Project PARETO –
DOE's Produced Water Optimization Initiative

Pipeline Hydraulics

PARETO
The Produced Water Optimization Initiative

Tysons Corner, VA

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Carnegie Mellon University
Georgia Tech
GROUNDWATER PROTECTION COUNCIL
U.S. DEPARTMENT OF ENERGY

Refresher: Project Premise & Capabilities

PARETO
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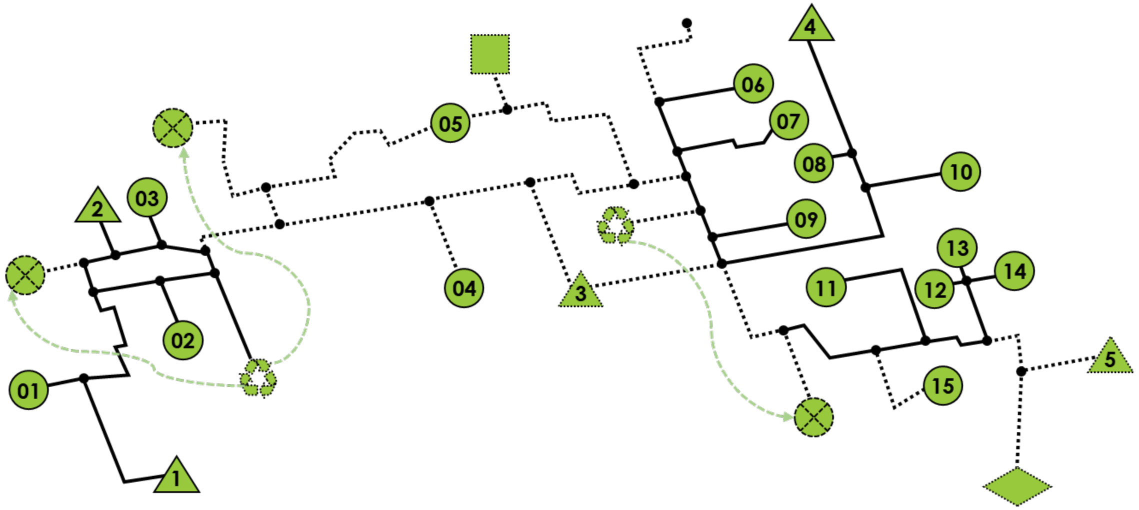
Premise: Develop a free and trusted software program ("PARETO") to help organizations transport, treat, store, inject and/or reuse produced water from onshore oil & gas operations.

- Supports infrastructure build-out decisions
  - E.g., pipelines, storage, injection, treatment, etc.
- Ensures mass balances across the network
  - Flow balance at each node in the facility
- Ensures feasibility of operational constraints
  - E.g., capacity limitations, expansion restrictions, etc.
- Facilitates scenario analysis
  - "what-if" analysis for various operational or investment decisions



PARETO is designed to help practitioners solve practical problems in PW management.

Motivation: Operational & Strategic Challenges

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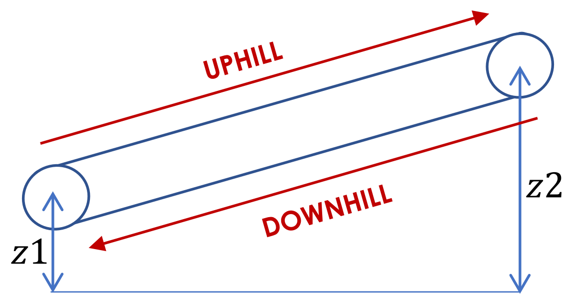
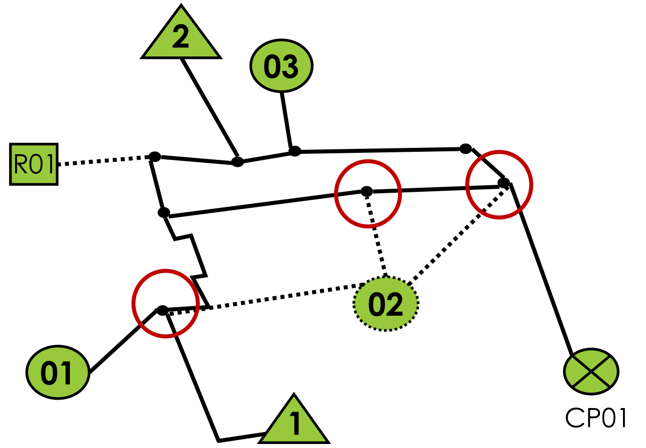
- Preventing violations of pressure bounds
  - Elevation changes and frictional losses cause pressure changes
  - Pipeline design influences operating pressure bounds
  - Managing flows and pressures with pumps and valves



- Integrating new wells with existing network
  - High volume and pressure from flowback of new wells
  - Design pipelines and integration points for new wells
  - Prevent shut-off of old wells due to high flowback pressure



PARETO is not aiming to replace rigorous hydraulics simulators.
The goal is to support mid-/long- term network design decisions considering hydraulics.

