HYDROLOGICAL PROCEDURE NO. 18

HYDROLOGICAL DESIGN OF AGRICULTURAL DRAINAGE SYSTEMS

1977

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

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DRAINAGE AND IRRIGATION DIVISION
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CONTENTS

Synopsis

The procedure outlines the philosophy behind the hydrologic design of an agricultural surface drainage system in coastal areas the drainage of which is subject to the influence of tide levels, the basis and the procedure for performing such a design. Because of the lack of precise information on crop tolerance to flooding and on reduction of crop yields due to varying severity of flooding, a general guide has been given in this procedure on the choice of the designed critical flood duration.

1. INTRODUCTION

1.1 General

In any agricultural land, excess water becomes a drainage problem when it affects the yield (or even results in severe crop damage), interferes with tillage, land preparation, fertilizer application, harvest operation, etc. To varying extent this excess water may be removed through natural processes such as surface runoff, deep percolation, evaporation and transpiration, but these processes are often too slow to prevent damage to crop and drainage must be resorted to in order to remove the water faster.

1.2 Definition

Agricultural drainage may be defined as the artificial removal and disposal of excess water from agricultural land.

1.3 Source of excess water

The source of excess water may be precipitation, excess irrigation water, overland flow or underground seepage from adjacent areas, artesian flow from deep aquifers, flood water from channels, or water applied for such special purposes as leaching salts from the soil or temperature control.

1.4 Drainage classification

Agricultural drainage is divided into two broad classes: surface and subsurface. Some drainage systems serve the dual purpose of surface and subsurface drainage.

2. SCOPE OF THE PROCEDURE

In Malaysia, a good portion of the fertile agricultural land is located in low lying swampy areas, often near the sea coast, the drainage of which is subject to the influence of tide levels. Natural drainage in such areas is usually inadequate and drainage improvement is a prerequisite before they can be profitably developed for agricultural purposes.

The relatively heavy rains falling with high intensities are the main source of excess water in these areas. Excess water is commonly disposed of by surface drainage systems. This procedure deals with the hydrological aspects pertaining to the design for such drainage systems.

3. ROLE OF HYDROLOGY

For the design of a drainage system, the estimation of the quantity, duration and frequency of occurence of the excess water is a prerequisite. This is done by using accepted methods and principles in hydrology.

4. LAYOUT OF AN AGRICULTURAL DRAINAGE SYSTEM

To effect surface drainage, a system of drainage channels is provided, and in some cases, land surfaces are reshaped as necessary to eliminate ponding and to establish slopes sufficient to induce gravitational flow overland through channels and/or drains to the outlet. A typical drainage system comprises field drains, constructed on individual farm lots which discharge into collector drains. The latter in turn discharge into a main drain which forms the main outlet for the drainage area concerned. A field drain thus collects all the excess water from the area contributing to it and the collector drain collects water from the field drains leading to it. Where the system under consideration is big, sub-main drains into which collector drains discharge are introduced.

5. DESIGN PHILOSOPHY

The main objective of an agricultural drainage system is to protect the crops from damage due to excess water caused by heavy rainfall. An ideal case for crop protection in such a situation would be to remove the excess water as soon as it occurs. However, it is neither practicable nor feasible to design a surface drainage system to meet this requirement, because of the high intensity of rainfall which requires the construction of a very intense network of drains of very large capacities. This will result in the sacrifice of a significant portion of the land area protected, besides making the cost prohibitive. This consideration provides the rationale for the choice of a drainage system whose capacities are such that some temporary ponding of a part or the entire drainage area is allowed to occur provided the duration of such a ponding would not result in unacceptable crop damage. As will be seen later, for the application of this procedure the duration of ponding would be related to the duration of storm selected for design consideration.

Rainfall is a stochastic process, and it is possible to estimate the frequency of occurrence of storms of given durations, based on past rainfall record of the area. By the same consideration as the foregoing paragraph it is not possible to design a drainage system to deal with excess water resulting from all storms. The problem resolves itself when a decision is taken to accept in the design a certain level of risk of the drainage system failing to meet the requirement for crop damage protection. Such a risk is based on economic considerations tempered with judgement on the part of the designer. In effect, the choice of a risk level means the choice of a storm of a given return period.

