TATA CONSULTANCY SERVICES
Experience certainty.

Efficient booster pump placement in water networks using graph theoretic principles

TCS : Iyswarya Narayanan, Venkatesh Sarangan, **Arun Vasan,** Anand Sivasubramaniam
UMD: Aravind Srinivasan
IITM : B.S.Murty, Shankar Narasimhan

Why look at water ?

Important angle of sustainability

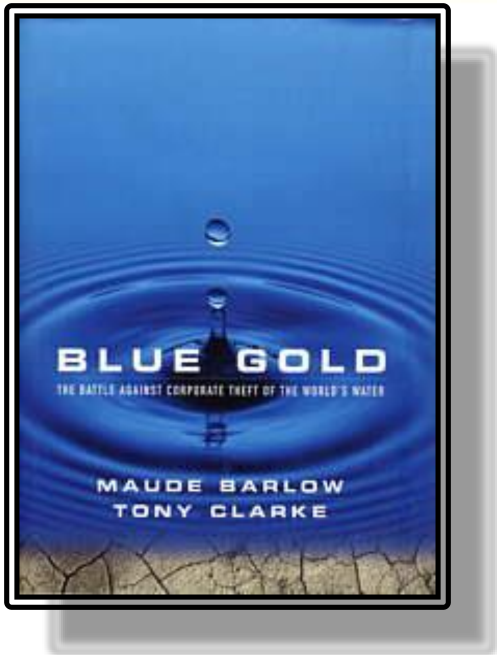
- Directly for human consumption
- Indirectly through industrial products/processes

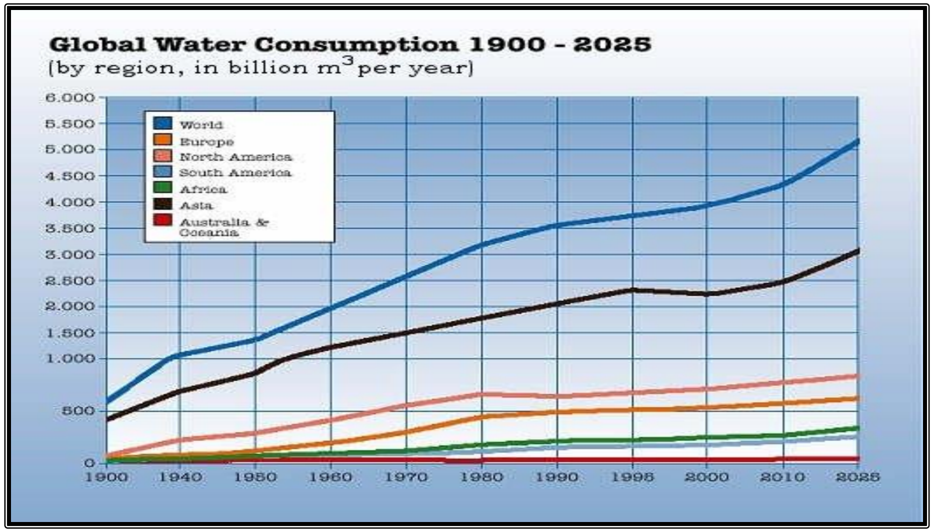
Blue gold

- Limited supply
- Ever-increasing demand

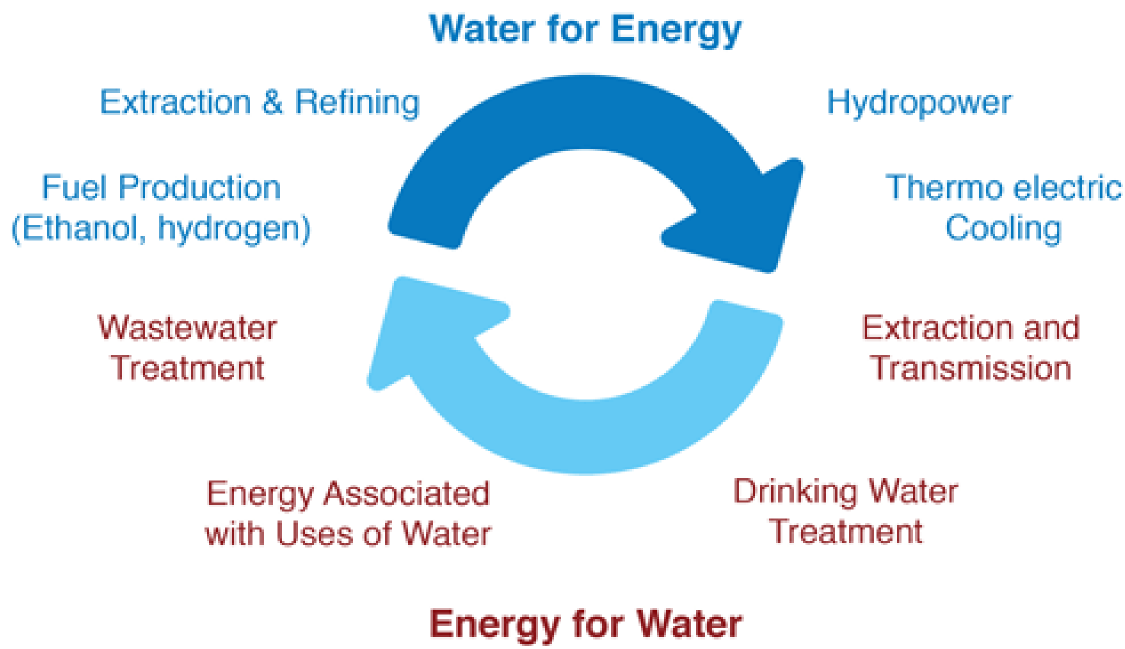
The role of Computer Science

- Optimization
- Analytics
- Management





WATERGY



Water is used to “produce” energy

- 41% of US freshwater use is for energy [EPA]

Energy is used to “move” water

- Across qualities and locations
- 31% of the opex of water utilities is energy

California’s Water-Related Energy Use

- **30% of all Natural Gas**
  - Enough to supply 60% of CA home’s gas needs: 7.2 million homes
- **20% of all Electricity**
  - Enough to supply entire state’s electricity needs: Oregon or Mass

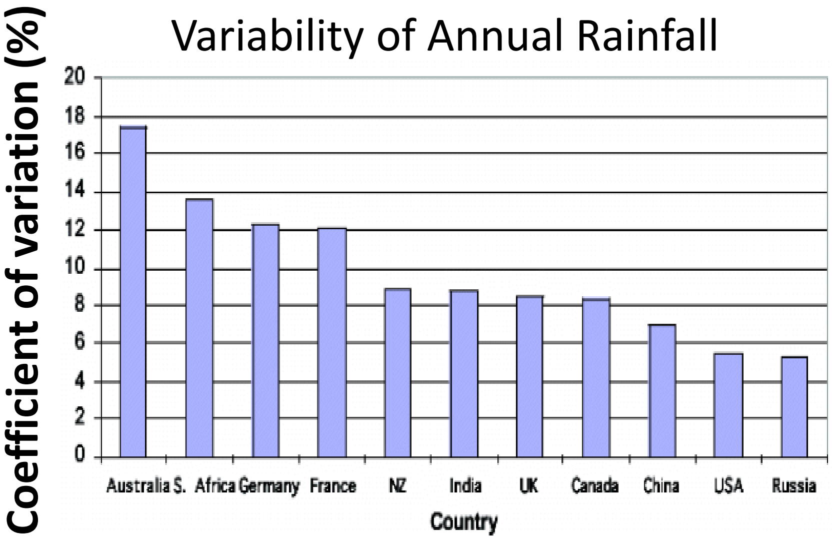
The role of water utilities

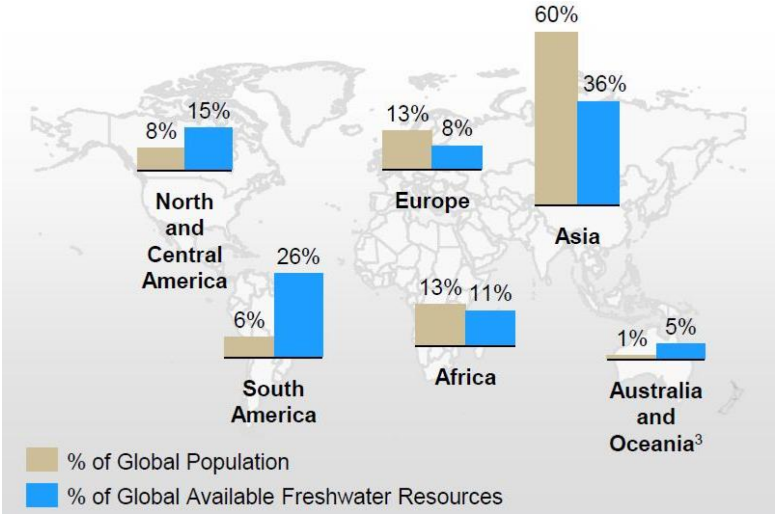
Variation in per-capita water availability