PARETO & Hydraulics

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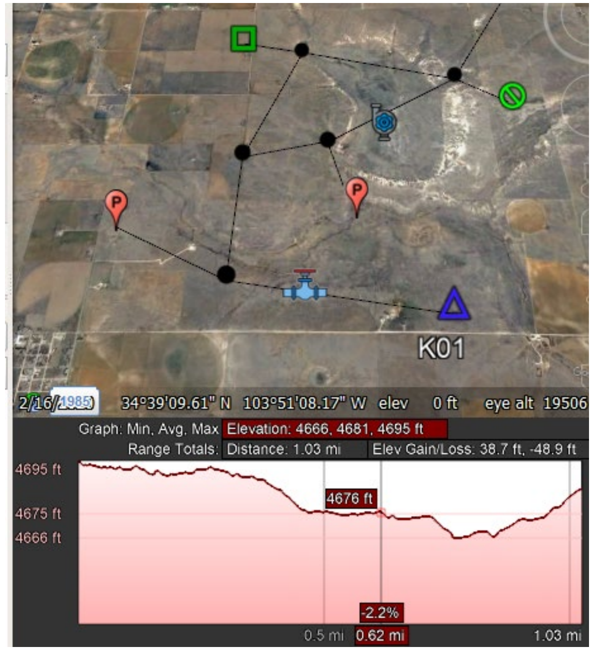
Motivation: feedback from the PARETO Stakeholder Board!

- Fluctuations in fluid flows and pressures
  - E.g., addition of new wells, elevation changes, etc.
- Existing tools fail to capture the design space and often fail to converge or close mass balance

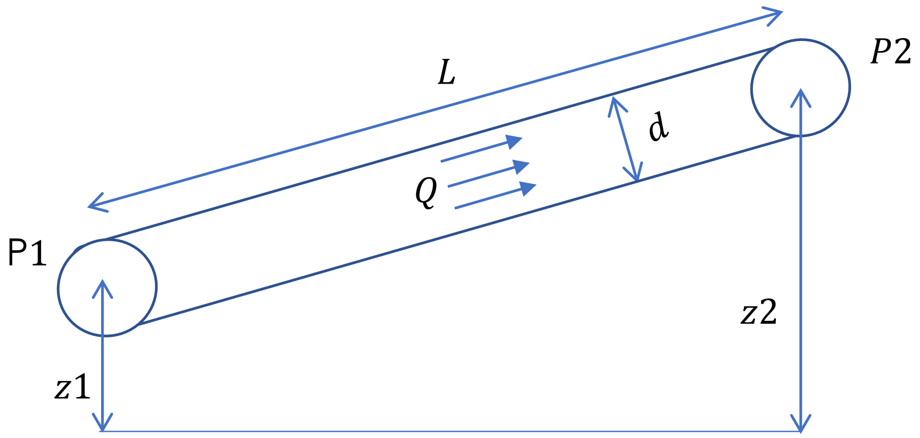


Action: Incorporate a robust hydraulics module into PARETO!

- Consider elevation changes explicitly
- Ensure ***mass balance*** and ***network feasibility***
- Factor pressure considerations into network design

The team is working towards validating & improving rigorous hydraulics implementation within PARETO.

Modeling Hydraulics in Pipelines



Q = volumetric flow (m^3/s)
V = velocity (m/s)
P = pressure (Pa)
z = elevation (m)
h = head loss (m)
γ = density * g ($kg/m^2/s$)
C_{HW} = Hazen-Williams constant
L = Length of pipeline segment (m)
d = pipeline diameter (m)

Modeling hydraulics (based on energy balance)

$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{P_2}{\gamma} + z_2 + h^{Friction} + h^{Valve} - h^{Pump}$$

Hazen–Williams Formula $$h^{Friction} = 10.704\left(\frac{Q}{C_{HW}}\right)^{1.85}\left(\frac{L}{d^{4.87}}\right)$$

Darcy-Weisbach Equation $$h^{Friction} = 0.5\left(\frac{Q}{A}\right)^{2}\left(\frac{\rho L f_{darcy}}{d}\right)$$

Model equation

$$P_2 = P_1 + (z_1 - z_2)\gamma - 10.704\left(\frac{Q}{C_{HW}}\right)^{1.85}\left(\frac{L}{d^{4.87}}\right)\gamma + \Delta P_{pump} - \Delta P_{valve}$$

(assuming V^2 is relatively small)

PARETO's hydraulics module computes pressures at each node and determines the need for pumping or throttling to keep pressures within allowable limits.

