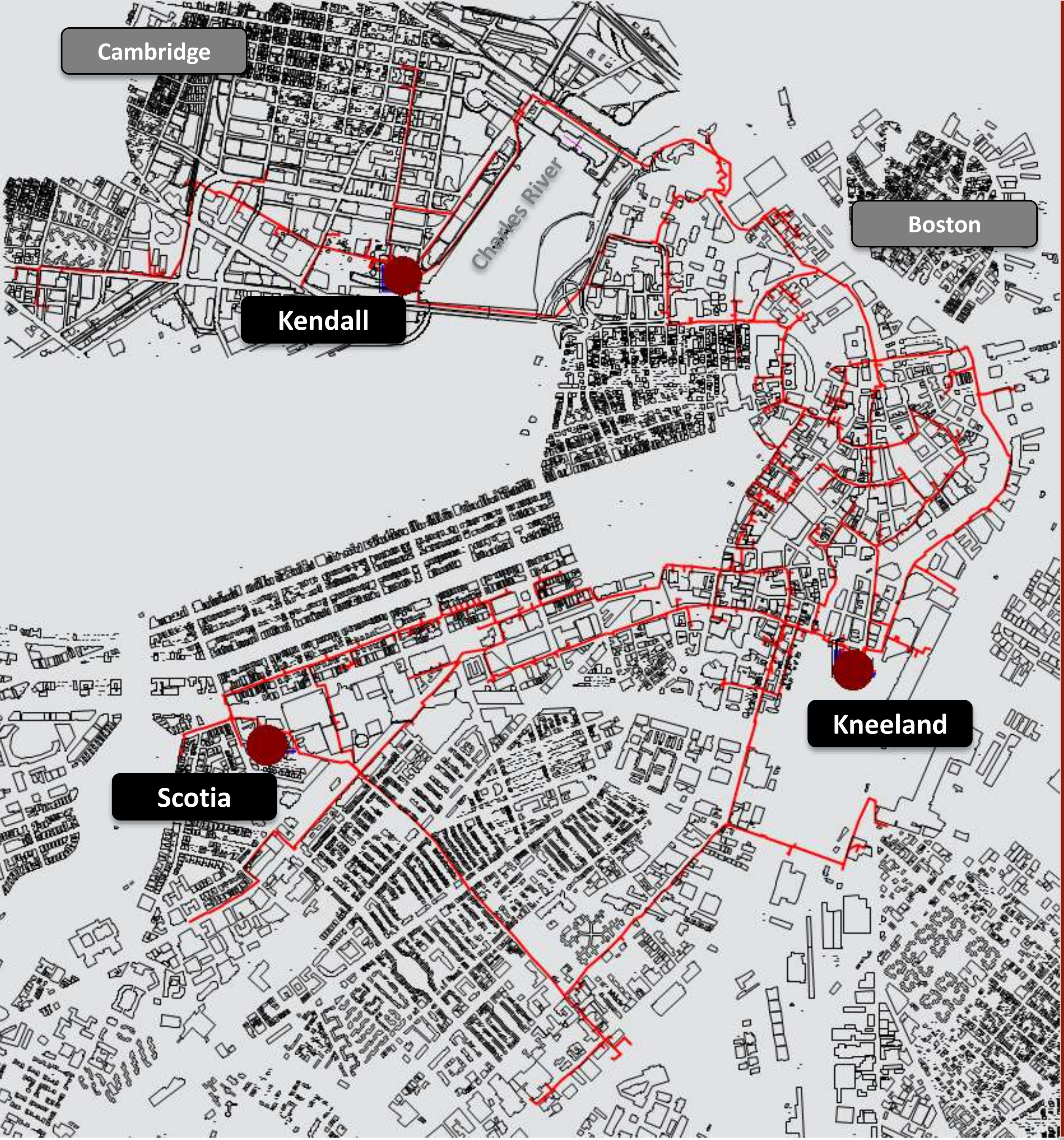
Hydraulic Modeling
Driving the Business Case

Boston & Cambridge Steam Distribution Systems

IDEA2015



Boston & Cambridge Distribution Systems

22	Miles of Piping
16	Boilers
2	Cogenerators
262	MWe
3,200,000	lb/hr Installed
1930-1949	Established

Kendall

1940's (2002 repower)
256 MW Combined Cycle
1 x Gas Turbine & HRSG
3 x Steam Turbines
2 District Boilers
3 Power Boilers
1,500 Mlb/hr capacity
Natural Gas

Kneeland

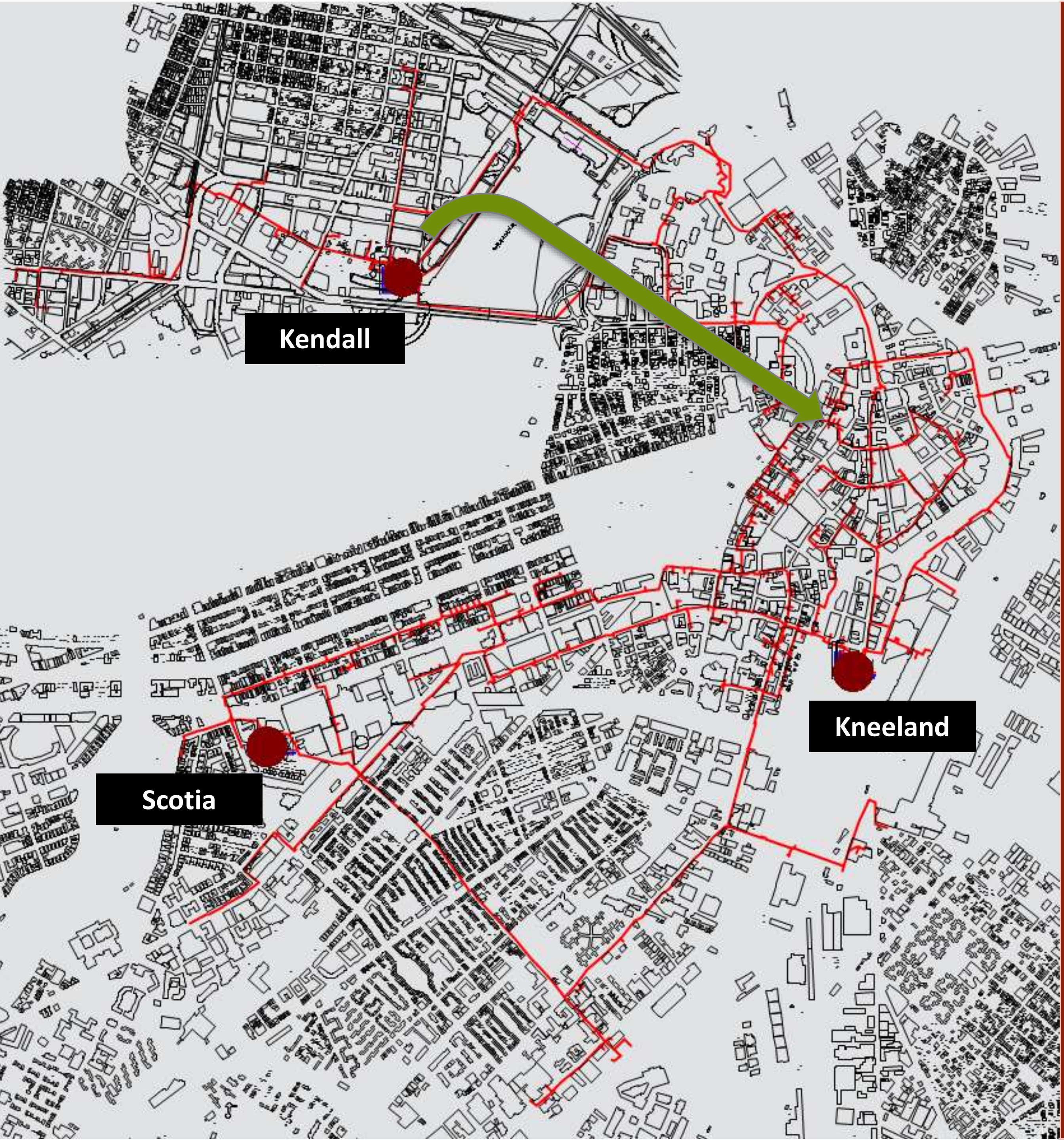
1930's
4 x District Boilers
1,300 Mlb/hr capacity
Natural Gas

