Precipitation

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Overview

The study of precipitation forms a major portion of the subject of Hydrology. Here, a brief introduction is given to familiarize with the important aspects of rainfall and in particular, with the collection and analysis of rainfall data.

Precipitation Process

Introduction

The term *precipitation* denotes all forms of water that reach the earth from atmosphere. The usual forms are

- Rainfall
- Snowfall
- Hail
- Frost and
- Dew

Of all these, only *Rainfall* and *Snowfall* contribute significant amounts of water. Rainfall being the predominant form of precipitation in India, the term *Rainfall* will be used synonymously with *Precipitation*.

Formation of Precipitation

Necessary conditions

- The atmosphere must have moisture
- Sufficient nucleii must be present to aid condensation
- Weather conditions must be good for condensation of water vapour
- products of condensation must reach the earth

(The nucleii are usually salt particles or products of combustion, which are available in plenty in the atmosphere)

Formation Process

The process can be summarized as follows.

- Under proper weather condition, water vapour condenses over nucleii to form tiny water droplets of sizes less than 0.1mm
- Water droplets remain in suspension in the cloud
- Wind speed facilitates movement of clouds with droplets in suspension
- Water droplets come together and form larger drops
- Larger drops precipitates down
- A considerable portion of the precipitation gets evaporated back to the atmosphere

Forms of Precipitation

Common forms of precipitation are

- Rain
- Snow
- Drizzle
- Glaze
- Sleet
- Hail

Rainfall is the principal form of precipitation in India. The term rainfall is used to describe precipitations in the form of water drops of sizes $\geq$ 0.5mm and $\leq$ 6mm. On the basis of intensity, rainfall may be classified as

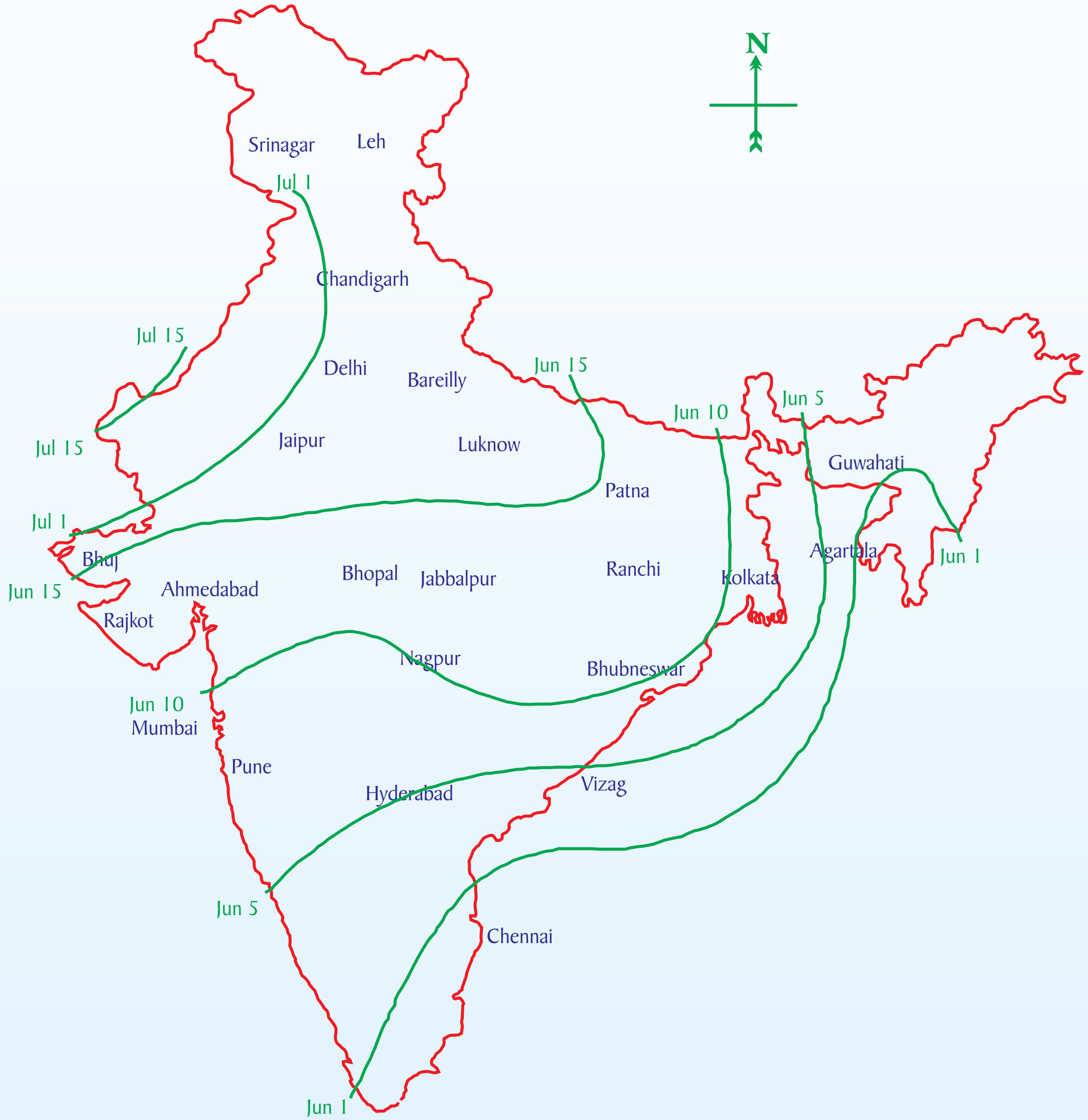
Type	Intensity
1. Light rain	$\leq$ 2.5 mm/h
2. Moderate rain	2.5 mm/h to 7.5 mm/h
3. Heavy rain	$\geq$ 7.5 mm/h

Precipitation Characteristics

Climate in Indian subcontinent can be divided into two major seasons and two transitional period

1. South-West Monsoon (June-September)
2. Transition-I, Post Monsoon (October-November)
3. Winter Season (December-February)
4. Transition-II, Summer (March-May)

South-West Monsoon



Monsoon-Onset

Monsoon Movement

The monsoon originates in the Indian ocean. It first appears in the southern parts of Kerala by the end of May. The monsoon wind advances across the country in two branches:

- the Arabian sea branch

  It sets in the extreme southern parts of Kerala in the first week of June. Then it moves northwest over Karnataka, Maharashtra and Gujarat.

- the Bay of Bengal branch

  It sets in Assam. Then it covers the north eastern regions of the country and turn westwards to advance into Bihar and Uttar Pradesh.

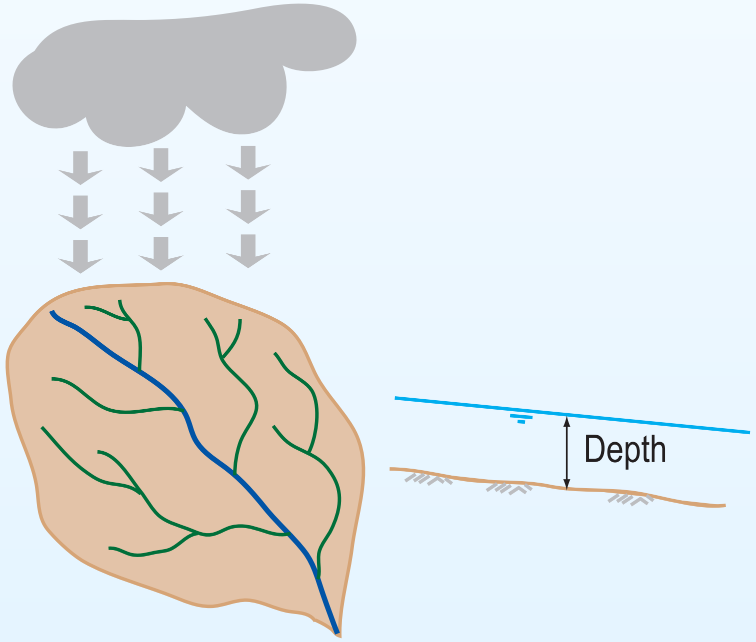
Both the branches reach Delhi around the same time by the fourth week of June. The monsoon winds increase from June to July and begin to weaken in September.

Area	Monsoon Rainfall (cm)
Assam and north-eastern states	200-400
West Coast and Western Ghats	200-300
West Bengal	120-160
UP, Haryana, Punjab	100-120

Measurement of Precipitation

Introduction

Precipitation is expressed in terms of the depth to which rainwater would stand on an area, if all the rain were collected on it.
Thus, $1cm$ of rainfall over a catchment area of $1km^2$ represents a volume of water equal to 10^4m^3.
In case of snowfall, an equivalent depth of water is used as the depth of precipitation.



Raingauge

The precipitation is collected and measured in a **Raingauge**. The term such as *pluviometer*, *ombrometer* and *hyetometer* are also sometimes used to designate a raingauge.

A raingauge essetially consists of a cylindrical-vessel assembly kept in open to collect rain. To enable the catch of raingauge to accurately represent the rainfall in the area surrounding the raingauge, standard settings are adopted.

1. The ground must be level and in the open.
2. The instrument must represent a horizontal catch surface.
3. The raingauge must be set as near the ground as possible to reduce wind effects, but it must be sufficiently high to prevent splashing, flooding, etc.
4. The instrument must be surrounded by an open fenced area of at least $5.5m \times 5.5m$.

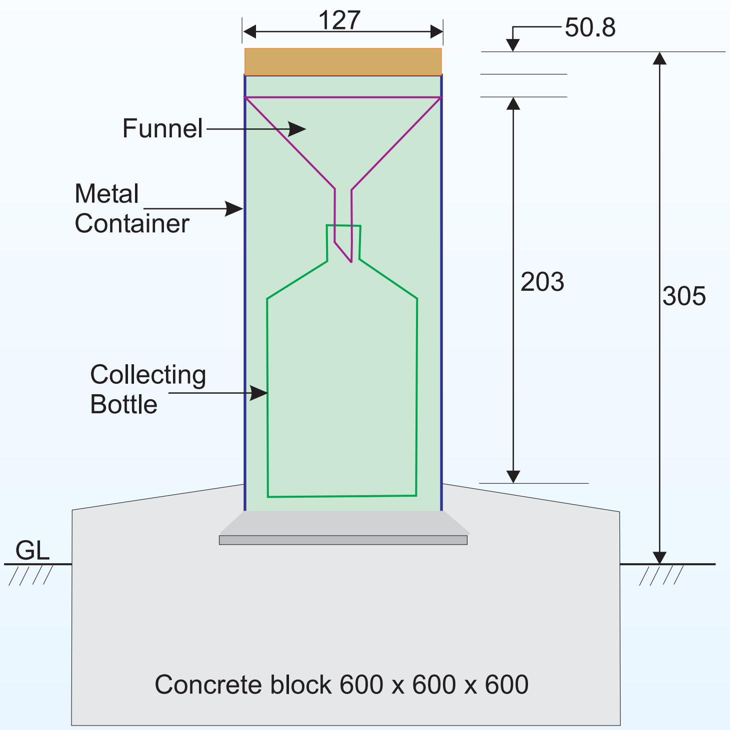
Types of Raingauge

Two different categories of raingauges are available

- Non-recording raingauges
- Recording raingauges.

Nonrecording Raingauges

In India, the non-recording raingauges used are known as *Symon's gauge*.



Symon's Gauge

The funnel discharges the rainfall catch into a receiving vessel. The water contained in the receiving vessel is measured by a suitably graduated measuring glass, with accuracy up to $0.1mm$.

Recording Gauges

- Tipping-Bucket Type
- Weighing Bucket Type
- Natural-Syphon Type

Tipping Bucket Gauge

This is a $30.5cm$ size raingauge. The catch from the funnel falls into one pair of small buckets. These buckets are so balanced that when $0.25mm$ of rainfall collects in one bucket, it tips and brings the other one in position. The tipping actuates an electrically driven pen to trace a record on a clock-work driven chart.

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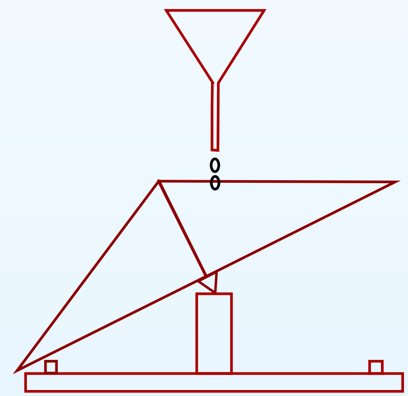

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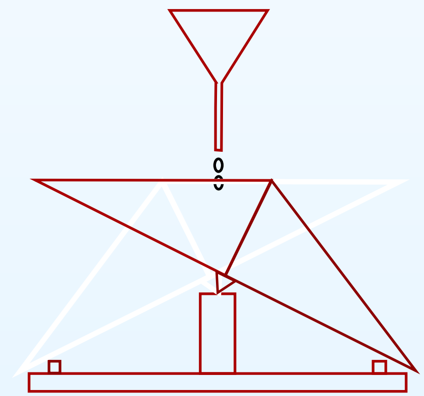

Other Gauges

- Weighing Bucket Gauge

  In this raingauge rainwater from the funnel empties into a bucket mounted on a weighing scale. The weight of the bucket and its contents are recorded on a clock-work driven chart. This instrument gives a plot of accumulated rainfall against elapsed time, i.e., the *Mass Curve* of rainfall.
  .

- Natural Syphon Gauge

  This type of gauge is also known as Float Type Gauge. Here the rainfall collected by a funnel shaped collector is led into a float chamber causing a float to rise. As the float rises, a pen attached to the float through a lever system records the elevation of the float on a rotating drum driven by a clock-work mechanism. A syphon mechanism empties the float chamber when te float has reached a pre-set maximum level. This type of raingauge is adopted by the Bureau of Indian Standards (IS:5235-1969).

Raingauge Network

Specifications (WMO)

The catching area of a raingauge is very small compared to the areal extent of the storm. Hence, to get a representative picture of a storm over a catchment, the number of raingauges should be as large as possible. However, associated cost of procurement, installation and maintenance restrict the number of gauges. The World Meteorological Organisation (WMO) recommends the following densities.

1. In flat regions of temperate, Mediterranean and tropical zones:
   - Ideal: 1 station for $600 - 900 km^2$
   - Acceptable : 1 station for $900 - 3000 km^2$;
2. In mountainous regions of temperate, Mediterranean and tropical zones:
   - Ideal: 1 station for $100 - 250 km^2$
   - Acceptable : 1 station for $250 - 1000 km^2$;
3. In arid and polar zones: 1 station for $1500 - 10,000 km^2$.

Specifications (BIS)

From practical considerations of Indian conditions, IS: 4987-1968 recommends the following densities as sufficient.

1. In plains: 1 station per $520km^2$;
2. In regions of average elevation $1000m$: 1 station per $260 - 390km^2$;
3. In predominantly hilly areas with heavy rainfall: 1 station per $130km^2$.

10% of the raingauge stations should be equipped with self-recording gauges to know the intensities of rainfall.

Adequecy

If there are already some raingauge stations in a catchment, the *optimal number* (N) of stations that should exist to have an *assigned percentage of error* in the estimation of *mean rainfall* is obtained by statistical analysis.

$$N = (C_v/\epsilon)^2$$

Where, N = optimal number of stations, ϵ = allowable degree of error in the estimation of mean rainfall, C_v = coefficient of variation in the rainfall values recorded at the existing stations.
If there are m existing stations in the catchment and rainfall values recorded by these stations are: $P_1, P_2, \ldots, P_m$, then

$$C_v = \frac{100 \times \sigma_{m-1}}{\bar{P}}$$

$$\sigma_{m-1} = \sqrt{\frac{\sum_{i=1}^{m} \left(P_i - \overline{P}\right)^2}{m-1}} \; ; and \quad \bar{P} = \frac{\sum_{i=1}^{m} P_i}{m}$$

Example on Adequecy

A catchment has six raingauge stations A, B, C, D, E. In a year, the *annual* rainfall recorded by the gauges are as follows:

Station	A	B	C	D	E	F
Rainfall (cm)	82.6	102.9	180.3	110.3	98.8	136.7

For a 10% error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment.

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Hence, three additional stations are required.

Data Processing

Normal Rainfall

Before using the rainfall records of a station, it is necessary to first check the data for

- continuity, and
- consistency.

The continuity of a record may be broken with *missing rainfall data* due to many reasons such as damage or fault in a raingauge during a period. The missing data can be *estimated* by using the data of the *neighboring stations*.

In these calculations, the *normal rainfall* is used as a standard of comparison. *The normal rainfall is the average value of rainfall at a particular date, month or year over a specified 30-year period*. The 30-year normals are recomputed every decade.

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Estimation of Missing Rainfall Data

Suppose, there are m raingauge stations in a catchment. Normal annual rainfall values, $N_1, N_2, \ldots, N_m$ of these stations are known. In a particular year, annual rainfall data of one station station X among these m stations is missing, but other precipitation values, $P_1, P_2, \ldots, P_{m-1}$ are available. It is required to estimate the missing rainfall data P_x of station X.

If the normal annual precipitations at various stations are within about 10% of the normal annual precipitation at station X, then *Arithmetic Average Method* can be used. Otherwise, *Normal Ratio Method* is to be adopted.

1. Arithmetic Average Method

$$P_x = \frac{\sum_{1}^{m-1} P_i}{m-1}$$

2. Normal Ratio Method

$$P_x = \frac{N_x}{m-1} \times \left[\sum_{1}^{m-1} \frac{P_i}{N_i} \right]$$

Example

The normal annual rainfall st stations A, B, C and D in a basin are $80.97, 67.59, 92.01$ and $76.28\, cms$ respectively. In a particular year, the station C was inoperative and the stations A, B and D recorded annual precipitations of $91.11, 72.23$ and $79.89\, cms$ respectively. Estimate the rainfall at station C in that year.

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$$99.41cm$$

Test for Consistency

If the conditions relevant to the recording of a raingauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. Some of the common causes for inconsistency are:

1. Shifting of the station to a new location
2. Neighborhood of the station undergone a marked change
3. Change in the ecosystem due to natural calamities (like forest fire, landslides, etc.)
4. Observational error from a certain date

The checking for consistency of a record is done using *Double Mass Curve* technique.

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5. P_x and $P_a v$ values are written in two columns, in reverse chronological order
6. Accumulated values of P_x, i.e., $\sum P_x$ and accumulated values of P_{av}, i.e., $\sum P_{av}$ are calculated.
7. On an arithmetic graph paper, $\sum P_x$ are plotted along y-axis and $\sum P_{av}$ are plotted along x-axis. Years are marked near the points.

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7. On an arithmetic graph paper, $\sum P_x$ are plotted along y-axis and $\sum P_{av}$ are plotted along x-axis. Years are marked near the points.
8. The curve obtained joining the points is the double mass curve.

