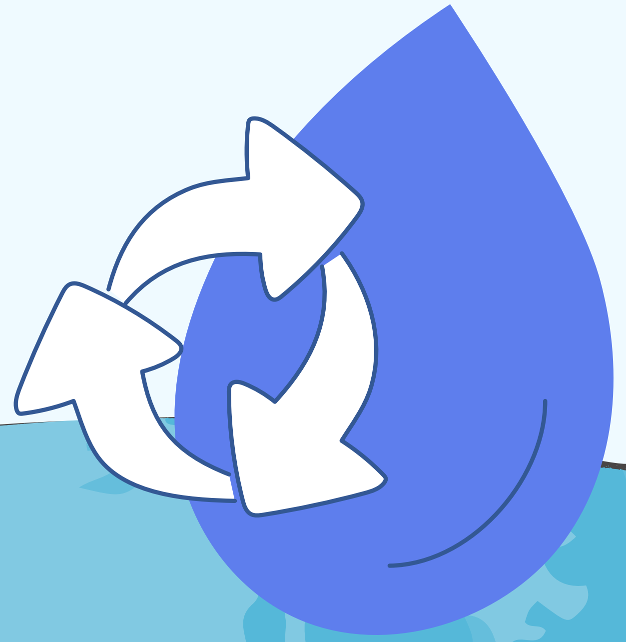
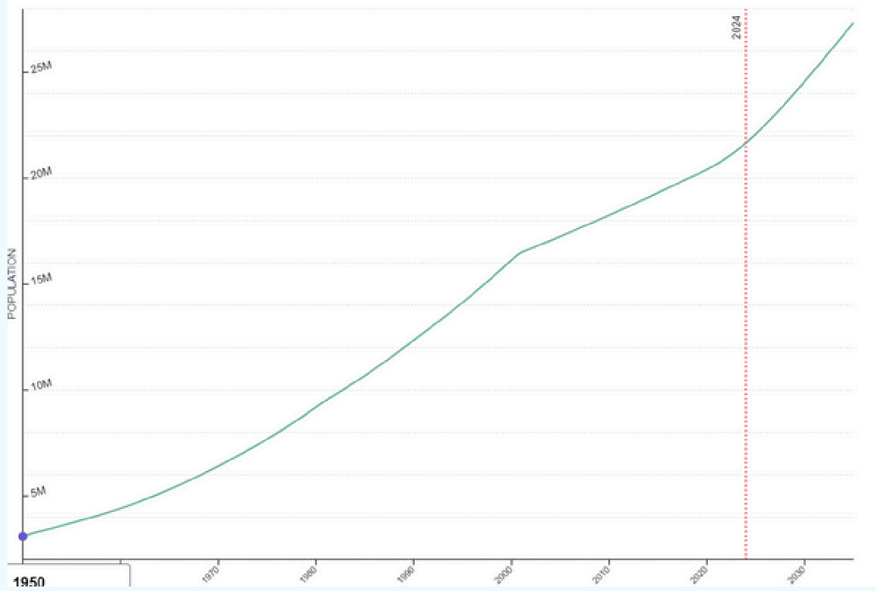
ILP MODELS FOR WATER DISTRIBUTION SYSTEM OPTIMISATION

A PRESENTATION BY
SPARSH AMARNANI



Motivation



Rapid Urbanisation

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Variable Water Supply

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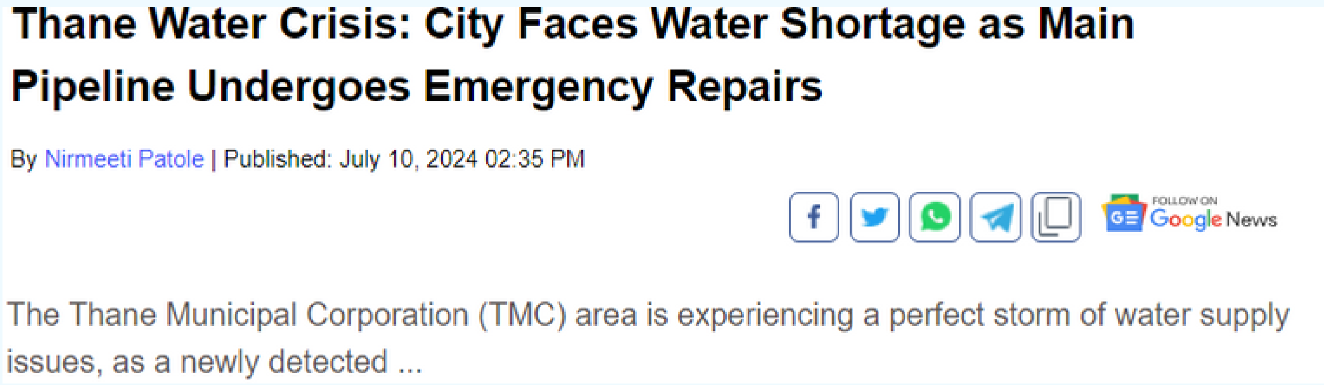

Thane Water Crisis: City Faces Water Shortage as Main Pipeline Undergoes Emergency Repairs

By Nirmeeti Patole | Published: July 10, 2024 02:35 PM

The Thane Municipal Corporation (TMC) area is experiencing a perfect storm of water supply issues, as a newly detected ...


Water cut announced for Mumbai

Richa Pinto / TNN / May 25, 2024, 16:40 IST

Mumbai faces water shortage with BMC announcing 5% and 10% water cuts. Citizens urged to conserve water until sufficient rainfall improves reservoir levels. Indian Meteorological Department forecasts timely monsoon arrival. Water cuts also apply to Thane, Bhiwandi-Nizampur Municipal Corporation. BMC provides list of water-


Water

Tanker economy revealed: Rajasthan's groundwater level takes a dip as water mafias emerge

Water shortages in Rajasthan need no introduction; but the extent of the crisis covers a lot more than what meets the eye

Water problems

WHAT IS WDS OPTIMISATION ?

DECISION VARIABLE

Hydralic Components that we can choose like ,pipes, pumps and valves

OBJECTIVE FUNTION

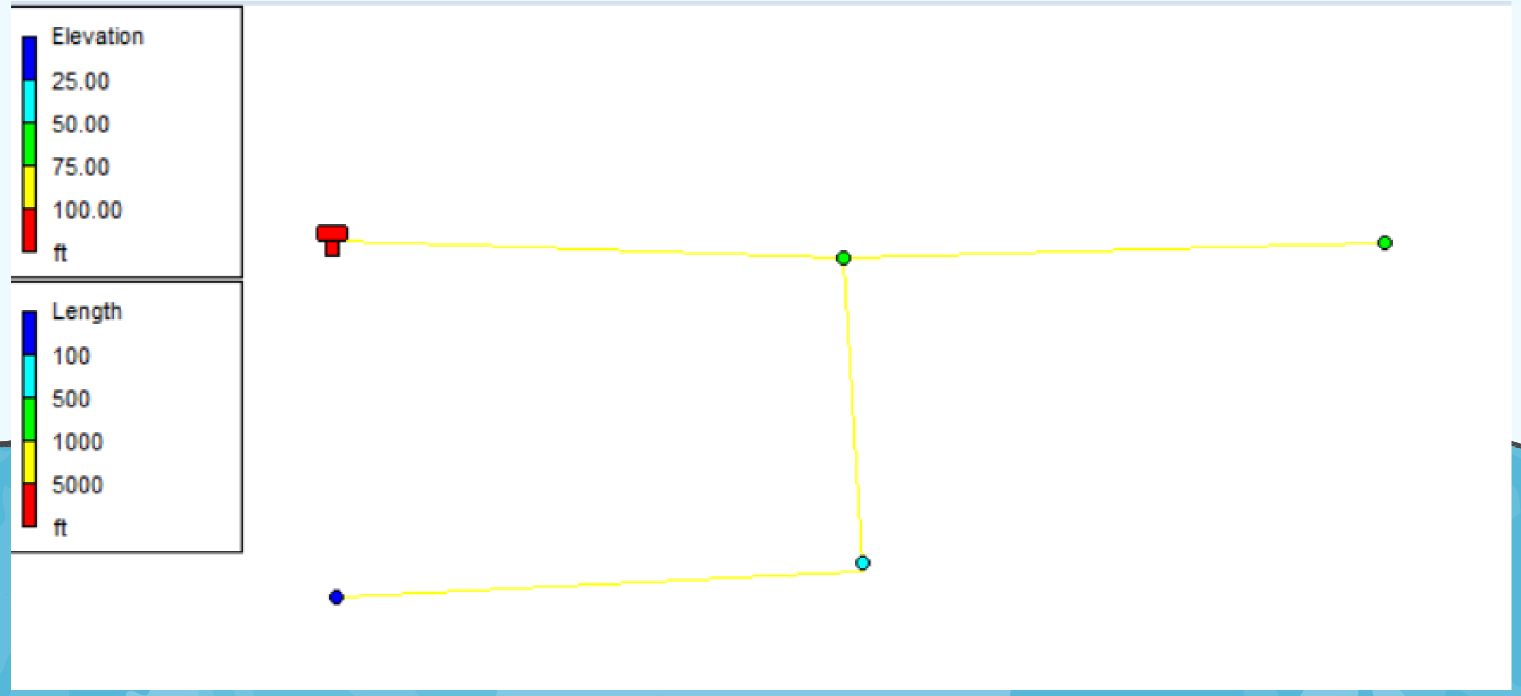
Variables that are dependent on our choices that we want to minimize or maximize, like cost, water quality or greenhouse gas emmisions.

