Domestic Water Use and Piped Water Supply (PWS)

Om Damani

(Adapting from the slides of Milind Sohoni, Pooja Prasad, and Puru Kulkarni)

The importance of drinking water

- A core need-like food, shelter.
- Part of the Development Engineering Services-*sadak, bijli, pani, informal sector*

- Impacts: health, migration, livelihoods.
- Rural: 40 lpcd of clean water, Urban: 85-100 lpcd.
- And now fodder and water for cattle.
- Concurrent List but was increasinly centrally sponsored.
- Supply and then sanitation.

Nothing to report	$\Rightarrow$	Presumed Good Exceptions	$\Rightarrow$	Presumed Bad Coverage

Many Indicators

- Census: Type of source, distance, ownership, adequacy, seasonality.
- NSSO: Part of the basic amenities framework.
- Unicef, WB, NRDWP-MIS.

Many Indicators

- Census: Type of source, distance, ownership, adequacy, seasonality.
- NSSO: Part of the basic amenities framework.
- Unicef, WB, NRDWP-MIS.

And how are we doing?

Year-round drinking water availability.

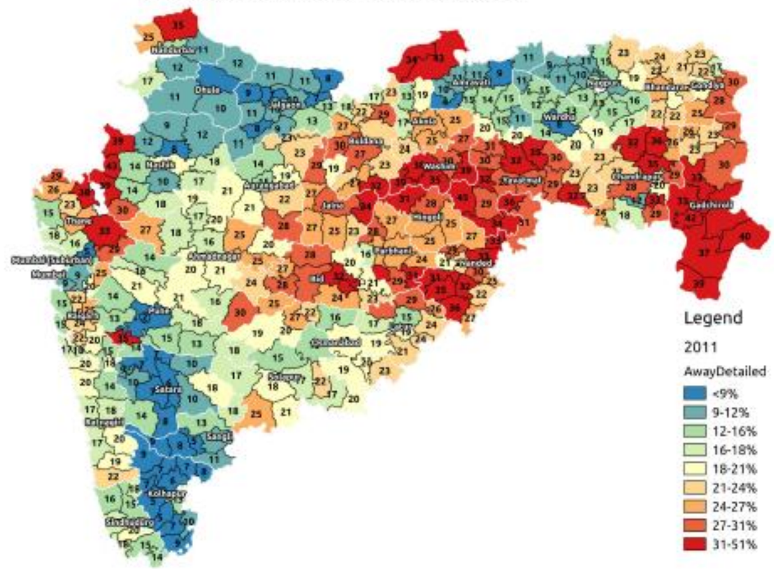
Year	Rural	Urban
2012 (69th NSSO), per 1000	858	896
Maharashtra	**745**	931
2008	862	911

after spending 10,000 crores in the interim!

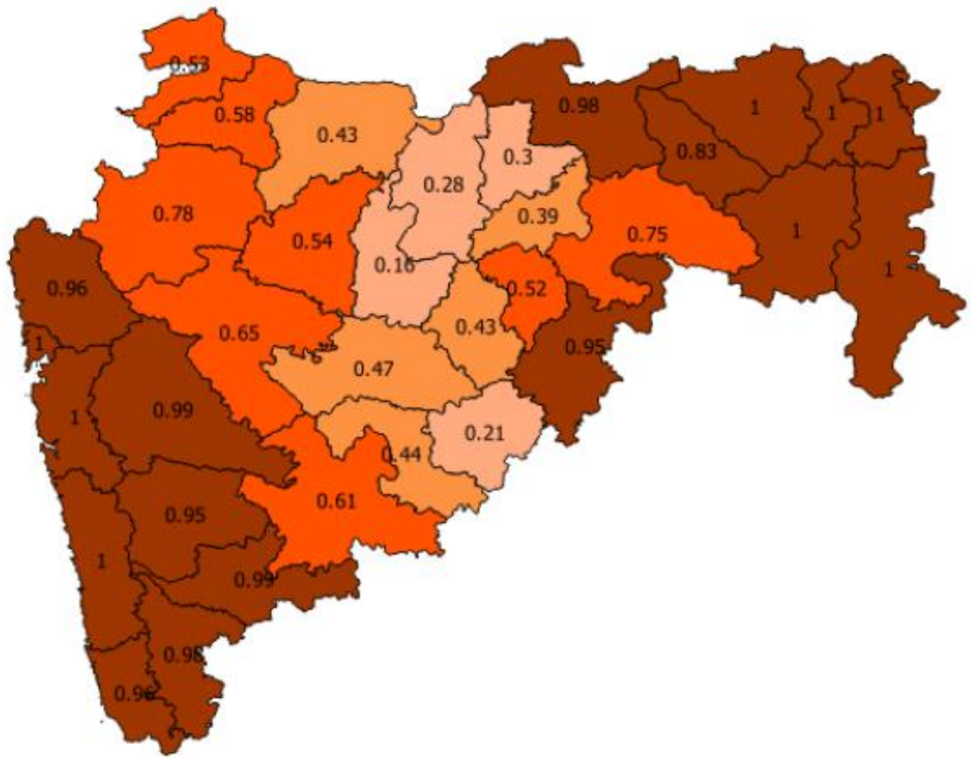
Rural Maharashtra: 2001 and 2011

Percentage of Rural Households with Primary Source more than 500m away (2001)

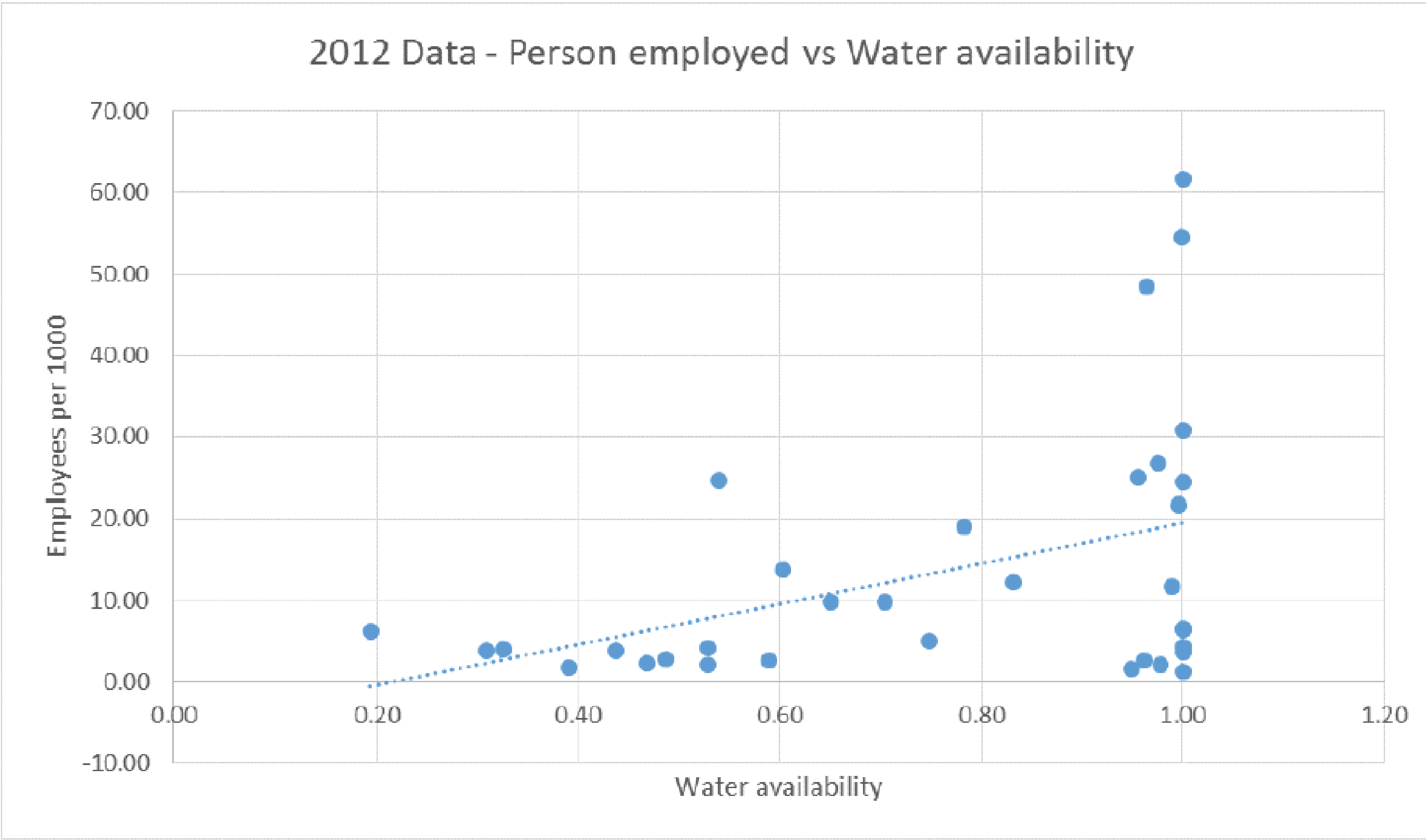
Percentage of Rural Households with Primary Source more than 500m away (2011)



Urban Drinking Water



Drinking Water and formal sector jobs



Why is this happening?

- Question 1: What was the past? How is the present different?
- Question 2: What constitutes a *contemporary* drinking water solution.
- Question 3: What is failing?
- Question 4: What is to be done?

- Question 1: What was the past? How is the present different?
  - Past was generally GW and a mixture of public-private.
  - Only big towns had a WS supply system. Engineering system tied to the municipality. *User fees*.
- Question 2: What constitutes a *contemporary* drinking water solution.
  - A sustainable source. A well-functioning and well-designed engineering system.
  - A sustainable financial and institutional mechanism.
- Question 3: What is failing?
  - Regional failure of source. Competition between various sectors. Poor engineering capacity. Simple solutions are inadequate.
  - Energy costs. Inequality. Insufficient political and social understanding. No social contract.

Water group at CTARA-Areas of Research

- Water Supply Schemes
  - rural water supply, single vs. rural regional
  - SW vs. GW as drinking water sources
  - Bulk water systems, tariff
  - simulation and design software, standard protocols for analysis
- Groundwater: regional and local
  - GSDA data set of 5000+ wells. Trends, scarcity and uncertainty.
  - Thumbnail conceptual models. Primary and secondary data.
  - SWAT models and taluka/mini-watershed level water balance.
  - Watershed modelling, regional data models
- Stakeholders. GoI and GoM policy and programs.
  - NRDWP, Jalswarajya and now MSNA and Jal Yukta Shivar
  - MEETRA, GoM agencies, TEQIP.
  - Aroehan, Rural Communues, Shashwat, colleges and NGOs.

Upcoming Areas

- Regional DW security
  - Taluka and district level water budgets. GSDA processes.
  - Socio-economic linkages. Village plans, *Jal-yukta Shivar*.
- Rural and small town planning.
  - Water and sanitation for small towns-(Manchar, Karjat) and large GPs. Parbhani
- Water quality and linkages
  - DW quality, the 1 cu.m. scheme, vending, agriculture linkages.
- Water and Energy
  - PWS and lift irrigation schemes and their energy demands.
- Urban water and water treatment
  - Decentralized STP and case studies, effluent treatment, groundwater-sanitation connection

Agenda

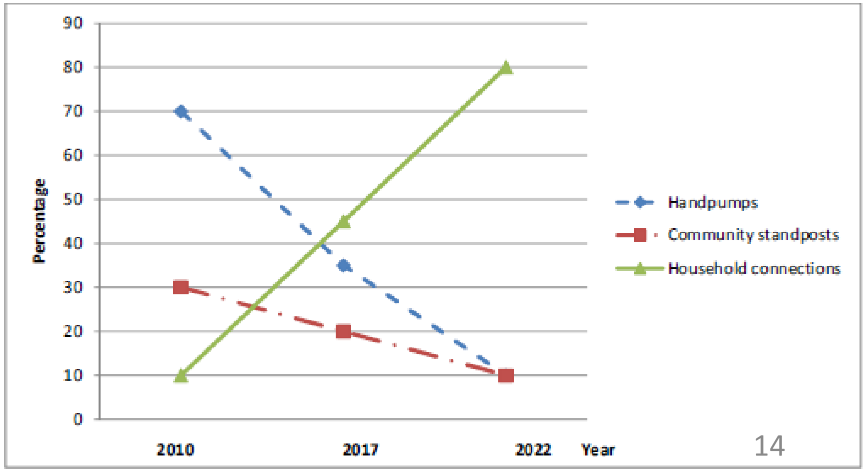
- Introduction to Piped water schemes (PWS)
- Design of PWS
  - Define demand
  - Service level consideration
  - Source identification
  - ESR location and capacity design
  - Pipe layouts
  - ESR staging height and Pipe diameter
  - Pump design
  - Cost optimization

Water sources for different uses

Relevance of PWS

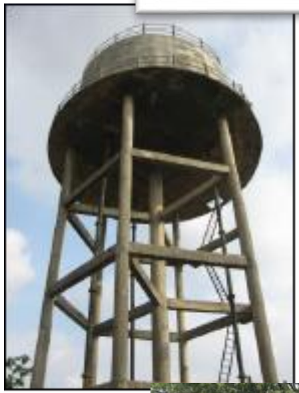
- The need for PWS
  - Falling ground water levels
  - drudgery removal, aspiration for many rural households, improved water quality in case of WTP
- GoI strategic goal to have 90% of all households with PWS by 2022
  - Currently at about 30%