Scotia

1960's
3 x District Boilers
360 Mlb/hr capacity
Oil

Managing an Intersection of Events

- Kendall Station Repowering in 2002
- Kendall Station Elimination of River Water Cooling
- Veolia expansion of cogeneration
- Veolia long term management of aging infrastructure

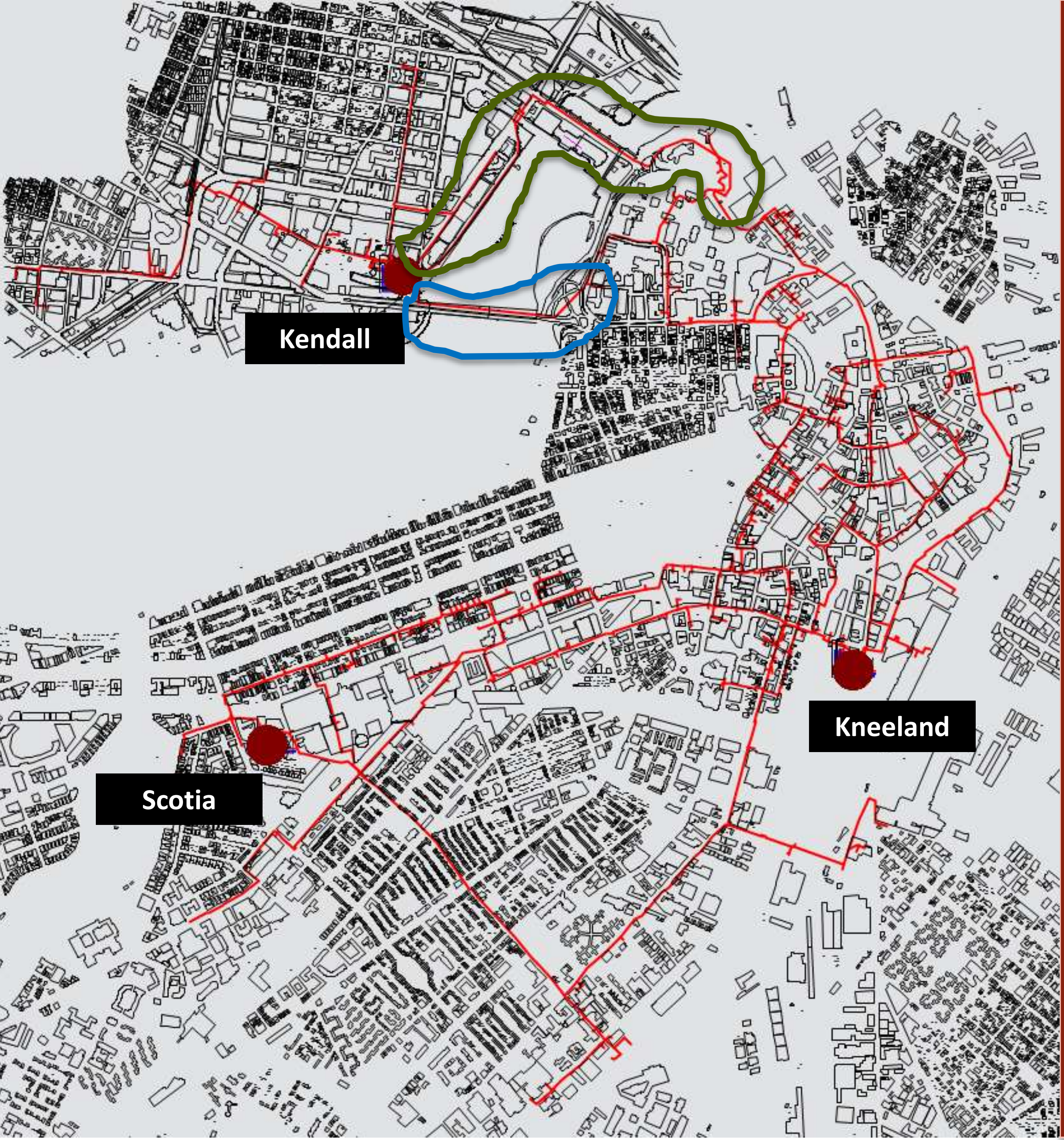


Maximize cogeneration steam import into the Boston system

How we ultimately accomplished this and the part hydraulic modeling played along the way.

Assembling a Solution to the Problem

- How Do We Optimize the “new” steam source
  - New pipeline – what size?
  - PRV’s and distribution pressures
- How do we maximize cogeneration steam within the system
  - Alteration of Boston boiler dispatch to induce steam flow from cogeneration facility. How much from what boiler, where and at what pressure
  - Maximize dispatch of cogeneration facility. Owned by 3rd party
- How Do we tackle these issues
  - We had a lot of data
  - We had a lot of expertise within the Boston business
  - We had some tools.