- Across time over years
- Across geographic areas

Utilities

- Efficient and typical way of water supply
- Stand between limited supply and increasing demands
- Smooth over variability
- Differentiator between sufficiency and scarcity





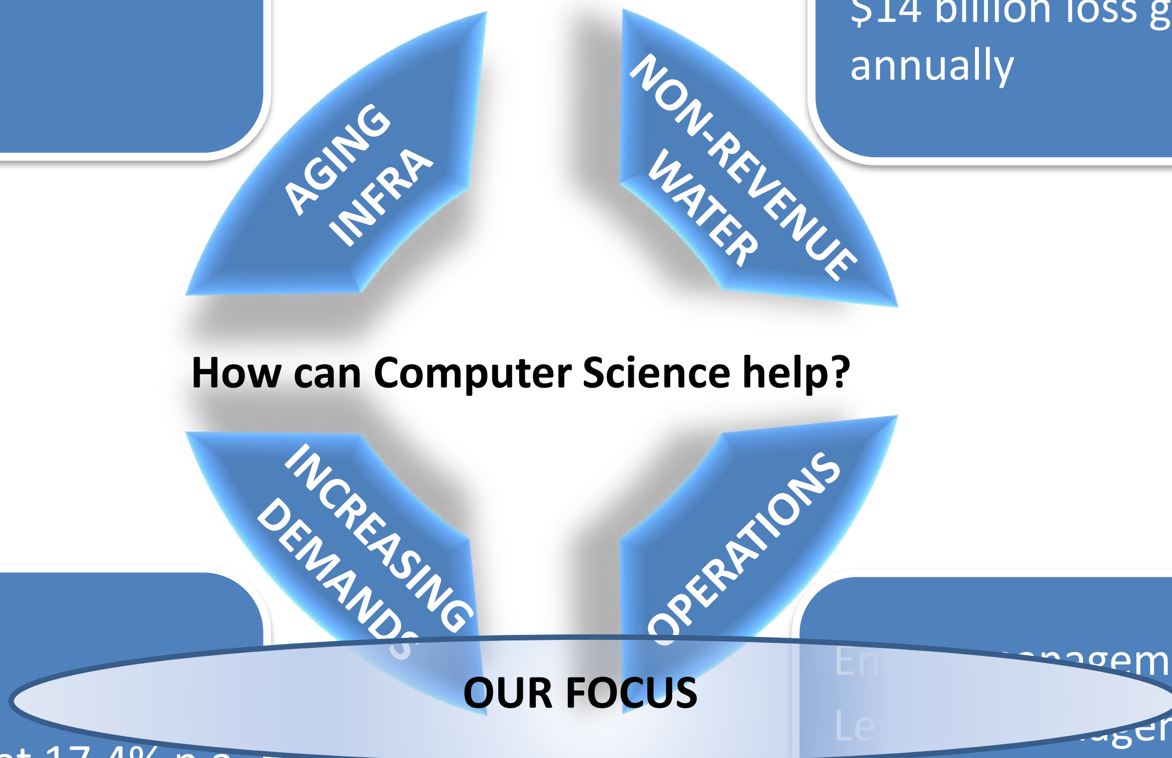
Pain-points of water utilities

Most utilities old

US needs $300 billion over 20 years

40% of global water not billed

$14 billion loss globally annually



Demand growing at 17.4% p.a.

En [illegible] anagement

Le [illegible] agement

Contamination management

Integrated asset management

Computing for Water Delivery

Planning

- Multi-grade supply
- Infrastructure Planning and maintenance
  - Algorithms
- Decentralized vs. centralized treatment plants
  - Networking
- Pricing strategies
  - Algorithmic Game Theory

Operations

- Sensor placement
  - Contamination
  - Leak detection
  - Trace back
- Striping delivery across multiple channels
- Criticality analysis
  - Centrality measures

Metering/Control

- Optimal pressure for pumps
- Scheduling of pumps to exploit energy spot pricing
- Analytics on metered data

Outline

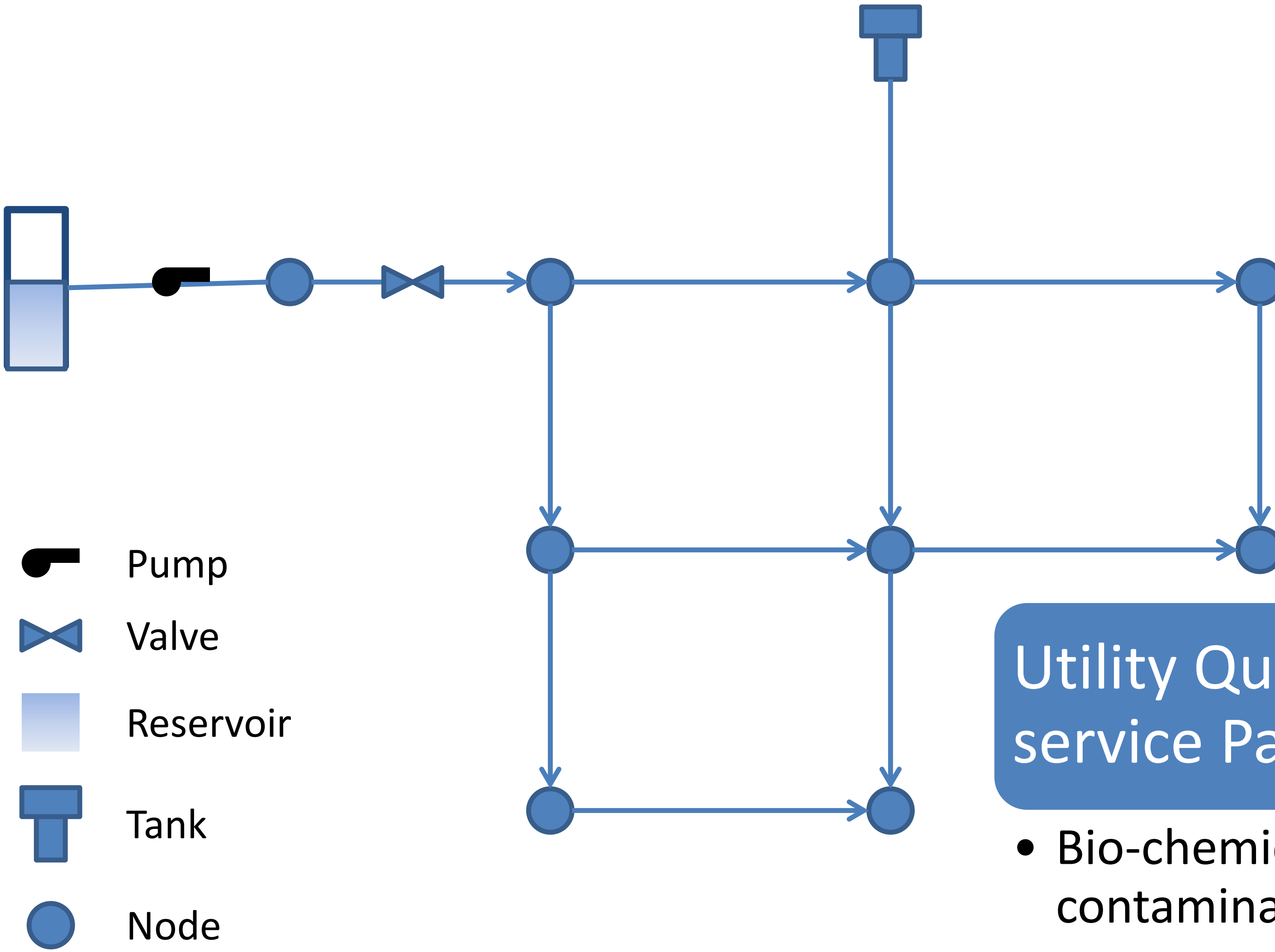
Computing in Water delivery

Booster pump placement

- The problem
- Solution strategy
- Evaluation

Summary

A typical water utility network



Utility Quality of service Parameters

- Bio-chemical - odorless, contaminant-free
- Mechanical - **Minimum pressure of delivery**

