# THESIS

A STUDY OF THE RAINFALL AND FLOODS
AT EAST LANSING, MICHIGAN

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A Study of the

Rainfall and Floods

at

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THESIS

# INTRODUCTION

The purpose of this thesis is twofold:-

1. To develop a formula which can be used by practicing engineers in the design of storm water carriers.

2. To enable forecasts to be made of the rise in the Red Cedar River at East Lansing and the Grand River at Lansing for various rainfalls likely to produce floods.

In view of the annual destructive floods in this vicinity this latter information is of particular value in warning riparian owners of the likelihood of flood so that they may take necessary means to insure themselves and property against loss.

# INTENSITY OF PRECIPITATION.

For the design of sewers or storm water carriers, the intensity of precipitation is very important. The annual, monthly, daily and hourly rates are useful chiefly in problems of water supply, but useless in sewer design. The short, sharp shower taxes the capacity of the sewer and forms a "flood wave" parallel to the fluctuation in intensity of the storm at a time sufficiently subsequent thereto to allow the water to reach the sewer from pavements, yards and roofs.

Until recent years no considerable amount of trustworthy information on intensity of precipitation was available, since all rainfall records included little more than the total precipitation in each storm. Moreover not until the establishment of self-recording rain-gages became somewhat general and not until these had been maintained for a sufficient period was there sufficient information on which to predicate definite statements as to the relation of intensity of rainfall to the length of time during which the rain might fall continuously at any given rate.

Kuichling in 1889 investigating the rainfall in Rochester, N. Y., studied such records as were available and expressed formulae, from the data, for storms of periods less than one hour and for storms greater than one hour.

Prof. Talbot in 1891 analysed in detail the rainfall records reported by the U. S. Weather Bureau. The greater part of them were records of ordinary rain gages, but in a few

cases were those of self-recording gages. Thus he devised formulae for intensity of storms in certain parts of the U. S. But these formulae are general and do not fit any particular city. Recently with the increasing use of automatic rain gages and with the greater use of the rational method of design among sewer engineers, the records of automatic rain gages in the more important cities have been separately analyzed in detail, and curves have been prepared which have been used as a basis of design in these cities.

This is what the writers have done in Curve III. We plotted the points, time in minutes as abscissae and the rate of rainfall per hour as ordinate. Then we drew in a smooth curve which would take in most of these points but not all of the severe storms which is never done in any case. It is considered a waste in money to put in big sewers to carry off the water for those storms which happen once in ten years, or once in fifteen. Hence for East Lansing we have a curve which could be used for sewer design. For any short period of time, say ten minutes, follow up until the curve is struck and we read 3.5 inches of rainfall. That is, for ten minutes the maximum rate of rainfall which is likely to occur here will be at the rate of 3.5 inches per hour, except those unusual storms which occur once in ten or fifteen years.

It is customary in designing city sewers to express the relationship between time and intensity of rainfall in the form of an equation. We derived the equation of the time and intensity curve for this locality by plotting the curve inked in black as shown in Curve III. We took values from this curve and plotted them on log-arithmetic paper. The points were found to lie nearly on a straight line which indicates that the curve was of the form $Y = a\,x^{n}$. Determining the constants from the empirical data we have $Y = 12.5\,X^{-.528}$.

Prof. Hoad, of Michigan, in working on the design of sewers for Flint, devised a modification of the Talbot formula which is more easily adapted to local conditions $I = R\,\frac{80}{t + 20}$ where "R" = maximum rate for one hour, "t" is the duration in minutes and "I" is the intensity in inches. By substitution in the equation of the time and intensity curve, we find that $I = R\,\frac{90}{t + 30}$ which is adapted to this locality.

## FUTURE ESTIMATES.

Where rainfall records of only a few years must be made the basis of engineering computations, it becomes important to inquire how reliable such records may be.

Alex. A. Binnie, member of the Institute of C. E. draws some conclusions in the Society Proceedings, Vol. 109, P. 89 - 172. He says "Dependence can be placed on any good record of twenty five years duration to give a mean rainfall correctly within two per cent of the truth". Mr. Rafter reviewing the paper says, "For records from twenty to thirty five years in length the error may be expected to vary from 3.25 down to two per cent and that for shorter periods the variation of the error is slightly higher".

Mr. Henry has drawn the following conclusion. For a ten year period the following variations from the normal have occured;

| | | |
|---|---|---|
| New Bedford | + 16 per cent | - 11 per cent |
| Cincinnati | + 20 per cent | - 17 per cent |
| St. Louis | + 17 per cent | - 13 per cent |
| Ft. Leavenworth | + 16 per cent | - 18 per cent |
| San Francisco | + 9 per cent | - 10 per cent |

Mr. Henry found for a total 40 year period that the average variation was + or - 5 per cent. But it is a fact that the rainfall for a particular locality may average considerably below the mean for many years after which may follow, perhaps, an equally long period of surplus. A study of Curve I and table I verifies this statement, and also agrees with Mr. Henry's conclusions. From 1876 to 1885 the surplus over the average was 15.3% and under the average by 13.8%. The mean is 31.24 inches which is the average for a 50 year period. So we may expect this mean to be about 2.5% + or - .