The Method

This method is based on the principle that when each recorded data comes from the same population, they are consistent. The steps followed are:

1. Let the station under consideration is X
2. 5 to 10 raingauge stations in the neighbourhood of X are selected
3. Annual (or monthly) rainfall data of station X as well as of the neighboring stations are collected covering a long period (say 30 years)
4. Average rainfall values of the neighbouring stations, P_{av} are calculated
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Past records are corrected following the slope of the present records.

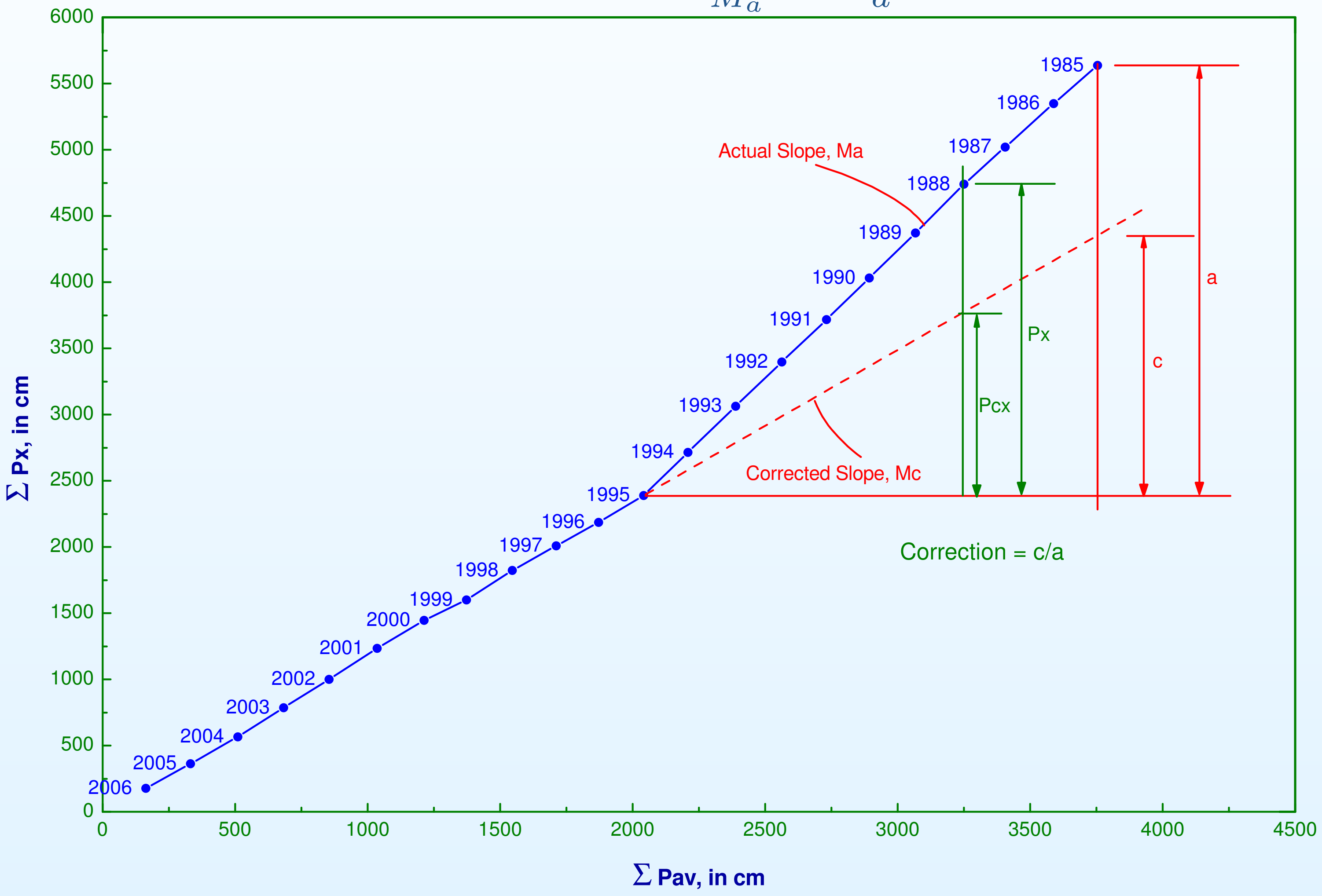
Example

Year	P_x of Station	P_i of Neighbouring Stations				P_{av}	$\sum P_x$	$\sum P_{av}$
	X	A	B	C	D			
1985	125	125	160	178	201	166.0	3640	3754.5
1986	125	132	185	205	210	183.0	3515	3588.5
1987	125	95	155	189	185	156.0	3390	3405.5
1988	125	148	172	186	225	182.8	3265	3249.5
1989	125	138	169	172	217	174.0	3140	3066.8
1990	125	122	154	169	199	161.0	3015	2892.8
1991	125	132	164	174	204	168.5	2890	2731.8
1992	125	138	169	182	211	175.0	2765	2563.3
1993	125	146	173	188	209	179.0	2640	2388.3
1994	125	137	168	175	194	168.5	2515	2209.3
1995	205	139	171	177	192	169.8	2390	2040.8
1996	175	122	162	172	182	159.5	2185	1871.0
1997	186	128	168	178	188	165.5	2010	1711.5
1998	223	133	172	183	203	172.8	1824	1546.0
1999	156	114	166	176	186	160.5	1601	1373.3
2000	211	141	172	188	205	176.5	1445	1212.8
2001	235	147	177	197	207	182.0	1234	1036.3
2002	212	138	164	185	198	171.3	999	854.3
2003	221	141	171	178	202	173.0	787	683.0
2004	202	135	179	192	207	178.3	566	510.0
2005	188	125	165	185	201	169.0	364	331.8
2006	176	120	161	180	190	162.8	176	162.8

Double Mass Curve

Corrected precipitation,

$$P_{cx} = P_x \frac{M_c}{M_a} = P_x \frac{c}{a}$$



Data Presentation

Rainfall Mass Curve (data)

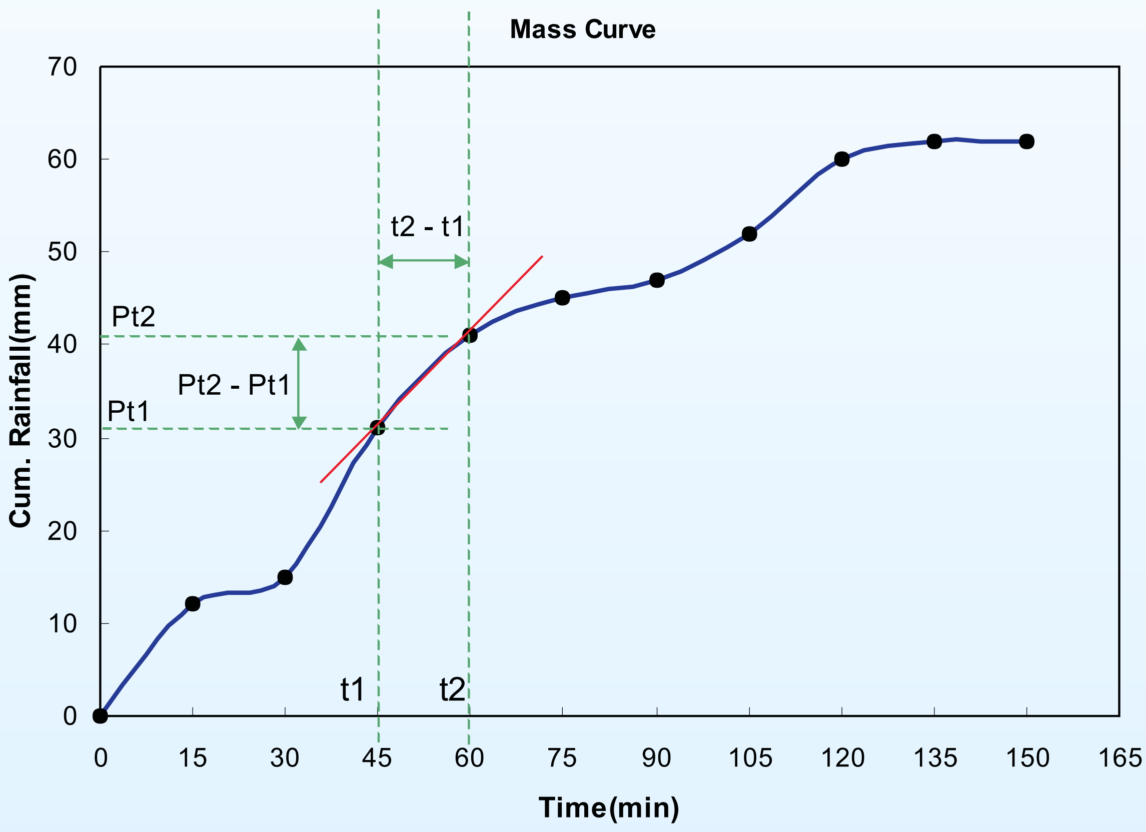
Rainfall mass curve is a plot of accumulated rainfall against time, plotted in chronological order. Data obtained from floating type and weighing bucket type raingauge are of this form.

Time(min)	Cum. Rainfall(mm)
0	0
15	12
30	15
45	31
60	41
75	45
90	47
105	52
120	60
135	62
150	62

Rainfall Mass Curve (plot)

Mass curve of rainfall is very useful in extracting information about duration and magnitude of a storm. Slope of the curve at a particular time give the rainfall intensity at that time.

Rainfall intensity, $i = \frac{dP}{dt} = \frac{P_{t2} - P_{t1}}{t2 - t1}$



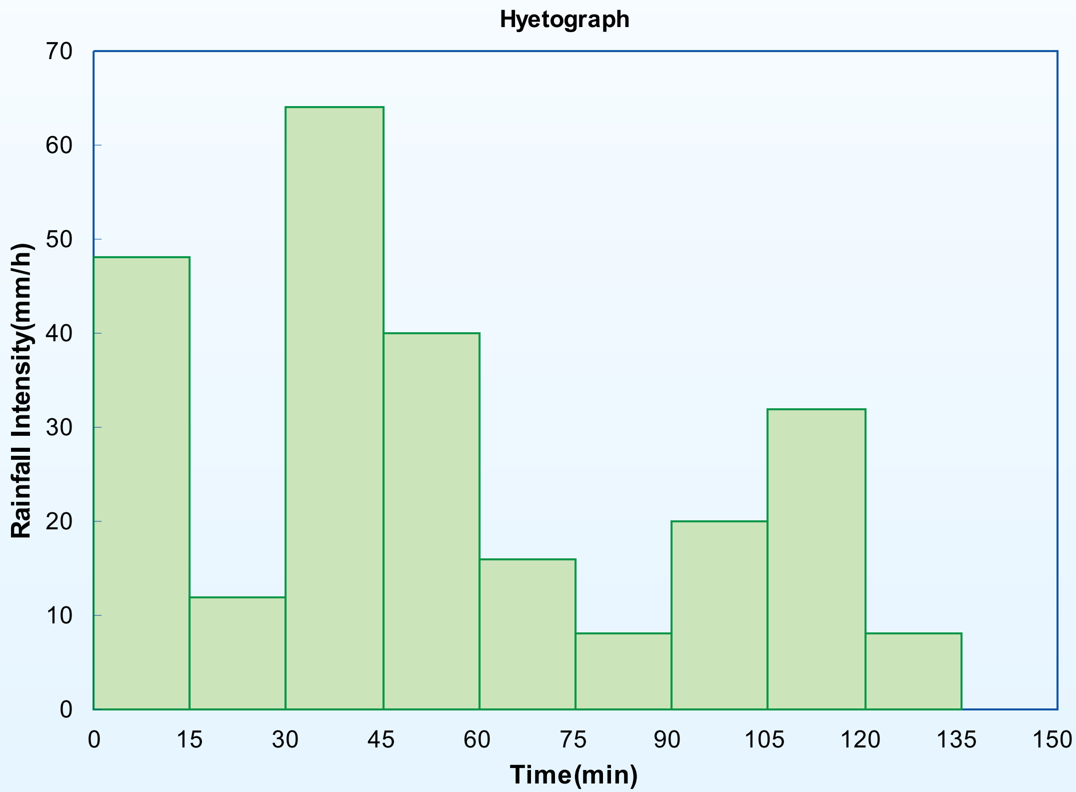
Hyetograph (data)

A hyetograph is a plot of intensity of rainfall against the time interval. The hyetograph is derived from the mass curve and presented as a bar chart.

Time (min)	Cum. Rainfall (mm)	Inc. Rainfall (mm)	Intensity (mm/h)
0	0	-	-
15	12	12	48
30	15	3	12
45	31	16	64
60	41	10	40
75	45	4	16
90	47	2	8
105	52	5	20
120	60	8	32
135	62	2	8
150	62	0	0

Hyetograph (plot)

The area under the hyetograph represents the total rainfall received during the duration of rainfall.



Average rainfall over an area

Point Rainfall

Point rainfall refers to the rainfall data of a raingauge station. Depending on the need, data can be listed as daily, weekly, monthly, seasonal or annual values for various periods. These represents only point sampling of the areal distribution of the storm. However, hydrological analysis requires a knowledge of the rainfall *over an area*, such as over a *catchment*. To convert the point rainfall values measured by various raingauge stations into an average value over a catchment, following methods are used.

1. Arithmetic mean method
2. Thiessen polygon method
3. Isohyetal method

Arithmetic mean method

If there are small variations in the rainfall values measured by the stations, this method can be used.
If $P_1, P_2, \ldots, P_n$ are the rainfall values obtained from n raingauge stations within a catchment, then the average precipitation $\bar{P}$ is given by

$$\bar{P} = \frac{P_1 + P_2 + \ldots + P_n}{n} = \frac{\sum_{i=1}^{n} P_i}{n}$$

In practice, this method is rarely used.

Thiessen polygon method

In this method, the rainfall recorded at each station is given a weightage on the basis of an area closest to that station.

1. Draw the catchment area to a scale and mark the raingauge stations on it.

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4. The polygons formed by the perpendicular bisectors (and part of catchment boundary) are the influence areas of each station.

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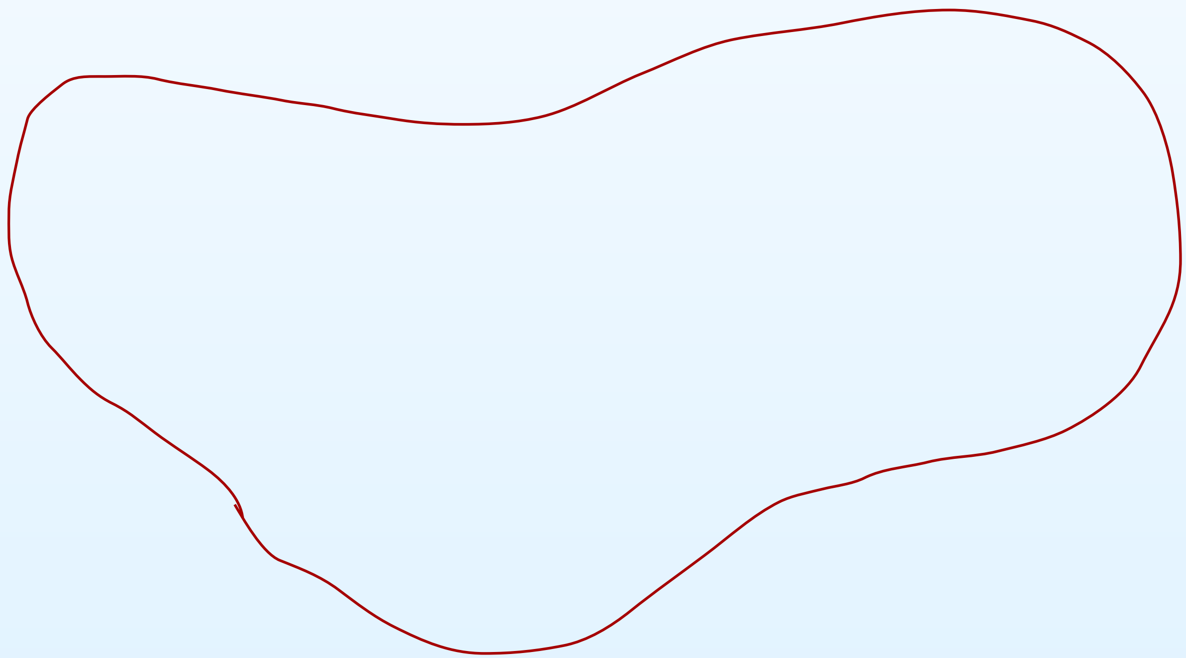

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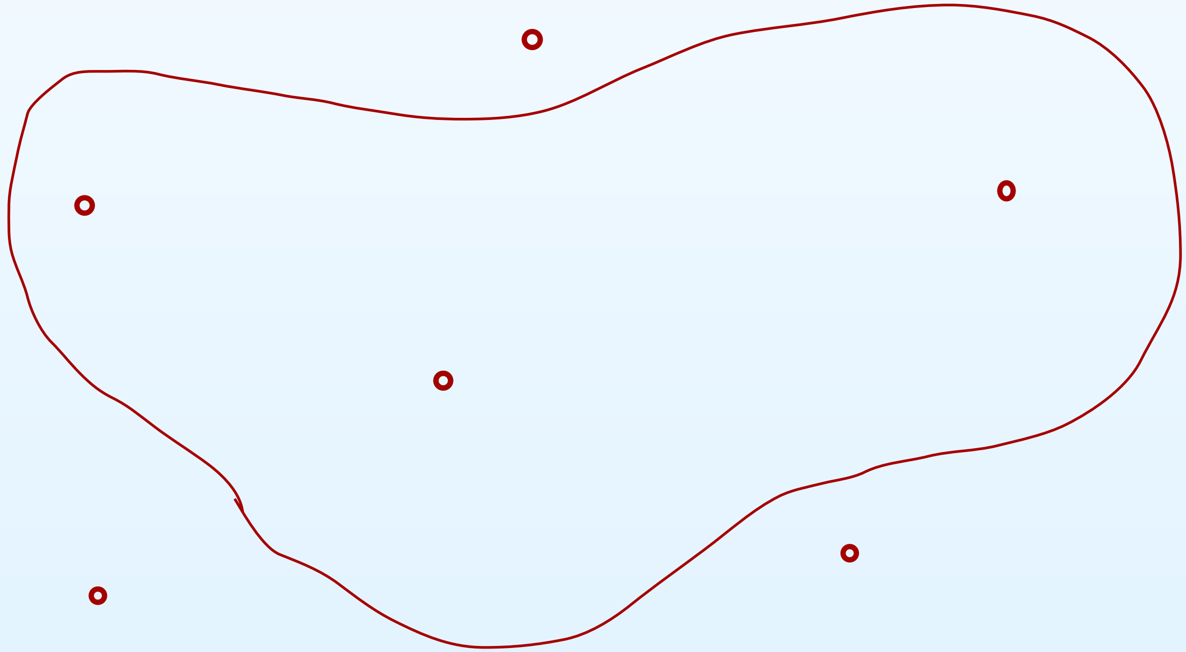