Modeling Hydraulics in PARETO

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Model equations

Pressure balance

$$P_{\tilde{l}t} = P_{lt} + (z_l - z_{\tilde{l}})\gamma - h_{l\tilde{l}t}^{Friction}\gamma + \Delta P_{l\tilde{l}t}^{Pump} - \Delta P_{l\tilde{l}t}^{Valve}$$

Frictional loss

$$h_{l\tilde{l}t}^{Friction} = 10.704\left(\frac{Q}{C_{HW}}\right)^{1.85}\left(\frac{L}{d^{4.87}}\right)$$

(Hazen–Williams Formula)

or,

$$h_{l\tilde{l}t}^{Friction} = 0.5\left(\frac{Q}{A}\right)^{2}\left(\frac{\rho L f_{darcy}}{d}\right)$$

(Darcy-Weisbach Equation)

Pumping cost

$$C_{Pumps} = C_{fixed}y_{l\tilde{l}}^{Pump} + \nu^{Electricity}\gamma + h_{l\tilde{l}}^{Pump}F_{l\tilde{l}t}^{Piped}$$

Pumping installation

$$\Delta P_{l\tilde{l}t}^{Pump} \leq M y_{l\tilde{l}}^{Pump}$$

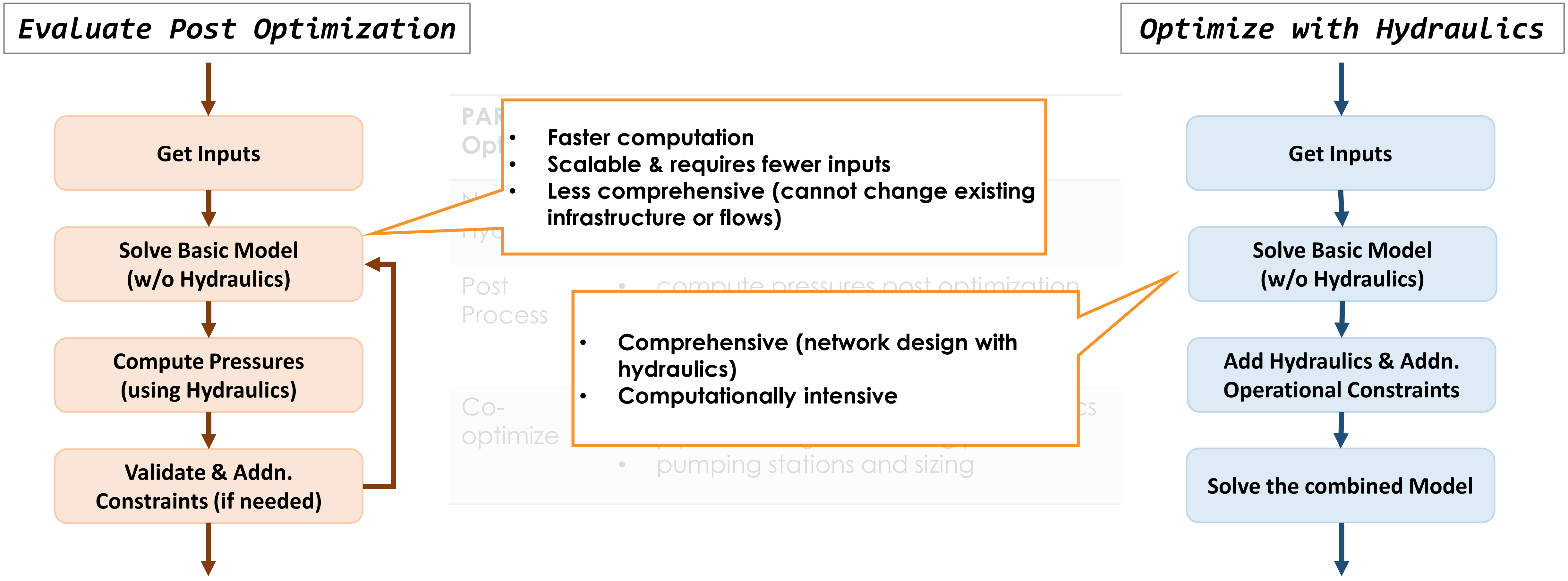
Pressure bounds

$$P_l^{lower} \leq P_{lt} \leq P_l^{upper}$$

Q = volumetric flow (*m*^{3}*/s*)
V = velocity (*m/s*)
P = pressure (*Pa*)
z = elevation (*m*)
h = head loss (*m*)
γ = density * g (*kg/m*^{2}*/s*)
C_{HW} = Hazen-Williams constant
L = Length of pipeline (*m*)
d = pipeline diameter (*m*)

PARETO's hydraulics model is an option for users to select when pressure analysis is needed.