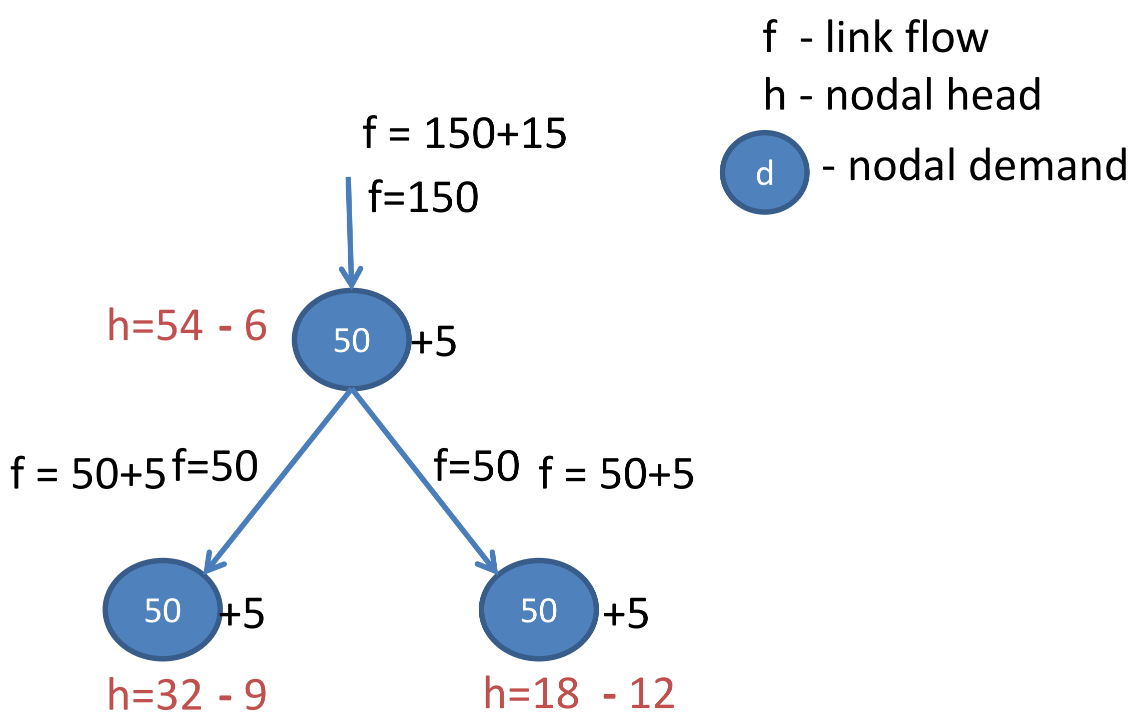
The problem

Increasing demands

Increasing flows

Drop in pressure ≈ k. Flow^2

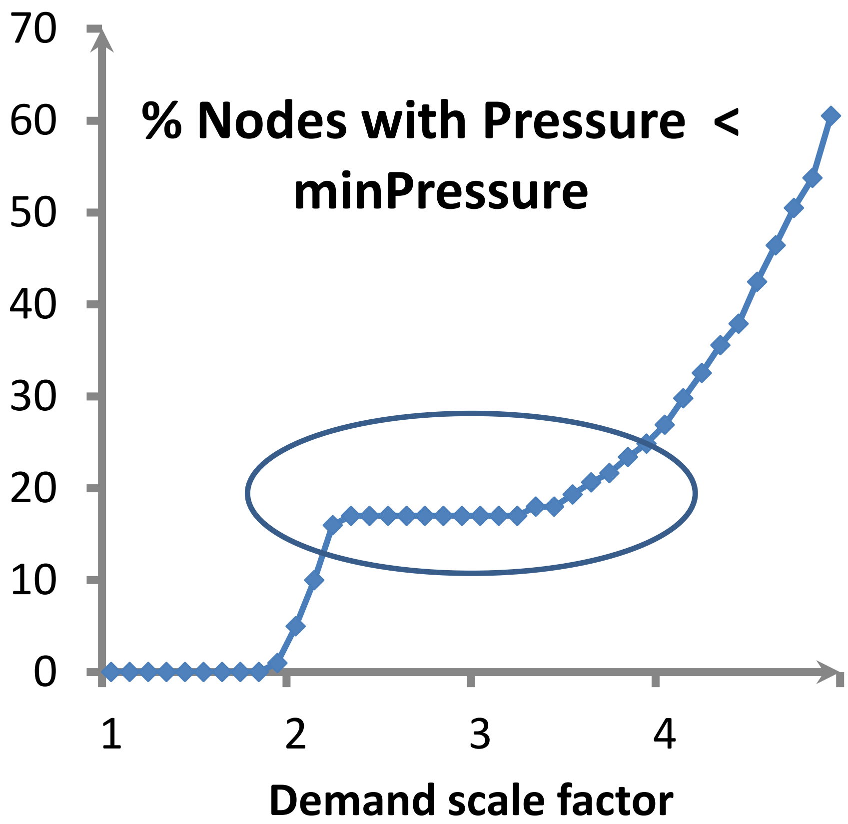
Reduced pressure



How to meet pressure requirements

- **Minimizing extra energy**
- **Minimizing extra energy + capex**

Booster pumps for ensuring minimum pressure



% Pipes with flow > maxFlow = 0

Pipes can handle flow

- But pumps cannot

Need booster pumps

- Where should these pumps be placed?
- What should their capacities be ?
- Wrong choices can be off by 50%