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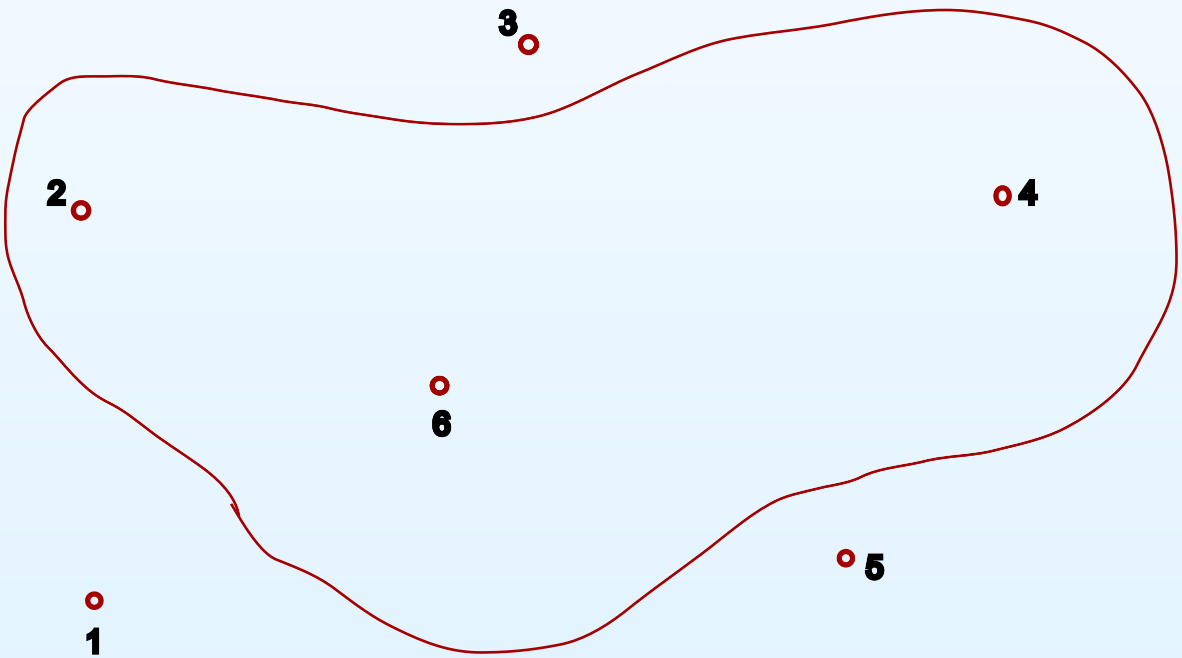

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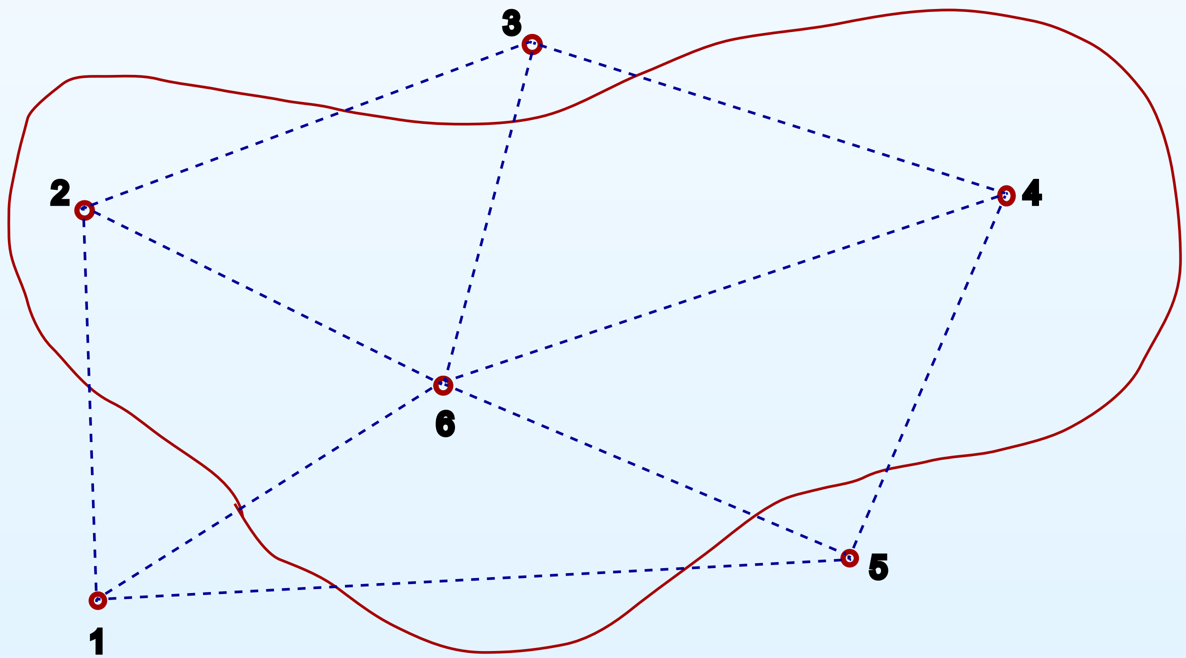

Thiessen polygon method

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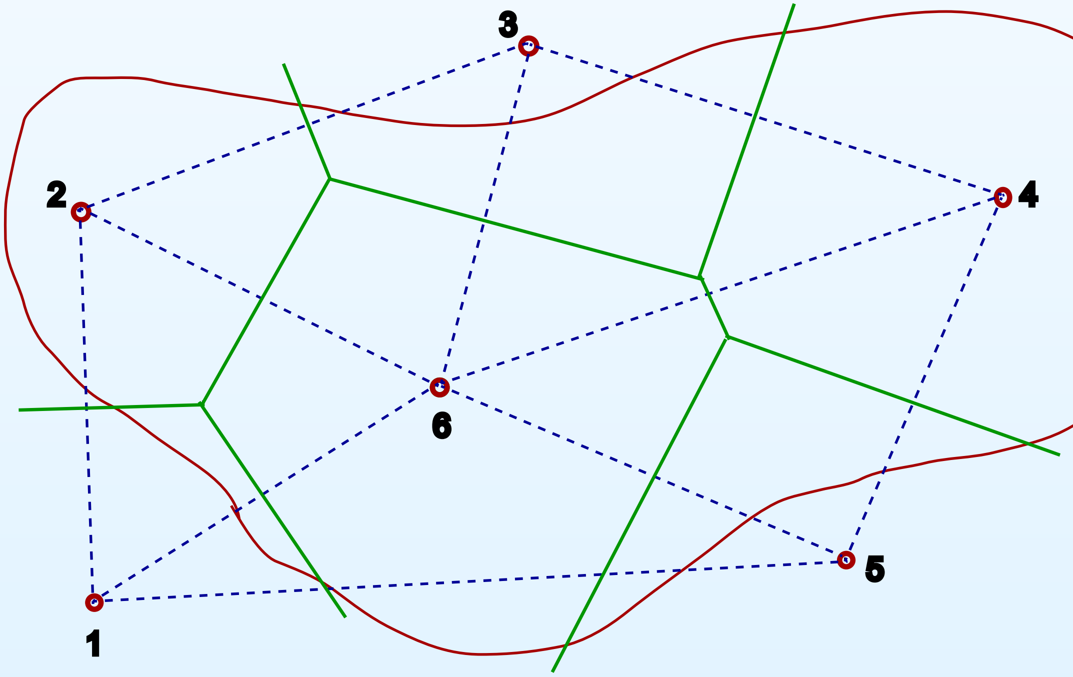


Thiessen polygon method (contd..)

If there are n number of raingauge stations in and around the catchment and if $A_1, A_2, \ldots, A_n$ are the respective influence areas of Thiessen Polygon, then the average precipitation is given by

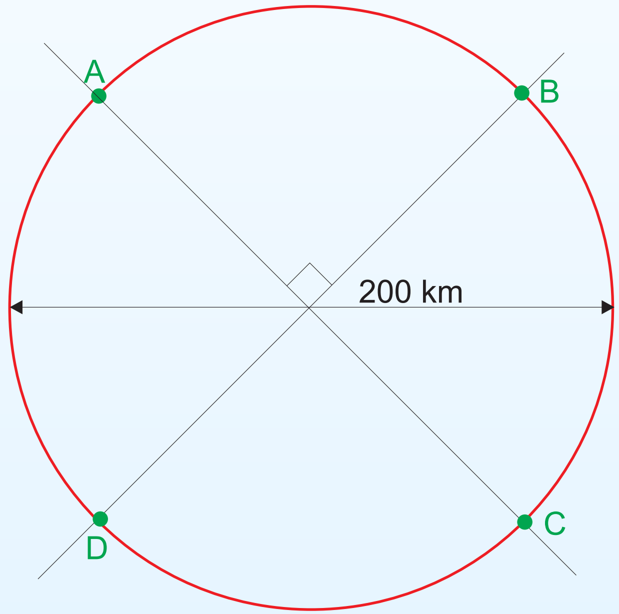
$$\bar{P} = \frac{P_1A_1 + P_2A_2 + \ldots + P_nA_n}{A_1 + A_2 + \ldots + A_n} = \frac{\sum_{i=1}^{n} P_iA_i}{\sum_{i=1}^{n} A_i} = \sum_{i=1}^{n} P_i \frac{A_i}{A}$$

The ratio A_i/A is known as the *weightage factor* for each station. Once the weightage factors are calculated, those becomes constant for a fixed network of raingauge stations and the calculation of $\bar{P}$ becomes very easy.

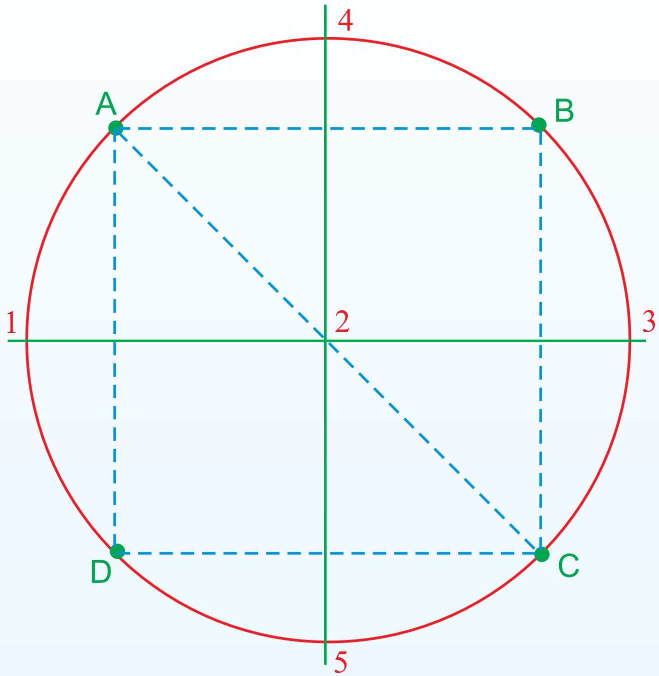
It should be remembered that these weightage factors are independent of the storm.

Example

Four raingauge stations are located in a catchment area, approximated by a circle of radius $100km$, as shown in the figure. Annual precipitation recorded by these station in the year 2003 are: $A(85cm), B(130cm), C(105cm), D(98cm)$. Draw the Thiessen polygon and calculate the average annual precipitation on the catchment in 2003.

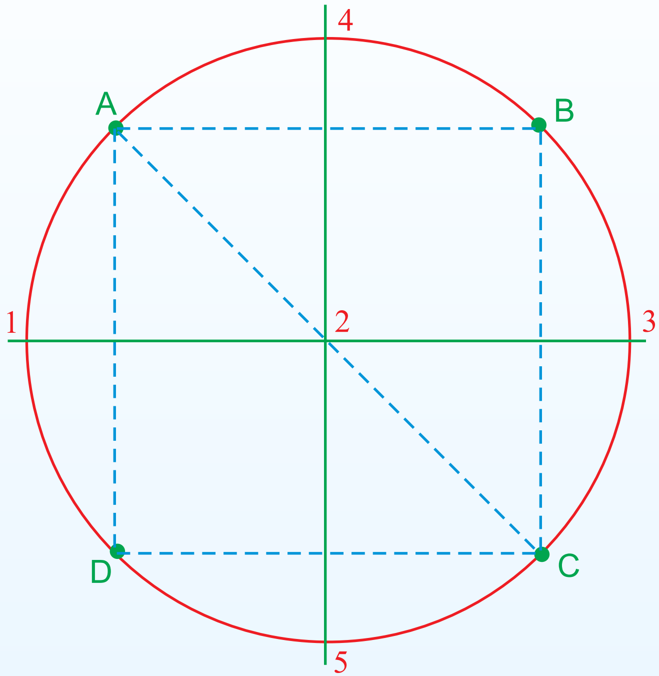


Solution



Raingauge	Polygon	Area (km^2)
A	1-2-4-A	7853.982
B	3-2-4-B	7853.982
C	3-2-5-C	7853.982
D	1-2-5-D	7853.982

Solution



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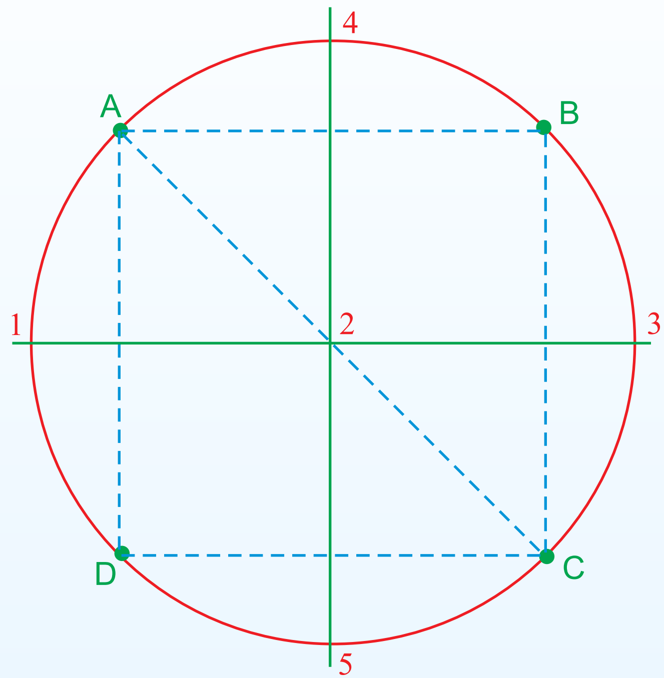
D	1-2-5-D	7853.982

$$\bar{P} = \frac{85 \times 7853.982 + 130 \times 7853.982 + 105 \times 7853.982 + 98 \times 7853.982}{7853.982 + 7853.982 + 7853.982 + 7853.982}$$

Solution

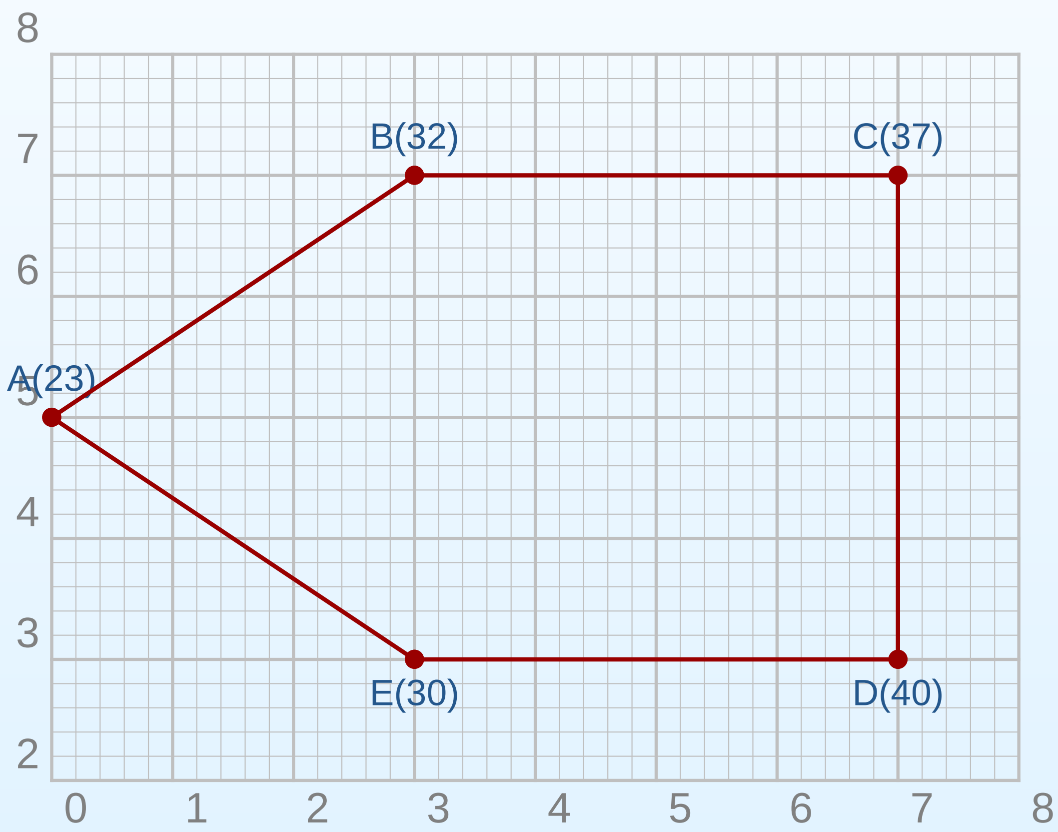


Raingauge	Polygon	Area (km^2)
A	1-2-4-A	7853.982
B	3-2-4-B	7853.982
C	3-2-5-C	7853.982
D	1-2-5-D	7853.982