In order to evaluate the amount of excess water, the moisture conditions throughout the basin at the beginning of the storm must be known. For design purpose it is not possible to determine the antecedent conditions throughout the catchment under all situations. For simplicity it may be assumed that the antecedent condition of the catchment is fully saturated. This means that losses would be neglected.

6. BASIS OF DESIGN

In the design, the capacities of the drainage systems are such that some temporary ponding of a part or the entire drainage area is allowed to occur provided that the duration of such a ponding would not result in unacceptable crop damage. In this case, the design of the system would be based on storm volume and not on the peak rate of flow. However, to check the maximum depth and extent of flooding, the peak rate of flow for the design storm has to be determined.

7. DESIGNED HYDROGRAPHS – SYNTHETIC HYDROGRAPHS

7.1 Measured Hydrographs

It is common practice to use hydrographs obtained from field measurements, for design purposes. In the design of agricultural drainage systems, measured hydrographs are not suitable for the following reasons:–

(a) Often measurements are made in catchments which are undeveloped or partially developed, having substantial detaining media and therefore do not represent the post-drainage conditions which are fully developed and contains only minimum detaining media as imposed in the design. This is substantiated by overseas studies (1), which revealed that the post-drainage peak discharge has been raised to about three times its pre-drainage value and that the lag time and time base have been greatly shortened.

(b) Most of the discharges obtained from measurements made in the lower plain reaches of streams, (having similar characteristics as those of pre-drainage areas) are not accurate because of the influence of tide levels and other detaining media downstream of the points of measurements.

Synthetic hydrographs will therefore be used as the designed hydrographs in this procedure.

7.2 Synthetic Hydrographs

For convenience, basic hydrograph is usually represented by a triangle. In section 5, it was concluded that the catchment would be assumed as fully saturated at the beginning of the storm and all other losses would be neglected. In such a case, the triangular hydrograph could be simplified to an isosceles triangular hydrograph (Fig. 1). However, when the duration of storm is greater than the time of concentration (t_c), the hydrograph would be represented by an isosceles trapezium (Fig. 2). Further, if the duration of storm is very much greater than the time of concentration, then the hydrograph would be represented by a rectangle (Fig. 3).

7.3 Designed Inflow Hydrographs

The designed inflow hydrograph is triangular (isosceles), trapezoidal or rectangular depending on whether the designed duration of storm is equal to, greater than or very much greater than the time of concentration (t_c) which is defined as the time required for the water to flow from the most remote point of the catchment to the point being investigated, (See Appendix 1 for the estimation of time of concentration t_c from velocity estimates and watercourse lengths).