PARETO's Hydraulics Module Framework



Hydraulics module caters to the varying needs of the user: assess network operations (post-process) or design new infrastructure (co-optimize)

PARETO's Hydraulics Module Framework

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```
class Hydraulics(Enum):
    false = 0
    post_process = 1
    co_optimize = 2
```

```
CONFIG.declare(
    "hydraulics",
    ConfigValue(
        default=Hydraulics.false,
        domain=In(Hydraulics),
```

```
def pipeline_hydraulics(model):
    """
    The hydraulics module asssists in computing pressures at each node
    in the network accounting for pressure drop due to friction using
    Hazen-Williams equation and due to elevation change in the topology. This model
    consists of a pressure balance equation for each pipeline and bounds for
    pressure. The objective is to minimize the total cost of installing and operating pumps.
    This method adds a block for hydraulics with all necessary variables and constraints.
    Currently, there are two methods to solve the hydraulics block:
        1) post-process method: only the hydraulics block is solved for pressures
        2) co-optimize method: the hydraulics block is solved along with the network
    """

    # Create a block to add all variables and constraints for hydraulics within the model
    model.hydraulics = Block()
    mh = model.hydraulics
```

```
if model.config.hydraulics != Hydraulics.false:
    model_h = pipeline_hydraulics(model)

    if model.config.hydraulics == Hydraulics.post_process:
        # In the post-process solve, only the hydraulics block is solved.

        mh = model_h.hydraulics
        results_2 = opt.solve(mh, tee=True)