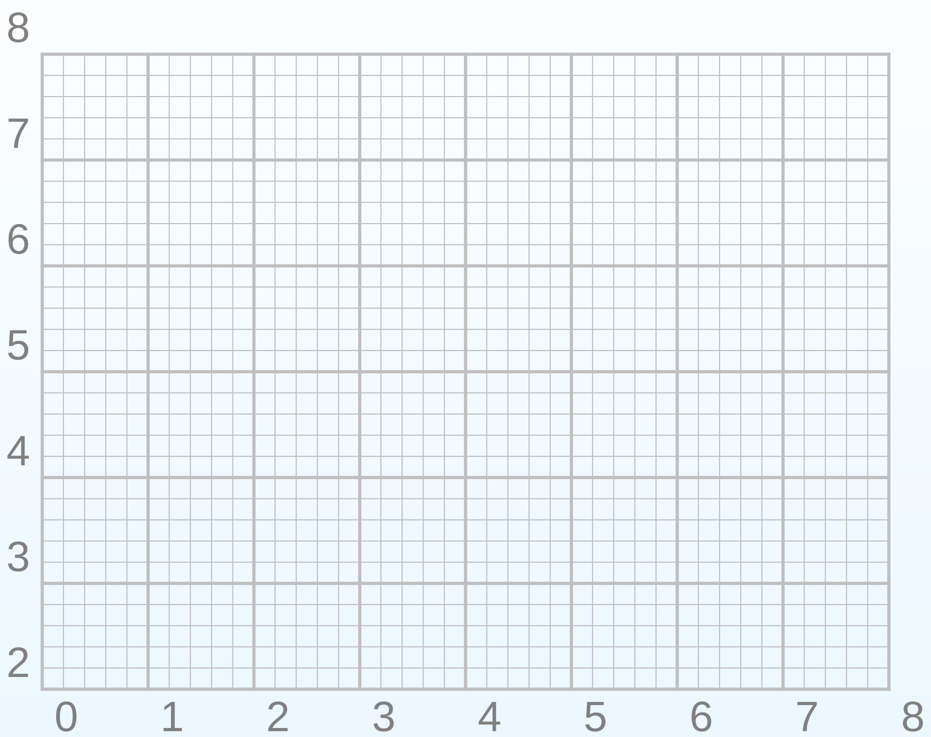
$$\bar{P} = \frac{85 \times 7853.982 + 130 \times 7853.982 + 105 \times 7853.982 + 98 \times 7853.982}{7853.982 + 7853.982 + 7853.982 + 7853.982}$$
$$= 104.5cm$$

Example2

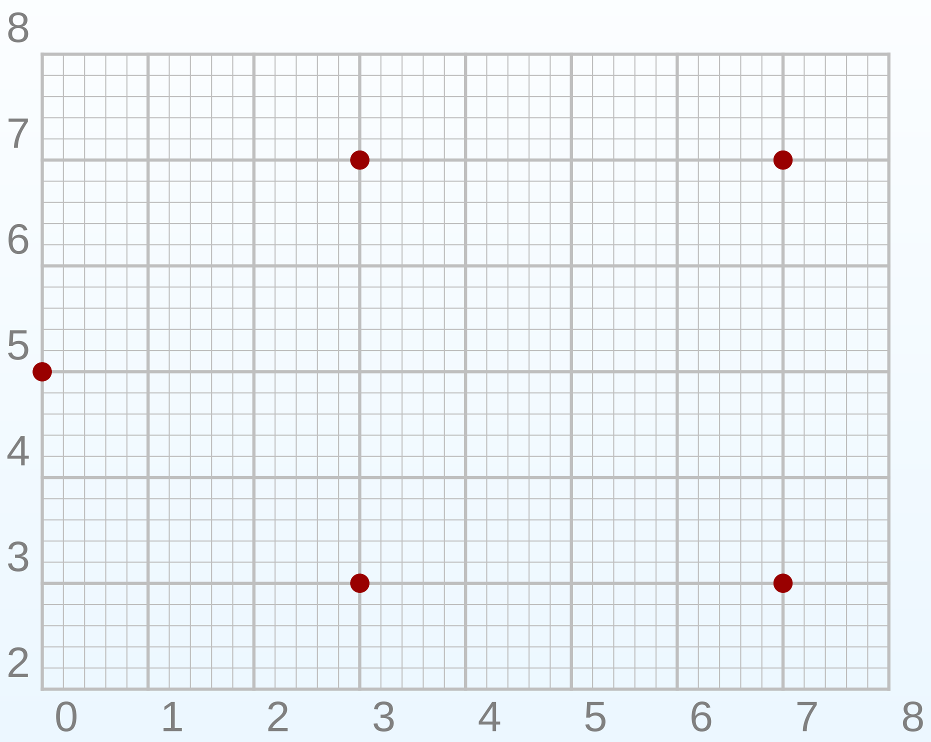
A catchment is approximated as a square of side $10km$ and an isosceles triangle of height $7.5km$ and base $10km$, as shown in the figure. Five raingauge stations, A, B, C, D and E are located at the corners of the catchment. Rainfall recorded by these stations in mm during a particular storm are shown within the parenthesis. Draw the Thiessen polygon and find the mean precipitation over the catchment.