(i) *duration of storm equal to the time of concentration.*

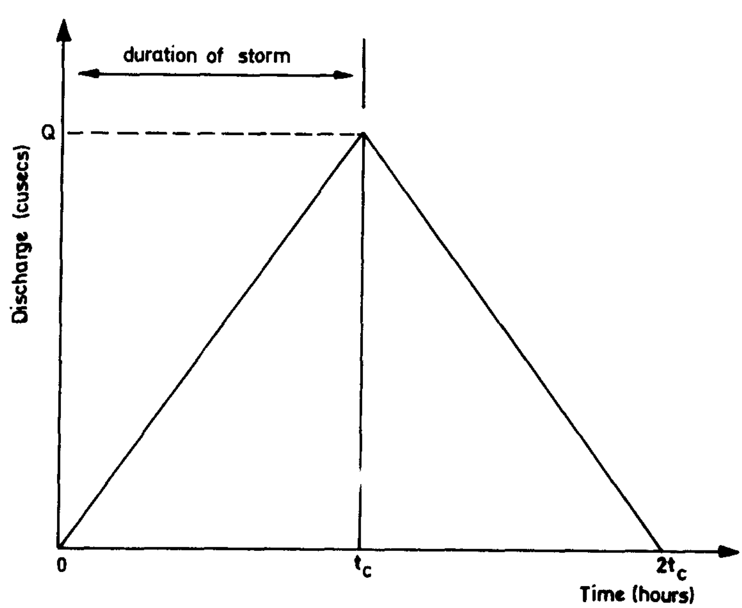

Fig. 1

(ii) *duration of storm greater than the time of concentration.*

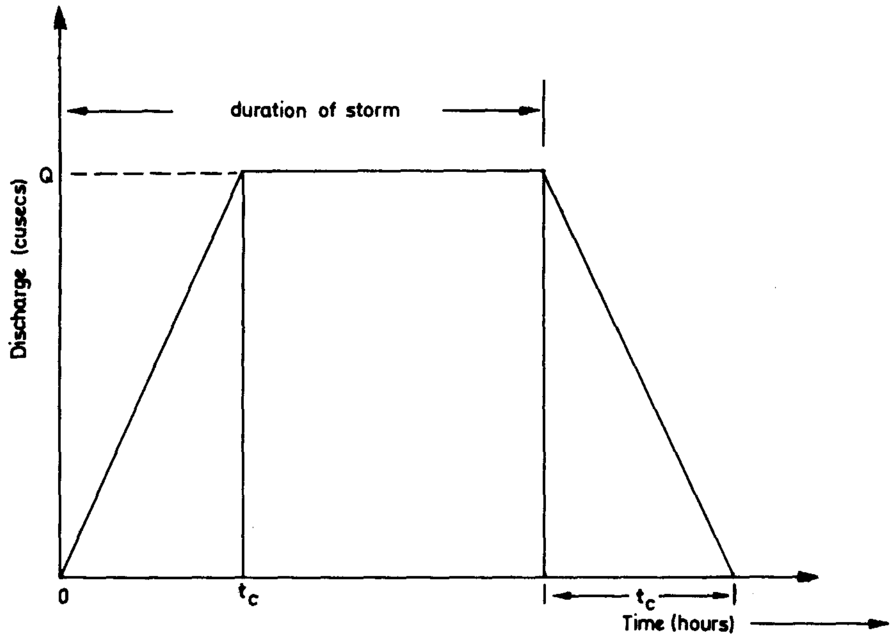

Fig. 2

(iii) *duration of storm very much greater than the time of concentration.*

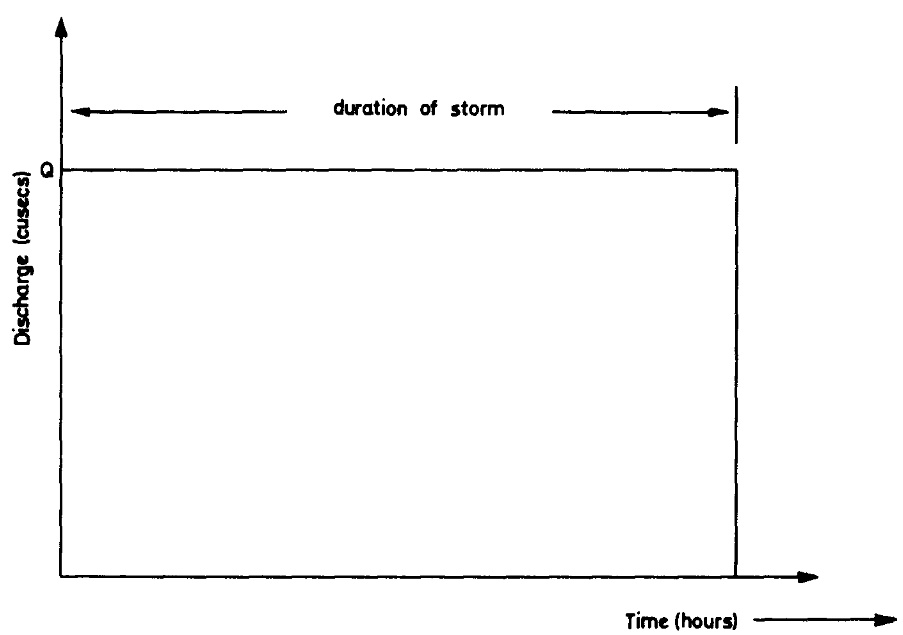

Fig. 3

7.4 Designed Cumulative Inflow Hydrographs

As storm volume is the prime concern in the design, it is necessary that cumulative inflow hydrographs (representing volume of flow for a given duration) are derived from designed inflow hydrograph.

