_1 to obtain his equation for resistance in a well.

$$h_1 = 0.21 \quad C_1 \frac{Q^2 L}{D^5} \qquad (3)$$

H. L. White (11), in a paper published in 1937, stated that the size of gravel in the gravel envelope should be determined from the size of sand in the formation and that the size of screen openings should be as large as possible without allowing the gravel of the envelope to go through it. He gave the following specifications for the gravel to be used:

1. Size - A function of the sand size to be screened out

2. Shape - Spherical is ideal

3. Character - Hard granite-like material

4. Condition - Clean washed and of uniform size

Muskat (5), 1937, stated that the production capacity of a well is very sensitive to the value of the permeability of the zone immediately surrounding the well bore. If the annular zone adjacent to the well bore has a permeability greater than that of the remaining aquifer then the production rate of the well will be greater. However, these effects do not increase in proportion to the radius of the zone of greater permeability.

Bennison (2), 1939, stated that the proper well screen to use in the construction of a permanent dependable well is a more important problem than average drillers or users think. The ideal screen should be cheaply and easily constructed of materials that will last forever and make available all the water in the formation with limited drawdown. The important points to remember in considering a well screen are:

1. It is not a strainer to hold out all or a large part of the formation around it, but rather it is a stabilizer or device to support the water-bearing formation during the development and subsequent pumping.

2. The screen openings should be relatively large and based on an intelligent interpretation of a sand analysis and local ground conditions.

3. The screen should have as much opening and as little blank space as possible in order not to shut off the natural openings in the water-bearing formation.

4. If smaller particles are placed in the voids between larger particles in the formation, there will be a reduction in the total volume of open space.

5. The uniformity of grading of the mixture, therefore, is more important from the water-yielding standpoint than the size of particles themselves.

6. Santini (7) in a study reported in 1942, determined the coefficient of capacity of several types of well screens. This coefficient of capacity, C_s, was considered to be the area of the slot openings in a screen divided by the total area of the outside surface of the screen, both expressed in the same units. The author stated that this coefficient multiplied by the original porosity of the aquifer will give the new porosity of the aquifer. Thus, a screen with a high coefficient is desirable.

The Corps of Engineers (10), 1942, was interested in the design of drainage wells for several contemplated well systems along the Mississippi River levees. An investigation was initiated by them to determine design criteria for these drainage wells. To accomplish this, field and laboratory tests were conducted on the following four types of drainage wells: (a) brass well screens, (b) perforated non-metallic pipes with filters, (c) porous concrete drain pipes, and (d) gravel-filled wells. The tests consisted of determining the discharge efficiency of various types of wells, and the maximum slot or mesh size of brass well screen, and the size and gradation of gravel filters that will safely drain a foundation sand. The gravel filter tests consisted of placing a filter 1½ to 2 inches thick of pea gravel around a perforated well screen with 0.10 to 0.15 inch perforations, and observing the quantity of material washing into and through such a filter.

Probably the most significant finding of the field investigation was the successful use of perforated or porous nonmetallic pipes as drainage wells. The materials of which the perforated wells were constructed had no effect on their relative discharge efficiencies - the essential requirements being the proper installation of a correctly designed filter around the pipe and sufficient area.

The criteria used for designing the gravel filters for the perforated pipes were those discussed by Taylor (9). These design criteria were:

$$\frac{15\%\text{ size of filter}}{85\%\text{ size of foundation}} \leq 4 \text{ to } 5 \leq \frac{15\%\text{ size of filter}}{15\%\text{ size of foundation}}$$

The validity of these criteria was established in both field and laboratory tests. The results of the field and laboratory tests indicated little difference in the discharge efficiency of new brass screens of the same length, diameter, and with perforations or slots which had not yet had an opportunity to corrode or clog. In clean sands screen sizes as small as 0.008 inches were not found to restrict the flow into the well.

The results of the tests on gravel-filled wells indicated that wells of this type have a low discharge efficiency. The reason for this was the frictional resistance encountered by the water flowing upward through the gravel in the well and the resistance encountered in flowing to and through the relatively few perforations in the casing.

The effect of friction and velocity head losses in the riser and discharge pipes of a well screen in reducing its discharge efficiency was demonstrated in the field experiments. Such losses reduce the effective net artesian pressure head producing flow and thereby reduce the well efficiency. In general, the inside diameter of the riser pipe should be designed so as to prevent the creation of excessive friction and velocity head losses.

The city of Elizabeth, North Carolina (8), 1944, made a specialized study to determine the most effective size screen and gravel for its particular wells. The city's water supply is obtained from 109 shallow gravel-packed wells in Dismal Swamp. The water table is a few inches below ground surface and the water-bearing formation consists of fine sand, therefore it was necessary to pack the wells with gravel. Major troubles in the operation of the wells occurred due to the entrance of fine sand into the piping system and the clogging of the well screens. Experiments with several types of gravel packing and different kinds of screens resulted in much added knowledge as to the best type of well to build and the type of screen to install. It was found that the best type of screen was a slotted screen No. 20 (0.020 in.) and the most satisfactory size for the gravel pack was from 1/16 to 1/8 in. in diameter.

Statistics compiled by Millis (1), 1947, show that out of 320 wells for which records had been examined, 285 had been abandoned. Of these 285 abandoned wells 280 had been abandoned because of screen clogging and incrustation.

Summary

Although irrigation engineers and well drillers realize that the selection of a proper gravel and slot size is a very important factor in the construction of gravel-packed wells there have been few scientific investigations made to determine the most efficient sizes. Much experience and a knowledge of previous wells in the region are relied on in the selection of proper gravels and screens. There is a definite need for information on the efficiency of well screens because failure to choose the proper screens with proper gravel will reduce the capacity of the well, increase the pumping lift, and if too much sand is pumped through the perforations it may cause the well to collapse. In each of these an economic loss occurs.

The work by the Corps of Engineers seems to corroborate Lehr's findings in 1926. In each of these publications the importance of the friction and velocity head losses in the riser are emphasized. In fact, Lehr's findings are based on this being the entire resistance of the well. For a new well screen this is probably very nearly correct because the loss through the screen will be very small. However, Lehr was working with only one screen and this screen had an effective slot area equal to one-third the entire surface area of the screen. This should be an efficient screen. Perhaps if a screen with fewer perforations had been used and greater velocities through the perforations had been obtained, the loss through the perforations would be significant. The presence of a gravel pack around the screen will also have a definite effect on the loss through the perforations.

The Corp of Engineers' laboratory tests on gravel-filled wells were rather limited in scope and it seems that the thickness of the gravel envelope was too small.

Chapter III

METHODS AND MATERIALS

To find the hydraulic properties of a well screen when surrounded by a gravel envelope it is necessary to measure the loss of head, at various discharges, through the gravel envelope and through the well screen. The method used in setting up the apparatus and obtaining the loss of head is discussed in this chapter. The loss of head was first measured through each well screen operating in clear water with no gravel envelope surrounding it. After these data were obtained for each screen, gravel envelopes containing 1 inch, ½ inch, and ¼ inch gravel were placed around each screen and the resulting losses of head through the screen and gravel measured at various discharges.

Well screens

Seven well screens were used in this investigation. Each screen was 2 feet in effective length and 1 foot in nominal diameter. Three of the screens, designated herein as A, B, and C, were made of bronze and had slot openings of 0.040 in., 0.100 in., and 0.200 in. respectively. These screens are constructed in such a way that the water openings are continuous slots. Wire of triangular cross section is welded to a framework of ribs in a spiral manner such that the wire is continuous from one end of the screen to the other. The pitch of the spiral determines the width of the slot. The triangular shaped wire, having the narrow edge to the inside, gives an opening which is V-shaped. This is a much desired characteristic in well screens because any particle which is small enough to start through the slot will pass on through it.

Another screen, designated as D, is constructed of black iron in the same manner as the bronze screens A, B, and C except that the wire in this screen is "half-round" instead of triangular in cross section. The slot width in this screen is 0.100 in.

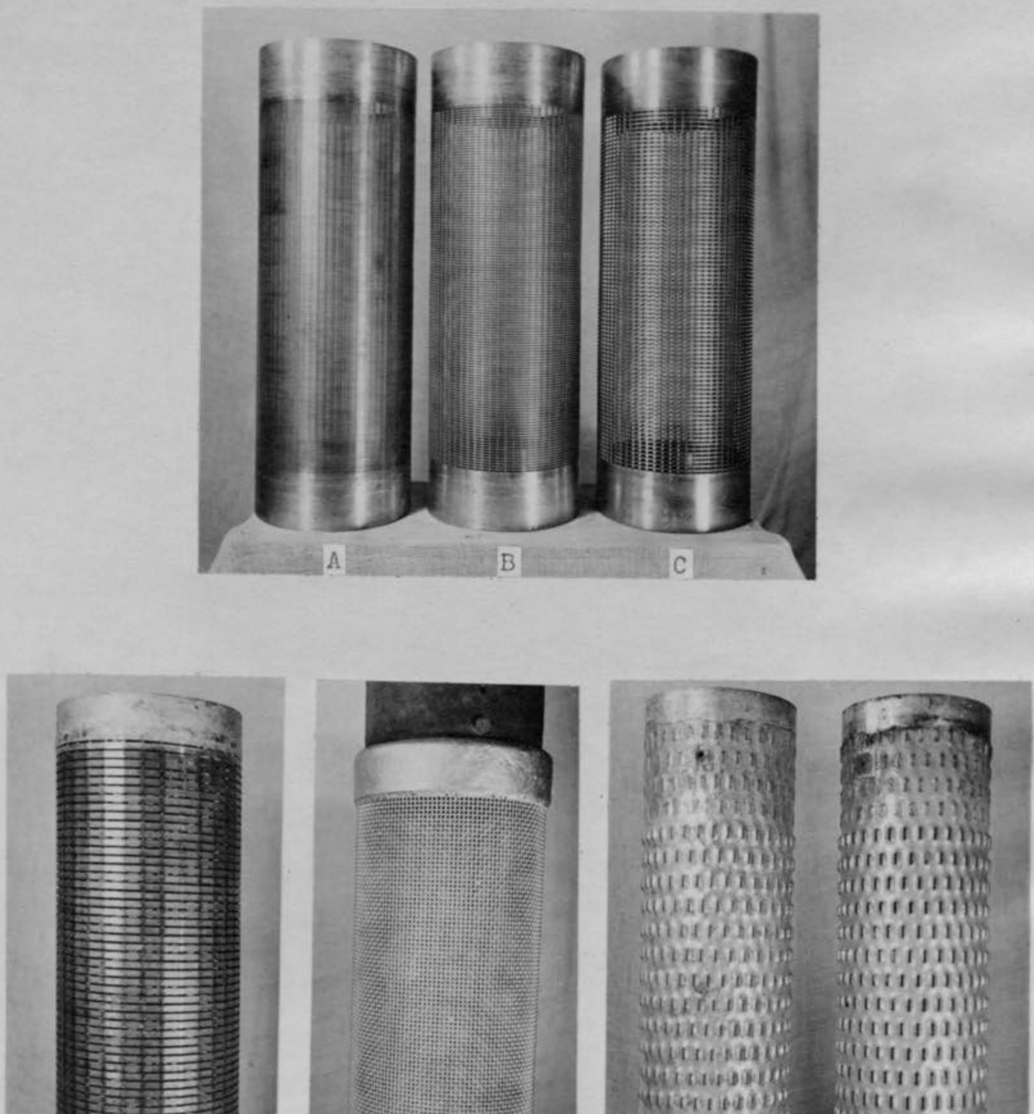


PLATE I. Types of well screens used in tests.

One-inch gravel

One-half inch gravel

One-quarter inch gravel

PLATE II. Gravels used in gravel envelopes.

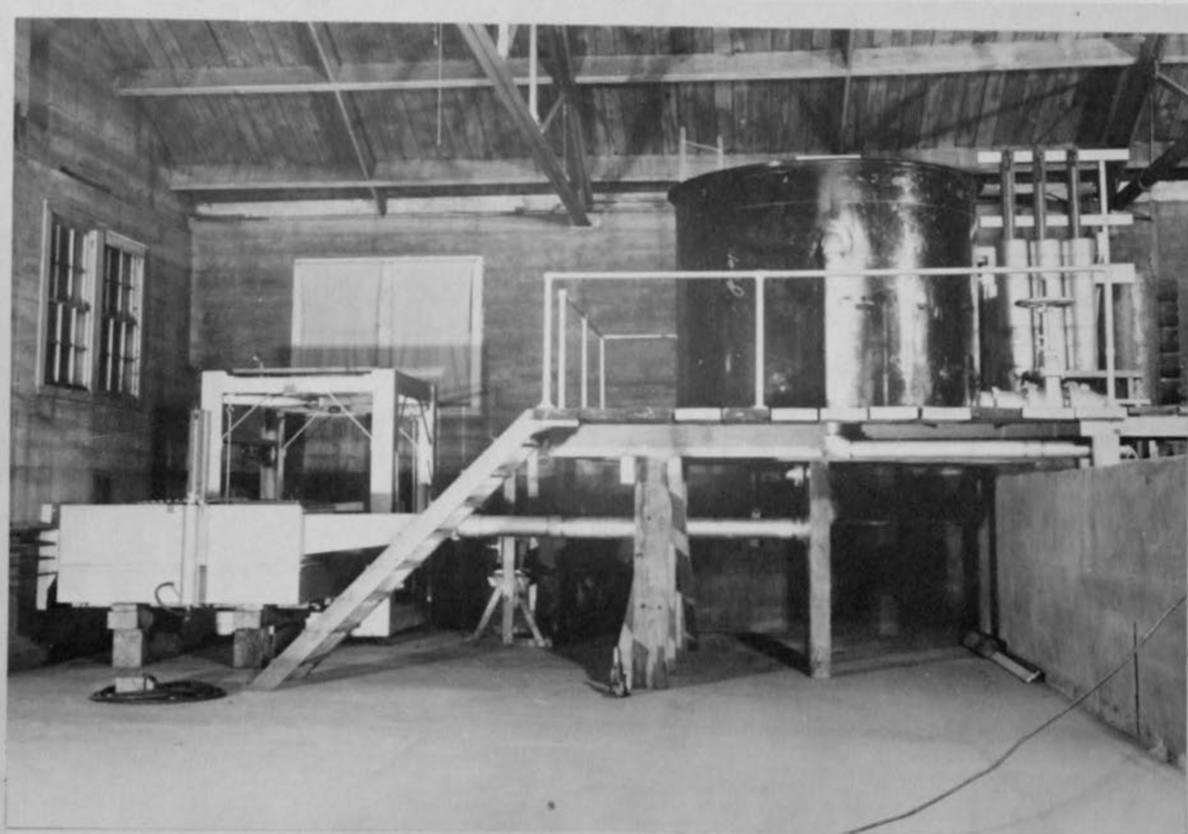


PLATE III. Experimental apparatus for testing well screens. Hook gages appear at upper right, weir box at lower left and the experimental tank is in the upper right center on the platform.