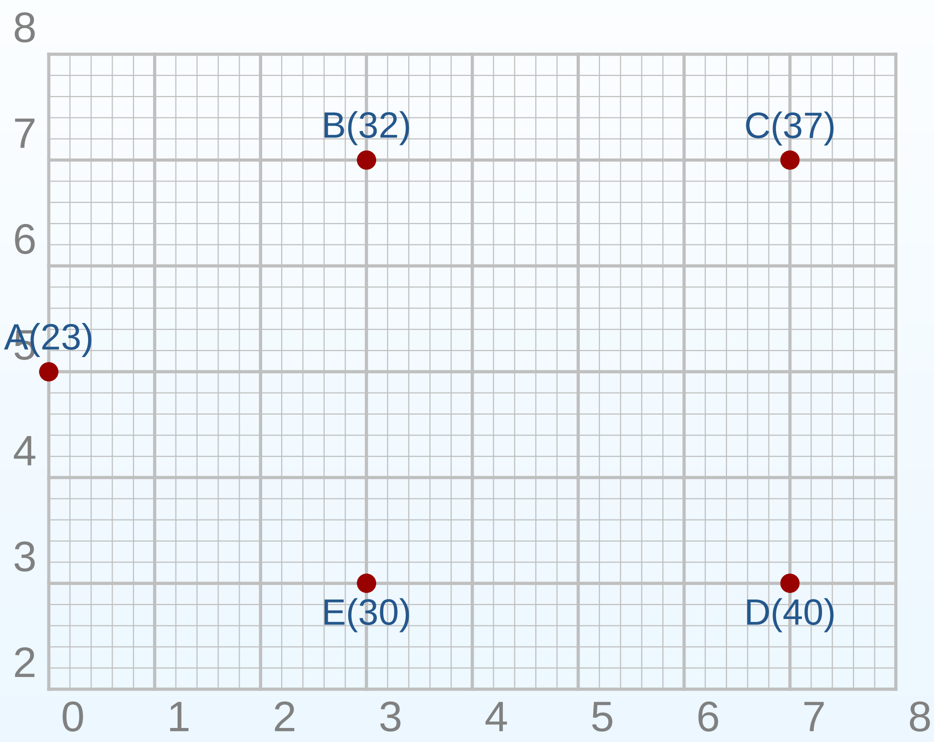
Solution



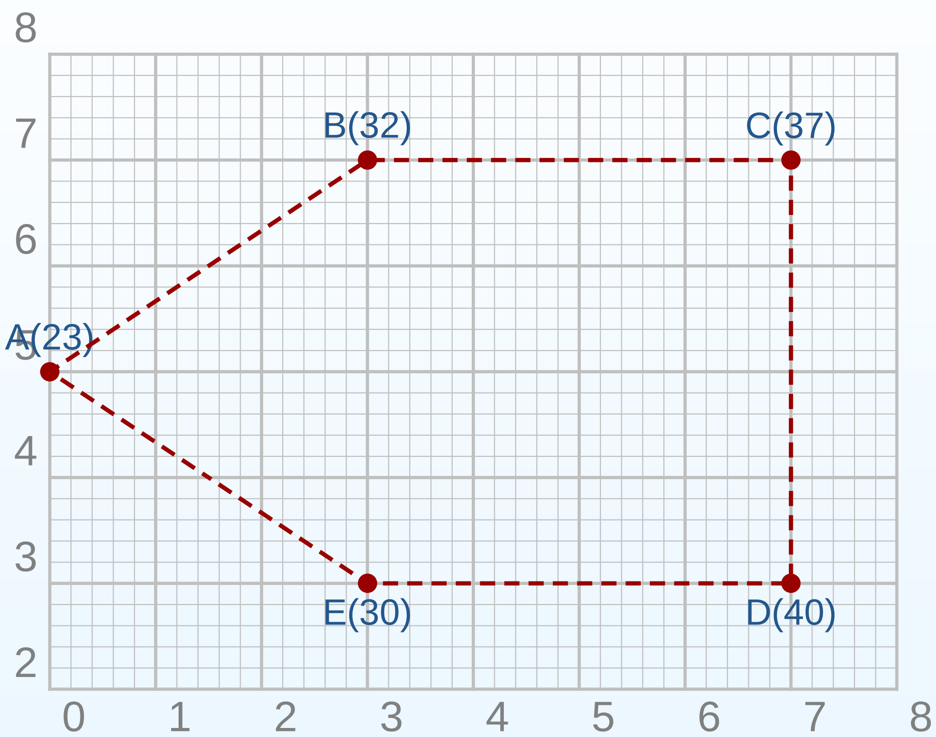
Solution



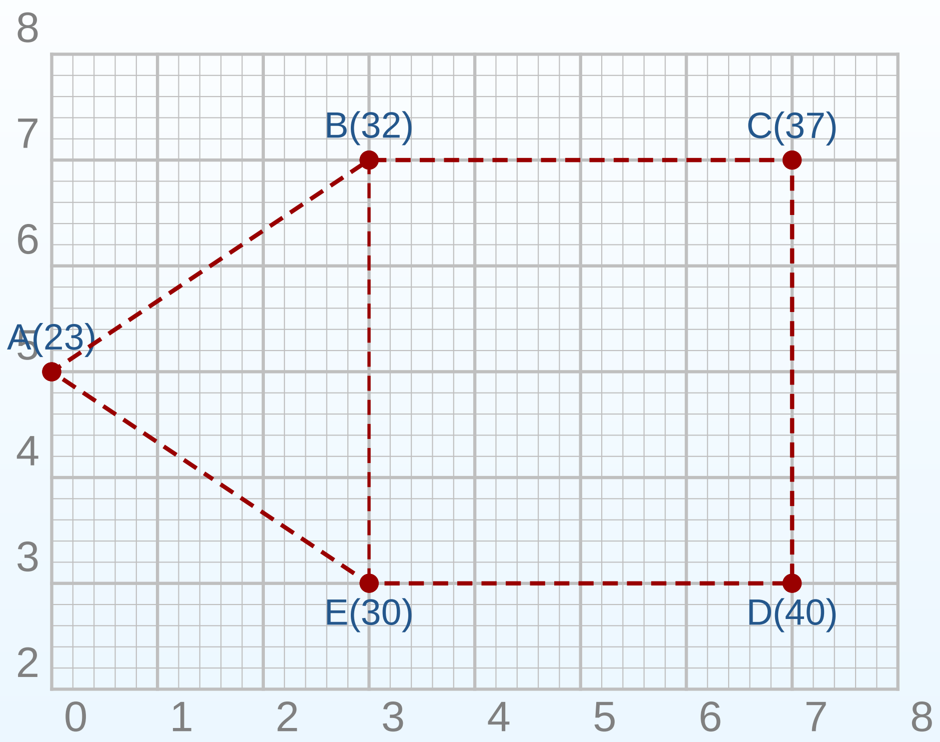
Solution



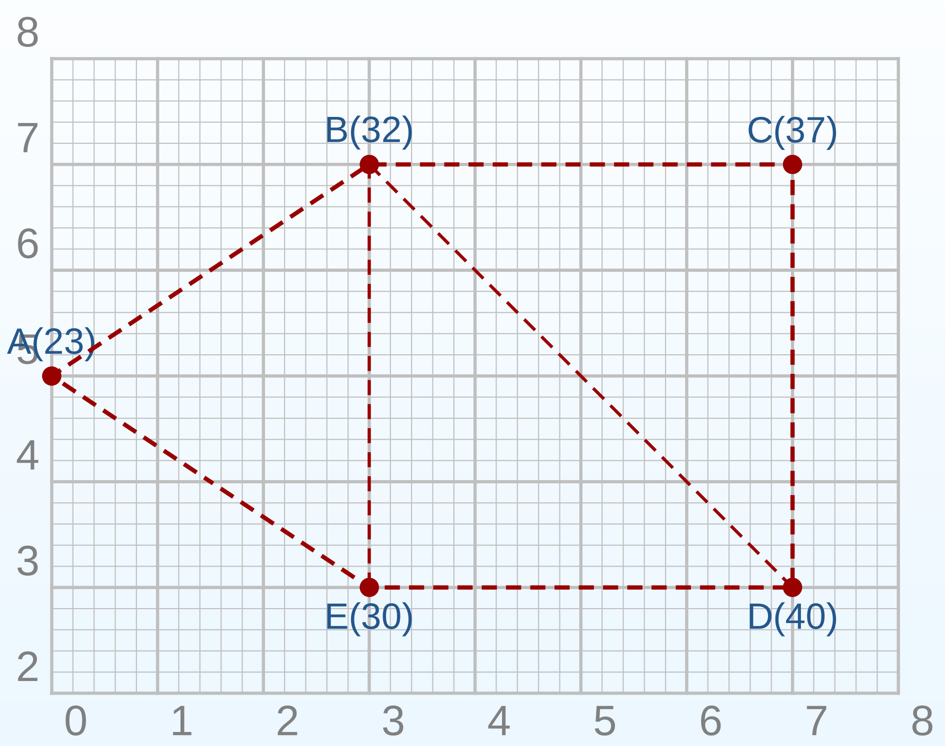
Solution



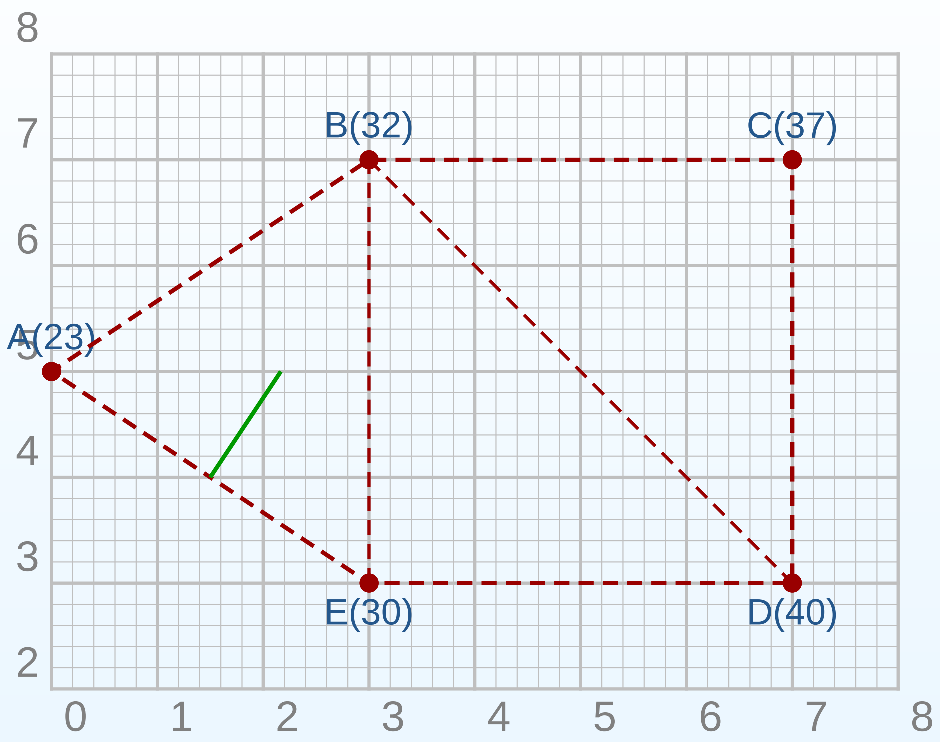
Solution



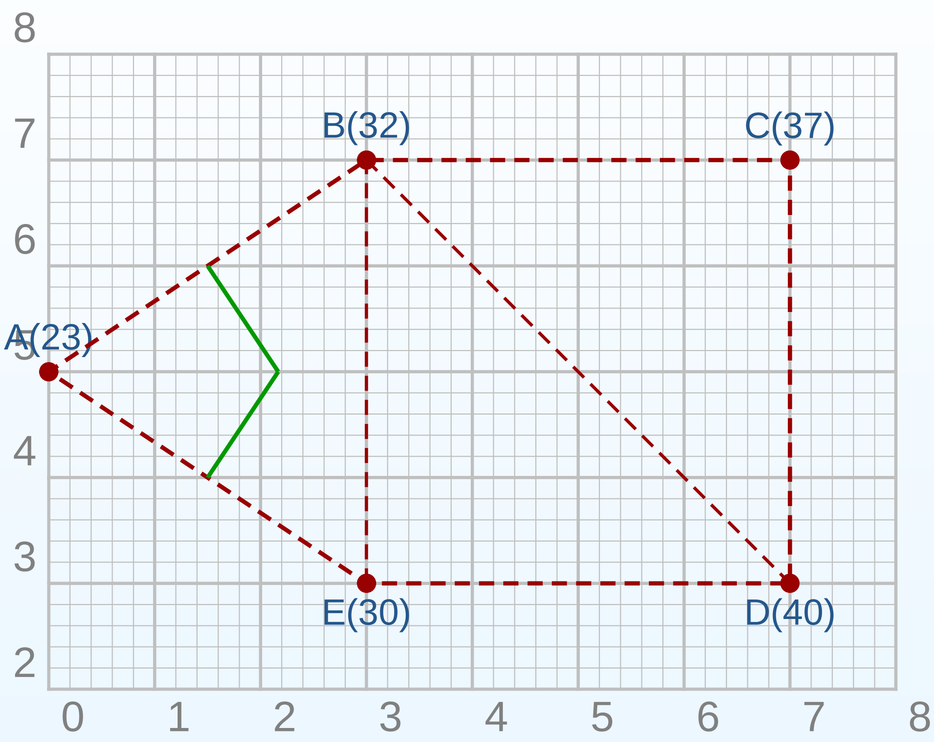
Solution



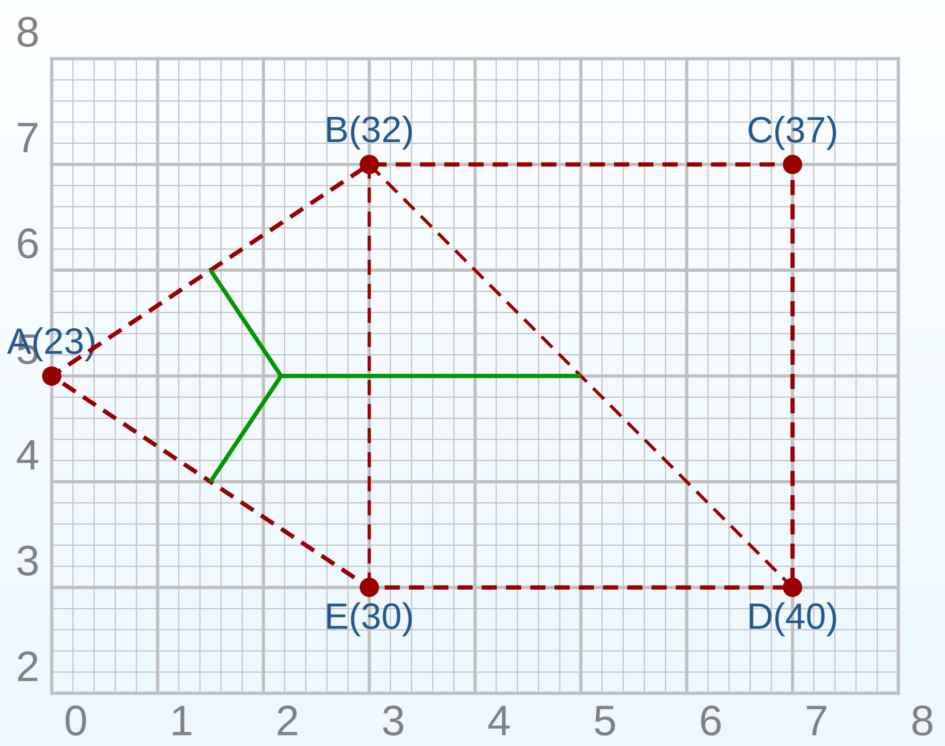
Solution



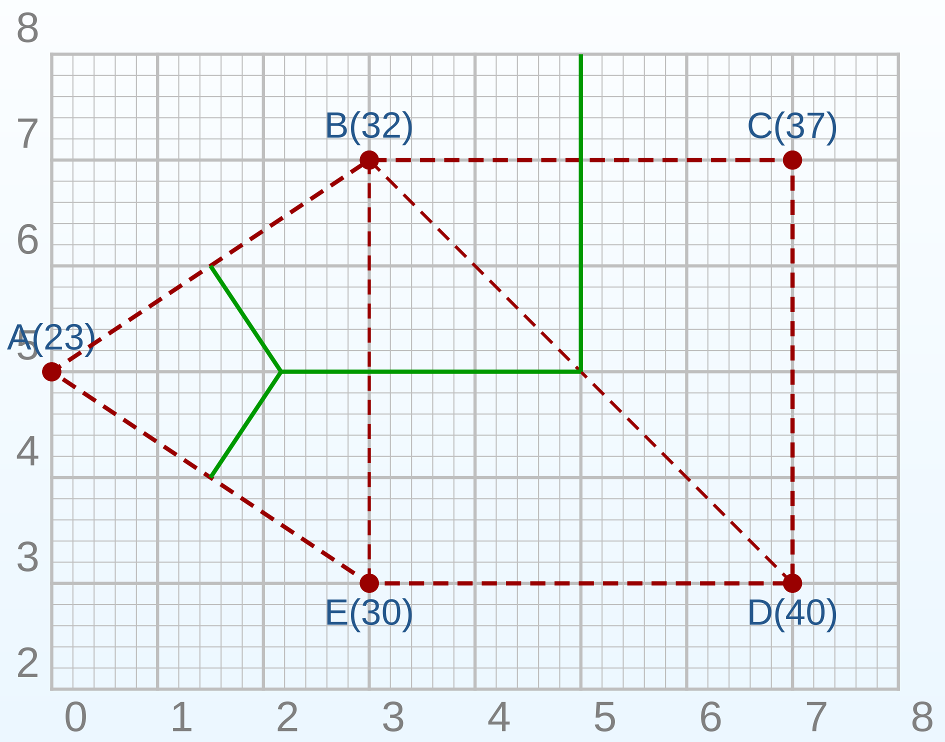
Solution



Solution



Solution



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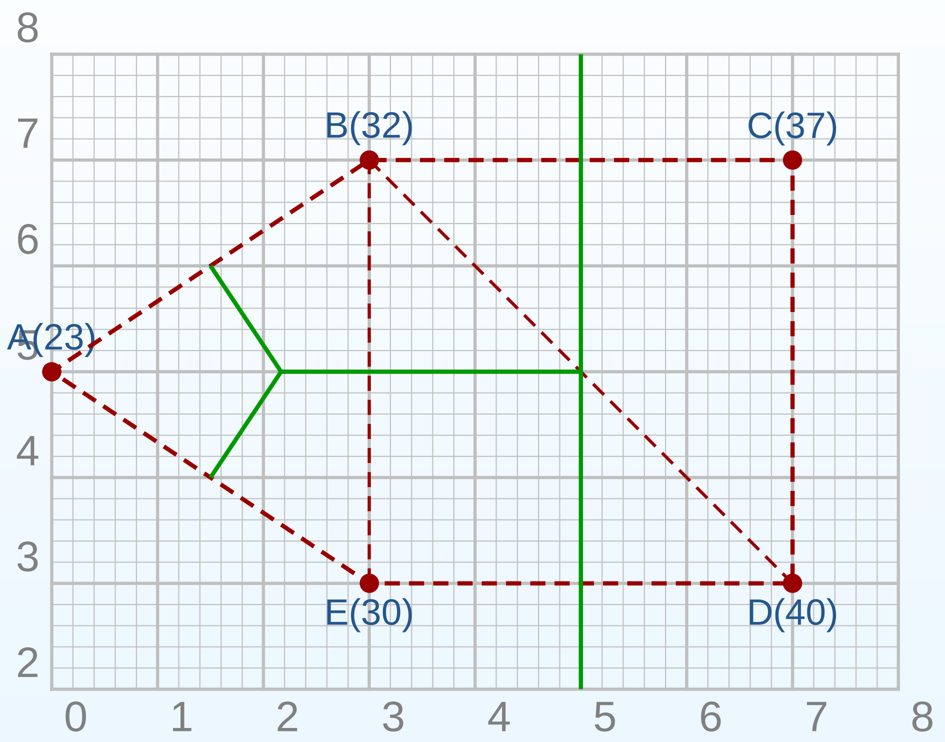

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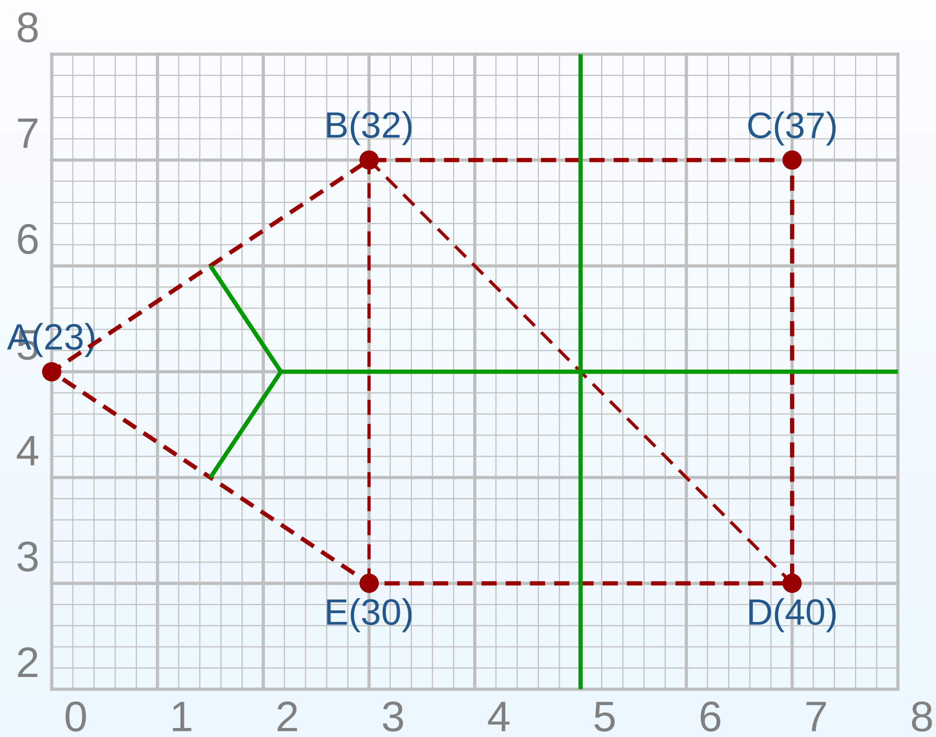
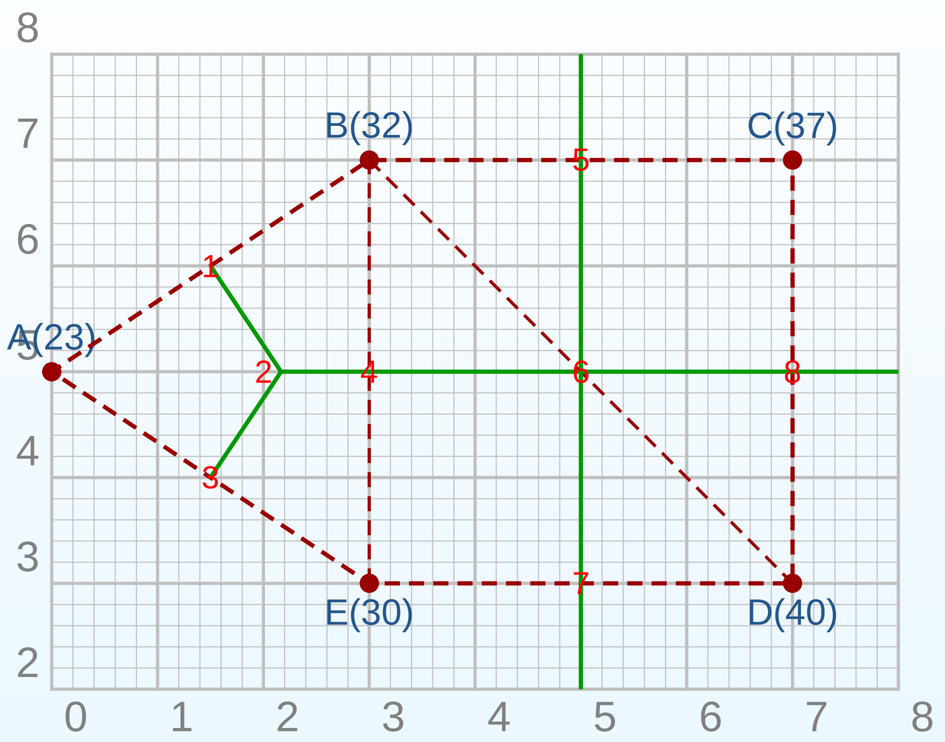
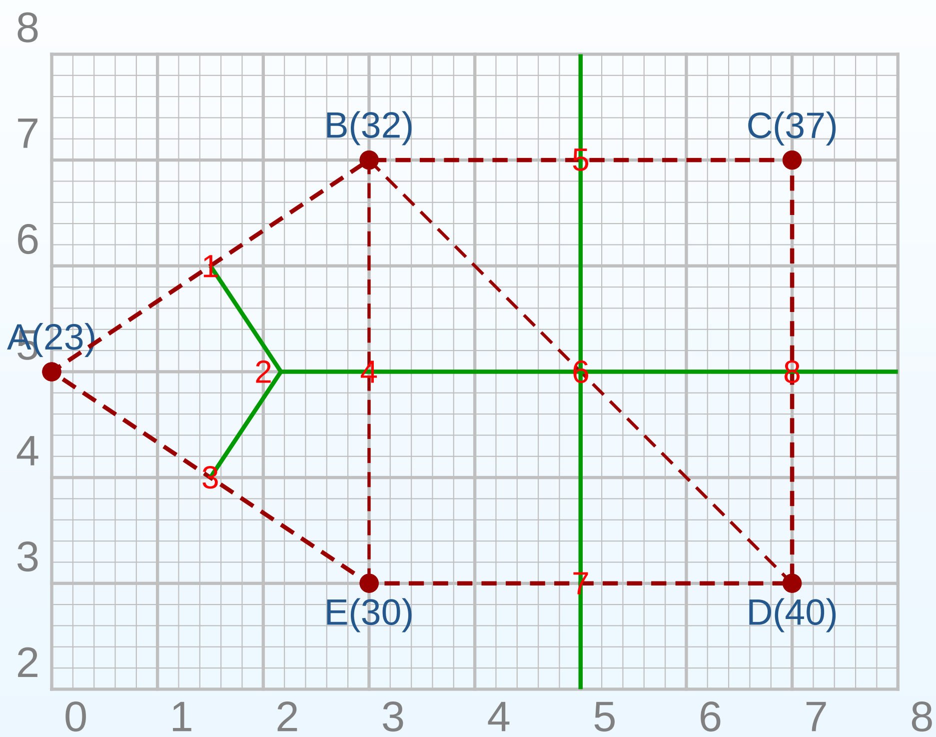


Solution

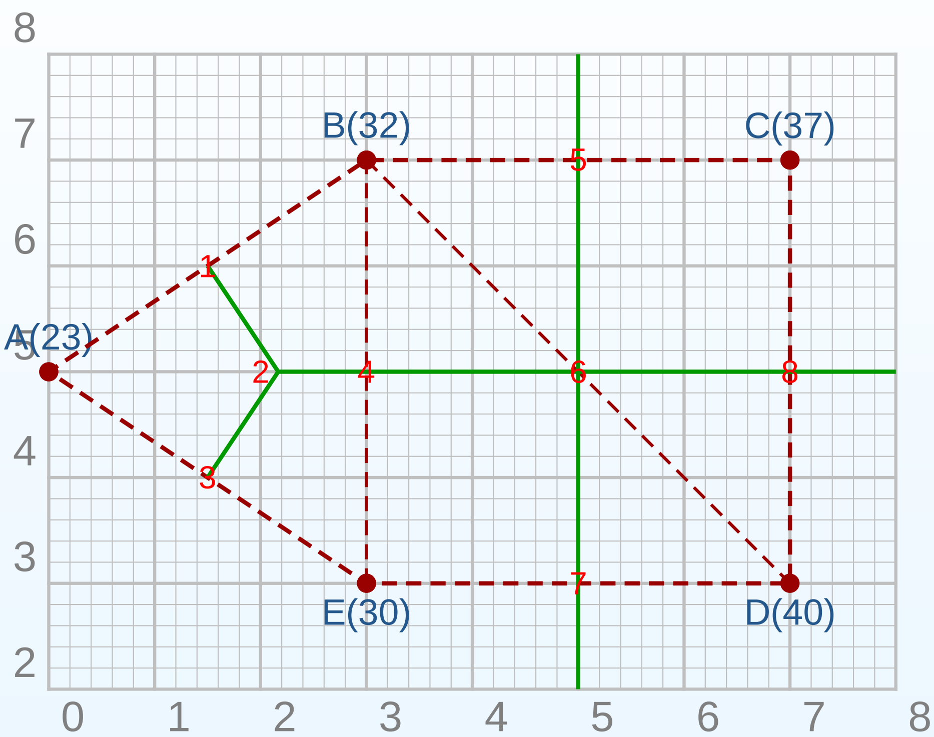


Solution



Raingauge	Rainfall (P_i)	Polygon	Area (A_i)	$P_i \times A_i$
A	23	1-2-3-A-1	13.542	311.466
B	32	1-2-4-6-5-B-1	36.979	1183.328
C	37	5-6-8-C-5	25	925
D	40	8-6-7-D-8	25	1000
E	30	3-2-4-6-7-E-3	36.979	1109.37
Total			137.5	4529.164

Solution



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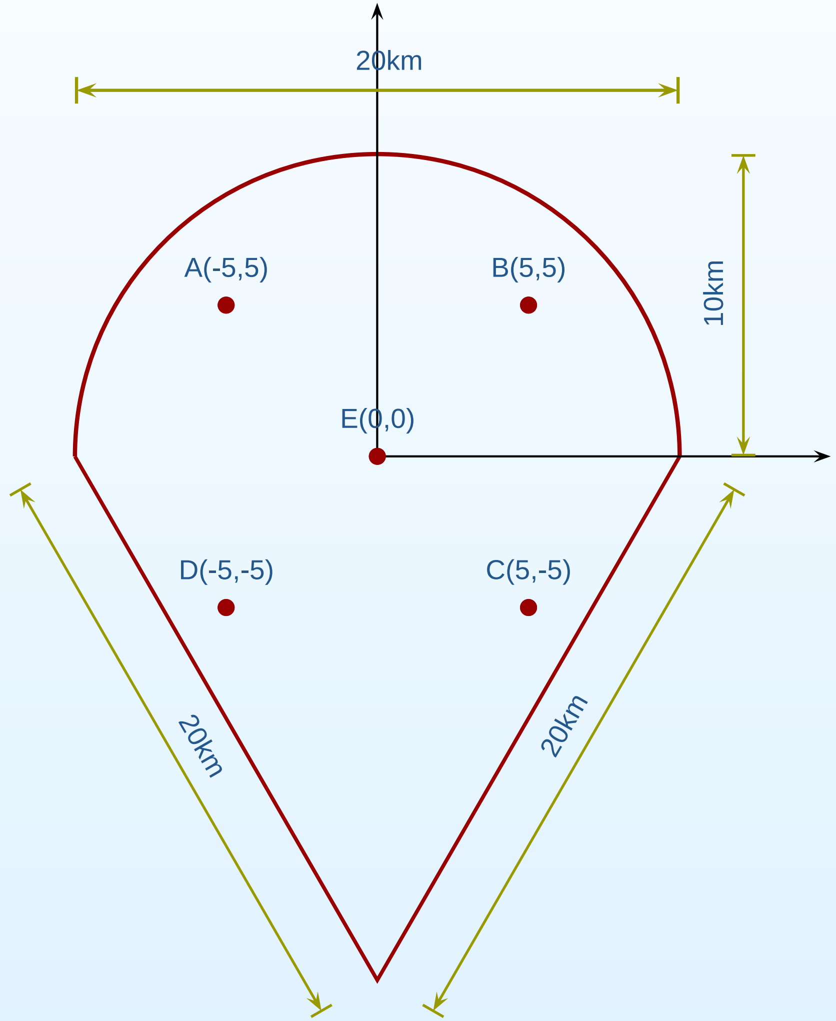
D	40	8-6-7-D-8	25	1000
E	30	3-2-4-6-7-E-3	36.979	1109.37
Total			137.5	4529.164

$$\bar{P} = 4529.164/137.5 = 32.94mm$$

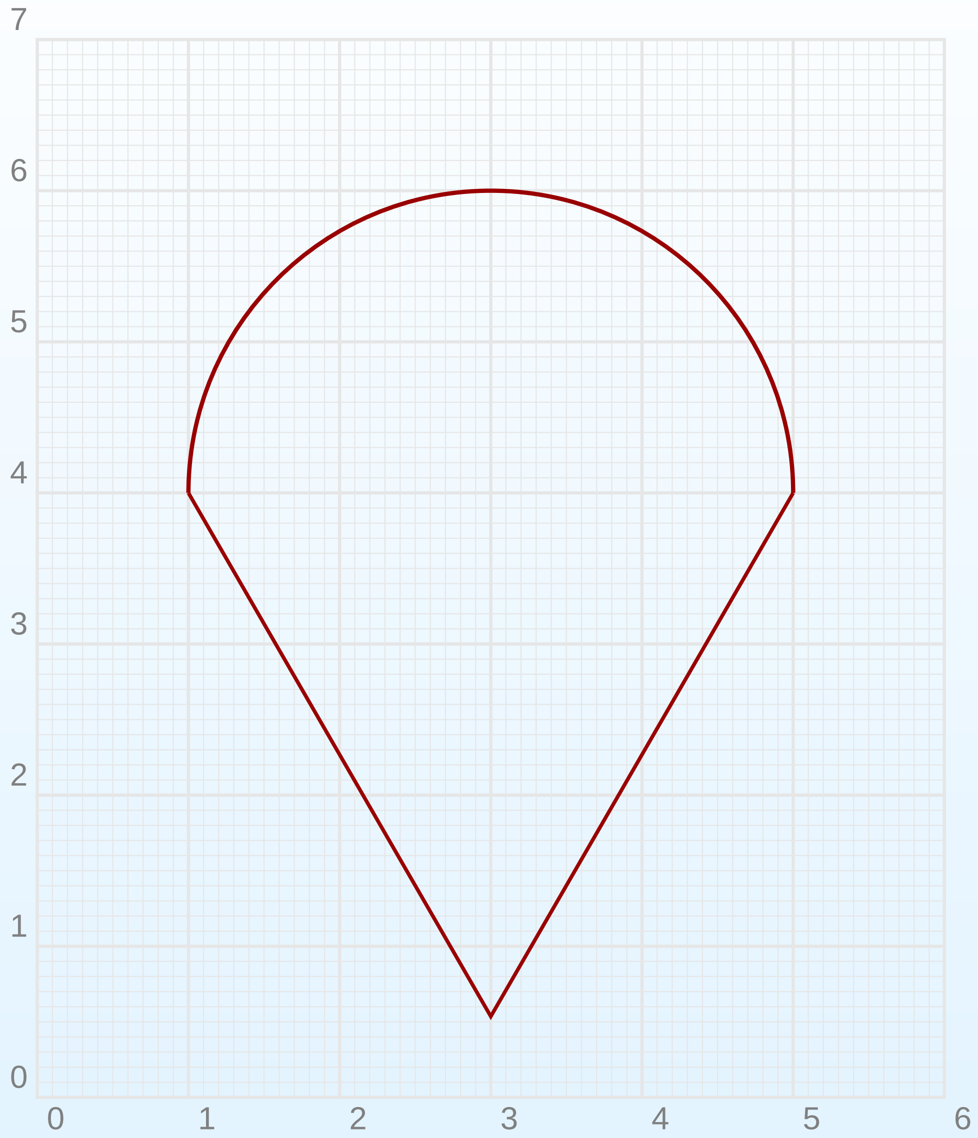
Example3

A catchment area is approximated by a semi-circle on top of an equilateral traingle of sides 20km, as shown in the figure. There are five raingauge stations A, B, C, D and E and the annual rainfall values obtained from these are 32cm, 43cm, 54cm, 28cm and 59cm respectively. Draw the thiessesn polygon and obtain the mean annual rainfall.

