THESIS

An Investigation of Flood Flows in Eaton's Canyon.

by

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Following the report of the Board of Flood Control Engineers to the Board of Supervisors of Los Angeles County, the writer became interested of the flood flow measurement of mountain streams. In order to make this the subject of a thesis it was necessary to find a suitable stream to investigate. Eaton's Canyon was selected, about five miles northeast of Throop College and easy of access. This canyon, although having a drainage area of only 6.65 square miles has an unusually large run-off, in fact it is fifth in intensity of all the streams in the county. This large run-off results from the fact that the water is allowed to rush down the steep slopes almost entirely without checking, the sides of the mountains having only a slight growth of shrubbery and trees.

There are five practical methods of determining stream discharge, namely, by means of (1) the current meter and the sectional area, (2) non-recording gages, (3) recording gages, (4) the wier, and (5) the hydraulic radius, sectional area and the slope.

The current meter indicates the velocity of flow of the water but can only be used where the channel is uniform and the stream free from eddy currents caused by obstructions. Having the velocities at different depths and points across the stream the discharge may be found by multiplying the mean velocity by the area of the section.

Non-recording gages may be grouped into (1) direct gages, consisting of fixed, graduated staffs on scale boards on which the water rises and the stage is observed directly, and, (2) indirect gages, consisting of graduated scale boards located above the the water surface, to which the index of the stage of the water is transferred by means of a movable chain or rod of known length operated either automatically by means of a float or by the observer whenever a record is desired.

Recording gages make a record of stage either continuously by a curve, the coordinates of which indicate the time and the stage, or at stated intervals of time by a printing device. The essential parts of the recording gage are, (a) a float which rises and falls with the surface of the water, (b) a device for transferring this motion of the float to the record, either directly or through a reducing mechanism, (c) the recording device, and (d) the clock.

In general any structure may be called a weir which is placed in a stream for the purpose of raising the surface of the water. A weir for measuring discharge must have a well-defined form and a reasonably level crest of permanent shape and elevation and must not allow any appreciable leakage through, beneath or around it. Weirs may be used for measuring the quantity of water in streams because water flows over them in accordance with known definite laws.

As no observations or data were taken until after the 1916 flood, it was necessary to abandon the first four methods and to resort to the method of the hydraulic radius, sectional area and slope.

Owing to the roughness and irregularity of the stream channel it was difficult to select courses of even short lengths in which the cross sections were uniform. The two most favorable courses were taken. The first course extends 243 feet down stream from a point approximately 200 yards below the bridge on the Mount Wilson Toll Road, and the second is 223 feet in length and is located one-quarter of a mile down stream from the first. By means of a transit used as a level, and a rod, seven cross sections were taken in the first course and six in the second. Elevations were taken at intervals of one foot for the entire width of the stream at each section.

In locating high water marks the writer was forced to confine himself to the flood of 1916 which was larger than that of 1915 but smaller that the flood of 1914, all reliable traces of which have disappeared in the two years which have elapsed since that time. In fact, in the two courses investigated and also in the intervening space, only three old high water marks were found and some doubt existed as to whether they were the direct result of the high water in the stream or left by smaller tributaries. These old marks could not be relied upon as useful data as they varied between 0.2 and 1.5 feet above the 1916 flood marks. From the remarks of the men who were in the canyon at the time of the 1914 flood the writer believes that its crest was from six to eight inches above that of the 1916 flood. After the cross sections were taken in the field they were plotted on cross section paper (sheets 2 and 3 of blue prints) and their areas and wetted perimeters found by means of a planimeter and map measurer respectively. The hydraulic radius, r, was then calculated for each section from the formula $r = \frac{A}{P}$.

The writer is indebted to Mr. Frank G. Olmstead of Los Angeles for a series of blue print charts, based upon the Chezy and Kutter formulae, for determining stream velocities when the value of "n", which is the coefficient of roughness, the slope and the value of r, are given. The ordinates are velocities and the abscissae are values of r. These charts are designed for slopes up to 0.001 but Mr. Olmstead also furnished a table of multipliers for slopes up to 0.2 for use with them.

