Water and Development

Part 2b: Surface Flows

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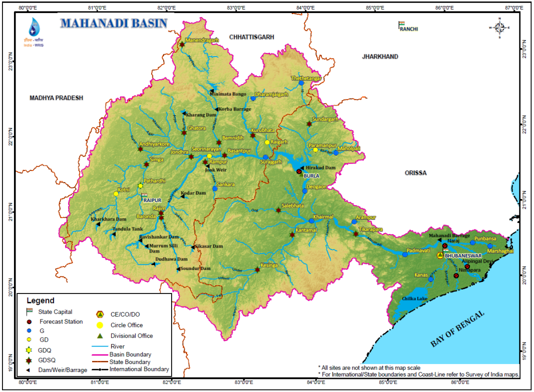
What happens when it rains?

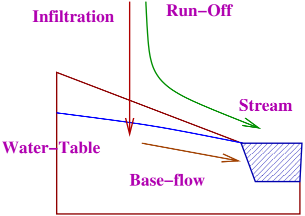


- What happens when a drop hits the ground?
- How much flows? Where does it go?
- How do we measure and estimate rain and flow?

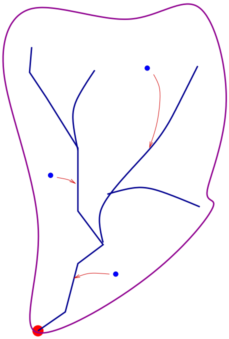
Precipitation to Run-Off

Many stages from Precipitation to Run-Off

- Interception: The contact of the raindrop with vegetation.
- Stem-Flow: Flow of water from plant to soil.
- Infiltration: Coversion of liquid-water to soil moisture.
  - Saturation: All soil pores get filled with water.
- Run-Off: Two components:
  - Overland-flow: Post saturation! Excess flow reaches streams.
  - Base-flow: Groundwater releases moisture into streams.

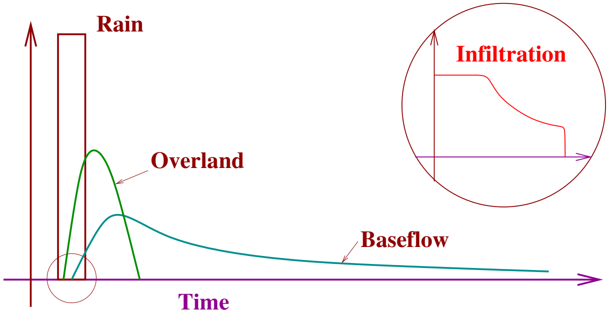


What happens when it rains



$$
\begin{aligned}
\text{stream}(t) &= \text{only-surface}(t) + \text{sometime-in-ground}(t) \\
\text{precip}(t) &= \text{infil}(t) + \text{only-surface}(t) \\
\text{infil}(t) &= \text{sometime-in-ground}(t) + \text{all-time-in-ground}(t) \\
\text{out}(t) &= \text{stream}(t) + \text{all-time-in-ground}(t) \\
\text{precip}(t) &= \text{out}(t)
\end{aligned}
$$

What happens when it rains



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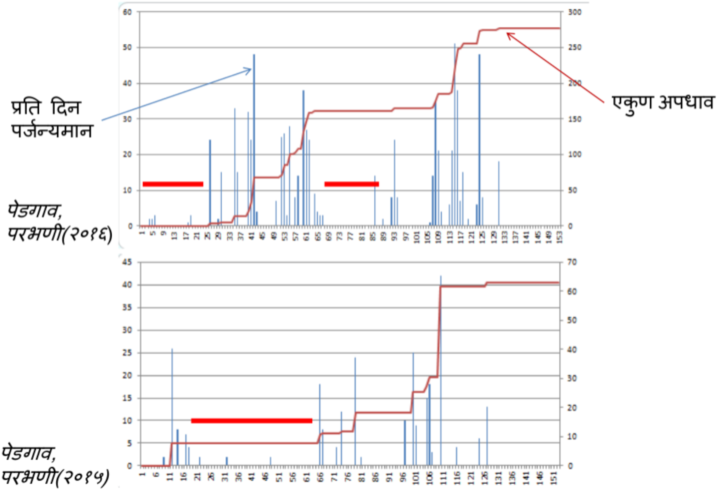
\text{precip(t)} &= \text{out(t)}
\end{aligned}$$