Leverage existing infrastructure

Mass General Hospital Line

14” steam line

3,000 feet of piping

Access to excess capacity

Install Pipeline

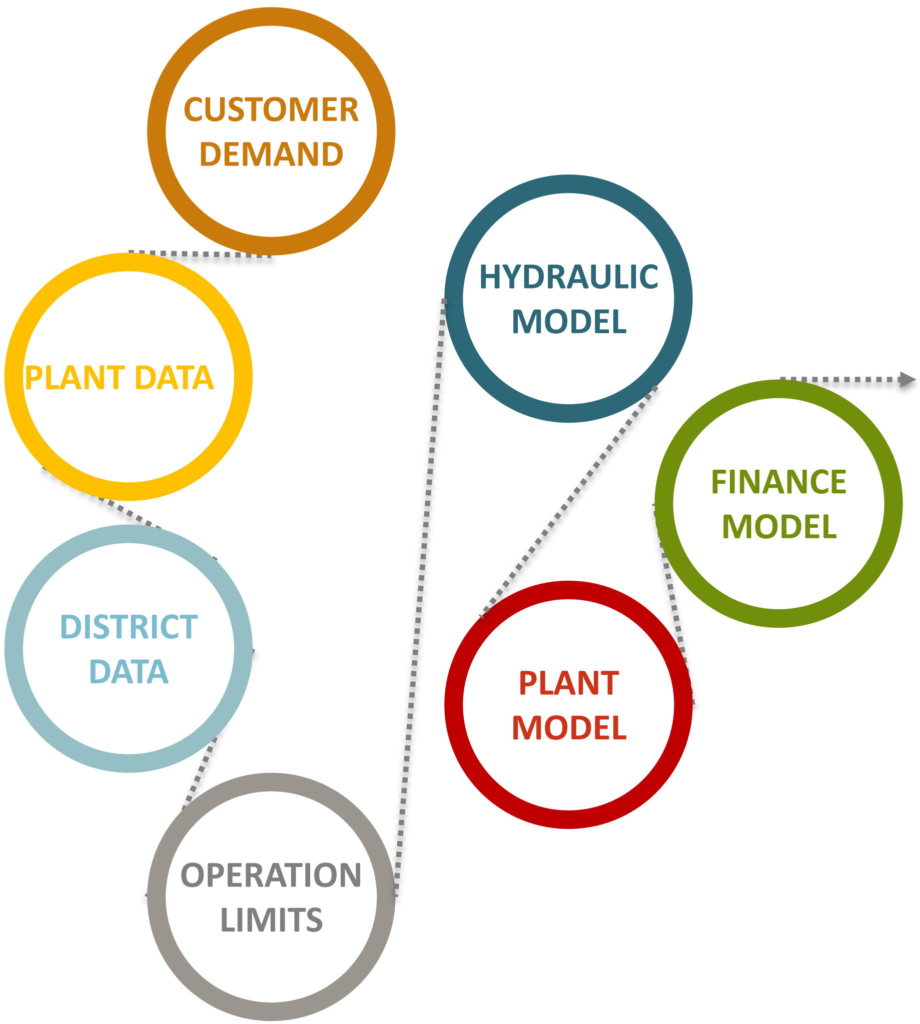
Lechmere Viaduct Pipeline

18” steam line

7,000 feet of piping

Direct discharge from Kendall Station to Boston steam system

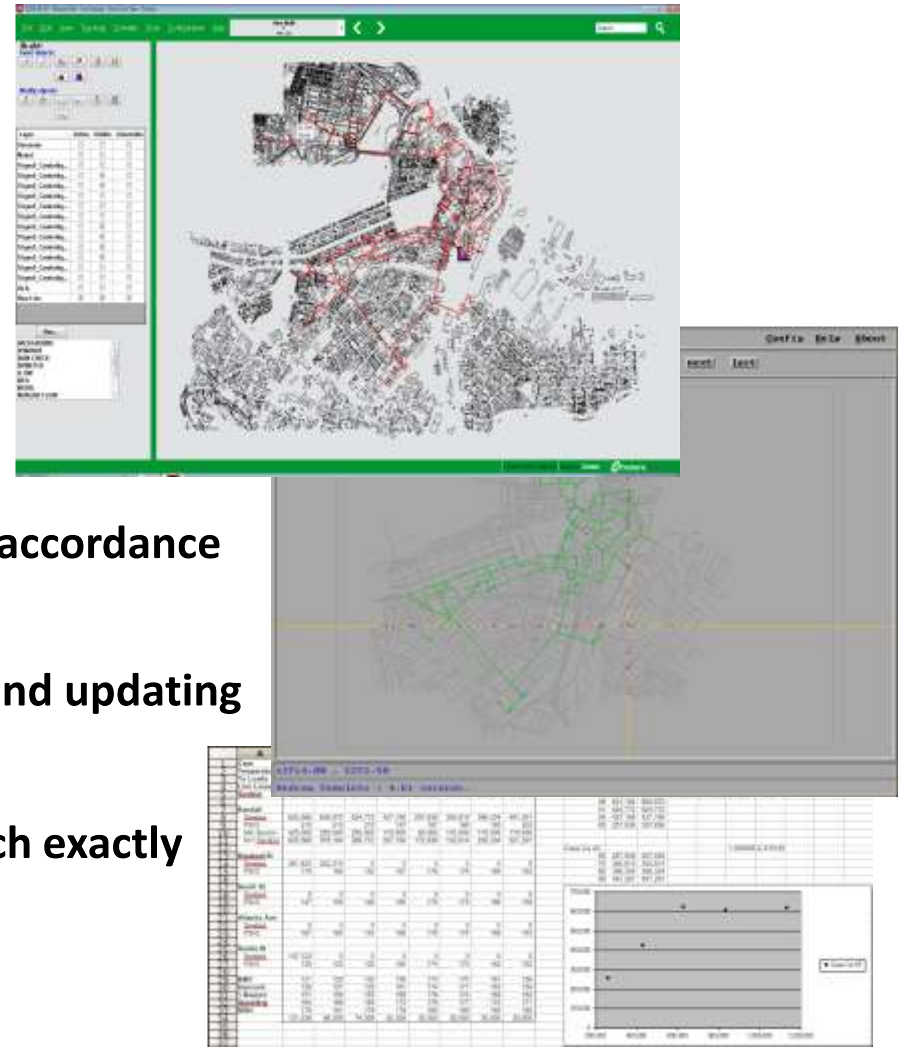
Energy management



- Needed a hydraulic modeling tool to validate existing design decisions being discussed
- Needed insight into system-wide hydraulic relationships
- Needed insight into how plant efficiencies vary with different operating regimes
- Needed resulting fuel, power and dispatch information to flow easily into financial models for decision making.
- Needed to be flexible and easy to manipulate to deal with consistent "what if" scenarios

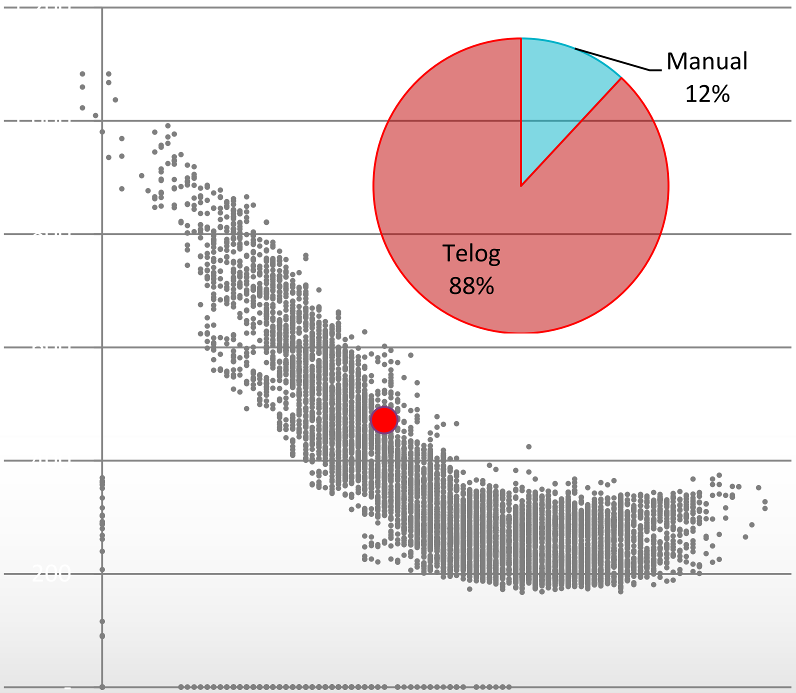
Step 1: Building the Distribution Model

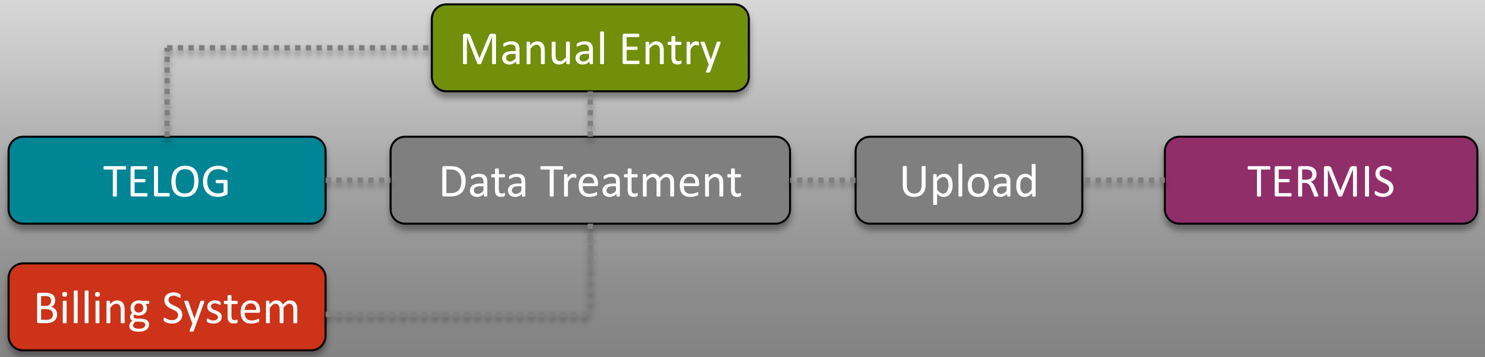
1. What did we already have
2. Select a software, TERMIS
3. Converted old files as a starting point
4. Updating all piping and connections in accordance with P&IDs
5. Removing old customers, adding new and updating existing
6. Arrive at a modeled piping system which exactly represented what was in the field