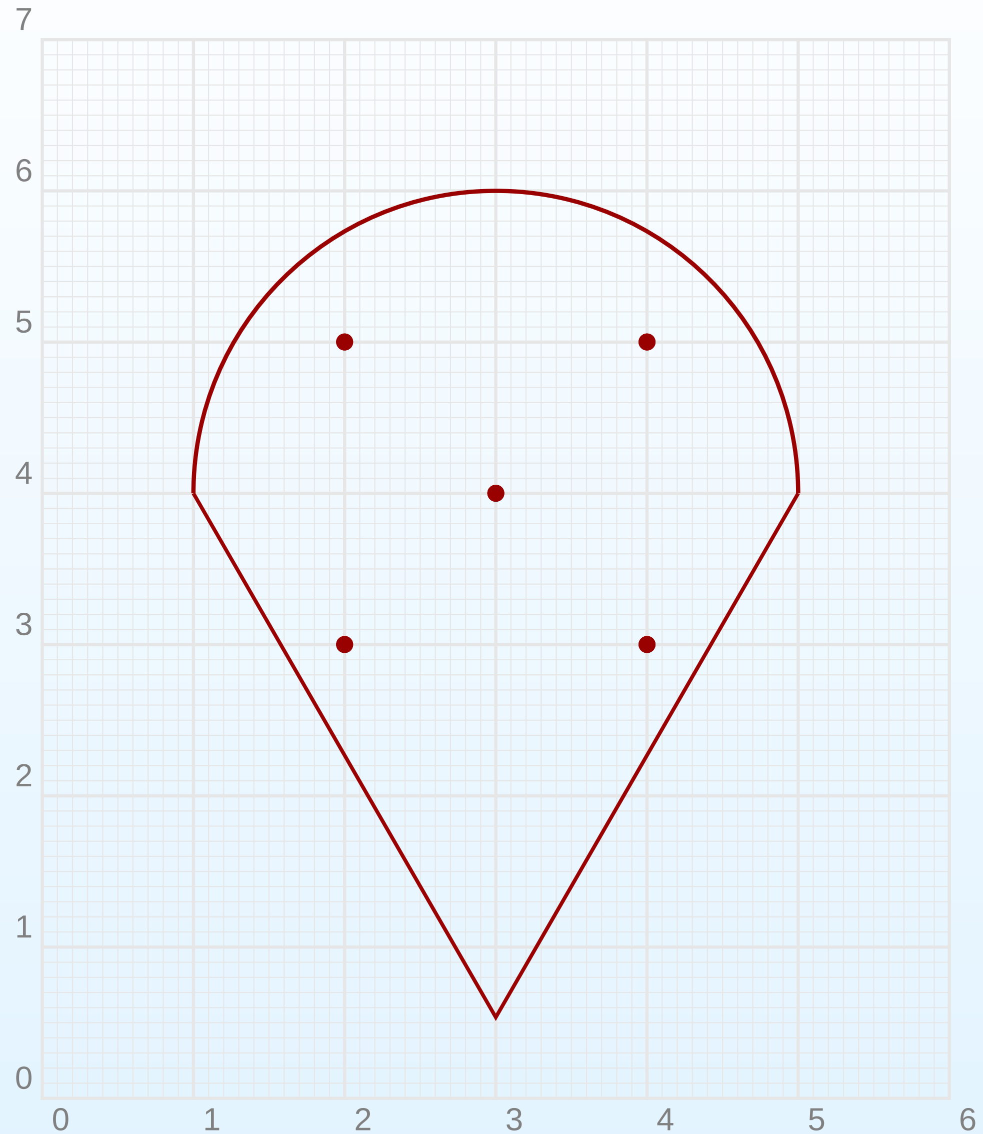


Solution

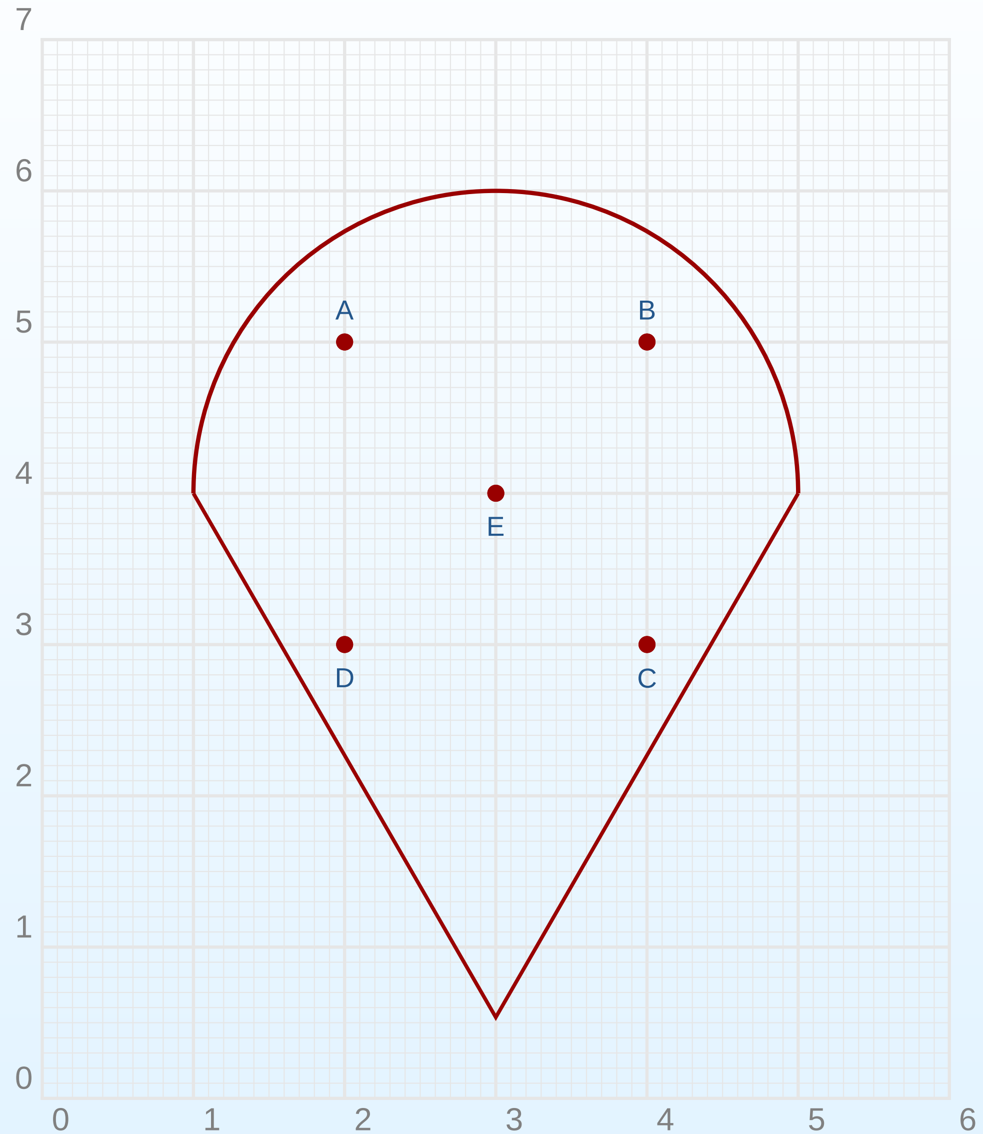
Solution



Solution



Solution



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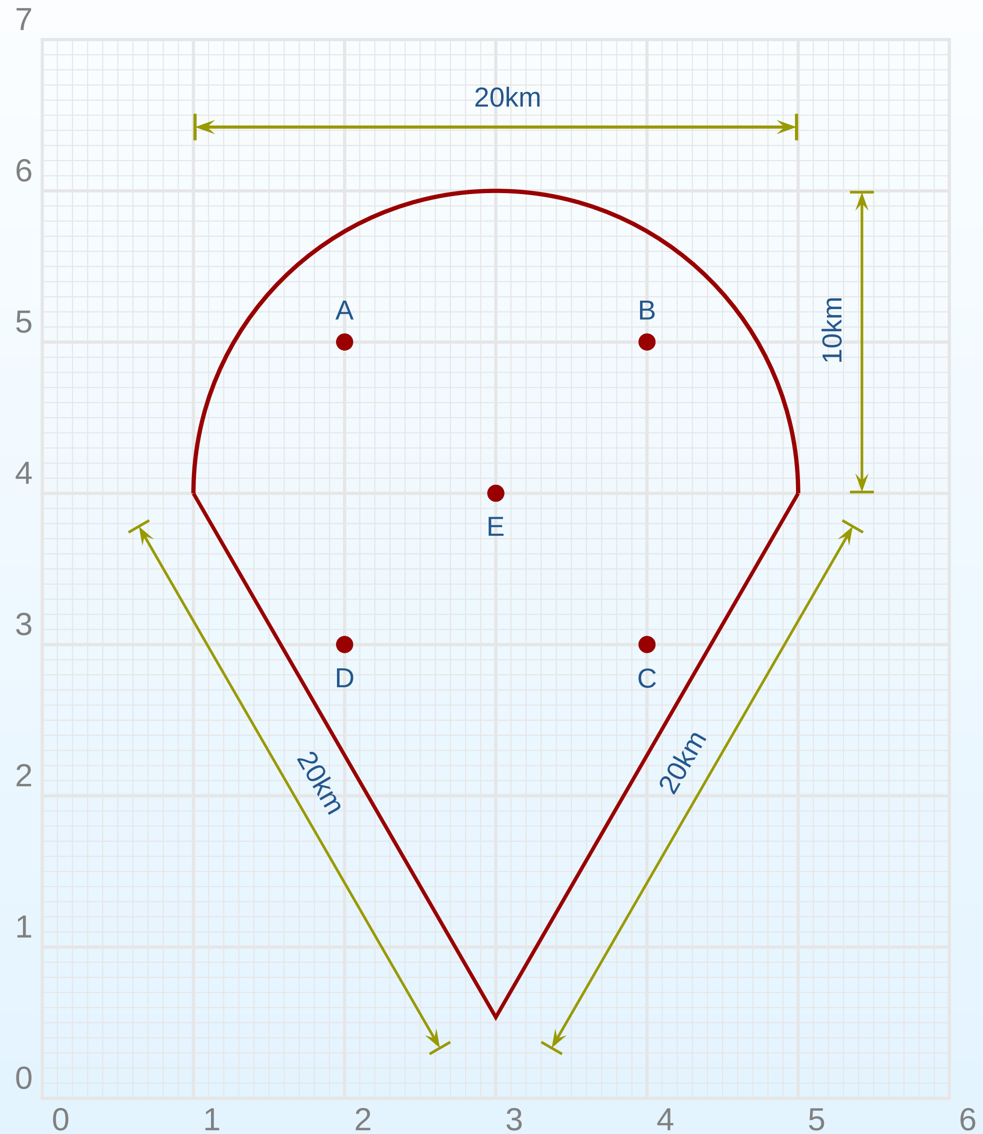

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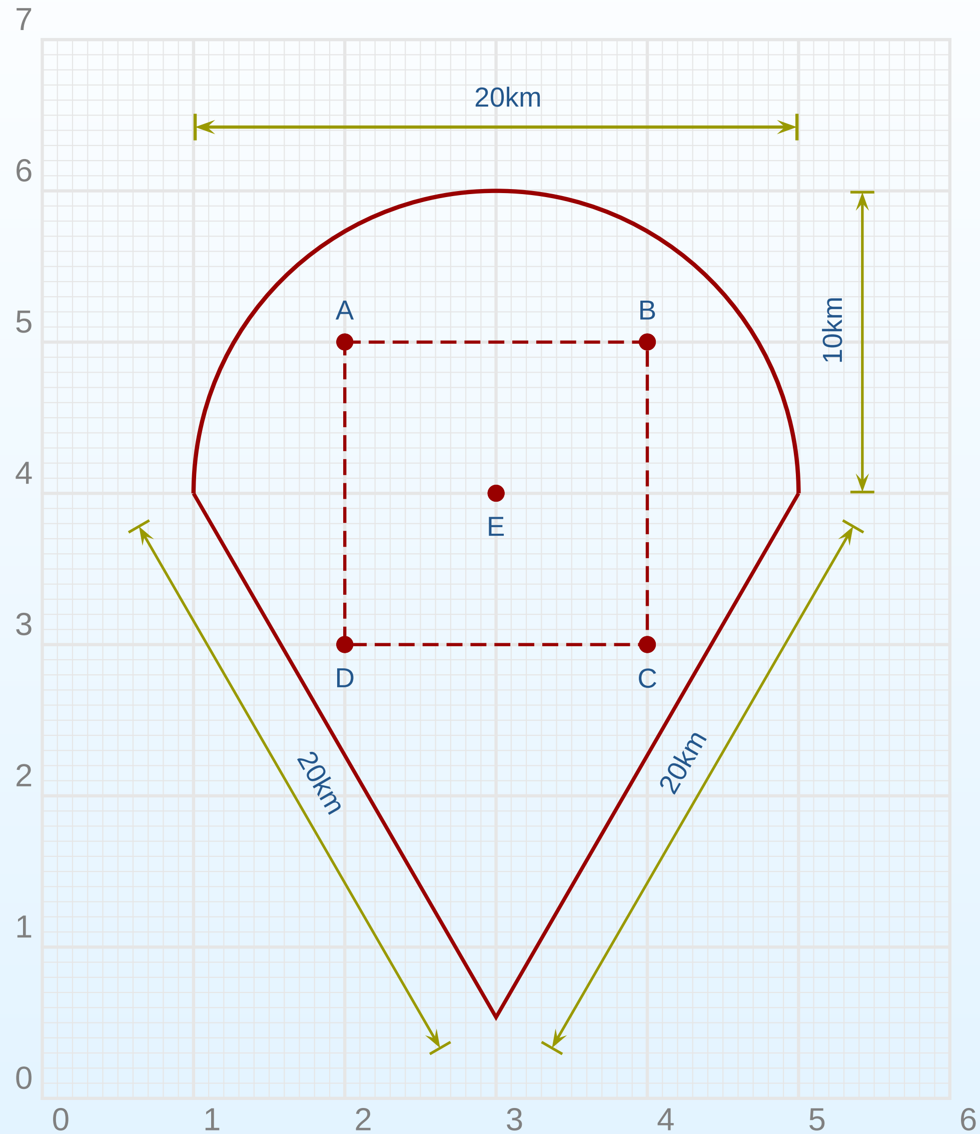

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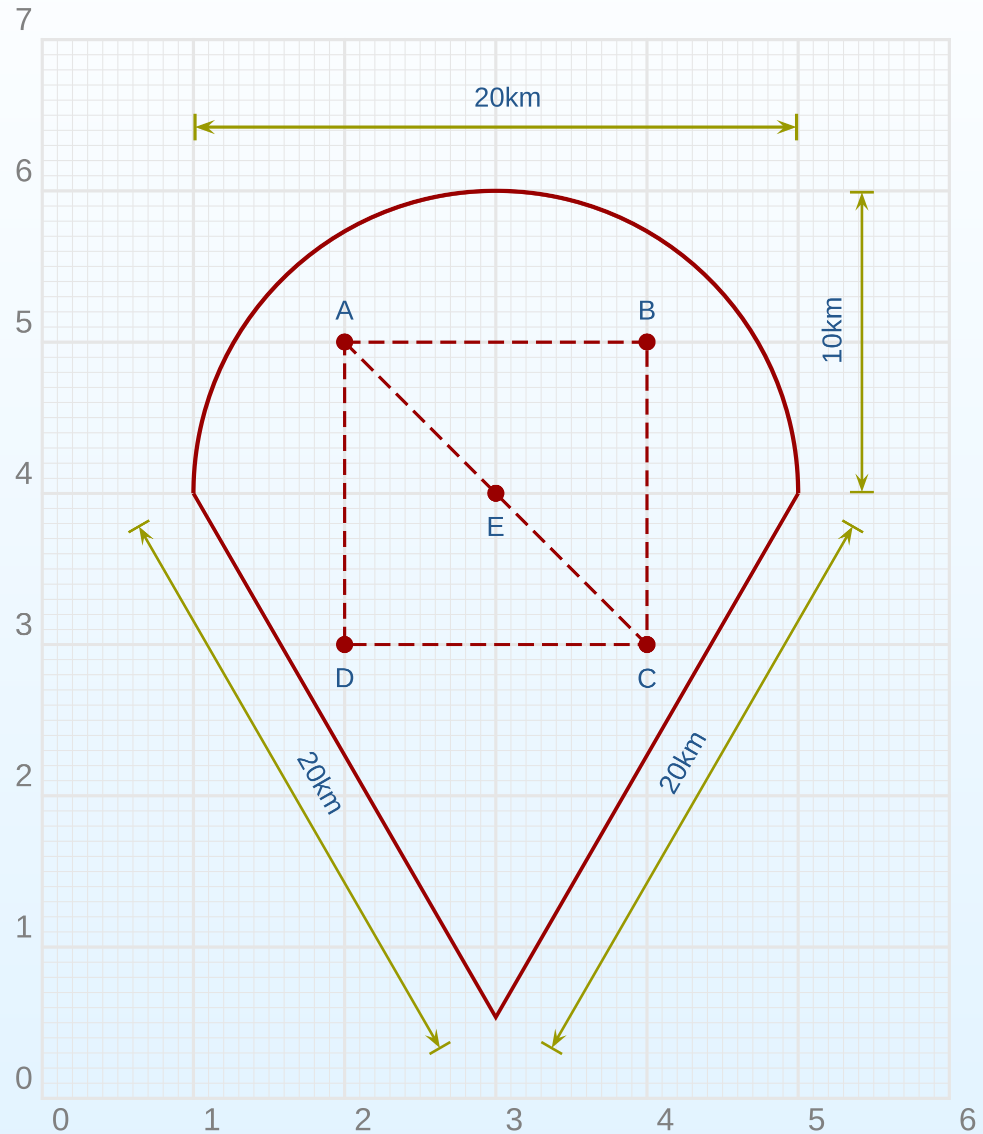