Immediate Runoff

Dry spells



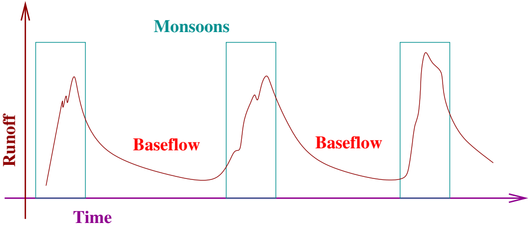
Stream-flow and Base-flow

- The stream flow is largely baseflow for most of the year.
- Only in the monsoon is there a run-off component.
- A simple exponential flow model:

$$flow = Ae^{-\alpha t} + B$$

where A, B and α are parameters of the watershed.

- A small α signifies good health.
- If flow is negative, assume it to signify that the stream is dry.



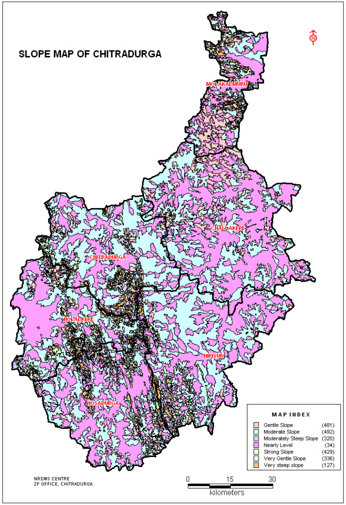
Infiltration and Stream-flow

Infiltration

- This is the part of precipitation which flows out of the watershed through rivers and streams.
- Overall Indian average is about 43% , in Konkan its above 93 % .
- The difference
  - is stored in reservoirs and tanks.
  - recharges ground-water.
  - evaporates or is consumed.
- Stram-flow is a function of rain-intensity, slope, land-conditions, forest-cover, existing soil-moisture and many other things.

- How do I estimate stream-flow and infiltration?
- How do I modify these?

Slope



- Both stream-flow and infiltration depend greatly on the slope.
- Slope-maps are an important input for developing Stream-flow and infiltration models for the water-shed.
- Infiltration models are easier and depend on point conditions.
- Stream-flow models are more difficult and also must model drainage and thus, floods.

Computing flows-The Leaky Bucket Model

Regions	S1	S2	S3	S4	S5
Area Ha.	220	330	510	430	290
Capacity (TCM)	13	34	100	70	30
Storage (TCM)	2	8	12	12	20
Infiltration α	0.4	0.5	0.6	0.3	0.5
ET b (mm)	3	5	6	6	7

$$\begin{aligned} storage_i(n+1) &= (1-\beta) * storage_i(n) - ET_i(n) + \Delta_i(n) \\ \Delta_i(n+1) &= \min(cap_i - storage_i(n+1)), \alpha \cdot rainfall_i(n)) \end{aligned}$$

Rain f (mm)	S1	S2	S3	S4	S5
Day 1	11	11	9	9	9
Day 2	0	0	0	0	0
Day 3	2	2	2	3	2

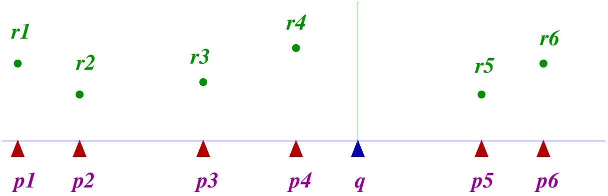
Measuring Rain (wikipedia)

Standard : Funnel-top, and a measuring cylinder.

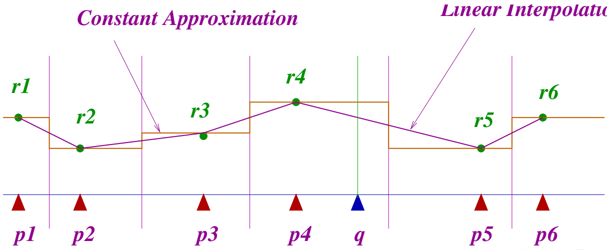
Tipping bucket : Funnel, with water falling on a see-saw. Pulse generated every 0.2mm. Now standard in India.