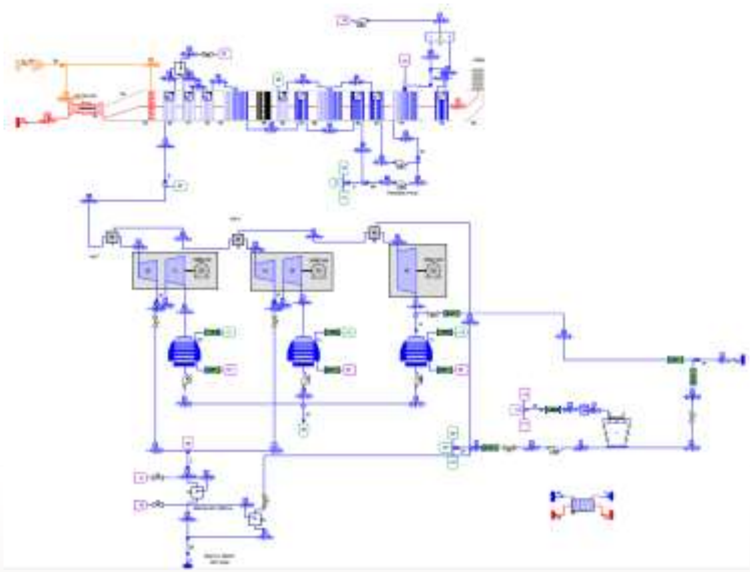
Step 2: Incorporating Consumer Data

1. **Building a bridge to the billing and metering systems**
2. **Selecting the right data points**
3. **Managing manual data entry and predictive analysis**
4. **Constructing an upload process and platform for all consumer data**

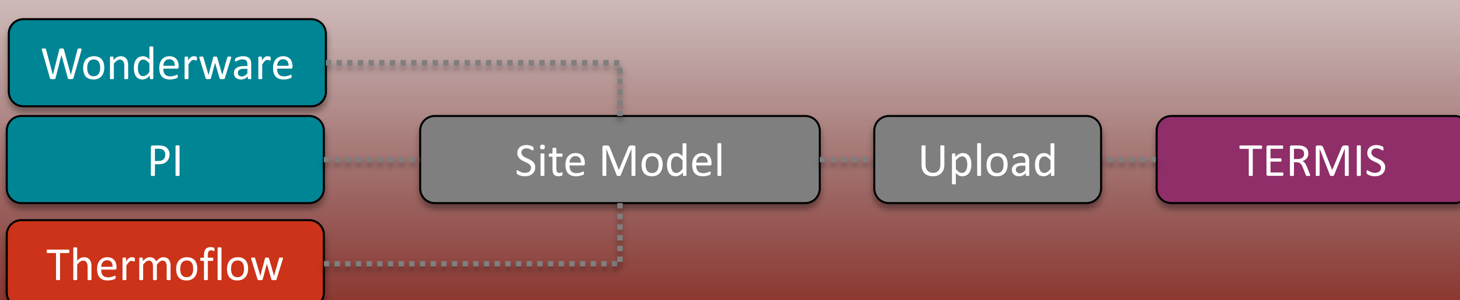




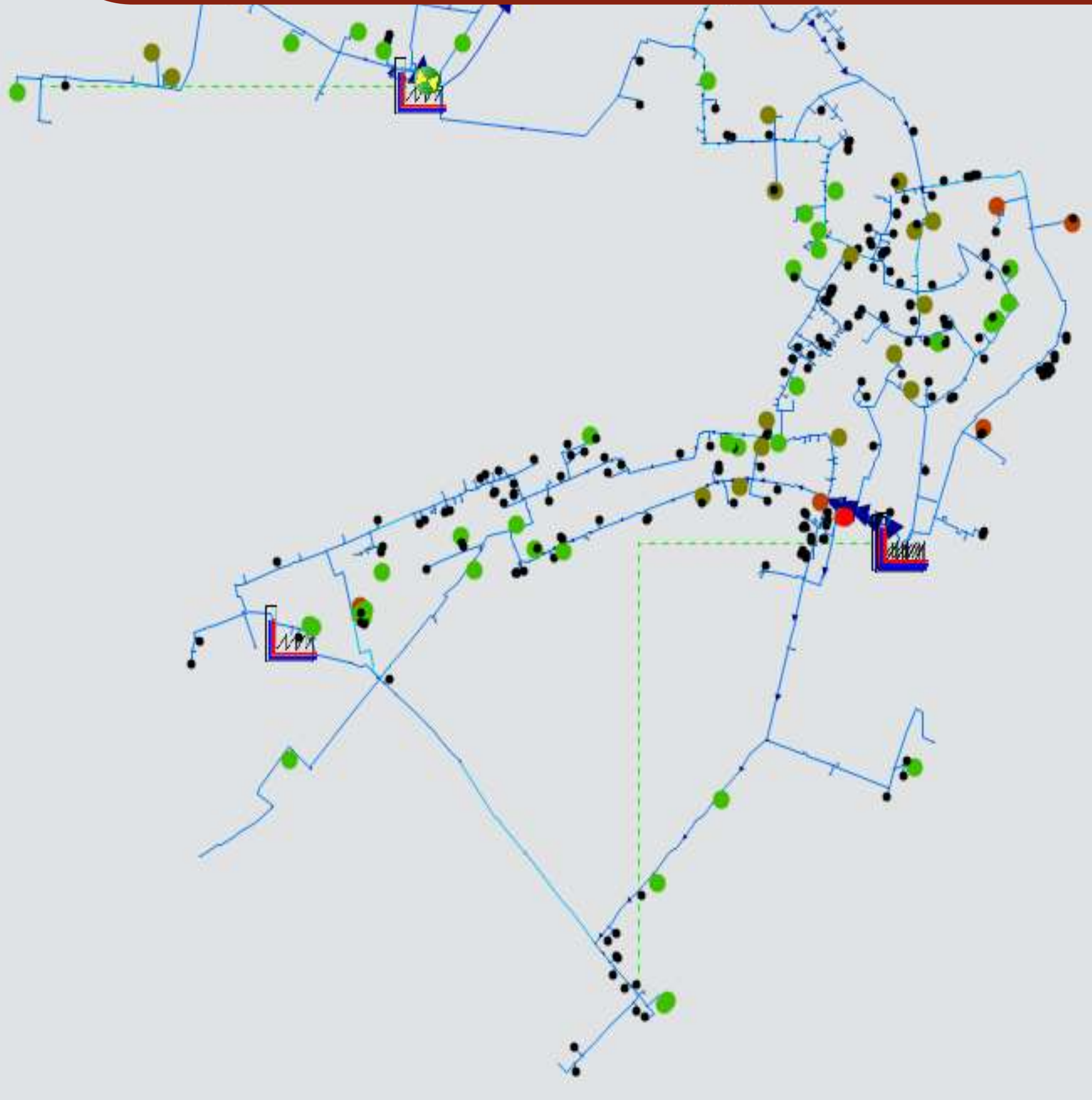
Step 3: Plant Data, Models and Limits



1. Building a bridge to the plant SCADA systems
2. Assemble virtual plant models
3. Correspondence with site on plant specifics
4. Validate site models with plant data and site personnel
5. Site model for each facility that operates as a function of load demanded from the facility. In turn, provides efficiency, parasitic losses, equipment dispatch, etc…