CONSTRAINTS

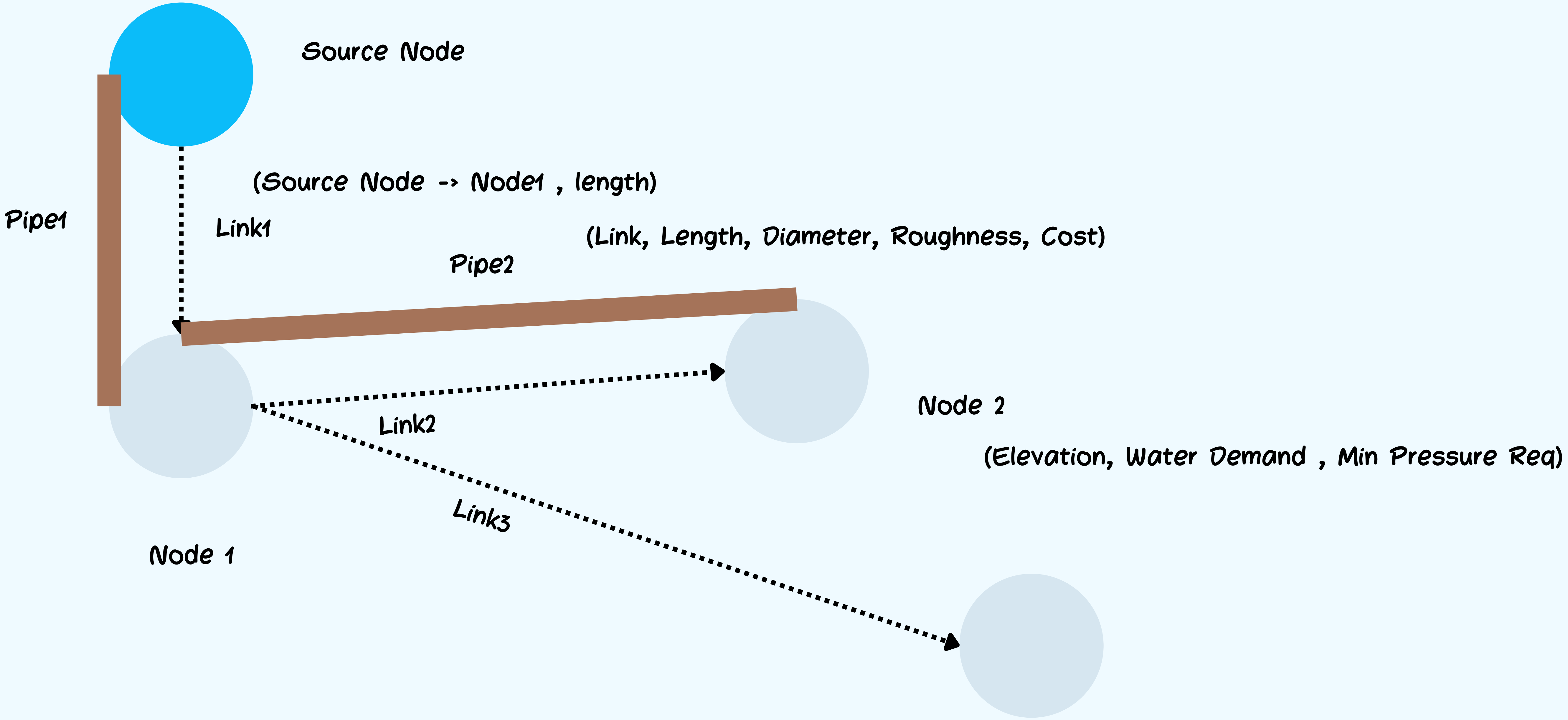
Hydraulic constraints are given by physical laws governing the fluid flow in a pipe network.

System Constraints like water demands and water quality requirement

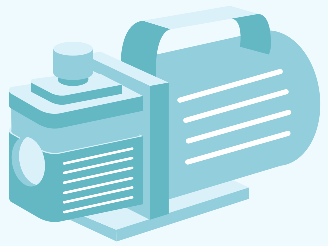
THE GOAL IN DESIGING A SOFTWARE WHICH CAN OPTIMISE THIS IS THAT WE CAN UPDATE OUR WATER NETWORKS WITH INCREASING WATER DEMANDS OR CHANGE IN WATER SUPPLY