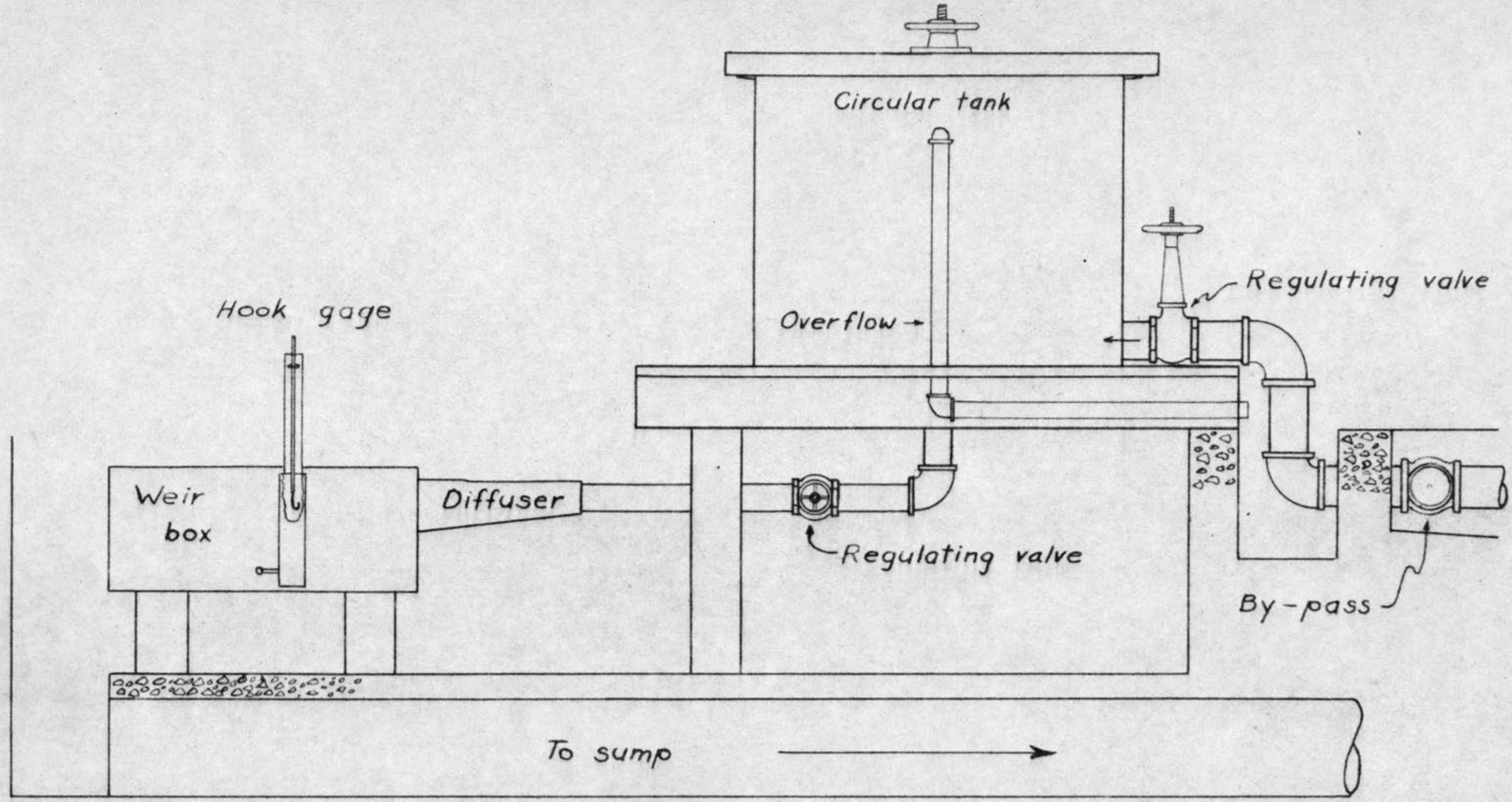


Figure 1.– EXPERIMENTAL APPARATUS

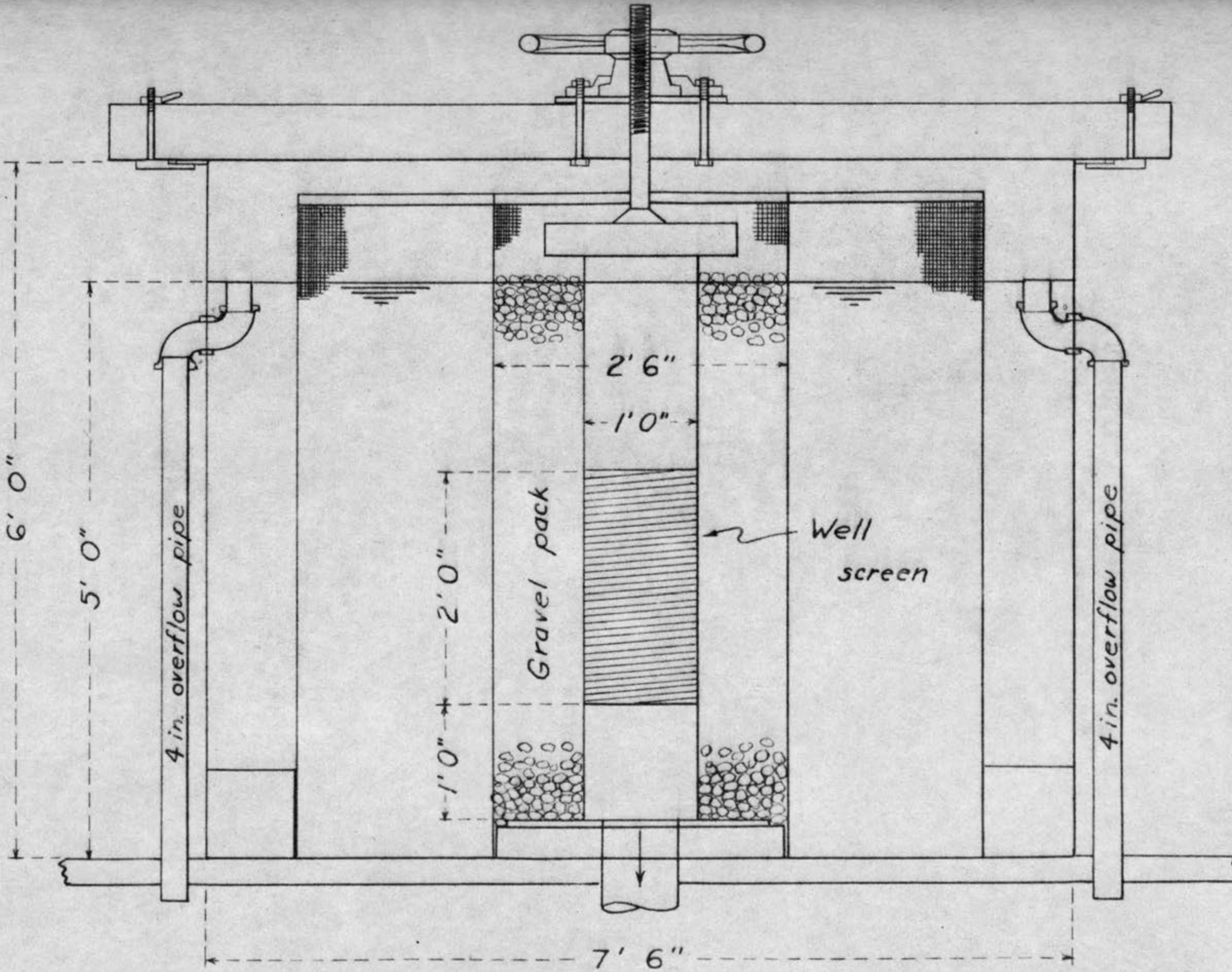


Figure 2.- CROSS SECTION OF EXPERIMENTAL TANK

Two galvanized iron screens designated as F and G, were used. These screens have widths of slot opening of 1/16 in. and 1/8 in. respectively. The openings in these screens are punched slots 3/4 in. long and are placed on 1¼ by 1 3/4 in. centers. They are punched from the inside to give a V-shaped opening.

The final screen used in the investigation was a wire mesh screen, designated as E. The openings in this screen are 0.145 in. square. This screen was constructed in the laboratory by shaping and welding the wire mesh into a cylinder of the desired length and diameter.

Photographs of all the screens are shown in PLATE I.

Gravel

The gravel used in each of the gravel packs contained particles that were approximately the same size. No tests were run with envelopes containing a gradation of particle sizes. Each screen was tested with envelopes of three different gravels. The particle sizes used, as mentioned before, were 1 in., ½ in., and ¼ in. River-bed gravel was used because this gravel has been subjected to erosion which tends to round off the sharp corners leaving the gravel more or less spherical in shape.

The 1 in. gravel passed a 1½ in. sieve and was held on a 1 in. sieve. The ½ in. gravel passed a 5/8 in. sieve and was held on a 3/8 in. sieve. The ¼ in. gravel passed a ½ in. sieve and was held on a ¼ in. sieve. Photographs of the three sizes of gravel are shown in PLATE II.

General arrangement of apparatus

A photograph of the equipment used in making the tests is shown in PLATE III. A schematic diagram appears in Fig. 1. The equipment was installed in a recirculating pump system. The water was pumped through an 8 inch pipe to the apparatus by a turbine pump. It then passed, by gravity flow, through the well screen and the weir box into the return channel. The return channel, being connected to the pump sump, completed the circuit.

The tank which housed the well screens was 7½ ft. in diameter and 6 ft. in depth. To maintain a constant depth in the tank two overflow pipes 4 ins. in diameter were placed upright on either side of the tank at a height of 5 ft. from the tank floor as shown in Fig. 2. This 5 ft. depth was maintained for all tests.

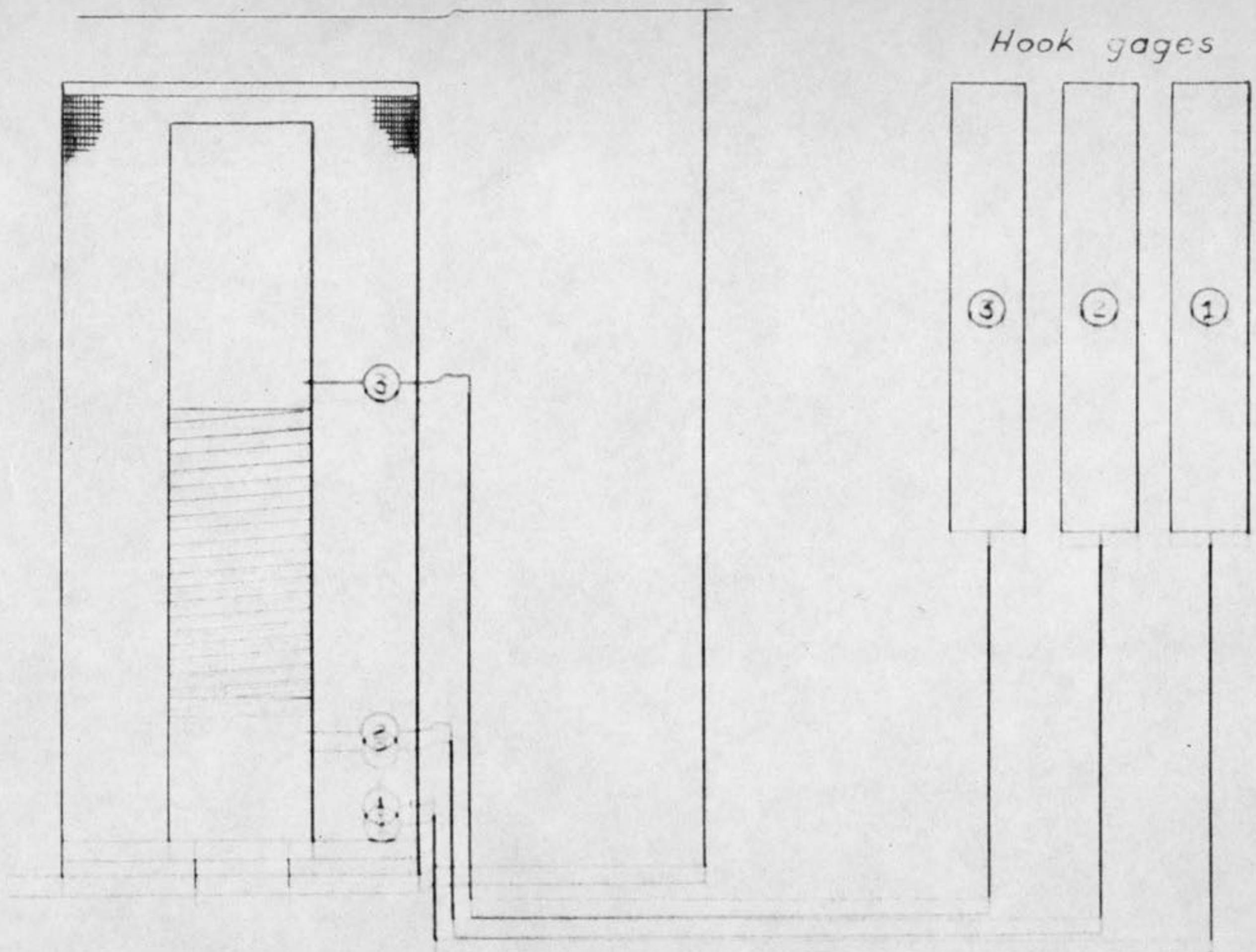


Figure 3. PIEZOMETER POSITIONS WITH NO GRAVEL PACK

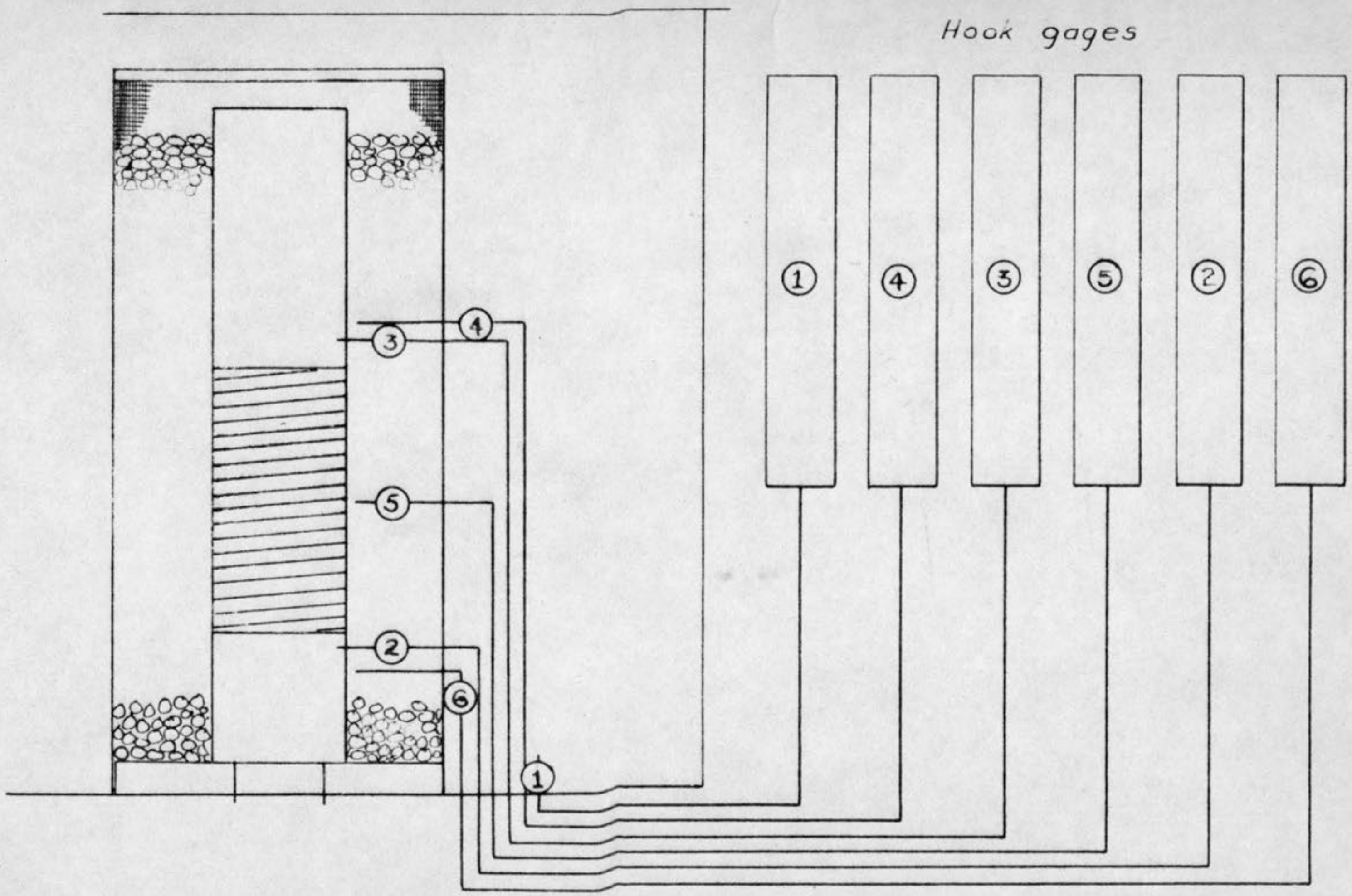


Figure 4. - PIEZOMETER POSITIONS WITH GRAVEL PACK

Installation of well screens

The 2-ft. well screens had to be extended to slightly over 5 ft. in order to utilize the 5 ft. of depth in the tank. This was accomplished in screens A, B, C, D, and E by fitting a length of 10 in. pipe to each end of the well screen. This could be done in these screens because they are constructed with pipe couplings at either end. The photograph of screen E, PLATE I, shows this extension. In screens F and G this extension was accomplished by fitting a length of well casing on either end of the screen. This slip joint was sealed with tar to prevent leakage. These extensions of the various screens were arranged so that the perforated section of each screen occupied the same relative position in the tank. The bottom of the perforated section was approximately 12 in. from the bottom of the tank in each case.