Step 4: Validation and Tuning



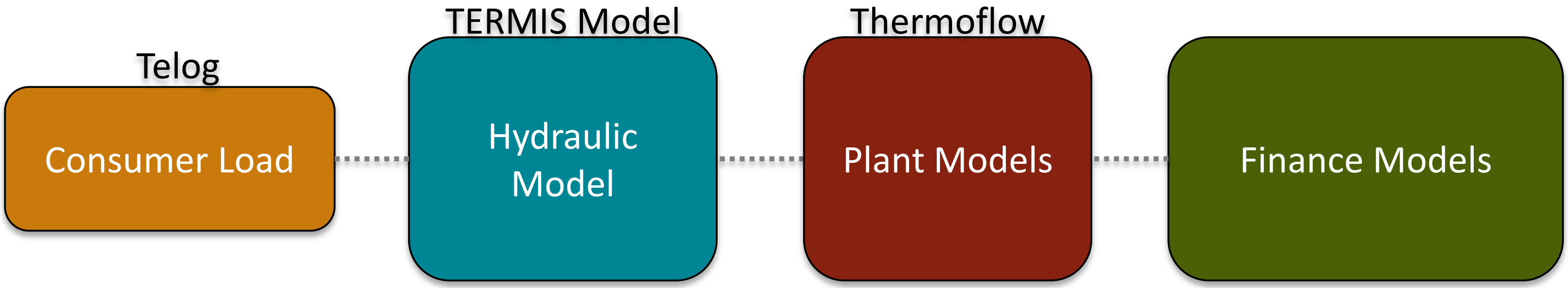
- Select high-load condition for system
  - Select a cold time/date
  - Load consumer load into model
  - Run the model
  - Model determines plant send-outs and pressures throughout the system
- Import billing meter pressures
  - Compare actual billing meter pressures to those predicted by the hydraulic model
- Repeat process from high to low system loads
  - Perform check for a multitude of consumer loads and operating ranges.
  - Fix piping errors, adjust pipe friction factors, system heat losses, etc…
- Ultimately arrive at a system model that accurately represents the system dynamics and validated against actual operation

The Model Process

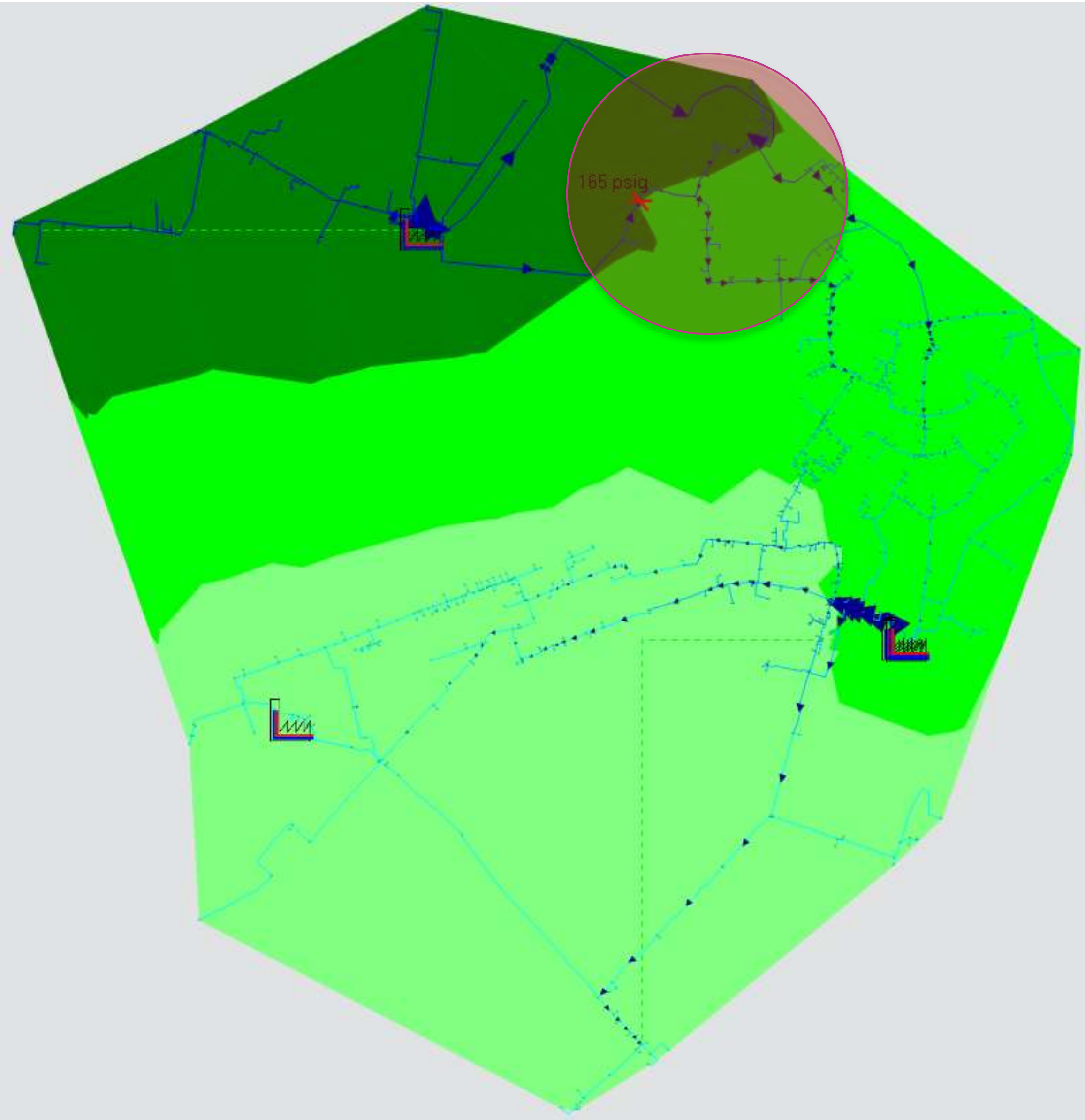
1. Hydraulic model runs and determines the optimal delivery flow and pressure from each steam source to maximize the steam source that has been selected – in our instance, the cogeneration steam source.

2. Plant models take desired steam flow/pressure and determine the optimal equipment arrangement to meet the desired demand.

3. Plant models provide fuel consumption, power output and dispatch viability to financial models. Unit viability in market and dispatch economics are determined and dispatch arrangement is settle upon.