Estimating Data

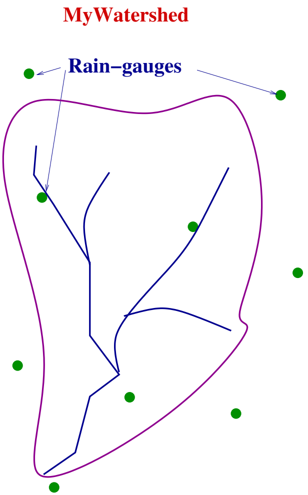
Frequent Situation: Data observed at discrete points p_i. Estimate to be made for another point q.



Two simple options. Constant and Linear interpolation.

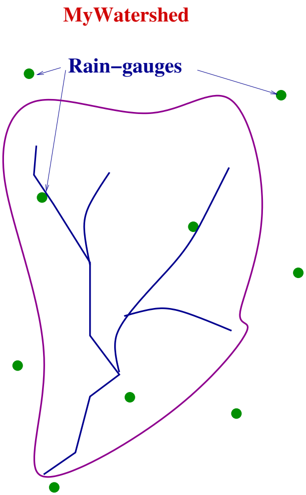


MyWatershed-estimating total rainfall



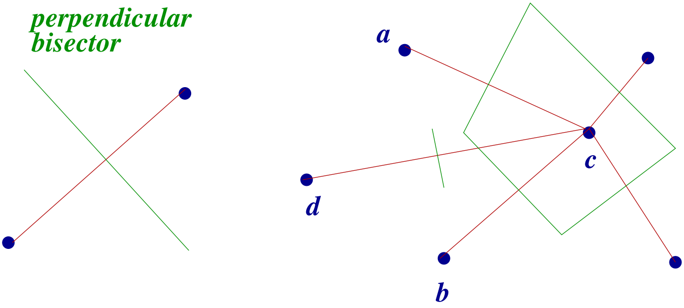
- Shown here is my watershed with the locations of rain-gauges.
- Estimate the total rainfall over my watershed (**in cubic-meters** .

MyWatershed-estimating total rainfall



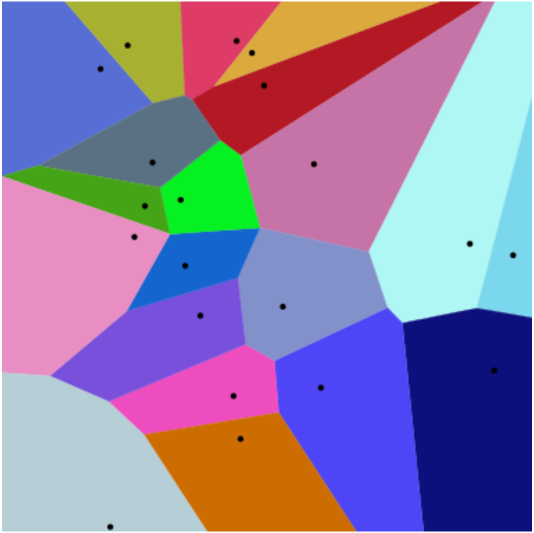
- Shown here is my watershed with the locations of rain-gauges.
- Estimate the total rainfall over my watershed (**in cubic-meters** .
- Question: What should I assume as the rainfall at point p?
- Heuristic: Assign to each point p, the rainfall at the closest gauge.

The Voronoi

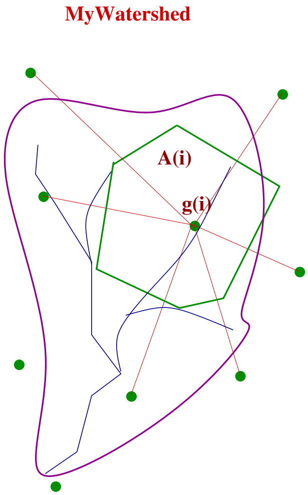


region(c): All points for which c is the closest.
Note that it depends on the presence of other points.

