ODA-UNESCO project:
Promotion of energy science education for sustainable development in Lao PDR

Theme 5: Small-scale Hydropower

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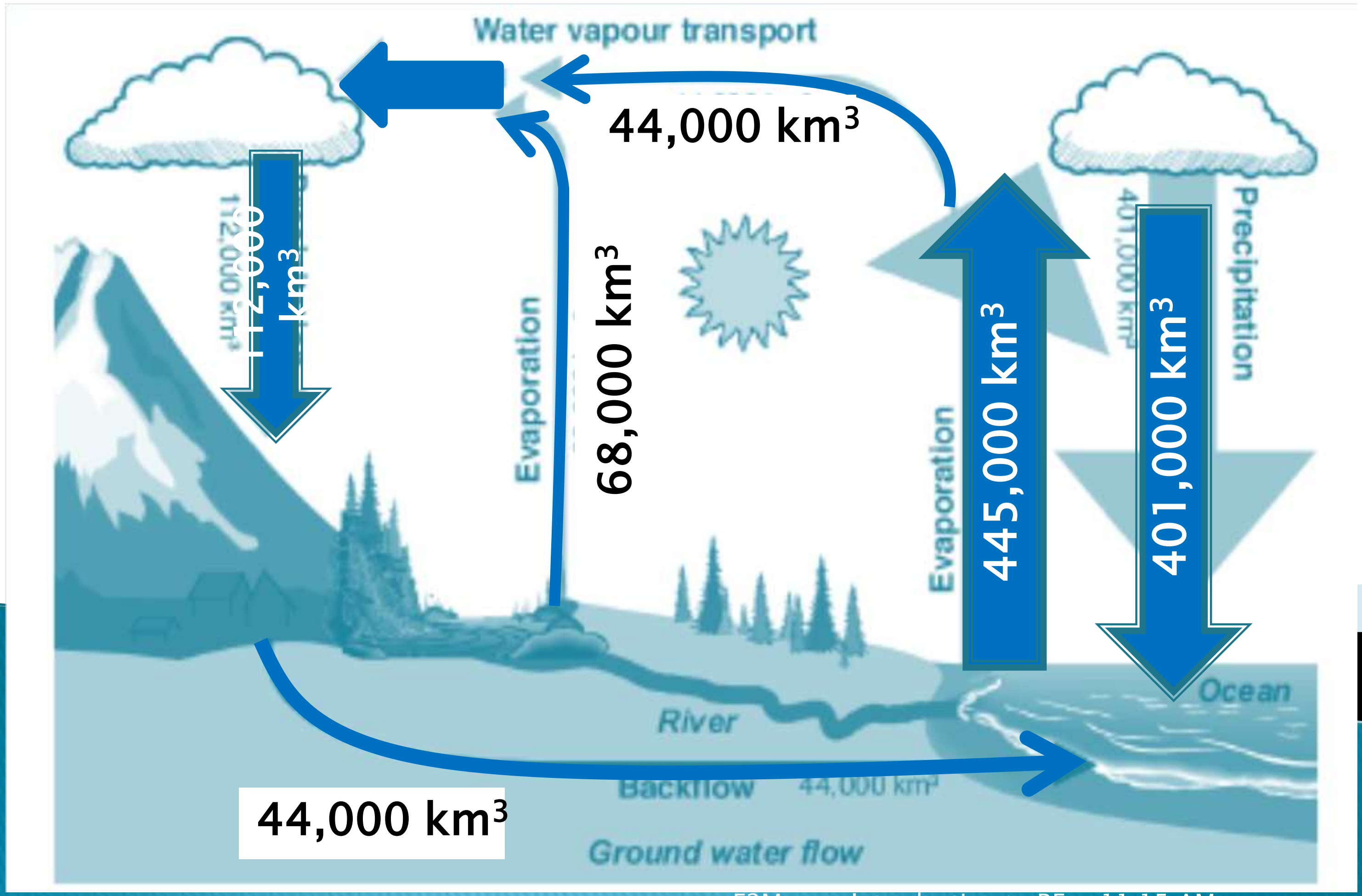
- Fundamentals of Hydropower
- Why Small-scale Hydropower?
- Small-scale hydropower Potential assessment
  - ✓ Hydrological Analysis
  - ✓ Site survey

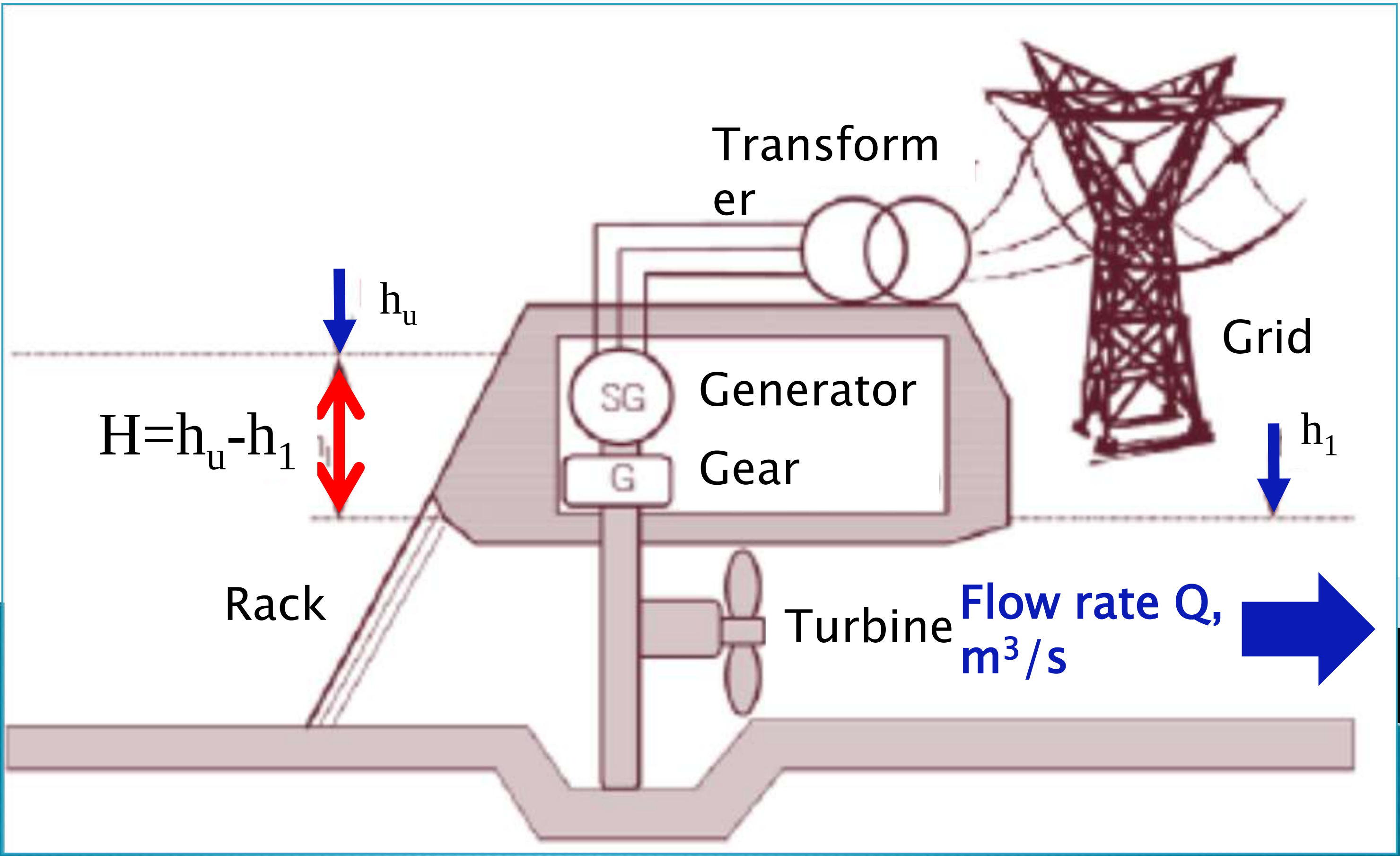
Fundamentals of Hydropower

- <u>Hydrological cycle</u>



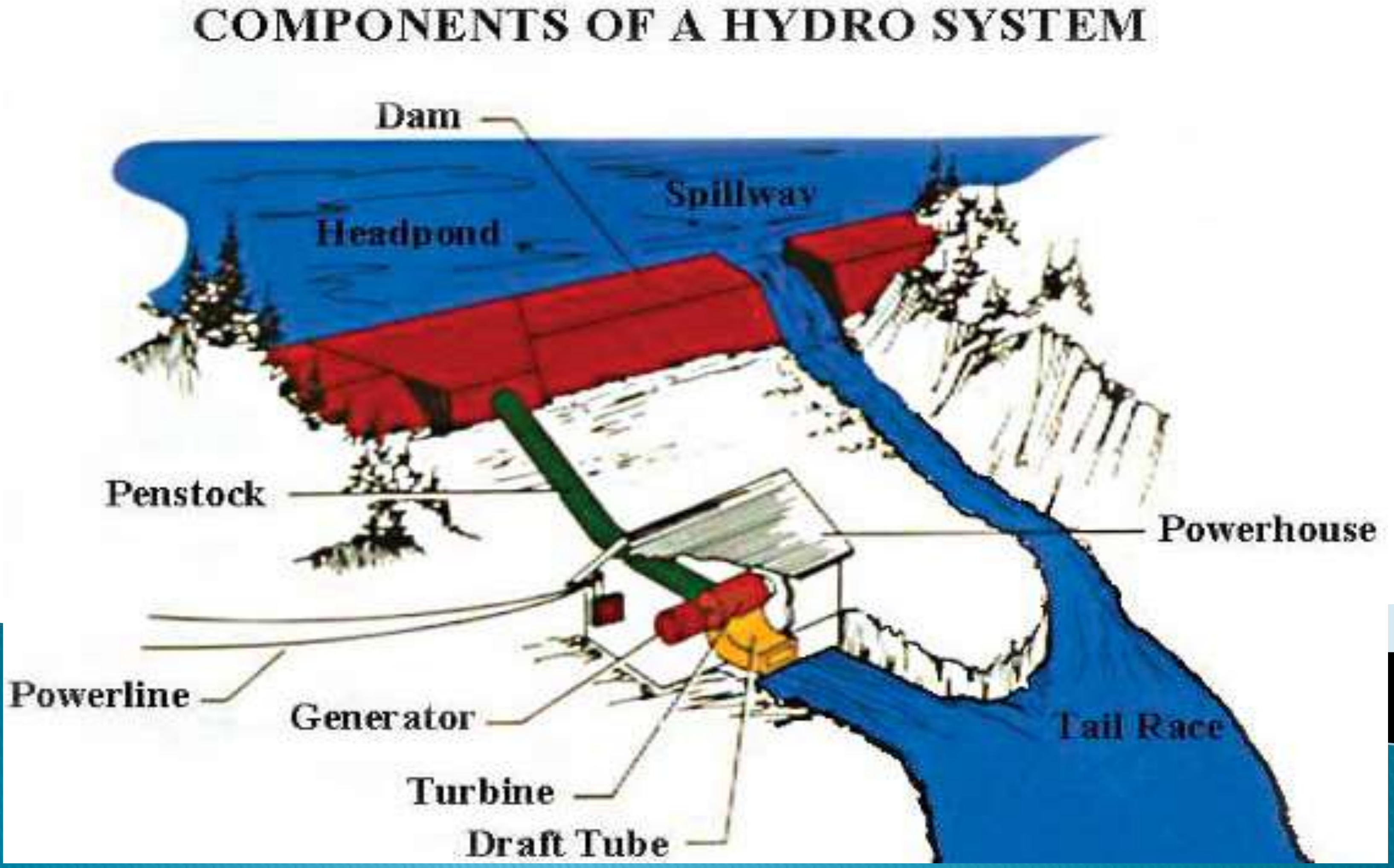
Fundamentals of Hydropower

- **Hydropower: Principle Hydro Electric Power Plant**



Fundamentals of Hydropower

Hydropower Power Plant components



Hydropower Fundamentals

HP Classification

- **By installed capacity**
  - PICO <1 kW, (somewhere <5 kW)
  - MICRO: 1–100 kW (somewhere <200 kW)
  - Mini 100–1000 kW
  - Small 1–10 MW (In Lao case: <15 MW)
  - Large or full scale: > 10 MW
- **By Heads**
  - Low head (<15 m)
  - Medium Head (15–50 m)
  - High head (> 50 m)

Hydropower FUndamentals

HP Classification

PICO (≤ 1 kW)

Hydropower Fundamentals
HP Classification

80kW

MICRO
6-100 kW

70kW

55 kW

Hydropower Fundamentals
HP Classification

MINI (101-1000 kW)

500 kW

Hydropower Fundamentals:

HP Classification

2 MW

Small (< 15MW)

Hydropower Fundamentals:
HP Classification

- **Full scale hydropower (> 10 MW)**

Dam Name	Country	Installed capacity
Nam Ngum 1	Laos	150 MW
NamTheun 2	Laos	1098 MW
ITAIPU	Brazil-Paraguay	14,000 MW
Three Gorges	China	22,000 MW

- Hydropower Fundamentals:

Run-off river scheme

→ Enlarged forebay

➢ Run-off river scheme with Enlarged forebay

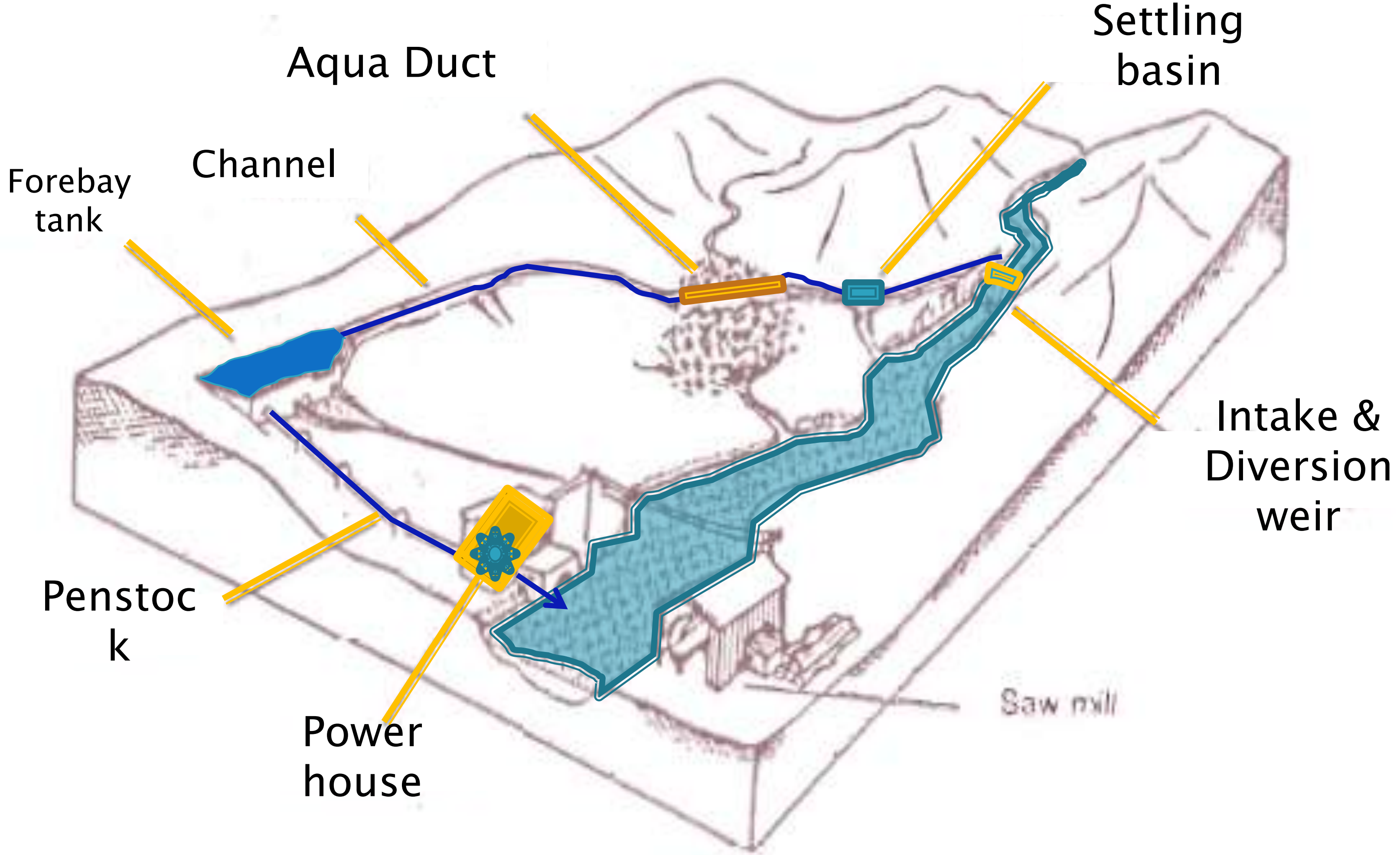
Hydropower Fundamentals

HP Classification

- **Supply Destination**
  - stand alone or captive (with isolated mini grid)
  - grid-connected: to feed power to grid network

Hydropower Fundamentals:

Components of Small scale-hydropower Scheme



Why Small-scale Hydropower?

- **Advantages of Small-scale Hydropower**
  - ✓Uses Renewable energy resources
  - ✓Relies on a non-polluting, indigenous and locally available source of energy
  - ✓Can replace petroleum-based generating systems
  - ✓Uses a well-proven technology, well beyond research and development stage
  - ✓environmental impacts can be kept at very low level

Why Small-scale Hydropower?

- **Advantages to other "renewables"**
  - ✓High efficiency (70-90%)
  - ✓High capacity factor - 50% (PV-10%, Wind-30%) → reliable for captive systems
  - ✓High level of predictability, varying with annual rainfalls
  - ✓Slow rate of changes: gradually from day to day→ Good correlation with demand
  - ✓Proven, robust and long lasting equipment

Why Small-scale Hydropower?

- **Other Advantages:**

✓Alternatively, SHP can be used as shaft power (mechanical works): grain mill, water pumping

✓Due to small size→ allow involvement of local villagers during the construction phase

✓Suitable locations are widely spread → good for decentralized electrification

✓Encouraged local production of parts/ equipment

✓ wide range of design and construction materials are available locally

Why Small-scale Hydropower?