The well screen and fittings were held in place over the outlet in the center of the tank with a screw jack operating through a 6 by 6 in. timber as shown in Fig. 2. The timber was attached firmly to the tank with L-shaped clamps on each end. To prevent leakage a 3/4 in. rubber gasket was placed between the end of the screen and the floor of the tank.

A 4-mesh wire cloth screen 30 in. in diameter and 6 ft. in length was placed around the well screen. This was used as an outside boundary for the gravel envelope. A 9-in. gravel envelope was thus obtained in the annular space between the 12 in. well screen and the 30 in. wire mesh screen. Although serving no purpose this screen was in place during the tests in which no gravel envelopes were used.

Piezometer arrangement

The arrangement of the piezometers for the tests on the screens with no gravel pack surrounding them is shown in Fig. 3. Hook gage No. 1 measured the head of water in the tank outside the well screen. Hook gages No's.2 and 3 measured the head inside the well screen at the bottom and top of the screen respectively. The difference between the heads outside and inside the well screen is the loss through the screen.

The piezometer arrangement for measuring the losses with a gravel pack around the screen is shown in Fig. 4. In this case hook gage No. 1 measured the head of water outside the gravel pack. Hook gages No's. 2 and 3 again measured the head inside the well screen. Hook gages No's. 4, 5 and 6 measured the head just outside the screen in the positions shown. The loss of head through the screen in this case was taken as the difference between the head measured at No. 2 and the average of the heads measured at No's. 4 and 6. The loss through the gravel envelope was taken as the difference between the head measured at No. 1 and the average of No's 4 and 6. Hook gage No. 5 measured the head outside and midway along the screen. The readings of this gage were affected by the velocities encountered there, and for this reason were not used in the analysis of the results.

Each hook gage was equipped with a vernier which read to one one-thousandth of a foot. In reading the hook gages the nearest five ten-thousandths was estimated. To reduce error each hook gage was read five times and the average of these five values was used in computing the head losses.

The hook gages were all installed on a platform anchored to a firm concrete foundation. This platform was in no way connected to the tank structure. This eliminated the possibility of settlement of the tank affecting the zero readings of the hook gages.

Installation of the gravel packs

Uniform compaction of the gravel envelopes was necessary in order to obtain comparable results. To accomplish this each gravel pack was placed around the well screen while the tank was full of water. The gravel was poured in at the water surface in small increments to reduce the possibility of stratification. When the annular space between the well screen and the thirty-inch wire mesh screen was filled with gravel, the wire mesh screen was given six blows with a hammer at each quarter point to compact the gravel. It seems logical that if the loss of head through a given size of gravel pack was the same for each screen then the compaction was uniform. These losses were measured and appear to be fairly constant.

The well screen, once installed in the experimental tank, remained there until tests had been completed on all three sizes of gravel packs. Upon completion of tests with one size of gravel, the tank was drained and the new pack was placed around the screen after the old pack had been removed. The well screen was held rigidly in place during this operation by the screw jack.

Discharge measurement

Discharge measurements were made with a calibrated 90° v-notch weir set in the end of a weir box which was 6 ft. long, 3 ft. 2 in. wide and 2 ft. 6 in. deep. To quiet the flow in the weir box a lattice type baffle was installed 5 ft. upstream from the weir. The depth of flow over the weir was measured with a hook gage whose connection to the weir box was 3 ft. upstream from the weir.

The discharges at which the various losses were measured were 0.125, 0.250, 0.500, 1.000, 1.500, and 2.000 c.f.s. For plotting purposes each discharge was divided by the effective length of screen to give all discharges in c.f.s. per foot of well screen.

To observe the effect of the length of screen on the losses, screens A, B, D, and E were tested with 3 in., 6 in., and 24 in. of screen exposed. These different lengths of screen were obtained by wrapping all but the desired length of the screen with sheet rubber.

Chapter IV

ANALYSIS OF DATA

There are a number of factors which affect the hydraulic efficiency of well screens. From the mechanics of flow it seems evident that there must be some relation between screen coefficient and the loss of head through the screen. The screen coefficient may be defined as the perforated area divided by the total surface area of the screen, the quantity being expressed as a percentage.

Other factors that may be significant include the effect of a gravel pack surrounding the screen, the effect of the length of screen, and the effect of gravel size. There are undoubtedly other factors such as shape of slot opening, mineral content of the water, temperature of the water, and material from which the screen is constructed which affect the efficiency of the screen when installed in a well. However, the effect of these factors was beyond the scope of this study so they were maintained as "constant" quantities.

Relationship between screen coefficient, C_s, and the loss of head through the screen

The screen coefficient was determined for each screen and the values are as follows:

Screen A	31.59%
Screen B	53.59%
Screen C	69.78%
Screen D	21.10%

Screen E 33.64%
Screen F 2.54%
Screen G 4.77%

In Fig. 5 the relationship between these coefficients and the loss of head at various discharges has been plotted. These losses are those that were measured while the screen was operating with no gravel pack surrounding it. The figure shows that when the coefficient is about 15% or greater, it has little or no effect on the loss of head through the screen. However, there is a slight decrease in the loss of head between coefficient values of from 20 to 30%. Below 15% there is a sharp rise in the loss of head as the coefficient decreases.

The losses for these screens when surrounded by gravel envelopes of 1-inch, 1/2-inch and 1/4-inch gravel are shown in figures 5(a), 5(b) and 5(c). These curves reveal the same trends as those for the screens without gravel envelopes except that the sharp increase in losses occurs nearer to coefficient 20 than to 15. Furthermore, the curves indicate that the increase in the losses occurs at increasingly higher screen coefficients as the size of the gravel decreases. This trend is to be expected because the smaller gravel obstructs more of the openings than the larger gravel.

It appears that if a screen has sufficient perforated area the loss of head is practically independent of the shape of the openings. This area must be at least 15% of the total area for the higher discharges. However, for discharges as low as 0.125 cfs per ft. the minimum coefficient can be as low as 5% and show no greater loss than a screen with a higher coefficient.

This phenomenon can be explained by the fact that when a screen has sufficient perforated area there is very little loss of head in passing the water through the slot openings. Practically all the measured loss of head is due to the loss inside the well screen. Each jet of water must be turned through 90° and in so doing an energy loss occurs. This loss of head is practically the same for all screens having a C_s value above 15%.

When the C_s value for a screen becomes less than 15% the loss of head through the slots becomes significant as is demonstrated by the rise in the curves of Fig. 5. The water must pass through the slots at a greater velocity because of the reduced perforated area. If this velocity is great enough a significant loss is likely to occur. Perhaps the loss of head inside the screen becomes greater also. With increased velocity the momentum of the jets is increased and a greater amount of

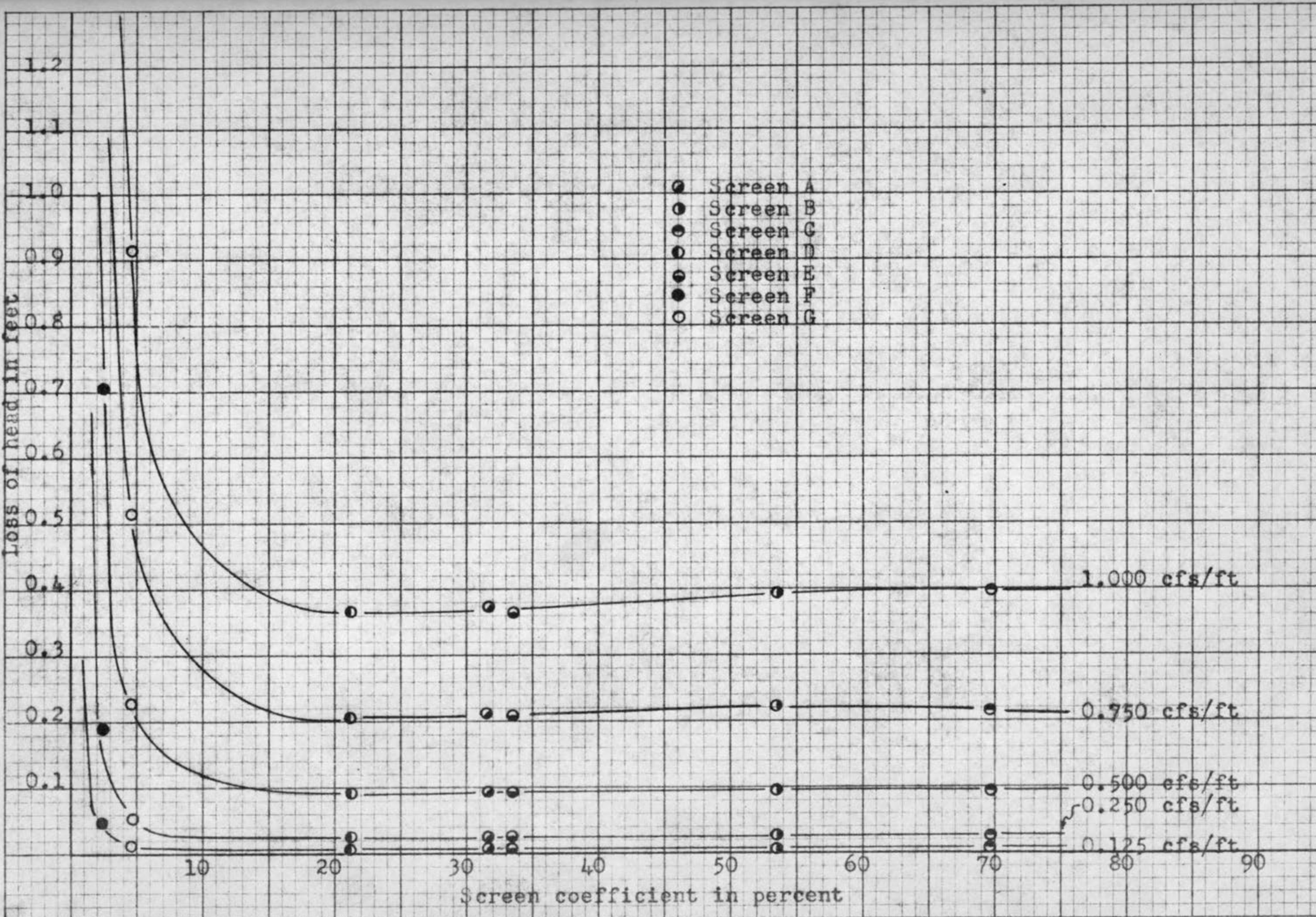


Fig. 5.--Loss of head at various discharges in relation to screen coefficient.

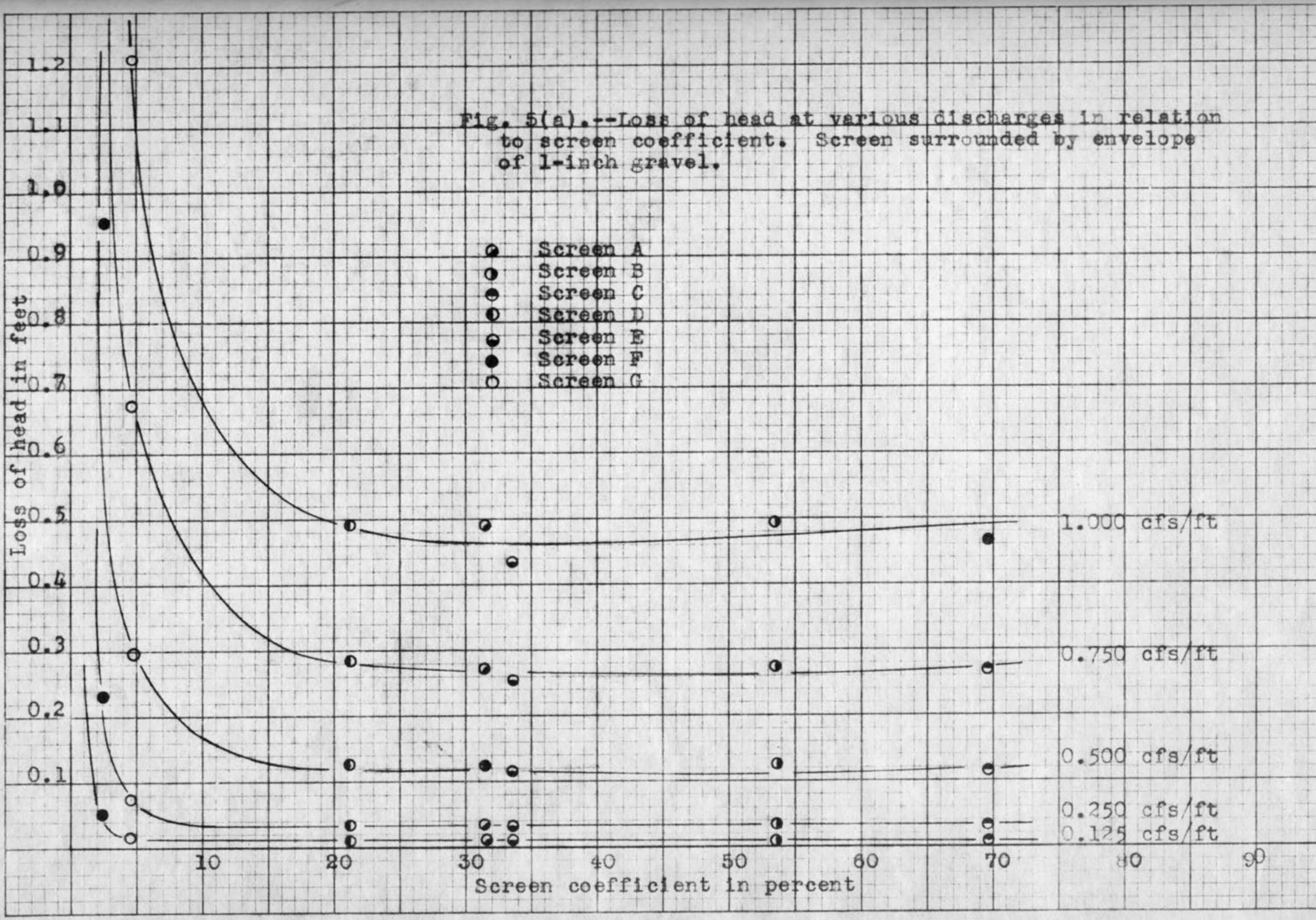
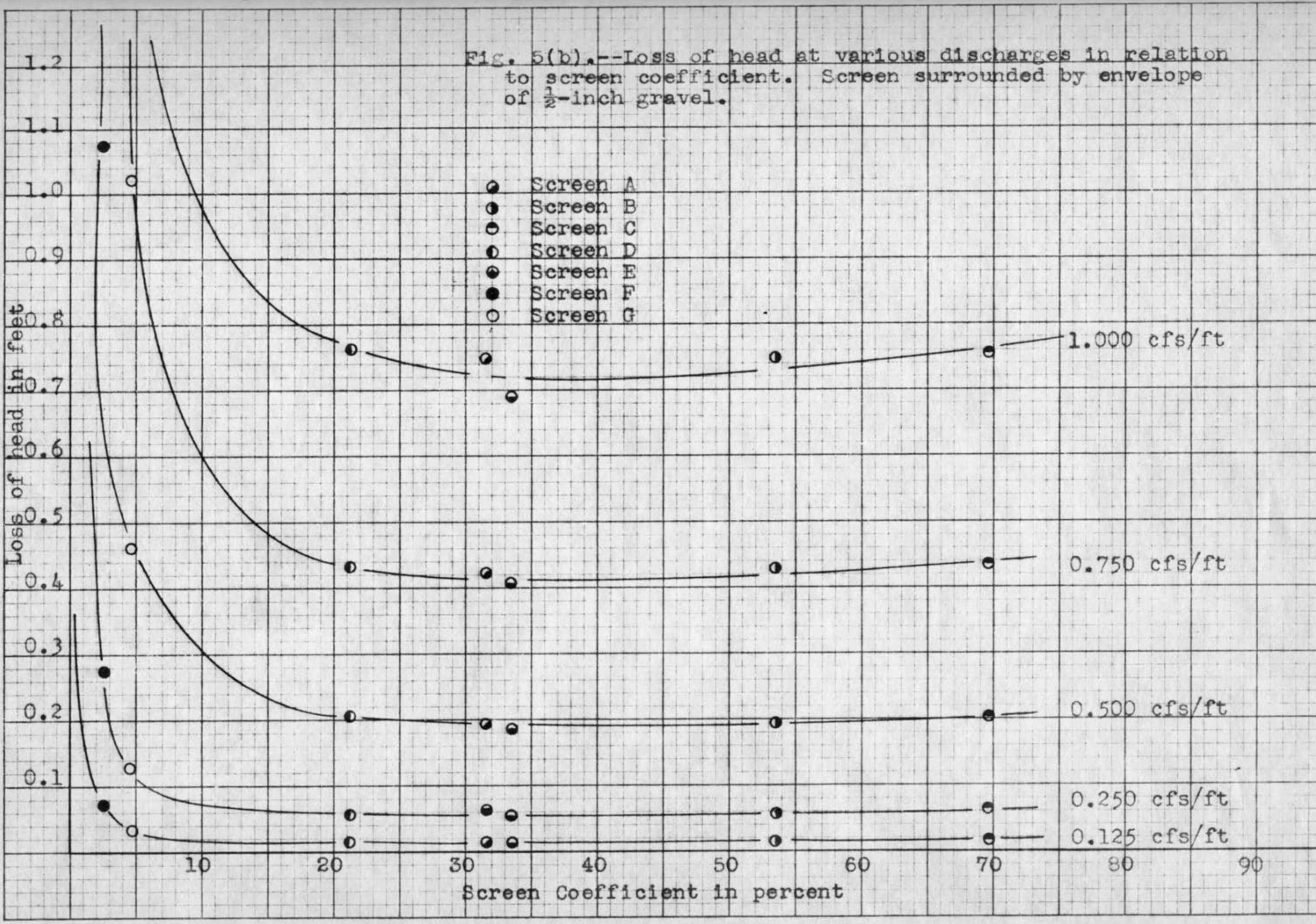