    elif model.config.hydraulics == Hydraulics.co_optimize:
        # Currently, this method is supported for only MINLP solvers accessed through GAMS.
        # The default solver is Baron and is set to find the first feasible solution.
        # If the user has SCIP, then the feasible solution from BARON is passed to SCIP, which is then solved to a gap of 0.3.
        # If the user do not have these solvers installed then it limits the use of co_optimize method at this time.
        # Ongoing work is geared to address this limitation and will soon be updated here.
```

PARETO & Hydraulics: demo using a toy case study

PARETO Motivating Example: Overview

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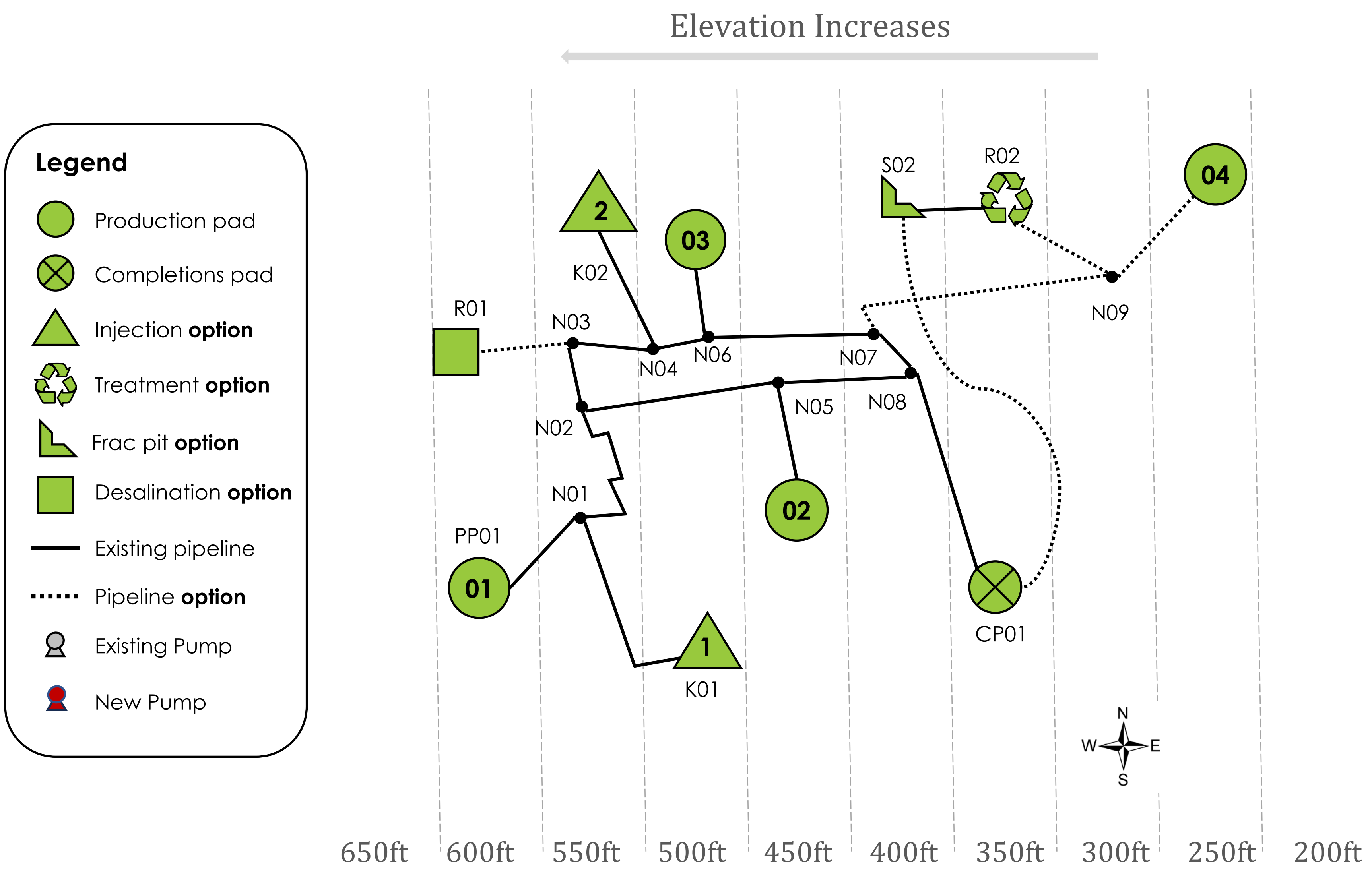

Given:

Existing network infrastructure

Potential expansion opportunities