Source: NRDWP Strategic Plan 2011-2022, GoI

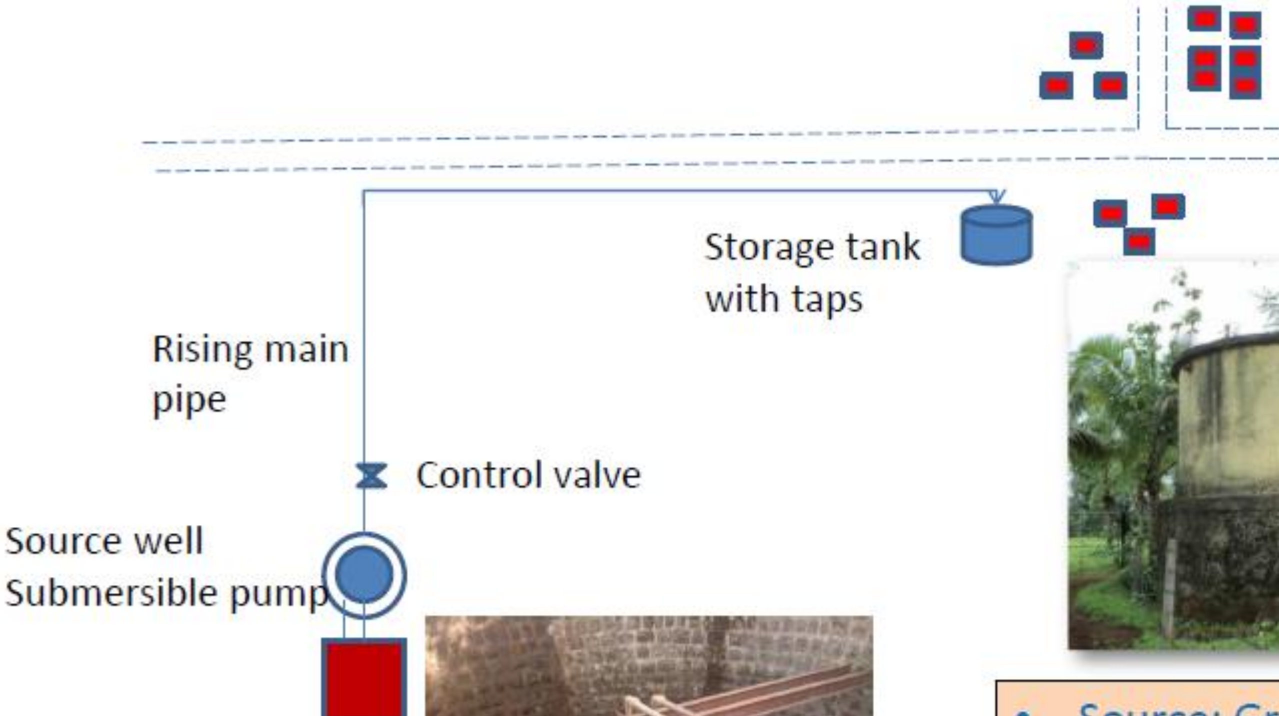


PWS Components

- Source
  - Groundwater, surface water
- Transmission
  - Network of pipes, tanks
- Delivery
  - Public stand-posts, household taps

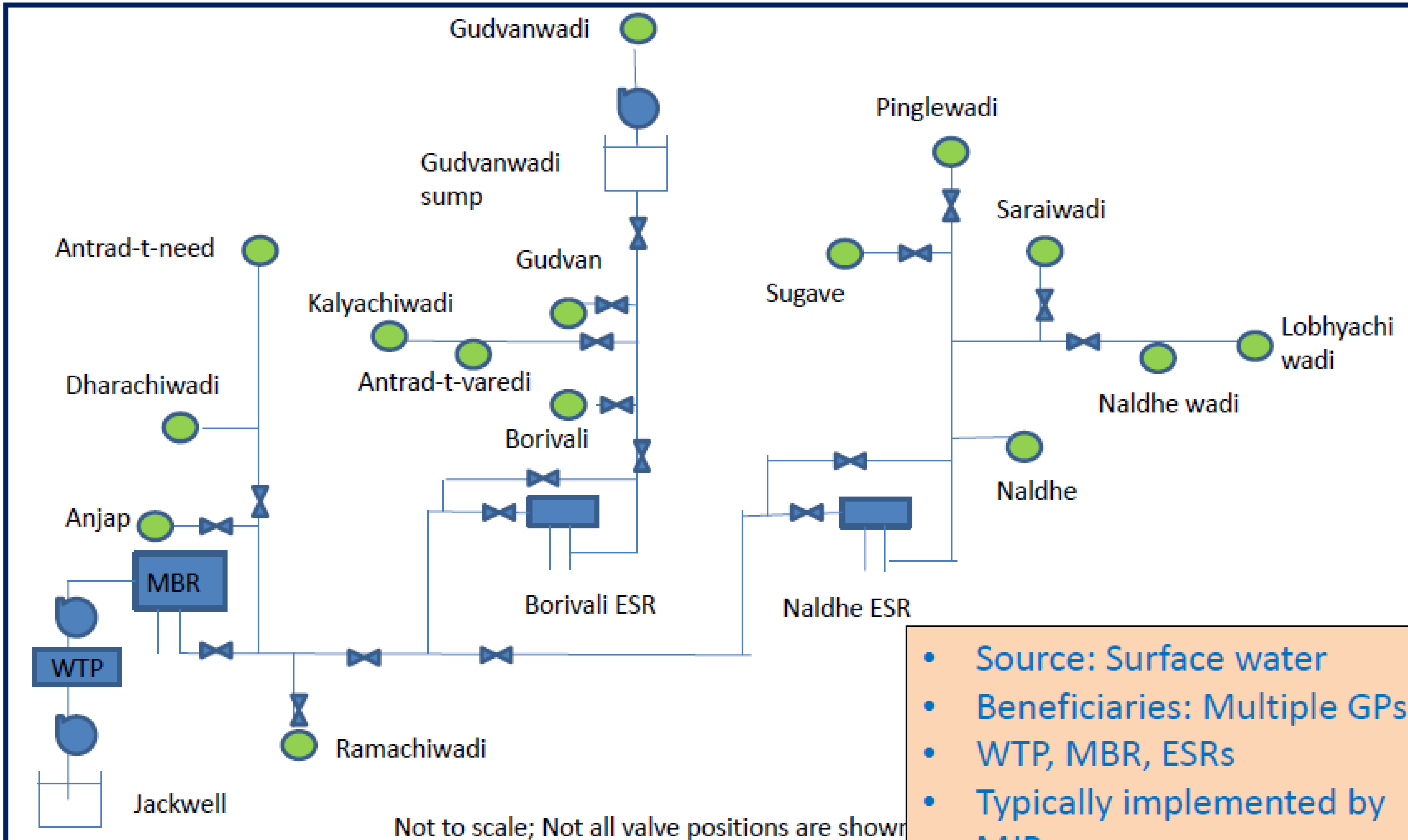


Typical Single Village PWSS



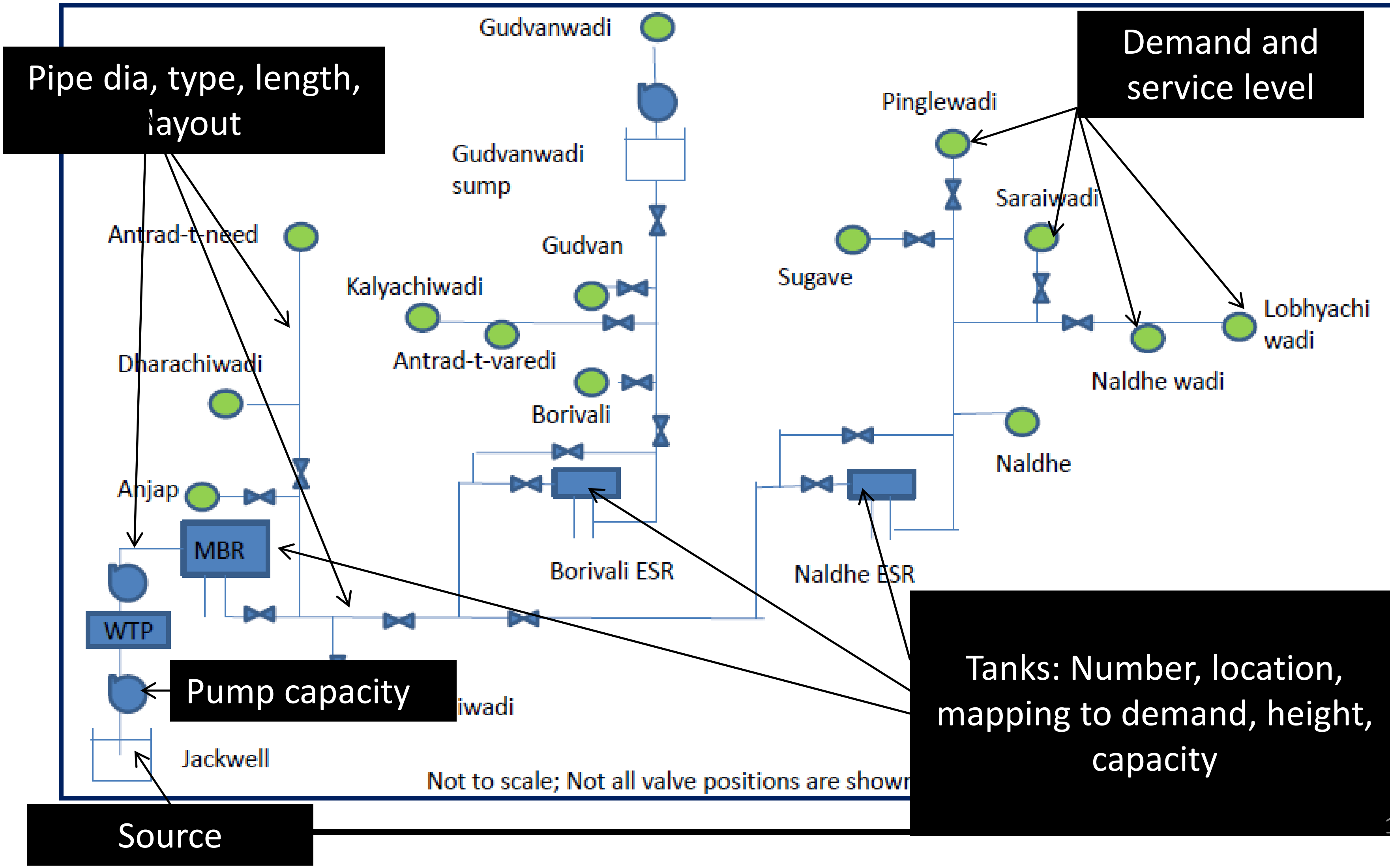
- Source: Groundwater
- Beneficiaries: One or more habitations within a GP
- One or more storage tanks
- Typically implemented by MI, RDW or private TSP

Multi village scheme (MVS) or Rural Regional scheme (RR)



- Source: Surface water
- Beneficiaries: Multiple GPs
- WTP, MBR, ESRs
- Typically implemented by MJP

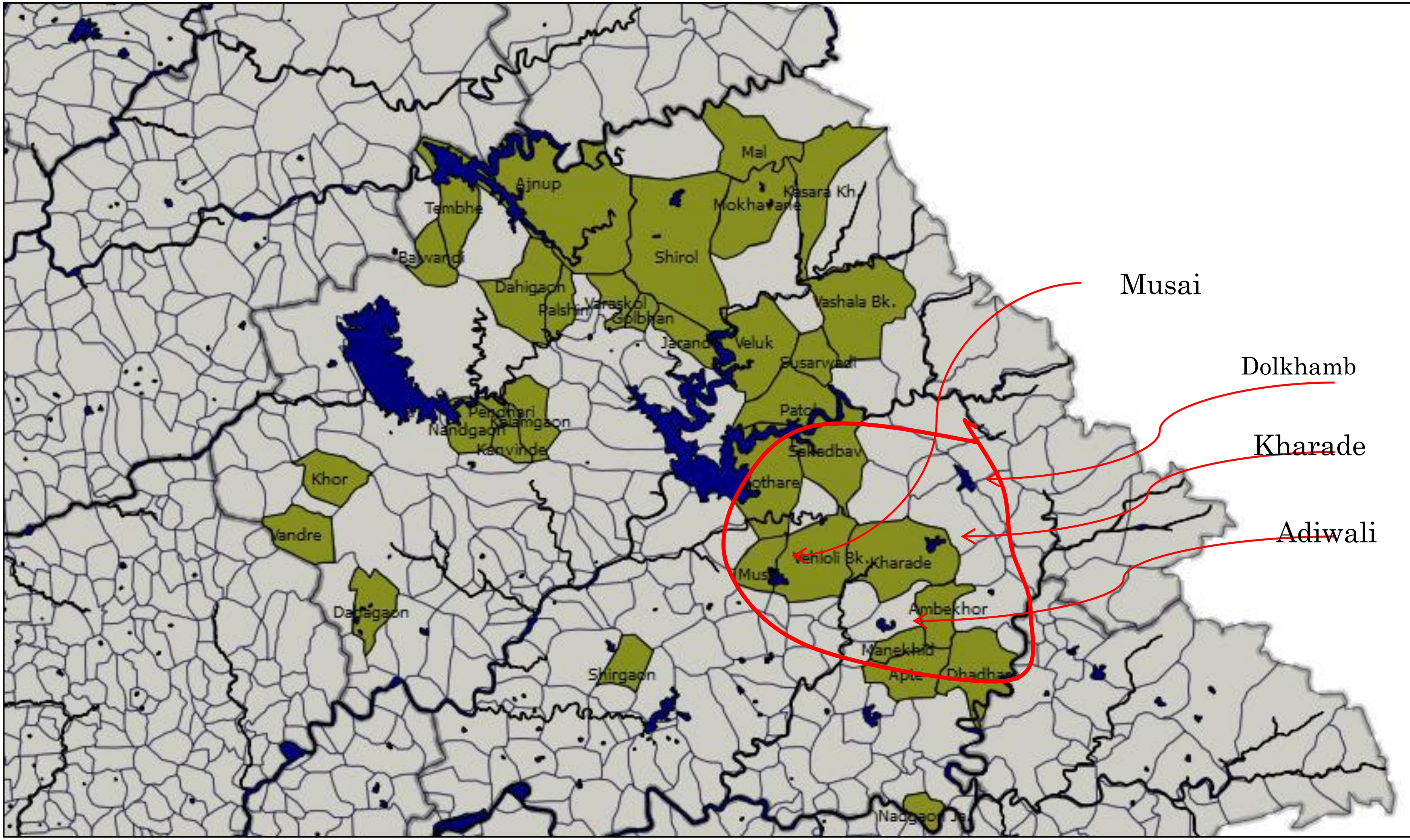
Designing a PWS – what does it entail?