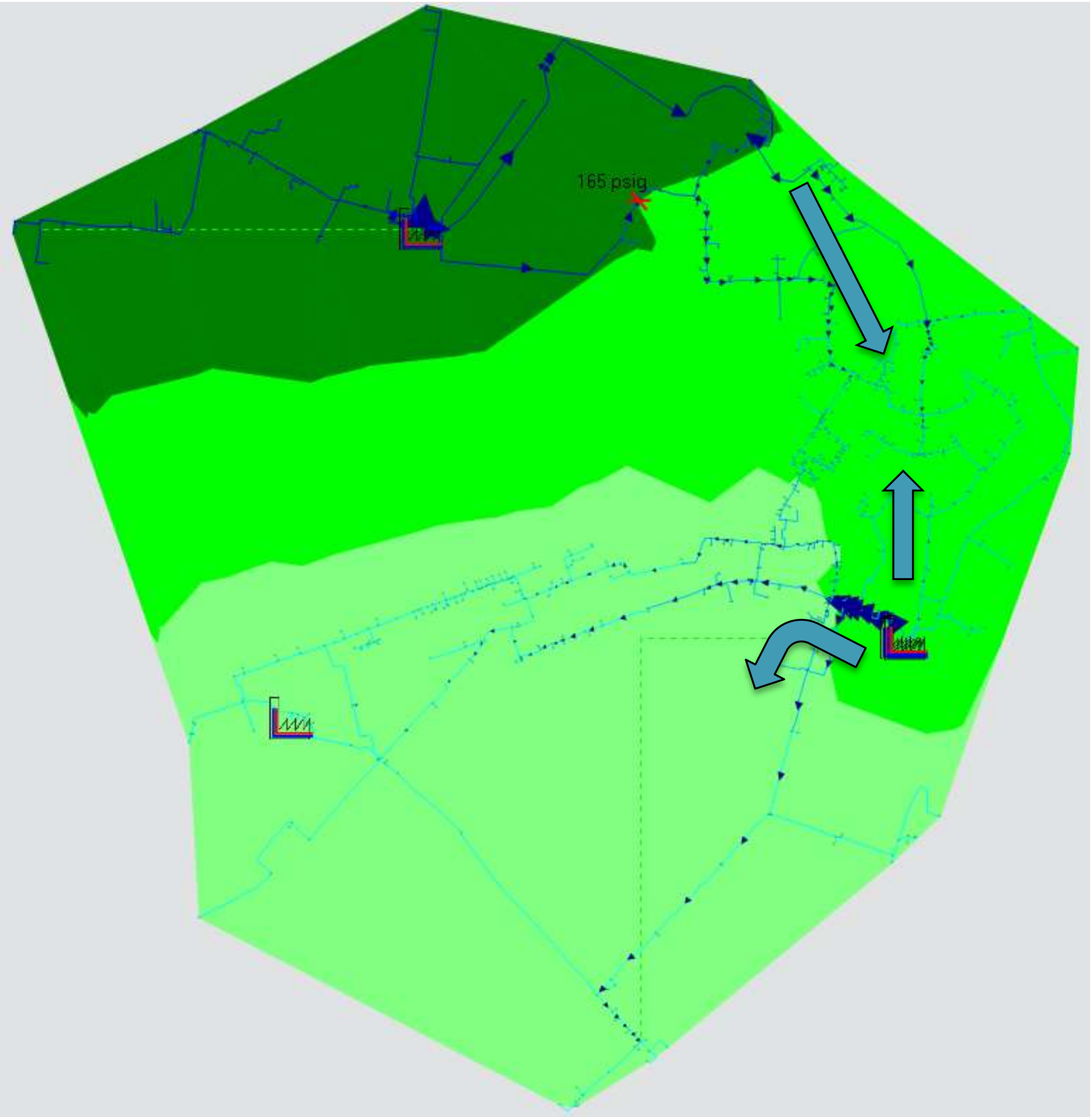
Modeling Insights- LVP Size Validation



Increases in LVP size didn't lead to the expected increase in cogenerated steam flow

Increases in pipe sizes above 18" settled into a system of diminishing returns

Modeling Insights – Opposing Pressures



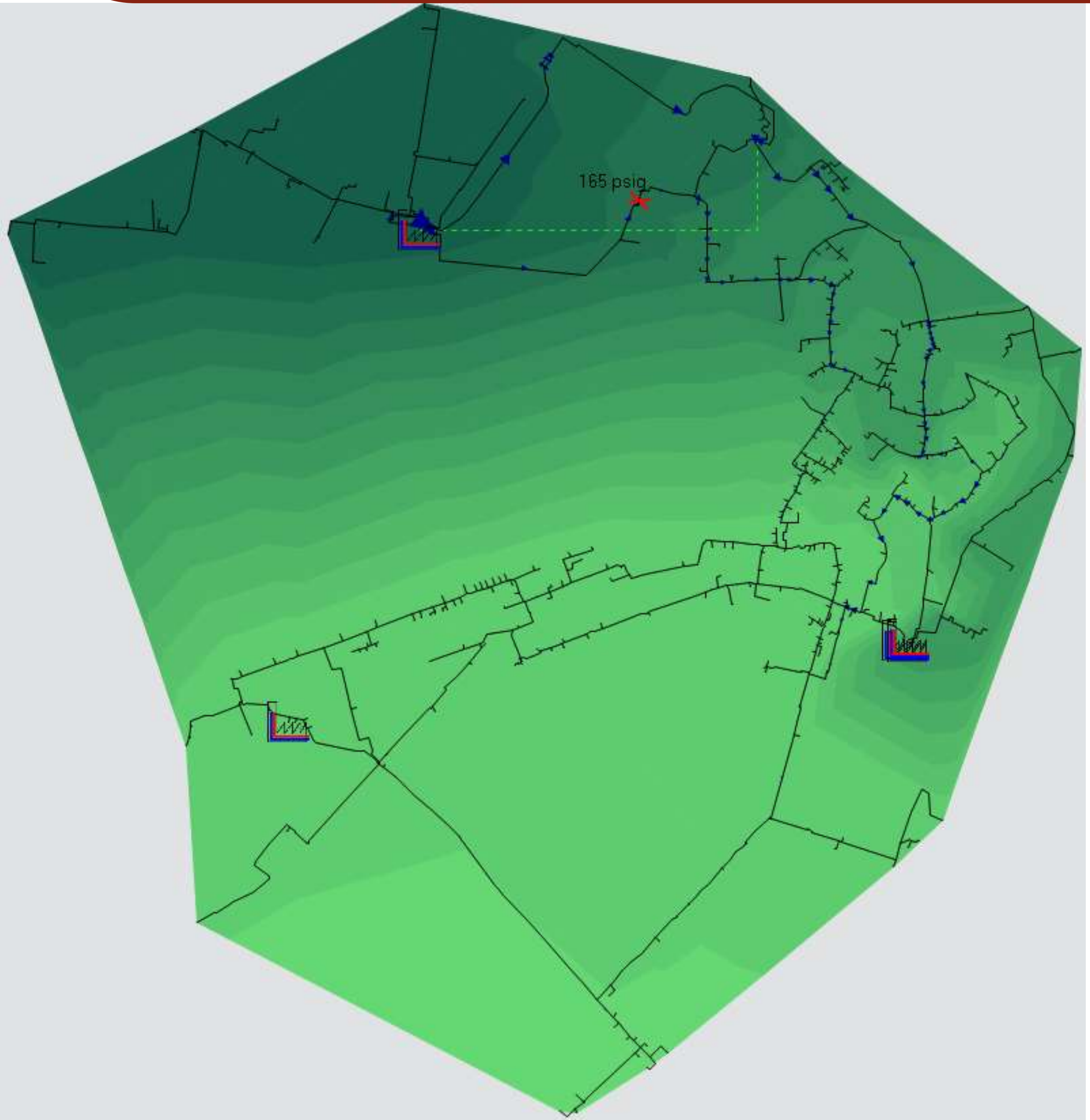
System restrictions West of Kneeland requires elevated delivery pressures to meet Southern system pressure obligations.

