Calculating potential of water harvesting from road catchments

Introduction

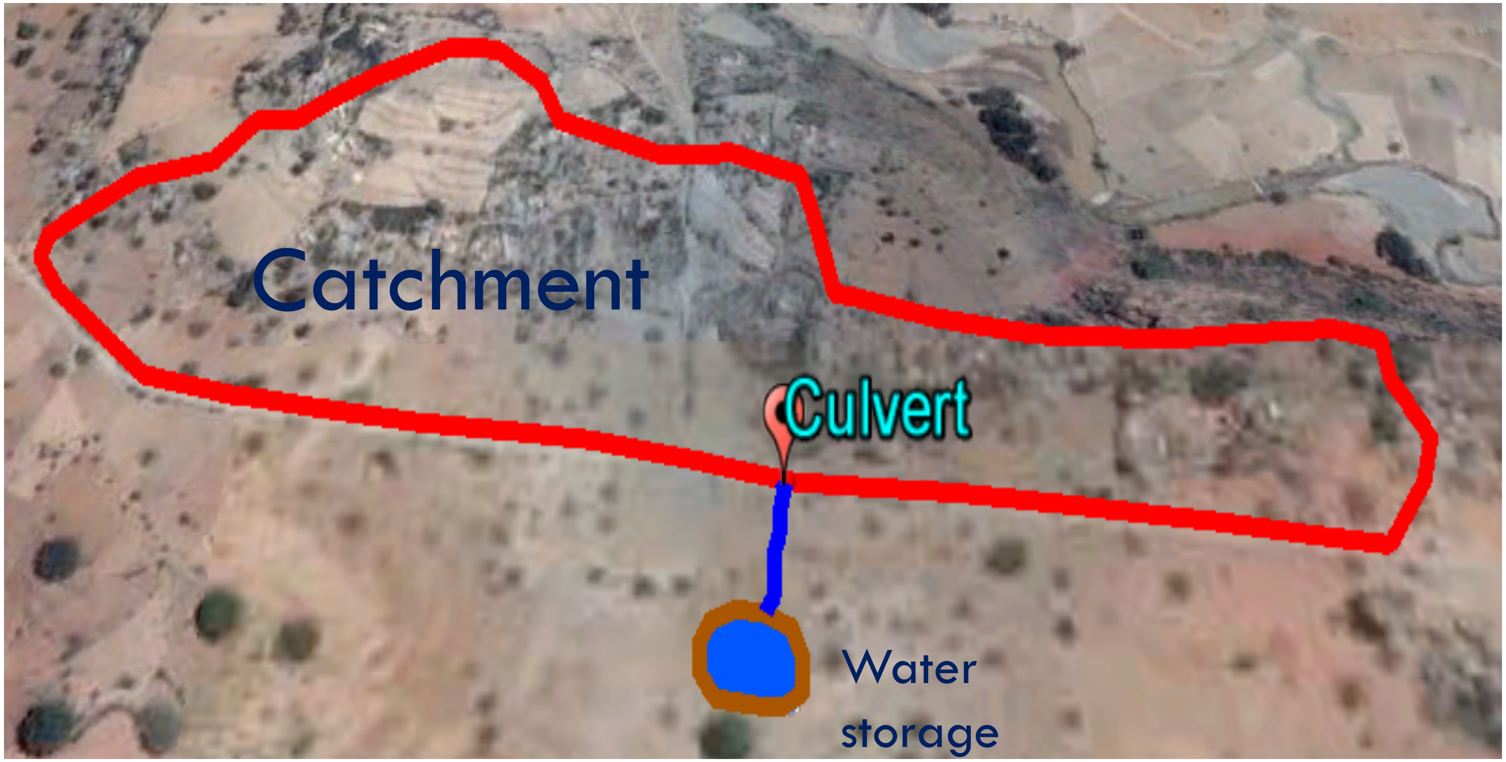
- Water harvesting is the collection of runoff for a productive use (Critchley and Siegert, 1999)
- Unless it is properly managed, **concentrated** water from road catchments can be damaging
- Some of the negative effects of concentrated water emanating from culverts and bridges are:

  ✓ Downstream erosion of land leading to gully formation
  ✓ Downstream deposition of sediments
  ✓ Damaging road structures, mainly hydraulic structures

Introduction

Fig. Example of gully formation downstream of a road along the Freweyni to Abreha-we-Atsibha road route

Introduction



Introduction

- With proper planning and management, concentrated water from road catchments could be utilized for different agricultural uses:
  - ✓ Diverted to farmlands for supplemental irrigation
  - ✓ Channelled to deep trenches, percolation ponds, etc. for ground water recharge

- With known water **potential to harvest from road catchments**, it would be possible to manage the available water for **different water uses** and to **size different water harvesting systems.**

Calculating potential of water harvesting form road catchments

- The Runoff Volume Equation for calculating the **potential of water harvesting (m^3) is**

$$V = C * P * A * E$$

Where, V = is potential of water harvesting (m^3)
C = weighted runoff coefficient for the catchment area
P = Dependable annual rainfall, usually 80% (m)
E = Efficiency factor for accounting losses, usually taken 0.7 (Danida, 2006)

- Water losses could be due to evaporation and seepage

Estimation of annual dependable rainfall

- Requires records of annual precipitation from meteorological station/s nearby to the road
- Determine the most probable annual rainfall for the area
- Nowadays 80% of dependable rainfall is taken
- Annual rainfall records arranged in descending order, and ranked from 1 to n, in which n belongs to the number of annual rainfall records
- Probability of exceedance computed using probability distributions, for example, Weibul formula
- $P = m/(n+1)$

where m is the rank of each rainfall for a given year based on ranking on descending order

Calculating potential of water harvesting from road catchments

- Example: Annual rainfall records for the Freweyni Station, Tigray

Year	Rainfall (mm)
2001	778.0
2002	405.2
2003	466.9
2004	604.6
2005	341.9
2006	642.0
2007	537.0
2008	567.6
2009	306.7
2010	670.5
2011	623.6
2012	549.0

Year	Rainfall (mm)	Rank	Probability of exceedance = m/(n+m)
2001	778.0	1	0.08
2010	670.5	2	0.15
2006	642.0	3	0.23
2011	623.6	4	0.31
2004	604.6	5	0.38
2008	567.6	6	0.46
2012	549.0	7	0.54
2007	537.0	8	0.62
2003	466.9	9	0.69
2002	405.2	10	0.77
2005	341.9	11	0.85
2009	306.7	12	0.92
		80% dep.	380

Determination of runoff coefficient

- Runoff coefficient is dimensionless that relates runoff to precipitation
- Runoff coefficient depend on land use, slope, soil type, etc.
- Runoff coefficient is determined for various **land uses** or using known **slope** and **soil hydrologic group**
- The soil hydrologic group describes the rate of water infiltration and depends on soil type

Table 5-10: Typical Hydrologic Soils Groups for Ethiopia

	Soil Types	Hydrologic Soil Group
Ao	Orthic Acrisols	B
Bc	Chromic Cambisols	B
Bd	Dystric Cambisols	B
Be	Eutric Cambisols	B
Bh	Humic Cambisols	C
Bk	Calcic Cambisols	B
Bv	Vertic Cambisols	B
Ck	Calcic Chernozems	B
E	Rendzinas	D

Source: Drainage Design Manual (ERA, 2013)

Determination of runoff coefficient

Table 5-5: Recommended Runoff Coefficient C for Pervious Surfaces by Selected Hydrologic Soil Groupings and Slope Ranges