- **Disadvantages**:
  - ✓Associated with higher capital cost (usually > 2000 US$/kW)
  - ✓Requires a considerable amount of specialist know-how
  - ✓require a simple but continuous effort for operation and maintenance:
    - Lack of organizational capacities
    - Lack of cash

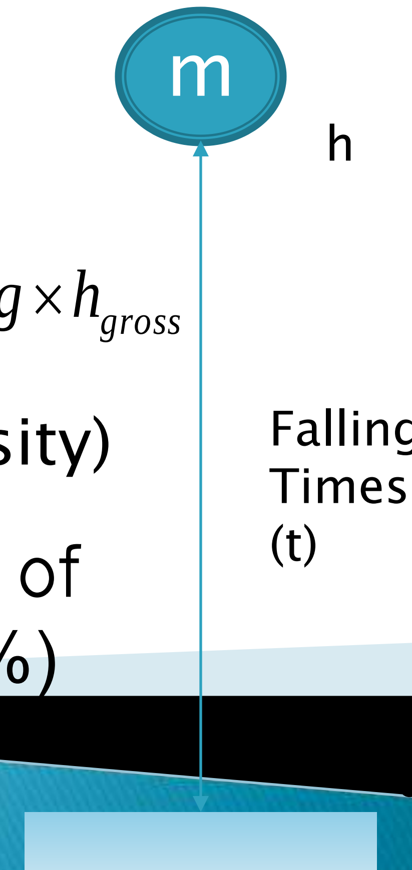
Small scale Hydropower Fundamentals

• Power of Falling Water

Potential energy of body of mass m (kg and elevated on h (m):

$$E = m \times g \times h$$

Gross Power produced:



$$P_{gross} = \frac{E}{t} = \frac{m}{t} \times g \times h_{gross} = \frac{\rho \times V}{t} \times g \times h_{gross} = Q \times \rho \times g \times h_{gross}$$

(V– falling water volume; ρ–water density)

$$\eta_o = \frac{P_{net}}{P_{gross}}$$

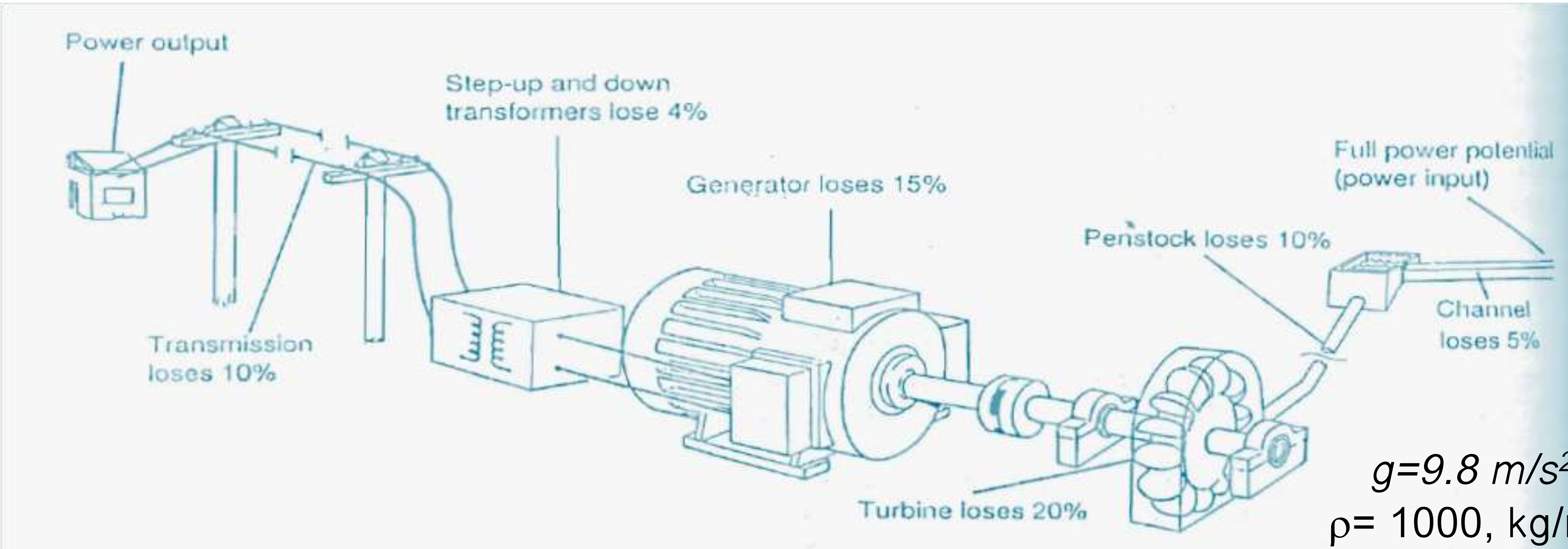
η_e= Overall efficiency of energy conversion (%)

$$\Rightarrow P_{net} = \eta_o \times \rho \times g \times Q \times h_{gross}$$

(P_{net}– Net Output Power)

Small-scale Hydropower: Fundamentals

Power of falling Water



g=9.8 m/s²;
ρ= 1000, kg/m³;

$$\eta_o = \eta_{channel} \times \eta_{penstock} \times \eta_{turbine} \times \eta_{generator} \times \eta_{transformers} \times \eta_{transmission}$$
$$= 0.95 \times 0.90 \times 0.80 \times 0.85 \times 0.96 \times 0.9 \approx 0.5$$

$$P_{net} = \eta_o \times P_{gross} = \eta_o \times Q \times \rho \times g \times h_{gross} = 0.5 \times 1000 \times 9.8 \times Q \times h_{gross}, \; \mathrm{W_e}$$

$$P_{output} = \mathbf{5.0} \times Q \times h_{gross}, \; \mathbf{kW_e}$$

SHP potential assessment: planning

Stages of SHP Potential assessment :

1) <u>Desk study</u> (or hydrology study)

- ✓To study on geological, hydrological and socio-economic conditions of the proposed site
- ✓May identify appropriate site without site visit
- ✓May know that there is no any potential at the proposed site, and hence no need to do site visit → save money
- ✓Accuracy of project costs estimation at this stage is ±30%

SHP potential assessment: planning

2) **Reconnaissance visit:**

a short site visit (usually 1 day visit) to verify the desk study results:

- ✓ Existing hydropower potential
- ✓ Appropriate power demand
- ✓ Site Accessibility

SHP potential assessment: planning

3) Pre-Feasibility Study

- ✓ to determine which of several proposed projects, sites or technical options are most attractive for SSHP development
- ✓ Preliminary assessment are reviewed and worked out with more details
- ✓ Accuracy of cost estimates: **±20-25%**

SHP potential assessment: planning

4) Feasibility Study(FS):

- ✓Assessment whether the implementation of the proposed scheme is desirable or not
- ✓Project Developer will make final decision and to locate funding on the base of FS
- ✓Accuracy of cost estimates: ±10-15%

Desk study:

- **Hydrological data analysis (desk study)**
  - ✓ To estimate minimum flow
  - ✓ Necessary to visit the stream during the ‘smallest flow’ (usually driest period)
  - ✓ Involve a Hydrograph and Flow Duration Curve
  - ✓ Two approaches:
    - **Area-Rainfall method**
    - **Correlation method**

Desk study

- **Area-Rainfall method**

✓ **Local map scale** 1:50,000; **better** 1:20000 **or** 1:10000

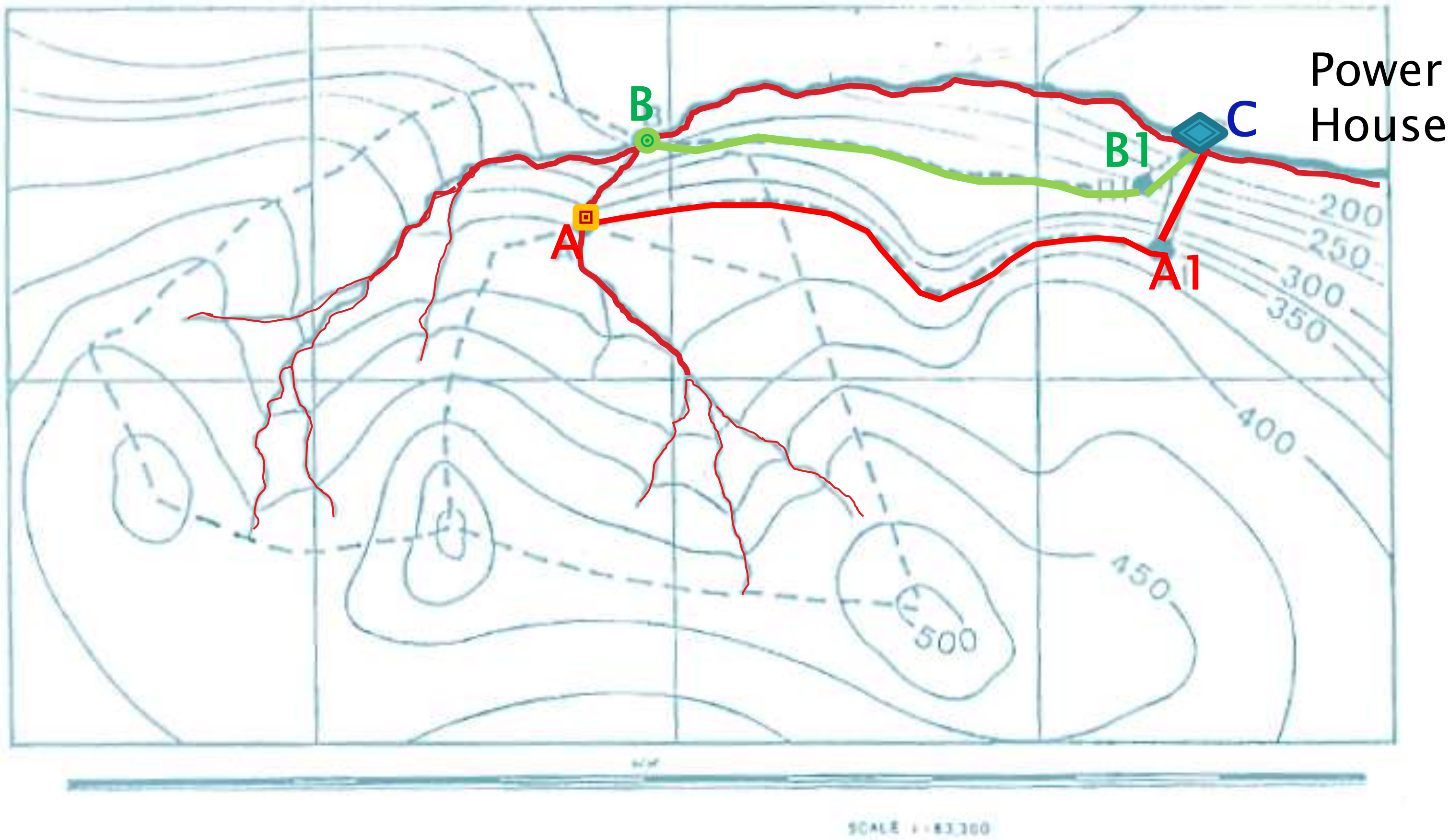
✓ **Necessary Statistic data/ information**

- **Rainfalls**
- **Hydrograph**
- **Flow Duration Curve (FDC)**

Desk study

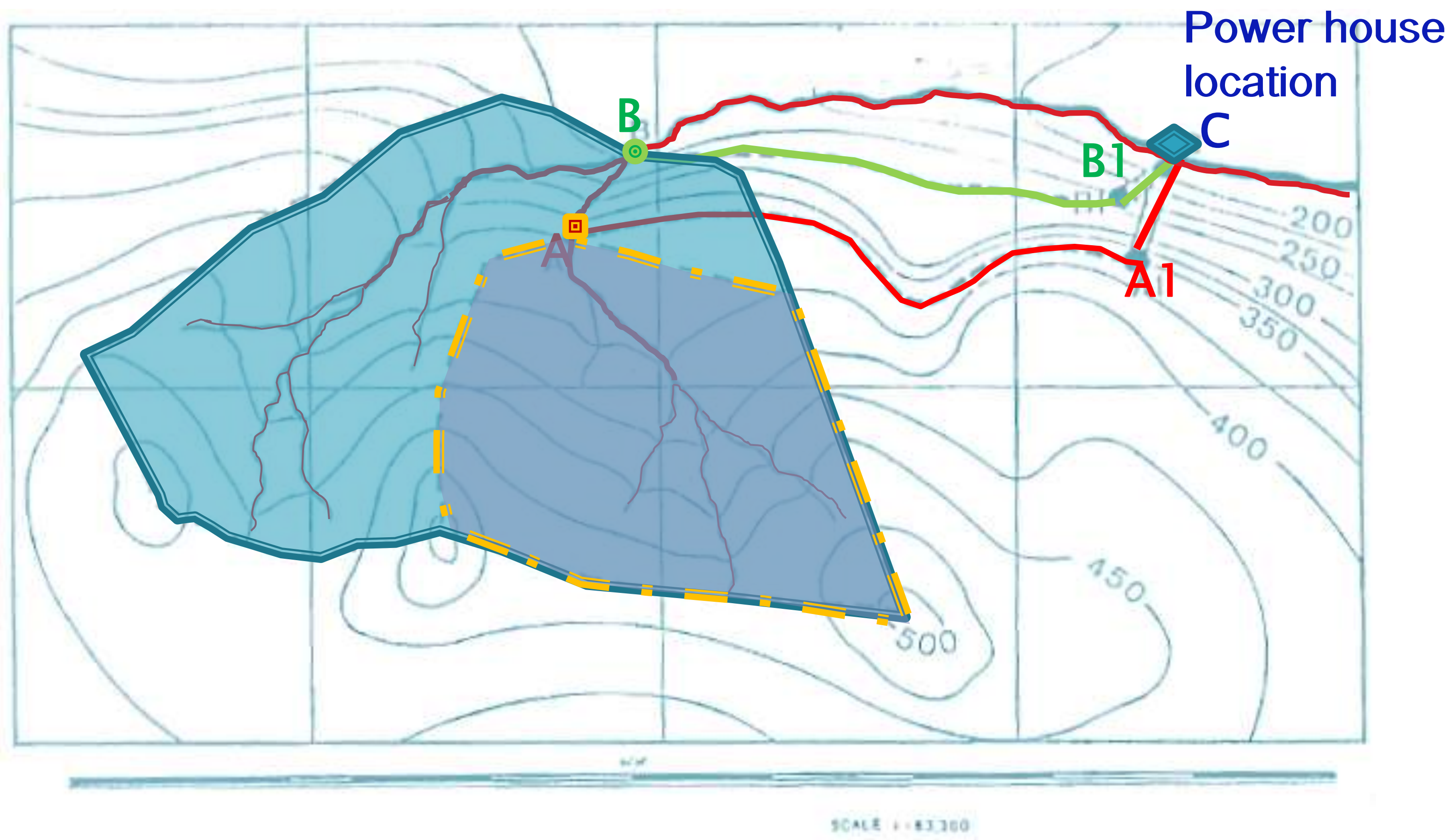
➢ Rainfall-area method

- Example : how to define project location on the map



Desk study

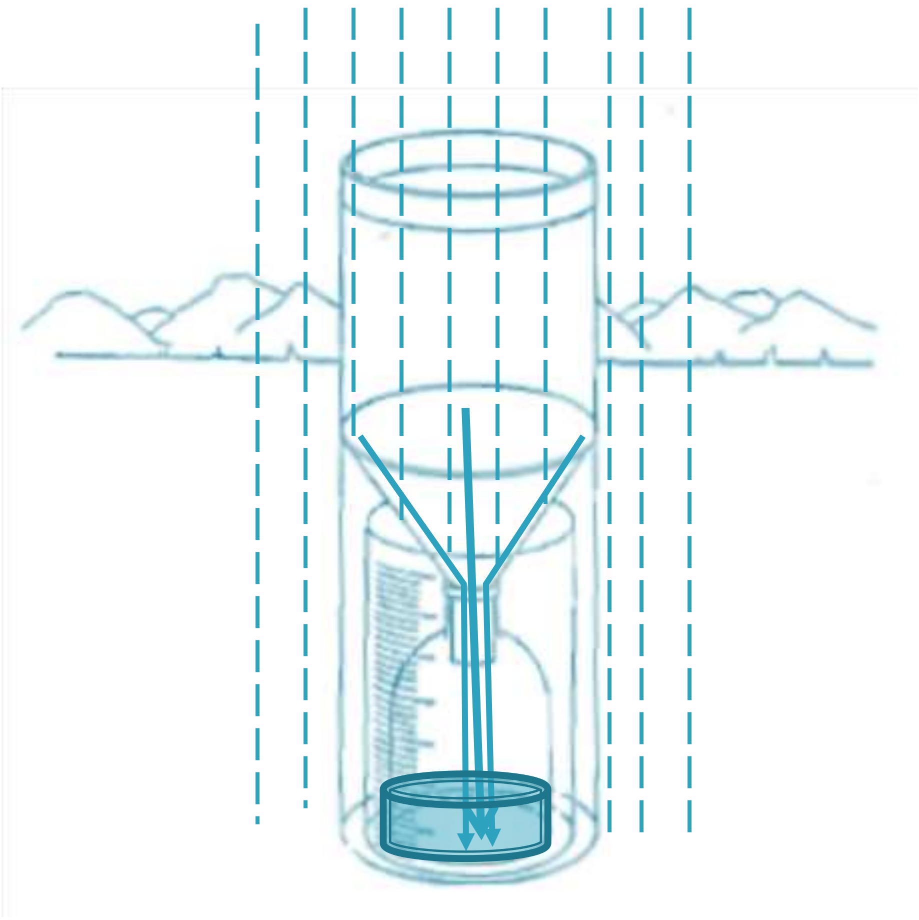
- **Rainfalls-area method**
  - Catchment area definition