Design of a PWS scheme

- Characterize demand
  - Identify habitations
  - Population
    - account for growth (ultimate stage population)
    - account for cattle population
  - LPCD norm for design (40/ 55/ 70/130 etc.)
- This gives us requirement for average daily demand from the source
  - ultimate stage population * lpcd

Identify source options



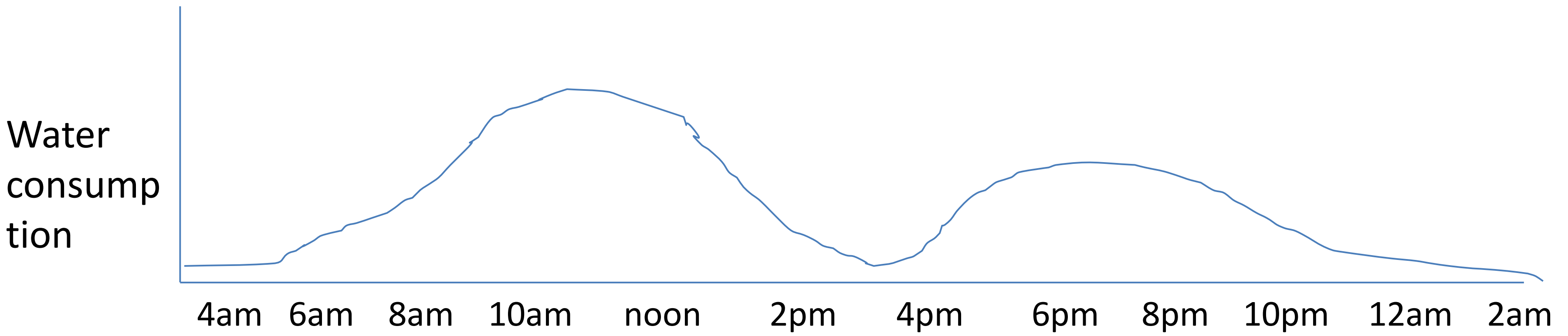
Source: Analysis of tanker fed villages in Shahpur by Divyam Beniwal, Pallav Ranjan

Considerations for source identification

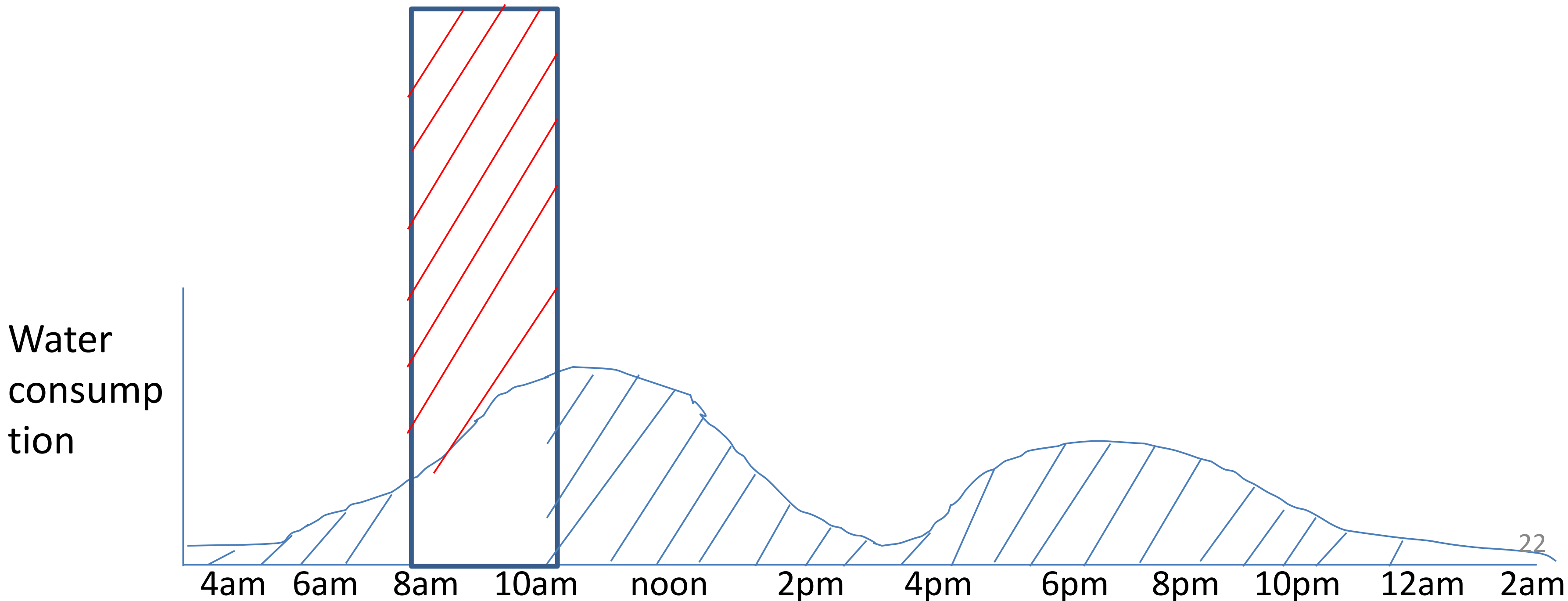
- Yield
  - Will it meet the demand?
    - Surface source: reservation for drinking water
    - Ground water: Perform an yield test
- Water quality
  - WTP required for a surface source
- Distance from target habitations
  - Long distance => long pipelines => high investment cost
  - high frictional losses & high leakages => hence, high recurring operational cost
- Elevation difference between source & target
  - Big difference => high pumping cost (recurring)
  - If source is at higher elevation => low operational cost

Design parameters depend on demand pattern

- 24x7 water service



- Intermittent service



How does service level impact asset design

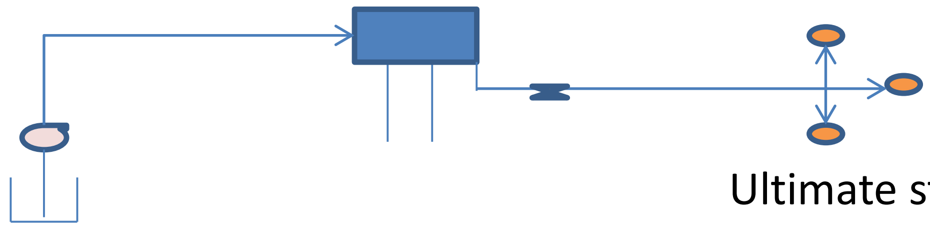
- Total daily demand supplied in 2 hours => 12x increase in average outlet flowrate
  - How does this impact
    - Pipe diameter?
    - ESR storage capacity?
    - Pump capacity?
  - In general, 24x7 service => lower asset cost compared to intermittent service

Flowrates

- Demand flow rate
  - Variable for 24x7 supply: depends on consumption
  - Intermittent supply: depends on designed service hours
- Supply flow rate
  - Amount of water to be pumped (demand + x% leakages etc.)
  - Pumping hours
    - Depends on electricity outages

ESRs help in meeting the demand flow rate while maintaining supply at a constant average flow rate

Example

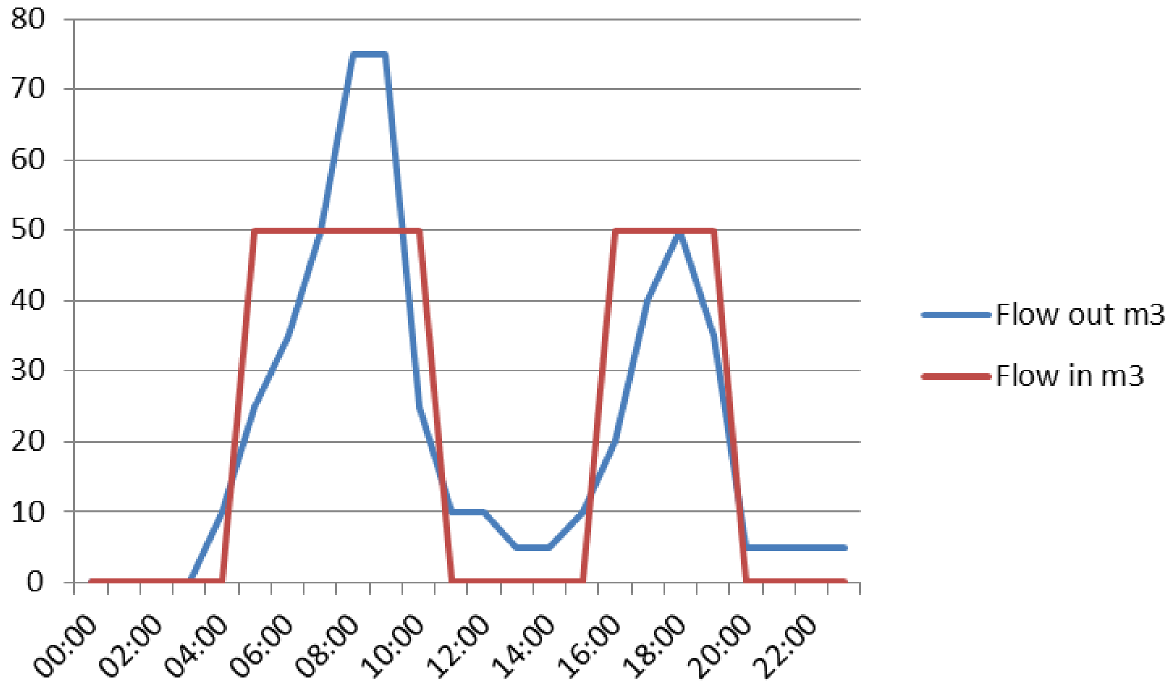


Ultimate stage
population = 10,000

- Demand = 10,000*50 lpcd = 50 m^3 per day
- Service Hours
  - 24 hours service : Average demand flowrate = 50/24 m^3/hr = **2.08** m^3 **/hr**
    - Caution: this is **average** flow taken over service hours
- Pumping hours: Assume 10 hours
  - Supply flow rate = 50 m^3 /10 hr= 5m^3/hr in 10 hours

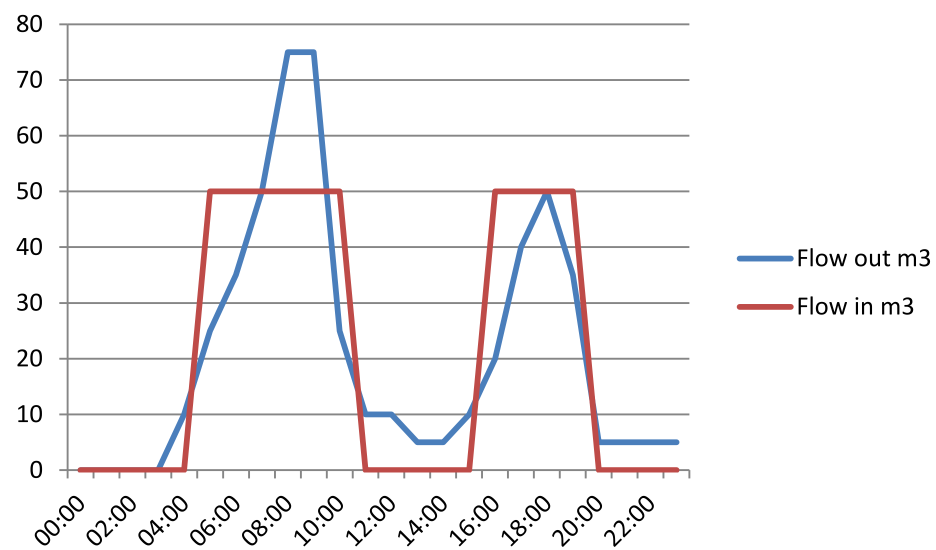
Example contd.

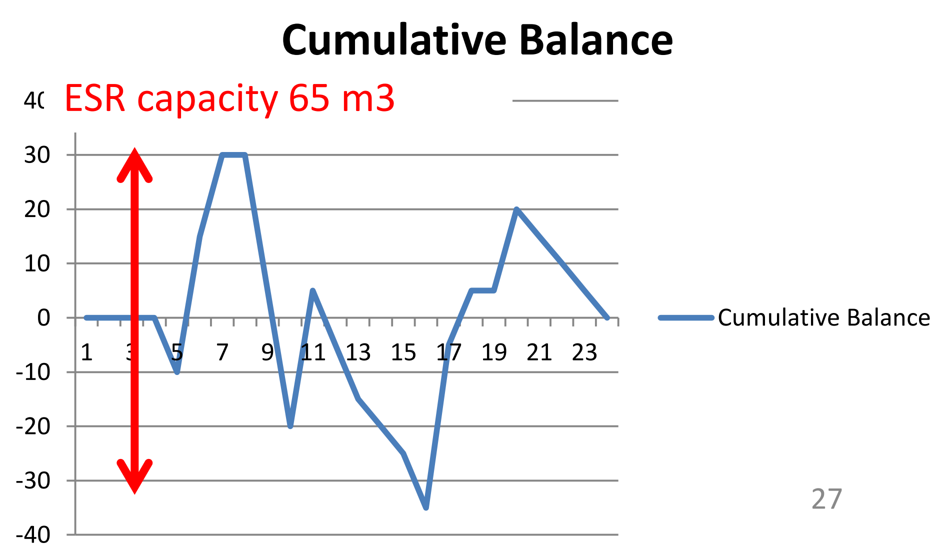
- Consumption is usually variable
  - 24 hour service (variable demand)
  - 10 hours of pumping (supply)