Capacities & costs

Production, Flowback forecasts

Constraints:

Flow directions

Available choices for treatment

Determine:

Optimal network design

Flows and costs

PARETO Motivating Example: Basic Run

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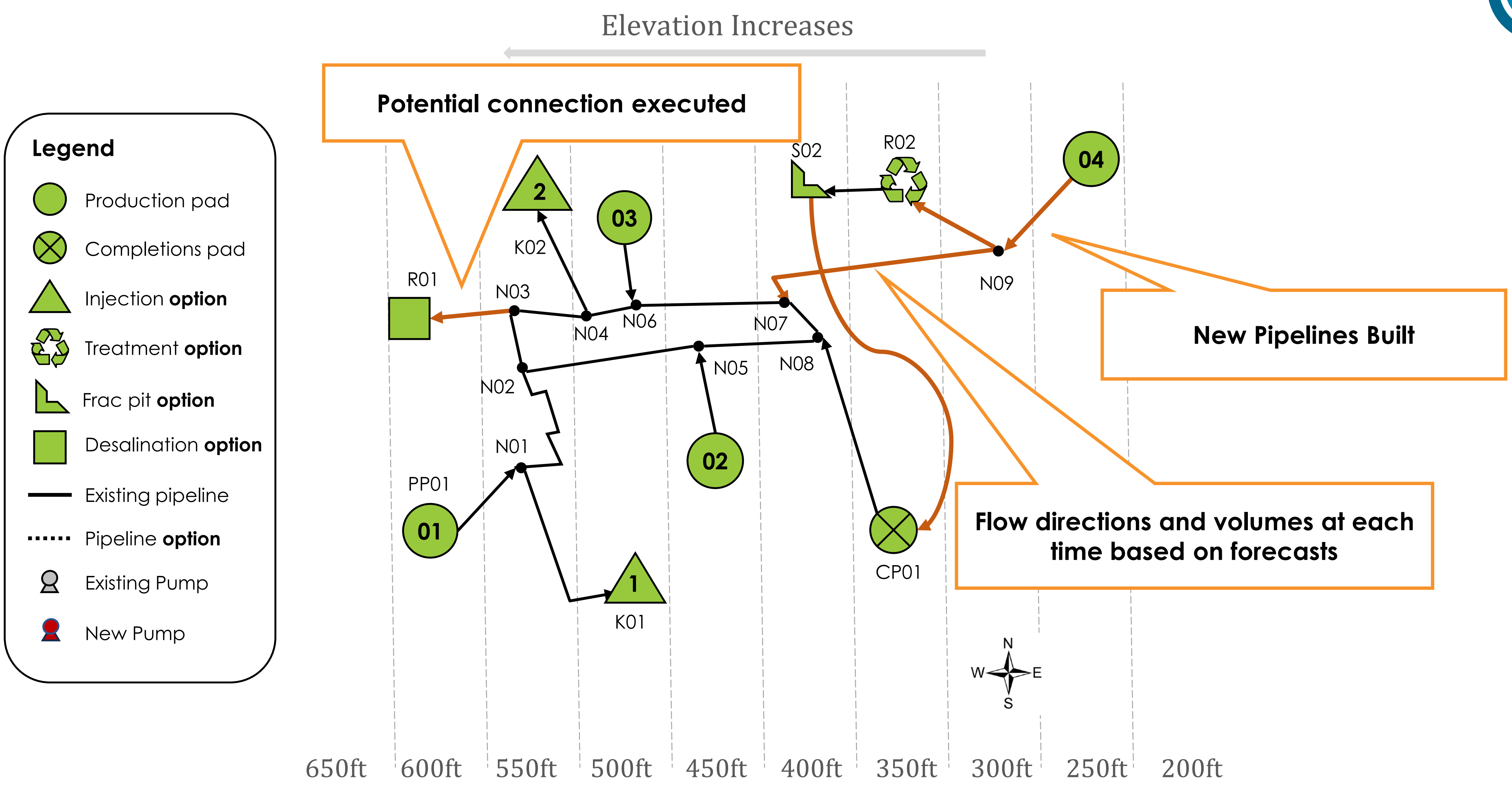

PARETO Motivating Example: Hydraulics Post Process

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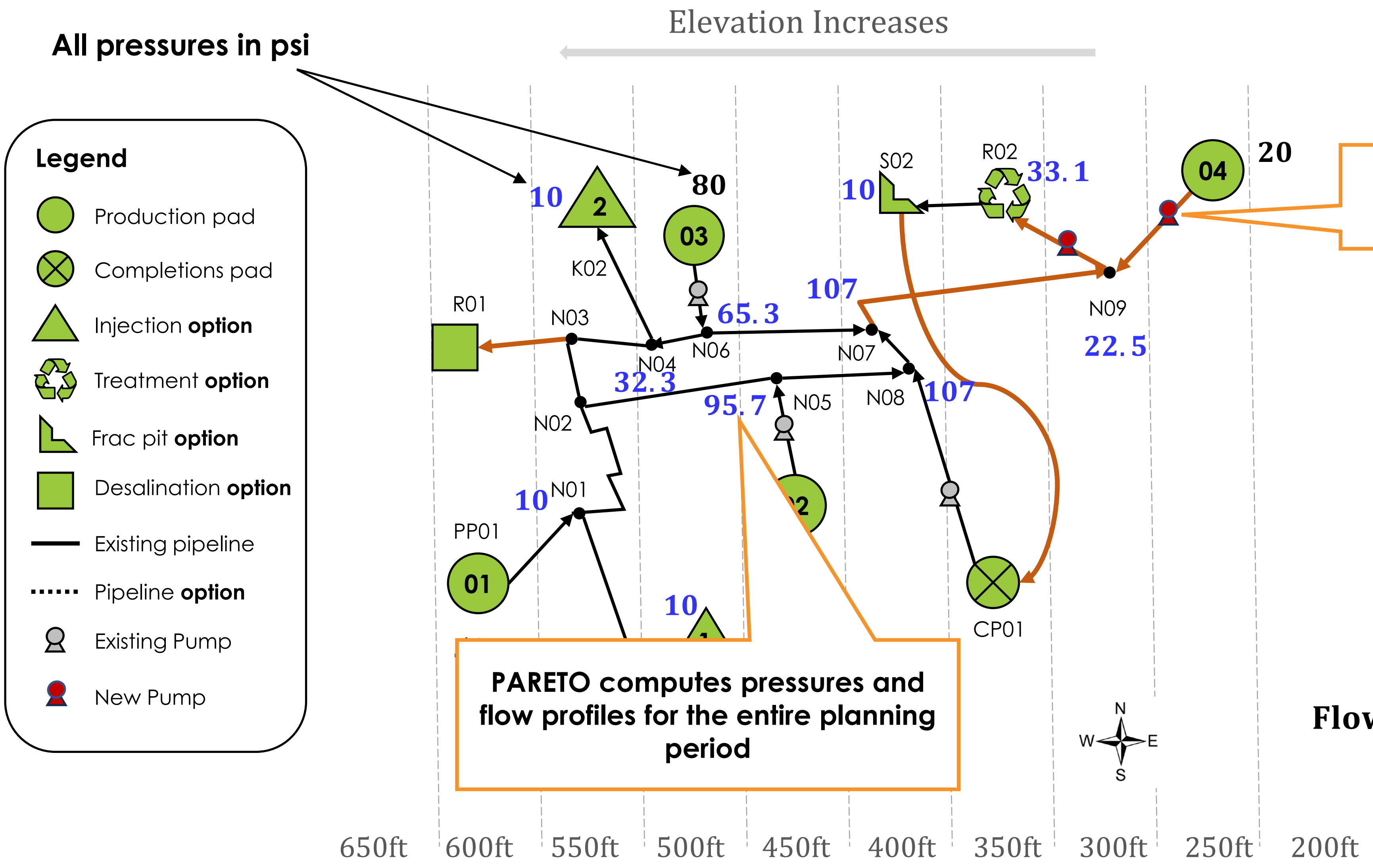
All pressures in psi



PARETO computes pressures and flow profiles for the entire planning period

For this point in time, 2 pumps are required

Existing Pumps

Constraints:

Min. Offload Pressures (K01 – K02, CP01)

Min. AOP (10 psi) & Max AOP (150 psi)

Determine:

Pressures at all nodes

New Pump stations, if needed

Flows & Pressures are a snapshot in time

PARETO Motivating Example: Hydraulics Post Process