Desk study

Rainfalls – Areas method

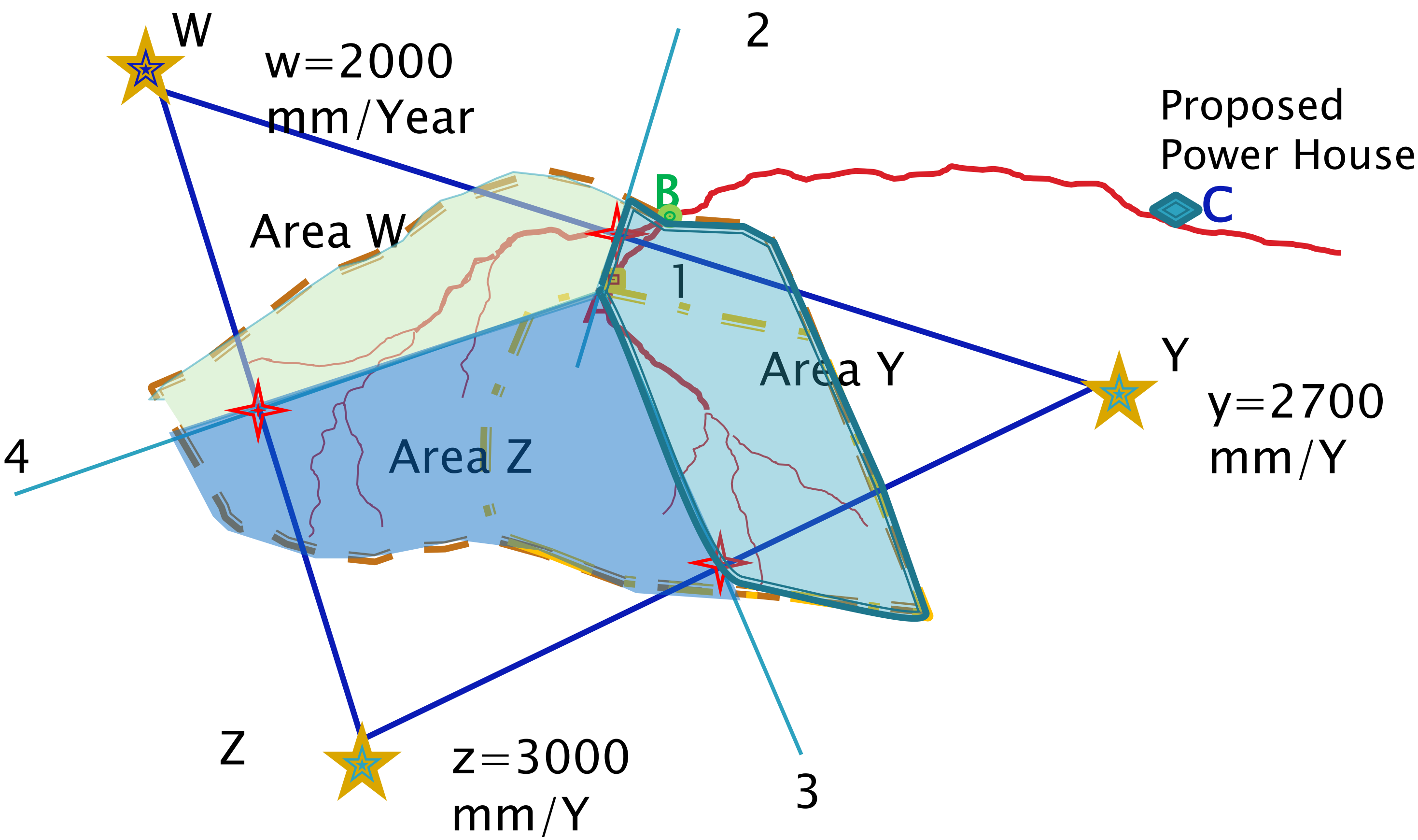
- Rain gauge



Desk study

Area-Rainfalls method

- Calculation of rainfalls in catchment areas

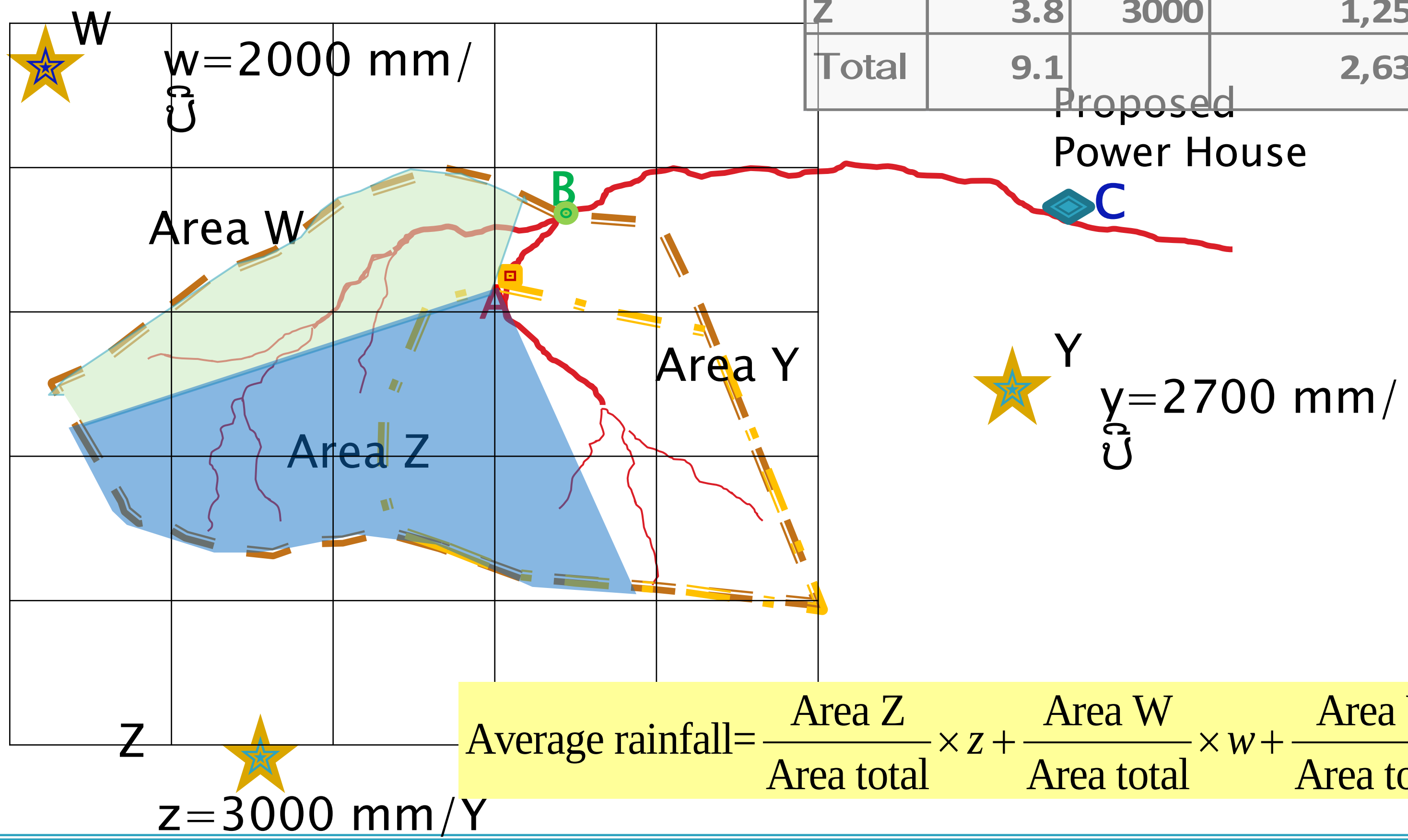


Desk study

❑ Area-Rainfalls method

- Example of rainfalls calculation

	Area	rain falls	Proportion rainfalls
W	2.5	2000	549
Y	2.8	2700	831
Z	3.8	3000	1,253
Total	9.1		2,633

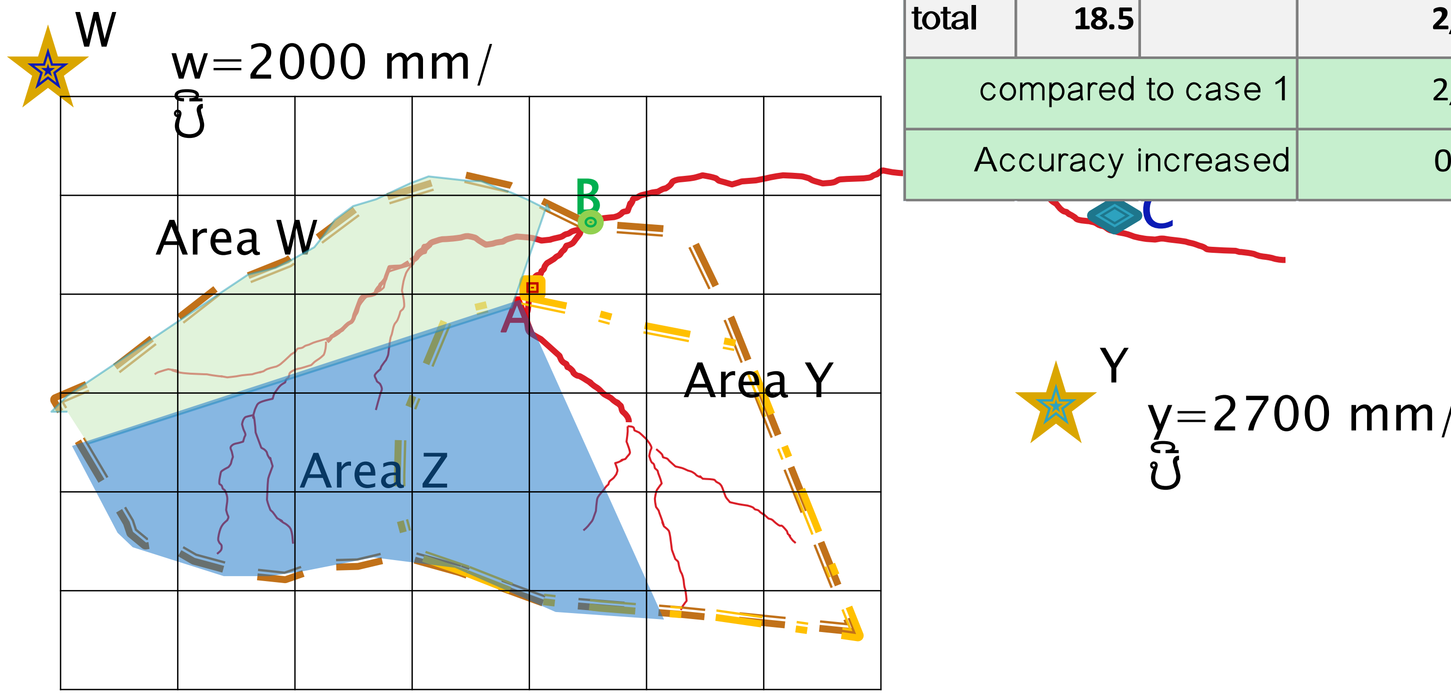


$$\text{Average rainfall} = \frac{\text{Area Z}}{\text{Area total}} \times z + \frac{\text{Area W}}{\text{Area total}} \times w + \frac{\text{Area Y}}{\text{Area total}} \times y$$

Desk study

- **Area-Rainfalls method**
  - **Example**

	Area	Rain falls	Proportion
W	4.5	2000	486
Y	6.5	2700	949
Z	7.5	3000	1,216
total	18.5		2,651
compared to case 1			2,633
Accuracy increased			0.70%



Z

z=3000 mm/

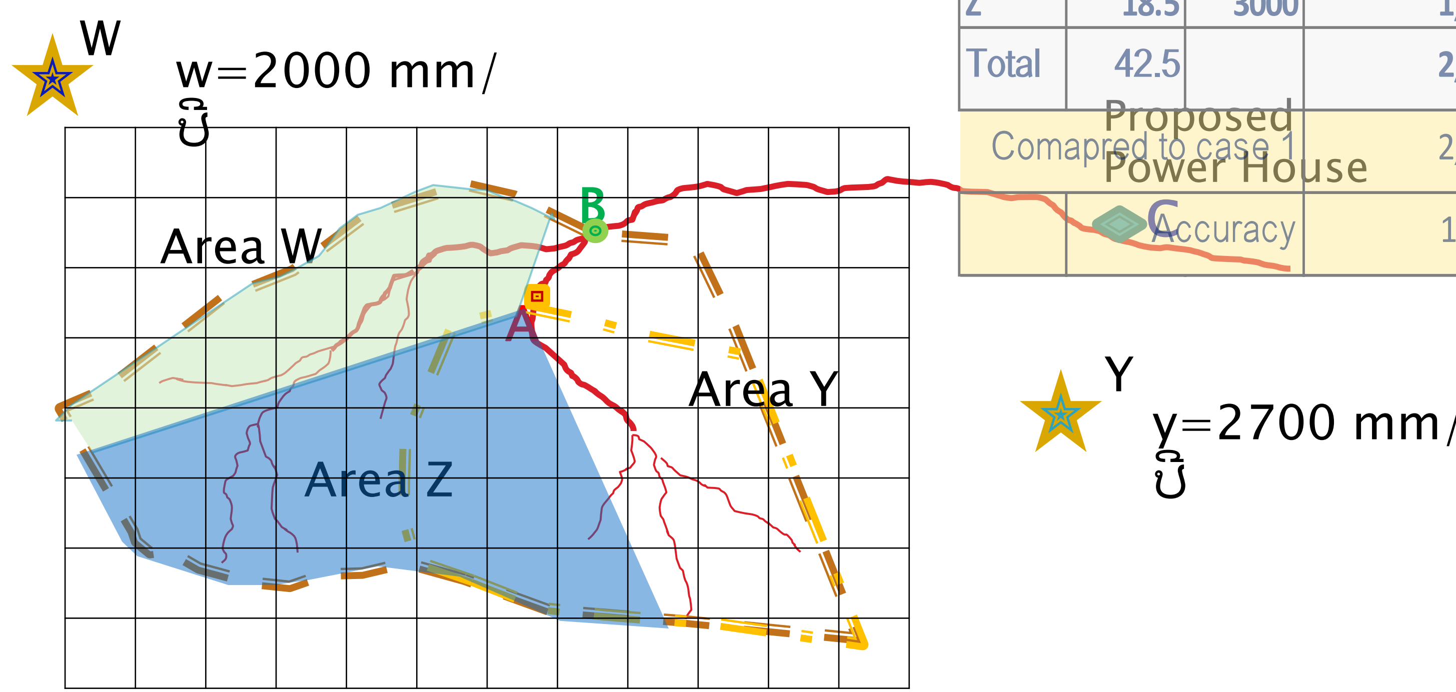
$$\text{Average rainfall} = \frac{\text{Area Z}}{\text{Area total}} \times z + \frac{\text{Area W}}{\text{Area total}} \times w + \frac{\text{Area Y}}{\text{Area total}} \times y$$

Desk Study

Area-Rainfalls method

- Example

	Area	Rain falls	Proportion
W	10	2000	471
Y	14	2700	889
Z	18.5	3000	1,306
Total	42.5		2,666
Comapred to case 1			2,633
		Accuracy	1.23%

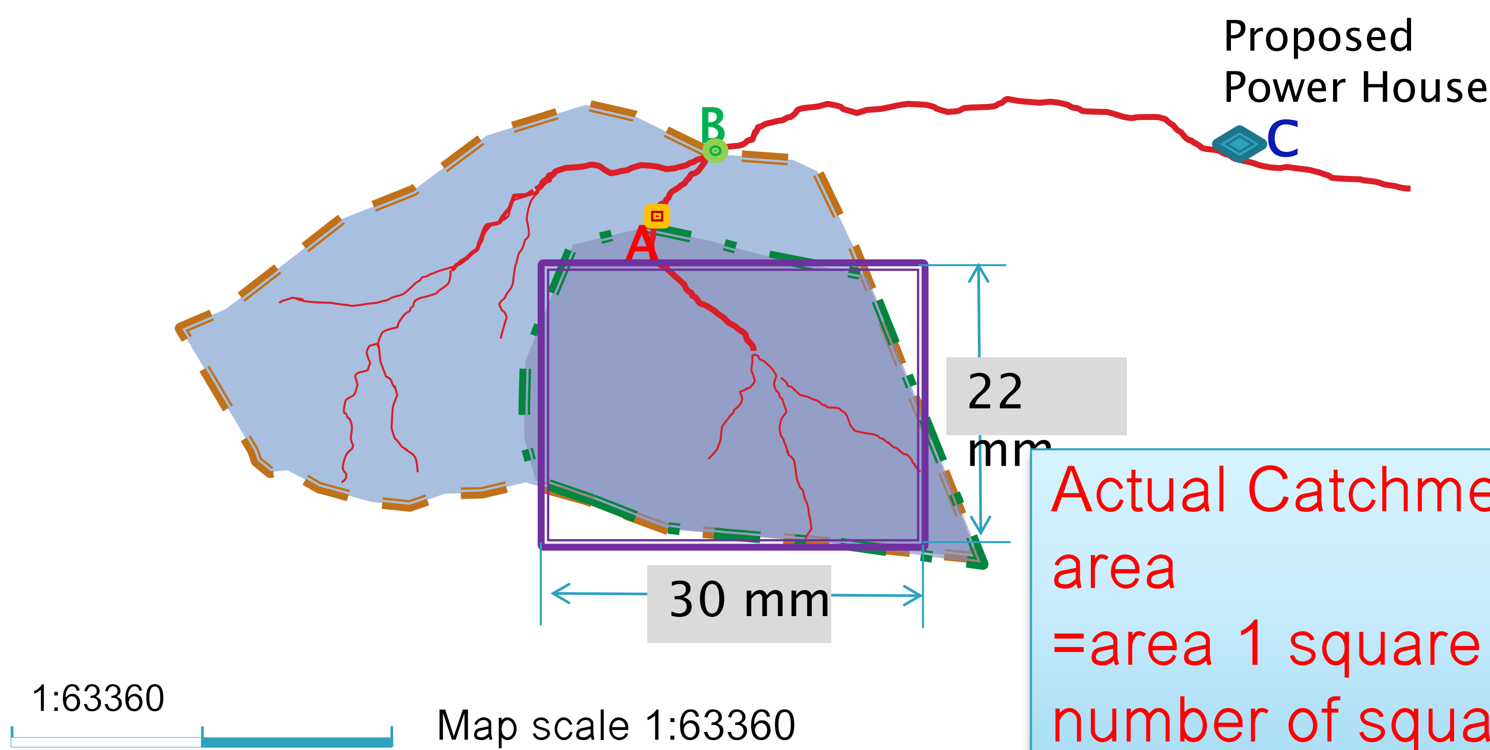


$$\text{Average rainfall} = \frac{\text{Area Z}}{\text{Area total}} \times z + \frac{\text{Area W}}{\text{Area total}} \times w + \frac{\text{Area Y}}{\text{Area total}} \times y$$

Desk study

- **Area-Rainfalls method**
  - Catchment area of site A

Size of square
=(30x63.36)x(22x63.36)
$=2.652\times10^{6}\ m^{2}$



Actual Catchment area
=area 1 square x number of squares
$=2.652\times10^{6}\ m^{2}$

Desk Study

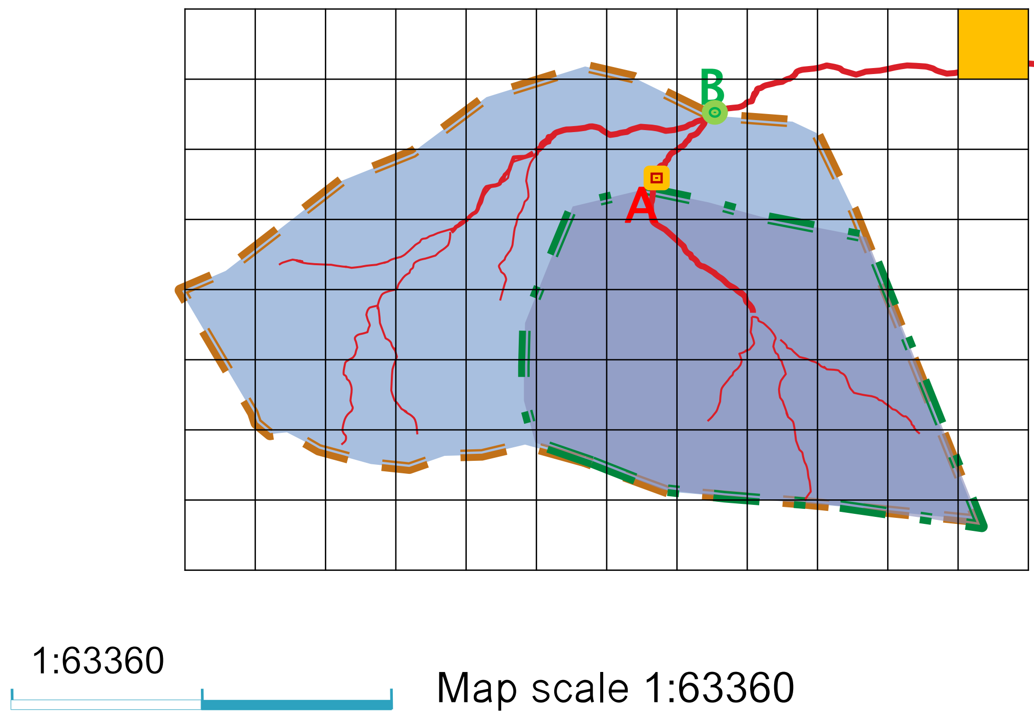
Area-Rainfalls method

- Catchment area of site A
- Annual Discharge Flow Discharge (ADF)