The value of "n" in Kutter's formula,

$$c = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{s}\right)}$$ was assumed as

0.035 which corresponds to a "canal in earth in bad order with stones and weeds in great quantities." The bed of Eaton's Canyon is very rough and contains large quantities of rock ranging in size from sand to boulders four feet in diameter. This condition suggested the above value for "n" and upon investigating the report of the Flood Control Engineers of Los Angeles County, the same value seemed to have been used in most of their computations relating to similar conditions. This was deemed sufficient justification for the use of this value in the computations.

The value of C in the exponential formula $V = Cr^{0.67} s^{0.54}$ was assumed as 49. For rough natural channels the value of C varies from 75 to 45 and as the channel in Eaton's Canyon is rough it was necessary to take a low value for C.

The length of the courses and the slope were determined by the stadia and vertical angle method. The stadia reading on the rod for the first course was 243 feet and the vertical angle two degrees. The horizontal distance is equal to $243 \times \cos 2^o = 243 \times .99939 = 242.86$ feet. The drop is equal to $243 \times \sin 2^o = 243 \times .03490 =$ 8.5 feet. The slope then is equal to the drop in elevation divided by the horizontal distance or $\frac{8.5}{242.86}$ which is equal to 0.035.

The stadia reading for the second course was 223 feet and the vertical angle 1^{o} 45'. The horizontal distance equals 223 x cos 1^{o} 45' = 223 x 0.99953 = 222.9 ft. The drop is equal to 223 x sin 1^{o} 45' = 223 x 0.03054 = 6.81 feet. The slope is equal to 6.81 divided by 222.9 or 0.0307.

The next step after having the value of "n", the hydraulic radii and the slope, was to find the velocity. This was done in three ways, i.e. with the chart, by Kutter's formula and by the exponential formula After obtaining the velocity, the value found was multiplied by the area to give the discharge. The discharge was found by each of the three methods described above. The first solution incolved the individual discharge at each cross section. After finding these their average was found for each course. The other two solutions differed from each other only in the method of obtaining the hydraulic radius. In the first the average of all the separate hydraulic radii was taken and the velocity found and multiplied by the mean area to give the discharge. In the second, an average was taken of all the wetted perimeters and the average area divided by it. Then the velocity was found and multiplied by the average area to obtain the dischrage.

An example will be given of the three methods for determining the velocities i.e. by the chart, by Kutter's formula and by the exponential formula. The same data will be used for each solution and will consist of the mean hydraulic radius and the mean area of course II. The hydraulic radius is 2.933 and the area 116.1 sq. feet.

As the chart is only designed for slopes up to .001, the velocity must be found for that slope and then multiplied by a factor for a grade of 0.0307.

For a hydraulic radius of 2.933 and a slope of .001 the velocity is 2.8. Then by multiplying this value by 5.54, the velocity is obtained for the slope of .0307. This is 15.22 feet per second. Now by multiplying this by the average area which is 116.1 square feet, the discharge is found to be 1769 cubic feet per second.

Substituting the values of n, r, and s in Kutter's formula,

$$C = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{s}\right)} \qquad \text{we have}$$

$$C = \frac{\frac{1.811}{0.035} + 41.65 + \frac{0.00281}{0.0307}}{1 + \frac{0.035}{\sqrt{2.933}}\left(41.65 + \frac{0.00281}{0.0307}\right)}$$

$$= \frac{51.8 + 41.65 + 0.0915}{1 + .0204\,(41.65 + 0.0915)}$$

$$= \frac{93.54}{1.852}$$

$$C = 50.5$$

Substituting this value in Chezy's formula, $V = C\sqrt{rs}$, we have $V = 50.5\sqrt{2.933 \times .0307}$, $V = 50.5 \times 0.3$ or $V = 15.17$ feet per second.

Now, multiplying this by the area we have $15.17 \times 116.1 = 1761$ cubic feet per second.