(i) *duration of storm equal to the time of concentration.*

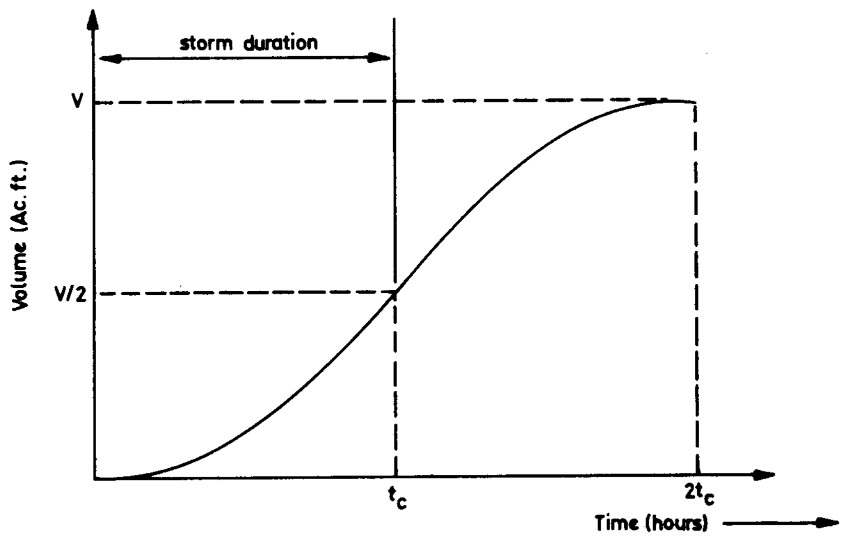

Fig. 4

Note: The curve is made up of two parabolas.

(ii) *duration of storm greater than the time of concentration*

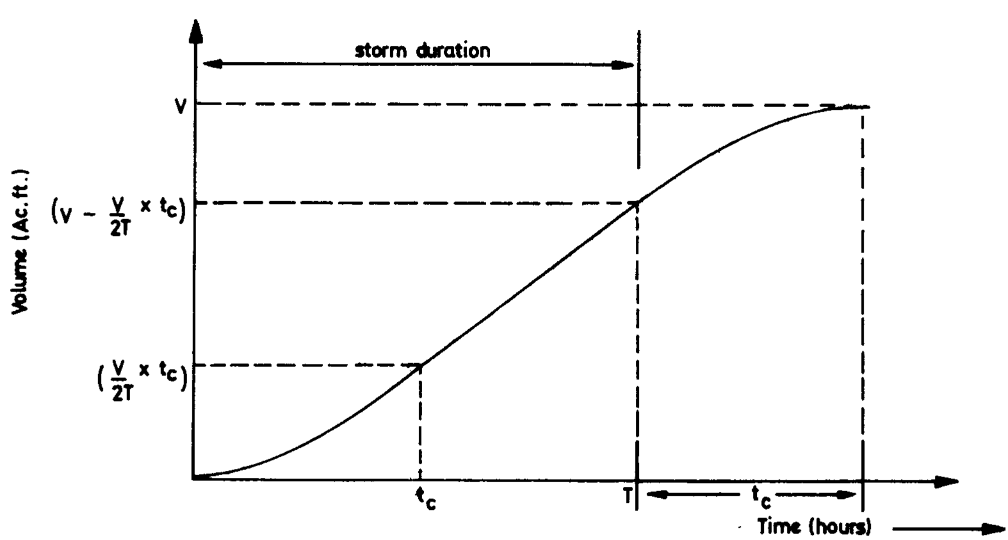

Fig. 5

Note: The curve is made up of two parabolas connected by a straight line at the centre.

(iii) *duration of storm very much greater than the time of concentration.*

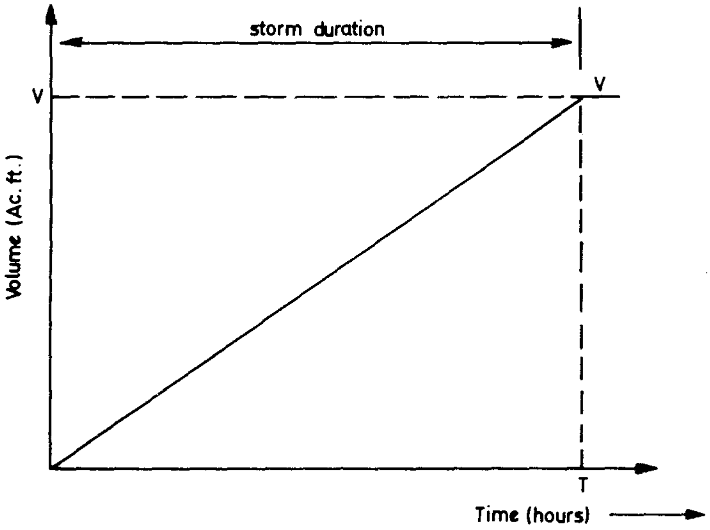

Fig. 6

Note: The curve is a straight line.