In designing water works in England it has been the custom to assume as the mean rainfall for the three driest years 80% of the mean. In this country the lowest percentages for the one, two, and three driest years with the exception of a few extreme cases are about the same over a large portion of the U. S. and may reasonably be placed at 60, 70 - 75 per cent for the East and South with a reduction to 50, 60 and 70 respectively for the Northwest and plains region. Looking at Table I we see for the region that the percentage for the first three direct years are 61.8, 67.4 and 78.3 which is very close to the standard of 60, 70 and 75. Detroit gives 65, 72 and 79 with a mean rainfall of 32.5 for a period of 46 years.

| Driest Wettest | Period | Number of Years | Average Annual Rainfall | Discrepancy + and - with respect to mean for 54 Years | Per Cent of Discrepancy |
|---|---|---|---|---|---|
| Dry | 1894 | 1 | 19.30 | - 11.92 | -38.2 |
| Wet | 1883 | 1 | 48.36 | + 17.12 | +54.8 |
| Dry | 1894-95 | 2 | 21.05 | -10.19 | -32.6 |
| Wet | 1883-84 | 2 | 42.32 | +11.08 | +35.4 |
| Dry | 1893-95 | 3 | 24.46 | - 6.78 | -21.7 |
| Wet | 1883-85 | 3 | 40.19 | + 8.95 | +28.6 |
| Dry | 1892-95 | 4 | 25.83 | - 5.41 | -17.3 |
| Wet | 1880-83 | 4 | 40.24 | +9.00 | +28.8 |
| Dry | 1891-95 | 5 | 25.62 | - 5.62 | -18.0 |
| Wet | 1880-84 | 5 | 39.45 | +8.21 | +26.2 |
| Dry | 1890-95 | 6 | 26.67 | -4.57 | -14.6 |
| Wet | 1880-85 | 6 | 38.86 | +7.62 | +24.4 |
| Dry | 1889-95 | 7 | 26.25 | -4.99 | -15.95 |
| Wet | 1880-86 | 7 | 37.31 | +6.07 | +19.4 |
| Dry | 1888-95 | 8 | 26.29 | -4.95 | -15.8 |
| Wet | 1877-84 | 8 | 36.67 | +5.43 | +17.4 |
| Dry | 1887-95 | 9 | 26.94 | -4.30 | -13.8 |
| Wet | 1879-87 | 9 | 36.59 | + 5.35 | +17.10 |
| Dry | 1886-95 | 10 | 26.94 | - 4.30 | -13.8 |
| Wet | 1876-85 | 10 | 35.98 | + 4.78 | +15.3 |
| Dry | 1886-1900 | 15 | 28.26 | -2.98 | - 9.55 |
| Wet | 1873-1887 | 15 | 33.47 | +2.23 | +7.36 |
| Dry | 1885-1904 | 20 | 29.98 | -1.61 | -5.15 |
| Wet | 1866-1885 | 20 | 32.94 | +1.70 | +5.45 |
| Dry | 1886-1915 | 30 | 29.98 | -1.26 | -4.03 |
| Wet | 1876-1905 | 30 | 31.85 | + 0.61 | +1.95 |
| Dry | 1871-1910 | 40 | 30.90 | - 0.34 | -1.09 |
| Wet | 1866-1905 | 40 | 31.67 | -0.43 | +1.37 |

THE WATER YEAR.

Curve II. Max. Min. and Mean Monthly Rainfall Curves.

The Maximum Minimum and Mean Monthly rainfall curves show the monthly distribution in the mean year as compared with the minimum and maximum rainfalls for the various months.

For sewer design these curves have no significance, while for problems of water supply they are absolutely necessary. Especially valuable is that position of the diagram which divides the mean annual rainfall into the three periods which constitute the "water year". It is customary, in engineering problem relating to water supply, to study the run-off in three distinct periods of the year instead of the calender year as a whole. These three periods together is called the "water year". The first period which is from December to May inclusive is called the storage period, the second period, from June to August inclusive is called the growing period, and the last from September to November inclusive is called the replenishing period.

Such a division of rainfall into the periods constituting the water year should be followed by a similar division of the run-off of the Red Cedar River at East Lansing, to enable a thorough study to be made of the relation of rainfall to run-off. It was the original purpose of the writers of this thesis to investigate this relation in detail. Lack of time, however, makes it impossible to prepare the runoff data at this station with anything near the precision of the rainfall data, and any comparison between rainfall and run-off distribution not based on data of equal reliability would be futile and worthless. Hence it is with regret that this interesting relationship cannot be incorporated in this thesis.