Substituting in the exponential formula we have,
$V = 49 \times 2.933^{0.67} \times 0.0307^{0.54}$.

$$
\begin{array}{rl}
\log 2.933 = & .46731 \\
 & \underline{.67} \\
 & 327117 \\
 & \underline{280386} \\
 & .3130977 \quad \text{or} \quad .31310.
\end{array}
$$

$$
\begin{array}{rl}
\log 0.0307 = & 8.48714 - 10 \\
 & \underline{.54} \\
 & 3394856 - 5.4 \\
 & \underline{4243570} \\
 & 4.5830556 - 5.4 = 9.18306 - 10
\end{array}
$$

$$
\begin{array}{ll}
\log 49 = & = 1.69020 \\
\log 2.933^{0.67} & = .31310 \\
\underline{\log 0.0307^{0.54}} & \underline{= 9.18306 - 10} \\
\log V & = 1.18636 \\
\text{Whence } V & = 15.36 \text{ feet per second.}
\end{array}
$$

Multiplying this by the area--116.1 square feet--we obtain a discharge of 1782 cubic feet per second. By comparing the three results it will be seen that they agree very closely, in fact the greatest difference is only 0.735%. The results from the two courses also agree very closely, the greatest difference there being approximately 10%. The writer is inclined to favor the values found from the second course as the sections are more uniform. The sections in Course I vary between such wide limits that the results are probably not as reliable as those in course II.

The discharges as found by means of the chart for the individual sections will be found on blue print sheets 2 and 3. The remainder of the results and computations are recorded on sheets

Assuming that the crest of the 1914 flood was six inches above that of 1916, the resulting discharge would be approximately 2490 cubic feet per second for the seven square miles of drainage area or an intensity of 356 cubic feet per second per square mile. The intensity as given in the report of the Flood Control Engineers was 367 cubic feet per second per square mile.

One fact that should not be overlooked is that work of this character can only be approximate as there are numerous errors made in the selection of, a uniform section, the value of "n" in Kutter's formula, the location of high water marks, and the selection of a value for "C" in the exponential formula, which are accumulative and directly affect the results. Unless a thorough investigation is undertaken to determine the values of "n", "C", and high water marks, and a uniform section is available, the results can only be assumed as approximate.

COURSE I.

Section	Area	Wetted Perimeter	Hydrau. Rad. r	Vel. v from Chart	Discharge Q.
1	78.	27.45	2.84	15.69	1223
2	85.1	34.1	2.495	14.33	1222
3	82.6	30.5	2.75	15.45	1276
4	118.0	39.1	3.01	16.51	1950
5	154.0	45.0	3.42	17.99	2770
6	154.0	43.7	3.53	17.75	2732
7	164.5	44.7	3.68	19.00	3125
Average	119.5	37.79	3.103	16.67	2043

$$\text{Average } r = \frac{119.5}{37.79} = 3.16.$$

Then V from the chart equals 17.1 feet per second.

The discharge Q is then 2045 feet^3 per second

Using the average value 3.103 for r, a velocity of 16.81 feet per second is found from the chart.

This gives 2010 for the value of Q.

The velocities and discharges for the individual sections were checked with Kutter's and the exponential formulae and the difference was so slight that the computations will only be given for the two cases using the average value of "r".

Substituting in Kutter's formula the values,

n = 0.035, r = 3.16, s = 0.035 , the results are as follows : -

$$V = C\sqrt{rs}\,. \qquad C = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{s}\right)}$$

$$C = \frac{\frac{1.811}{0.035} + 41.65 + \frac{0.00281}{0.035}}{1 + \frac{0.035}{\sqrt{3.16}}\left(41.65 + \frac{0.00281}{0.035}\right)}$$

$$= \frac{51.75 + 41.65 + 0.0803}{1.+ 0.0197\,(41.65 + 0.0803)}$$

$$= \frac{93.48}{1.82}$$

$$C = 51.3$$

$$\text{Then } V = 51.3\sqrt{3.16 \times 0.035}$$

$$= 17.06 \text{ feet per second.}$$

And Q = 17.06 x 119.5 = 2040 cubic feet per second.

Substituting in Kutter's formula, the values,

n = 0.035, r = 3.103, and s = 0.035

$$V = C\sqrt{rs}. \qquad C = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{s}\right)}$$

$$C = \frac{\frac{1.811}{0.035} + 41.65 + \frac{0.00281}{01035}}{1 + \frac{0.035}{\sqrt{3.103}}\left(41.65 + \frac{0.00281}{0.035}\right)}$$

$$= \frac{51.75 + 41.65 + 0.0803}{1 + 0.0199\,(41.65 + 0.0803)}$$

$$= \frac{93.48}{1.83}$$

$$C = 51.1$$

Then $V = 51.1\sqrt{3.103 \times 0.035}$

$= 16.82$ feet per sedond.