ESR Capacity Sizing – Back to the Example

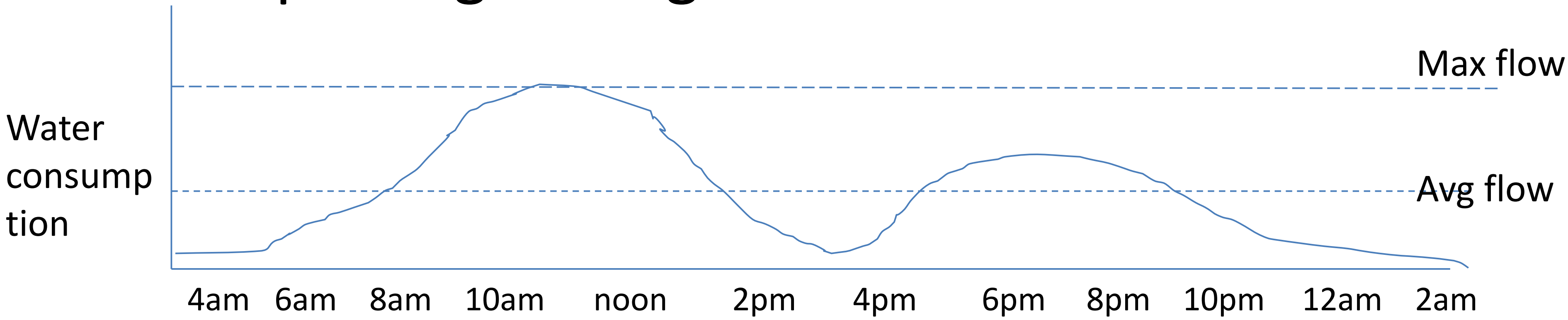
Hour	Demand %	Flow out m3	Flow in m3	Balance	Cumulative Balance
00:00	0%	0	0	0	0
01:00	0%	0	0	0	0
02:00	0%	0	0	0	0
03:00	0%	0	0	0	0
04:00	2%	10	0	-10	-10
05:00	5%	25	50	25	15
06:00	7%	35	50	15	**30**
07:00	10%	50	50	0	30
08:00	15%	75	50	-25	5
09:00	15%	75	50	-25	-20
10:00	5%	25	50	25	5
11:00	2%	10	0	-10	-5
12:00	2%	10	0	-10	-15
13:00	1%	5	0	-5	-20
14:00	1%	5	0	-5	-25
15:00	2%	10	0	-10	**-35**
16:00	4%	20	50	30	-5
17:00	8%	40	50	10	5
18:00	10%	50	50	0	5
19:00	7%	35	50	15	20
20:00	1%	5	0	-5	15
21:00	1%	5	0	-5	10
22:00	1%	5	0	-5	5
23:00	1%	5	0	-5	0
		500	500		





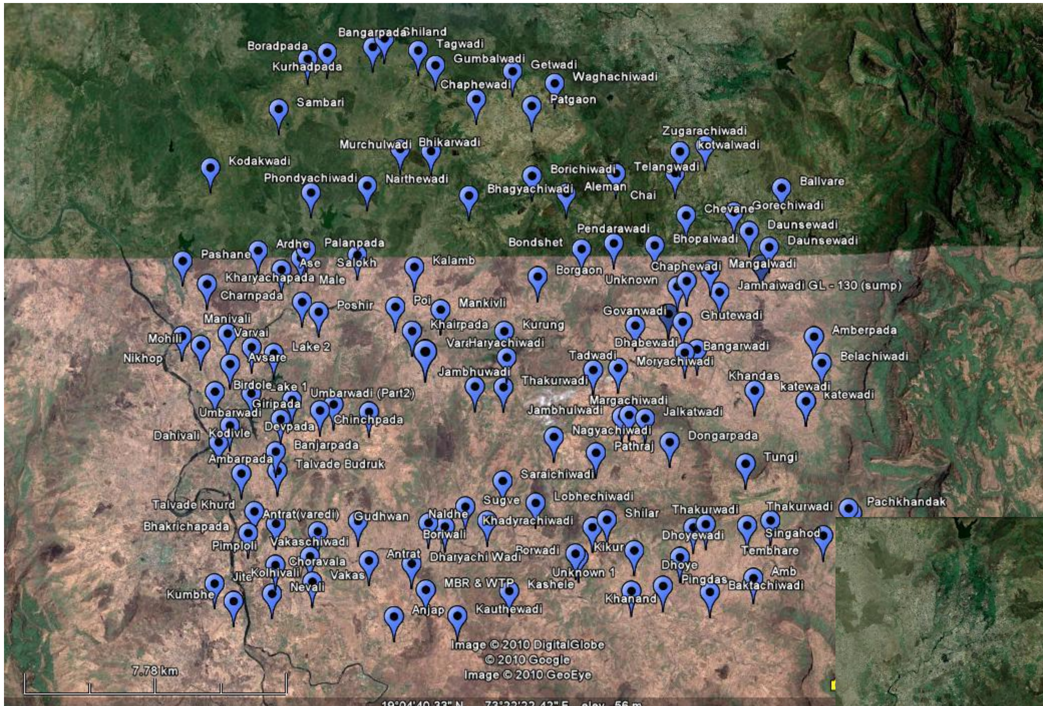
Benefits of ESRs

- Pump sizing for avg flow vs. max flow

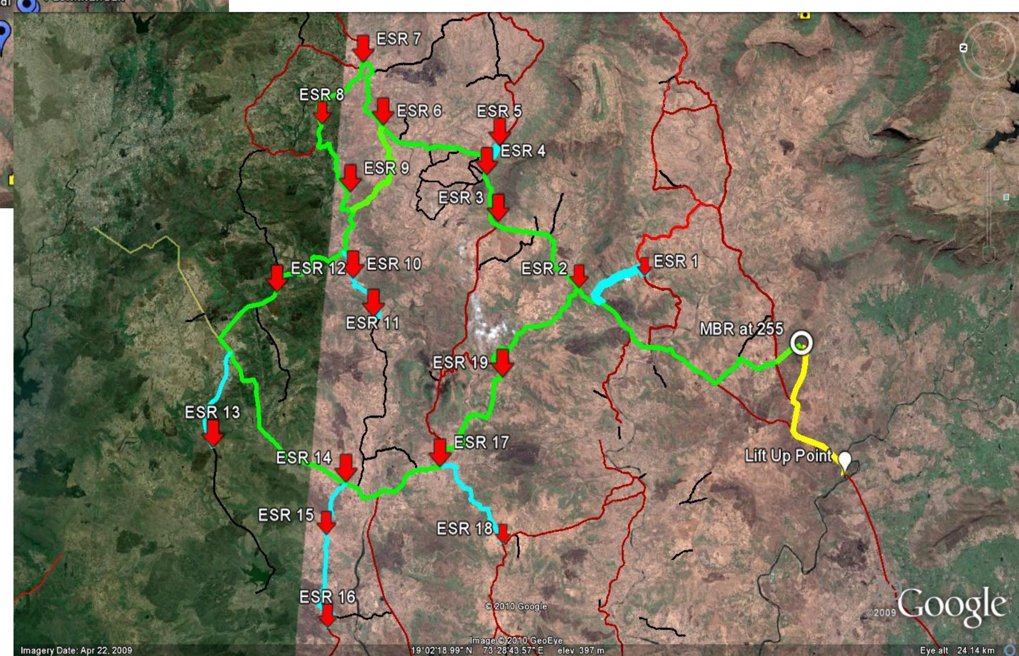


- Buffer capacity
  - Peak consumption times
  - Electricity outage
- Providing hydrostatic “head”

Location and count of ESRs



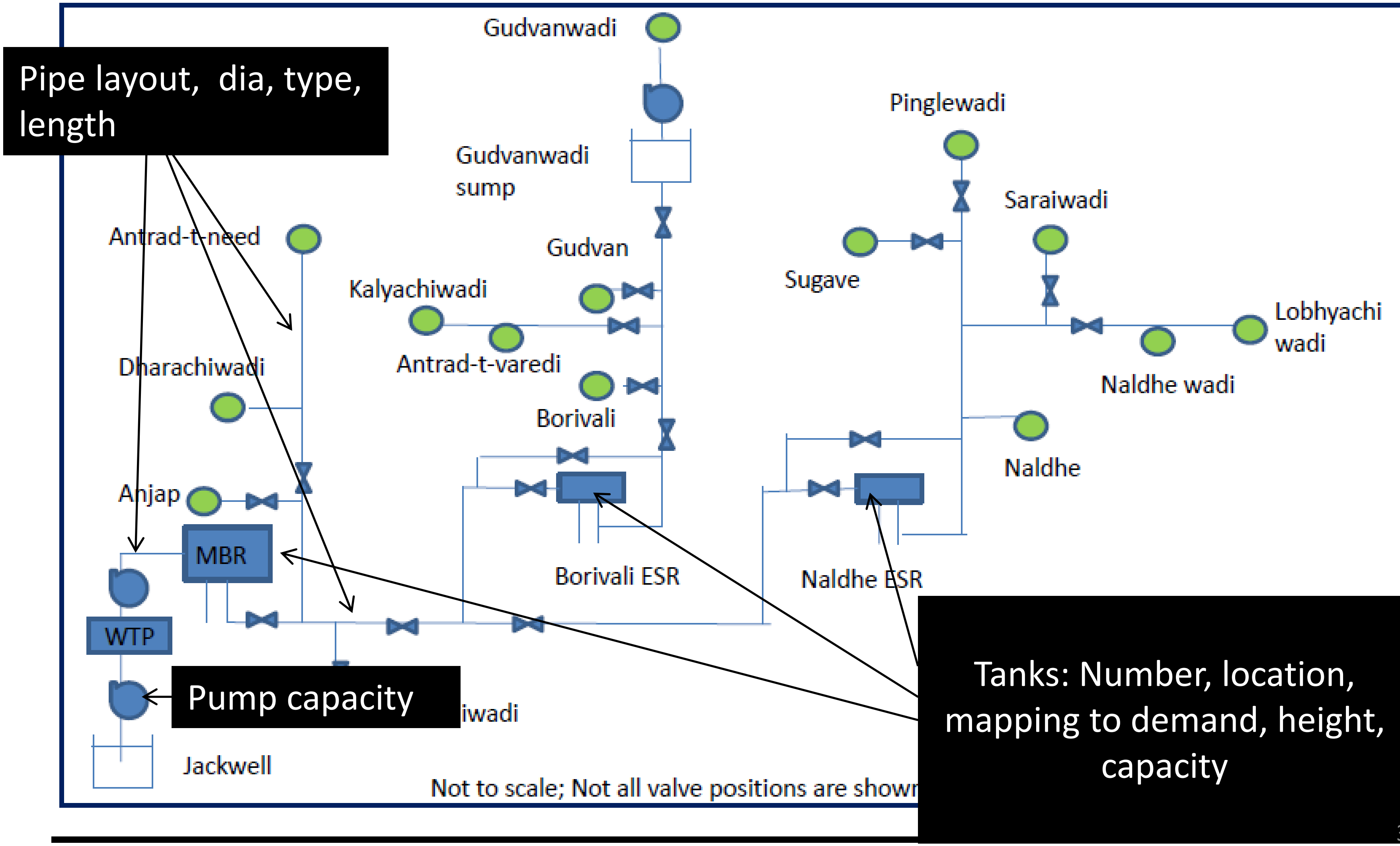
- Cluster based on
  - Distance
  - Elevation
  - Population
- Practical considerations – land availability



- Physical inspection required for accurate elevation data

Source: North Karjat Feasibility Study by Vikram Vijay and team

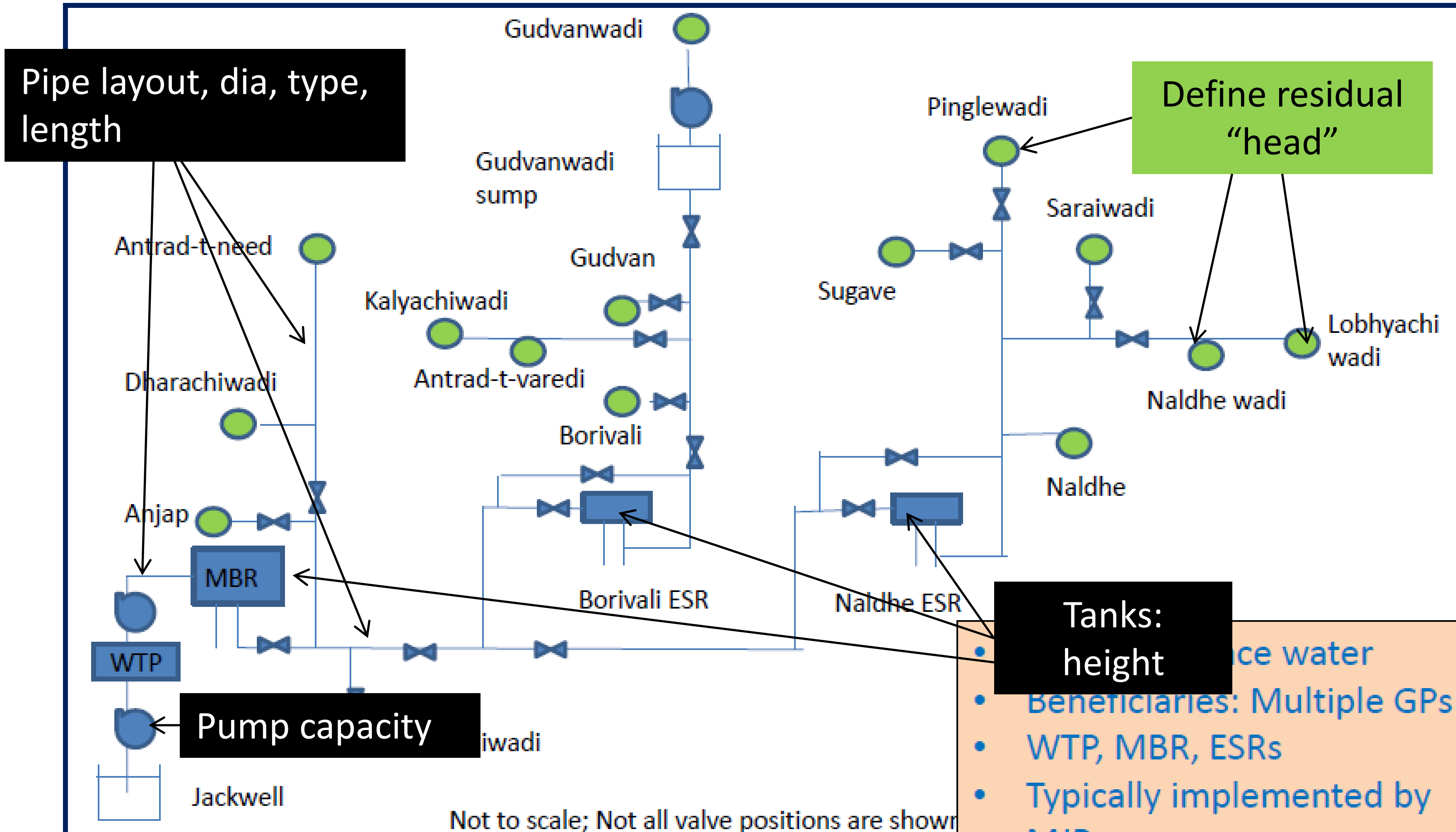
Design of transmission network – expected output



Why MBR?