The Domain decomposition

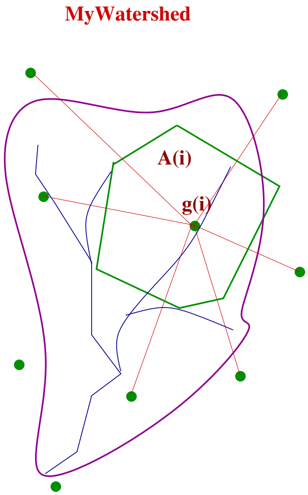


MyWatershed-the overlay



- Draw your watershed on a graph-paper.
- Let $g(i)$ be a gauge and let the reading at $g(i)$ be $r(i)$.
- We want to find all points p for which the closest point is $g(i)$.

MyWatershed-the overlay



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- Let $A(i)$ be the fraction of the area lying inside my waterhsed.

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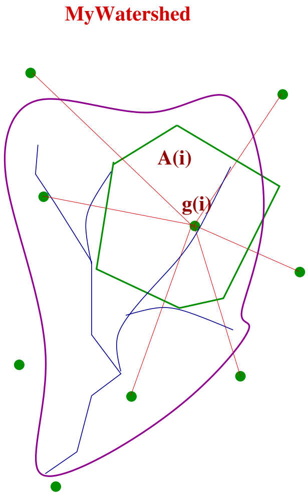

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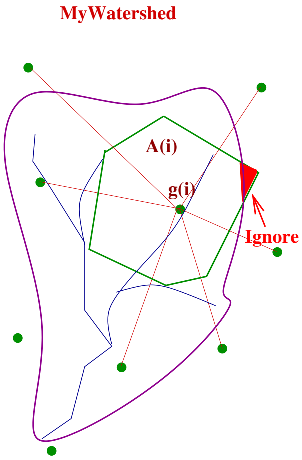
- Let $A(i)$ be the fraction of the area lying inside my waterhsed.
- The area $A(i)$ *belongs* to $g(i)$.

MyWatershed-the construction



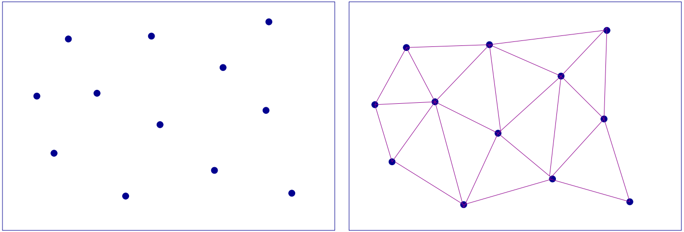
- Measure $A(i)$ using the graph paper. Ignore area outside the watershed.
- The sum $\sum_i A(i) = A$ the total area of the watershed.
- Average rainfall

$$r = \frac{\sum A(i)r(i)}{\sum A(i)}$$

Finally...

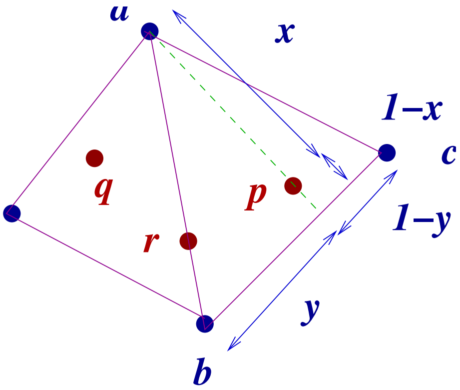
Total Volumne= $A.r$

Domain Decomposition



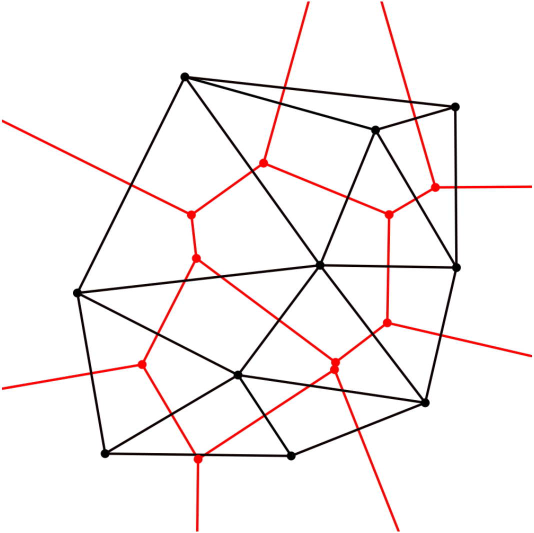
Division of the domain into *non-overlapping triangles*