8. DETERMINATION OF DESIGN DISCHARGES

8.1 Selection of designed return period (T)

The choice of a long return period will result in large system capacities, the cost of which is often prohibitive. On the other hand shorter return periods would result mostly in partial crop failures and/or reduction in yields. The choice of a suitable designed return period involves the use of economic optimization procedures. As the basic data necessary for these procedures, such as yield variations due to water/moisture levels and price fluctuations of the yields from time to time are not readily available, the selection of design return period will have to be based on past experience, both local and foreign, and judgement. The current practice is to use a 5-year return period for most agricultural crops. As a useful reference, an abstract from "Drainage and Agricultural Lands by U.S. Soil Conservation Service" (2) is given as follows:–

> "For general farm crops the level of protection normally planned is from a storm of 48 hours duration and with a frequency of occurrence of from 2 to 5 years. For high value crops with low tolerance to excess water, protection from the. 10-year frequency storm may be desirable, or special analysis may be warranted to remove for example, the excess from a 24 hour rainfall in a 24 or 36 hour period."

8.2 Selection of designed storm duration (t)

The choice of the designed storm duration which amount to the acceptable duration of flooding is a matter again involving the use of economic optimization procedures.

The crops commonly grown in this country include rubber, coconut, oil palm, cocoa, coffee, maize, banana, sorghum, papaya, pineapple, tobacco, vegetables etc. Precise information on the acceptable durations of flooding is not available. The following Table 1 gives values based on empirical experience tempered with some judgement:–

Table 1

Critical Flood Duration for Agricultural Drainage Design

Crop Type	Design Duration
Coconut, rubber, oil palm, orchards	72
Padi	72 (partial submergence) 48 (total submergence)
Banana, Cocoa, Coffee, Papaya	48
Maize, Sorghum, Pineapple	24
Tobacco, Vegetables	Very low tolerance and should not be planted in flood prone areas

8.3 Estimation of designed depth of rain storm X(T, t)

Using D.I.D. Hydrological Procedure No. 1 (3), the design depth of rain storm X(T, t), where T is the design return period and t is the design storm duration, could be estimated.

8.4 Determination of designed storm volume V

For any specific point of interest in field drain, collector drain, sub-main drain or main drain, the design storm volume V could be obtained by multiplying the catchment area (A) at that point by the design depth of rain storm X(T, t).

$$V = A \times X(T,\ t) \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

8.5 Determination of designed discharge Q

For the point of interest specified in the above section 8.4, the design discharge Q could be obtained by dividing the design storm volume V by the design storm duration t.

$$Q = \frac{V}{t} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2)$$

NOTE: This determination of design discharge holds true only if the point of interest lies outside the area, which is subject to inundation by ponding resulting from outlet constructions. If the point of interest lies inside the inundated area, then the design discharge is governed by the flow characteristics of the outlet.

9. CONCLUSIONS

The procedure gives the approach to obtain design discharges for drains outside the area which is subject to inundation by ponding resulting from outlet constrictions and the designed inflow and cumulative inflow hydrographs. In order to obtain the designed discharges of all the other drains, the flow characteristics of the outlet structures in conjunction with the designed cumulative inflow hydrograph must be studied. In the case of tidal gates, actual observations of tides in the close proximity of the outlet, particularly during the periods of heavy rainfall, should be made. As the agricultural drainage areas close to the sea coast are often flat lands, detailed contour mapping of the area should be done, so that there would be no difficulty in plotting the stage vs area, capacity curves.

Earlier, it has been stated that data such as yield variations of crops due to water/moisture levels, critical flood durations for the various crops grown locally are not available. Hence, a systematic determination of these in completed drainage schemes as well as from experimental plots should be done. There is also a need to review the performance of such completed drainage schemes with a view to determining their adequacy and weakness. This information would no doubt be very valuable to the designers of drainage schemes in the future.

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APPENDIX 1

ESTIMATING TIME OF CONCENTRATION FROM VELOCITY ESTIMATES AND WATERCOURSE LENGTHS

VELOCITY ESTIMATE GUIDE

Average slope from furthest point to outlet in precent	Average velocity feet per second
0 to 1	1.5
1 to 2	2.0
2 to 4	3.0
4 to 6	4.0
6 to 10	5.0

WORKED EXAMPLE

Determine the design discharge for a drain at a point latitude 4° 00′N and longitude 101° 00′E, draining 500 acres of coconut land. The longest water course length is 5300 ft. and the average ground slope is almost zero.