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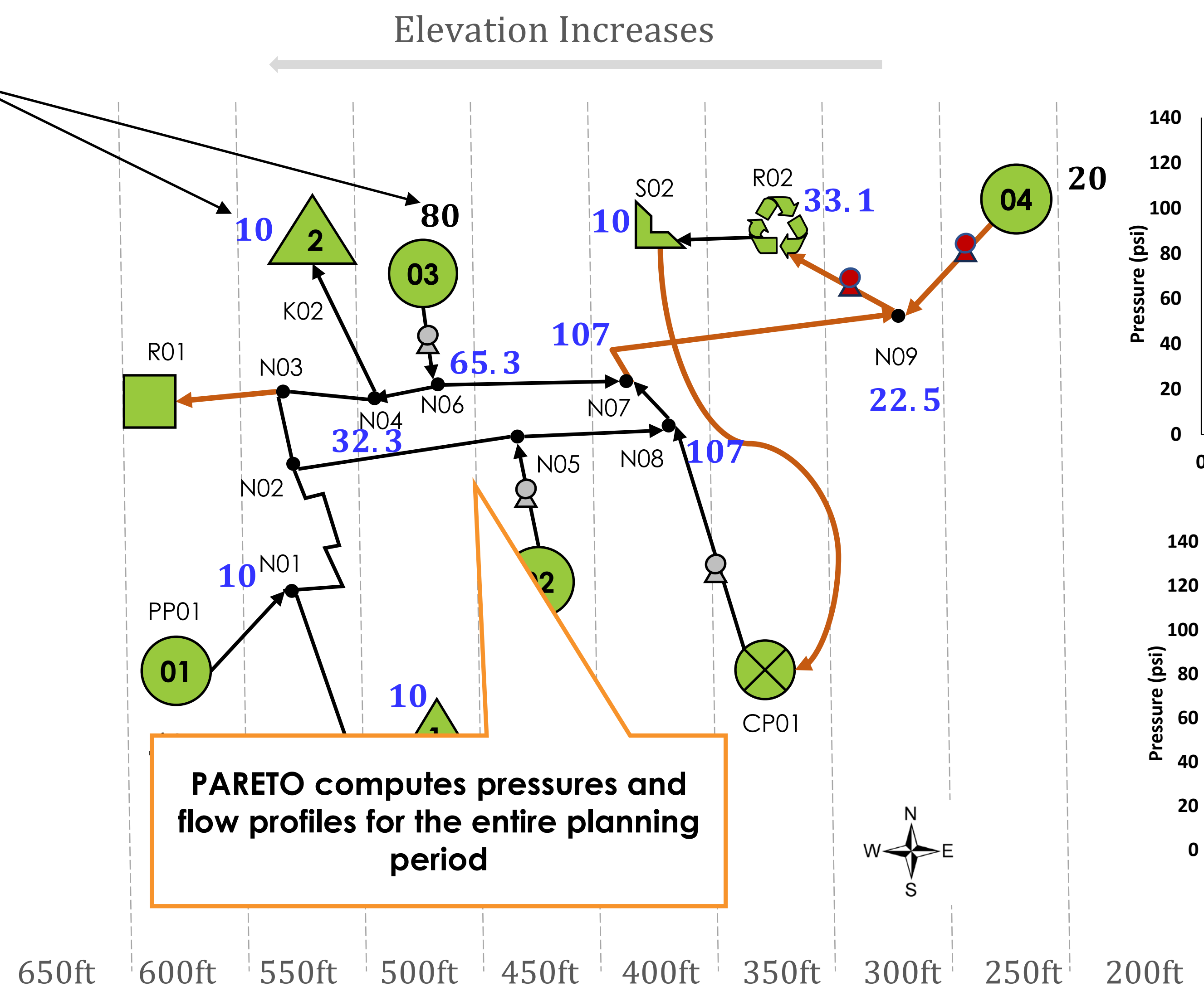
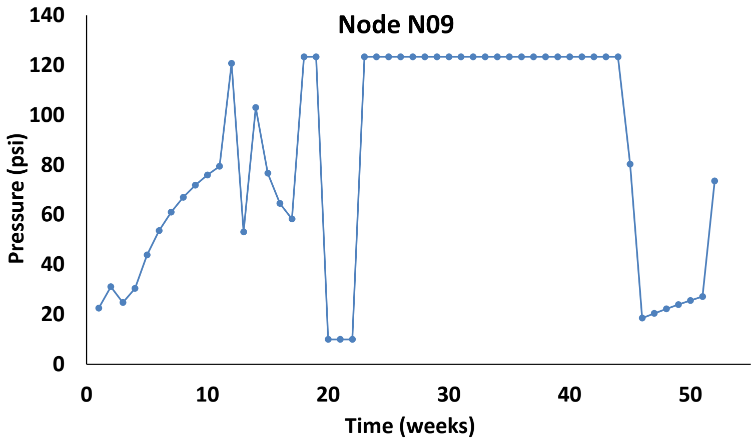
All pressures in psi

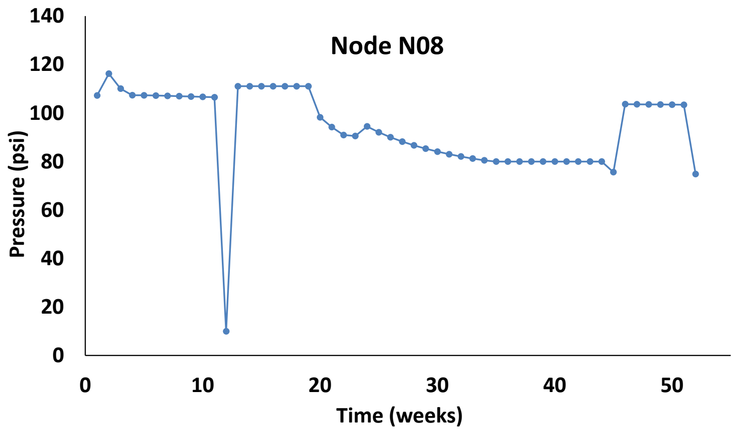
Legend

- Production pad
- Completions pad
- Injection **option**
- Treatment **option**
- Frac pit **option**
- Desalination **option**
- Existing pipeline
- Pipeline **option**
- Existing Pump
- New Pump



PARETO computes pressures and flow profiles for the entire planning period





PARETO Motivating Example: Pump Failures

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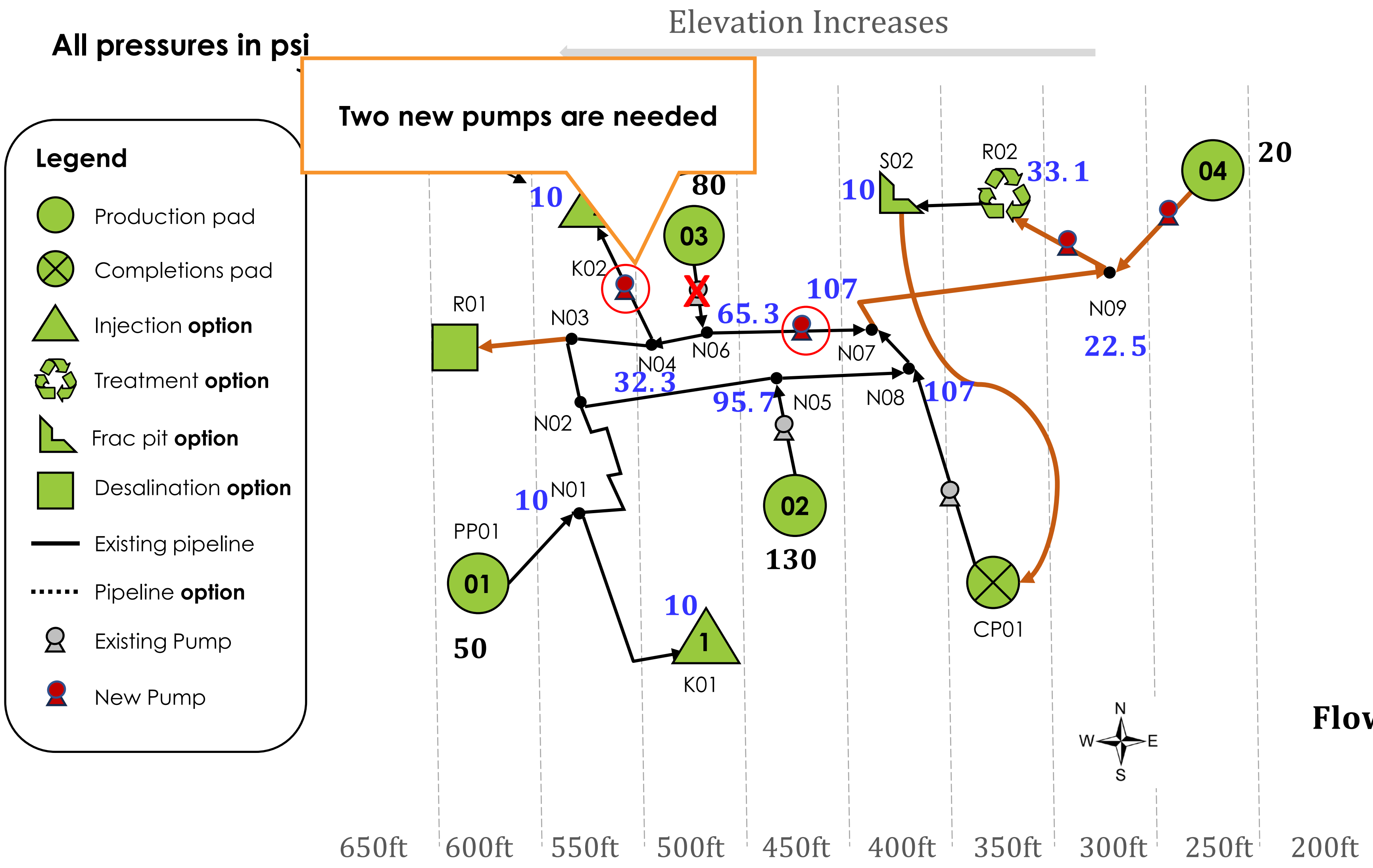
All pressures in psi



New Information:

Pump on line PP03-N06 has failed

Determine:

Pressures at all nodes

New Pump stations, if needed

Flows & Pressures are a snapshot in time

Plans and Extensions

- PARETO's Industrial Collaboration
  - Encouraging response from industrial collaborators on hydraulics implementation
  - Working on implementing the module on a new industrial case study

- PARETO's University Collaboration
  - Developing advanced optimization techniques and strategies for a comprehensive analysis of hydraulics
  - Time decomposition strategy for better initialization of the underlying MINLP problem
  - Linearization of pressure drop correlations to enable comprehensive analysis of network hydraulics

- PARETO UI
  - Team is working towards releasing hydraulics post-processing module integrated with next UI release
  - Comprehensive co-optimization methods to be available by Q4

The PARETO Team

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Thank You!

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