And $Q = 16.83 \times 119.5 = 2010$ cubic feet per second.

Substituting in the exponential formula the values, $C = 49$, $r = 3.16$, $s = 0.035$, the results are as follows :-

$$V = Cr^{0.67}\,s^{0.54} = 49 \times 3.16^{0.67} \times 0.035^{0.54}$$

$\log 3.16^{0.67}$	$= 0.33479$
$\log 0.035^{0.54}$	$= 9.21380 - 10$
$\log 49.$	$= 1.69020$
$\log V$	$= 1.23879$
V	$=$ 17.33 feet per second.

Then $Q = 17.32 \times 119.5 = 2070$ cu. feet per second.

Substituting in the exponential formula the values,

$C = 49$, $r = 3.103$, $s = 0.035$, the results are as follows :-

$$V = Cr^{0.67}\,s^{0.54} = 49 \times 3.103^{0.67} \times 0.035^{0.54}$$

$$\log 3.103^{0.67} = 0.32949$$

$$\log 0.035^{0.54} = 9.21380 - 10$$

$$\log 49 = 1.69020$$

$$\log V = 1.22349$$

$$V = 16.73 \text{ feet per second}$$

Then $Q = 16.73 \times 119.5 = 2000$ cu. feet per second.

COURSE II .

Section	Area	Wetted Perimeter	Hydrau. Rad. r	Vel. v from chart	Discharge Q
1	107.1	37.6	2.85	14.74	1580
2	124.5	38.3	3.24	16.35	2035
3	116.8	39.1	2.99	15.40	1800
4	129.0	38.35	3.36	16.73	2160
5	102.0	39.9	2.56	13.7	1398
6	117.3	45.1	2.6	13.86	1626

$$\text{Average } r = \frac{116.1}{39.725} = 2.925.$$

Then V from the chart equals 15.22 feet per second.

The discharge Q is then 1769 cubic feet per second.

Using the value 2.933 for r, a velocity of 15.22 feet per second is again obtained, giving the same discharge of 1769 cubic feet per second.

Substituting in Kutter's formula the values of, $n = 0.035$, $r = 2.925$, and $s = 0.0307$, the results are as follows :-

$$V = C\sqrt{rs}. \qquad C = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{}\right)}$$

$$C = \frac{\frac{1.811}{0.035} + 41.65 + \frac{0.00281}{0.0307}}{1 + \frac{0.035}{\sqrt{2.925}}\left(41.65 + \frac{0.00281}{0.0307}\right)}$$

$$= \frac{51.75 + 41.65 + 0.0915}{1 + 0.0205\,(41.65 + 0.0915)}$$

$$= \frac{93.4915}{1.855}$$

$$C = 50.4$$

Then $V = 50.4\sqrt{2.925 \times 0.0307}$

$= 15.12$ feet per second.

And $Q = 15.12 \times 116.1$

$= 1755$ cubic feet per second.

Using the values, in the same formula, of, $n = 0.035$, $r = 2.933$, and $s = 0.0307$, the results are as follows :-

$V = C\sqrt{rs}.$ $$C = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{s}\right)}$$

$$= \frac{\frac{1.811}{0.035} + 41.65 + \frac{0.00281}{0.0307}}{1 + \frac{0.035}{\sqrt{2.933}}\left(41.65 + \frac{0.00281}{0.0307}\right)}$$

$$= \frac{51.75 + 41.65 + 0.0915}{1 + 0.02045\,(41.65 + 0.0915)}$$

$$= \frac{93.4915}{1.853}$$

$$C = 50.4$$

Then $V = 50.4\sqrt{2.933 \times 0.0307}$

$= 15.12$ feet per second

And $Q = 15.12 \times 116.1$

$= 1755$ cubic feet per second.

Substituting the values $C = 49$, $r = 2.925$, and $s = 0.0307$, in the exponential formula, the results are as follows : -

$$V = C\, r^{0.67} \times s^{0.54}$$

$$= 49 \times 2.925^{0.67} \times 0.0307^{0.54}$$

$\log 2.925^{0.67} = 0.31231$

$\log 0.0307^{0.54} = 9.18306 - 10$

$\log 49 = 1.69020$

$\log V = 1.18557$

$V = 15.33$ feet per second

Then $Q = 15.33 \times 116.1$

$= 1780$ cubic feet per second.