Size of a square
$=(4x63.36)x(4x63.36)$, m^2
$= 144,658\ m^2$

4 mm x 4 mm

Number of squares(A)= 21
Catchment area (A):
= 21x144,658
$=3.04x10^6\ m^2$



Map scale 1:63360

Rainfalls = 2666 mm/year
=2.666 m/year
Water volume =
Catchment area x Rainfalls
$=3.04x10^6$ x 2.666 =
$8.1x10^6\ m^3$/year
$ADF_A=8.1x10^6\ m^3$/year
/(365x24x60x60 s/year)
$= 0.26\ m^3/s$

Desk study

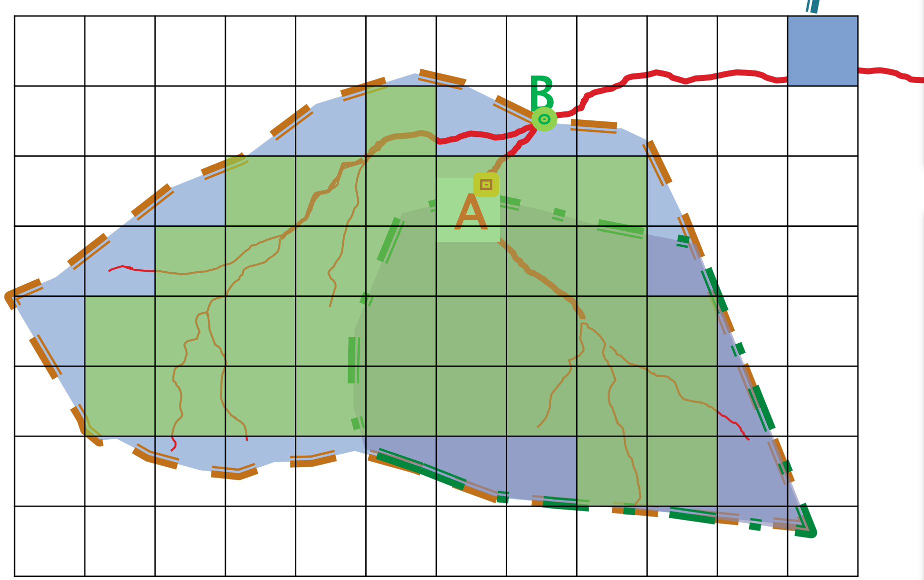
➢ Area-Rainfalls method

- **Catchment area of site B**

Square size
=(4x63.36)x(4x63.36), m^2
= 144,658 m^2

4 mm x 4 mm

No. of squares (B)= 46
Area of Catchment (B):
= 46x144658
=6.654×10^6 m^2



1:63360

ມາດຕາສ່ວນຂອງແຜນທີ່:1:63360

Rainfalls= 2666 mm/year
=2.666 m/year
Water volume =
Catchment area x Rainfalls
=$6.654\times10^6\times2.666$
= 17.74×10^6 m^3/ປີ
$ADF_B=17.74\times10^6$ m^3/year
/(365x60x60 s/year)
= 0.675 m^3/s

Desk Study

➤ Rainfalls-Area Method: Run-off :

Rainfalls = 2666 mm/year=2.666 m/year

Water volume = Catchment area x Rainfalls

$=6.654\times10^6(m^2)\times2.666\ (m/year)=17.74\times10^6\ m^3/year$

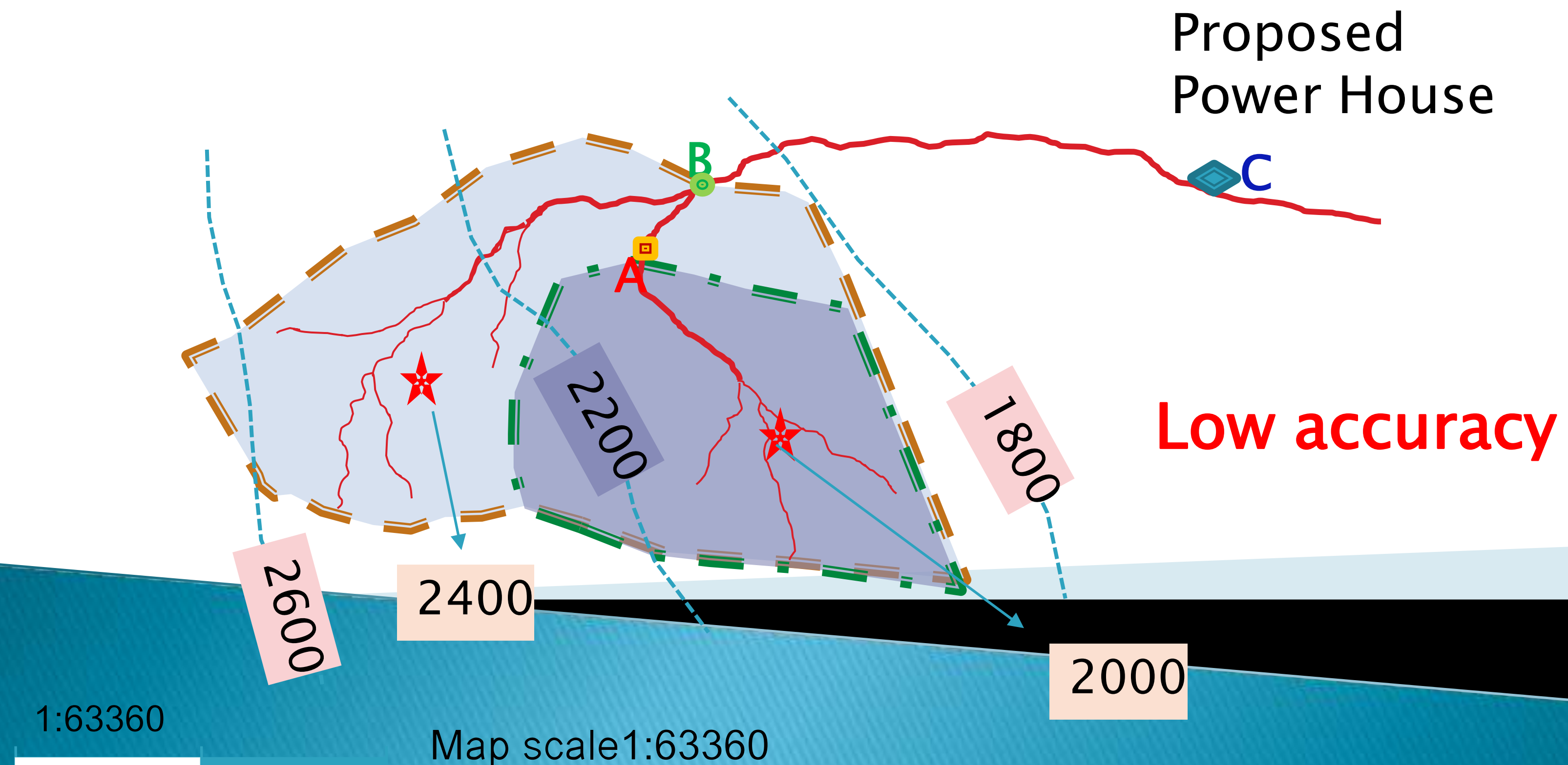
$ADF_B = 17.74\times10^6$ m³/ປີ/(365x60x60 s/ປີ)

$= 0.675\ m^3/s$

Run-off = Annual rainfalls - Evaporation

Desk study

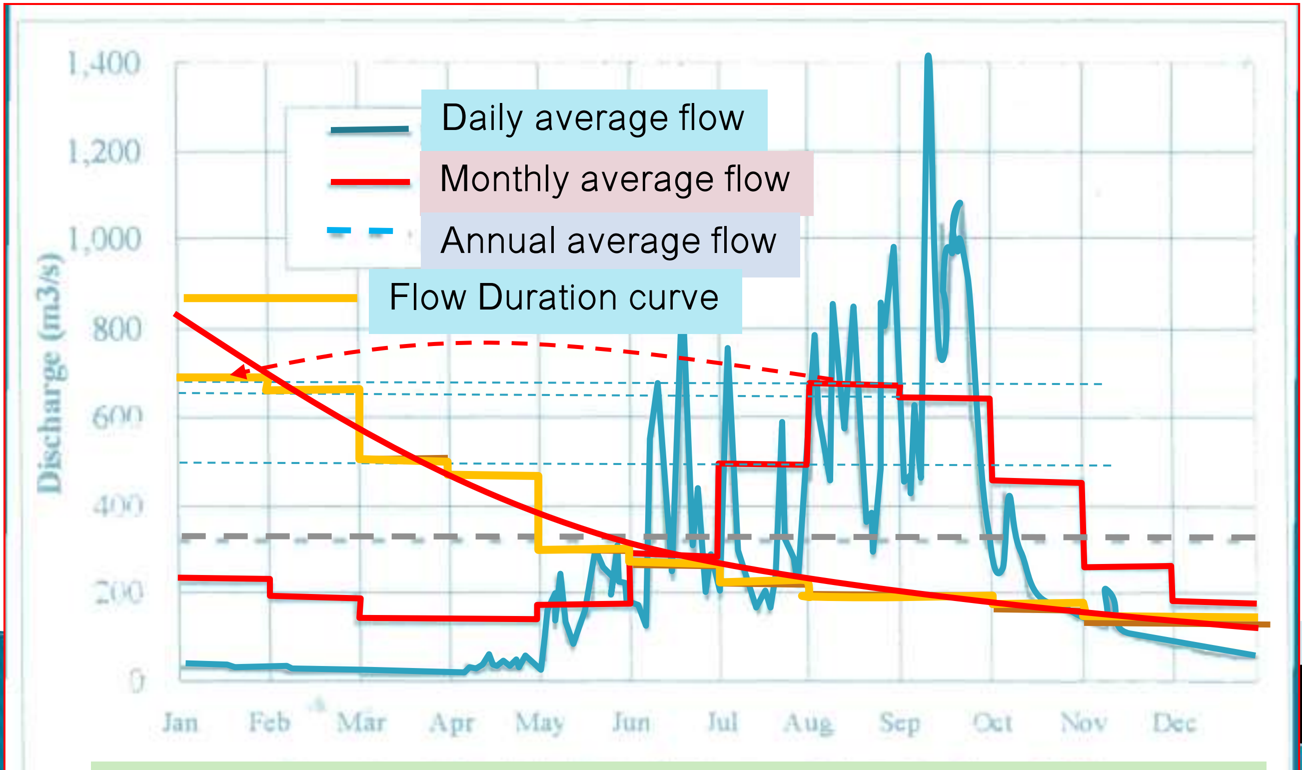
- **Area-Raifall method**
  - **In case of no Rain gauge**
  - **But there a map with Isohyets**



Correlation method

Hydrograph and Flow duration curve

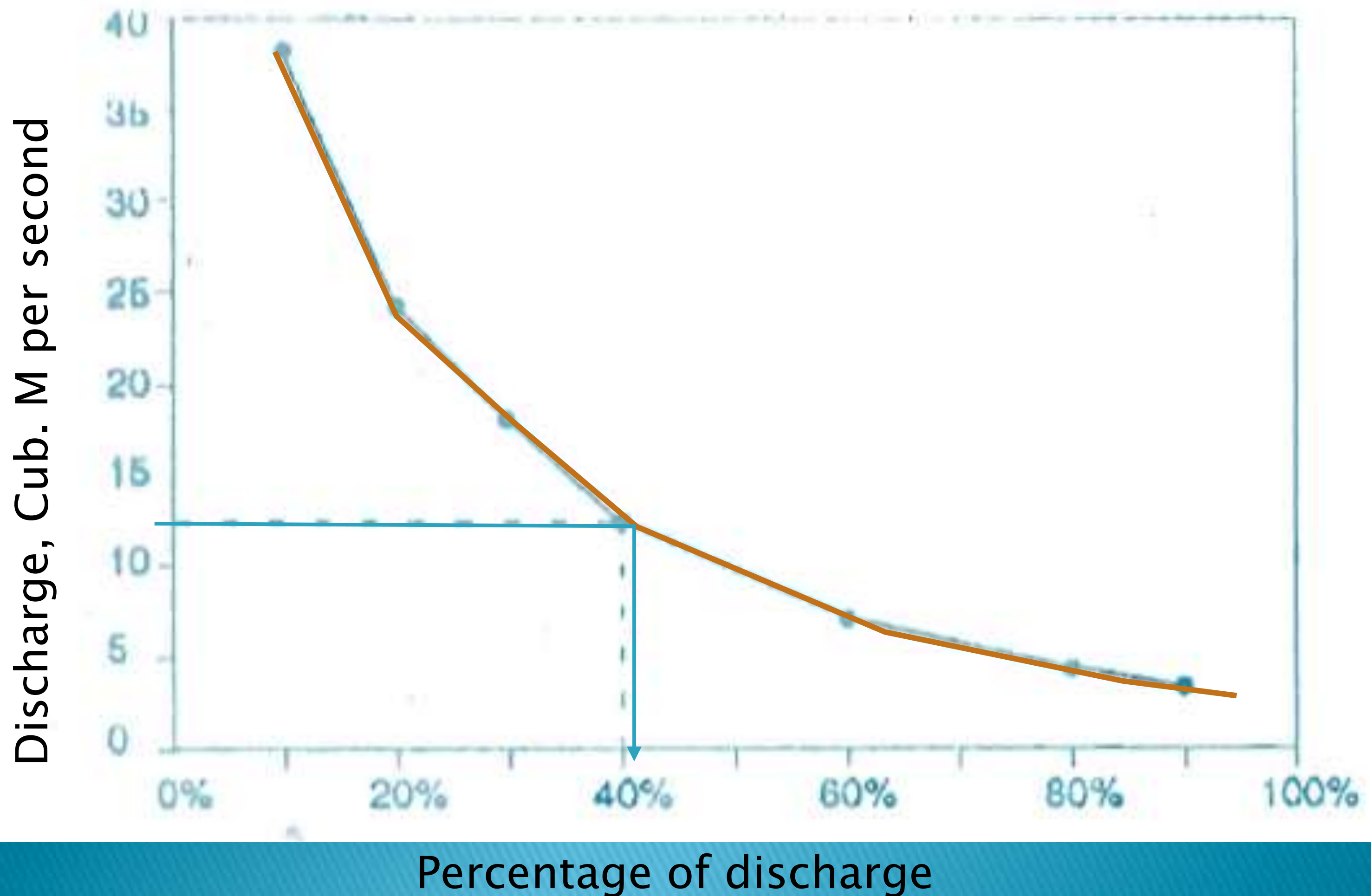
- Hydrograph Mean flows)



Annual and monthly Mean discharge of Nam Lik River 1991

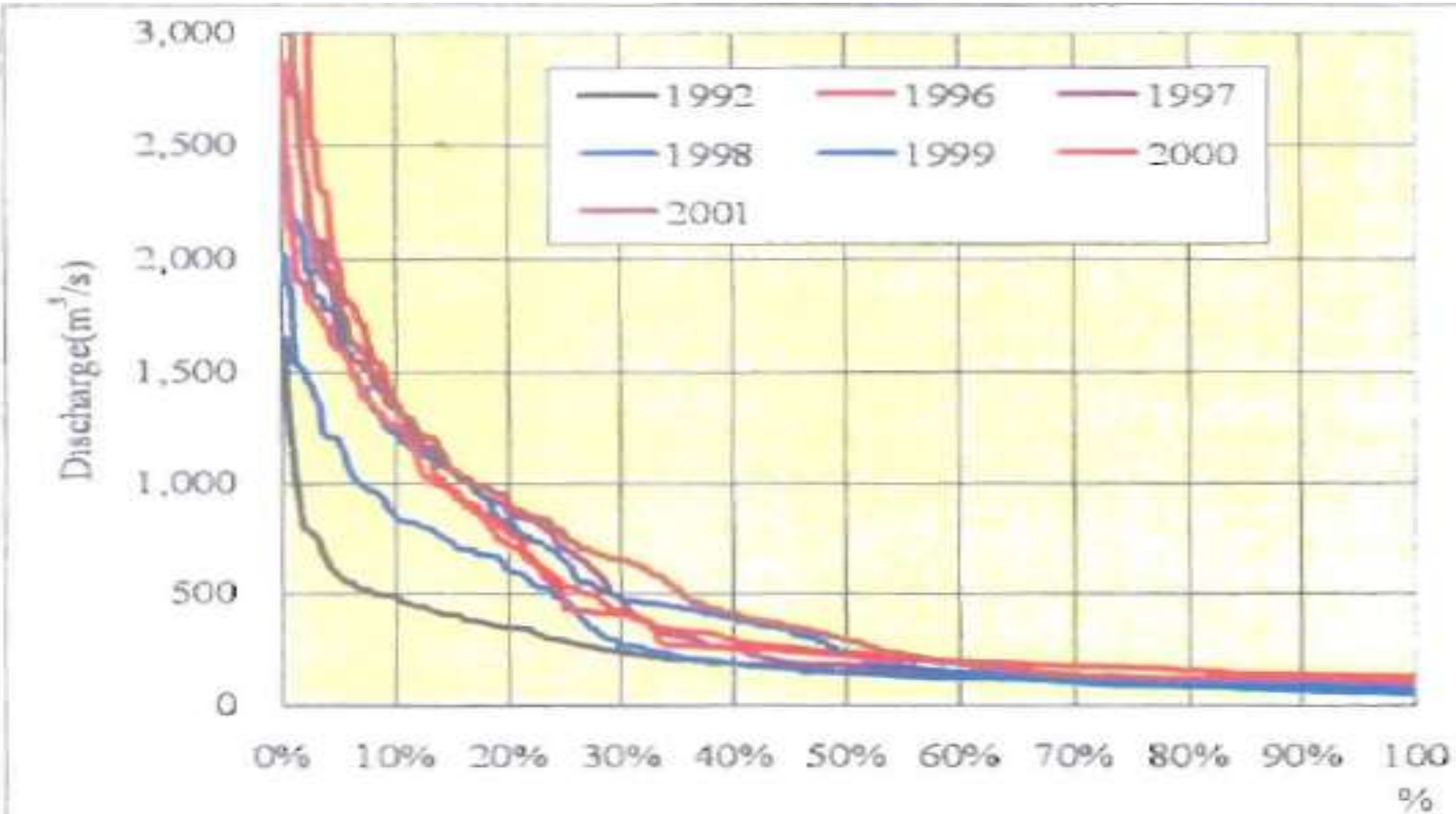
Correlation method

- Flow Duration Curve (FDC)