Problem formulation

Inputs

- Topology
- Network elements
- Demands

Outputs

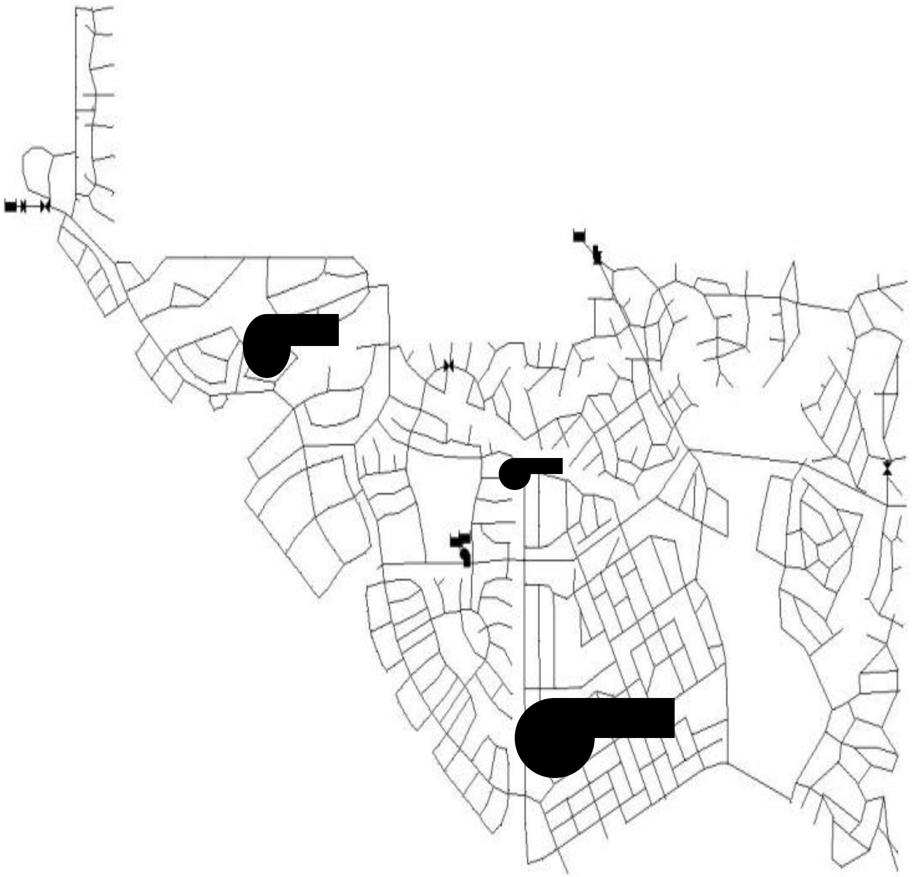
- **New** pump locations and capacities

Constraints

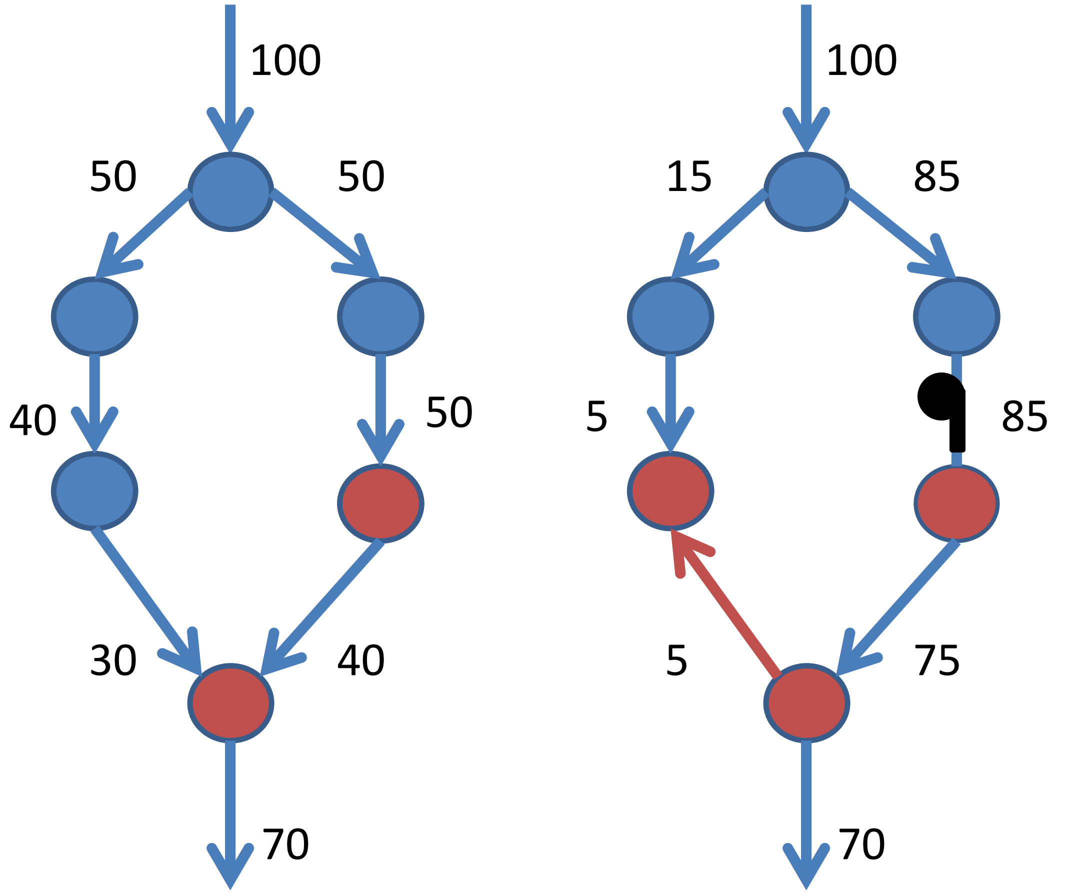
- Flow conservation
- Pressure drops
- Pressure > minPressure

Objectives

- Minimize Energy
- Minimize Energy + Capex



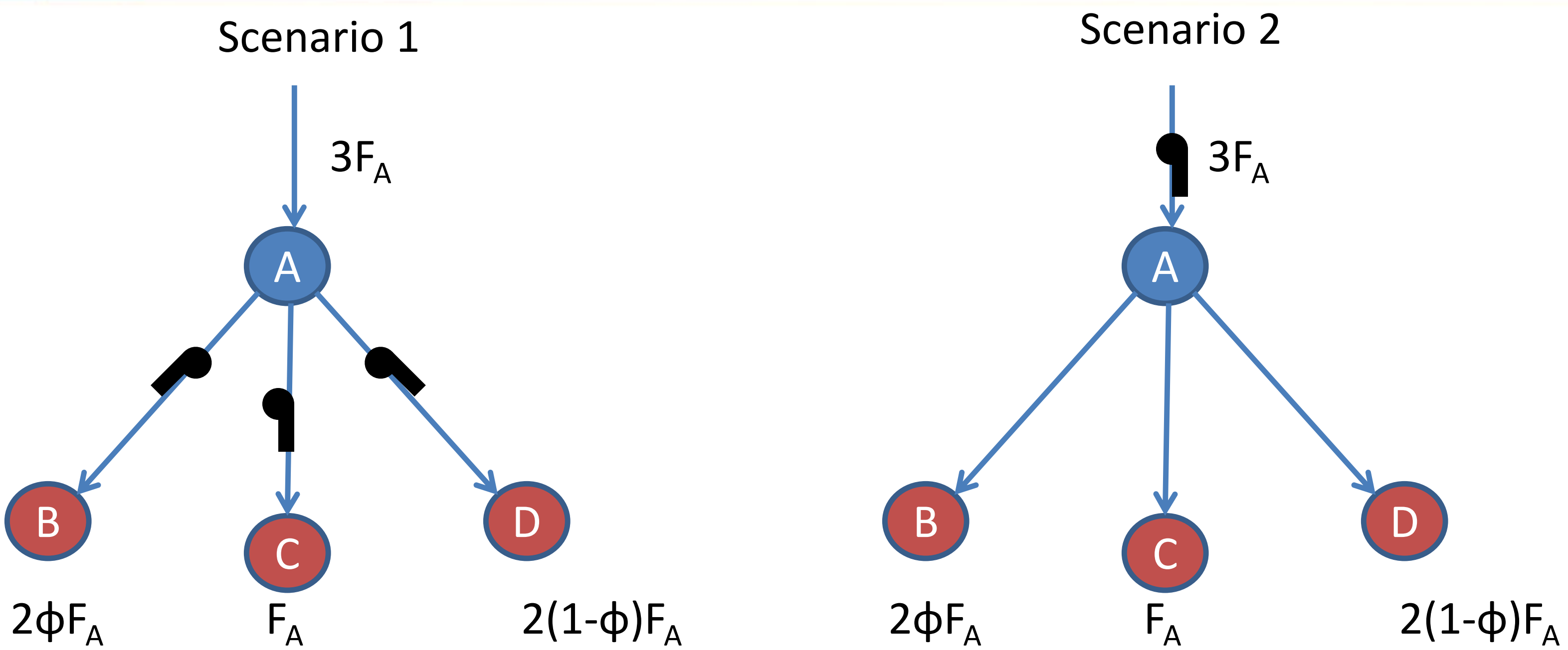
Challenge 1: Placement changes flows, …..