- MBR – Master Balancing Reservoir
- Feeds the ESRs
- Holds additional x hours of buffer capacity
- Balances fluctuations in demand from ESRs against supply

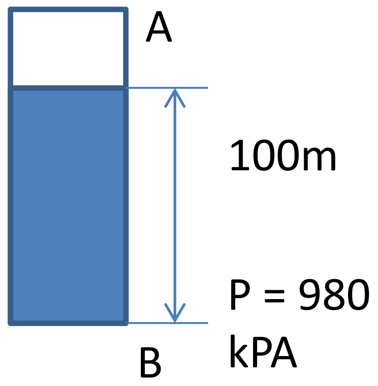
Design of transmission network



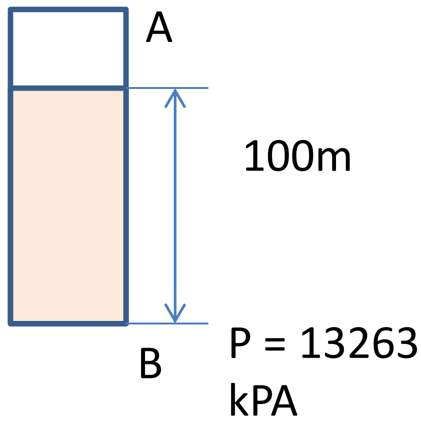
- ce water
- Beneficiaries: Multiple GPs
- WTP, MBR, ESRs
- Typically implemented by MJP

Use of “head” in specifications

- Assume a column of water
  - Pressure head at B = 100m
  - Pressure at B = ρ* g* h = 1000 kg/m3*9.8 m/s2 * 100m = 980kPa



- Pressure depends on density of fluid
  - Pressure at B for a column of mercury = 13534 kg/m3 *9.8 *100 = 13263 kPa

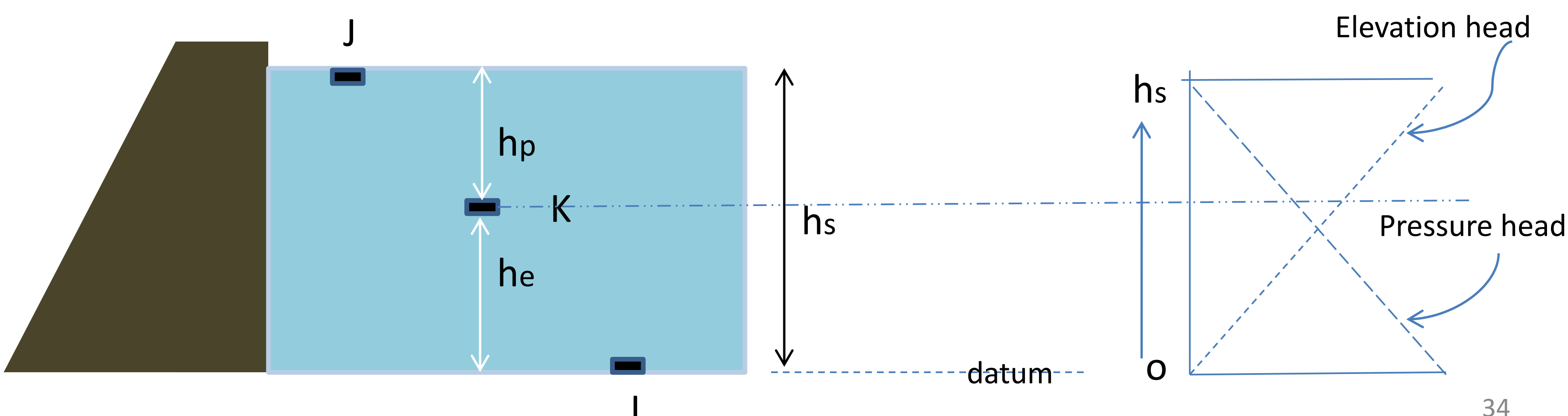


- Easier to specify required head or discharge head instead of pressure -> no longer dependent on the fluid density

What is head?

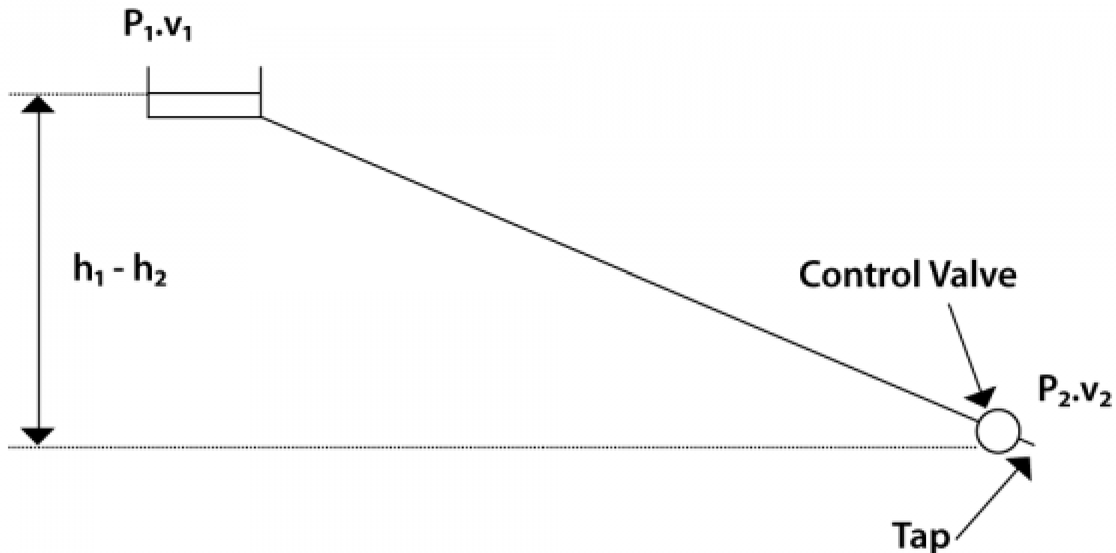
- Hydraulic head: Total energy in a fluid
  - Elevation head, pressure head, velocity head
- By Bernoulli's principle: Hydraulic head = elevation head+ pressure head + velocity head is constant

- Pressure head at A = elevation head at B = ρgh



Source: examples from Introducing Groundwater by Michael Price

Compute Residual Head at an Open Tap



$$P_2 - P_1 = \rho g h_1 - \rho g h_2 - \frac{1}{2}\rho {v_2}^2 - fh\rho g$$

$$\Delta P = \rho.g.(h_1 - h_2) - f_h.\rho.g$$

$$\Delta H = (h_1 - h_2) - f_h$$

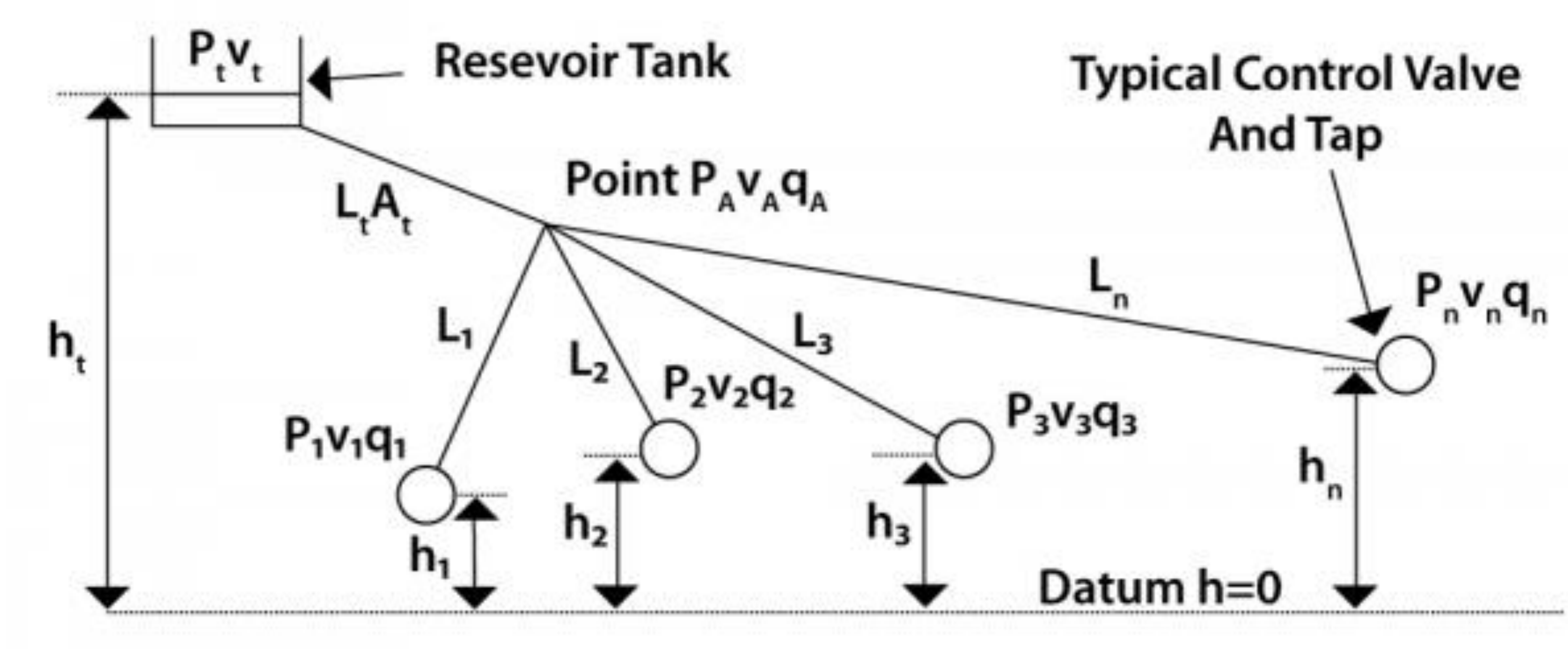
f_h= C*v = C*Q/A

Hence you can calculate residual head
Or discharge rate (Q)
If you know the other

Residual head non-zero at outlet: moving water
zero at outlet: stationary

From itacanet.org

Residual heads in a Distribution Network



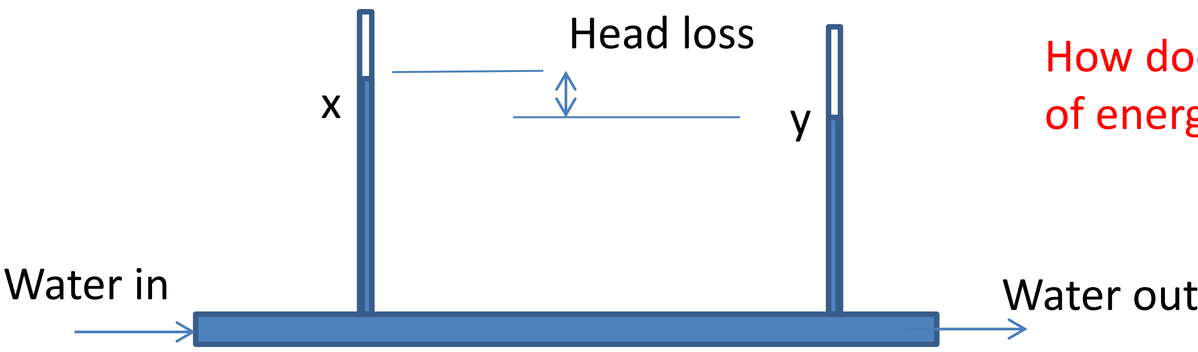
Think of all the points where terms in Bernoulli equation will change

Design ESR staging height

- Define minimum residual head at delivery points

- Minimum required staging height depends on
  - Elevation of supply / demand points
  - Minimum residual head requirement
  - and something else?

Frictional losses

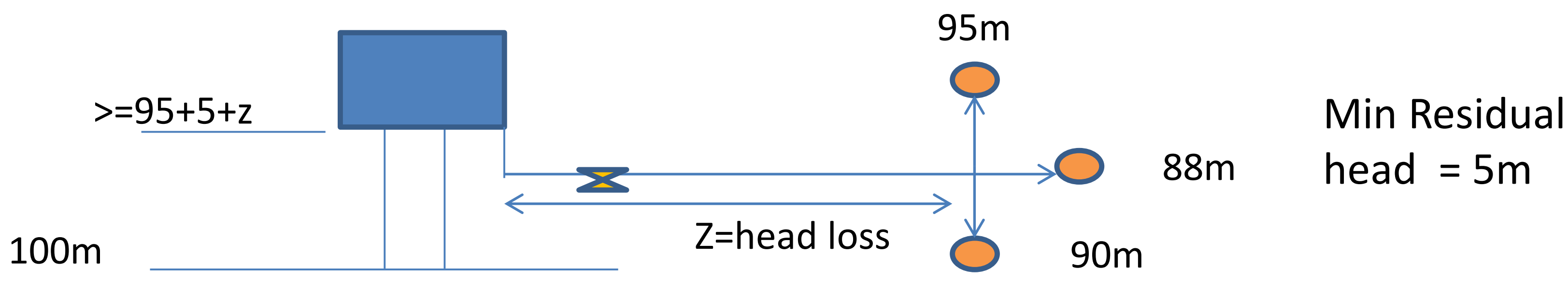


How does conservation of energy hold here?