Correlation method

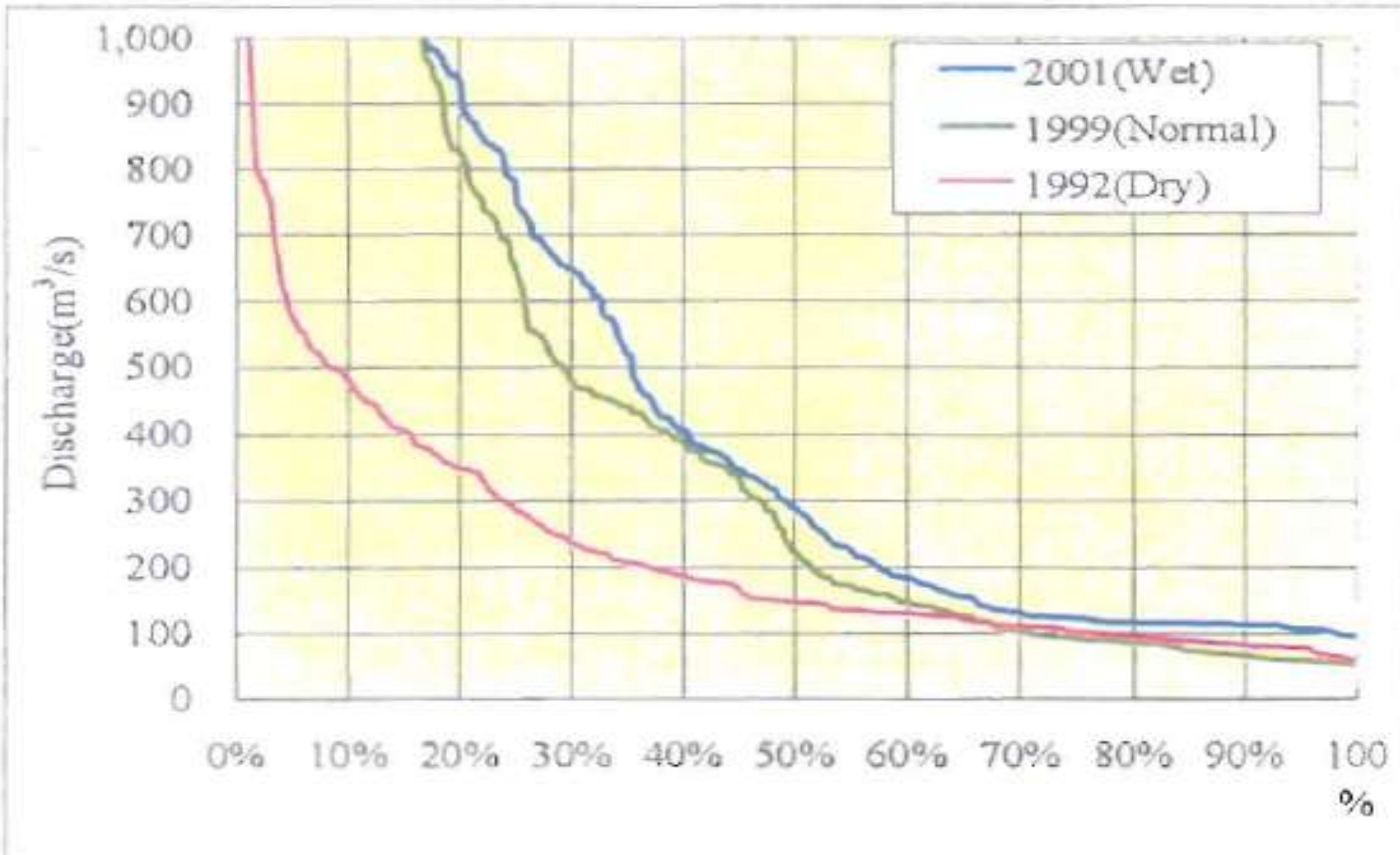
- Flow Duration Curve of Nam Ou River



Duration curve of Nam Ou River (1992, 1996-2001)

Correlation method

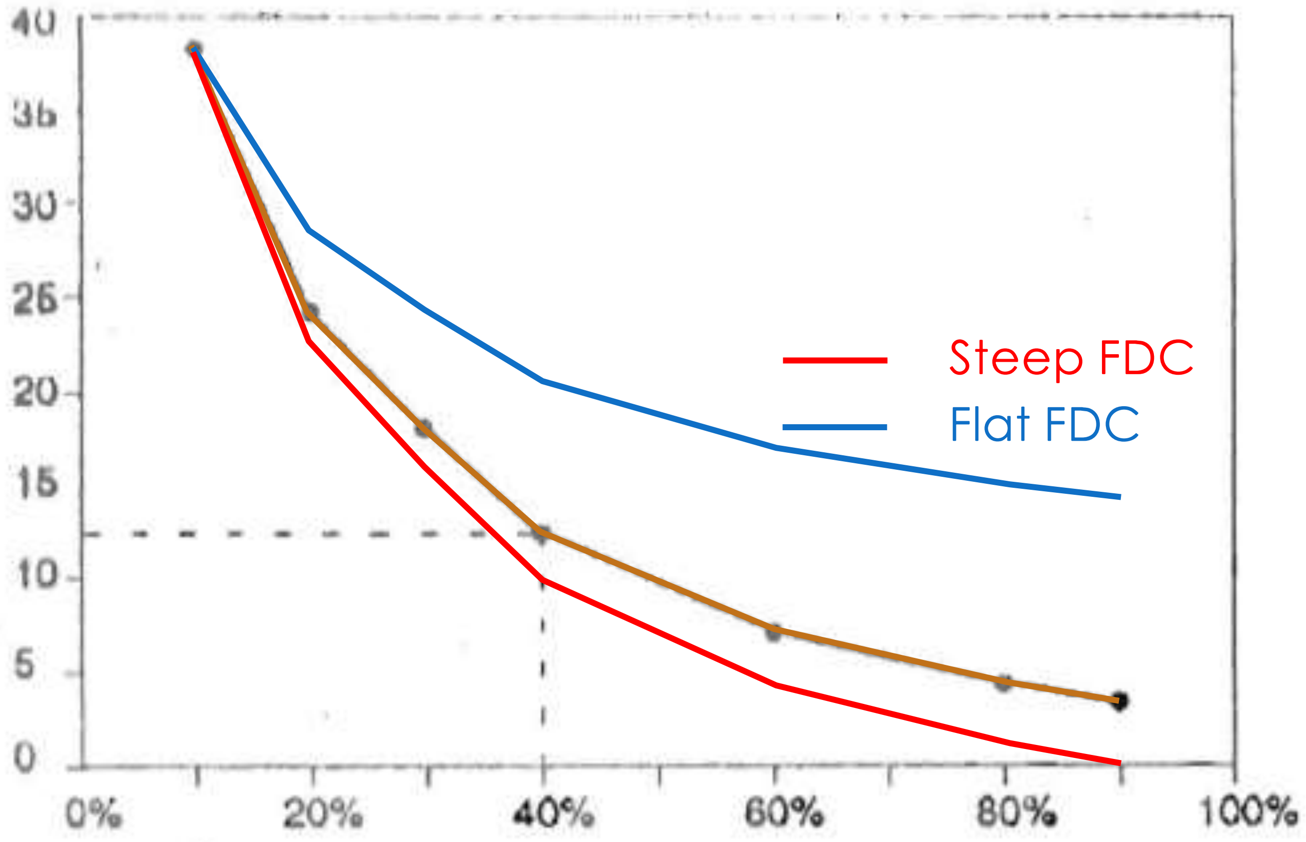
- FDC of Nam Lik River



Duration curve of Nam Lik (1992, 1996-2001)

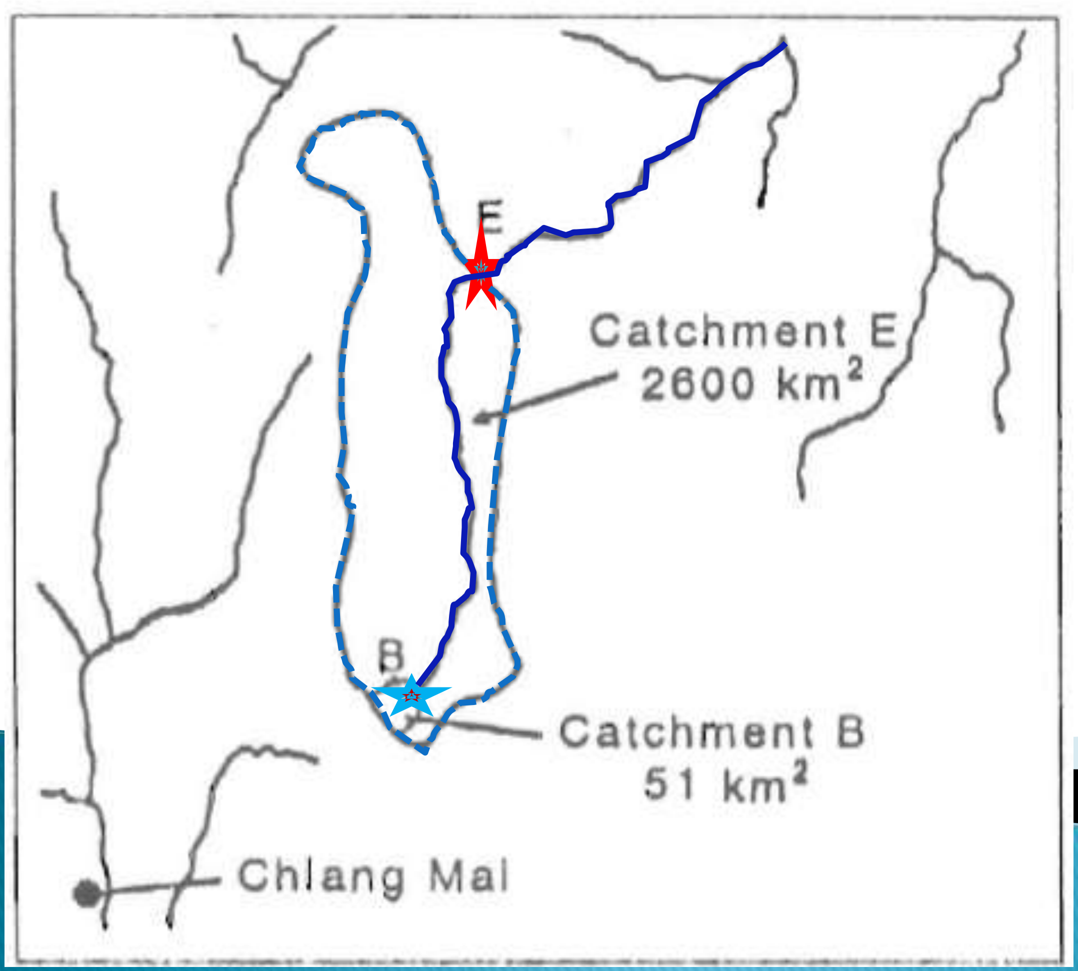
Correlation method

- Flow Duration Curve characteristics



Correlation method

- Absence of Rain gauge → to use data from near by gauged sites



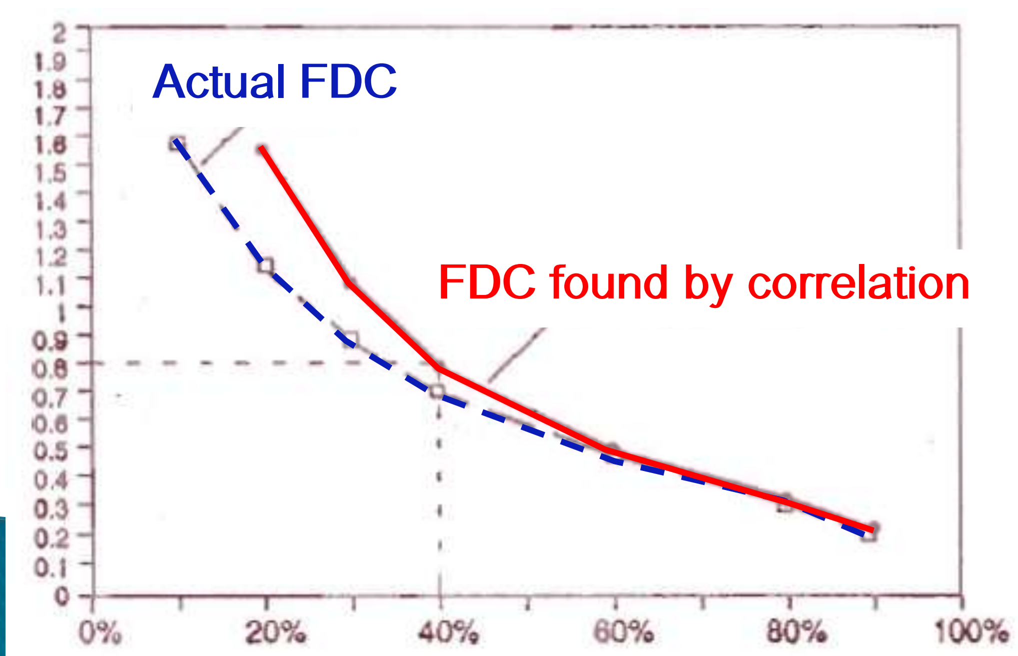
E - Gauged site

B –ungauged site

1) To do 10-12 measurements at B at random dates

Correlation Method

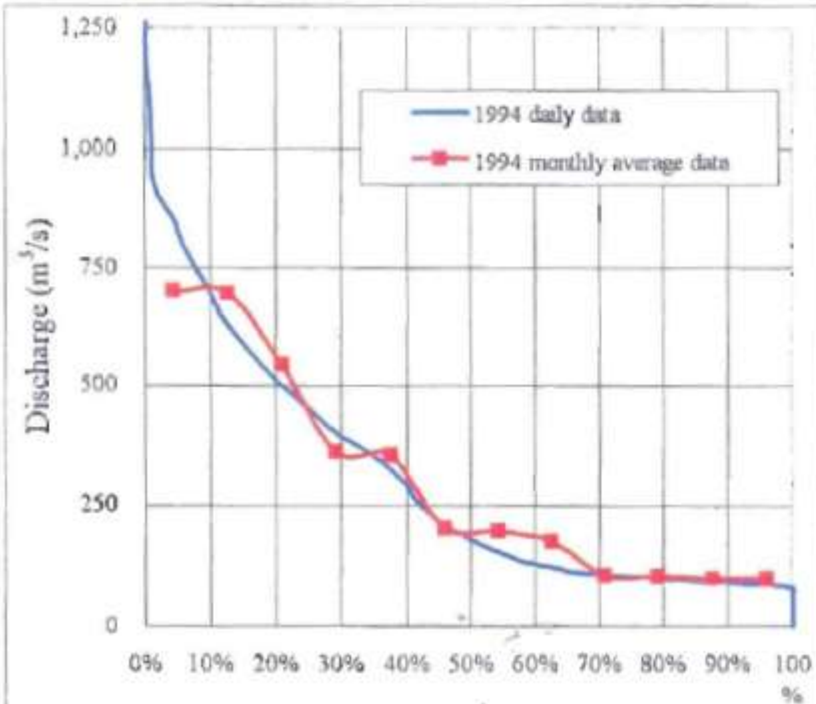
- **Absence of Gauged data**
  - Comparison of actual (measured) and found (correlated) FDC



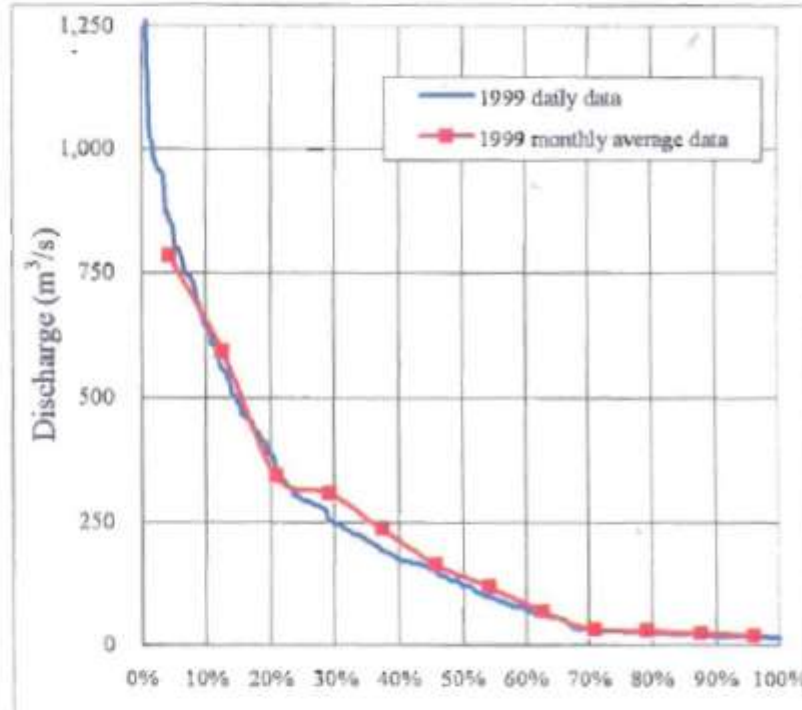
2) Plot the corresponding flows on a graph of flow at E vs. flow at B
3) Use the FDC of the gauged site to select a flow at a specific exceedence value
4) Not much different in dry season