Fig. 5(a).--Loss of head at various discharges in relation to screen coefficient. Screen surrounded by envelope of 1-inch gravel.
Screen A
Screen B
Screen C
Screen D
Screen E
Screen F
Screen G
Loss of head in feet
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.000 cfs/ft
0.750 cfs/ft
0.500 cfs/ft
0.250 cfs/ft
0.125 cfs/ft
10
20
30
40
50
60
70
80
90
Screen coefficient in percent

Fig. 5(b).--Loss of head at various discharges in relation to screen coefficient. Screen surrounded by envelope of ½-inch gravel.



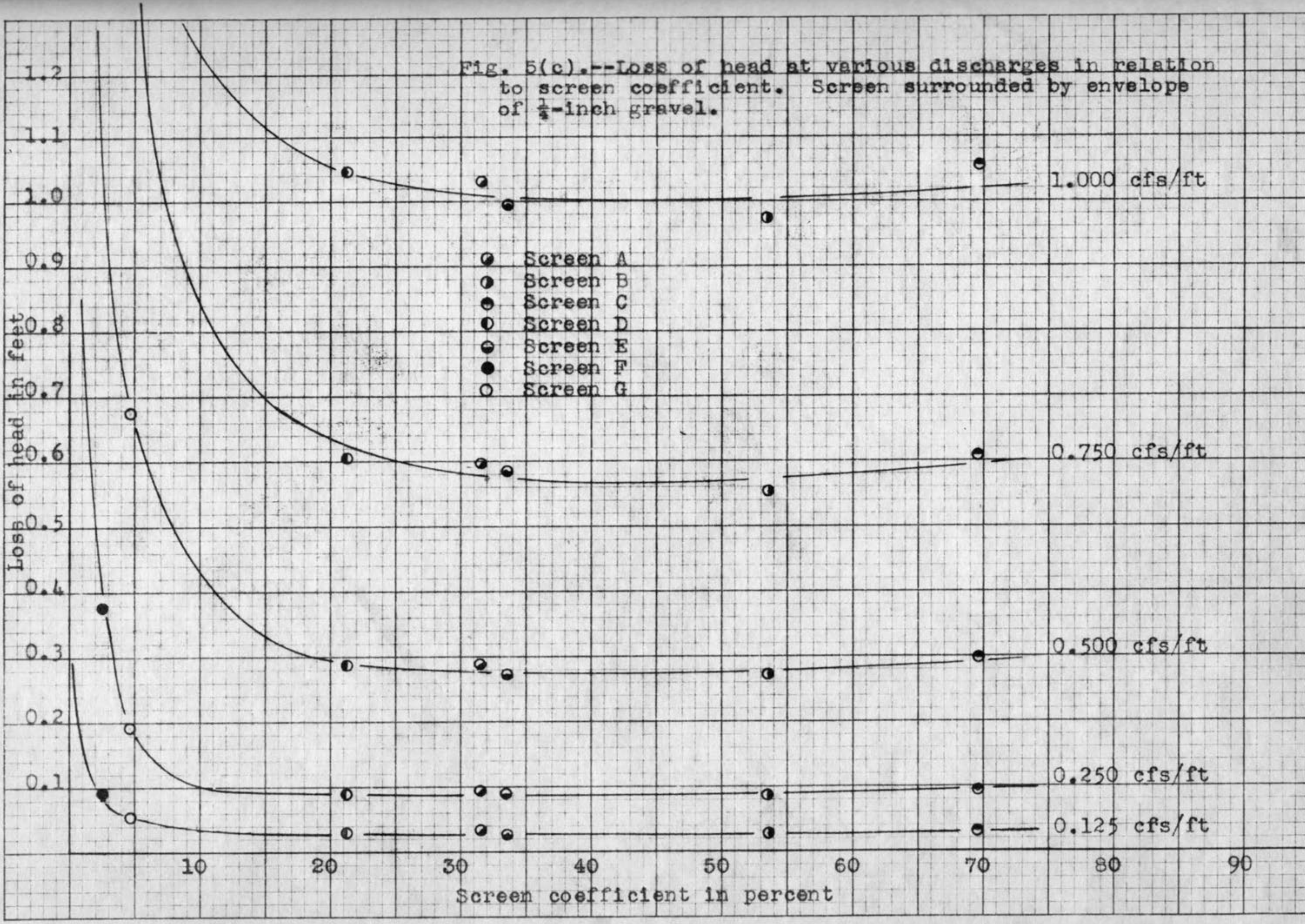


Fig. 5(c).--Loss of head at various discharges in relation to screen coefficient. Screen surrounded by envelope of ¼-inch gravel.
Screen A
Screen B
Screen C
Screen D
Screen E
Screen F
Screen G
1.000 cfs/ft
0.750 cfs/ft
0.500 cfs/ft
0.250 cfs/ft
0.125 cfs/ft
Loss of head in feet
Screen coefficient in percent
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
10
20
30
40
50
60
70
80
90

energy is dissipated in deflecting the jets through 90°. The turbulence also increases.

The decrease in the loss of head for screens having coefficients between 20 and 30% seems contrary to hydraulic concepts. It seems that if the perforated area increases then the loss of head should decrease. However, it must be remembered that the screens used in this investigation did not all have the same shape of perforations. Therefore there must be a shape factor that affects the loss of head through the screen. Screens D and E, which show this decrease in loss of head, have slot openings that are similar in shape in that the obstructed portion of the screens consist of round or half round wires. Evidently less loss occurs in passing the water through such an opening.

Effect of gravel pack on the head losses

The effect of the various gravel packs on the head losses was measured for each screen. These measured losses include only the loss of head through the screen and in the pipe. The losses through the gravel packs will be discussed later. The reading taken at hook gage No. 2 was used as the head inside the screen because this gage recorded the loss due to turbulence inside the screen as well as the loss of head through the slot openings. Figures 6-12 have been plotted showing the relationship between the head losses through the screens and the discharge per foot of screen. Each figure represents one screen with the curves being plotted for the following conditions:

1. The screen operating in clear water with no gravel pack surrounding it.

2. The screen operating with a 9-inch gravel pack of 1 in. gravel surrounding it.

3. The screen operating with a 9-inch gravel pack of 1/2 in. gravel surrounding it.

4. The screen operating with a 9-inch gravel pack of 1/4 in. gravel surrounding it.

The curves show that, for every screen, the loss of head increases as the discharge increases. The gravel packs have the effect of increasing this loss of head through the screen, with the 1/4 in. gravel causing the greatest loss and the 1 in. gravel the least. The losses appear to be approximately the same for all the screens with the exception of screens F and G. In these screens a greater loss of head occurs in all cases. These are the screens in which the area of slots was less than 5 percent of the total.

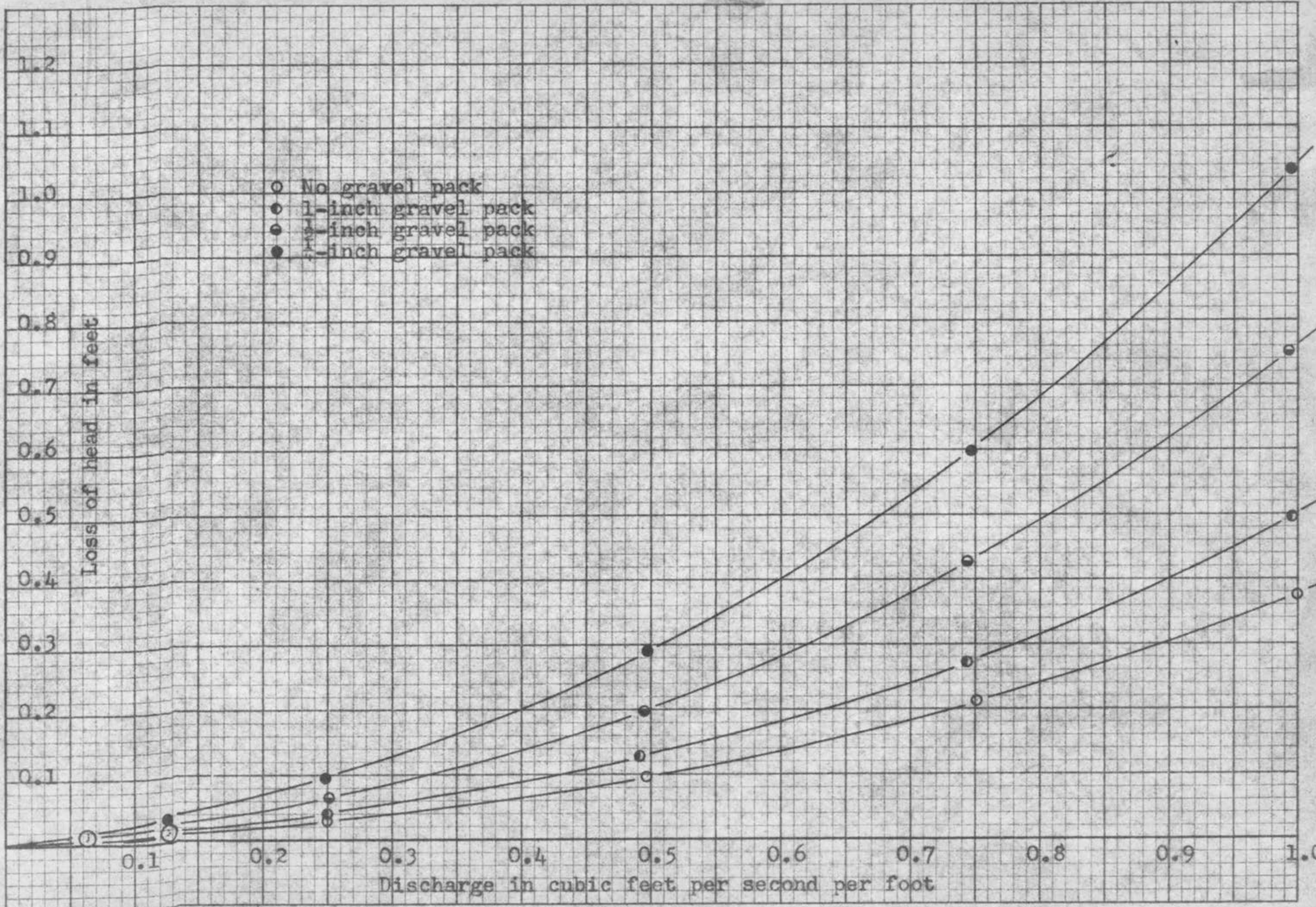


Fig. 6.--Summary of head losses for screen A.

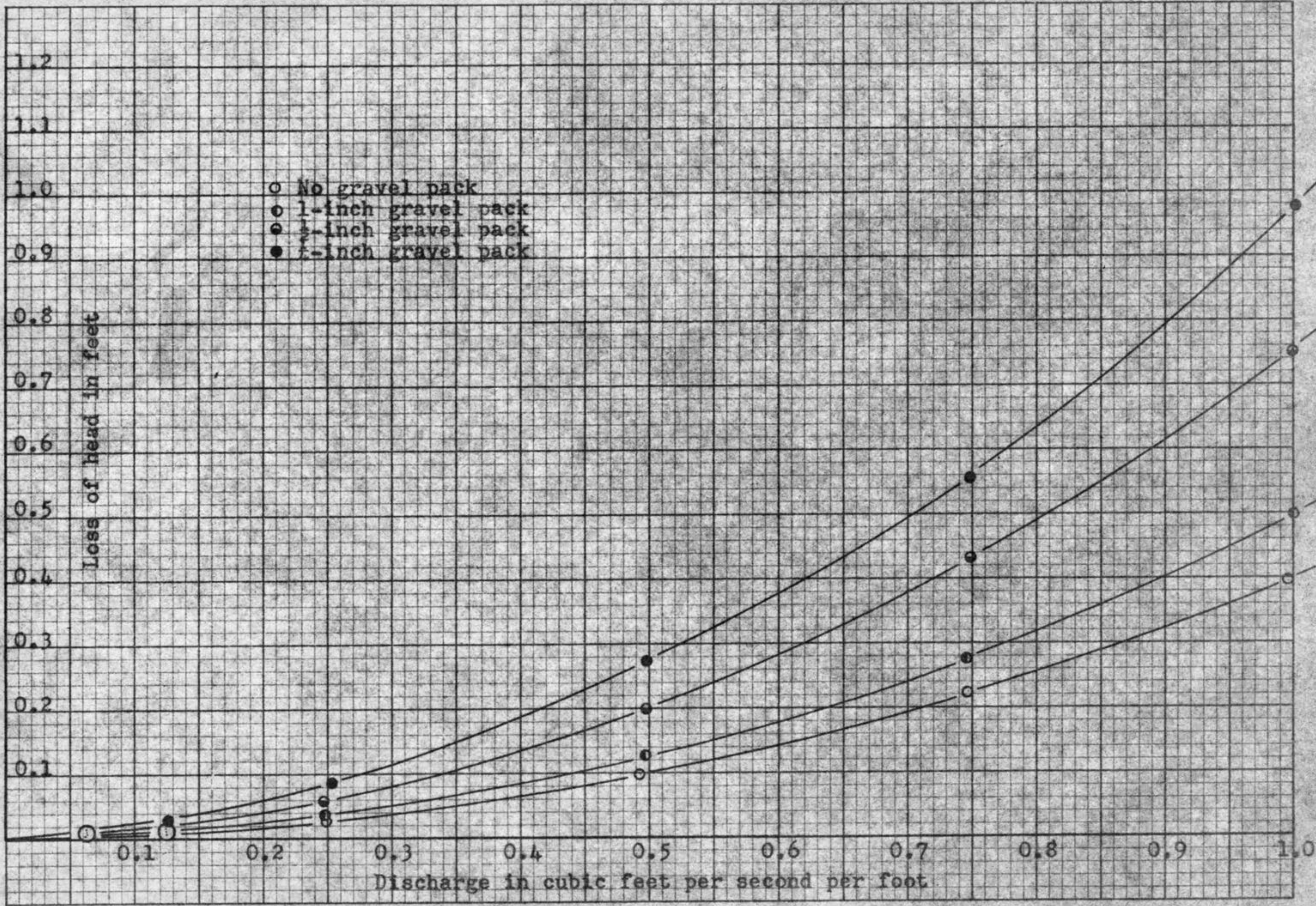


Fig. 7.--Summary of head losses for screen B.