Inputs of the Optimisation Model

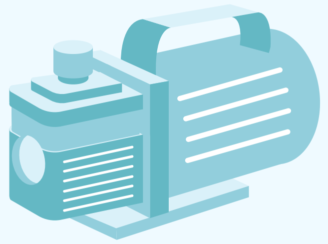


Pumps



Pump 1

Pump Cost, Pump Life Cycle, Minimum Pump Size, Efficiency



Pump 1

Tank Table

Base Cost, Unit Cost, Upper Limit Capacity, Lower Limit Capacity

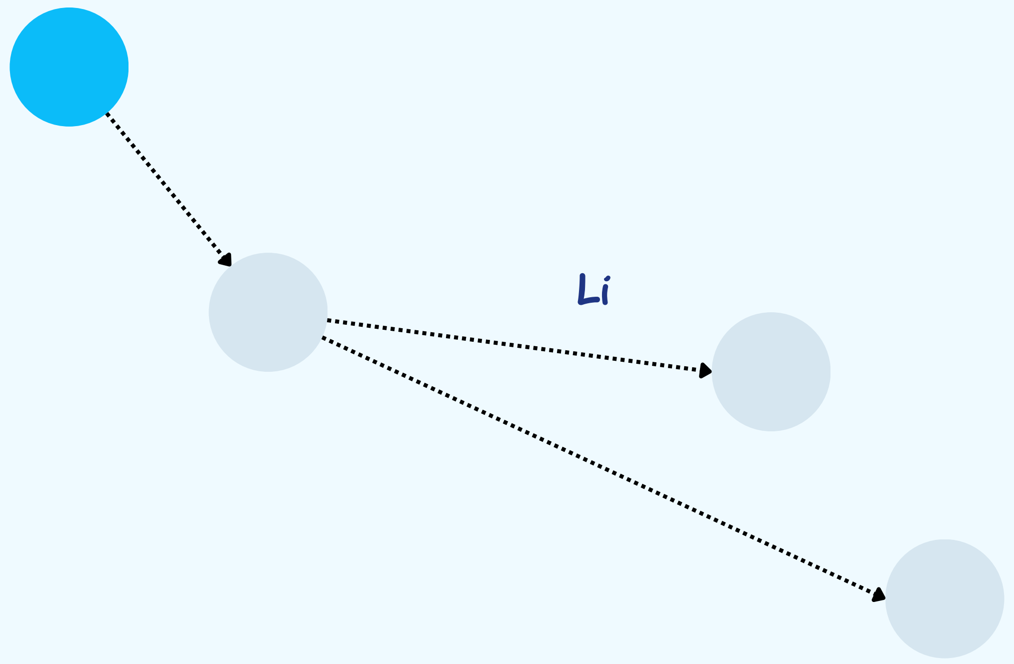
Tank 1

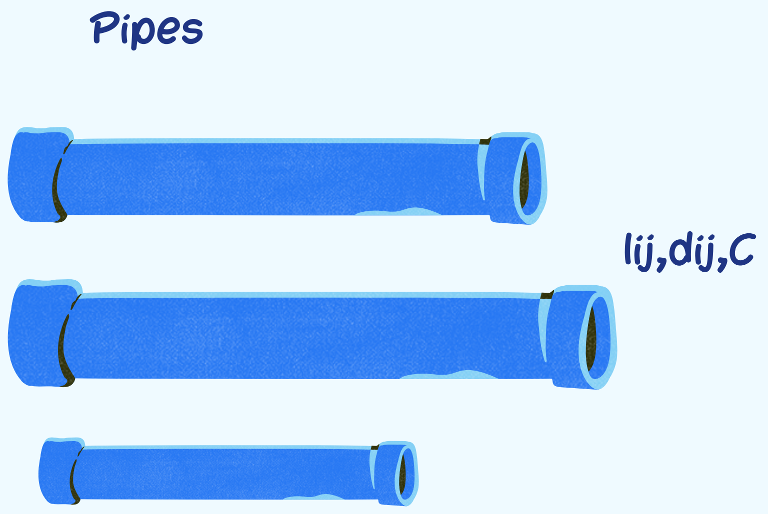
Tank 2

Tank 3

Other tank inputs : Maximum, Min Tank Height allowed,

PIPE ONLY MODEL OPTIMISATION





OUR GOAL IS TO PUT PIPES IN EACH LINK WHICH WILL MINIMIZE THE COST OF THE NETWORK

OBJECTIVE FUNCTION

minimize L : C(Di,j) * Lij sum over i and j

CONSTRAINTS

Length of Pipes

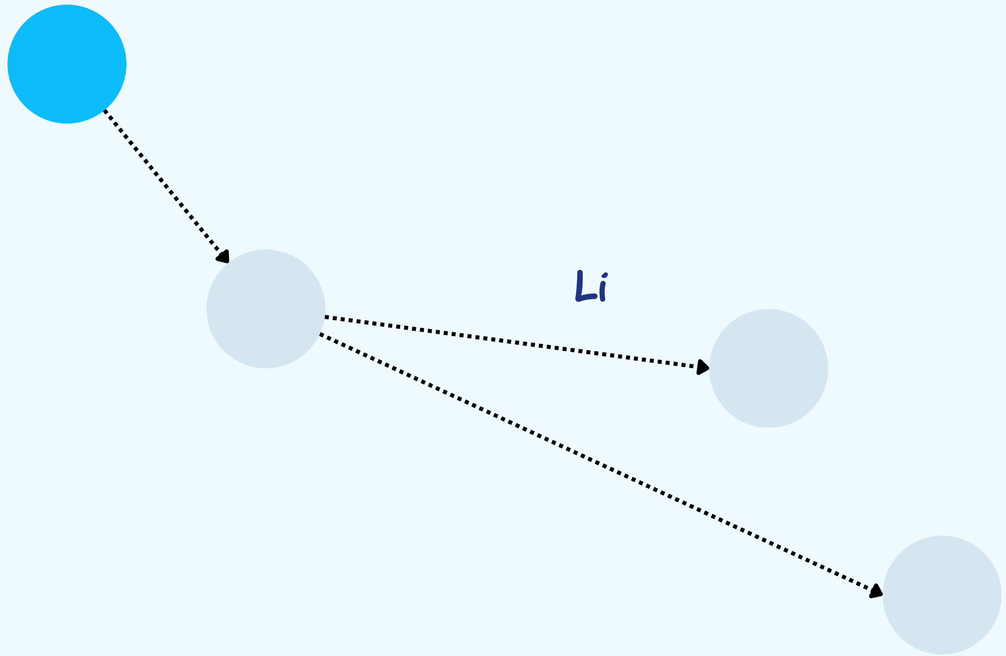
lij sum over j = Li

lij>=0

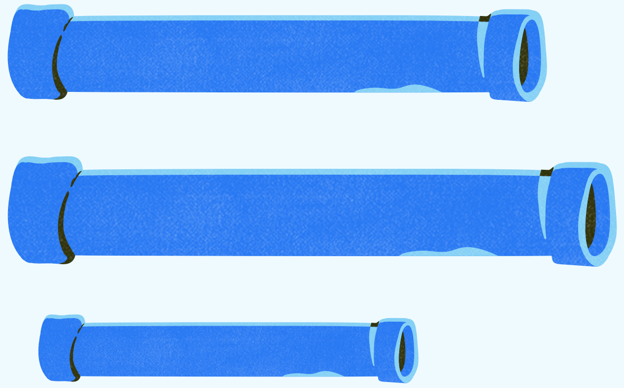
Pressure requirment at each node

Pn<= Hr -En-(HLij*Li)
sum over j and i
which are parent links

PIPES AND PUMP MODEL OPTIMISATION

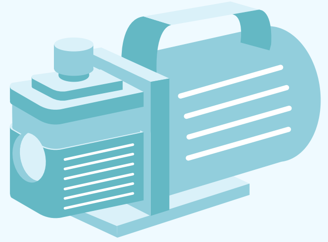


Pipes



lij,dij,C

Pump



What power pump should be applied at which link i

Efficiency of a pump, Max and minimum power allowed by a pump, Capital and Operational Cost of a Pump

OBJECTIVE FUNCTION

minimize L,p : Pipe Cost + (Cp * pi) + (EF * DF * SH *pi) for all i

CONSTRAINTS

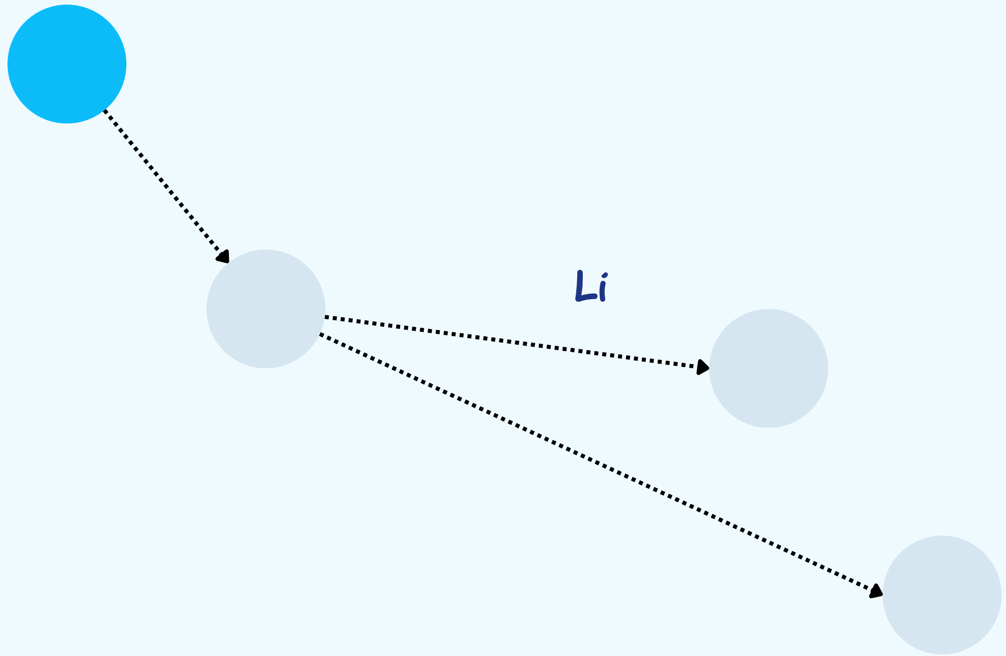
Presure on Link

phi= (eff * pi)/wtden * g*FLi

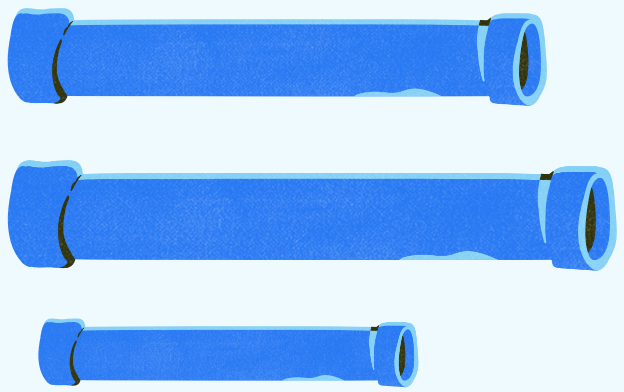
Pressure requirment at each node

Pn<= Hr -En-(HLij*Li) +phi sum over j and i which are parent links

PIPES AND PUMP MODEL OPTIMISATION

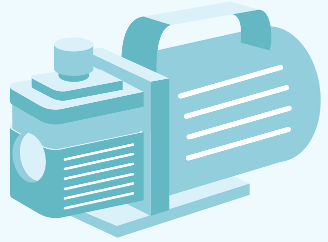


Pipes



lij,dij,C

Pump



What power pump should be applied at which link i

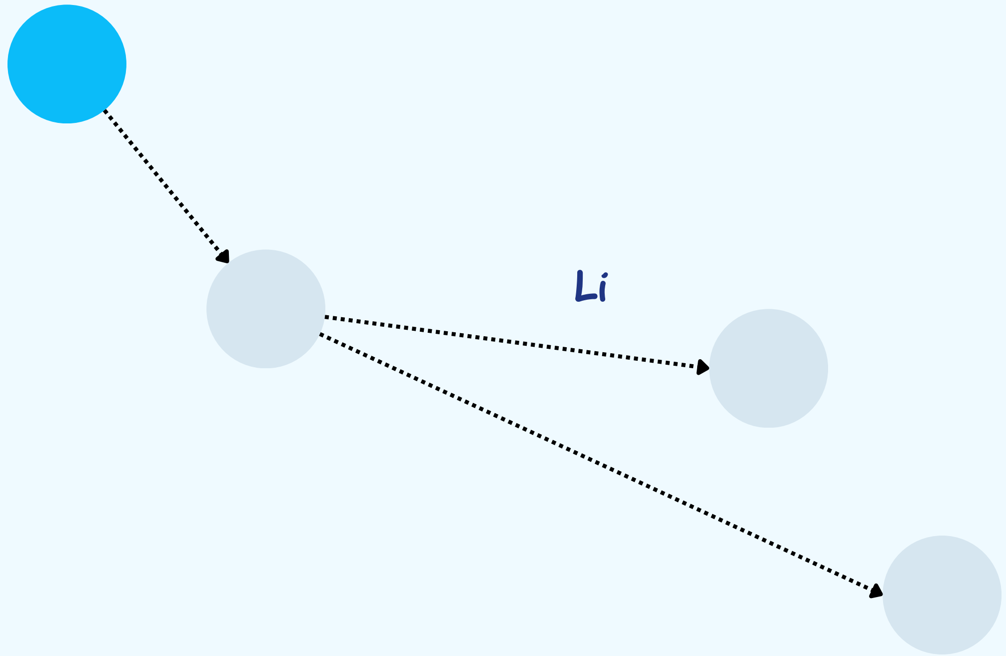
Efficiency of a pump, Max and minimum power allowed by a pump, Capital and Operational Cost of a Pump