- Total head loss (m of head loss/ km distance per m/s velocity)
  - Pipe roughness
  - Pipe length
  - Flow rate
  - Pipe diameter
- Pipe Roughness constant:
  - Published for different materials
  - Many models and empirical equations in literature to calculate head loss using this constant

Source: example from Introducing Groundwater by Michael Price

Design ESR height

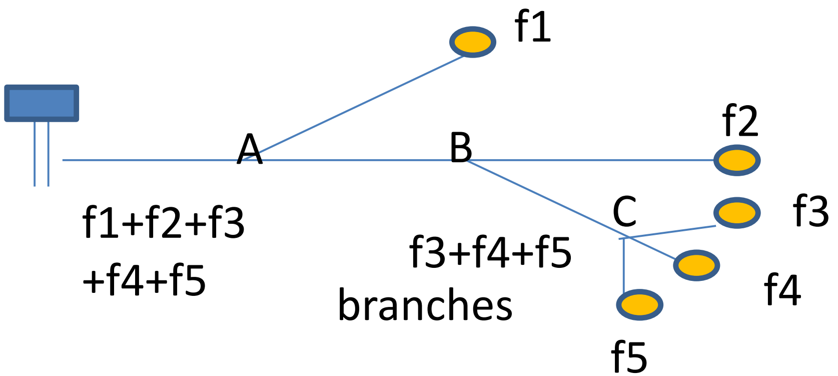


- When can we use a GSR?
- Trade-off between pipe dia and tank staging height
  - High staging height => low pipe diameter needed to achieve the same head why?
  - Also implies higher pumping cost (Upstream impact – recurring cost)

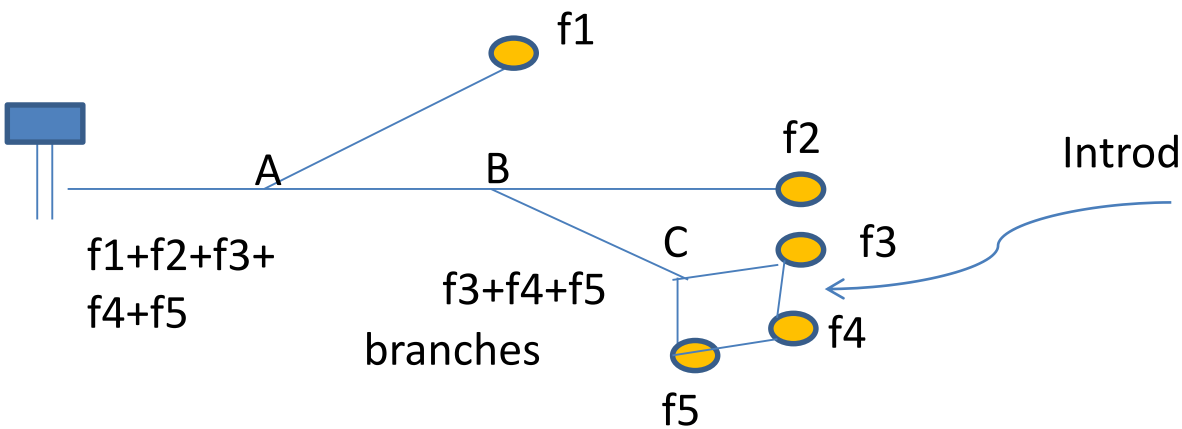
Pipe Types

- Pipe type usually driven by cost
- Most used types: PVC, GI (Galvanized Iron), HDPE (High density polyethylene), MDPE
  - PVC: Most commonly used; low cost, easily installed. Prone to leakages, requires frequent maintenance
  - GI: good for pipes installed over ground and can be easily welded but more expensive and prone to corrosion
  - HDPE/MDPE: cheap, inert, comes in rolls of hundreds of meter, very low leakage. Electrofusion of joints requires expensive equipment; lower availability

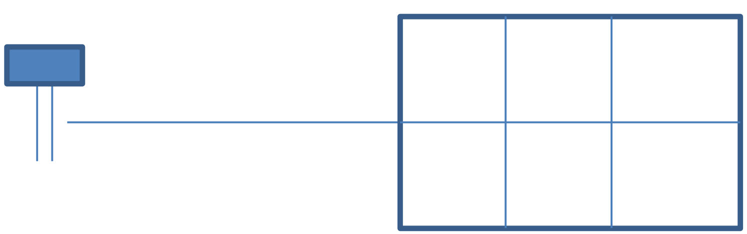
Pipe Layout



Branch network

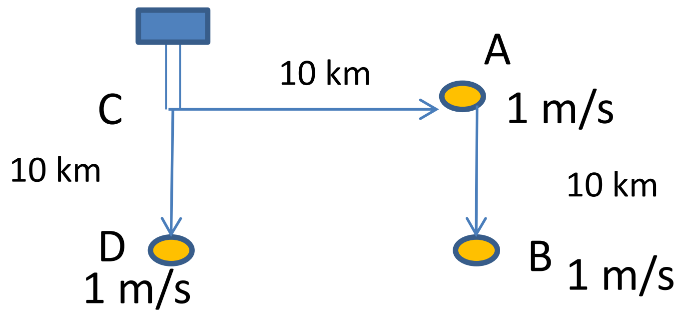


Introducing a loop



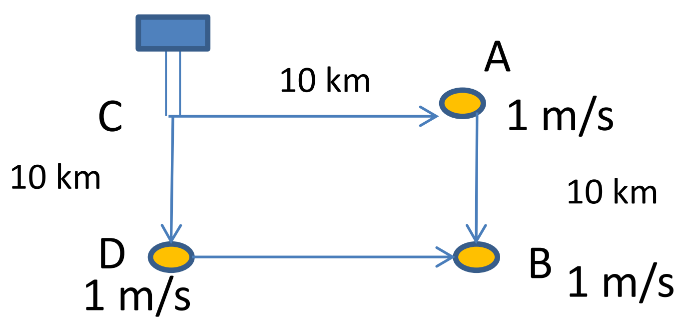
Grid network

Example - Loops



Frictional loss = 1m/ km per m/s velocity

Branch	velocity	loss
A-B	1m/s	10m
C-A	2m/s	20m
C-D	1m/s	10m



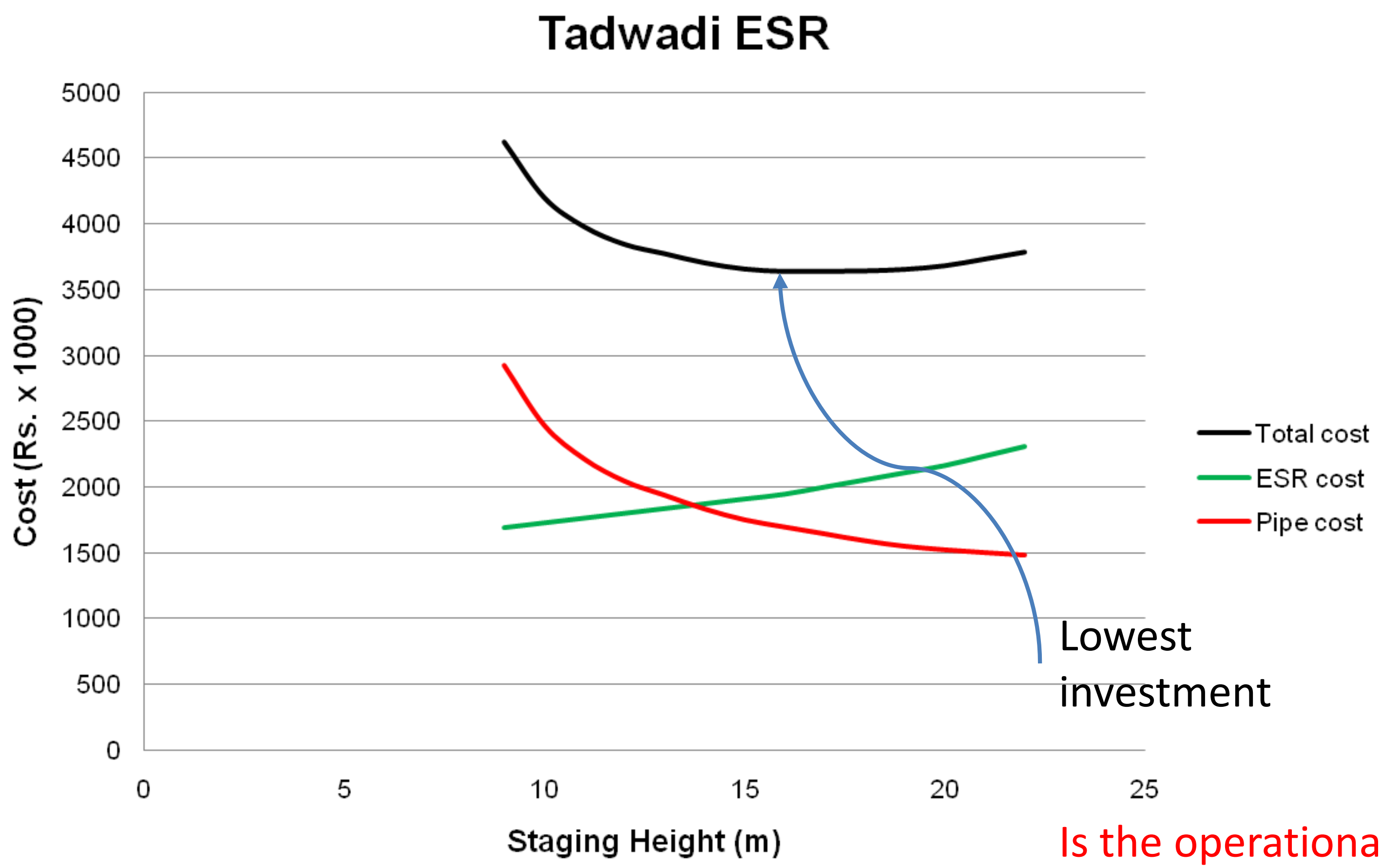
Branch	velocity	loss
A-B	0.5 m/s	5m
C-A	1.5m/s	15m
D-B	0.5m/s	5m
C-D	1.5m/s	15m

Introducing the loop reduced the ESR height requirement

Back to ESR height vs. pipe design

- Start with any reasonable ESR height
- List available options of {pipe dia, friction coeff, cost}
- For the given network and available pipe choices determine the optimal pipe choice for each branch such that the total pipe cost is minimized
- Optimization software such as Jaltantra/Loop may be used for this

Back to ESR height vs. pipe design



Is the operational cost acceptable?

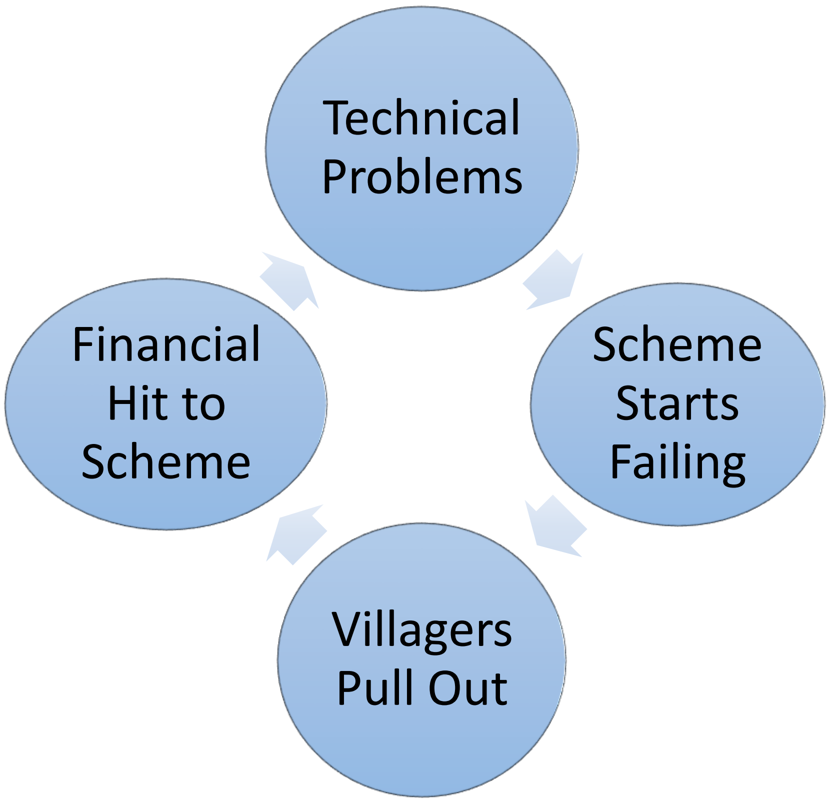
Pump specs

- Pump power is proportional to
  - $Q*\rho*g*h$
  - Q supply flow rate
  - h differential head between pump and MBR
  (static head + frictional head + velocity head)
  - ρ fluid density;

JalTantra

for Optimization of Village Piped Water Schemes

Issues in Design and Implementation of MVS
A Vicious Cycle



Problem Formulation

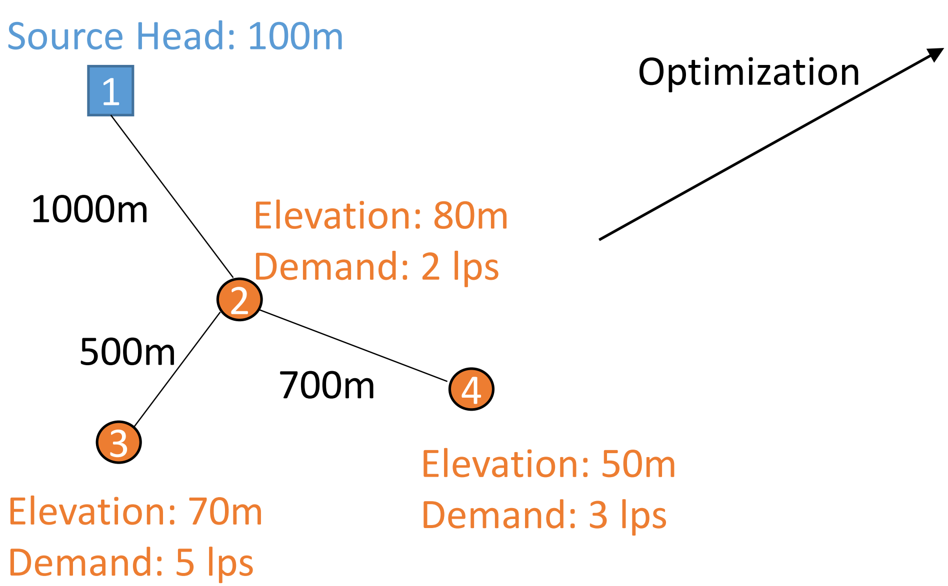
- **Input:**
  List of **(**village id, location, population)
  Source of water
  Links connecting the nodes
  Cost per unit length for different pipe diameters
- **Output:**
  For each link, length of different pipe diameters to be used
- **Optimization Objective :**
  Capital Cost of Pipes

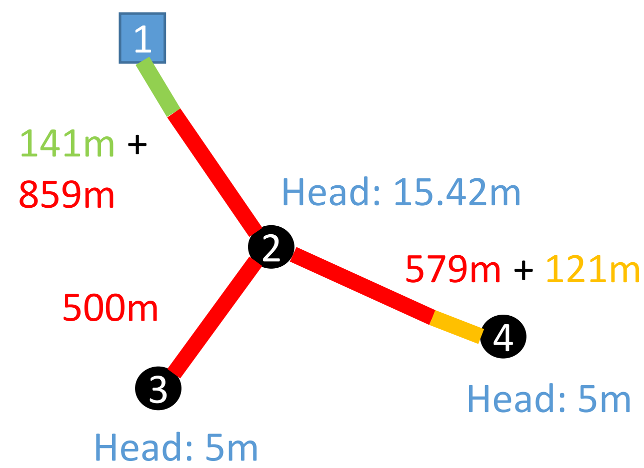
Minimum pressure required = 5m
Pipe roughness = 140