This causes Kneeland delivery pressures to directly oppose Kendall steam and reduced cogeneration steam imports

As such, when Kneeland is operating it takes up a disproportionate amount of the steam load

Issue exacerbated by turndown of older Kneeland equipment

Modeling Insights – Maintaining Pressure

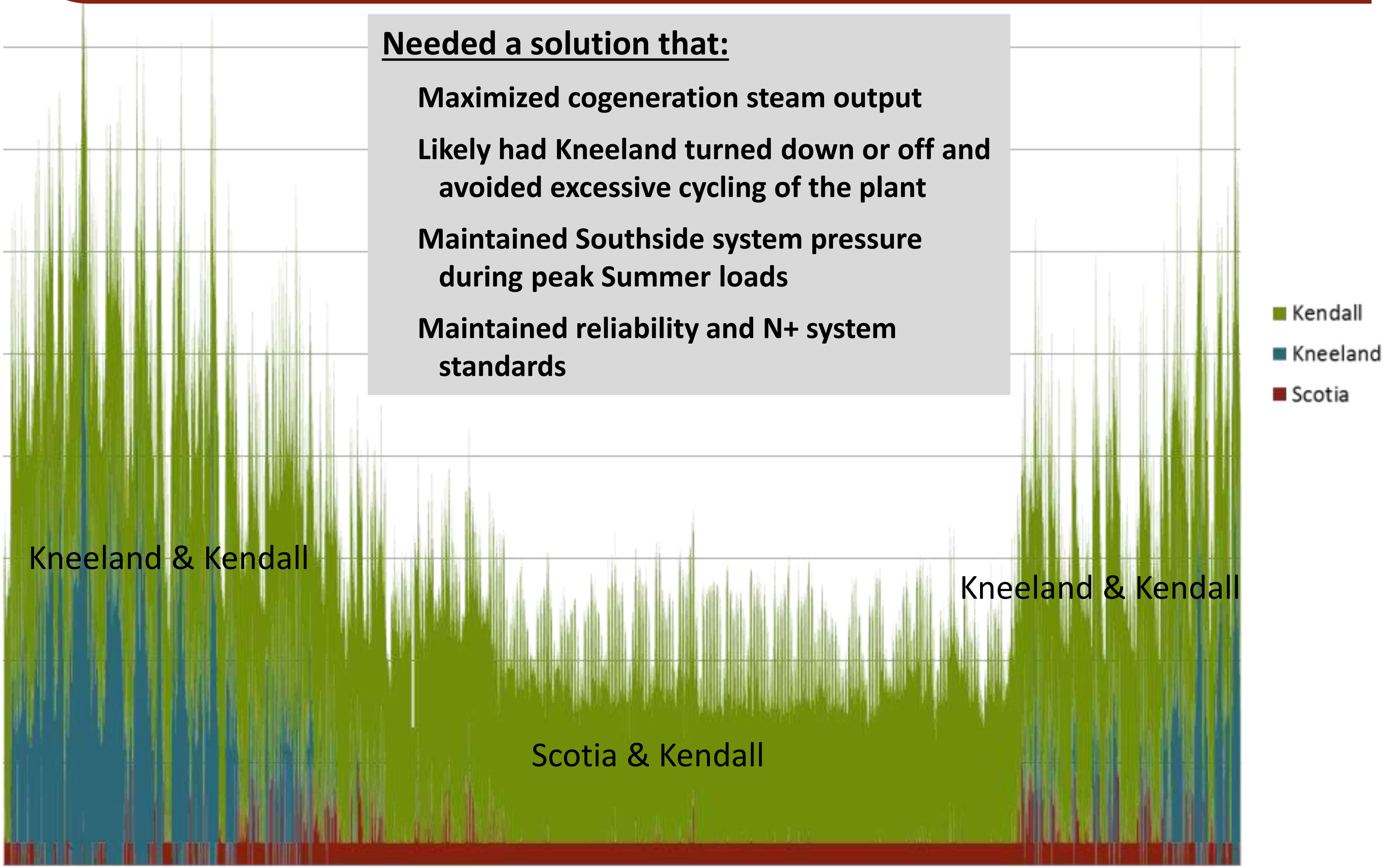


Modeling showed that, under certain load conditions, we needed a solution to manage Southern systems pressures when importing large portions of steam from Kendall.

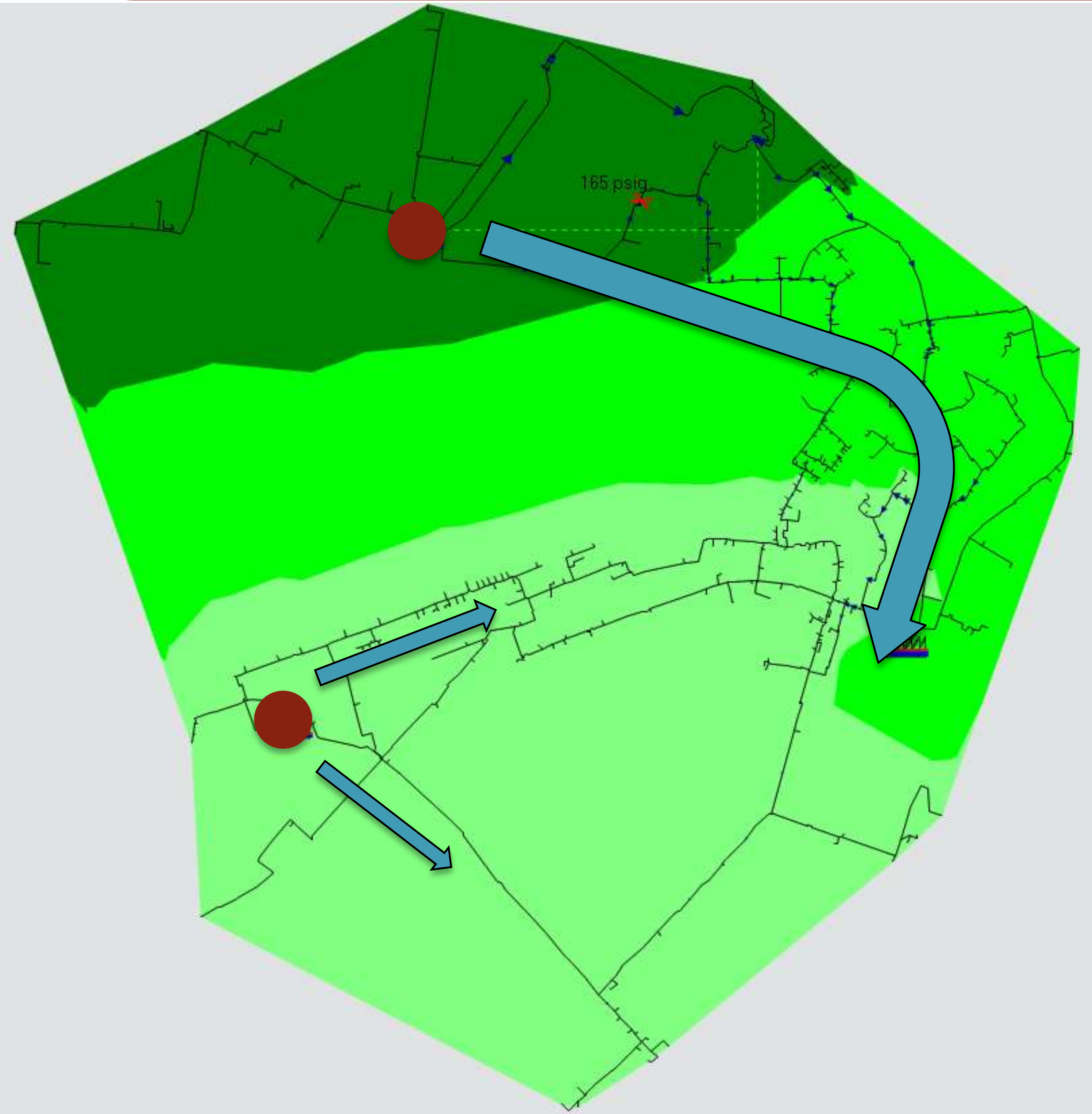
Moving to Solutions

<u>Needed a solution that:</u>

- Maximized cogeneration steam output
- Likely had Kneeland turned down or off and avoided excessive cycling of the plant
- Maintained Southside system pressure during peak Summer loads
- Maintained reliability and N+ system standards