CONSTRAINTS CONTINUED

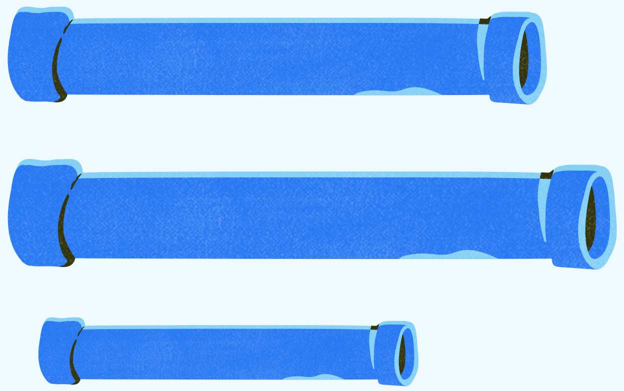
Power Constraints

PPmin<=pi<=PPmax

FINAL MODEL INPUTS

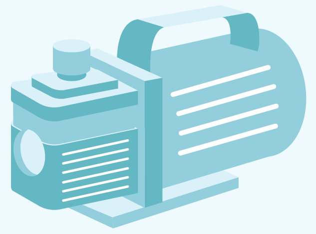


Pipes

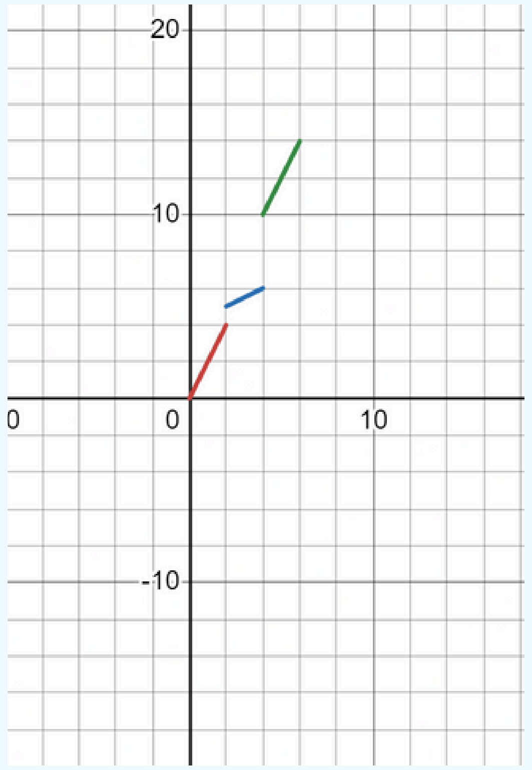


lij,dij,C

Pump



Efficiency of a pump, Max and minimum power allowed by a pump, Capital and Operational Cost of a Pump



Tank Cost Table

Base Cost, Unit Cost, Upper Limit Capacity, Lower Limit Capacity

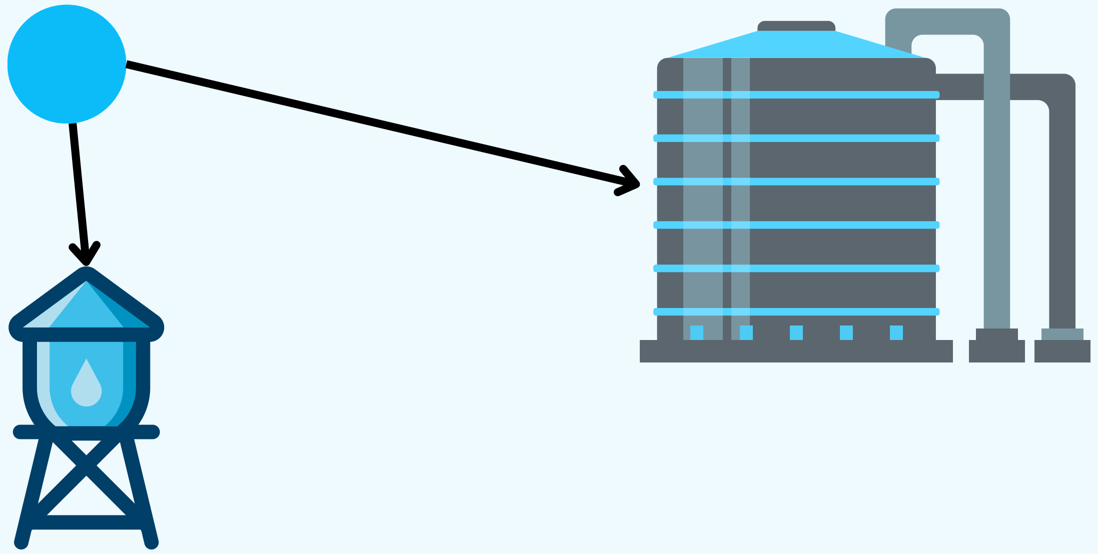
Tank 1

Tank 2

Tank 3

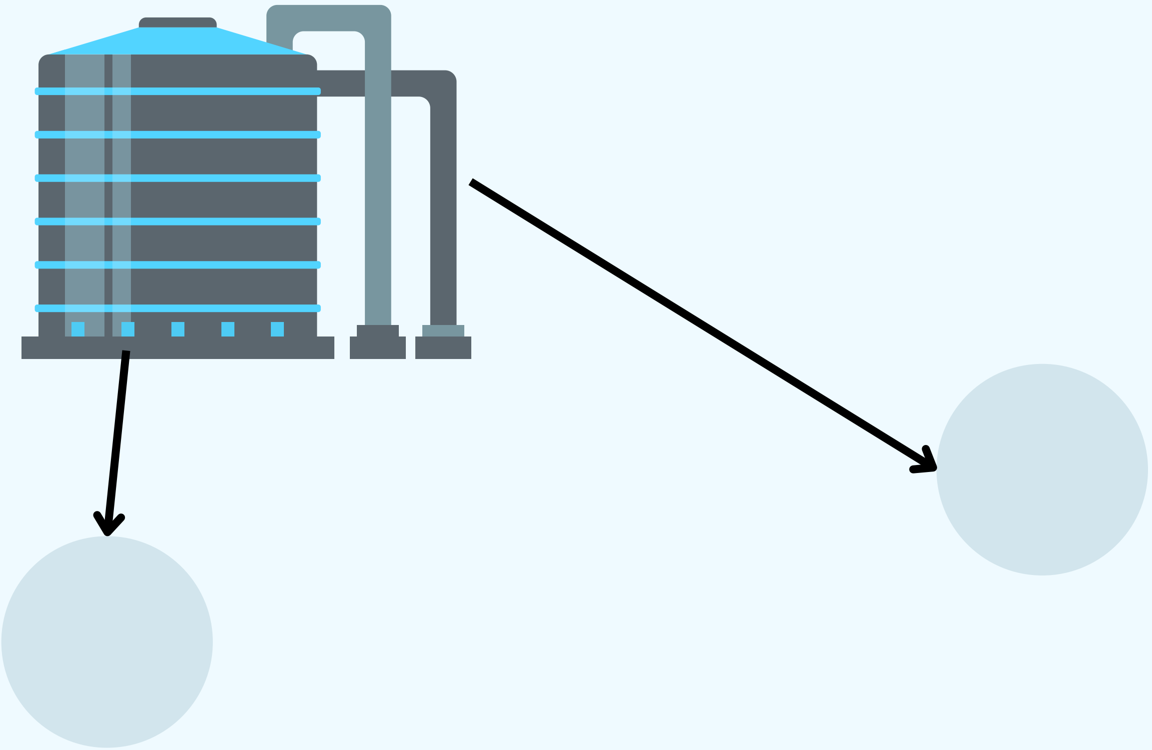
Other tank inputs : Maximum, Min Tank Height allowed,