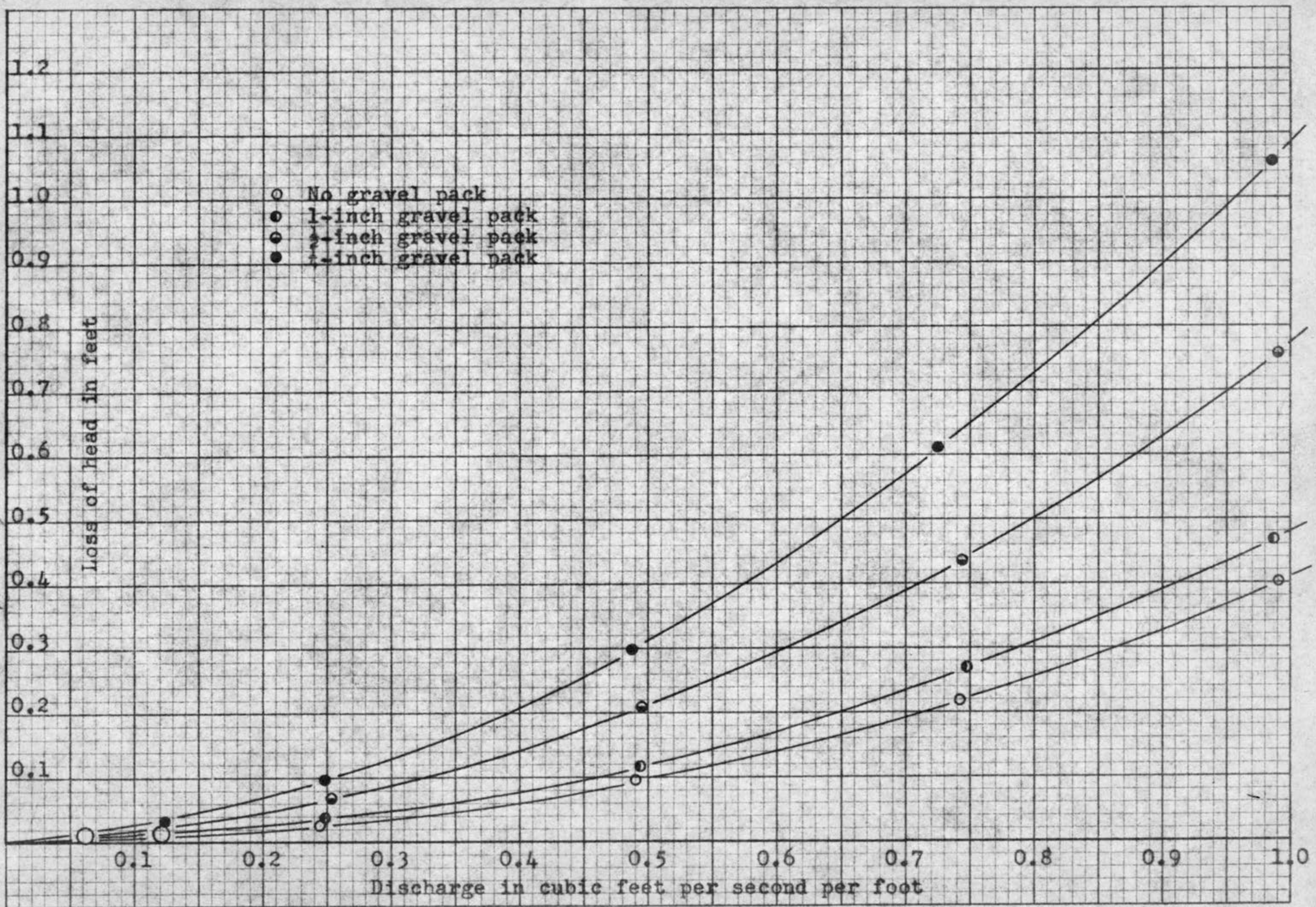


Fig. 8.--Summary of head losses for screen C.

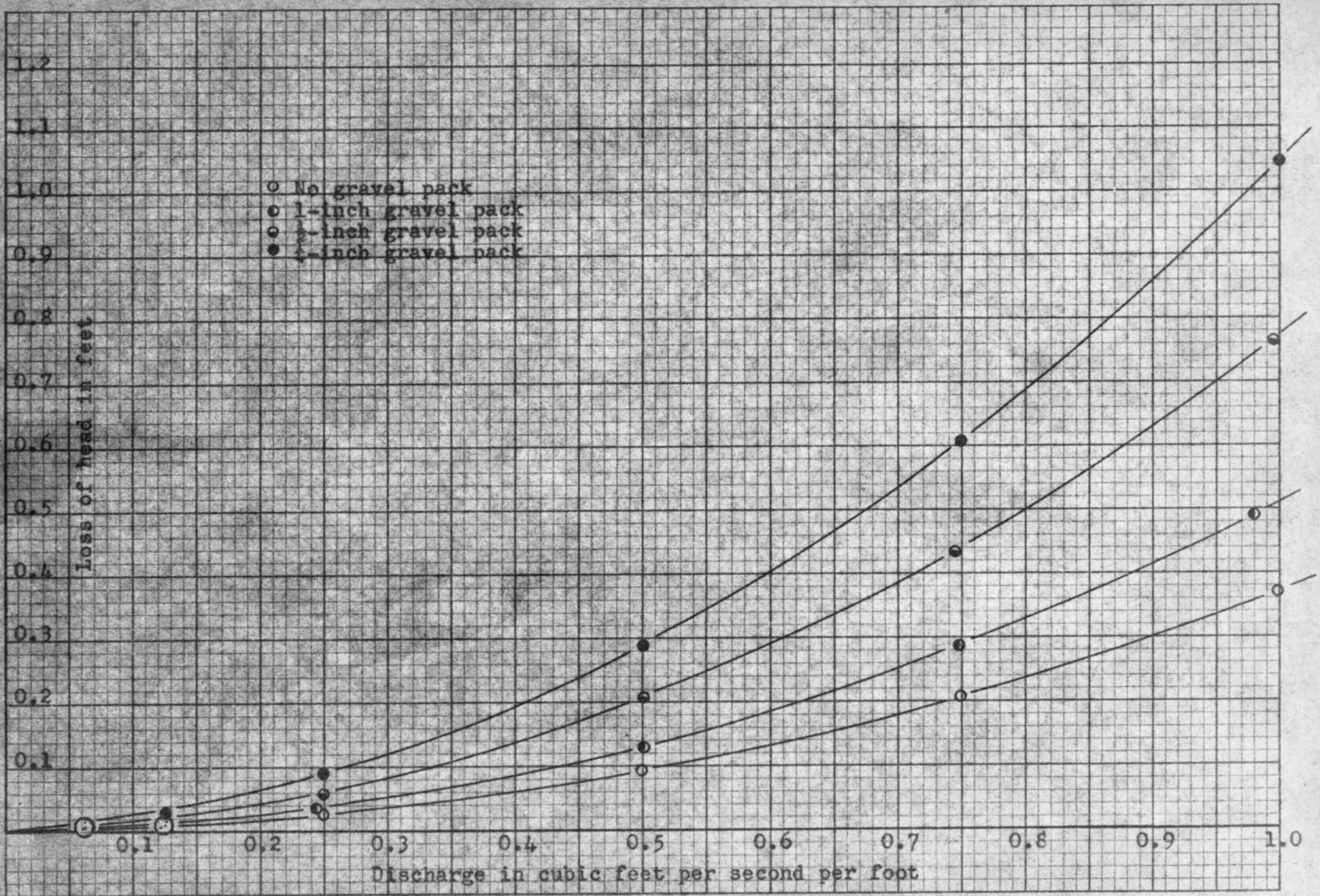


Fig. 9.--Summary of head losses for screen D.

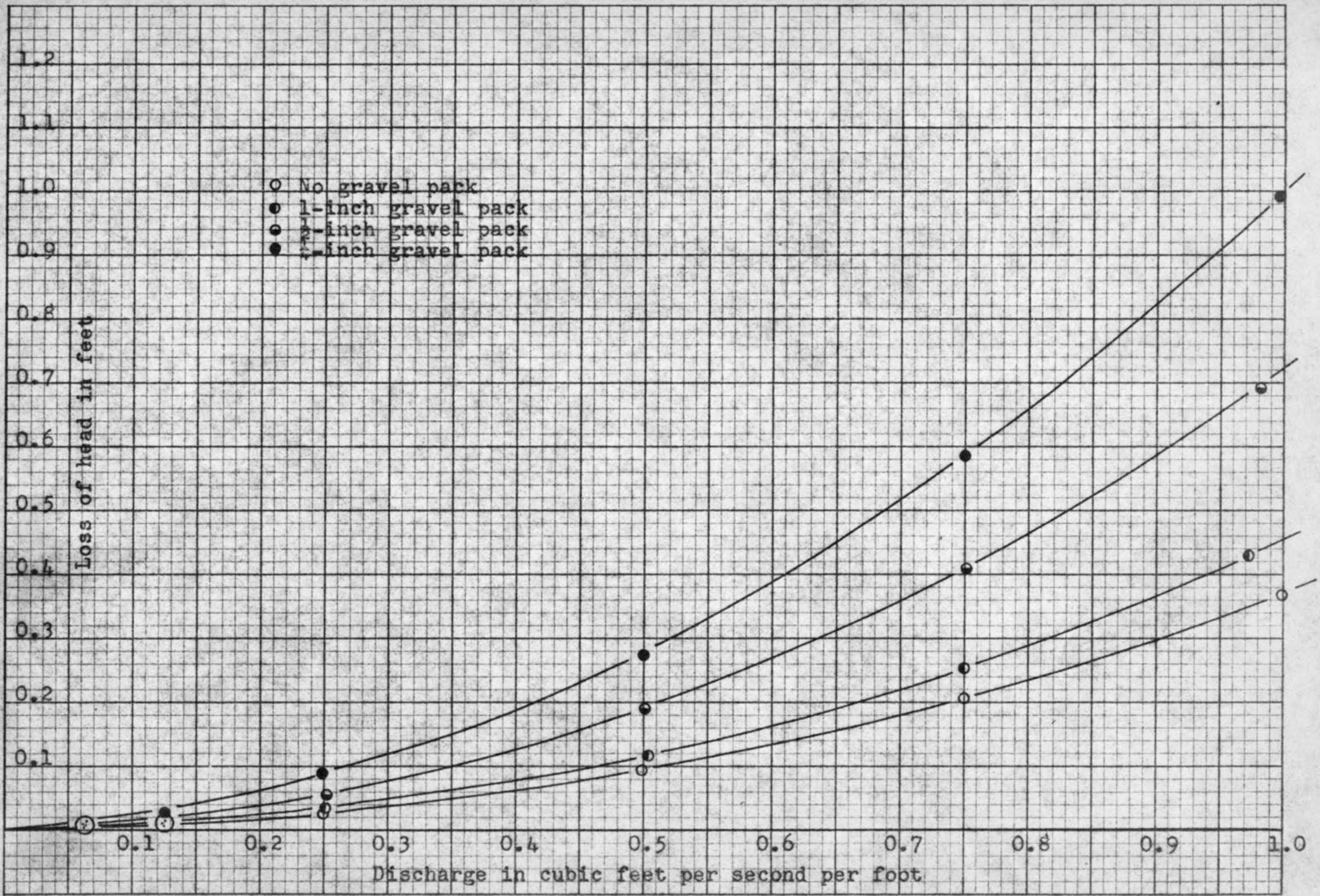


Fig. 10.--Summary of head losses for screen E.

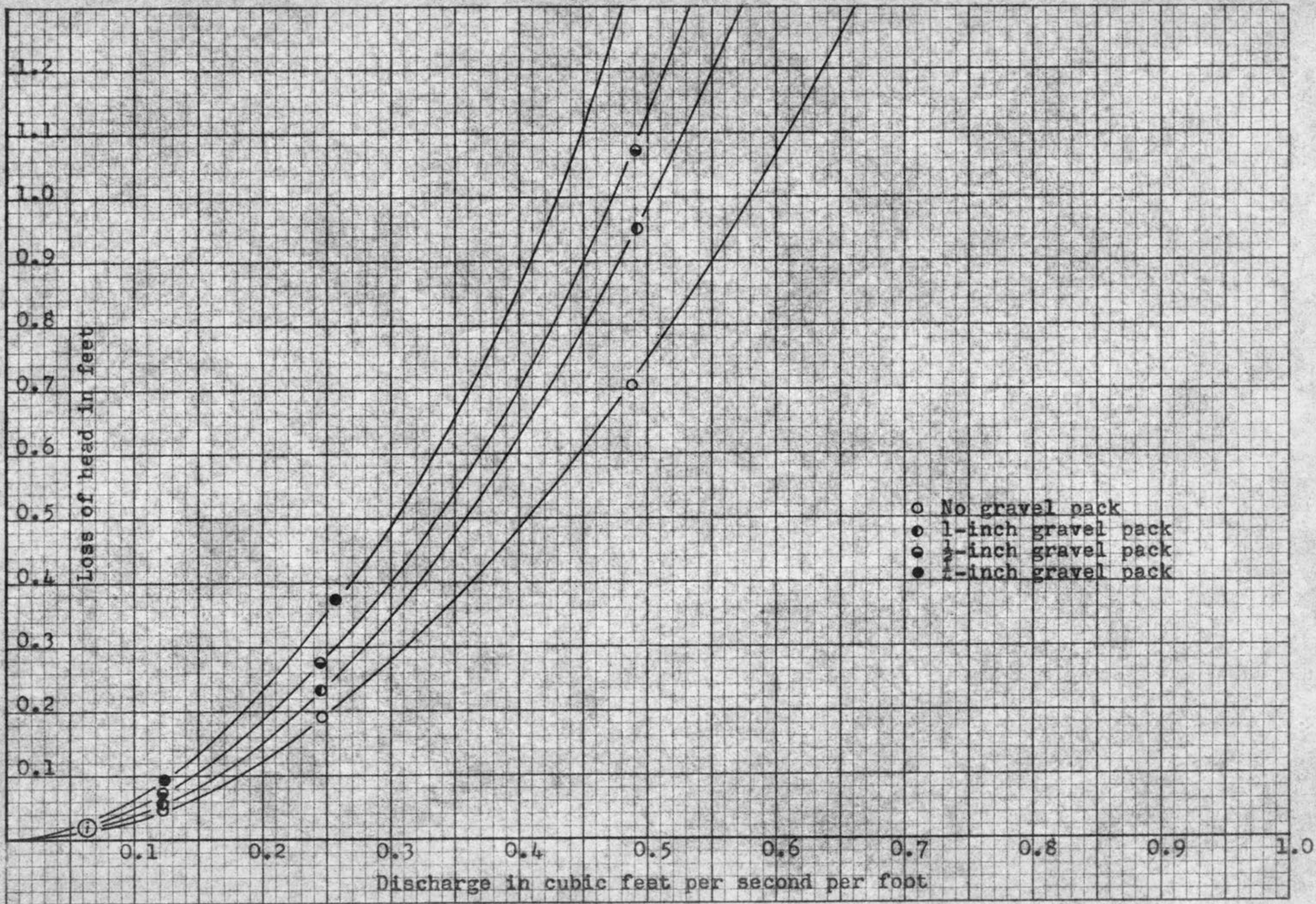


Fig. 11.--Summary of head losses for screen F.