Correlation method

- ## Example of FDC



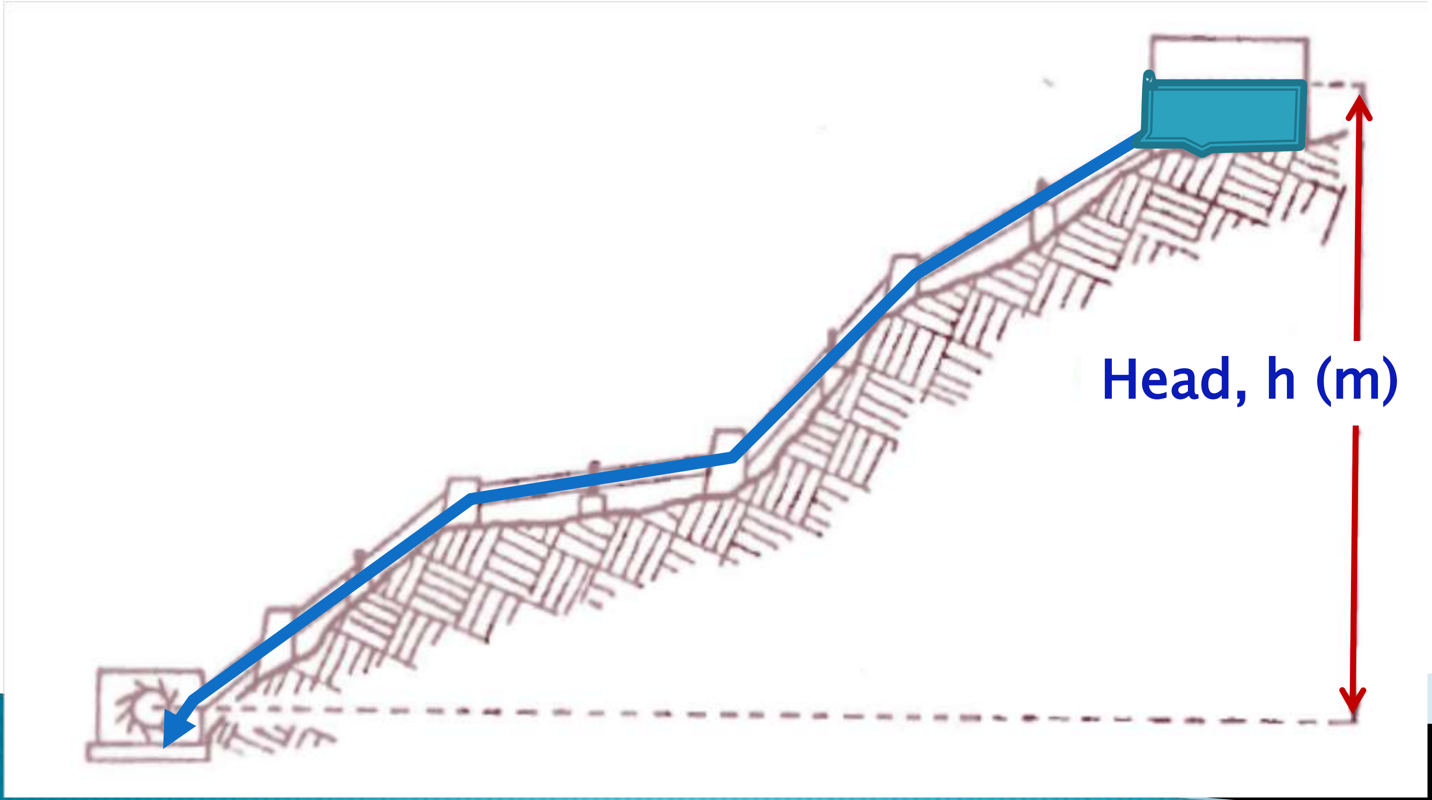
Comparison of Daily Data and Monthly Average Data of Duration Curve the Wet Year (1994, Nam Lik)



Comparison of Daily Data and Monthly Average Data of Duration Curve of Normal Year, Nam Lik River, 1999

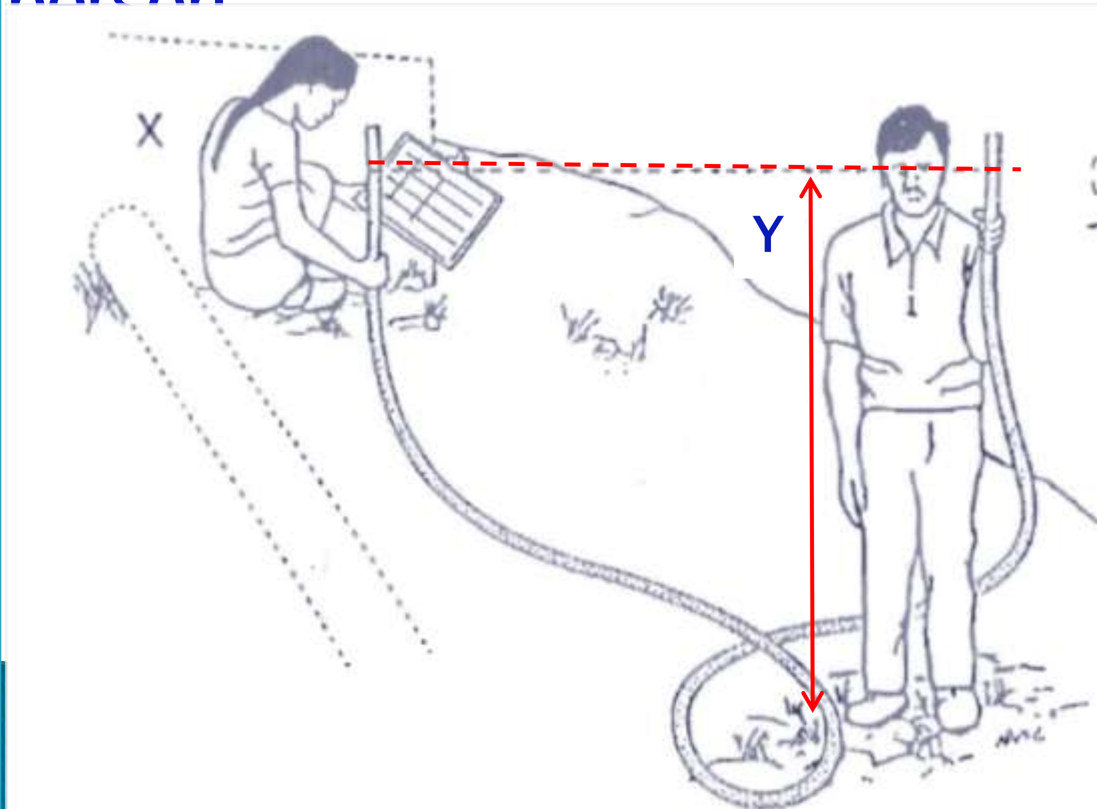
Site survey

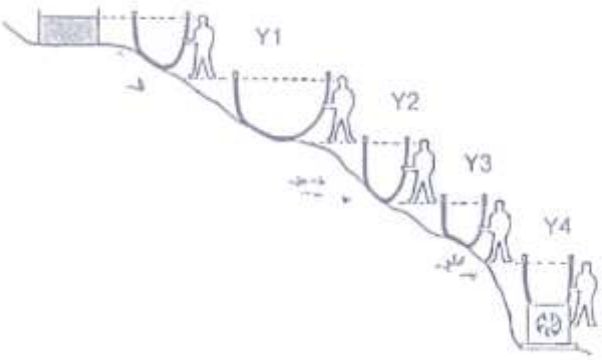
- Head Measurement



Site survey

- Head Measurement: water-filled clear tube and person

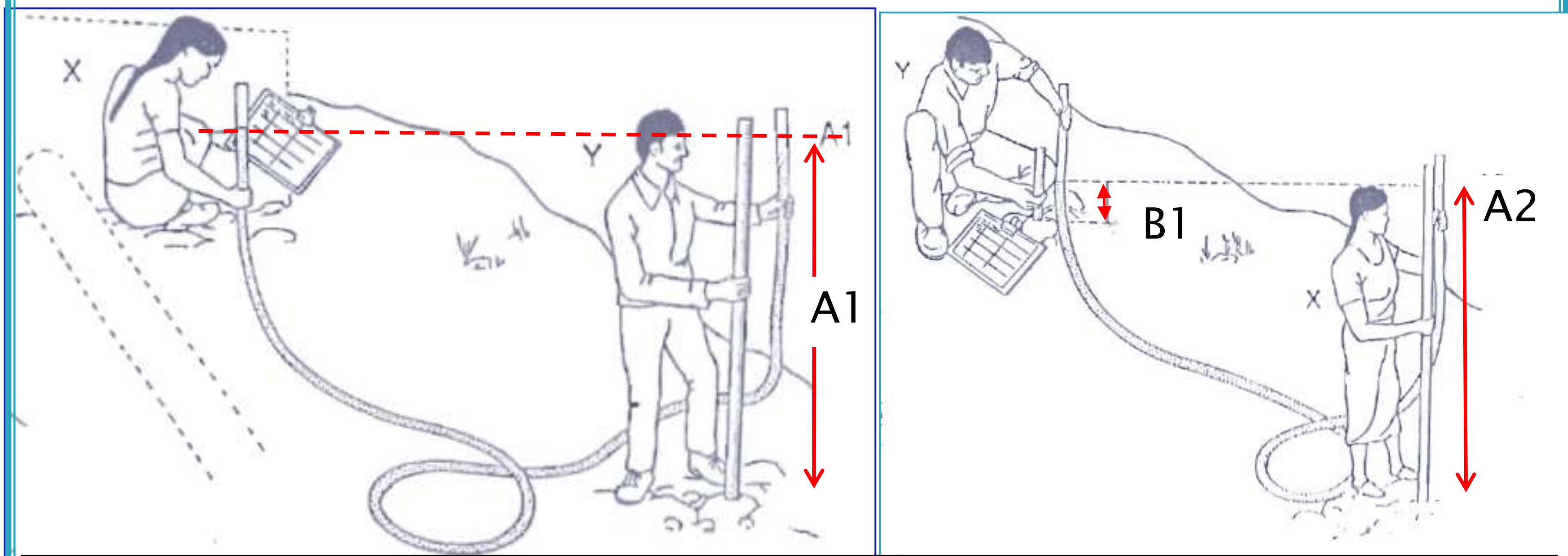




H(m) =Y1+Y2+Y3+Y4

Site Survey

- Head Measurement: water-filled tube and rode

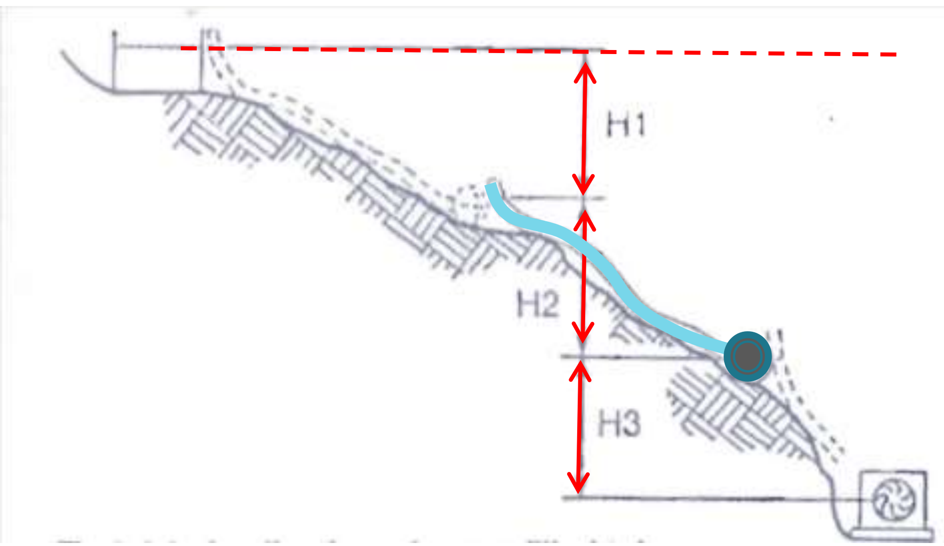


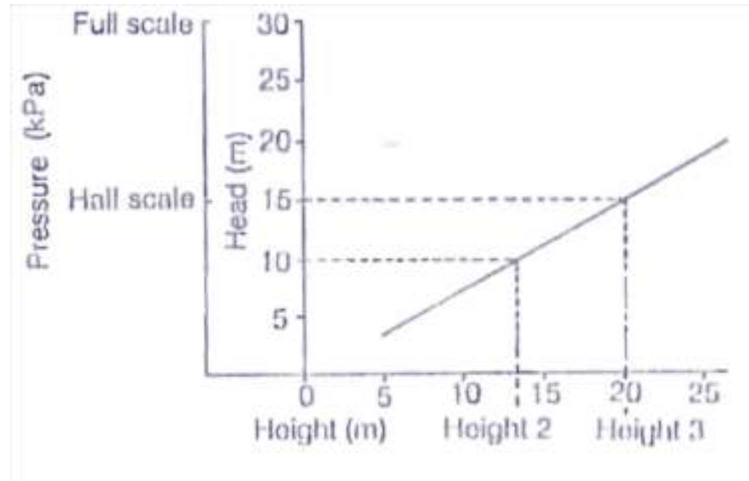
A1=	B1=	H1=A1-B1
A2=	B2=	H2=A2-B2
A3=	B3=	H3=A3-B3
H=H1+H2+H3+...		

Site Survey

- **Head Measurement:** water-filled tube with pressure

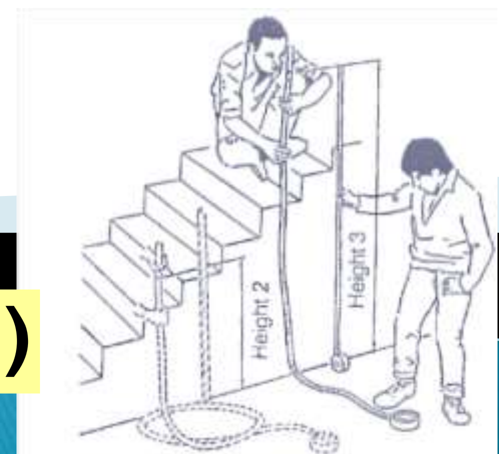
Can measure penstock length;



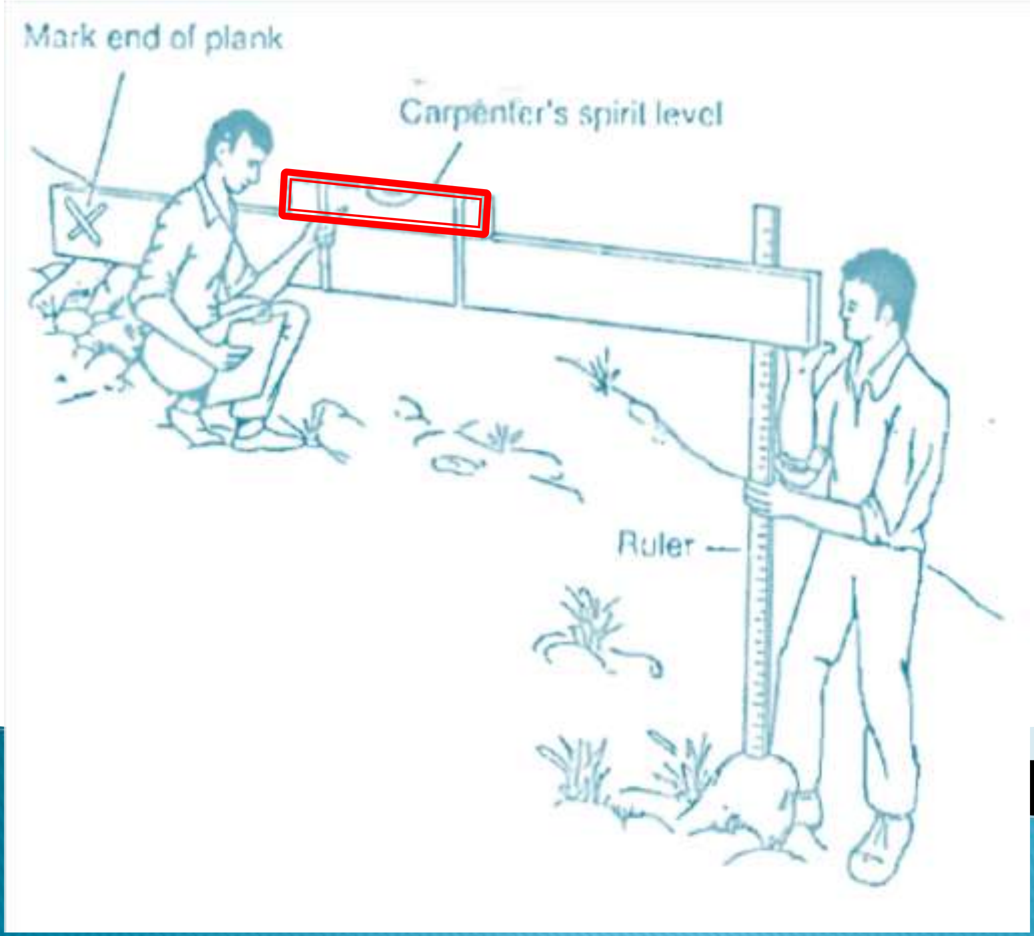


$$h(\mathrm{m}) = \frac{p\,(\mathrm{kPa})}{9.8}$$

$$h(\mathrm{m}) = 0.704 \times p\,(\mathrm{psi})$$



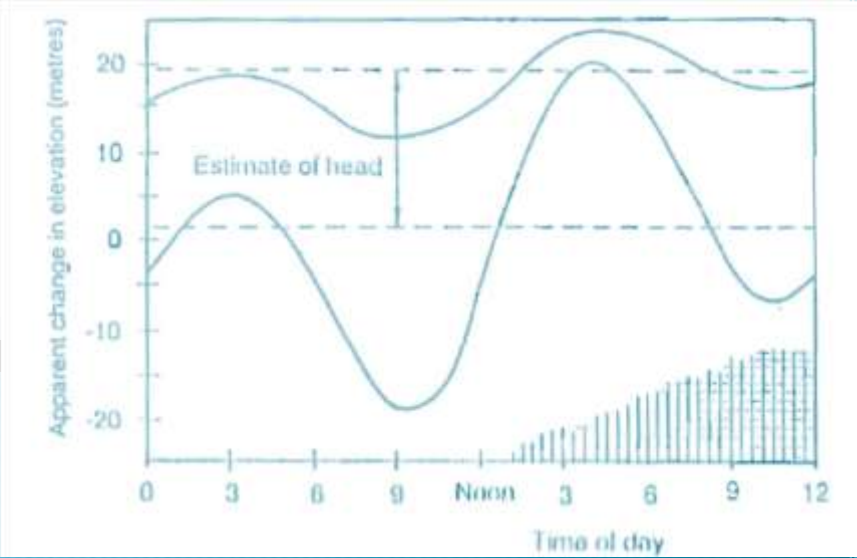
- Head Measurement: Carpenter's spirit level