Terrain Type	Soil Type			
	A	B	C	D
Flat, <2%	0.04-0.09	0.07-0.12	0.11-0.16	0.15-0.20
Rolling, 2-6%	0.09-0.14	0.12-0.17	0.16-0.21	0.20-0.25
Mountain, 6-15%	0.13-0.18	0.18-0.24	0.23-0.31	0.28-0.38
Escarpment, >15%	0.18-0.22	0.24-0.30	0.30-0.40	0.38-0.48

$$Weighted\ C = \frac{C1 * A1 + C2 * A2 + \cdots Cn * An}{A1 + A2 + \cdots An}$$

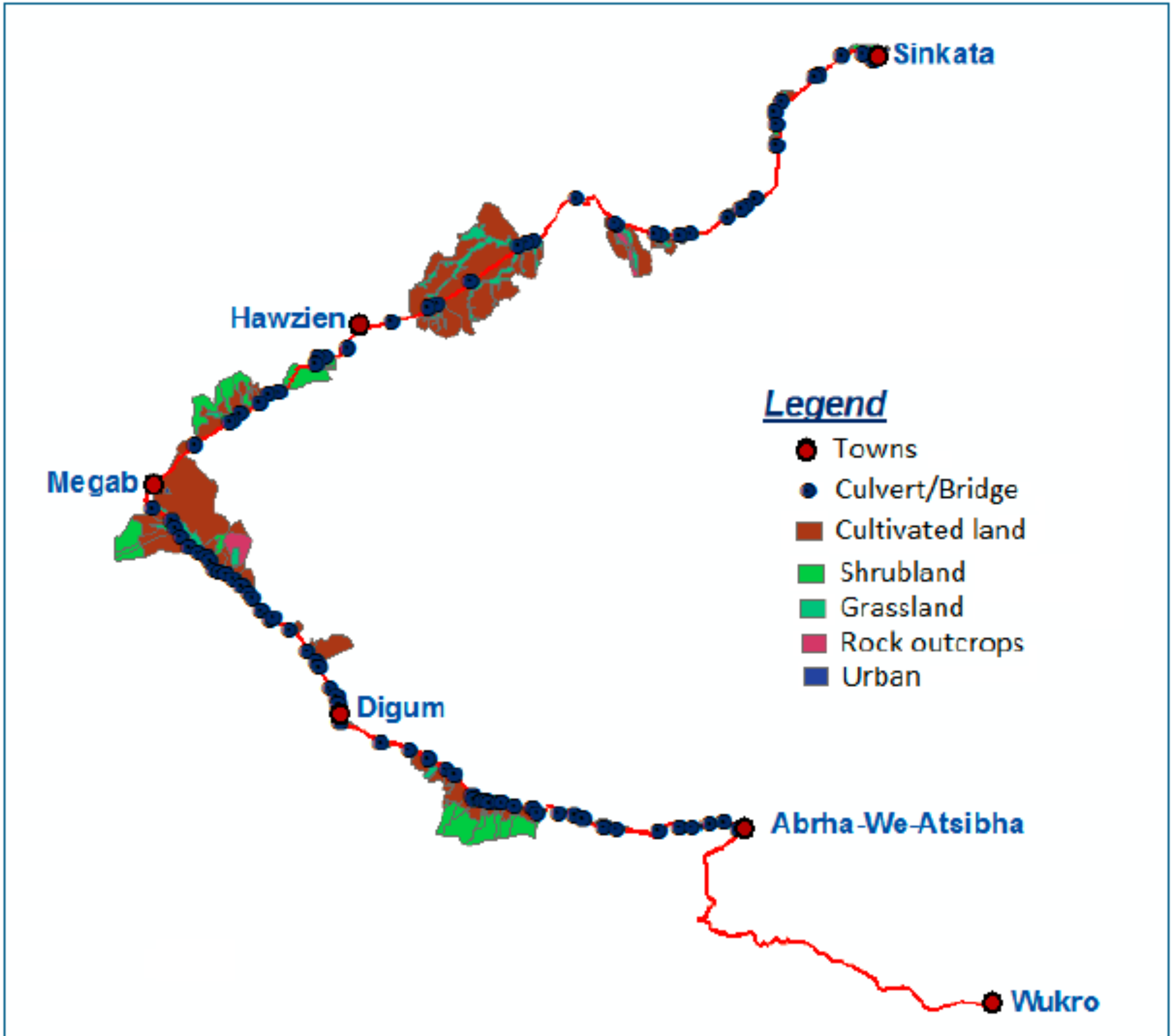
Determination of runoff coefficient

Table 5-6: Recommended Runoff Coefficient C for Various Land Use

Description of Area	Runoff Coefficients
Business: Downtown areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential: Single-family areas	0.30-0.50
Residential: Multi units, detached	0.40-0.60
Residential: Multi units, attached	0.60-0.75
Suburban	0.25-0.40
Residential (0.5 hectare lots or more)	0.30-0.45
Apartment dwelling areas	0.50-0.70
Industrial: Light areas	0.50-0.80
Industrial: Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30

(Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984)

Example: *water harvesting potential from road catchments at the outlet of 92 culverts/box bridges along the* ***Freweyni*** *to* ***Abreha-we-Atsibha*** *route in Tigray,* ***total potential of water harvesting is 1.34 Million cubic meter.***


Sinkata
Hawzien
Megab
Digum
Abrha-We-Atsibha
Wukro
Legend
Towns
Culvert/Bridge
Cultivated land
Shrubland
Grassland
Rock outcrops
Urban

Calculating potential of water harvesting from road catchments

- **General steps**
  - ✓ Delineate the catchment area using, e.g. arc-hydro, ArcSWAT, using **Google Earth** (identification of water-divide based on elevation profile)
  - ✓ Determine the area of each land use in the catchment
  - ✓ Estimate runoff coefficient
  - ✓ Estimate annual dependable rainfall
  - ✓ Finally, determine the runoff volume using the **Runoff volume Equation**

Calculating peak discharge at culvert/bridge outlets

- Peak discharge is used for **sizing the spillway** of a **water storage structure** such as ponds.
- In the absence of measured data, peak discharge is usually estimate using:
  - ✓ The **rational method** (catchment area <50 ha)
  - ✓ The SCS curve number method (catchment area >50 ha)
- Peak discharge using the rational method is estimated as:

$$\mathbf{Q = 0.00278\ CIA}$$

Where, Q: is maximum discharge (m^3/s)

C: is runoff coefficient

I : is average rainfall intensity for duration equal to time of concentration, mm/hr

A: is catchment area, in ha

Procedures for using Rational method in Ethiopia

- Determine the catchment area in hectares
- Determine the time of concentration, with consideration for future characteristics of the catchment