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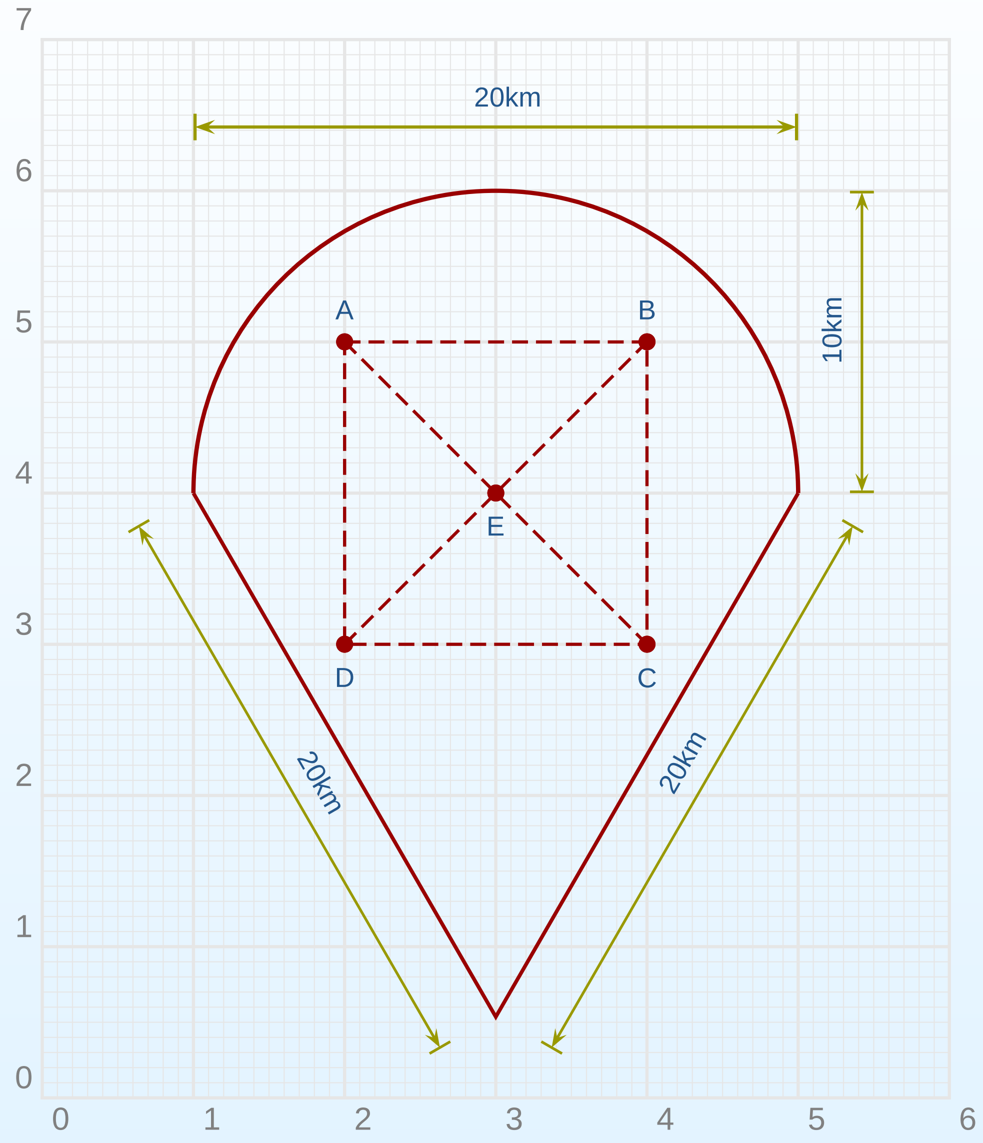
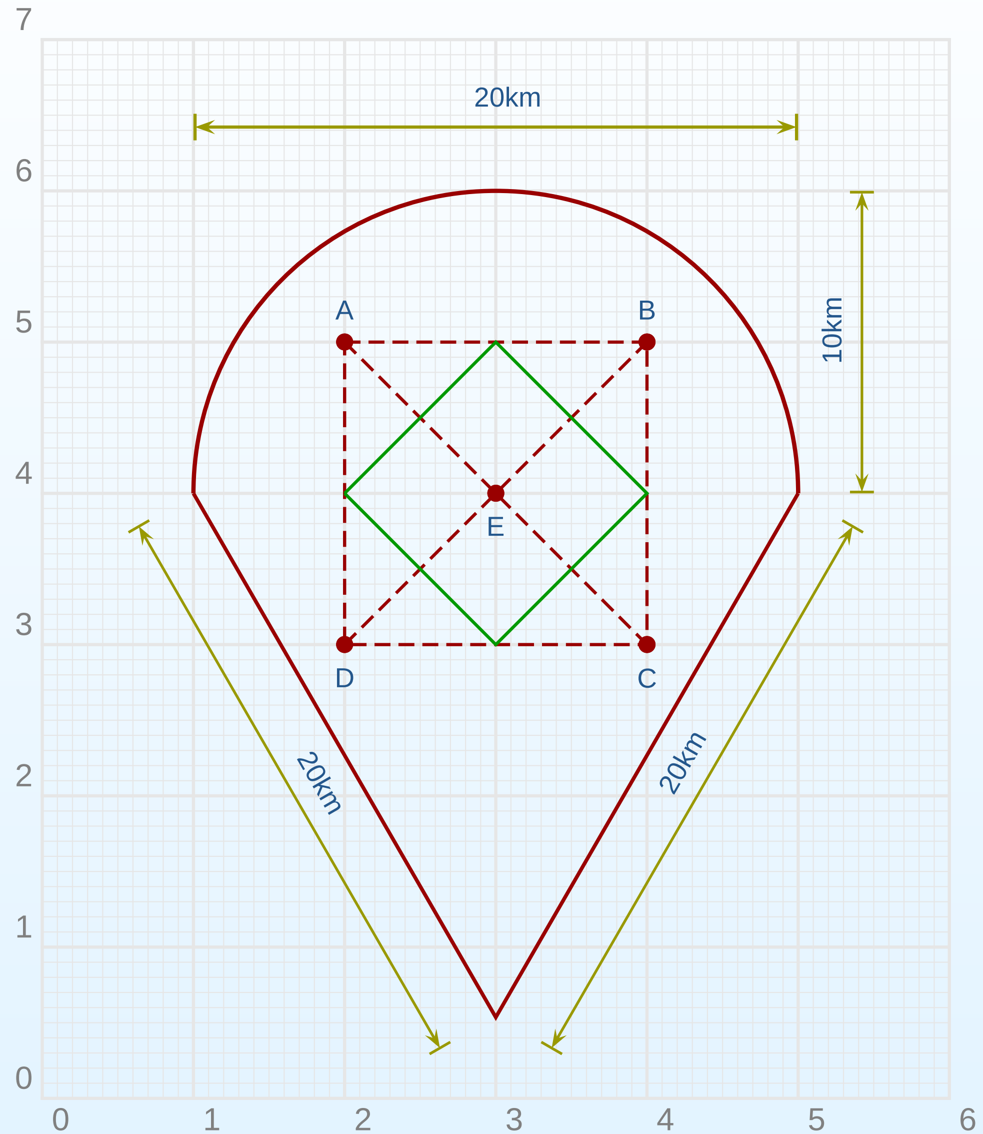


Solution



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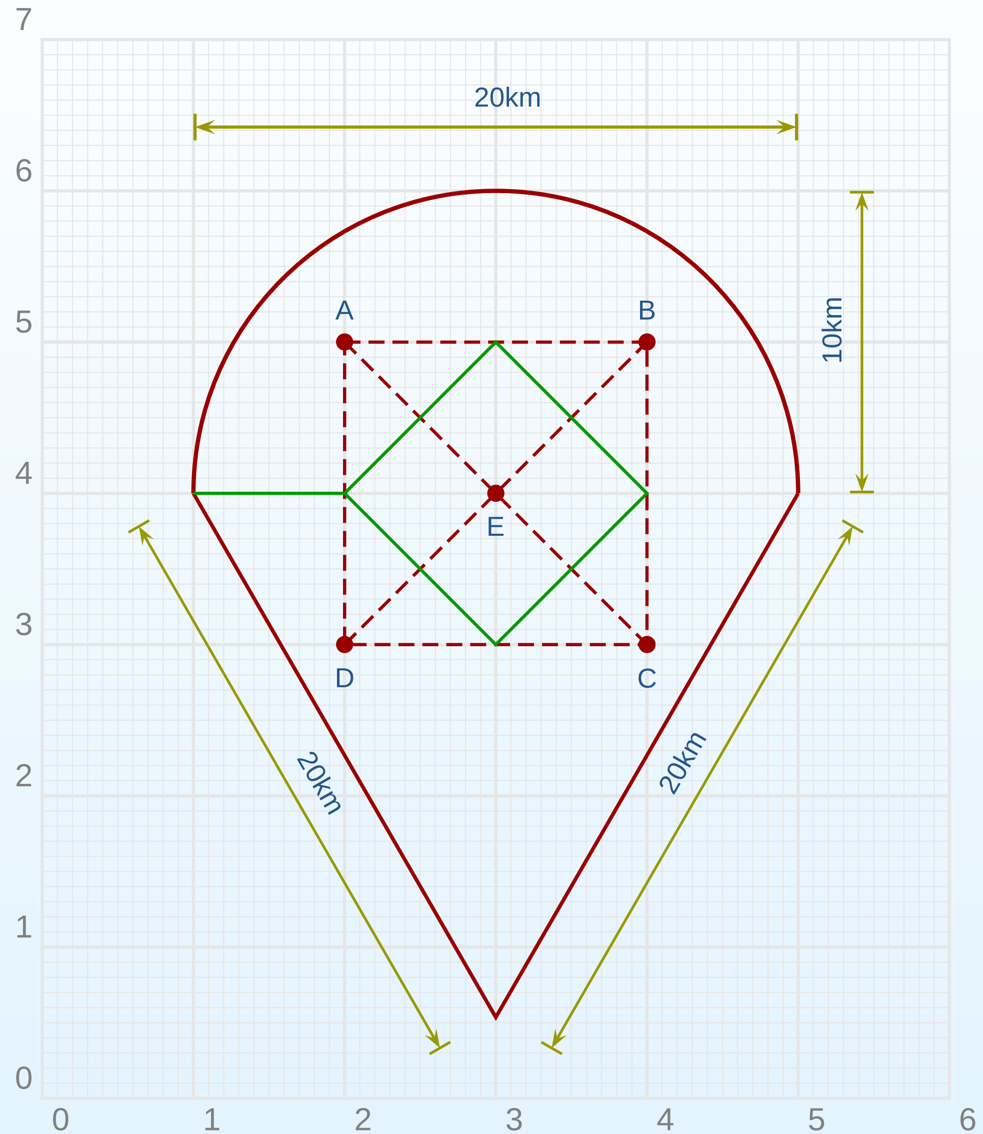

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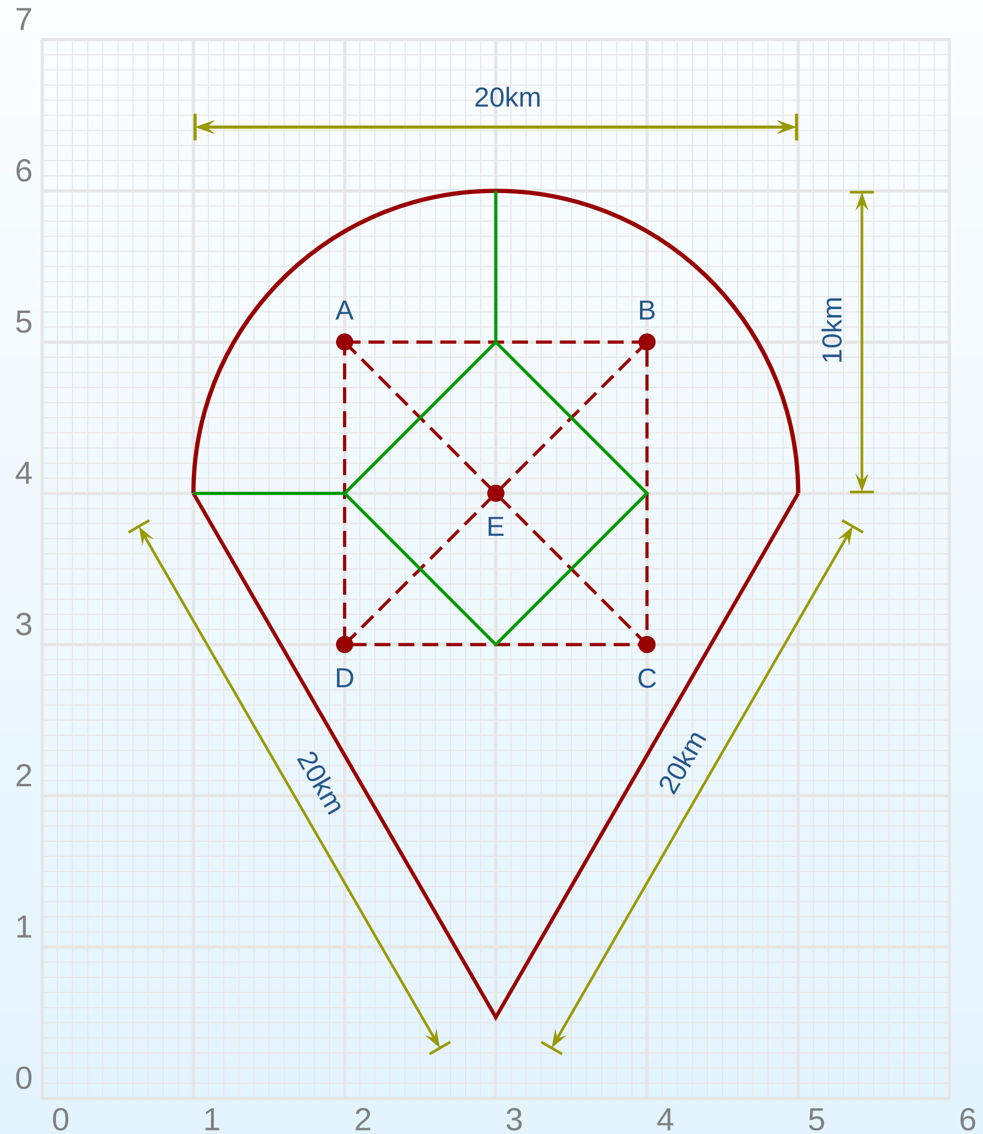

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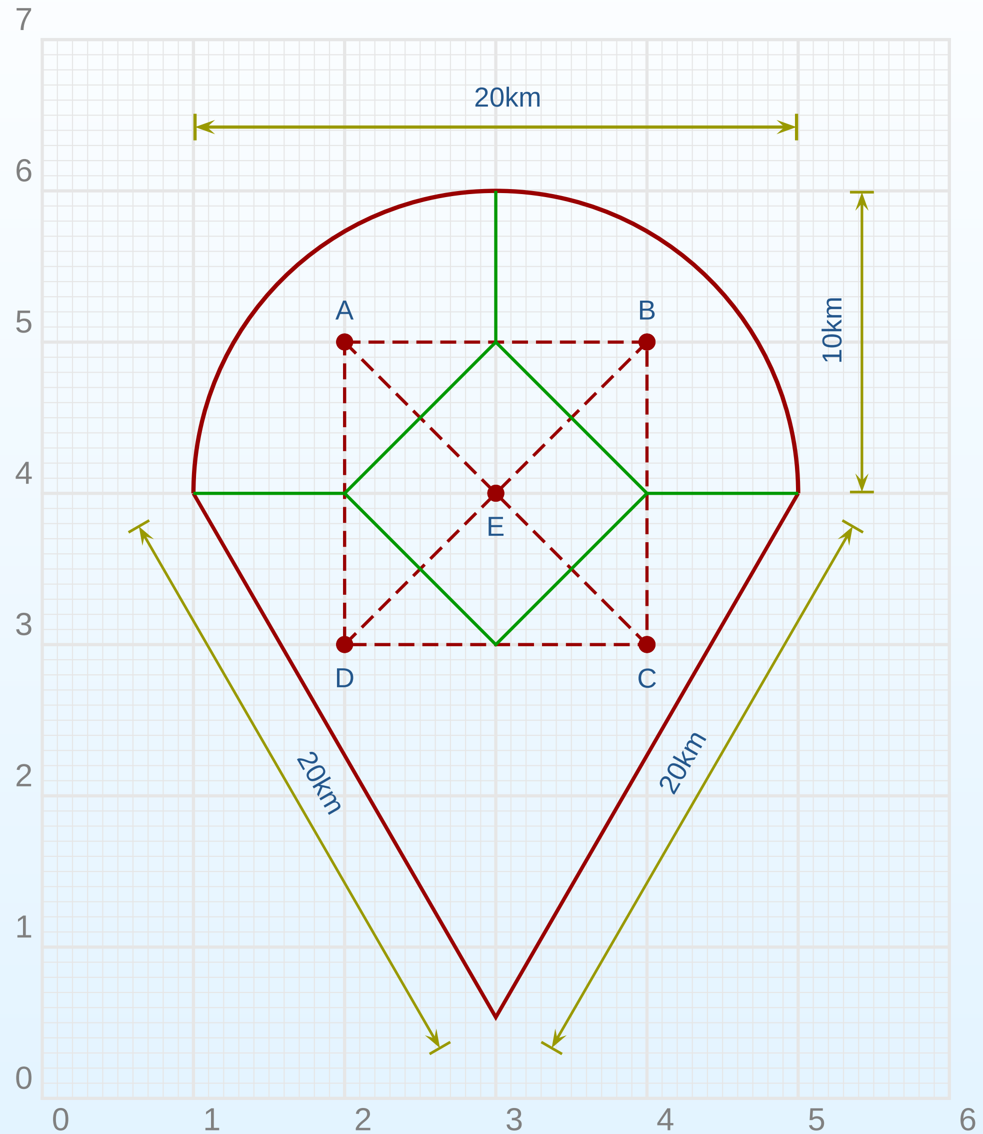