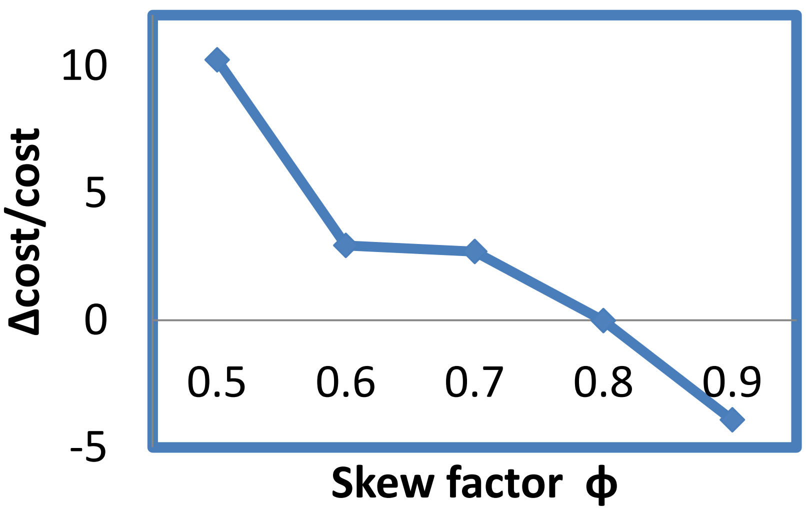


Expected: Boost in pressure at all the nodes

Observed: More change in path of lower resistance

Challenge 2: The capex – opex tradeoff





Energy cost

- Linear with capacity

Capex cost

- Sub-linear with capacity

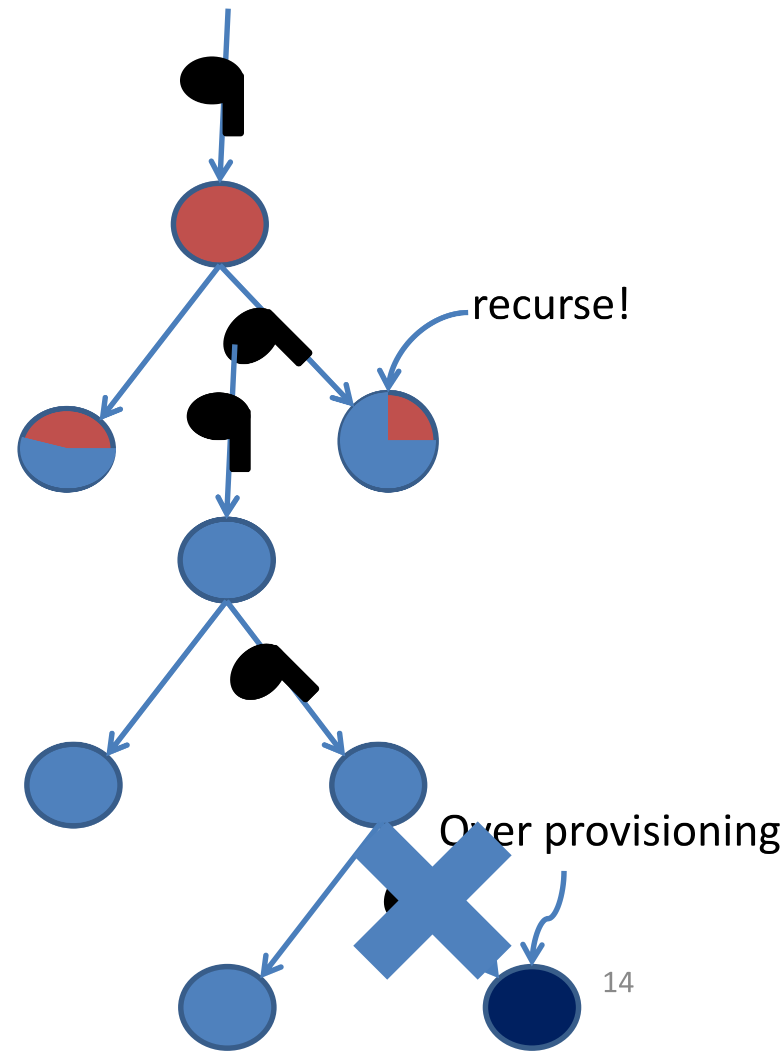
Solution for tree topologies

Minimize energy alone

- Boost at node → boost at **all descendants**
- So boost at node = min required at that node; Recurse

Minimize energy + capex

- Discrete pump sizes
- Over-provisioning possible
- Pruning strategies



Solution strategy for general topologies

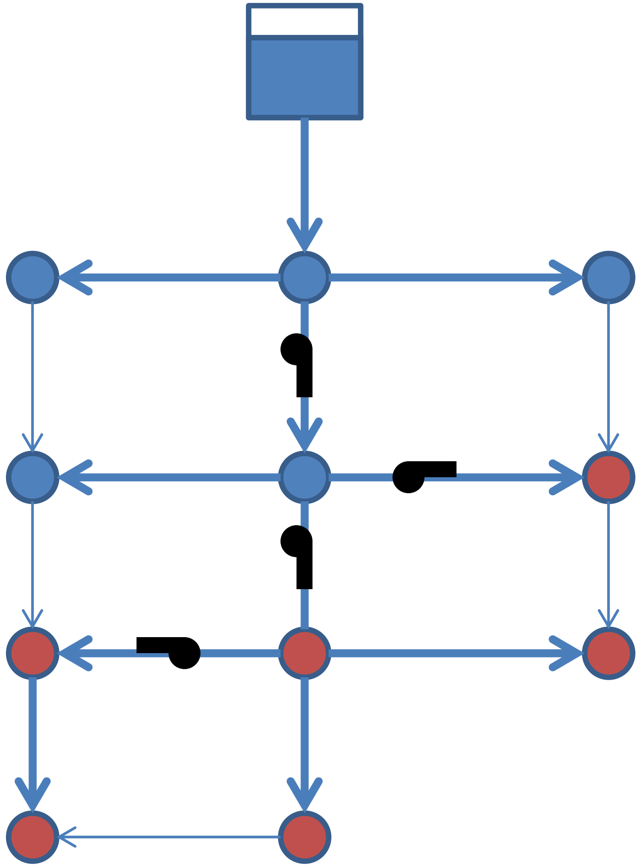
#1 Solve tree subgraph

- Identify tree subgraph by choosing edges appropriately
- Apply tree solution strategies to identify seed solutions

#2 Refine solution

- Ensure hydraulic constraints
- Identify new pumps using local search
- Repeat till convergence

Max flow spanning tree
Apply tree strategy and identify pumps
Change in flow – new deficiencies
Find new placements
Iterate till convergence