PRIMARY



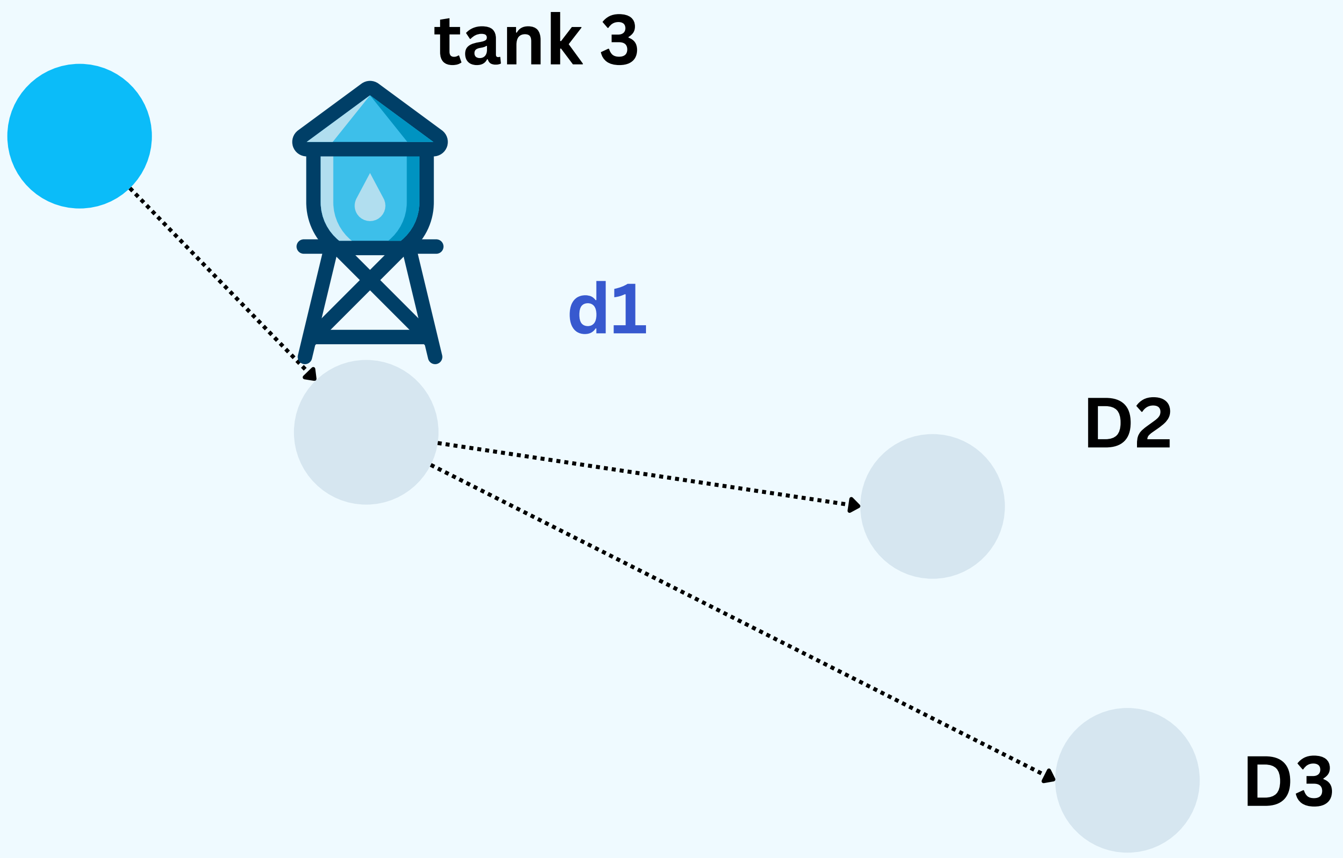
The primary network is the main system of pipes and infrastructure that transports water from the source (such as a water treatment plant or reservoir) to various storage facilities

The secondary network is the subsystem that distributes water from the primary network (or storage tanks) to individual demand nodes, such as households, businesses, and public facilities.



SECONDARY

OBJECTIVE FUNCTION WITH TANK



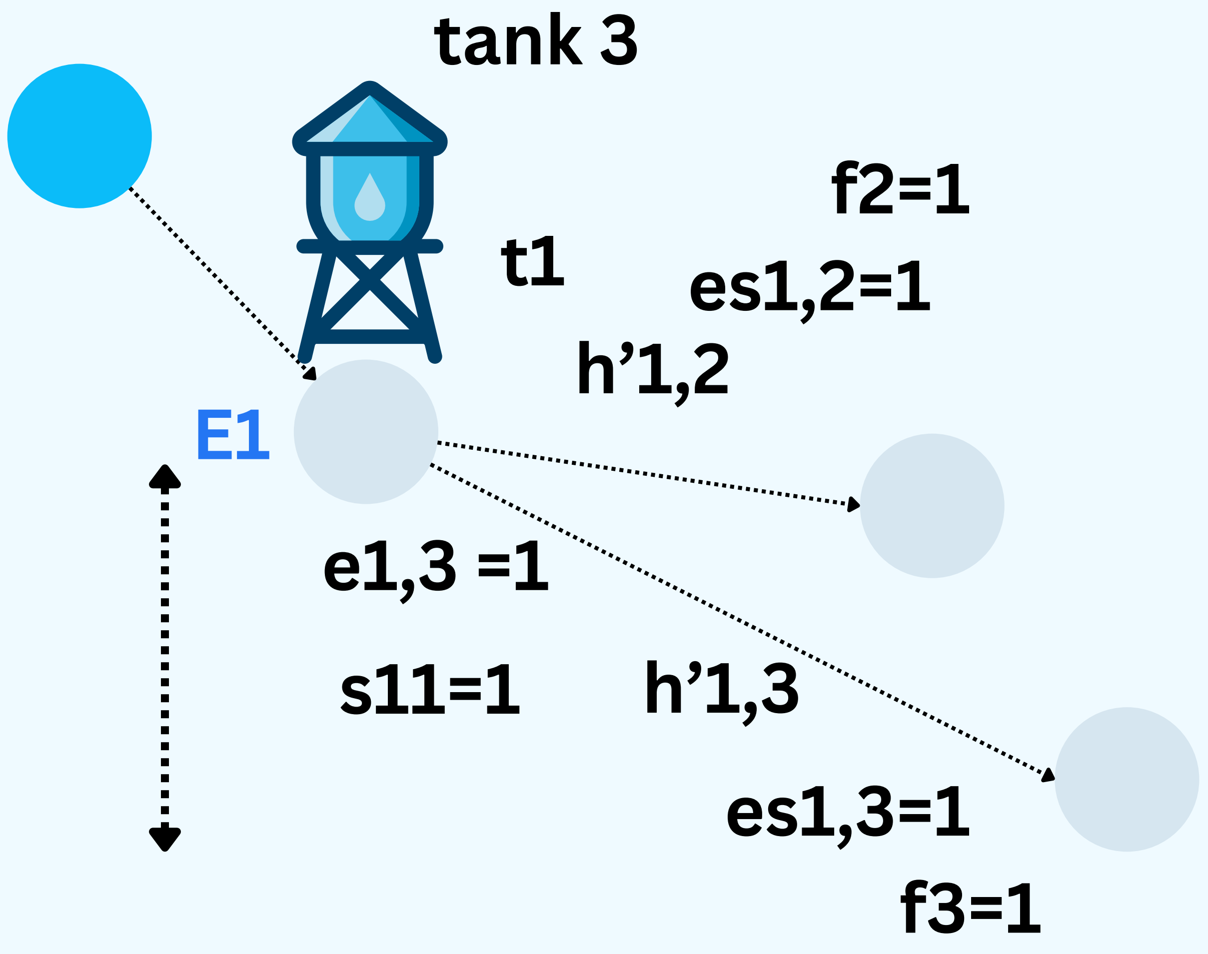
Head on link if tank is its source

d1=D2+D3

znk=dn*enk (linearlisation of the)

min l,p Cost of pipes + Cost of Pumps + enk * (Bk + UnitCk*(dn-LOk)) over all nodes (n) of the network and rows of the tank table (k)