Using the value of $r = 2.933$ (s and C the same), the results are as follows : -

$$V = 49 \times 2.933^{0.67} \times 0.0307^{0.54}$$

$$\begin{aligned}
\log 2.933^{0.67} &= 0.31310 \\
\log 0.0307^{0.54} &= 9.18306 - 10 \\
\underline{\log \quad 49} &= \underline{1.69020} \\
\log V &= 1.18636 \\
V &= 15.36 \text{ feet per second}
\end{aligned}$$

Then $Q = 15.36 \times 116.1$

$= 1782$ feet per second.

Course I looking upstream

Course I looking downstream

Course II looking upstream

Course II looking downstream

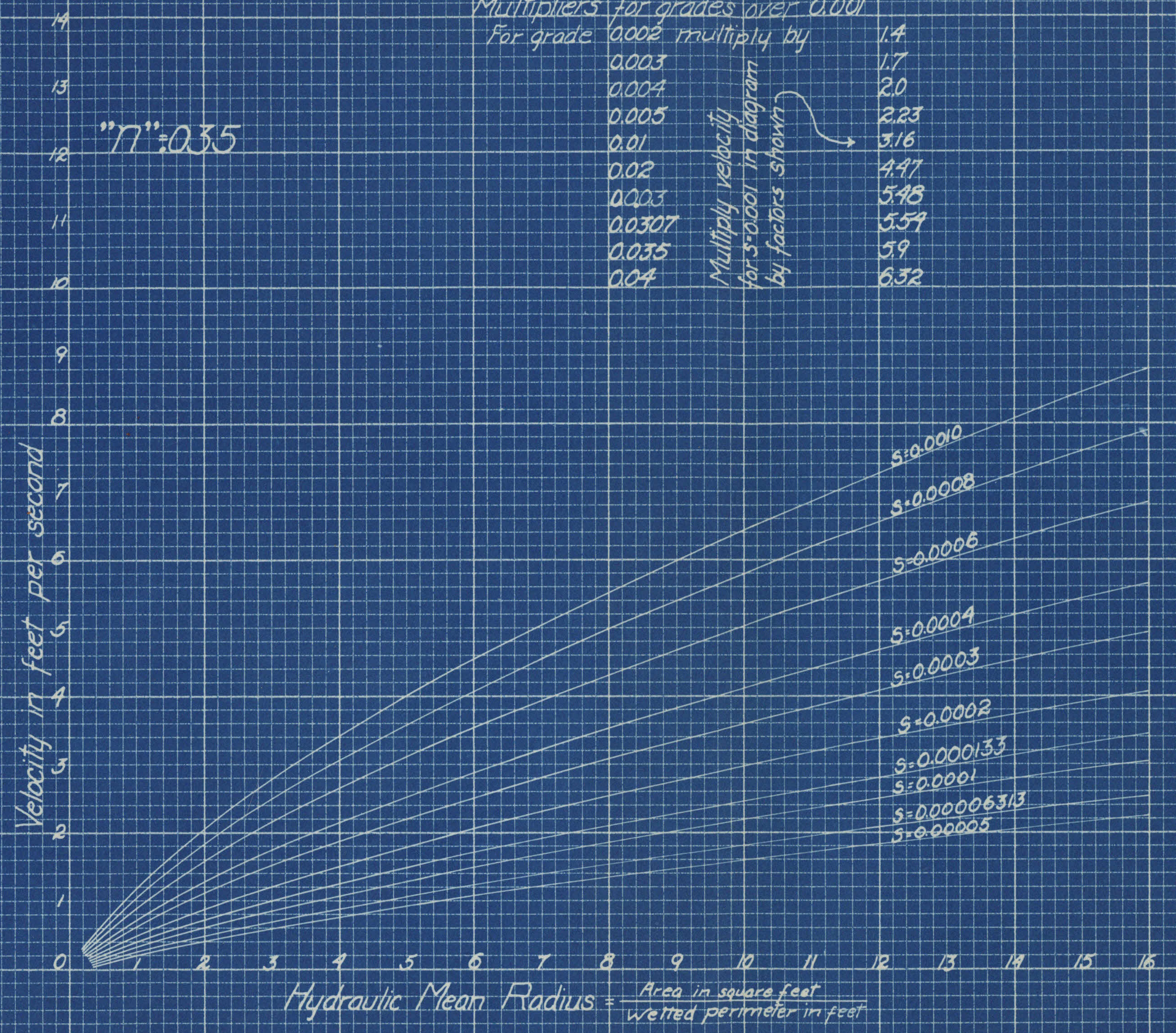
SHEET I

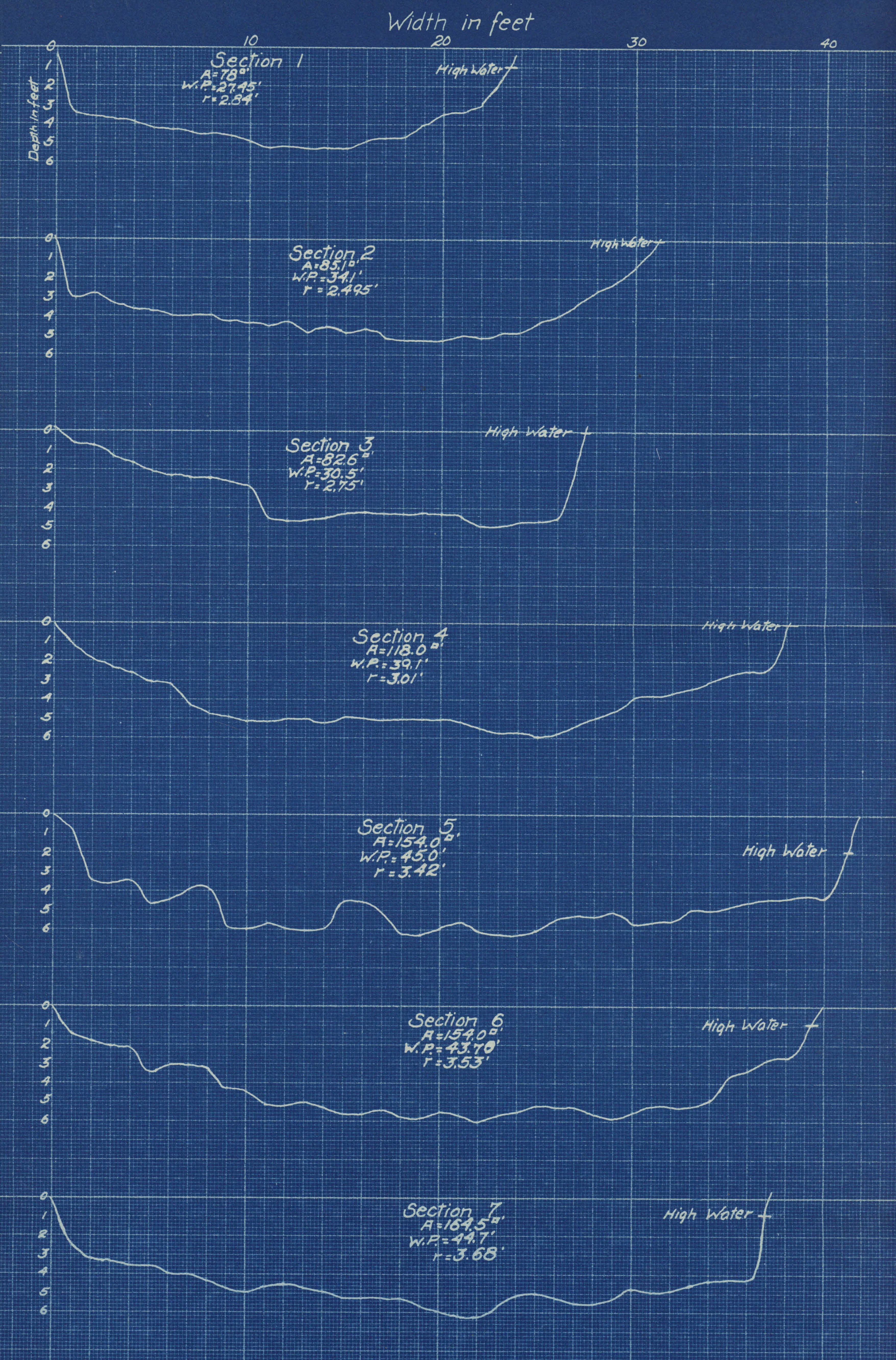
"n" = .035