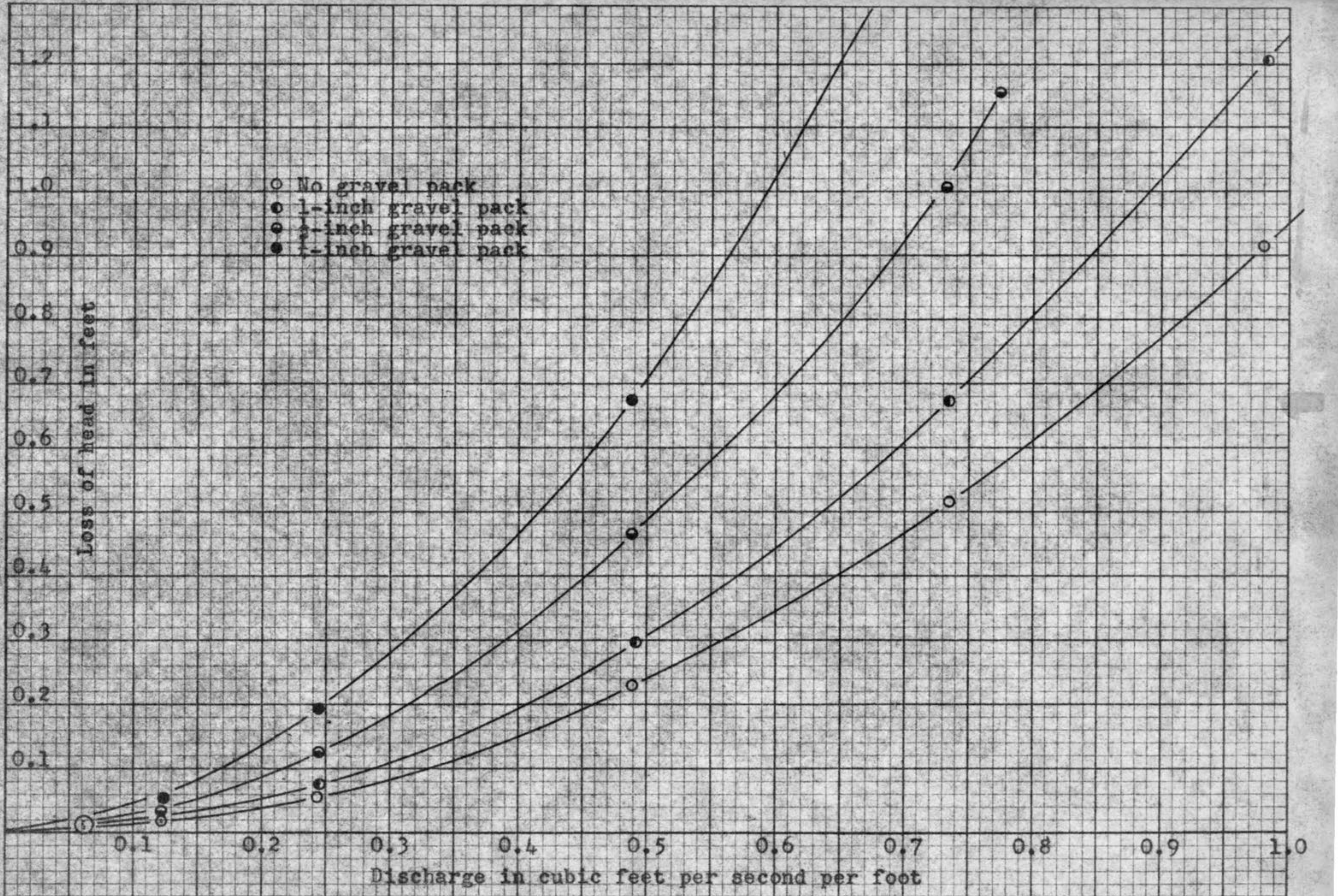


Fig. 12.-- Summary of head losses for screen G.

The fact that the loss of head increases with discharge is self-evident. The greater the quantity of water going through a screen the greater is the velocity and hence the greater the loss that occurs. The loss of head is similar to the friction loss in pipes in that it varies approximately as the square of the discharge.

The gravel packs surrounding the screens have the effect of increasing the losses. The gravel particles become arranged next to the perforations in such a way that the effective slot area is reduced. The larger gravel particles have larger pore spaces than the smaller gravels do and therefore they do not decrease the area nor increase the loss as much. This effect of decreasing the area decreases the C_s value of a screen. This reduction is apparently to a value lower than 15% because of the increased loss it causes. The smaller gravel particles decrease the coefficient more than the larger ones do.

The reason the loss of head at various discharges is approximately the same for all screens except screens F and G (Figs. 6-10) is that these screens all have C_s values above 15% and the major portion of the loss is occurring inside the screen and is equal in each screen. This criterion apparently holds even though the screens have a gravel pack surrounding them because the losses with gravel packs are also approximately the same for each of these screens.

Screens F and G show a greater loss (Figs. 11-12) because these screens have a C_s value much lower than 15% and therefore a large percentage of the loss can be credited to the loss of head in passing through the slot openings. In fact, the loss through these screens with no gravel pack surrounding them is practically as much as the loss through the other screens when surrounded by the 1/4 in. gravel pack.

Effect of length of screen

The next step in the investigation was to measure the losses of head at various discharges for different effective lengths of the screens. The effect of the length variation is shown in Figs. 13-16 which have been plotted for the following conditions:

1. The screen operating with twenty-four inches effective length.

2. The screen operating with six inches effective length.

3. The screen operating with three inches effective length.

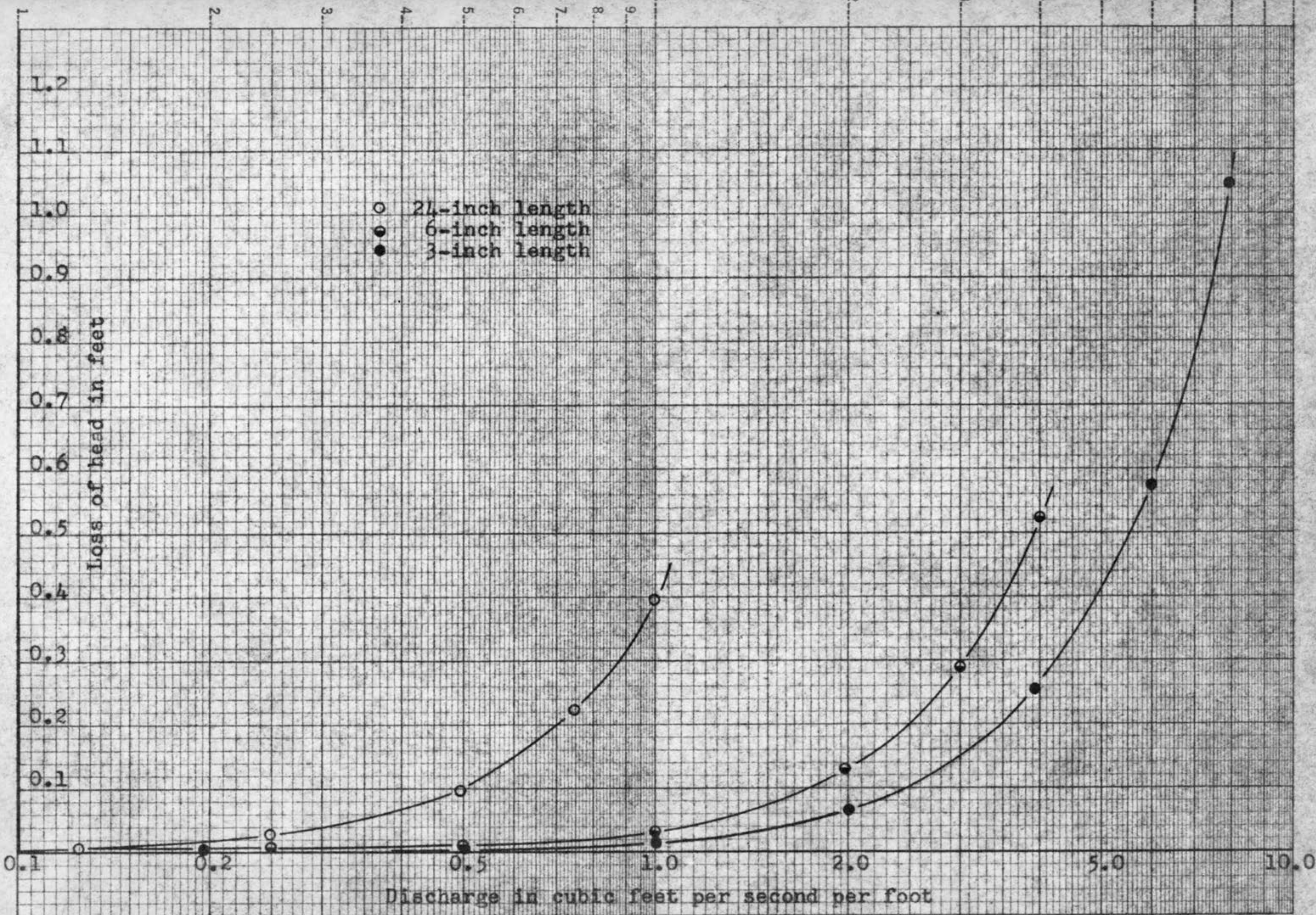


Fig. 13.--Summary of head losses for various lengths of screen B.

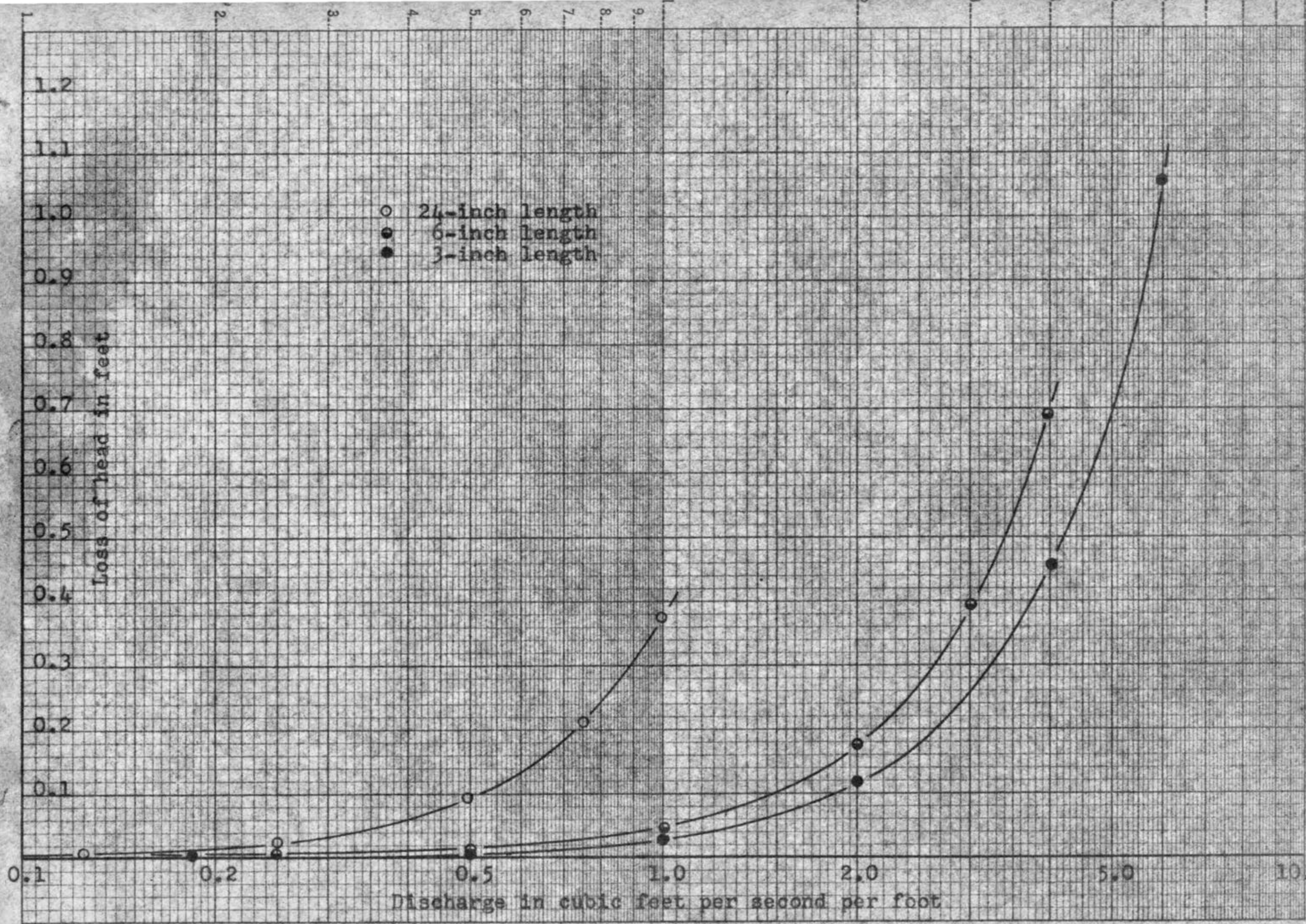


Fig. 14.--Summary of head losses for various lengths of screen A.

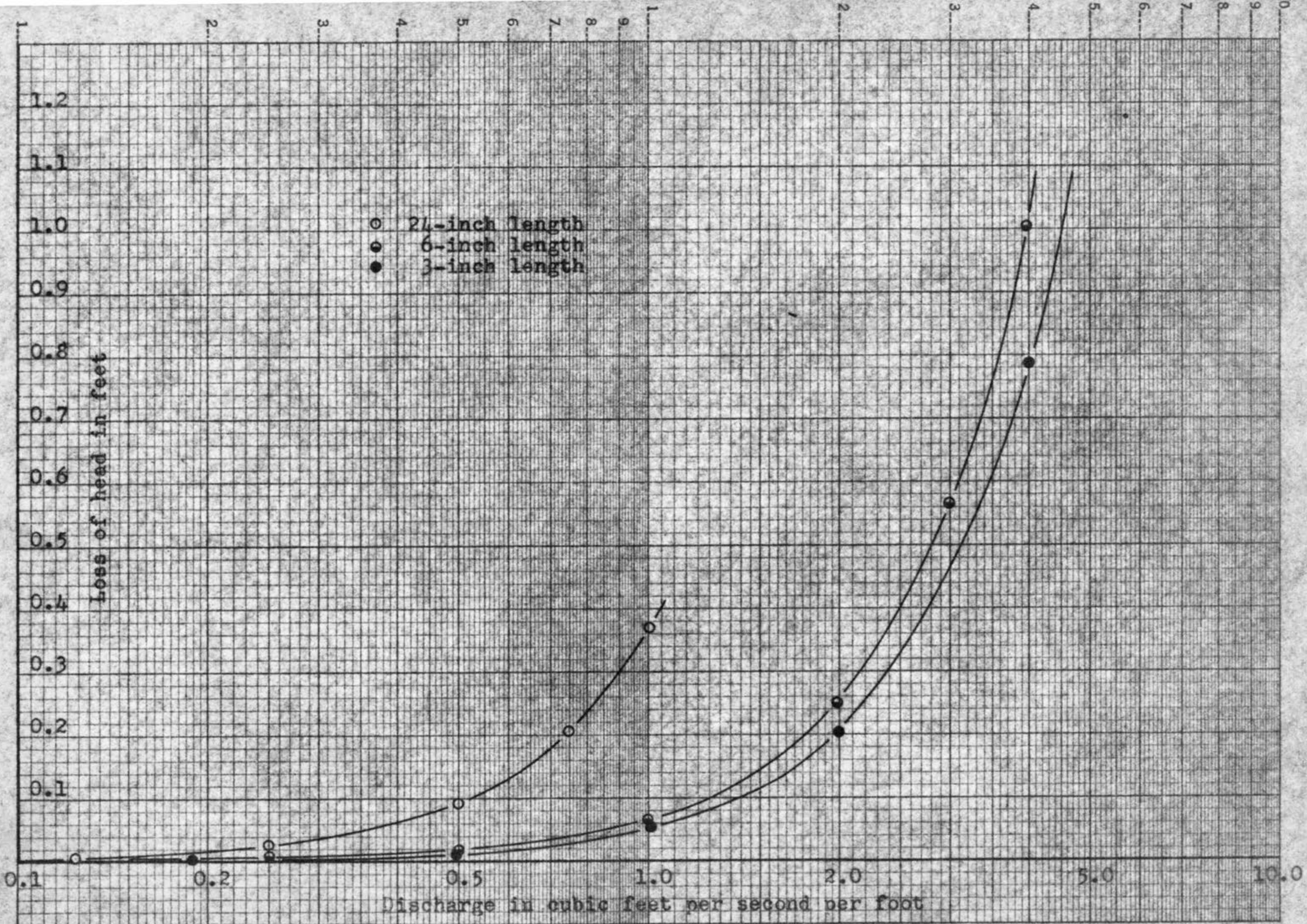


Fig. 15.-- Summary of head losses for various lengths of screen D.