Internal Section Formula

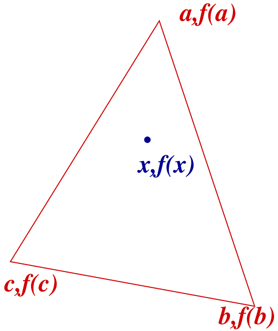


$$f(p) = (1 - x) \cdot f(a) + x \cdot (y \cdot f(c) + (1 - y) \cdot f(b))$$

Delaunay-Voronai Dual Decomposition



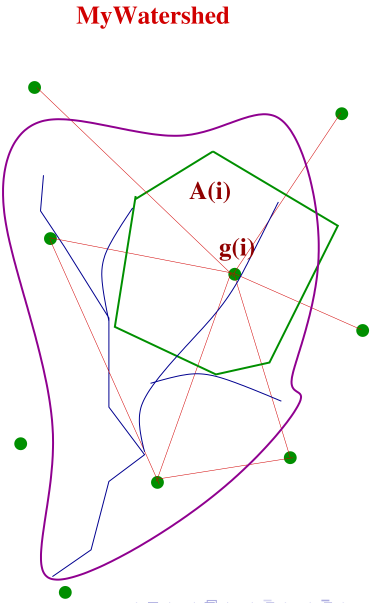
Other Options



$$x = u1.a + u2.b + u3.c$$

$$u1 + u2 + u3 = 1$$

$$f(x) = u1.f(a) + u2.f(b) + u3.f(c)$$



Measuring Stream-flows

V-notch weir.

- Suitable for small streams.
- A V-notch is inserted in the stream so that there is sufficient head behind the V-notch.
- Measurements are taken on the height of the stream-level on the V-notch.
- Flow: cu.m./s is given by an empirical relationship.

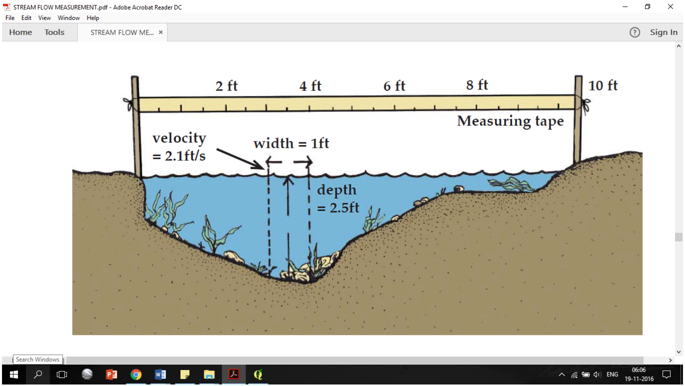
For a 90-degree V-notch: $Q = 2.5H^{5/2}$ where Q in cu.ft/s, and H is ht. of head above crest. Example: If $H = 0.25ft$ then $Q = 0.078$ cu.ft/s.

Measuring Stream-flows

For larger streams

- Use a stick-mounted flow-meter.
- Select a stream cross-section.
- Follow a schedule of measurements at various depths and points on the cross-section.
- Use formula to compute flow.