Multipliers for grades over 0.001

Multiply velocity for S = 0.001 in diagram by factors shown

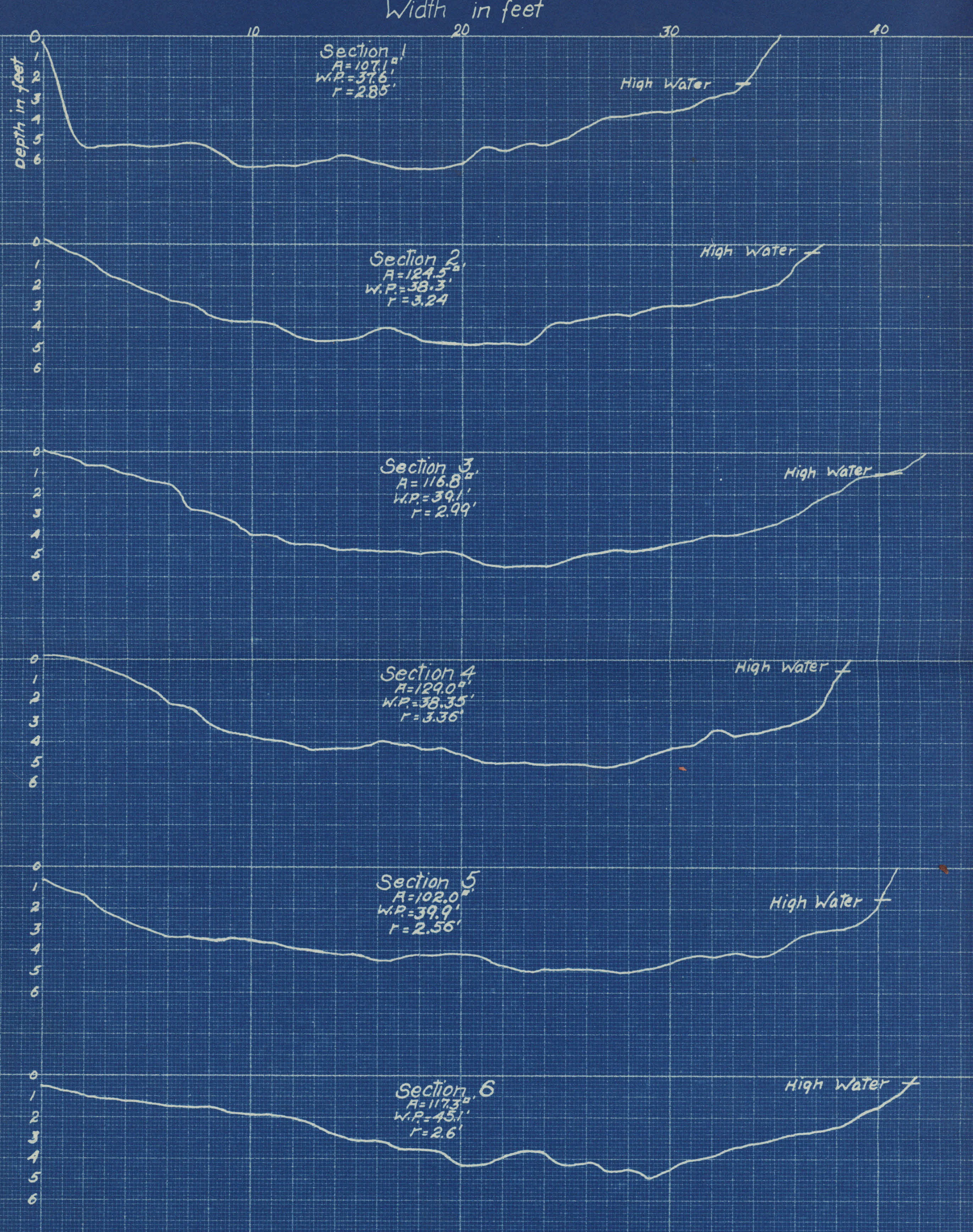
For grade	multiply by
0.002	1.4
0.003	1.7
0.004	2.0
0.005	2.23
0.01	3.16
0.02	4.47
0.003	5.48
0.0307	5.59
0.035	5.9
0.04	6.32





Cross Sections In Course I

SHEET III



Cross Sections In Course II