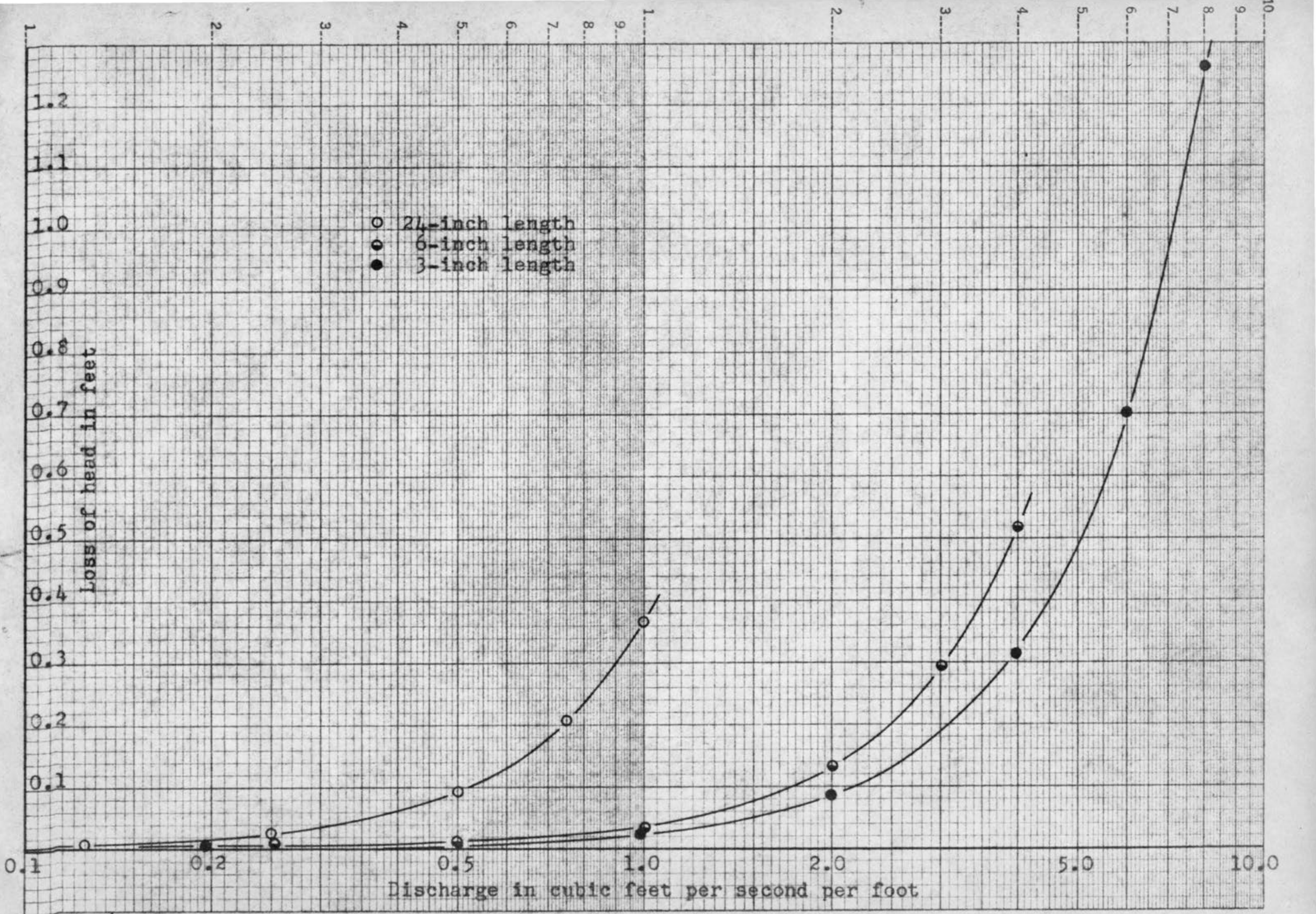


Fig. 16.--Summary of head losses for various lengths of screen E.

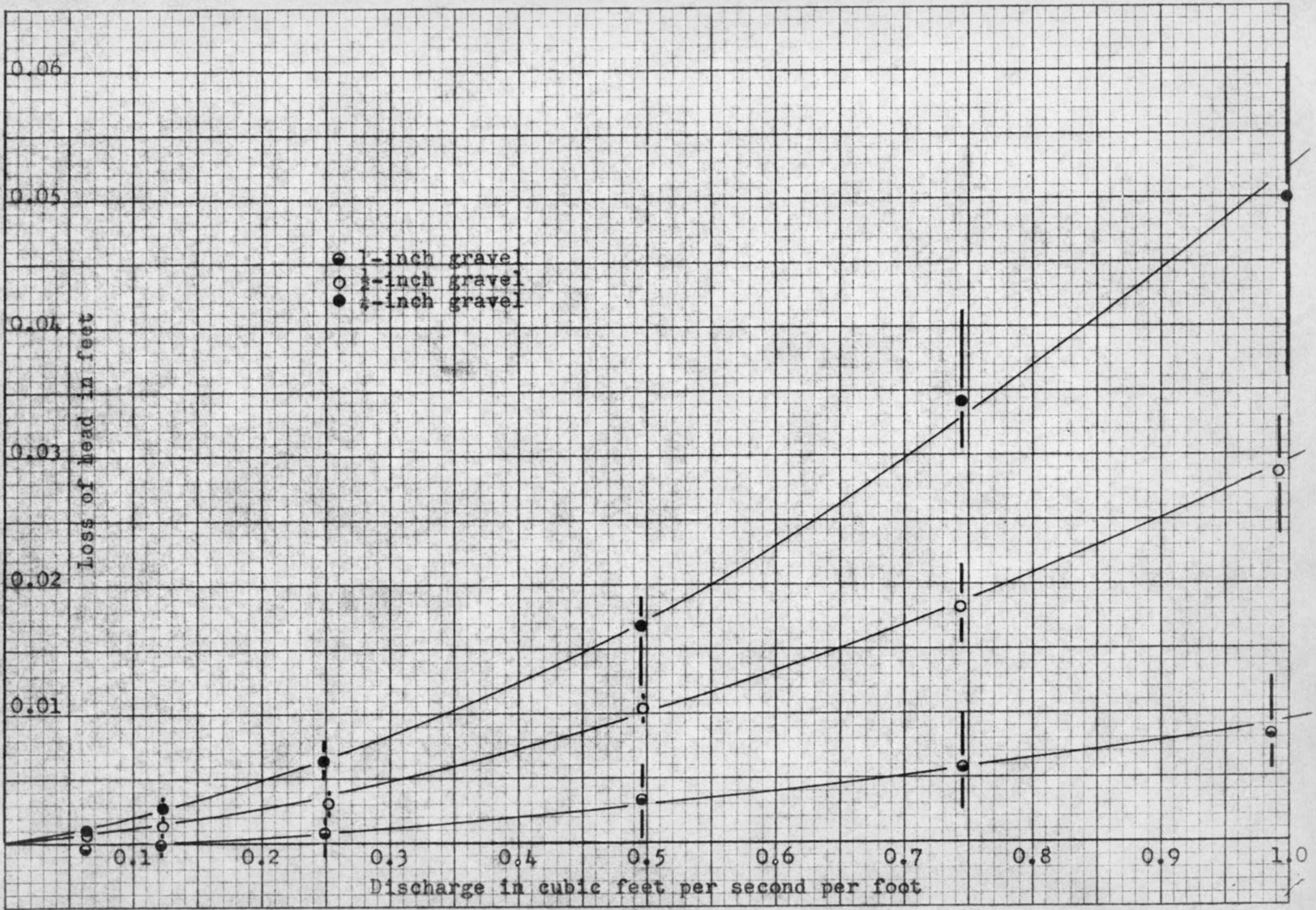


Fig. 17.--Summary of head losses through gravel packs.

The losses were measured while the screens were operating with no gravel pack surrounding them. The figures show that as the length of screen is increased the loss of head is also increased.

It has been pointed out that practically all the loss of head in these screens is due to the loss occurring inside the screen. If this is the case, then the loss could be expected to increase with effective length of screen. However the loss inside the screen does not vary directly as the length because as the length is increased the total discharge through the screen is increased even though the discharge per foot remains the same. This increase in total discharge greatly increases the velocity which results in an increased loss of head.

It can be seen from the curves that for an equal discharge through the screen the loss increases as the length decreases. The reason for this is that when the length of screen is decreased then the velocity through the perforations must increase to maintain the same discharge. When this velocity becomes great enough the loss through the slot openings becomes significant.

Loss of head through gravel

Figure 17 shows the loss of head through each size of gravel pack at the various discharges. For each size of gravel these losses were actually measured seven times for each discharge. The average of these seven losses has been used in the curve, with bars above and below the points to represent the extent of variation.

The loss of head increases as the discharge increases as could be expected. The loss of head through the gravel varies approximately inversely as the size of gravel. In other words, the loss through the 1/2 in. gravel is about twice the loss through the 1 in. gravel and the loss through the 1/4 in. gravel about 4 times that value. These losses are quite small when compared with the screen losses.

The reason the losses increase as the gravel size decreases is that, even though the porosity may be approximately the same for all three sizes, the size of opening is considerably smaller in the 1/4 in. gravel and therefore there is a greater total surface area which increases the friction.

Summary

The analysis of data may be summarized as follows:

1. The loss of head through a well screen increases with discharge.

2. Gravel packs surrounding a screen have the effect of increasing head losses through the screen.

3. The loss through the screen increases as the size of gravel in the gravel pack decreases.

4. Length of screen has a definite effect on losses through a screen. For the same discharge per foot of screen head losses decrease as length of screen decreases.

5. The losses through all well screens tested were approximately the same provided they had at least 15% of their surface perforated.

6. For screens that had less than about 15% perforation the loss of head increased rapidly as the perforated area was decreased.

7. The losses through the gravel pack are quite insignificant when considered in the over-all problem. The screen losses are much greater.

Chapter V

DISCUSSION

The data obtained in answering all the problems stated in the problem analysis seem to agree with the work of Lehr (4:50) and the Corps of Engineers (9:5) in that the loss of head through a well screen is divided into two parts. The greater part of the total loss of head in a well screen is due to the friction and velocity head loss inside the screen. The water passes through the slot openings rather freely and little loss of head occurs, but in turning the jets of water through 90° and pulling the water up through the well screen a significant loss of head occurs. If a screen has sufficient perforated opening this loss is practically the total loss for the well screen. Evidently Lehr (4) was justified in neglecting the loss of head through the screen slots. However, the screen must have sufficient perforated area for this to be true. If the perforated area is less than about 15% of the total area, the loss of head through the perforations becomes significant. When the C_s value is less than 15% for a screen the water must pass through the slots at a high velocity and the friction loss in the slot alone is perhaps as great as the loss inside the screen. Of course, some of the increased loss in these screens can be credited to the loss inside the screen because the greater velocities through the slots effect a greater momentum change in turning the jets.

It appears from Fig. 5 that if a screen has sufficient perforated area, above 15%, the loss of head is practically independent of the shape of the slot openings. However, a shape factor cannot be neglected because there is a slight decrease in the loss of head between coefficient values of 20 and 30%. The screens used in this investigation which showed this decrease in loss had different shaped openings than the other screens. The wires in these screens were round or half-round instead of V-shaped. Evidently a rounded slot edge is desirable to decrease the head losses.

Surrounding the well screen with a gravel pack causes an increased loss of head through the screen. This is due to the fact that the gravel, being adjacent to the perforations, causes a reduction in the perforated area. This reduction naturally causes an increased velocity through the remaining area which produces a greater loss. Head losses increase as the size of gravel particles in the pack decrease. The size of pores in the pack vary directly as the size of the particle, therefore the smaller gravel causes a greater reduction in the effective screen area.

In choosing the gravel for a gravel pack in a well the first consideration is that the gravel will not allow passage of fine material from the water-bearing formation into the well. The largest size possible should be chosen for this because the head losses decrease as the particle size increases. After the proper size of gravel has been decided upon the screen to be used should have the largest slot openings possible that will not allow the gravel particles to enter the well. This will insure, over a period of years, maximum pumping capacity with a minimum of head loss through the screen, because encrustation and clogging of the slots will not affect the losses until the coefficient is reduced to less than 15%.

In this study the maximum discharge per foot of screen used was much greater than could be expected in the field. However, using such a discharge aided in determining the general shape of the curves. By using large discharges per foot of screen greater losses were obtained than are practical because the discharge is above the practical range. However, the length of screen used was shorter than would naturally be expected in the field and it has been shown that for the same discharge per foot of screen the loss of head increases as the length of screen increases. So in using these curves for an actual well it must be remembered that the losses will be greater than those shown if the screen is greater than two feet in length.

It must be remembered also that in this study only the loss of head through well screens has been considered. The loss of head is only one of the many factors to be considered in choosing the proper type of well screen. Other considerations to be remembered are:

1. The screen must be made of non-corrosive material if it is to have long life.

2. The screen must be structurally strong enough to prevent collapse.

3. The cost of the screen must be acceptable.

4. The screen openings and gravel pack must be such that the well will not pump sand from the water-bearing formation.

Considering all of these factors possibly some of the screens found efficient with respect to the head losses would not prove so efficient in the field. As an example, screen E showed no greater loss than screens A, B, and C, however the openings in this screen are such that they could clog if subjected to fine enough gravels. Also, it is believed that this screen would not be very strong structurally. It certainly could not be driven into an aquifer. This screen would corrode much faster than the bronze screens.

Suggestions for further study

In this study the total screen losses were measured. There was no attempt to separate the loss through the slot openings from the loss occurring inside the screen. A supplemental study to determine the loss of head through various slot sizes and shapes would make it possible to determine what portion of the total loss could be attributed to the screen slots. This study could be made quite easily by taking a flat section of well screen and measuring the loss of head through it at various discharges.

It is suggested that the problem be extended further to include the effect of placing a sand formation outside the gravel pack. This study would provide much valuable data for, in addition to measuring the head losses, the amount of sand pumped through the gravel pack and screen could be measured. This is an important problem in selecting a well screen. Different sizes of sands could be used with several sizes of gravel packs to determine the most effective size of gravel pack for each sand size. Also, a graded gravel pack could be installed to see what effect that has on preventing sand flow.

In this study only one thickness of gravel pack was used. Perhaps other thicknesses should be investigated and especially so if a study is to be made with sand surrounding the gravel packs.

This thesis represents a study of only seven well screens. It would be interesting to extend the study to include many other types of well screens to see if the curves of Fig. 5 hold true for them. Perhaps it would be found that a shape factor has a greater effect on the screen losses than has been shown by this study.

Chapter VI

SUMMARY

Irrigation engineers and well drillers have long been faced with the problem of selecting the proper type of well screen to install in any particular well. They realize that the selection of a screen with proper slot openings is a very important factor in the construction of a well. Few scientific investigations have been made to determine the most efficient size and type of well screen to install. Much experience and a knowledge of previous wells in the region are relied on in the selection of a well screen.

This study has attempted to answer one phase of the problem. The loss of head at various discharges, has been measured through seven well screens. This has been done with the well screen operating in clear water with no gravel pack surrounding it, operating with a gravel pack containing 1 in. gravel, a gravel pack containing 1/2 in. gravel and one containing 1/4 in. gravel. The effect of the length of well screen on the losses was also measured.

The head losses were measured by placing piezometers both inside and outside the well screens. The difference in head between the piezometers gave the loss of head through the screen. The piezometric heads were measured with hook gages. The losses were measured with various discharges going through the screens. A 90° V-notch weir was utilized to measure the discharges.

It was found that the loss of head through a well screen increases as the discharge increases. Gravel packs surrounding a screen have the effect of increasing the head losses through it. This loss decreased as the size of gravel in the pack increased. The total loss of head due to a well screen consists of two parts. There is a loss of head occurring through the slot openings and also a loss of head which can be attributed to turbulence and friction inside the well screen. This latter loss is much the greater if the screen has sufficient perforated area per foot of length. In fact, the loss of head through the slot openings is quite insignificant until the perforated area becomes less than 15% of the total surface area.