Example Network

Commercial pipe info:

Diameter	Unit Cost
50	100
100	400
150	900





Diameter	Length	Cost
50	579	57.9k
100	1480	592.1k
150	141	126.9k
	TOTAL COST	776.9k

General Formulation for Piped Water Network Cost Optimization

- **Objective Cost:**

$$\sum_{i=1}^{NL}\sum_{j=1}^{NP} C(D_j)\,l_{ij}$$

Number of links (NL); Number of commercial pipes (NP); Unit cost of j[th] pipe ($C(D_j)$); Length of j[th] pipe of i[th] link (l_{ij})

- **Node Constraint:**

$$P_n \le H_R - E_n - \sum_{i \in S_n}\sum_{j=1}^{NP} HL'_{ij}\,l_{ij}$$

Min. pressure reqd. at node n (P_n); Head of source node (H_R); Elevation of node n (E_n); Links from source to node n (S_n); Unit headloss of j[th] pipe of i[th] link (HL'_{ij})

- **Pipe Constraint:**

$$\sum_{j=1}^{NP} l_{ij} = L_i$$

Total length of i[th] link (L_i)

- **Unit Headloss:**

$$HL'_{ij} = \frac{10.68 * \left(\dfrac{flow_i}{roughness_j}\right)^{1.852}}{diameter_j^{\,4.87}}$$

Future Work

Immediate Tasks

- Web Application
- GIS Integration
- Usability Features

Medium term

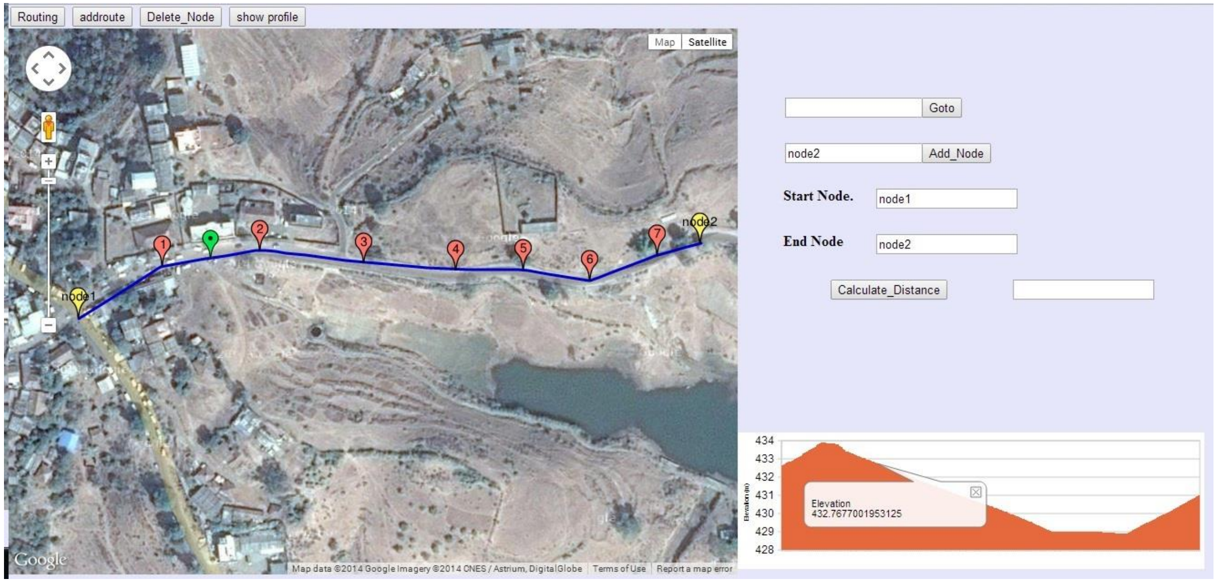
- Pressure Rating
- Pressure Reducing Valves
- Pumps
- ESR Elevation
- Operational Cost

Long term

- Multiple Sources Looped Network
- Cost Allocation
- ESR Location

Sample GIS Integration for Input Data

- Web based Application that runs Google Earth.
- Navigate to the region of interest using Google Earth.
- Mark the nodes by traversing a path for the network.
- Inter node distance and the elevation of nodes is displayed on the screen.
- When the user submits the data, it is formatted as JalTantra Input file.



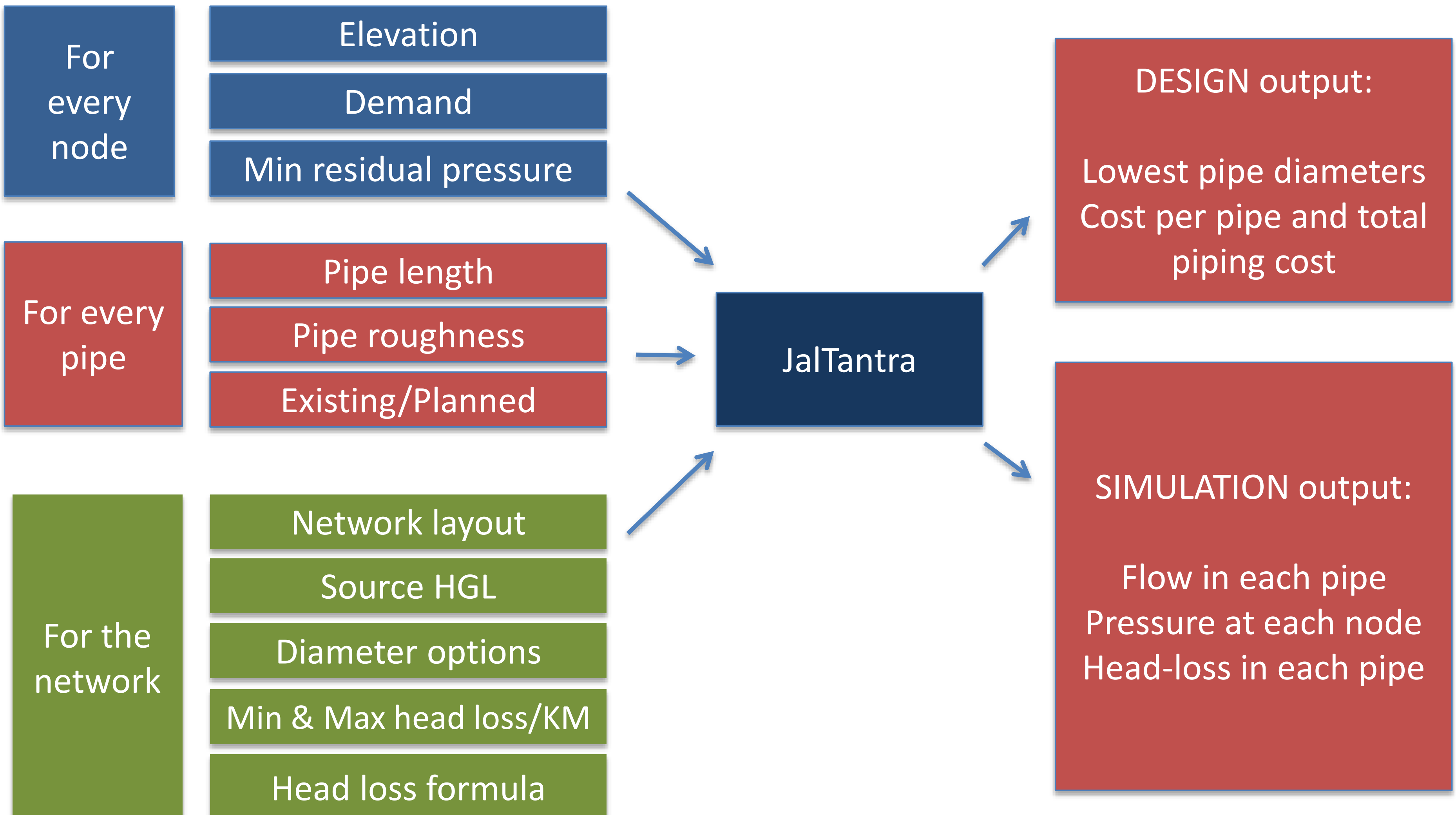
JalTantra vs. EPANET

Note: Network layout required for both.

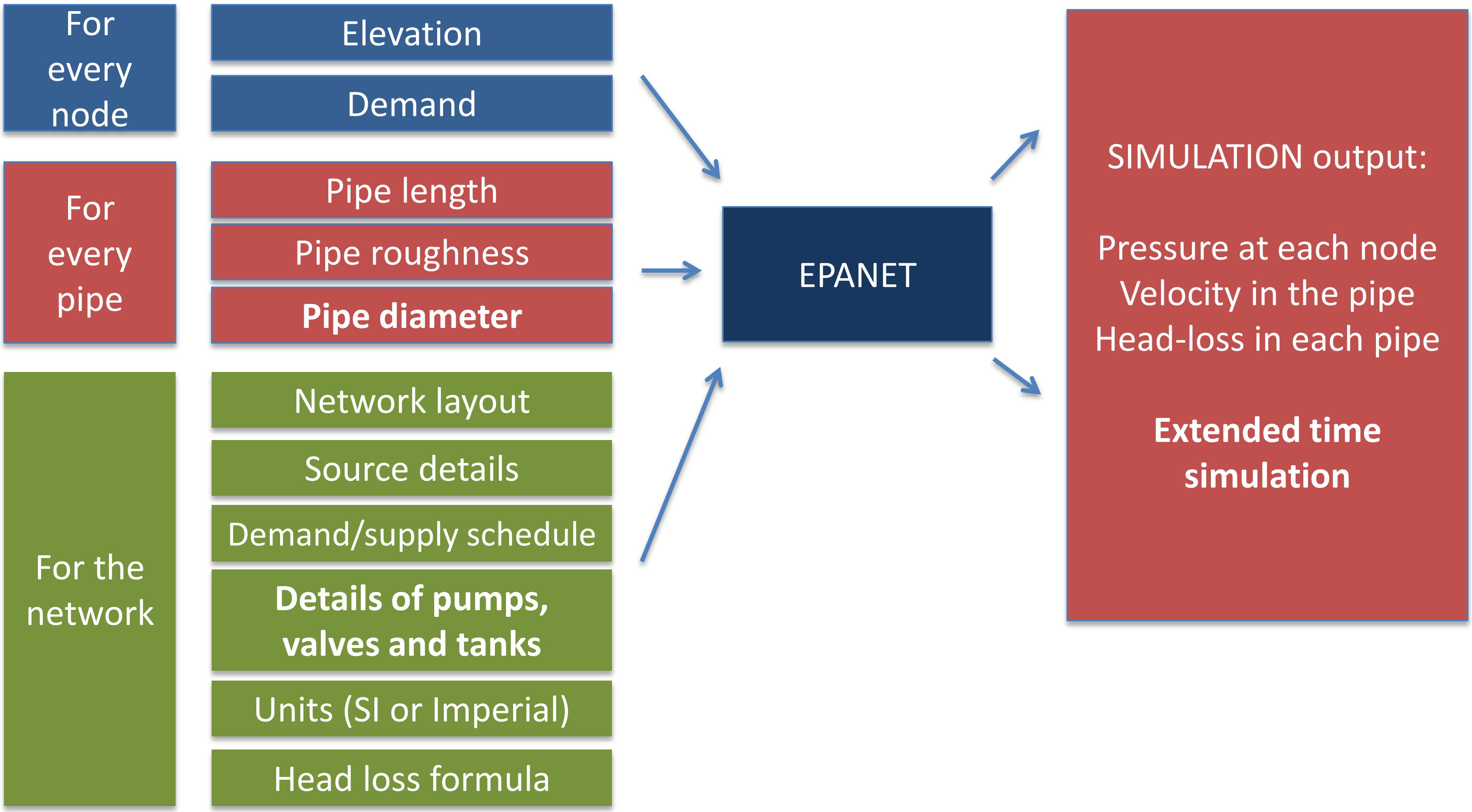
In general

- Use JalTantra for design: it optimizes pipe diameters (but only if the network is branched and gravity-fed)
- Use EPANET for simulation if the system has pumps, valves, loops, and time-variations in demand or supply