Benchmark Topology - Colorado Springs

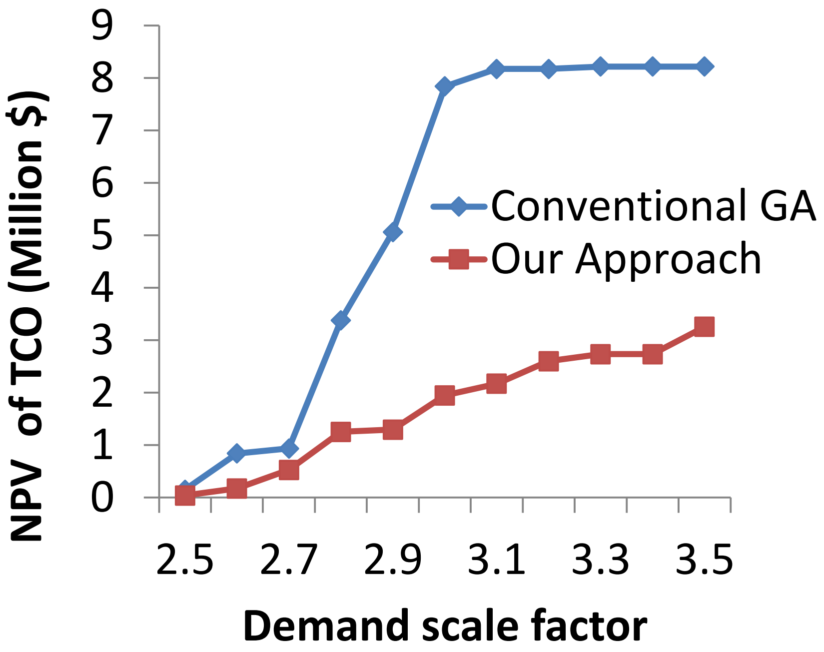
Network details

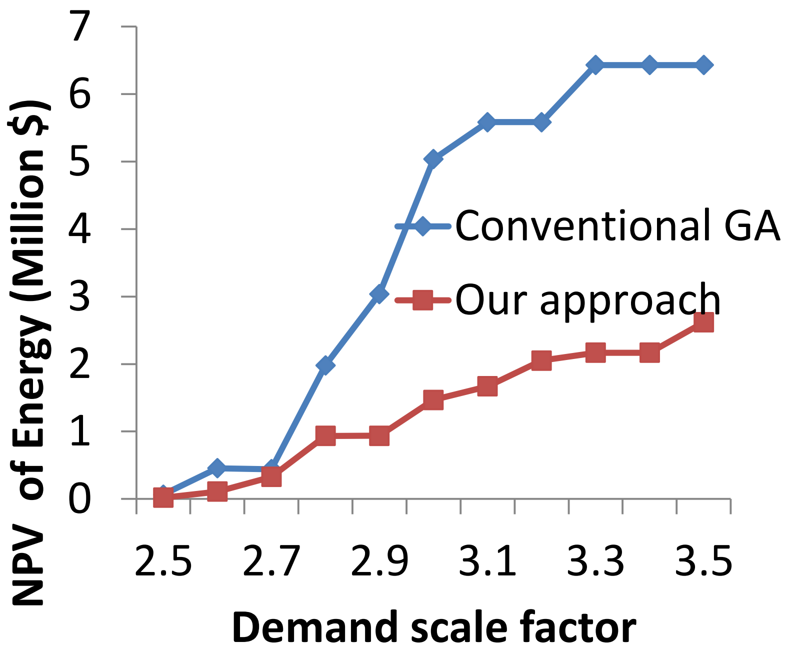
- Reservoirs – 2
- Junctions – 1786
- Pipes - 1985
- Pumps – 1
- Valves: 4 (Pressure Reducing Valves)
- Total demand : 8295 gpm

Capacity

- 100000 ppl, 12 MGD

Results from Colorado Springs (GA)





Better than conventional

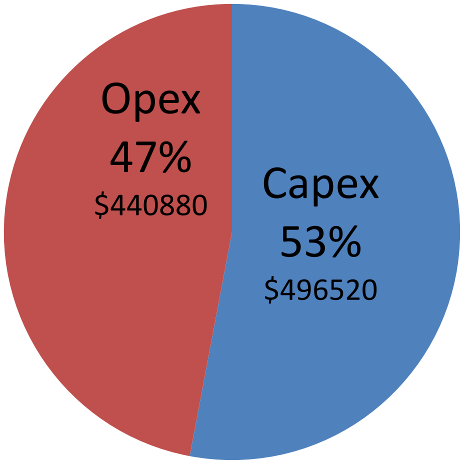
- Exploits structure
- Average reduction in TCO : 68%
- Average reduction in Opex : 65%

High drop in pressure

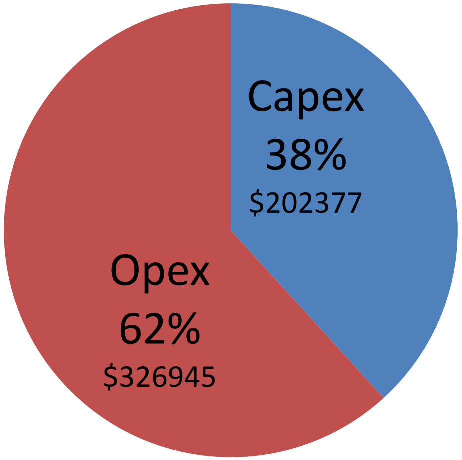
- Use economy of scale
- Significant improvement

The Capex-Opex Split

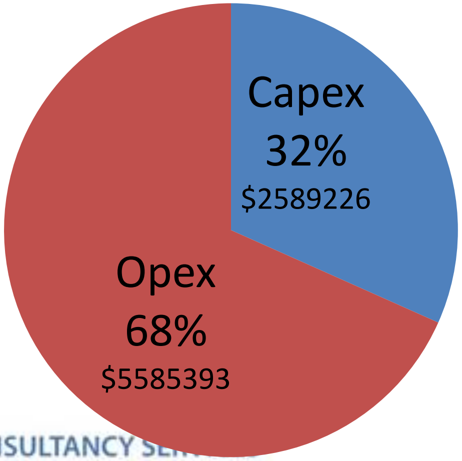
Scale Factor 2.7, GA - Random



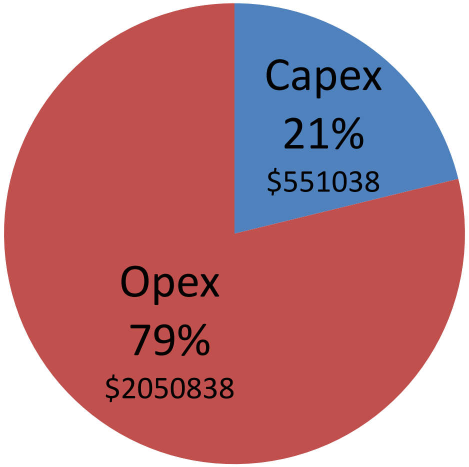
SF 2.7, GA - Our approach



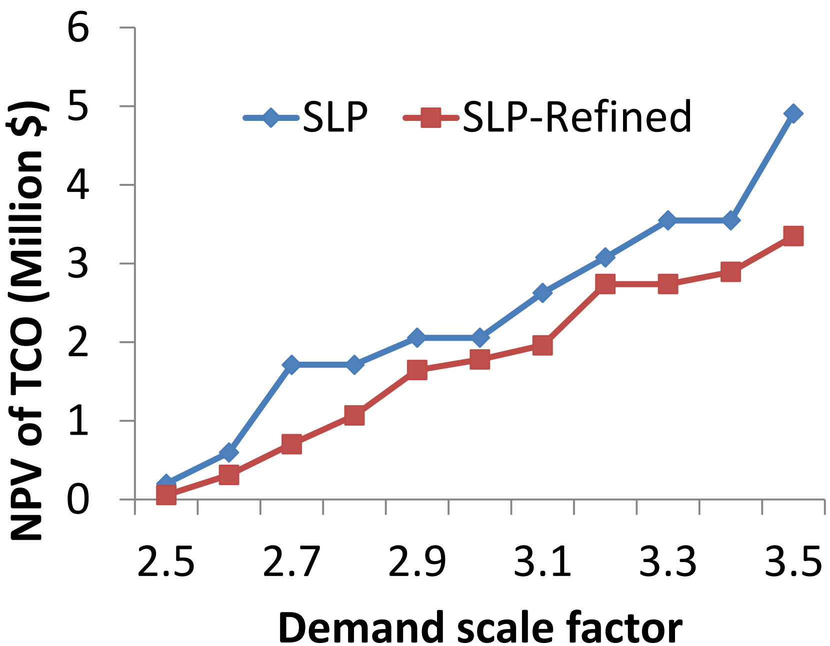
Scale Factor 3.2, GA-Random

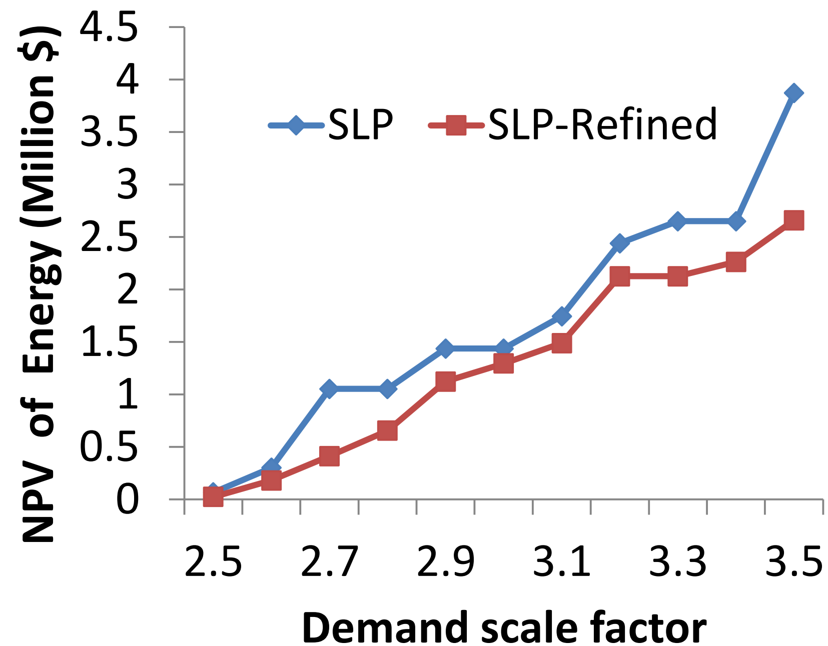


SF 3.2 GA-Our Approach



Results from Colorado Springs (SLP)