PRESSURE CONSTRAINT WITH TANK



Head on link if tank is its source

$h'ni=(tn+En)*esn + hn*(1-esn)$

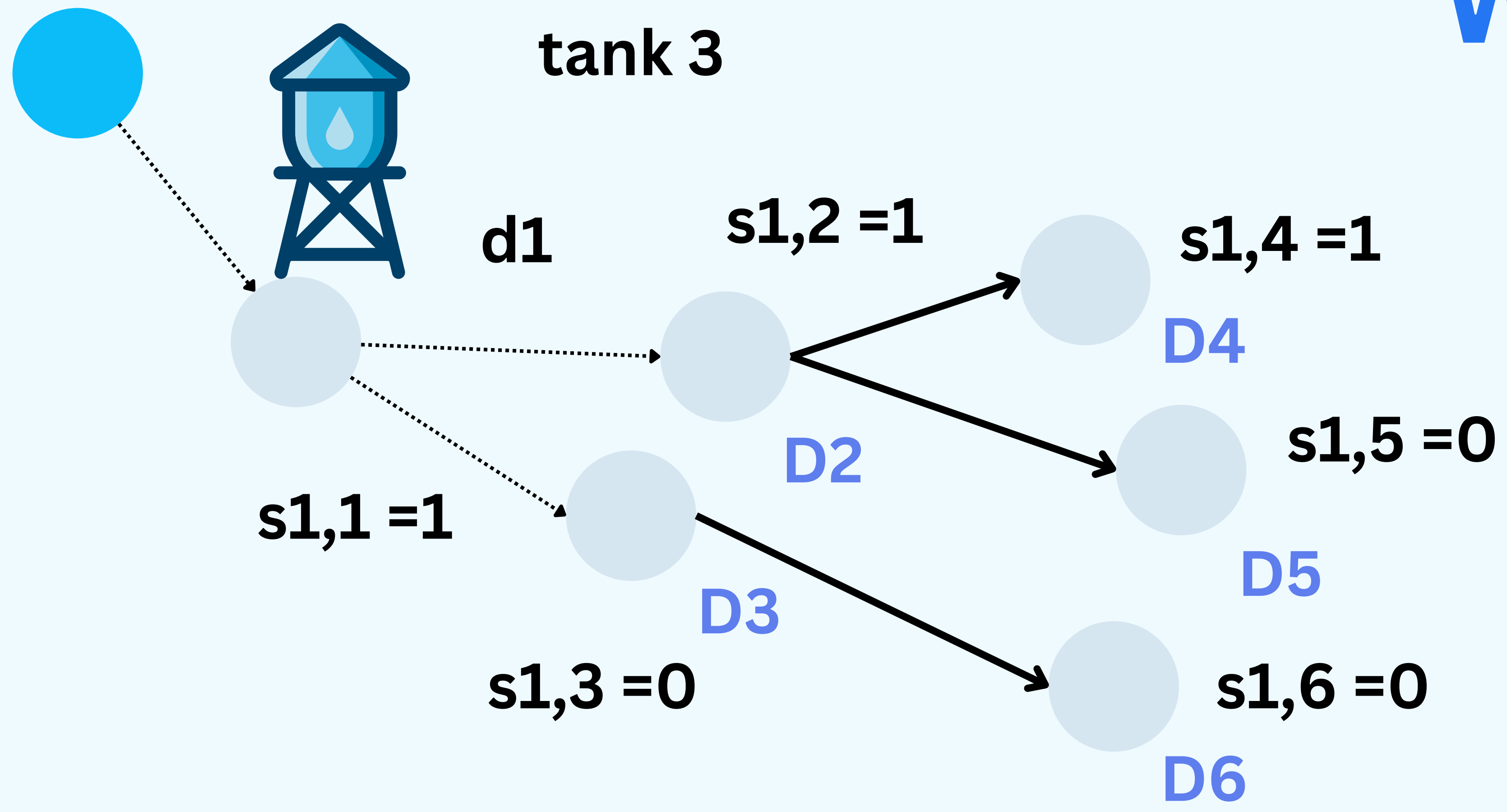
$h'1,2=t1+E1$

$esni=snn*(1-fi)$

$pn<=h'mi -hli$

If the starting node is a source node
then the head loss equation changes

CONSTRAINTS ON TANK AND THEIR DECENDANTS



Where m is a descendant of n

smm<=snn

snm<=snn

sum over all Ancestors of m snm=1

dn = snm*DEm

snm<=1-soo for all o in path of n,m

Nodes can serve their decendants if they serve their own

OTHER CONSTRAINTS

Only 1 tank per row:

sum over k enk =1

Capacity-demand Constraint:

dn>=LOk*enk

UPk+DE(1-enk)>=dn

EFFECT ON OTHER CONSTRAINTS

Splitting headloss calculation:

hli = sum over all pipe segments (HLPij*lpij+HLSij*[lij-lpij])

Primary and Secondary Flows:

FLPi/FLSi = SH/PH

Primary and Secondary Pumps:

pi = ppi+psi

HOW IS OUR MODEL IMPROVED

min x C.x
Ax<=B
x>=0
X is Integer

→

min x C.x
Ax<=B
x>=0
X is Rational

SOLVING A LINEAR INTEGER PROGRAM INVOLVES LINEAR RELATION

ILP' ← ILP

ILP' → New Relaxation'

ILP → Old Relaxation

IF NEW RELAXATION IS A STRICT SUBSET OF THE OLD RELAXATION THEN IT S A SMALLER SOLUTION SPACE FOR THE SAME PROBLEM

HEADLOSS IMPROVEMENT

Old model

lijp=lij*fi

Linearize

lijp>=0

lijp<=Li*fi

lij-Li*(1-fi)<=lijpj

lijp<=lij

New model

We introduce lijs which represents length of link for the secondary network

lijp+lijs=lij

sum over a link lijp = Li*fi

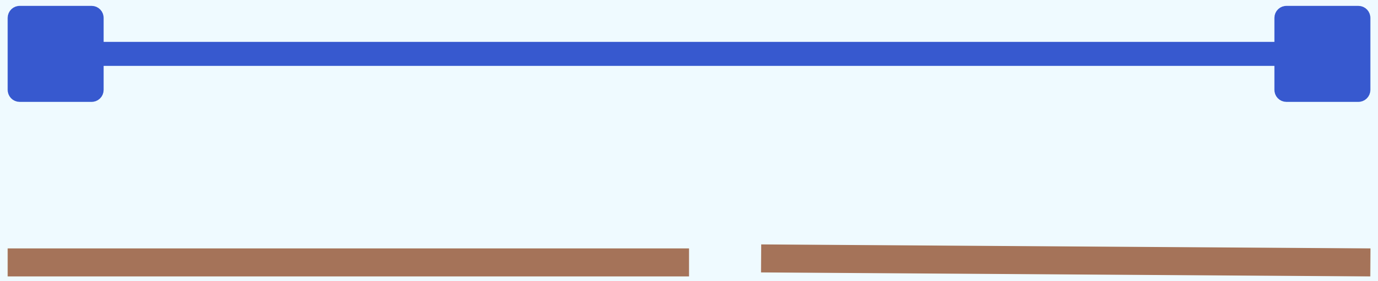
sum over a link lijs = Li*(1-fi)

HEADLOSS IMPROVEMENT STRICT SUBSET PROVE

Consider the point :

Link Length = L

Primary pipe segment =[L/2,L/2] ,f = 0.5



Secondary pipe segment =[0,0]

Link/Pipe Length = [L/2,L/2]

Old model Satisfied

lijp=lij*fi

$\downarrow$

L/2=L*0.5

New model Unsatisfied

lijp+lijs=lij	L/2=L/2
sum over a link ljp = L*fi	L/2=L/2
sum over a link lijs = Li*(1-fi)	0=L/2