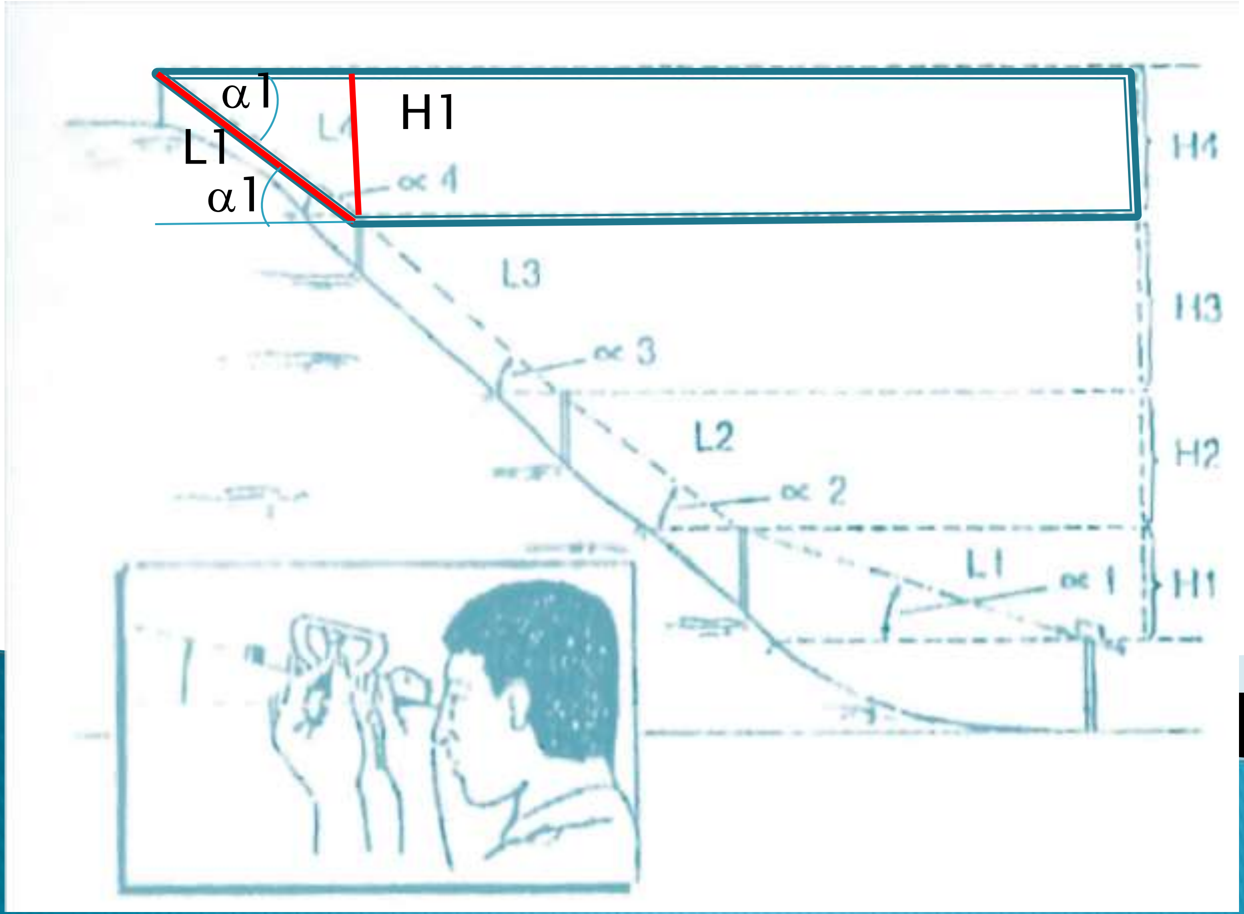
Site survey

- **Head Measurement: altimeter**
  - ✓ Useful for medium and high height
  - ✓ Sensitive to changes of air pressure, temperature and humidity
  - ✓ Skills needed to get high accuracy

Forebay		Powerhouse	
Reading	Time	Reading	Time
1000	10.15	900	10.20
1010	10.50	915	10.55
1015	12.00	930	12.30
1015	1.00	940	1.30



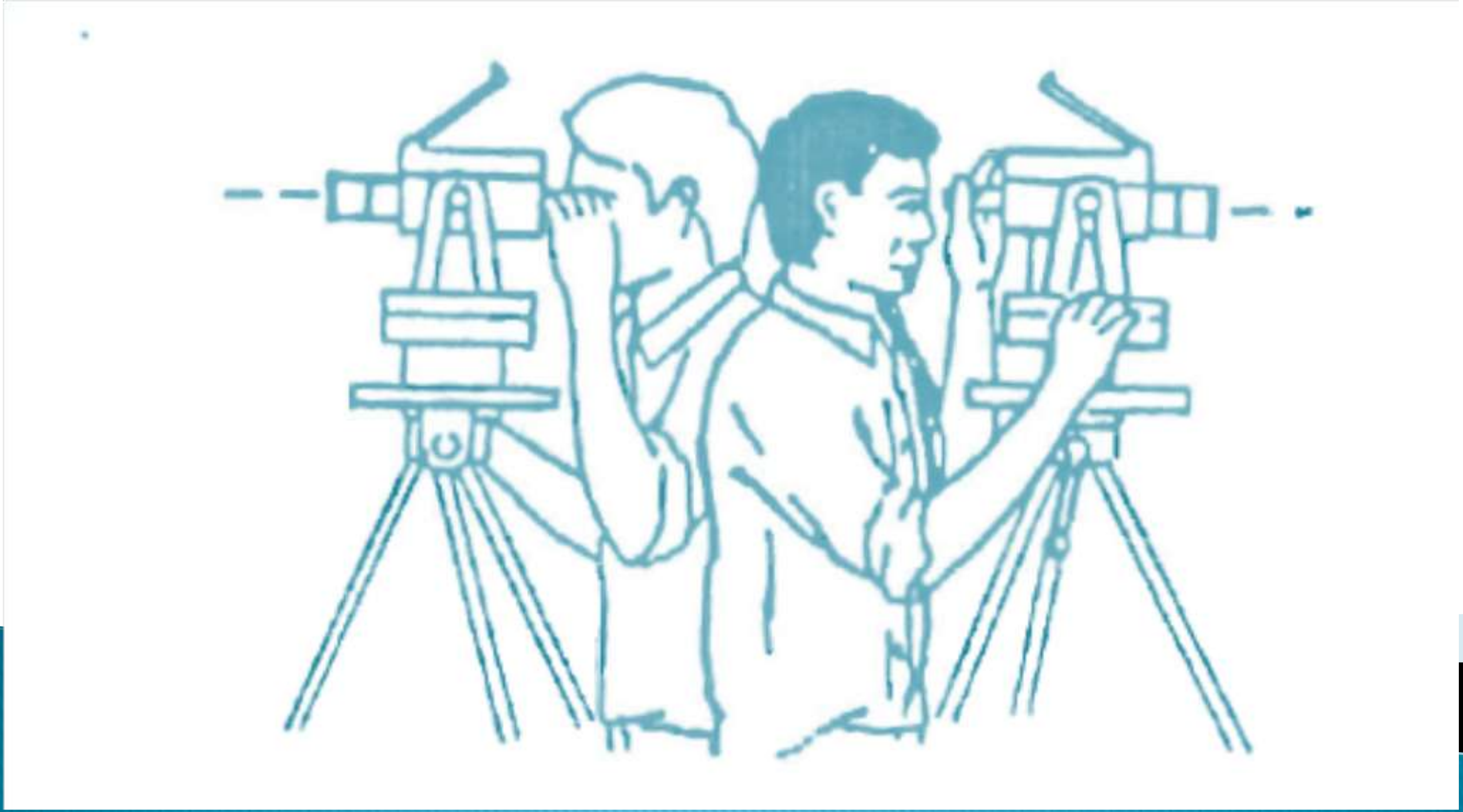
- Head Measurement: Clinometers



$H_1 = L_1 . \sin(\alpha_1)$

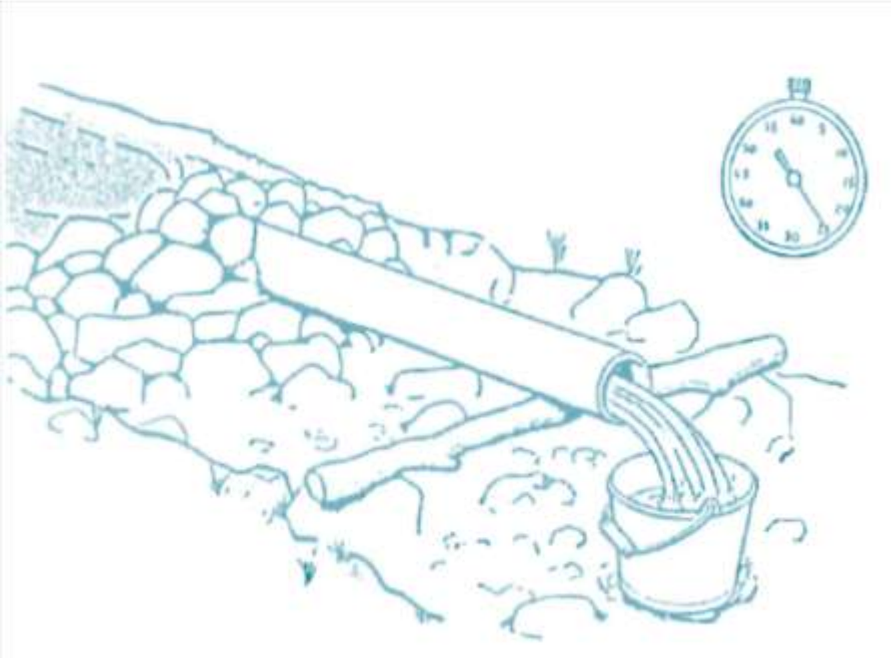
Site Survey

- Head Measurement: Sighting and Theodolites



Site Survey

- Site Flow Measurement: Bucket/Oil drum method



$$Q = \frac{V}{t}$$

$$V_{water} = \frac{m_{water}}{\rho_{water}}$$

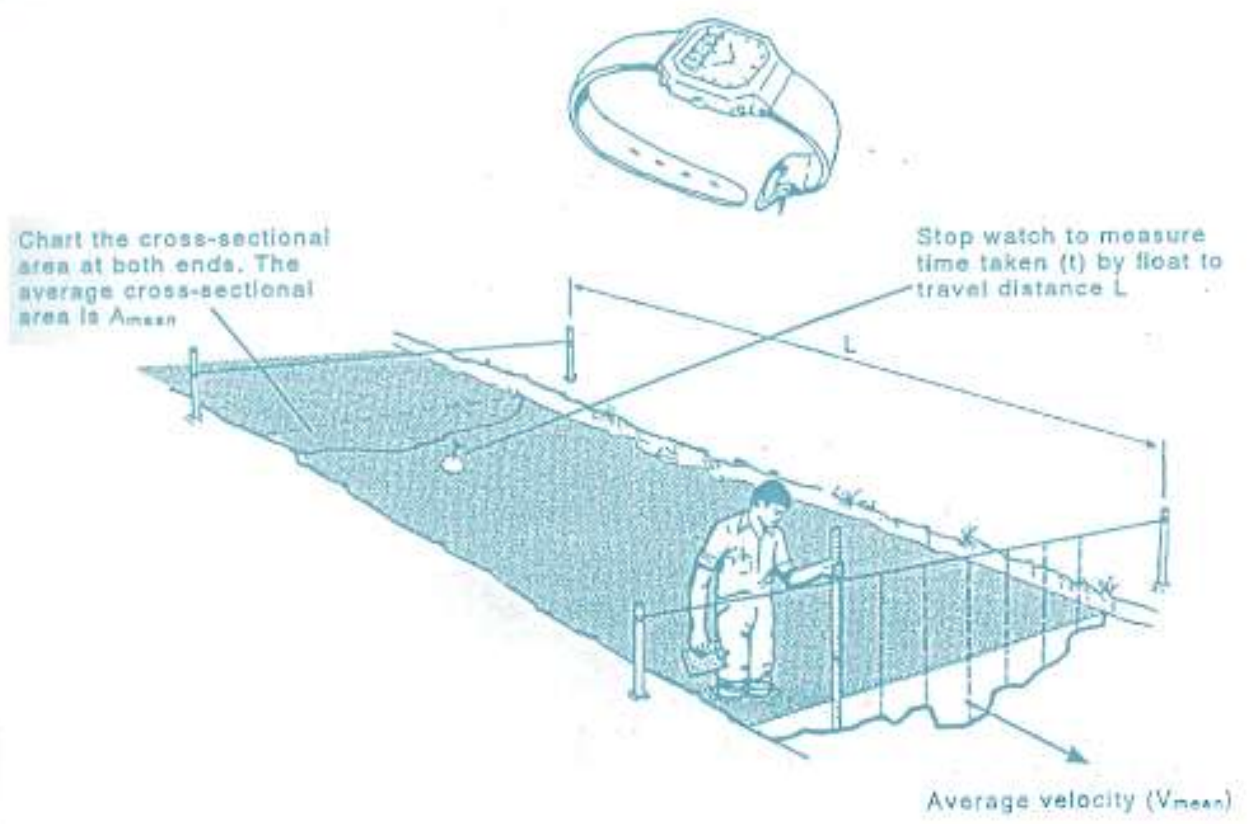
$$m_{water} = m_{(bucket+water)} - m_{bucket}$$

Bucket: suitable for flow rate < 5 L/s
200L Oil drum: < 50 L/s

- **Site Flow Measurement: Cross area & Velocity method**

$$Q = A \times v_{mean}$$

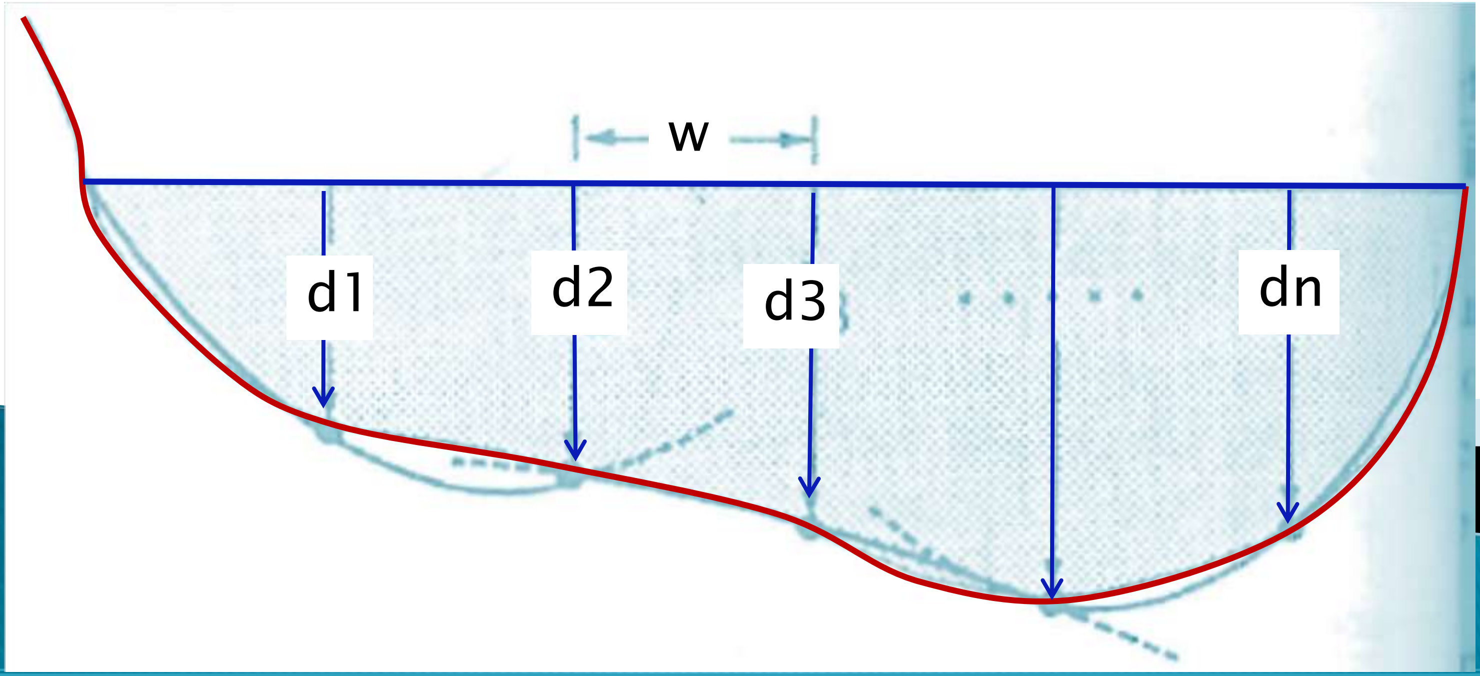
Q – Flow rate, m^3/s
A – Cross-sectional area, m^2
v_{mean}- average velocity, m/s



- Site Flow Measurement: A & V method
  - ✓ Cross section area of a stream/river

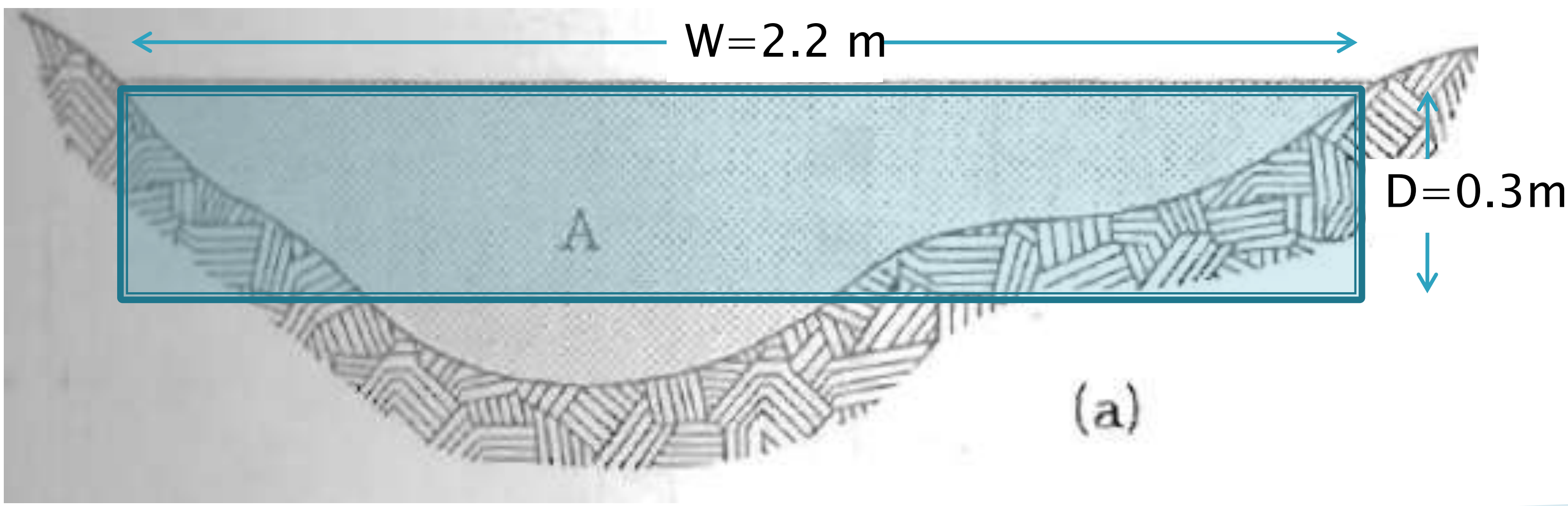
$$A = \frac{w}{3}\left[4\left(d_1 + d_3 + \ldots + d_n\right) + 2\left(d_2 + d_4 + \ldots + d_{n-1}\right)\right]$$

n–Odd number (1,3,5,...)