Some extremely interesting and useful information, however, has been compiled to show how the river at East Lansing and at Lansing responds to rainfalls of varying degrees of intensity.

RISE IN RIVER AND ITS CAUSES OR CONDITIONS WHICH WERE EXISTING AT THE TIME.

When an attempt is made to study the conditions which cause a rapid rise in the river, difficulties are encountered. It is important to know at what time of the year the rise was noted, also, was the run-off melted snow and ice or just the rain which fell during a storm? Similarily other causes should be sought which might influence the rise. No attempt is made here to get the exact run-off but to study the conditions which cause a rapid rise in the river or in other words to study the flood conditions. Metcalf and Eddy, Vol. I, discussing floods say, "It may happen in some cases that the maximum flow of streams will occur when a warm rainfall upon snow already on the ground or when the ground may be coated with ice in such a manner as to present a practically impervious surface, as well as allowing a portion of it to melt and run off with the rain. In those cases the total run-off may amount to 100% of the precipitation or even more. In the case of streams of considerable magnitude, where the time necessary for concentration is several hours or possibly even days and where the max. rate of precipitation, which probably prevailed over but a limited area, is a comparatively small factor in determining the max. rate of run-off, max. flood conditions are particularly likely to occur from rain falling upon snow or ice. In such cases it is desirable to estimate the approximate equivalent of the snow or ice upon the ground, in terms of depth of

water. The U. S. Weather Bureau "Instructions to Co-Operative Observers" states that when it is impossible to measure the water equivalent of snow by melting, one-tenth of the measured depth of snow on a level open place is to be taken as the water equivalent, although it is recognized that this relation varies widely in different cases, depending on the wetness of the snow. The water equivalent of snow may be as great as one-seventh or as small as one-thirty-fourth of the depth of the snow. These figures apply to recently fallen snow,; the water equivalent of snow which has been on the ground for some time and which is therefore compacted to some extent, would be greater. R. E. Horton states in the "Monthly Weather Review", May, 1905:—

"All records indicate that for the heavy and persistent snow accumulations occurring in New York and New England, a progressive growth in the water equivalent per inch of snow on ground will usually take place as the season advances, due to compacting by wind, rain and partial melting, and to the weight of the superincumbent mass on the lower layers. The water equivalent of compacted snow accumulation is commonly between one-third and one-fifth, or at least double that for freshly fallen snow.

"The relation between the thickness of an ice layer and the corresponding depth of water is more uniform, and for practical purposes one inch of ice may be considered as equivalent to 0.9 inch of rain."

In the case of sewer districts, max. run-off is much

less likely to occur from rain falling upon snow or ice. Rains of great intensity are of comparatively rare occurrence during the season when snow or ice are found. Moreover, the effect of snow upon the ground would usually be to retard the flow of water, the snow acting as a sponge during the time of heaviest precipitation, and causing the run-off to be at a more gradual rate than the rainfall during this portion of the storm. It is, however, possible under extreme conditions, that max. run-off might be caused by a warm rain of heavy intensity following after a period of comparatively light precipitation by which the snow has been saturated and nearly melted, so that the max. rate of run-off might even be in excess of the greatest rate of precipitation, and the possibility of this condition must always be born in Mind."

A study of the graphs in figure IV will at once show that the greatest rises in the river have occurred in the months when snow and ice have been on the ground. This condition followed by rapid rise in temperature with slight precipitation have produced our greatest floods here. For example, on January 31st, of this year, 1918 there were 12 inches of snow on the ground in compact form. Warm weather with slight precipitation followed and by February 15th there was one inch of snow. It is safe to say that all of this melted snow ran off in the river, for after February 14th the river was never less than 7.3 ft. deep. The height culminated March 15th when after 1.70" rain fell in 24 hours upon snow and ice the river rose to 12 ft. deep at East Lansing and 16.8 ft. at Lansing. So we see that

our greatest floods have occurred when a warm rain fell on ice and snow, and hence we can expect to look for floods in these months, namely, January, February, March and possibly April. To show how the river is affected more by melted snow and ice run-off than by heavy rains look at the graph representing September for 1917, 3.14 inches of rain fell in 24 hours the heaviest precipitation recorded here and yet the river rose only 1.4'. The dryness of the ground, of course, kept the river from rising very much.

Graph V is a curve constructed to show the months in which floods are most likely to occur. The curve for East Lansing was constructed through points which represented the number of times the river has risen over 5 ft. for each month, the curve for Lansing for those times which it rose over 8 ft. These records were taken from the period of 1911 - 1918 inclusive. The curve shows the greatest probability of floods to occur in March, which agrees with the records which show that the three greatest floods that have occurred here since 1904 have come in March.

## INDEX TO FOLDER.

Pocket has:
Sheet A
Sheet B
Sheet C

132
384
THS
Suppl.

U. S. D

WE

CHAR

TARY

132

MICH

132
384
THS
Sheet A

MICH