1. **Selection of design return period T**

   From section 8.1, the design return period is 5 years

2. **Selection of design storm duration t**

   From section 8.2, Table 1, the design storm duration (t) (for coconut) is 72 hours.

3. **Estimation of depth of rain storm X(T, t)**

   Using D.I.D. Hydrological Procedure No. 1, X(2, 72) and X(20, 72) are found to be 4.9 inches and 10.5 inches respectively.

   By plotting these values in the Depth – Return period plotting diagram for a constant storm duration, X(5, 72) is 7.4 inches.

4. **Determination of design storm volume V**

   $$\text{Design storm volume } V = 500 \times \frac{7.4}{12} \text{ Ac. ft.} = 308 \text{ Ac. ft.}$$

   $$\text{or} = 640 \times \frac{7.4}{12} \text{ Ac. ft./sq. mile} = 395 \text{ Ac. ft./sq. mile}$$

5. **Determination of design discharge Q**

   Storm volume V = 308 Ac. ft.
   Duration of storm t = 72 hours.

   $$\text{Design discharge } Q = \frac{308}{72} \text{ Ac. ft./hr.}$$

   $$= \frac{308}{72} \times 12 \text{ Ac. in/hr.}$$

   $$= 51 \text{ Ac. in/hr.}$$

   $$= 51 \text{ cusecs}$$

   $$\text{Design discharge } Q \text{ in cusecs/sq. mile} = \frac{395}{72} \times 12 = 66 \text{ cusecs/sq. mile}$$

NOTE:— The above calculation of the design discharge holds true only if the drain under consideration is outside the area which is subject to inundation by ponding resulting from outlet constrictions. If the point under consideration lies within the inundated area, then the design discharge is governed by outflow characteristics of the outlet.

(The following steps are illustrated here, as a guide for the design of outlet structure, which is outside the scope of the procedure).

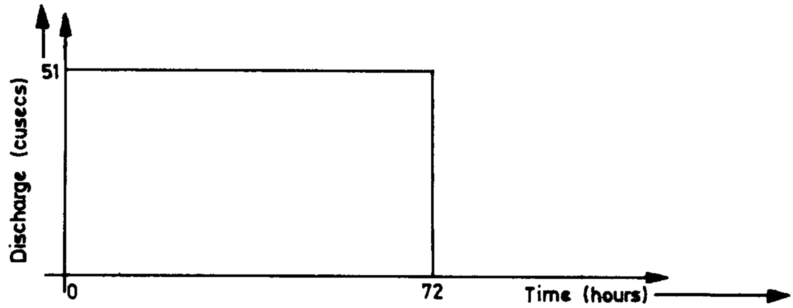
6. **Estimation of time of concentration**

From Appendix 1, the average velocity of flow corresponding to zero ground slope is 1.5 feet/second.

$\therefore$ Time of concentration = $\frac{5300}{1.5}$ seconds = 3,533 second = 1 hour (say).

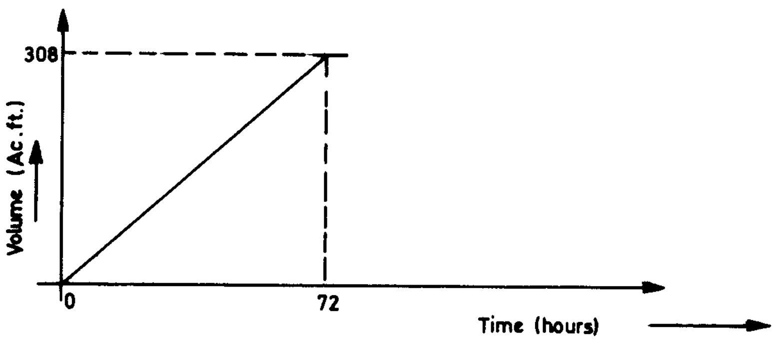
7. **Selection of shape of design inflow hydrograph**

From section 7.3, the design inflow hydrograph would be rectangular in shape, since design storm duration (72 hours) is very much greater than the time of concentration (1 hour).



8. **Design cumulative inflow hydrograph**

From section 7.4, the design cumulative inflow hydrograph is a straight line as shown below.



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