TANK COST IMPROVEMENT

Old model

znk=enk*dn eq0

Linearize

znk>=0

znk<=DE*enk

znk-DE*(1-enk)<=dn

dn<=znk

znk is the water demand of tank k at node n

DE is total wated demand of the network

New model

eq1 LOk*enk<=znk

eq2 znk<=UPk*enk

eq3 sum for all row for n enk =1

eq4 sum for all row for n znk =dn

lets say for node n we have 4 tanks

applying eq1&2 to enk

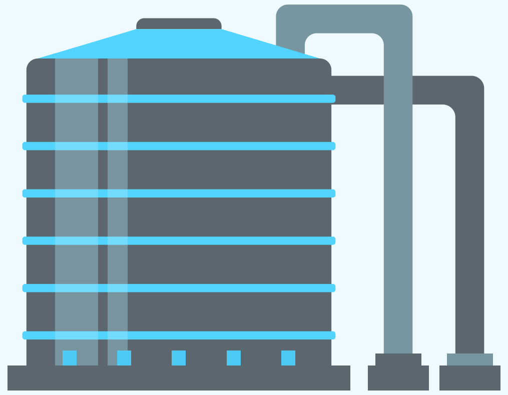
applying eq4 to znk

enk : 0 1 0 0

znk : 0 zn2 0 0

zn2=dn

TANK COST IMPROVEMENT : STRICT SUBSET PROOF



z1k : [d,d]
e1k:[1/2,1/2]
d1=d

LOk : [0,d]
UPk:[d,2d]
DE=2d

Old model is satisfied

znk>=0

znk<=DE*enk

znk-DE*(1-enk)<=dn

dn<=znk

New model is violated

eq1 LOk*enk<=znk

eq2 znk<=UPk*enk

eq3 sum for all row for n enk =1

eq4 sum for all row for n znk =dn

TANK COST IMPROVEMENT : BEST RELAXATION PROOF

z1k : [1,1]
e1k:[1/2,1/2]
d1=1

P1

t=1/2
n’=1
k’=1

z1k : [0,2]
e1k:[0,1]
d1=0

P2

LOk : [2,0]
UPk:[1,0]
DE=2

P3

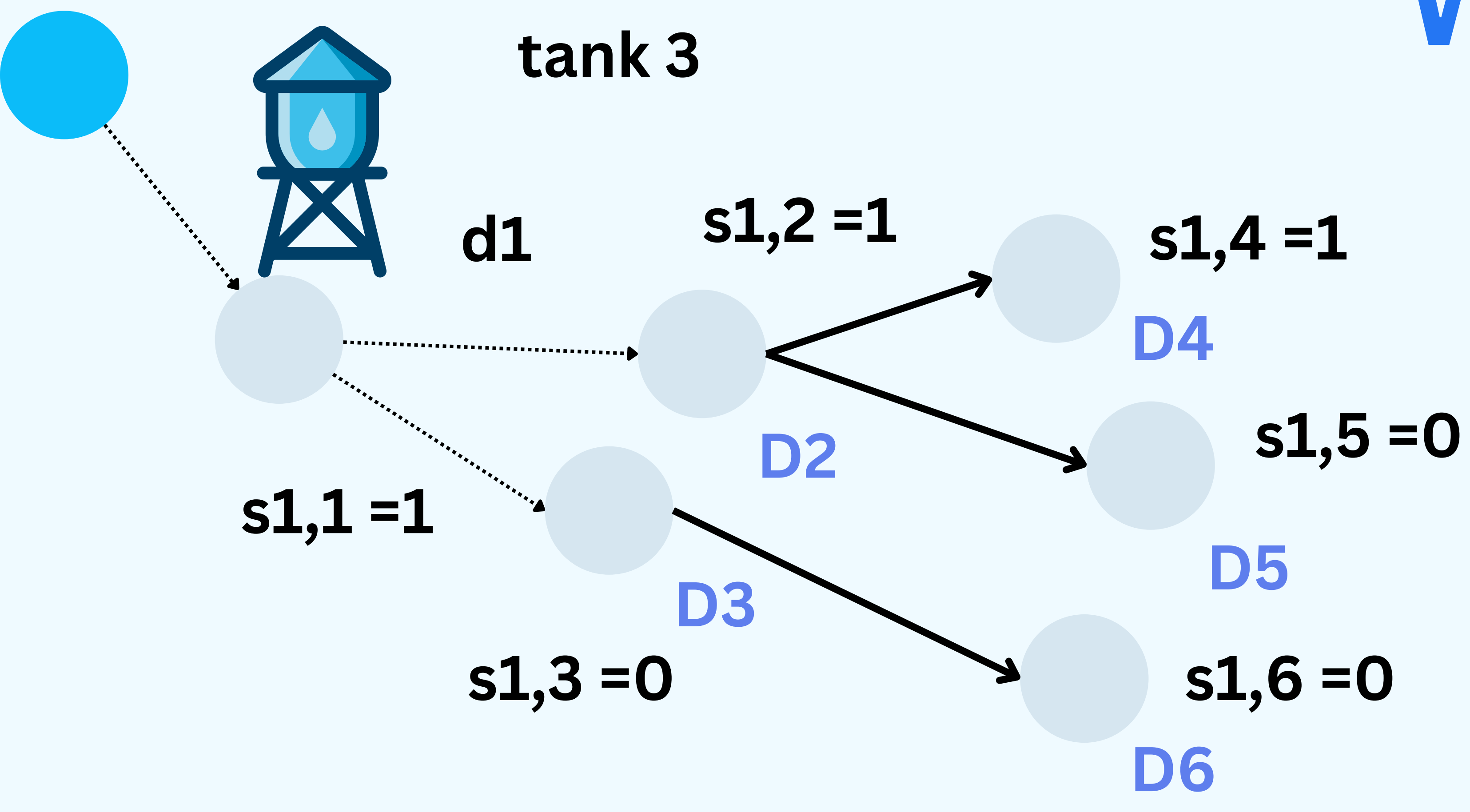
New model is Satisfied

eq1	LOk*enk<=znk
eq2	znk<=UPk*enk
eq3	sum for all row for n enk =1
eq4	sum for all row for n znk =dn

P1 = P2/2 +P3/2

Since P can be represented as a linear combination of two other points belonging to R2, P cannot be a corner point of R2.

TANK CONFIGURATION IMPROVEMENT : INITIAL MODEL



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smm<=snn

snm<=snn

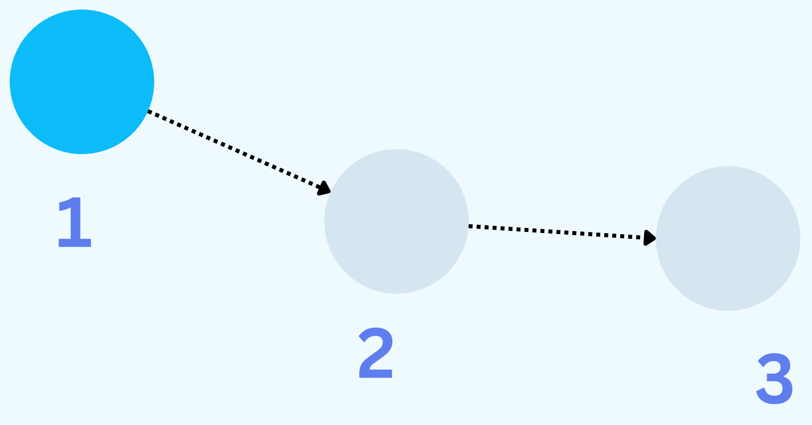
sum over all Ancestors of m snm=1

dn = snm*DEm

snm<=1-soo for all o in path of n,m

Nodes can serve their decendants if they serve their own

TANK CONFIGURATION IMPROVEMENT : TIGHTNESS PROOF



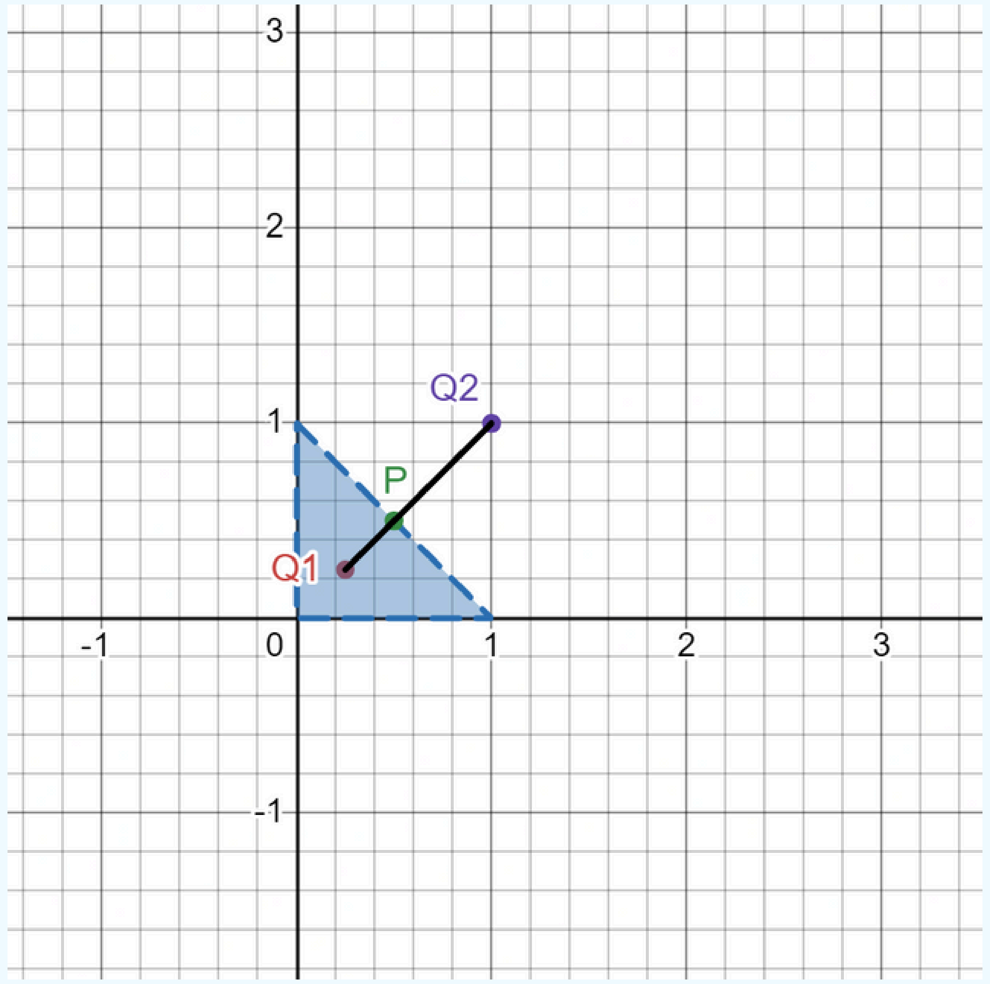
P : {1,0.5,0,0.5,0.5,0.5}

Q1 : {s11,s12,s13,s22,s23,s33}

Q2 : {s11,s12,s13,s22,s23,s33}

To prove

P
cannot be described as a linear combination of two distinct points that belong to R.



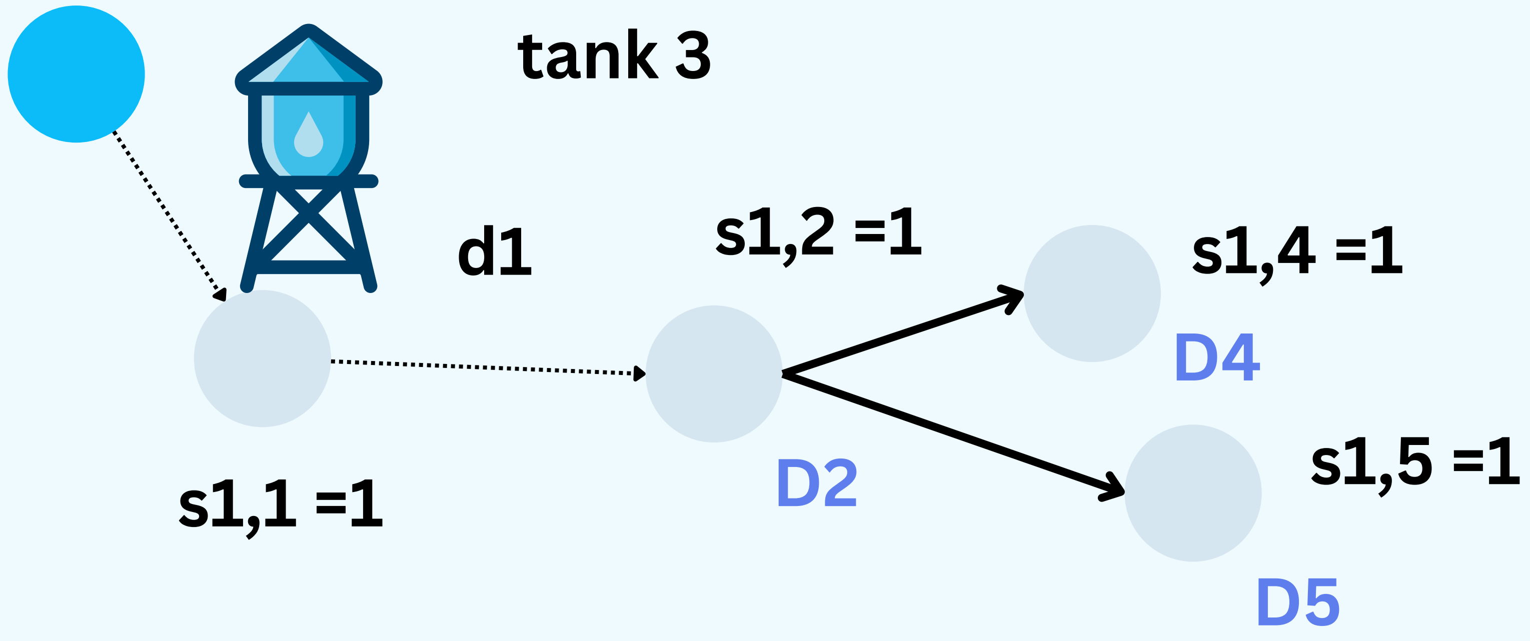
P = Q1+t(Q2-Q1)