Better than conventional

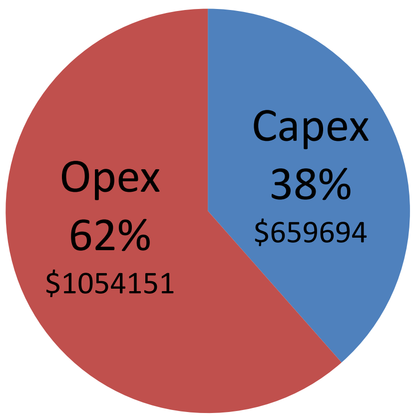
- Average reduction in TCO : 26%
- Average reduction in Opex : 23%

Works with deterministic search as well

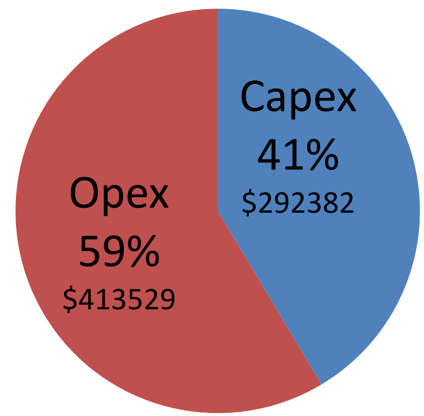
- Significant improvement

The Capex Opex Split

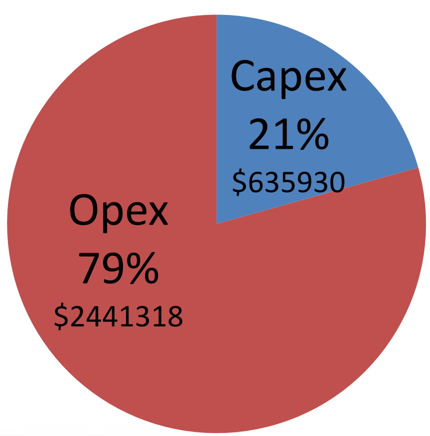
SF 2.7 SLP - Conventional



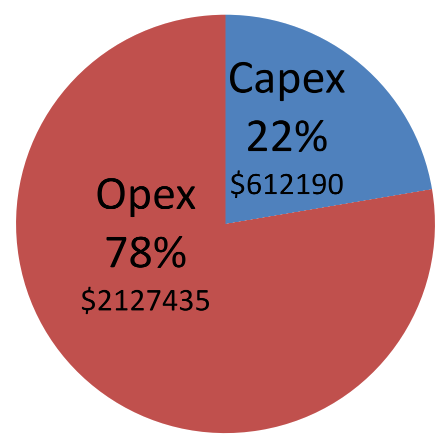
SF 2.7 SLP - Our Approach



SF 3.2 SLP - Conventional



SF 3.2 SLP - Our Approach



Summary

Water important

- Computing can help

Booster pump placement

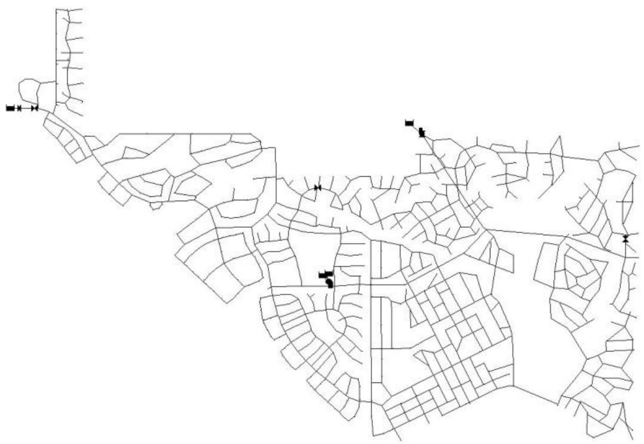
- Exploit structure to do better
- Decoupling approximation between hydraulics and search
- Improves both random and deterministic searches

Ongoing work

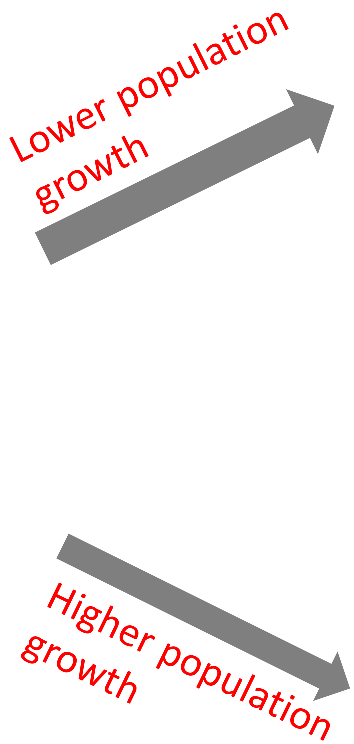
- Refine algorithms
- Contamination detection
- Criticality analysis

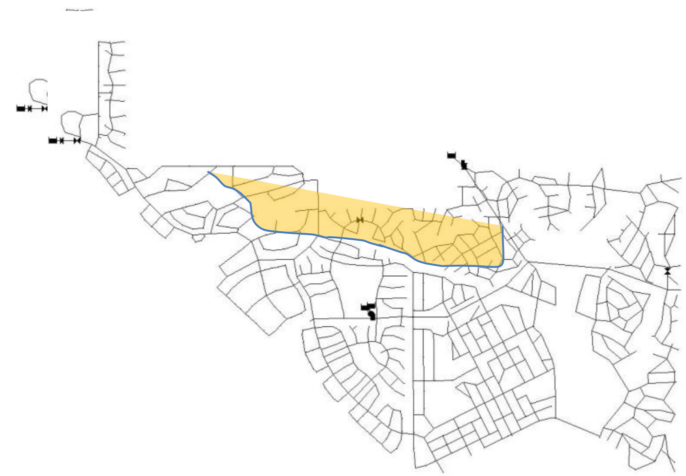
Thank You

Planning Scenario 1: To Keep pace with demand

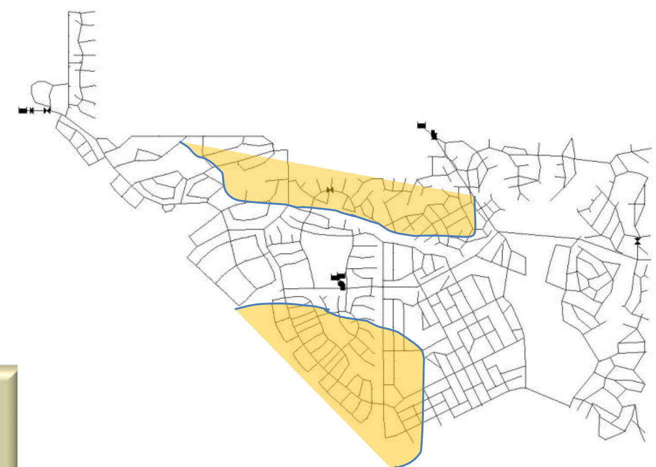


Existing Network



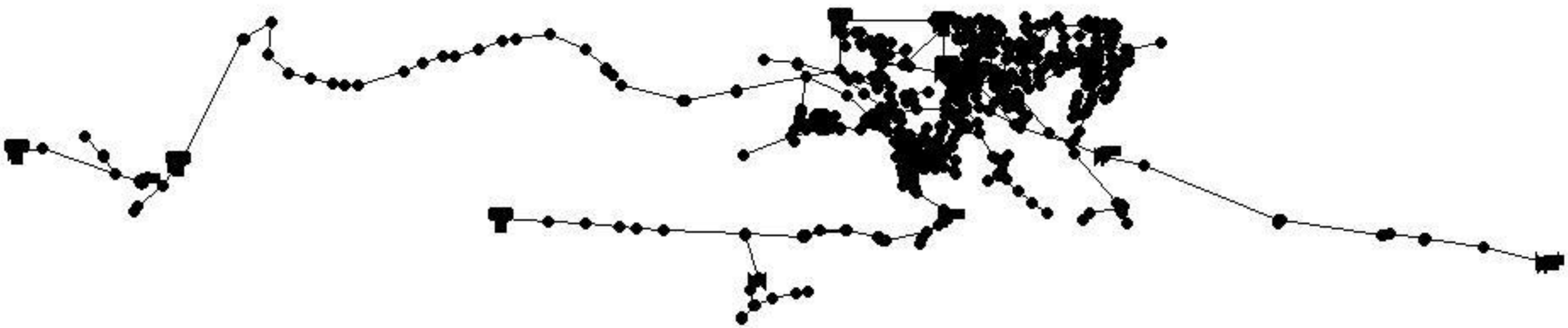


Pressure Deficient Areas



How can the utility enhance its infrastructure incrementally in a cost effective way to keep pace with the population growth?