$$T_C = \frac{1}{3000} * \left(\frac{L}{S^{1/2}}\right)^{0.77}$$

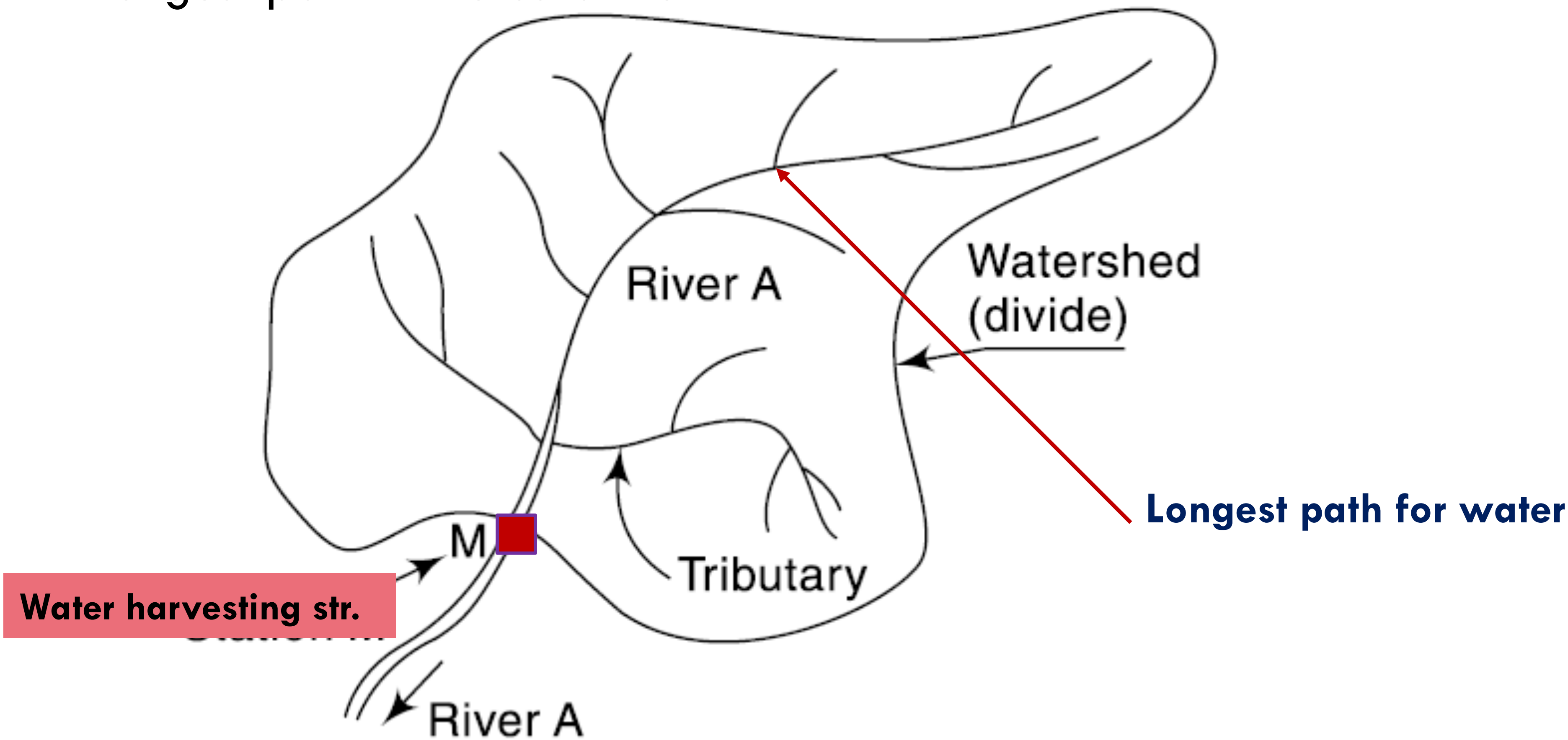
where Tc : is time of concentration in hours

L : is hydraulic length of the catchment (m), S is average slope of the catchment

- Determine rainfall intensity using the **Intensity-Duration-Frequency** (IDF) charts for a given region

Procedures for using Rational method in Ethiopia

- Time of concentration is the time taken for water to move along the longest path in the catchment



Procedures for using Rational method in Ethiopia

- Rainfall intensity depends on Tc and return period/design period
- Design period depends on the type of structure

Type of structure	Return period (years)
Highway culverts:	
Low traffic	5–10
Intermediate traffic	10–25
High traffic	50–100
Highway bridges	
Secondary system	10–50
Primary system	50–100
Urban drainage	
Storm sewers in small cities	2–25
Storm sewers in large cities	25–50
Airfields	
Low traffic	5–10
Intermediate traffic	10–25
High traffic	50–100

Procedures for using Rational method in Ethiopia

- IDF curves for different parts of Ethiopia

Meteorological Region	Station	Years of Record	Meteorological Region	Station	Years of Record
A1	Axum	17	B	Bedele	39
	Mekele	46		Gore	56
	Maychew	32		Nekempte	40
A2	Gondar	52		Jima	54
	Debre Tabor	15		Arba Minch	23
	Bahir Dar	45		Sodo	49
	Debre Markos	55		Awasa	36
	Fitche	44	C	Kombolcha	57
	Addis Ababa	57		Woldiya	29
	Debre Zeit	55		Sirinka	27
A3	Nazareth	46	D1	Gode	33*
	Kulumsa	43		Kebri Dihar	40
	Robe/Bale	29	D2	Kibre Mengist	33
A4	Metehara	24		Negele	51
	Dire Dawa	58		Moyale	29
	Mieso	42		Yabelo	34

Calculating Peak discharge using Rational method

- Rainfall intensity is determined based design return period and calculated time of concentration for a catchment