P,Q1,Q2 belong in R2

The papers proof shows that this condition is only possible when Q1=Q2=P

Thus P is a corner point with fractional value

TANK CONFIGURATION IMPROVEMENT : NEW MODEL



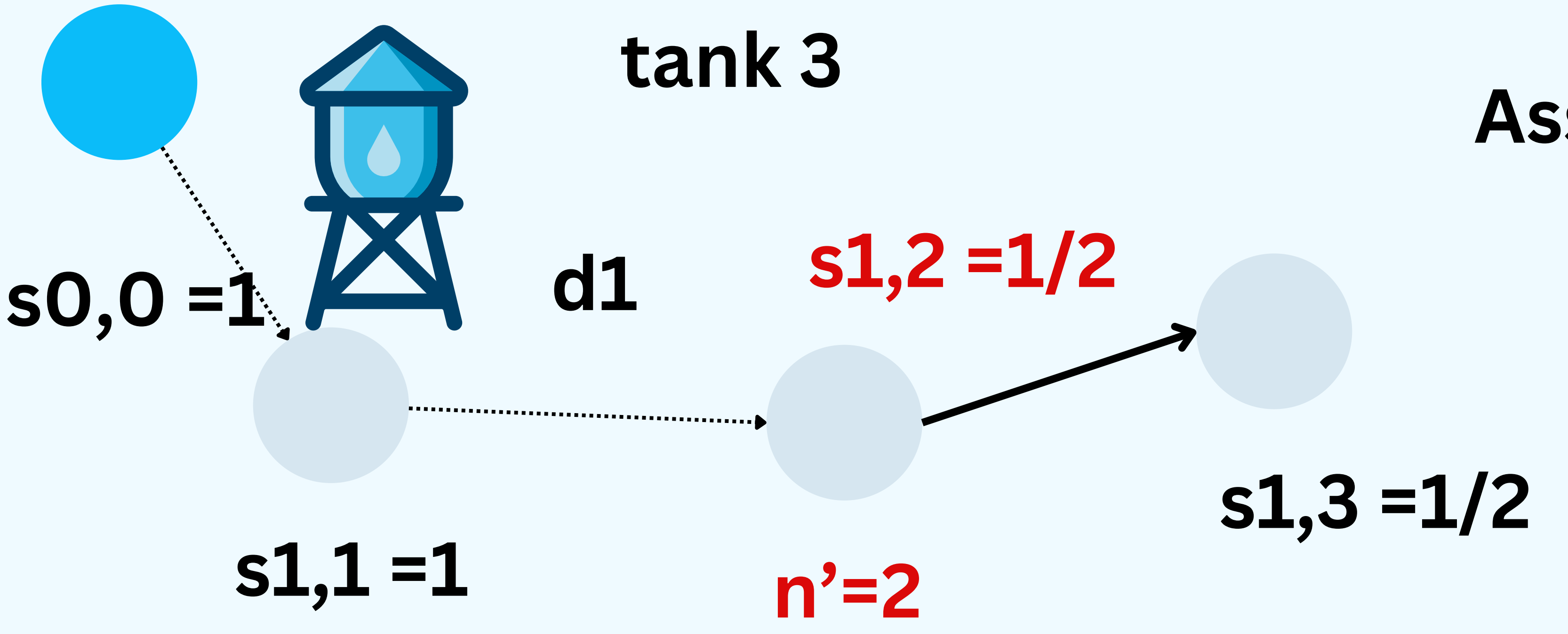
New Constraints

sum over n snm =1 for all ancestors of m

snm=snk where m is the child node and k is the descendant node

0<=snm<=1

TANK CONFIGURATION IMPROVEMENT : NEW MODEL TIGHTNESS



Assume this allocation of tanks is P

Claim 1

$s_{0,0}=1$, root node can never be fractional or zero

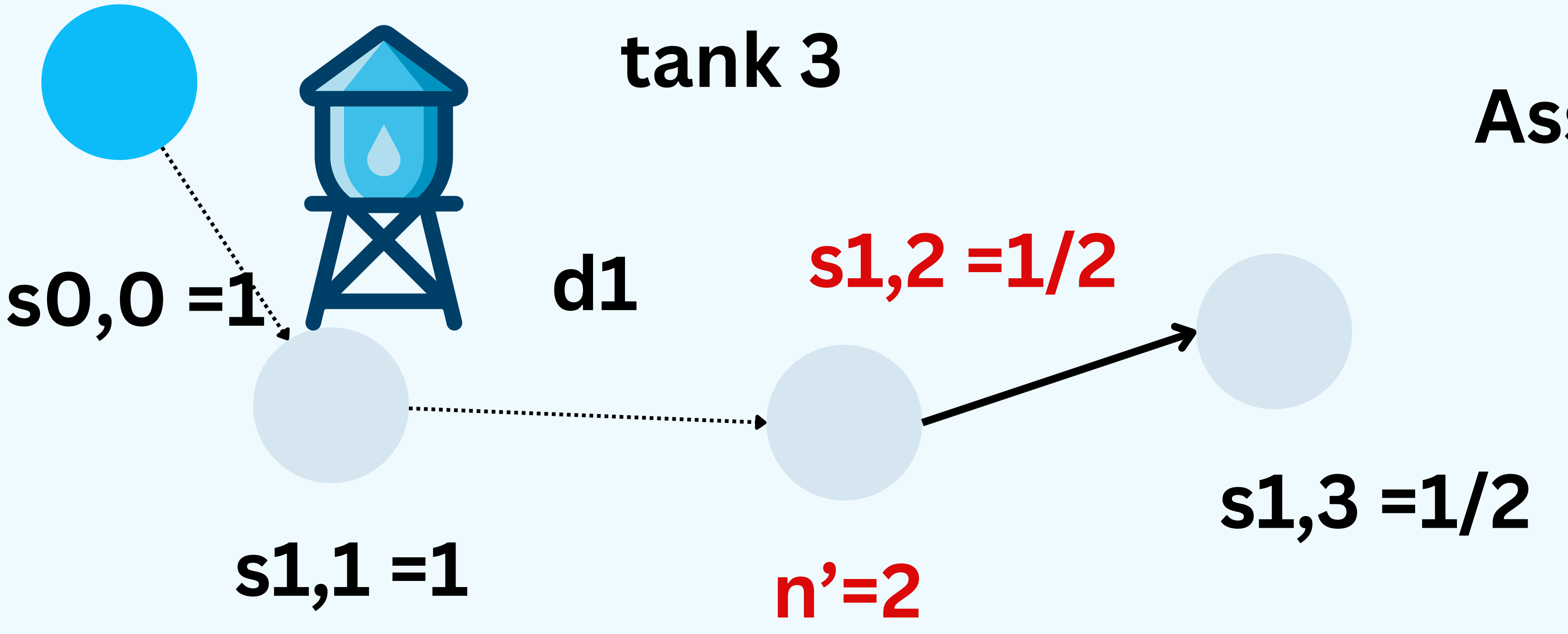
Claim 2

$s_{0,2}=0$, descendants of secondary networks do not depend on nodes above their source node

Claim 3

- Q1 is a valid allocation of our tank
- snm=snm of P for all m not in 2's path
- snm = snm /1-s1,2 for all n which are ancestors of 2
- s2m=0 for all m which are descendants of 2

TANK CONFIGURATION IMPROVEMENT : NEW MODEL TIGHTNESS



Assume this allocation of tanks is P

Claim 4

- Q2 is a valid allocation of our tank
- snm=snm of P for all m not in 2's path
- snm = snm /s1,2 for all n which are ancestors of 2
- s2m=0 for all m which are descendants of 2

Claim 5

P=s1,2*Q1+(1-s1,2)*Q2

CONCLUSION

The first ILP model took 45 mins to solve a 150 nodes network while this one took 5sec

The model is being used by BMC and Gujrat government to model their water networks

Paper models real-life networks from Maharashtra :

Future research opportunities with creating a pump scheduling algorithm and designing a model for looped networks