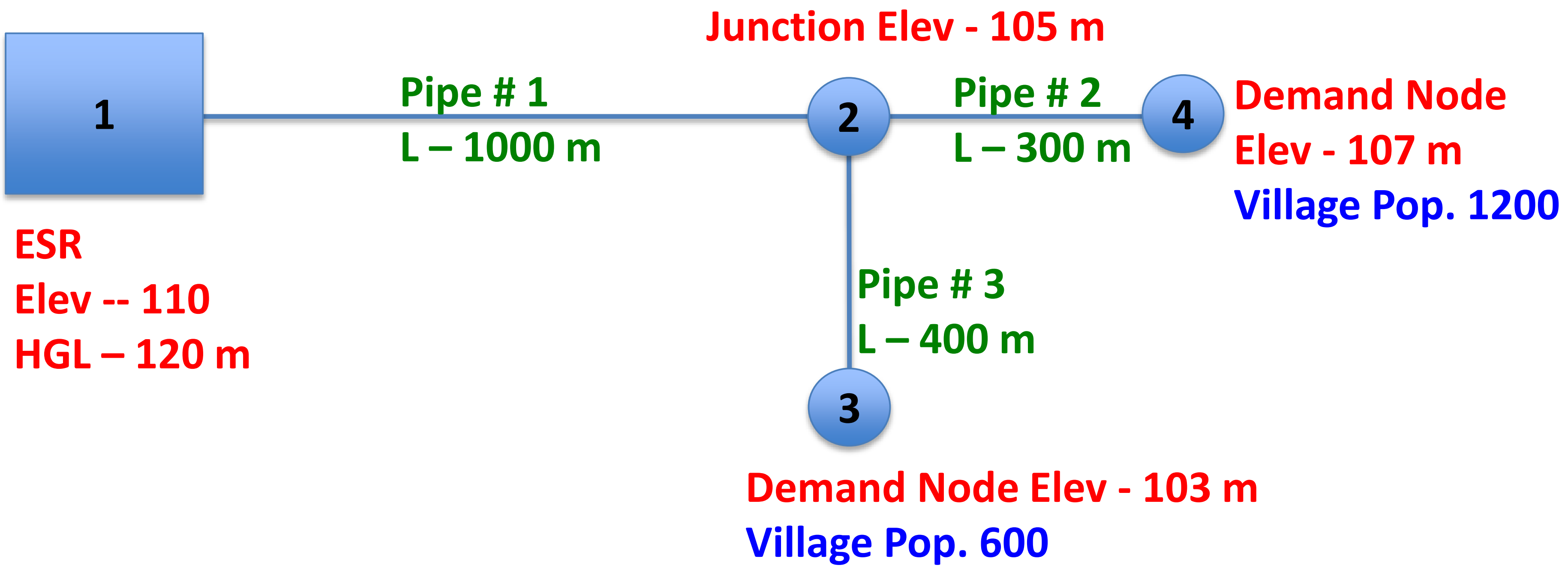
JalTantra input/output



EPANET input/output



Example network layout



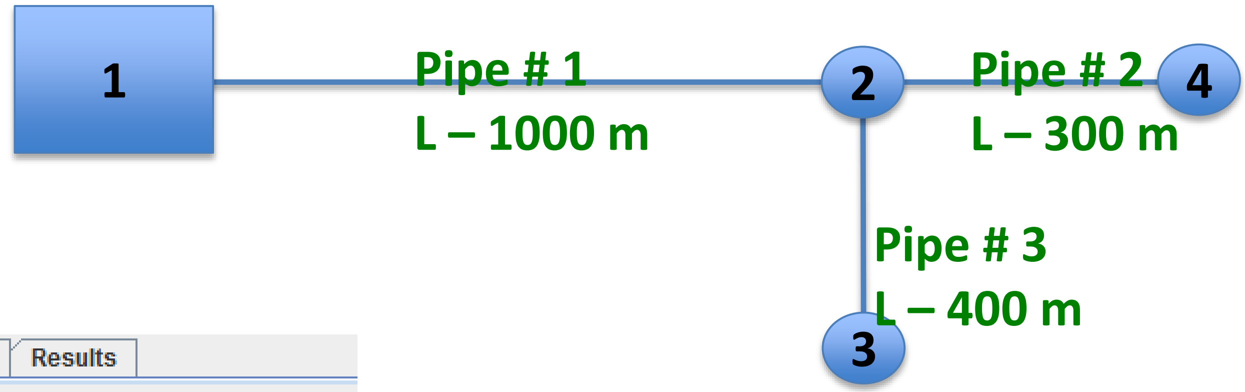
Demand calculation

- Rural supply norm: 55 lpcd
- Assume the ‘source’ is an ESR which will supply the full day’s water in 6 hours

Demand (lps) = pop. * 55 lpcd/(6 hr * 3600 s/hr)

Node 3 => 600 * 55/(6*3600) = 1.5 lps

Node 4 => 1200 * 55/(6*3600) = 3.0 lps



Node Data

General | Nodes | Pipes | Commercial Pipes | Results

Source Details:

NodeID: 1 Elevation: 110 Head: 125

	NodeID	Elevation	Demand	Min. Pressure
☐	2	105		
☐	3	103	1.5	
☐	4	107	3	

Pipe Data

General | Nodes | Pipes | Commercial Pipes | Results

	PipeID	Start Node	End Node	Length	Diameter	Roughness	Parallel Allowed
☐	1	1	2	1,000			☐
☐	2	2	4	300			☐
☐	3	2	3	400			☐

Commercial Pipe Data

General | Nodes | Pipes | Commercial Pipes | Results

	Diameter	Cost
☐	63	107
☐	75	150
☐	90	215
☐	110	319
☐	125	413
☐	140	517
☐	180	851

JalTantra input

JalTantra output

Node Results

General | Nodes | Pipes | Commercial Pipes | Results

Nodes | Pipes | Cost

NodeID	Demand	Elevation	Head	Pressure	Min. Pressure
1	0	110	120	10	8
2	0	105	115.628	10.628	8
3	1.5	103	112.129	9.129	8
4	3	107	115	8	8

Pipe Results

General | Nodes | Pipes | Commercial Pipes | Results

Nodes | Pipes | Cost

PipeID	Start Node	End Node	Length	Flow	Diameter	Roughness	Headloss	HLPerkm	Cost
1	1	2	970.263	4.5	110	100	4.302	4.433	309,513.904
1	1	2	29.737	4.5	125	100	0.071	144.654	12,281.372
2	2	4	300	3	110	100	0.628	2.092	95,700
3	2	3	400	1.5	63	100	3.499	8.748	42,800

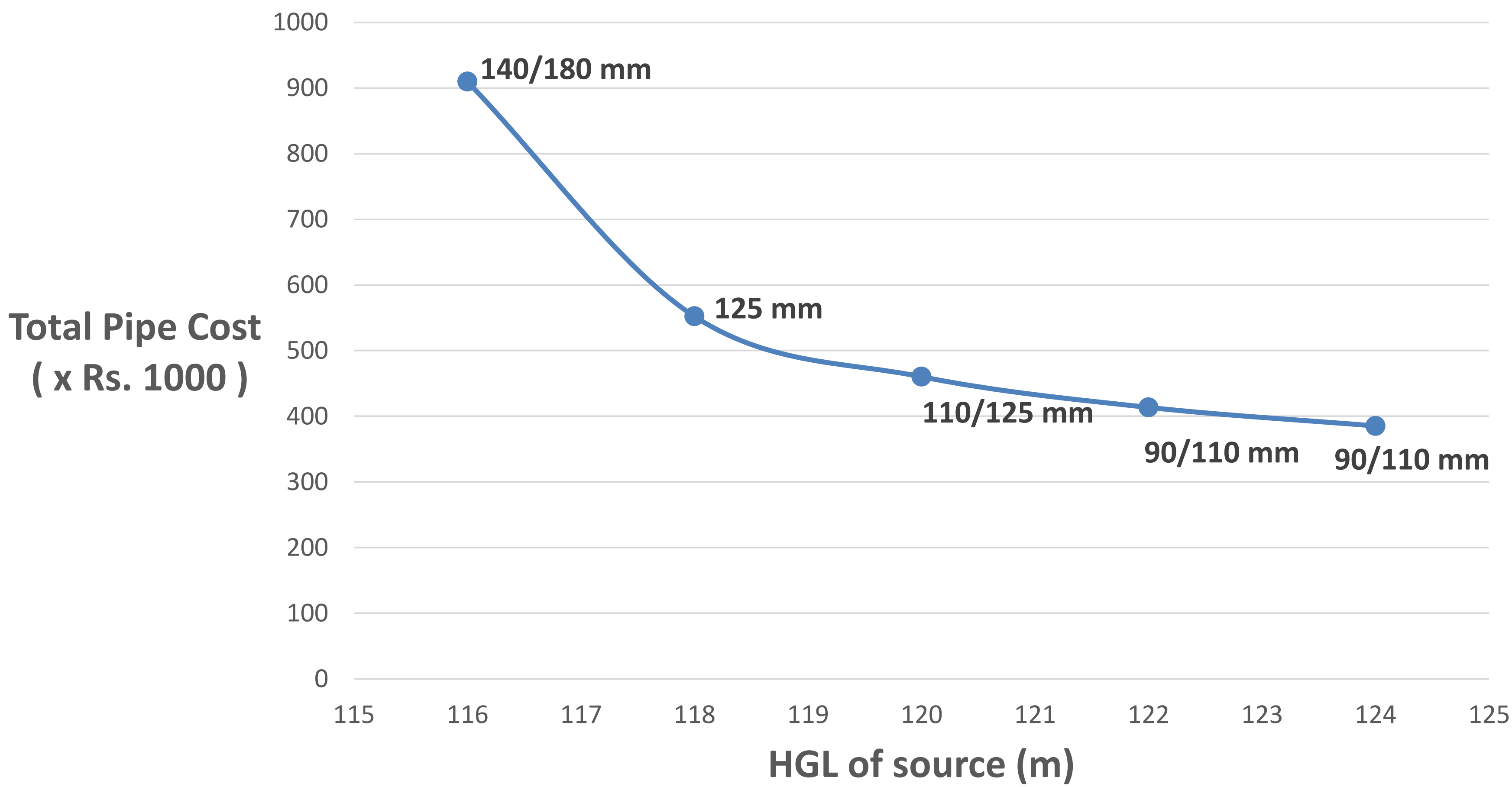
Cost Results

General | Nodes | Pipes | Commercial Pipes | Results

Nodes | Pipes | Cost

Diameter	Length	Cost	Cumulative Cost
63	400	42,800	42,800
110	1,270.263	405,213.904	448,013.904
125	29.737	12,281.372	460,295.276

HGL vs. Total pipe cost and Pipe 1 diameter



Increasing the source HGL often reduces total piping cost

EPANET

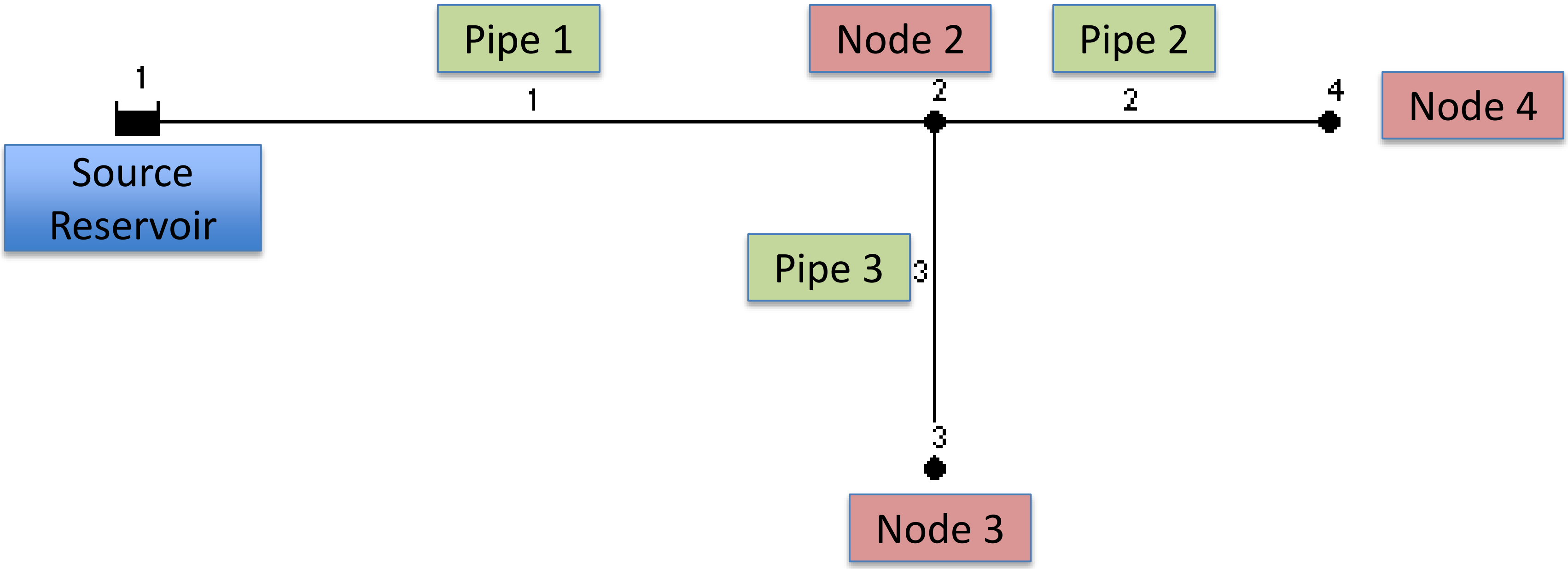
What does EPANET do?

- Public domain software for simulation of water distribution networks
- EPANET analyses the flow of water in each pipe, the pressure at each node, the height of water in a network.

Advantages:

1. Extended period hydraulic analysis for any system size.
2. Simulation of varying water demand, constant or variable speed pumps, and the minor head losses for bends and fittings.
3. EPANET can compute the energy consumption and cost of a pump.
4. Can model various valve types - pressure regulating, and flow control valves
5. Provides a good visual depiction of the hydraulic network
6. Data can but imported in several ways – the network can be drawn and data can be imported from Google Earth.
7. Water quality-Simulation of chlorine concentration in each pipe and at each node.

EPANET slide 1 (set up)



EPANET Output file- Nodes

Network Table - Nodes

Node ID	Elevation m	Base Demand LPS	Demand LPS	Head m	Pressure m
Junc 2	105	0	0.00	115.56	10.56
Junc 4	107	3	3.00	114.93	7.93
Junc 3	103	1.5	1.50	114.06	11.06
Resvr 1	120	#N/A	-4.50	120.00	0.00

EPANET Output file- Pipes

Link ID	Length m	Diameter mm	Flow LPS	Velocity m/s	Unit Headloss m/km
Pipe 1	1000	110	4.50	0.47	4.44
Pipe 2	300	110	3.00	0.32	2.09
Pipe 3	400	75	1.50	0.34	3.75

Extended period analysis

- EPANET Time Pattern: To make our network more realistic for analyzing an extended period of operation we will create a Time Pattern that makes demands at the nodes vary in a periodic way over the course of a day.
- The variability in demands can be addressed through multipliers of the "Base Demand" at each node.
- Nodal demands, reservoir heads, pump schedules can all have time patterns associated with them.
- As an example of how time patterns work consider a junction node with an **average demand of 3 lps**. Assume that the time pattern interval has been set to 4 hours and a pattern with the following multipliers has been specified for demand at this node-

Time Period	**1**	**2**	**3**	**4**	**5**	**6**
Multiplier	**0.5**	**0.8**	**1.0**	**1.2**	**0.9**	**0.7**

- Then during the simulation the actual demand exerted at this node will be as follows:

Hours	0-4	4-8	8-12	12-16	16-20	20-24
Demand	1.5	2.4	3.0	3.6	2.7	2.1

References

- Mokhada MVS design report: http://www.cse.iitb.ac.in/internal/techreports/reports/TR-CSE-2013-55.pdf
- Khardi Rural Piped Water Scheme http://www.cse.iitb.ac.in/internal/techreports/reports/TR-CSE-2013-56.pdf
- North Karjat RR scheme feasibility study: http://www.cse.iitb.ac.in/~sohoni/karjatshort.pdf
- Sugave MVS scheme analysis: http://www.cse.iitb.ac.in/~sohoni/mvs.pdf
- Tadwadi SVS scheme failure analysis http://www.cse.iitb.ac.in/~sohoni/svs.pdf