Decreasing the length of well screen has the effect of decreasing the head losses if the discharge per foot of screen is held constant.

The head losses through the gravel packs were found to be quite small when compared to the total loss through the well screen.

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Table 1.--SUMMARY OF HEAD LOSSES FOR SCREEN A

	LOSSES			
	Through Screen		Through Gravel	
Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Ft.	Discharge cfs/ft.
No gravel pack				
35	0.0030	0.0020		0.063
34	0.0070	0.0020		0.124
33	0.0250	0.0022		0.250
32	0.0940	0.0030		0.497
31	0.2110	0.0030		0.751
30	0.3740	0.0042		1.000
One-inch gravel pack				
314	0.0046	0.0030	-0.0015	0.063
315	0.0116	0.0051	-0.0011	0.125
316	0.0368	0.0099	-0.0014	0.250
317	0.1217	0.0273	0.0000	0.493
318	0.2737	0.0544	0.0025	0.745
319	0.4918	0.0911	0.0057	0.995
One-half inch gravel pack				
320	0.0065	0.0045	0.0005	0.063
321	0.0190	0.0119	0.0011	0.125
322	0.0608	0.0343	0.0028	0.251
323	0.1971	0.1005	0.0095	0.495
324	0.4224	0.2009	0.0172	0.744
325	0.7487	0.3442	0.0239	0.992
One-quarter inch gravel pack				
326	0.0115	0.0080	0.0000	0.062
327	0.0309	0.0230	0.0012	0.125
328	0.0922	0.0642	0.0048	0.249
329	0.2872	0.1875	0.0169	0.498
330	0.5993	0.3738	0.0306	0.748
331	1.0308	0.6232	0.0360	0.994

Table 2.--SUMMARY OF HEAD LOSSES FOR SCREEN B

	LOSSES			
	Through Screen		Through Gravel	
Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Ft.	Discharge cfs/ft.
No gravel pack				
55	0.0019	0.0020		0.063
56	0.0065	0.0015		0.125
57	0.0260	0.0024		0.249
58	0.0990	0.0014		0.493
59	0.2210	0.0015		0.747
60	0.3962	0.0008		0.996
One-inch gravel pack				
309	0.0033	0.0013	-0.0011	0.062
304	0.0091	0.0033	-0.0003	0.125
305	0.0329	0.0083	-0.0002	0.248
306	0.1225	0.0255	0.0025	0.496
307	0.2763	0.0511	0.0049	0.747
308	0.4954	0.0867	0.0062	1.002
One-half inch gravel pack				
296	0.0066	0.0043	0.0000	0.063
297	0.0181	0.0111	0.0009	0.125
298	0.0599	0.0337	0.0021	0.250
299	0.1984	0.0998	0.0106	0.498
300	0.4271	0.2011	0.0179	0.749
301	0.7485	0.3373	0.0271	0.999
One-quarter inch gravel pack				
289	0.0104	0.0092	0.0012	0.062
290	0.0280	0.0220	0.0030	0.126
291	0.0837	0.0578	0.0063	0.252
292	0.2719	0.1704	0.0188	0.499
293	0.5585	0.3324	0.0331	0.749
294	0.9716	0.5603	0.0494	1.001

Table 3.--SUMMARY OF HEAD LOSSES FOR SCREEN C

	LOSSES			
	Through Screen		Through Gravel	
Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Ft.	Discharge cfs/ft.
No gravel pack				
5	0.0020	0.0000		0.062
4	0.0060	0.0010		0.123
7	0.0250	0.0000		0.246
9	0.0960	-0.0010		0.492
8	0.2190	-0.0010		0.744
10	0.4000	0.0000		0.992
One-inch gravel pack				
266	0.0022	0.0032	-0.0002	0.062
267	0.0083	0.0025	-0.0001	0.122
268	0.0325	0.0084	0.0005	0.249
269	0.1172	0.0252	0.0031	0.494
270	0.2669	0.0522	0.0060	0.749
271	0.4651	0.0869	0.0081	0.988
One-half inch gravel pack				
273	0.0068	0.0048	0.0012	0.062
274	0.0190	0.0125	0.0022	0.123
275	0.0640	0.0370	0.0033	0.254
276	0.2062	0.1068	0.0111	0.496
277	0.4377	0.2133	0.0184	0.745
278	0.7555	0.3565	0.0278	0.992
One-quarter inch gravel pack				
280	0.0115	0.0095	0.0015	0.061
281	0.0315	0.0250	0.0034	0.125
282	0.0932	0.0682	0.0067	0.248
283	0.2987	0.2015	0.0182	0.489
284	0.6063	0.3940	0.0326	0.727
285	1.0561	0.6645	0.0468	0.986

Table 4.--SUMMARY OF HEAD LOSSES FOR SCREEN D

Obs. No.	LOSSES Through Screen Lower Gage Ft.	Upper Gage Ft.	Through Gravel Ft.	Discharge cfs/ft.
No gravel pack				
183	0.0020	-0.0002		0.061
182	0.0061	-0.0004		0.123
181	0.0230	0.0002		0.250
180	0.0913	0.0023		0.500
179	0.2042	0.0053		0.750
178	0.3681	0.0101		1.000
One-inch gravel pack				
346	0.0018	-0.0007	0.0002	0.063
347	0.0078	0.0008	0.0007	0.125
348	0.0324	0.0093	0.0011	0.247
349	0.1266	0.0376	0.0045	0.501
350	0.2848	0.0807	0.0070	0.749
351	0.4901	0.1365	0.0106	0.981
One-half inch gravel pack				
340	0.0053	0.0053	0.0007	0.062
341	0.0181	0.0124	0.0019	0.126
342	0.0594	0.0366	0.0042	0.250
343	0.2029	0.1108	0.0116	0.501
344	0.4328	0.2251	0.0189	0.746
345	0.7609	0.3868	0.0330	0.996
One-quarter inch gravel pack				
334	0.0120	0.0100	0.0000	0.062
335	0.0288	0.0218	0.0029	0.125
336	0.0899	0.0649	0.0075	0.250
337	0.2872	0.1951	0.0190	0.501
338	0.6036	0.3948	0.0340	0.750
339	1.0418	0.6678	0.0575	1.000

Table 5.--SUMMARY OF HEAD LOSSES FOR SCREEN E

	LOSSES			
	Through Screen		Through Gravel	
Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Ft.	Discharge cfs/ft.
No gravel pack				
225	0.0015	0.0008		0.062
224	0.0062	-0.0003		0.125
223	0.0230	-0.0005		0.250
222	0.0907	-0.0007		0.499
221	0.2045	-0.0006		0.750
220	0.3650	-0.0006		0.999
One-inch gravel pack				
360	0.0039	0.0003	-0.0013	0.063
355	0.0102	0.0022	-0.0012	0.124
356	0.0315	0.0063	0.0022	0.251
357	0.1157	0.0192	0.0061	0.503
358	0.2534	0.0387	0.0099	0.750
359	0.4297	0.0626	0.0129	0.973
One-half inch gravel pack				
370	0.0047	0.0037	-0.0007	0.062
369	0.0162	0.0102	0.0001	0.125
368	0.0544	0.0295	0.0025	0.252
365	0.1879	0.0902	0.0105	0.501
366	0.4090	0.1853	0.0216	0.751
367	0.6908	0.3025	0.0323	0.982
One-quarter inch gravel pack				
371	0.0108	0.0088	0.0012	0.064
372	0.0288	0.0226	0.0032	0.125
373	0.0875	0.0630	0.0075	0.249
374	0.2766	0.1841	0.0119	0.500
375	0.5852	0.3714	0.0411	0.750
376	0.9950	0.6114	0.0603	0.998

Table 6.--SUMMARY OF HEAD LOSSES FOR SCREEN F

	LOSSES			
	Through Screen		Through Gravel	
Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Ft.	Discharge cfs/ft.
No gravel pack				
406	0.0116	0.0076		0.062
407	0.0465	0.0405		0.123
408	0.1903	0.1746		0.247
409	0.7027	0.6495		0.489
410	1.6086	1.1715		0.737
				Max. capacity
One-inch gravel pack				
395	0.0145	0.0138	0.0014	0.062
396	0.0562	0.0527	0.0004	0.123
397	0.2319	0.2161	0.0002	0.248
398	0.9521	0.8936	0.0017	0.493
399	2.6697	1.8854	0.0037	0.685
				Max. capacity
One-half inch gravel pack				
400	0.0193	0.0178	0.0017	0.062
401	0.0708	0.0667	0.0023	0.122
402	0.2725	0.2595	0.0025	0.245
403	1.0768	1.0084	0.0082	0.491
404	2.0567	1.8854	0.0096	0.647
				Max. capacity
One-quarter inch gravel pack				
412	0.0270	0.0243	0.0020	0.062
413	0.0945	0.0890	0.0025	0.123
414	0.3755	0.3564	0.0060	0.258
415	1.3158	1.1755	0.0162	0.483
				Max. capacity

Table 7.--SUMMARY OF HEAD LOSSES FOR SCREEN G

	LOSSES			
	Through Screen		Through Gravel	
Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Ft.	Discharge cfs/ft.
No gravel pack				
254	0.0033	0.0014		0.061
253	0.0137	0.0091		0.122
252	0.0571	0.0406		0.244
251	0.2283	0.1617		0.489
250	0.5170	0.3663		0.735
249	0.9150	0.6572		0.980
One-inch gravel pack				
389	0.0046	0.0031	0.0009	0.061
390	0.0191	0.0151	0.0011	0.122
391	0.0798	0.0628	0.0022	0.247
392	0.2997	0.2338	0.0040	0.492
393	0.6739	0.5254	0.0048	0.734
394	1.2096	0.9465	0.0055	0.983
One-half inch gravel pack				
383	0.0107	0.0087	0.0022	0.061
384	0.0345	0.0300	0.0023	0.122
385	0.1258	0.1077	0.0028	0.247
386	0.4609	0.3919	0.0091	0.488
387	1.0225	9.8675	0.0154	0.731
388	1.1569	0.9802	0.0156	0.774 Max. capacity
One-quarter inch gravel pack				
377	0.0172	0.0161	0.0022	0.062
378	0.0562	0.0517	0.0028	0.123
379	0.1910	0.1745	0.0058	0.246
380	0.6785	0.6118	0.0167	0.487
381	1.5104	1.3958	0.0238	0.732 Max. capacity

Table 8.--SUMMARY OF HEAD LOSSES FOR VARIOUS LENGTHS OF SCREEN B

LOSSES THROUGH SCREEN

Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Discharge cfs/ft.
Twenty-four inch length			
55	0.0019	0.0020	0.063
56	0.0065	0.0015	0.125
57	0.0260	0.0024	0.249
58	0.0990	0.0014	0.493
59	0.2210	0.0015	0.747
60	0.3962	0.0008	0.996
Six-inch length			
159	0.0006	0.0000	0.094
160	0.0025	0.0005	0.250
161	0.0085	0.0015	0.499
162	0.0325	0.0045	0.994
163	0.1300	0.0183	1.989
164	0.2875	0.0425	2.999
165	0.5217	0.0762	3.998
Three-inch length			
151	0.0011	0.0004	0.196
152	0.0047	0.0017	0.504
153	0.0160	0.0065	1.005
154	0.0668	0.0287	2.004
155	0.2532	0.1119	3.969
157	0.5718	0.2559	5.990
158	1.0441	0.4609	7.940

Table 9.--SUMMARY OF HEAD LOSSES FOR VARIOUS LENGTHS OF SCREEN A

LOSSES THROUGH SCREEN

Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Discharge cfs/ft.
Twenty-four inch length			
35	0.0030	0.0020	0.063
34	0.0070	0.0020	0.124
33	0.0250	0.0022	0.250
32	0.0940	0.0030	0.497
31	0.2110	0.0030	0.751
30	0.3740	0.0042	1.000
Six-inch length			
136	0.0014	0.0012	0.097
135	0.0040	0.0025	0.250
134	0.0120	0.0055	0.501
133	0.0450	0.0185	1.010
132	0.1749	0.0709	2.001
131	0.3912	0.1596	3.002
130	0.6923	0.2799	3.998
Three-inch length			
144	0.0025	0.0021	0.184
145	0.0082	0.0055	0.500
146	0.0293	0.0190	1.000
147	0.1190	0.0799	2.001
148	0.4591	0.3259	4.026
149	1.0522	0.7428	5.990
150	1.9045	1.3800	8.000

Table 10.--SUMMARY OF HEAD LOSSES FOR VARIOUS LENGTHS OF SCREEN D

LOSSES THROUGH SCREEN

Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Discharge cfs/ft.
Twenty-four inch length			
183	0.0020	-0.0002	0.061
182	0.0061	-0.0004	0.123
181	0.0230	0.0002	0.250
180	0.0913	0.0023	0.500
179	0.2042	0.0053	0.750
178	0.3681	0.0101	1.000
Six-inch length			
172	0.0010	0.0005	0.093
173	0.0045	0.0025	0.251
174	0.0161	0.0095	0.500
175	0.0633	0.0395	1.002
176	0.2499	0.1525	1.999
177	0.5619	0.3470	2.996
178(a)	1.0042	0.6274	3.973
Three-inch length			
171	0.0017	0.0007	0.189
170	0.0128	0.0098	0.496
169	0.0530	0.0405	1.016
168	0.2004	0.1593	2.001
167	0.7888	0.6315	4.001
166	1.7745	1.4375	5.989

Table 11.--SUMMARY OF HEAD LOSSES FOR VARIOUS LENGTHS OF SCREEN E

LOSSES THROUGH SCREEN

Obs. No.	Lower Gage Ft.	Upper Gage Ft.	Discharge cfs/ft.
Twenty-four inch length			
225	0.0015	0.0008	0.062
224	0.0062	-0.0003	0.125
223	0.0230	-0.0005	0.250
222	0.0907	-0.0007	0.499
221	0.2045	-0.0006	0.750
220	0.3650	-0.0006	0.999
Six-inch length			
219	0.0010	0.0000	0.092
218	0.0030	0.0005	0.253
217	0.0092	0.0023	0.499
216	0.0339	0.0089	0.997
215	0.1301	0.0335	2.001
214	0.2912	0.0736	3.002
213	0.5160	0.1261	4.000
Three-inch length			
212	0.0020	0.0003	0.195
211	0.0074	0.0039	0.507
210	0.0224	0.0124	0.986
209	0.0826	0.0471	2.003
208	0.3113	0.1775	3.978
207	0.7000	0.3953	5.998
206	1.2602	0.7020	8.024

Table 12.--SAMPLE PAGE OF ORIGINAL DATA AND COMPUTATIONS

Obs. No. 314

Date 21 April 1949

Remarks Screen A with 1 in. gravel pack

Observer G. L. Corey

Hook gages	Hook gage readings 1	2	3	4	5	6	7
	1.8765	2.0530	1.8960	1.9780	2.0525	1.5440	1.3740
	1.8765	2.0530	1.8965	1.9780	2.0525	1.5440	1.3740
	1.8765	2.0530	1.8965	1.9780	2.0530	1.5440	1.3740
	1.8765	2.0530	1.8965	1.9780	2.0530	1.5440	1.3740
	1.8765	2.0530	1.8965	1.9780	2.0530	1.5440	1.3740
Average	1.8765	2.0530	1.8964	1.9780	2.0528	1.5440	1.3740
Gage constants	+0.1780	+0.0000	+0.1550	+0.0790	+0.0000	+0.5110	-1.0730
	2.0545	2.0530	2.0514	2.0570	2.0528	2.0550	0.3010

1. Loss of head through screen (lower gage) = ave. col. 4 & 6 - col. 3 = 2.0560 - 2.0514 = 0.0046

2. Loss of head through screen (upper gage) = ave. col. 4 & 6 - col. 2 = 2.0560 - 2.0530 = 0.0030

3. Loss of head through gravel pack = col. 1 - ave. col. 4 & 6 = 2.0545 - 2.0560 = -0.0015

4. Discharge as taken from weir table = 0.126 c.f.s. = 0.063 c.f.s. per ft.

Col. 1-6 correspond to hook gages 1-6 as shown in Fig. 4.
Col. 7 is the readings taken with the hook gage at the weir box

This represents one set of data taken in the laboratory. The results as used in the thesis appear as obs. no. 314, Table 1.

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