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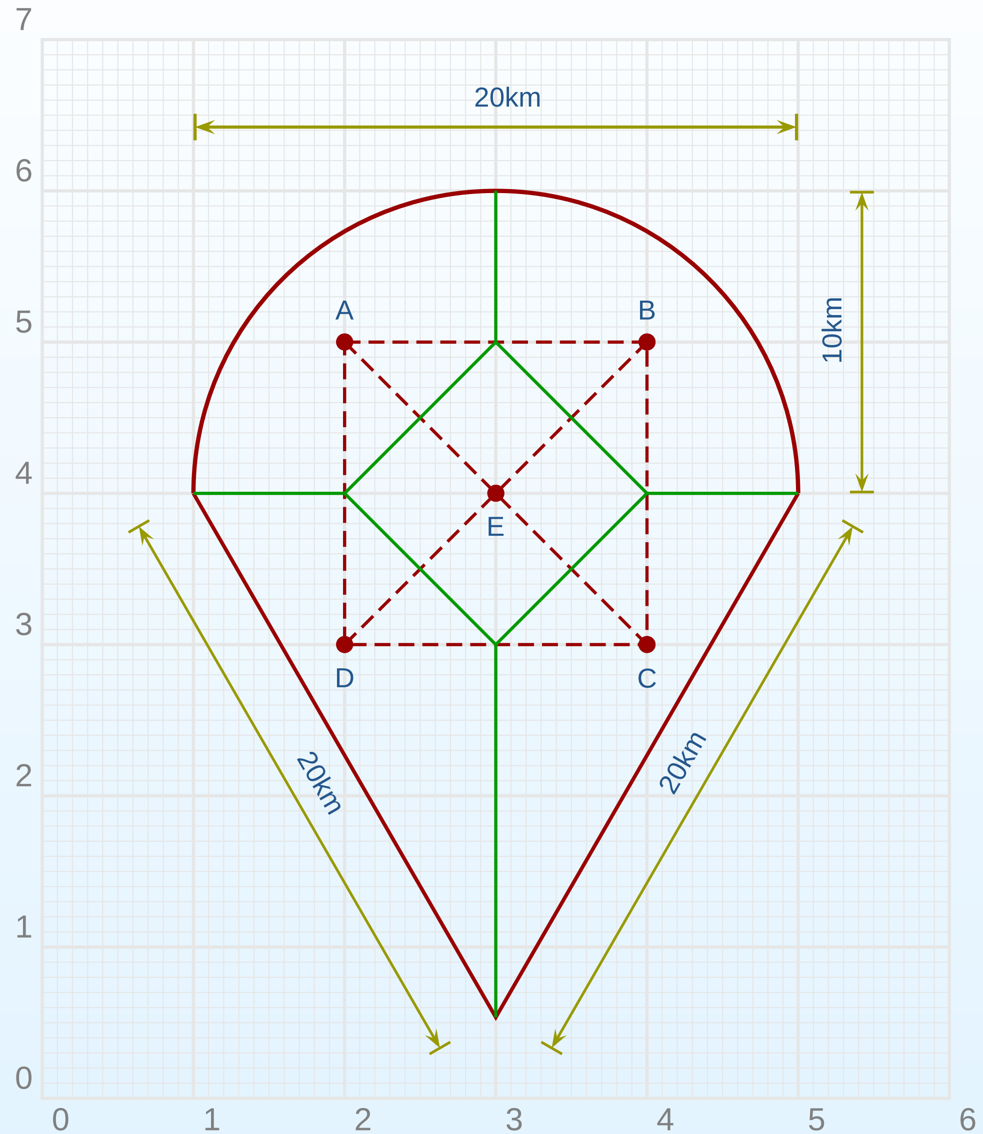

Solution (contd)

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Raingauge	P_i	A_i	P_iA_i
A	32	66.04	2113.28
B	43	66.04	2839.72
C	54	74.10	4001.4
D	28	74.10	2074.8
E	59	50	2950
Total		330.28	13979.2

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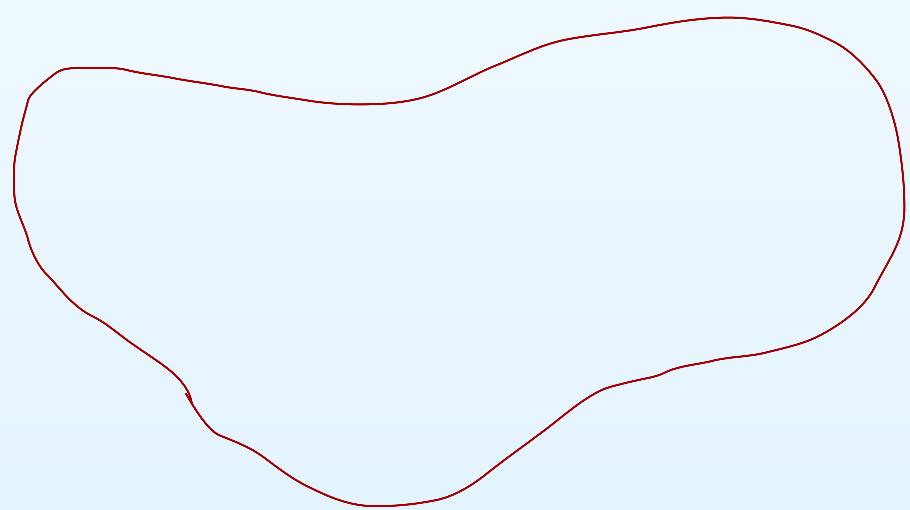
Then, $\bar{P} = 13979.2/330.28 = 42.33cm$

Isohyetal Method

Isohyet : An *isohyet* is a line joining points of equal rainfall magnitude.

Steps involved in the isohyetal method to determine the average rainfall:

1. The catchment area is drawn to scale and the raingauge stations are marked.
2. Rainfall values recorded by the stations are marked at the appropriate stations. Neighbouring stations outside the catchment are also considered.
3. Isohyets are drawn considering the rainfall values at the stations and using suitable interpolation scheme.
4. Area between two adjacent isohyets are measured using a planimeter. If the isohyets go out the catchment, the catchment boundary is used as the bounding line.



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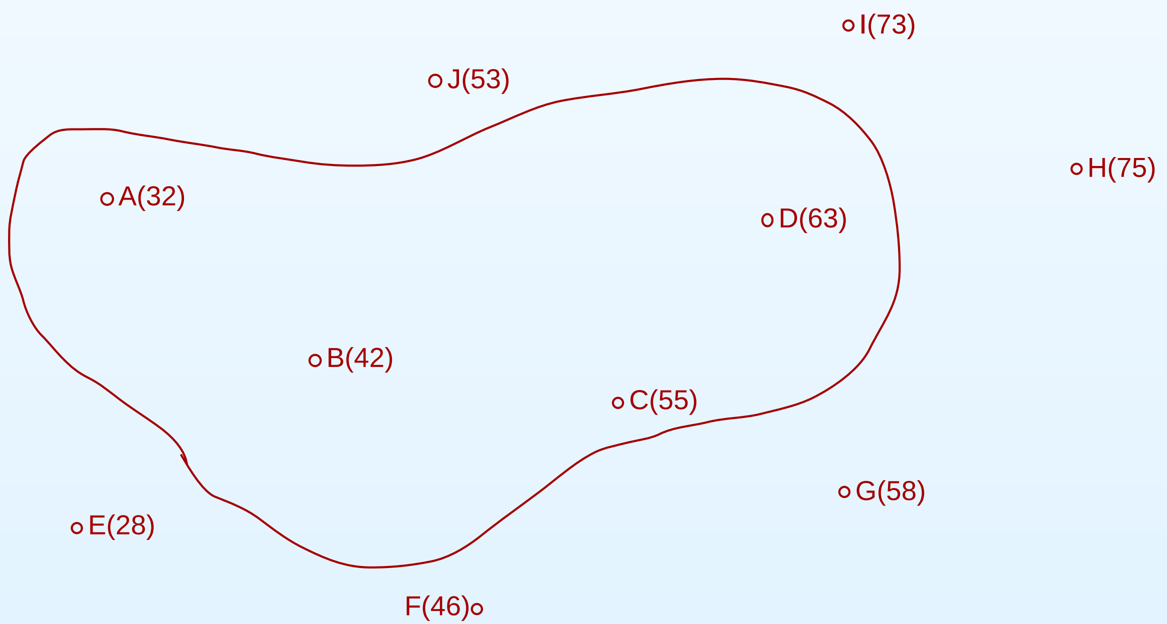

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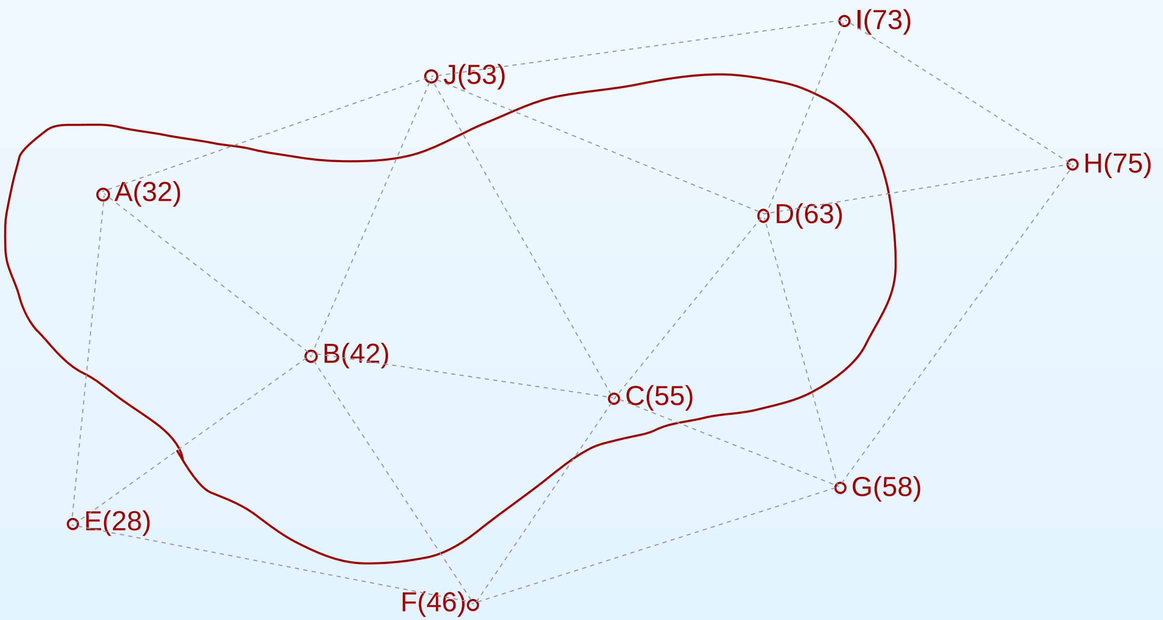

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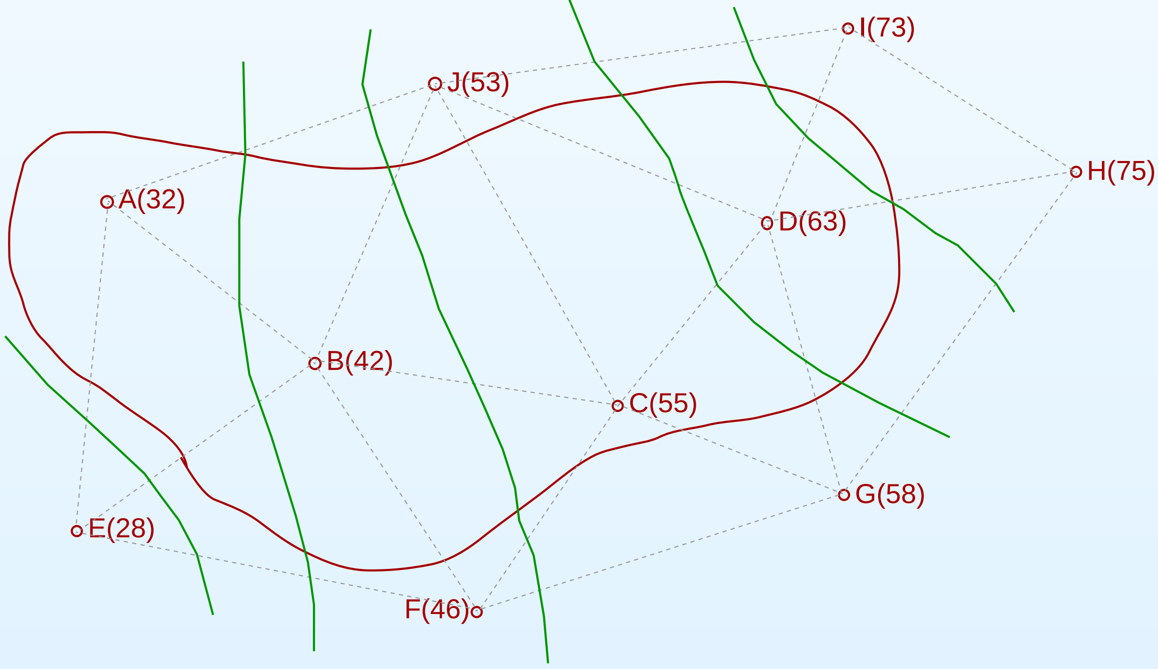

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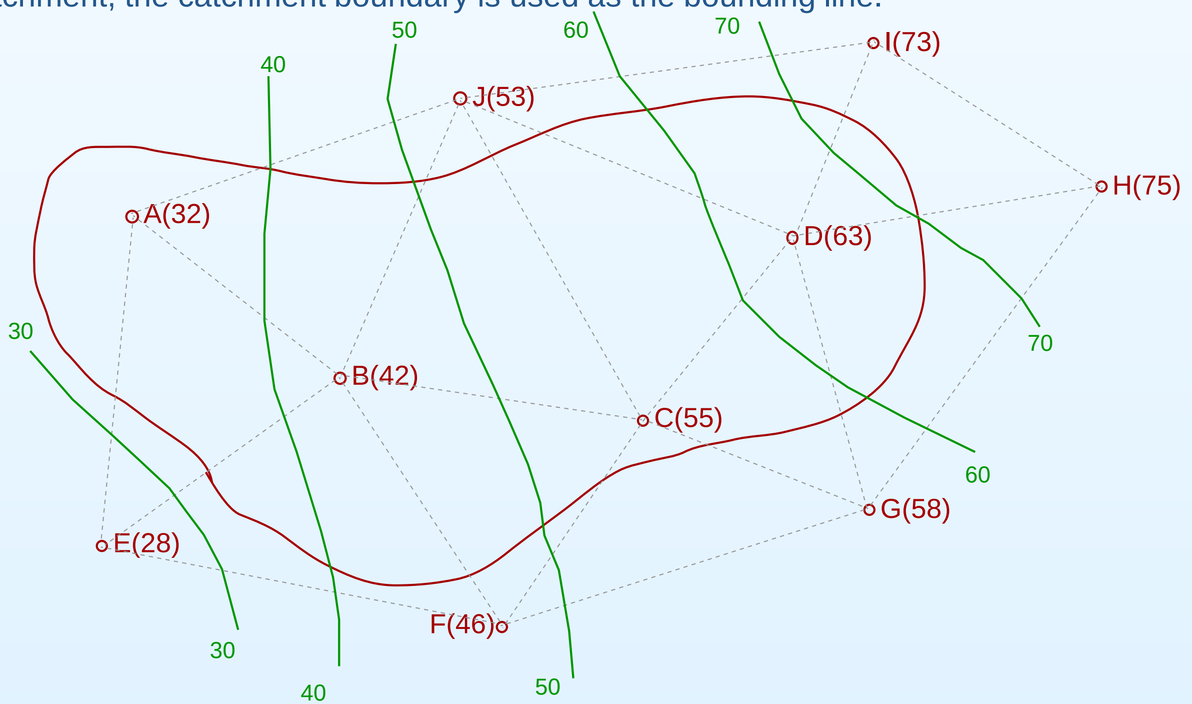

Isohyetal Method(contd.)

If $P_1, P_2, \ldots, P_n$ are the values of isohyets and if $A_1, A_2, \ldots, A_n - 1$ are the inter-isohyet area respectively, then the mean precipitation over the catchment is given by

$$\bar{P} = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + \ldots + A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A}$$

or,

$$\bar{P} = \frac{1}{A}\sum_{i=1}^{n-1} A_i \frac{(P_i + P_{i+1})}{2}$$

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Example

The isohyets due to a storm in a catchment were drawn and the area of the catchment bounded by isohyets were tabulated as below. Estimate the mean precipitation due to the storm.

Isohyets (cm)	Area (km^2)
14.0-12.0	30
12.0-10.0	140
10.0-8.0	80
8.0-6.0	180
6.0-4.0	20

Solution

Isohyets	Average Value of P $(P_i + P_{i+1})/2$	Area (km^2) A_i	$A_i P_i$
Col.1	Col. 2	Col. 3	Col. 2 x Col 3
14.0-12.0	13.0	30.0	390.0
12.0-10.0	11.0	140.0	1540.0
10.0-8.0	9.0	80.0	720.0
8.0-6.0	7.0	180.0	1260.0
6.0-4.0	5.0	20.0	100.0
	Total	450.0	4010.0

Then, $\bar{P} = 4010.0/450.0 = 8.91cm$

Solution

Isohyets	Average Value of P $(P_i + P_{i+1})/2$	Area (km^2) A_i	$A_i P_i$
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8.0-6.0	7.0	180.0	1260.0
6.0-4.0	5.0	20.0	100.0
	Total	450.0	4010.0

Then, $\bar{P} = 4010.0/450.0 = 8.91cm$

Problem

For a drainage basin of 600 km^2 area, isohyets drawn for a storm gave the following data:

Isohyetals (cm)	15 - 12	12 - 9	9 - 6	6 - 3	3 - 1
Inter-isohyetal area (km^2)	92	128	120	175	85

Estimate the average depth of precipitation over the catchment.