Measuring Stream-flows



Flow in Open-Channel

Mannings Eqn.

$$V = (1.49R^{2/3}S^{1/2})/n$$

where

- V is average velocity in ft/s
- R is surface-area/wet-perimeter in ft.
- S is the slope of the water

and n is as below:

Mountain streams	0.04
winding stream	0.035
natural streams	0.025
unlined canals	0.02
smooth concrete	0.012

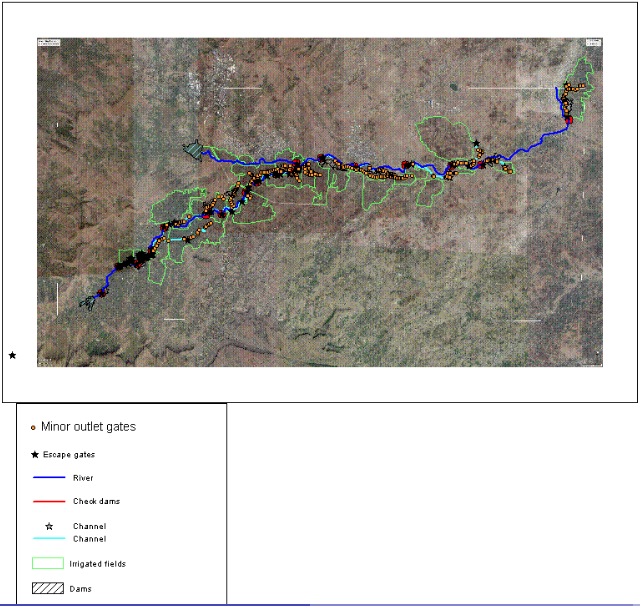
Example (Fetter) : An aquaduct is with a slope of 5ft/mile and with a rectangular cross-section of 50ft and water depth of 8ft. What is the average velocity?

- $R = (50 \times 8)/66 = 6.06$.
- $S = 5/(1760 \times 3) = 0.000947$.
- $n = 0.02$.
- $V = 3.048 ft/s$

Another Problem

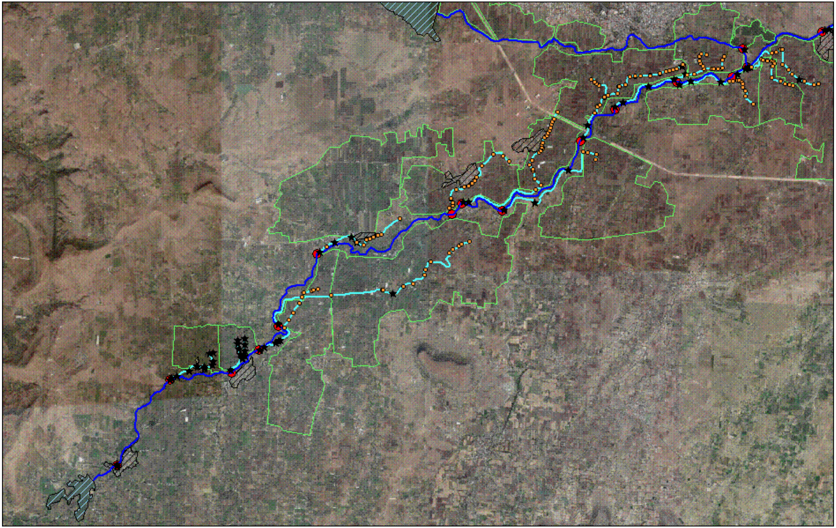
- Mumbai needs 3000 mega-liters/day which come from lakes about 100 km away and about 500 ft above Mumbai in elevation. Estimate the the number of pipes needed to transfer this water, if the diameter of these pipes is 2m.
- Estimate the total flow and the height of water in the *nalla* opposite Hostel 5 on a rainy day.

Diversion Based Irrigation



- Small *bandaharas* within stream and small canals to take away water.
- Few gates and flood based canal delivery.
- extraction through wells

Diversion Based Irrigation-A Section



Measuring other flows

- Infiltration: Standard models. Also Infiltrometer which measures infiltration and conductivity, a hydrogeological term.
  - slope, soil properties, vegetation.
- Transpiration: Standard data from experimental plots. Also FAO and agriculture department.
  - Typically depends on wind velocity, air temperature, humidity and also plant properties.
  - Typically about 100 to 200 times of wieght gained by plant. For crops, about 3mm per day.
- Evaporation. From soil as well as water bodies. 1mm-5mm per day. Depends on air temperature, humidity and velocity.
- Seepage, Groundwater flows: Depends on conductivity and *hydraulic heads*. Darcy's law.

Thanks