Site Flow Measurement: A & V method

- Cross section area calculation: Simple cross section

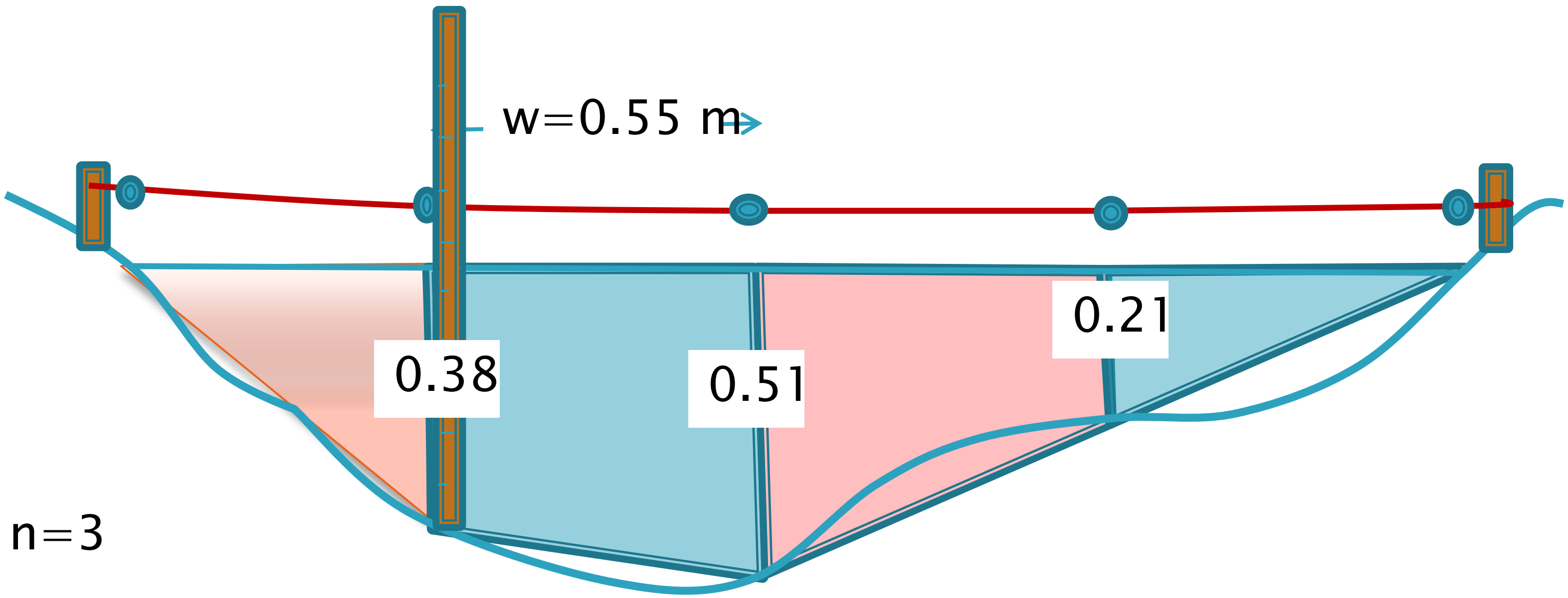


$$A = w \times d = 2.2 * 0.3 = 0.66 \text{ m}$$

Site Survey

•Site Flow Measurement: A & V method

✓ Un-uniform Cross section



$$A = \frac{w}{3}\left[4\left(d_1 + d_3 + \ldots + d_n\right) + 2\left(d_2 + d_4 + \ldots + d_{n-1}\right)\right]$$

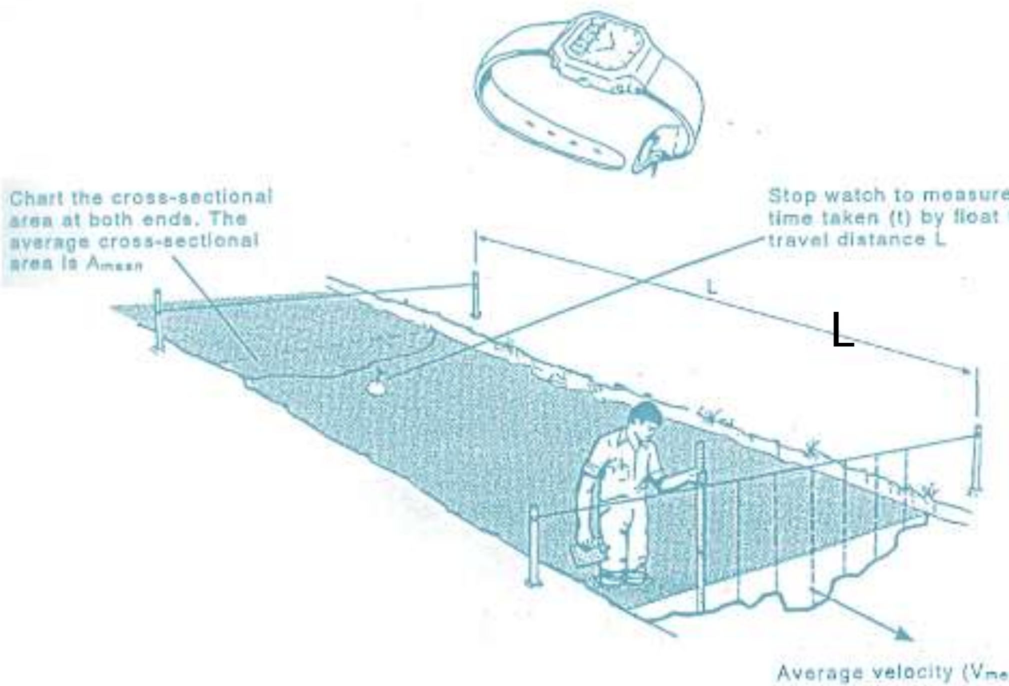
$$= \frac{w}{3}\left[4(d_1 + d_3) + 2(d_2)\right] = \frac{0.55}{3}\left[4 \times (0.38 + 0.21) + 2 \times (0.51)\right] = 0.62 \text{ m}^2$$

Site Flow Measurement: A & V method

- ✓ Measuring average flow velocity $\bar{V}$

$$v_s = \frac{L}{t}$$

$$\bar{V} = C \times v_s$$



Average velocity, $\bar{v}$ or v_{mean}

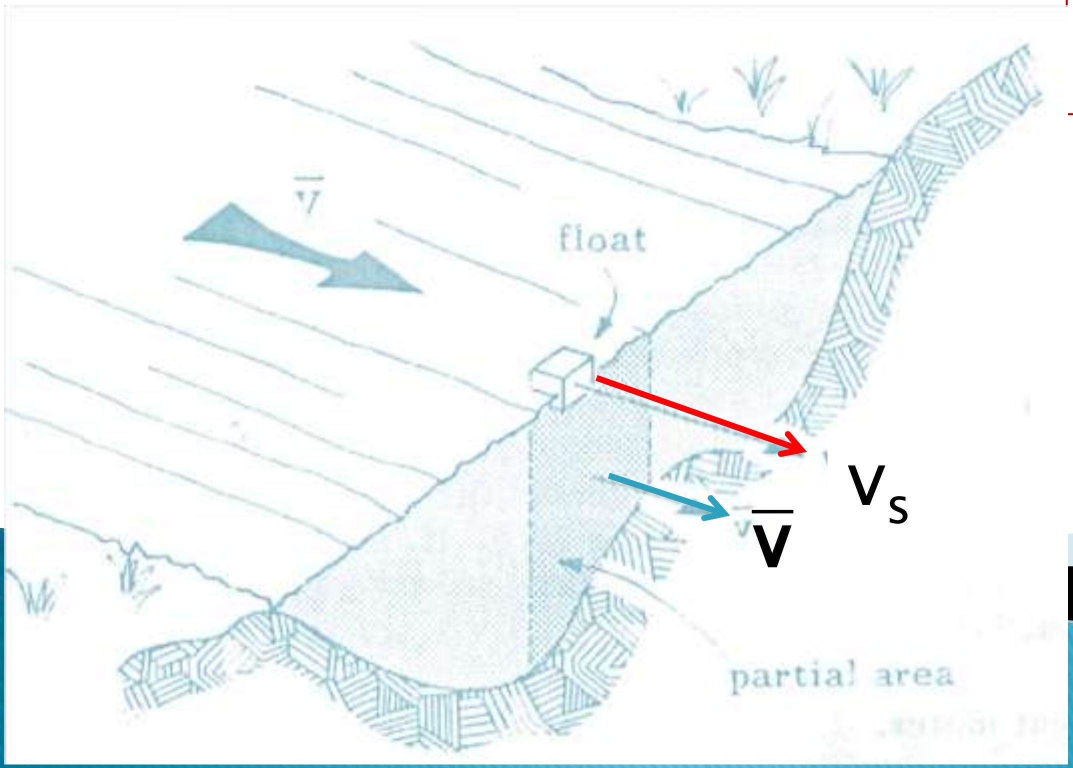
C=0.85- for smooth, rectangular concrete channels
C=0.75- for large, slow, clear stream
C=0.65- for small but regular stream with smooth stream bed
C=0.45- for shallow (0.5 m) turbulent flow
C=0.25- for very shallow and rocky stream

Site Survey

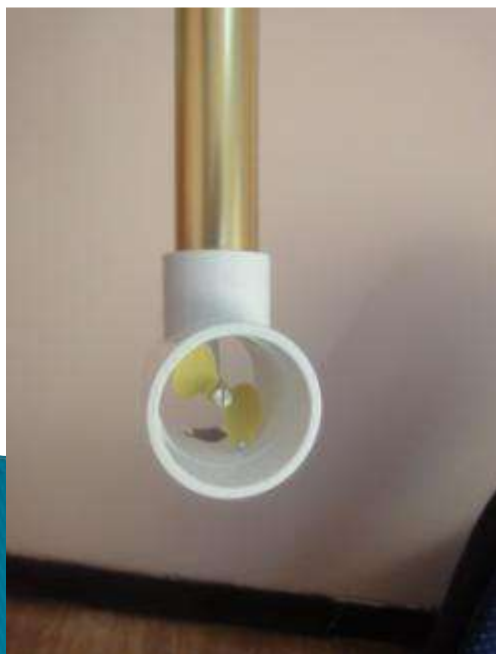
- Site Flow Measurement: A & V method
  - ✓ Average velocity in a partial area

V_s – Velocity in a Partial area $\qquad \bar{\mathbf{V}} = c \times \mathbf{V}_s$

c=0.75-Shalow stream
c=0.95-deep stream



- Site Flow Measurement: A & V method
  - Propeller Flow meter can measure:
    - Partial area velocity
    - Average stream velocity



Site Survey

- Site Flow Measurement: A & V method
  - Propeller Flow meter use

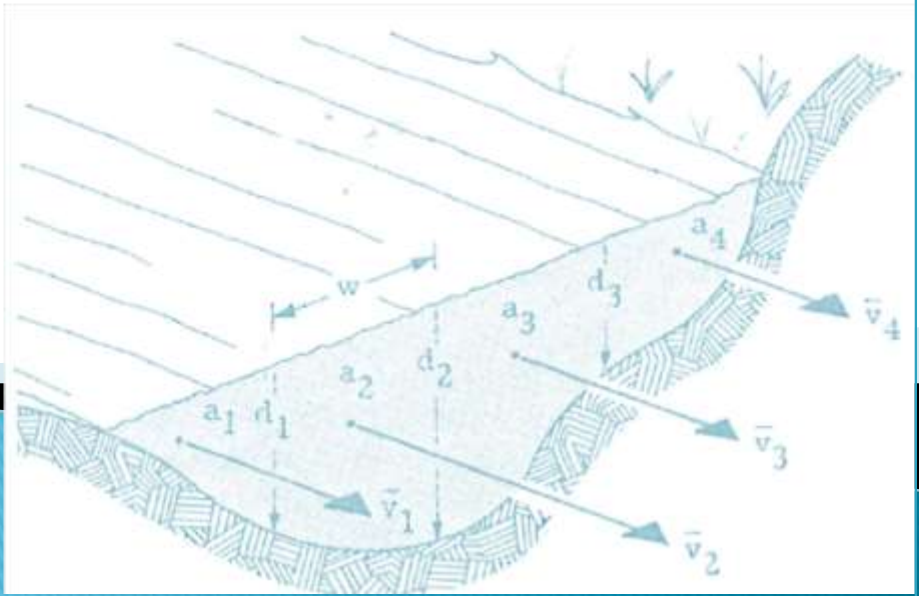
- Site Flow Measurement: A & V method
  - Total Flow rate = Sum of Partial Area Flow rate

$$Q = a_1\bar{v}_1 + a_2\bar{v}_2 + \ldots + a_n\bar{v}_n$$

where a1, a2,… partial areas

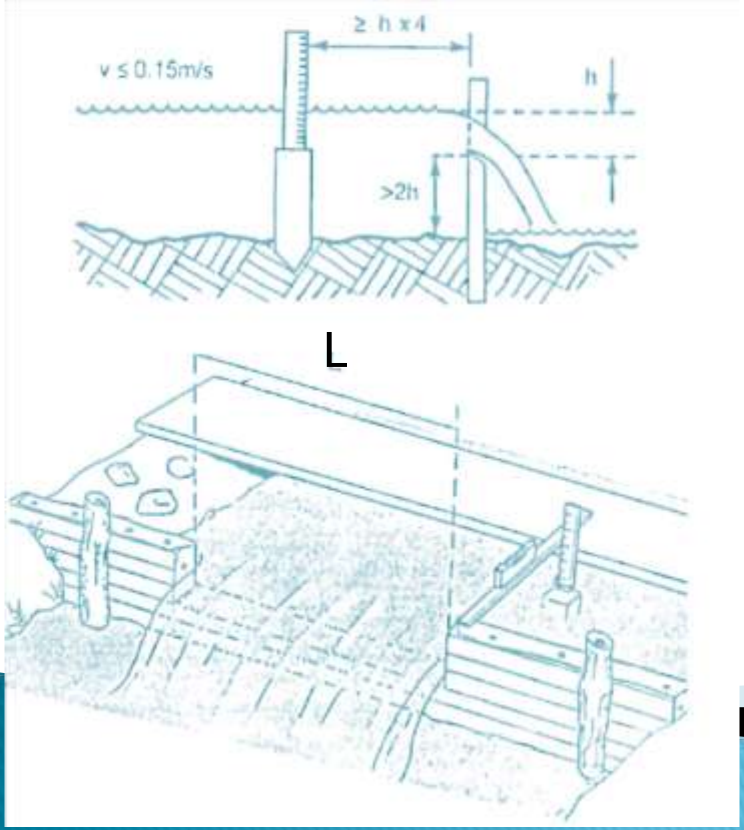
Example: partial area between d_2 and d_3

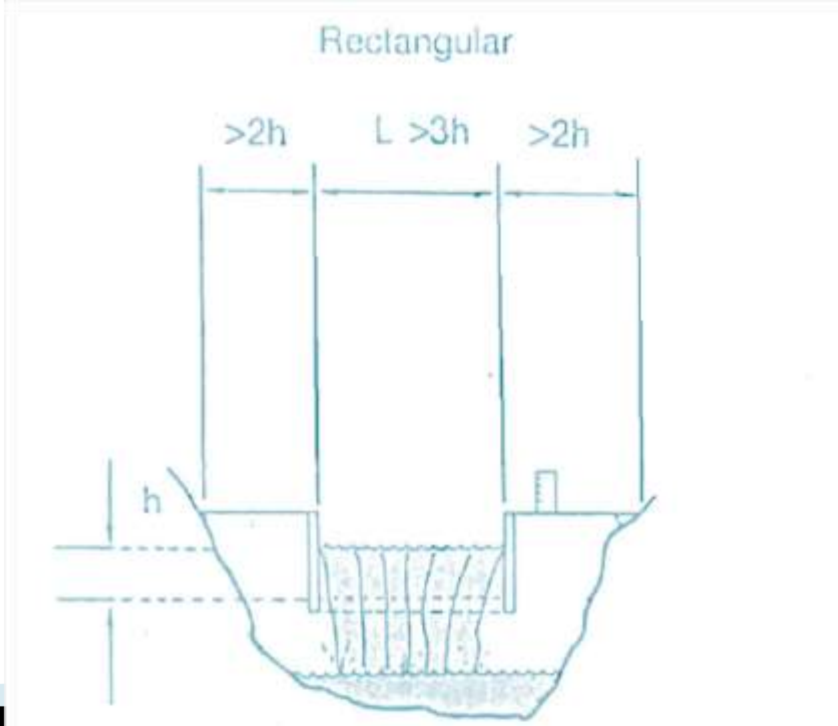
$$a_3 = \frac{(d_2 + d_3)}{2} \times w$$



Site Flow Measurement: Weir method

- Rectangular weir



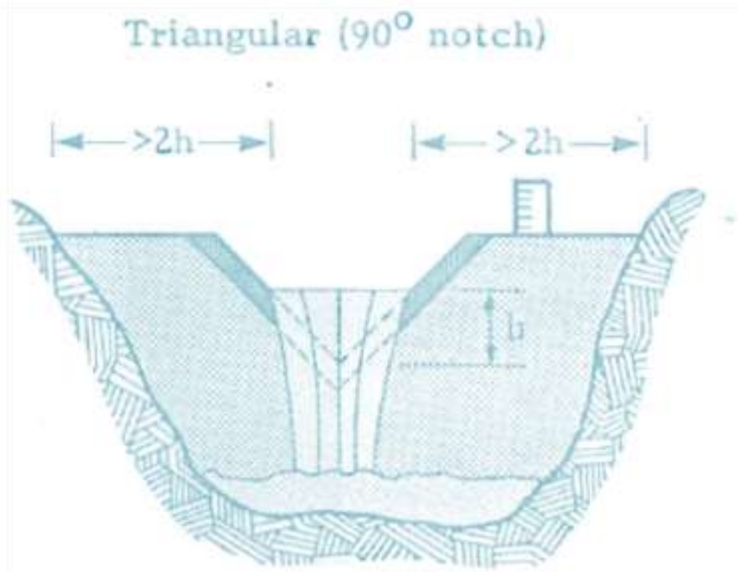


$$Q = 1.8(L - 0.2h)h^{3/2}$$

ໄຟຟ້ານ້ຳຕົກຂະໜາດນ້ອຍ Small-scale Hydropower

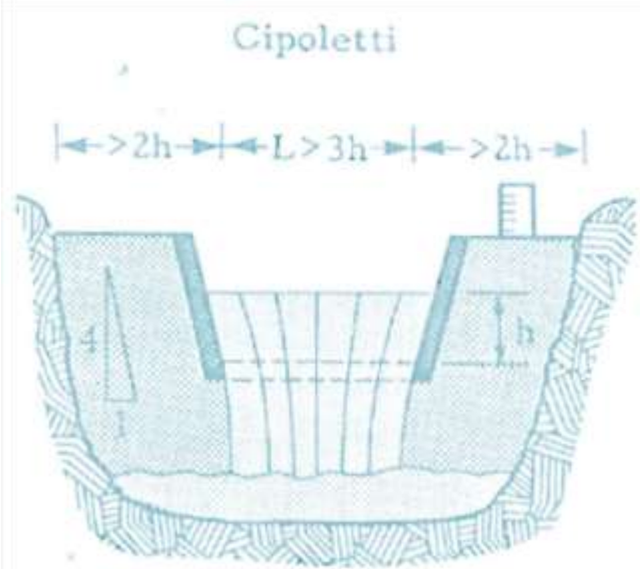
ວັດແທກອັດຕາການໄຫຼຂອງແມ່ນ້ຳ (Site Flow Measurement)

- ວິທີສ້າງຝາຍກັ້ນນ້ຳ ແລະປະຕູປ່ອຍນ້ຳ ຊະນິດອື່ນໆ



$$Q = 1.4h^{5/2}$$

ປະຕູສາມຫຼ່ຽມ (ມຸມສາກ)



$$Q = 1.9Lh^{3/2}$$

ປະຕູເປັນຮູບຄາງໝູ

Site Survey

- **Site Flow Measurement:** salt 'gulp' or salt dilution method
  - ✓ Quick measurement
  - ✓ High accuracy
  - ✓ Conductivity meter needed

Conductivity meter calibration

Assessment of small scale hydropower potential

Thank You !