Benchmark Topology - Richmond

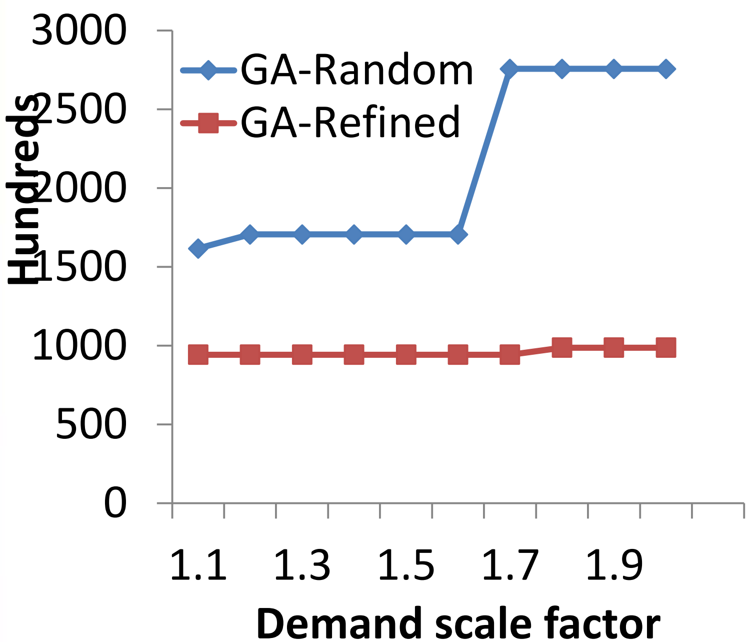


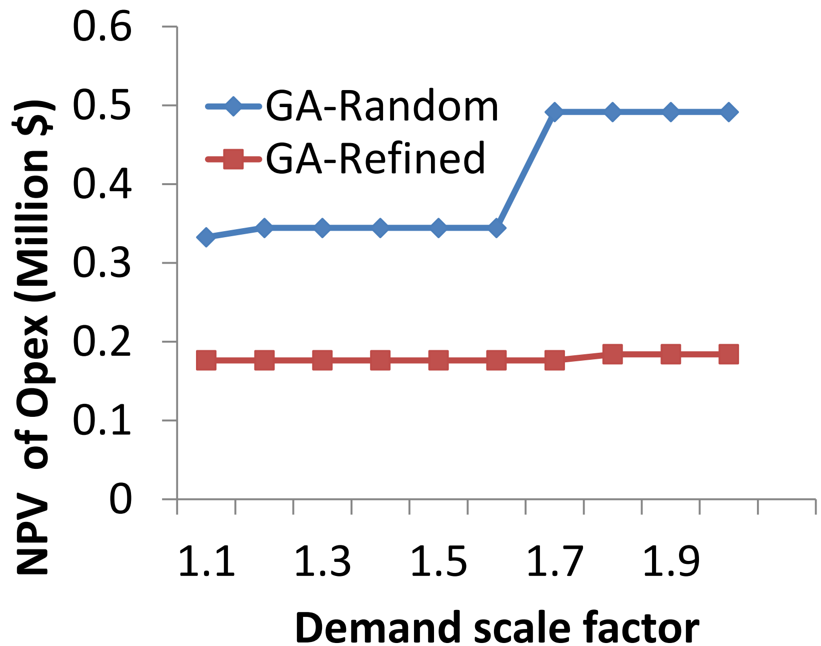
Network details

- Reservoirs – 1, Tanks - 6
- Junctions – 865, Pipes – 949
- Pumps – 7, Valves: 1 (Pressure Reducing Valve)

Demand 0.8 MGD, 7000 people

Results from Richmond (GA)





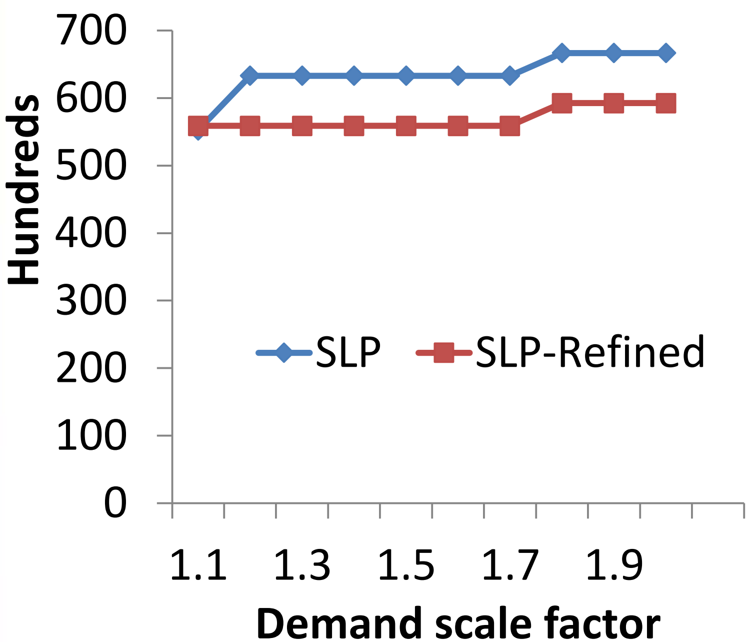
Better than conventional

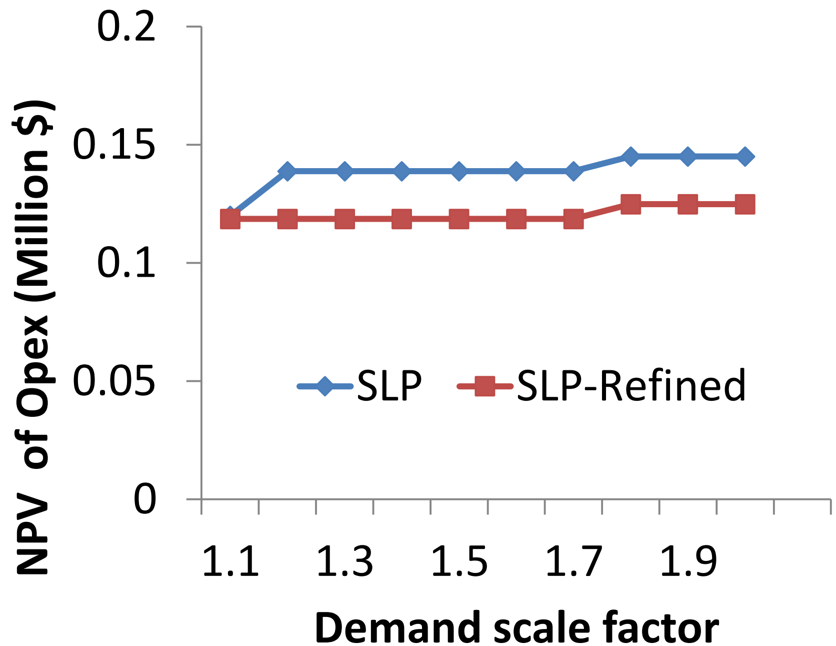
- Exploits structure
- Can improve conventional also
- Average reduction in TCO : 56%
- Average reduction in Opex : 54%

GA details

- 80% Crossover,5% mutation
- Guided random seeding
- Tournament Selection
- 500 Generation s
- 100 chromosomes/generation

Results from Richmond (SLP)





Better than conventional

- Exploits structure
- Can improve conventional also
- Average reduction in TCO : 13%
- Average reduction in Opex : 10%

Optimize opex, capex, TCO

- Saving energy ≠ saving TCO

Pump power distribution – Richmond Topology