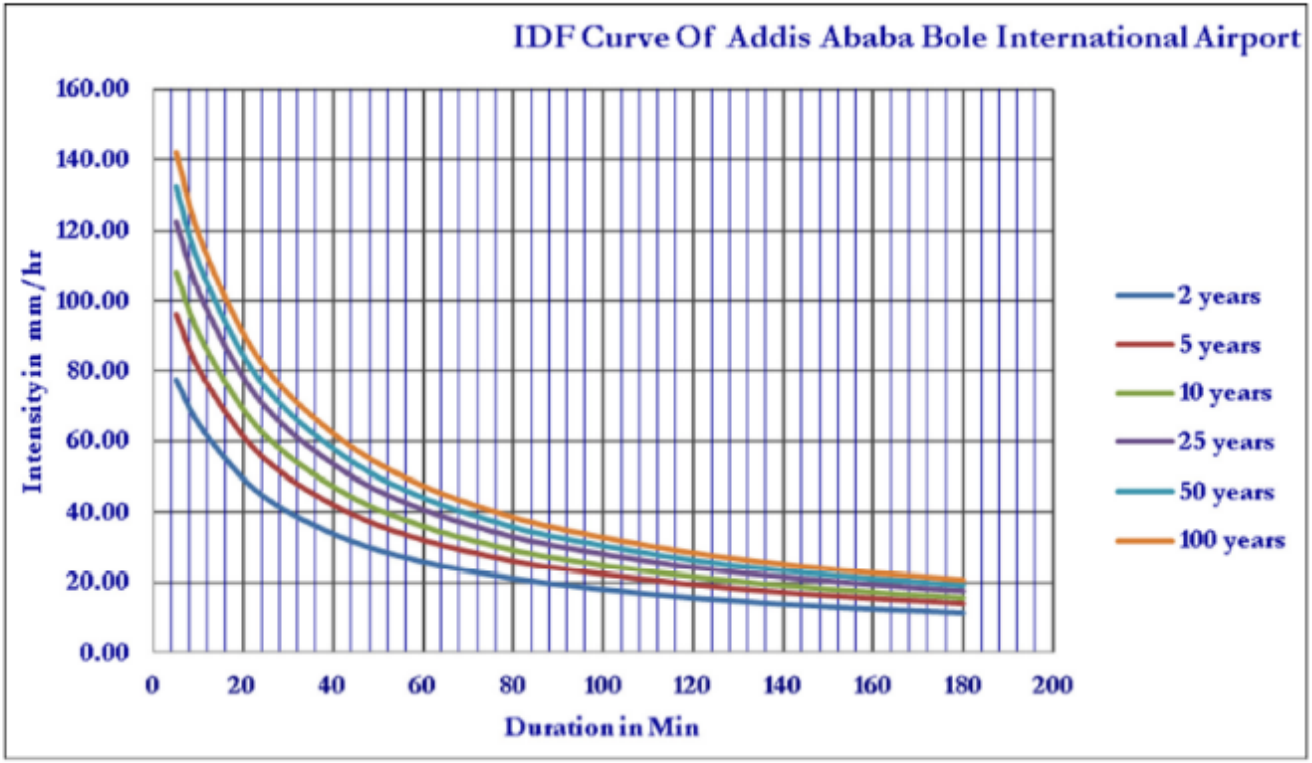


Figure 5-12: Typical Rainfall Intensity Duration Frequency Curve

Design considerations for water conveyance/channel

- ✓ Amount of water/ peak discharge
- ✓ Terrain slope affecting speed of water
- ✓ Alignment of the channel
- ✓ Stability of channel, earthen or lined channel
- ✓ Shape of the channel (e.g. rectangular, trapezoidal, etc.)
- ✓ Minimum speed of water to avoid siltation
- ✓ Channel surface roughness
- ✓ Free board
- ✓ Size of the channel (*Design ??*)

Design considerations for diversion channels from culverts

- *Design discharge for sizing channels*
  - ✓ *Estimate using the rational method*
  - ✓ *Calculate from existing culverts/bridges, i.e.*
  - ✓ *Q = A.V, where A cross-sectional area of the culvert, V is velocity of flow*
  - ✓ *Determine velocity of flow using flow measurements techniques (e.g. current meter, floating techniques)*

Thank you!