Moving to Solutions



- **Convert a small portion of Scotia load to gas and operate at a relatively low load**
- **Improved cogeneration steam import by 10%**
- **Avoids cycling of older equipment. Scotia runs balance with cogeneration rather than Kneeland**
- **Improves competitiveness cogeneration facility in wholesale electric market and increases amount of hours cogenerated steam is available**

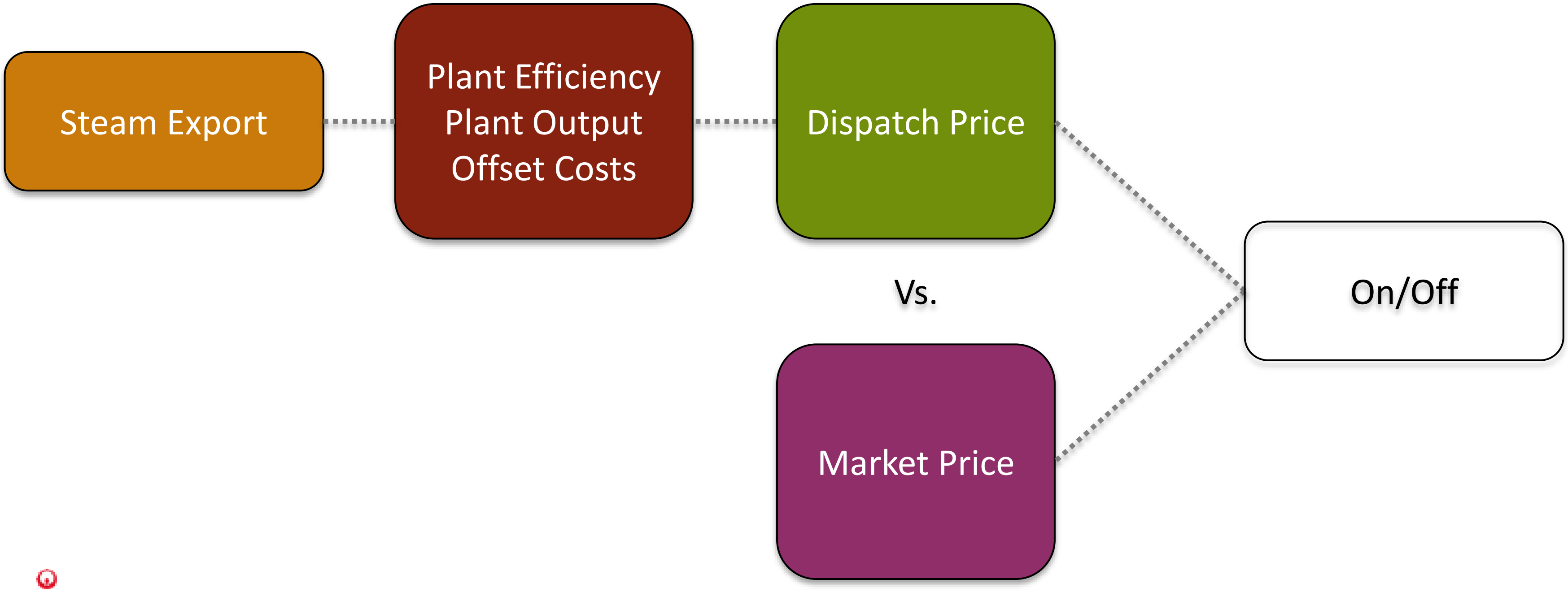
Valuation of Kendall to Acquisition

Use hydraulic model to predict steam export from facility

Use plant model to predict power output, efficiency, etc…

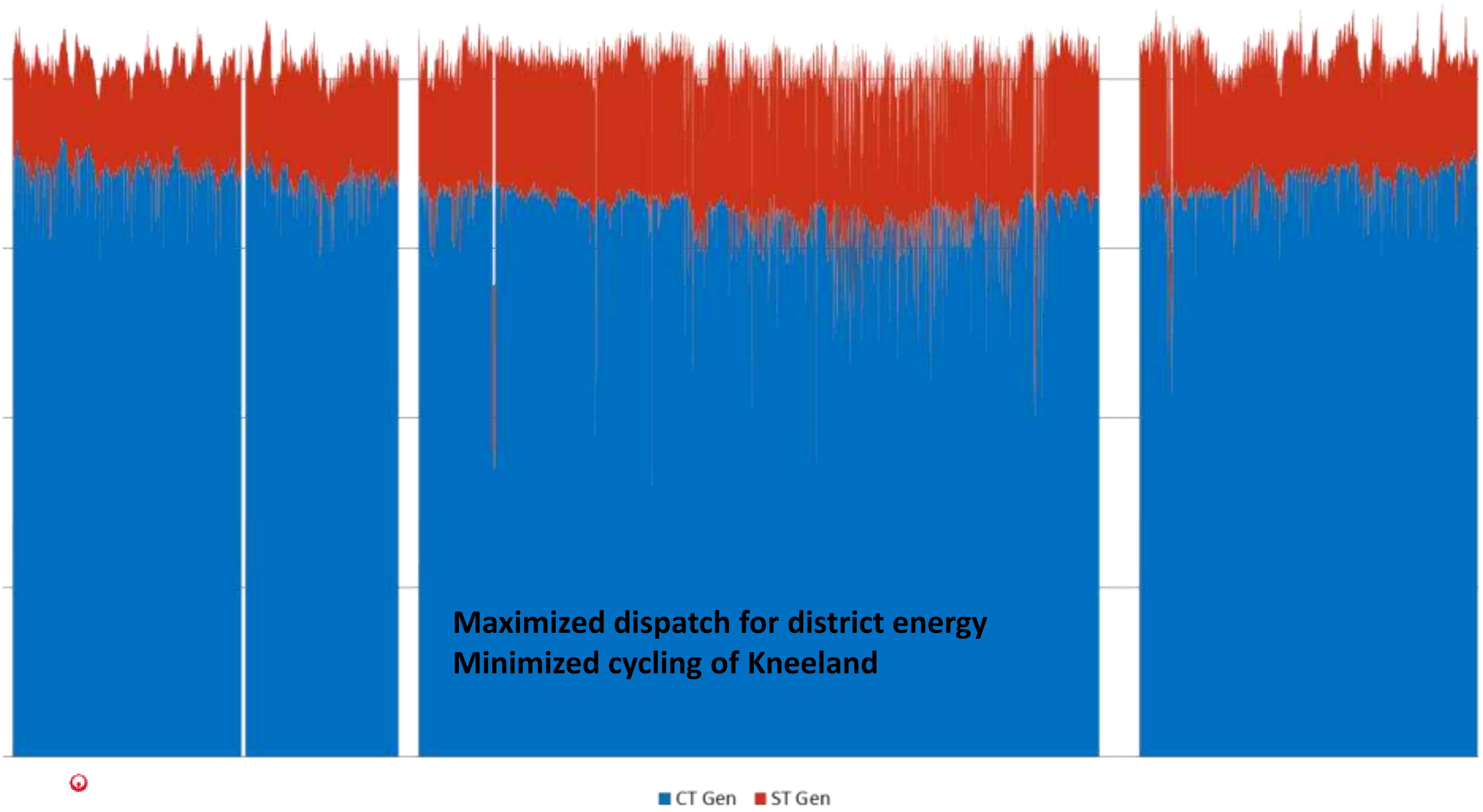
Assemble annual profiles and compare against market

Determinations of steam and power deliverables vs. costs to evaluate value of facility



Acquisition and Optimizing Dispatch

Valuation of plant export capabilities ultimately allowed the assembly of a competitive bid for the acquisition of the facility. Facility acquired in February 2014.



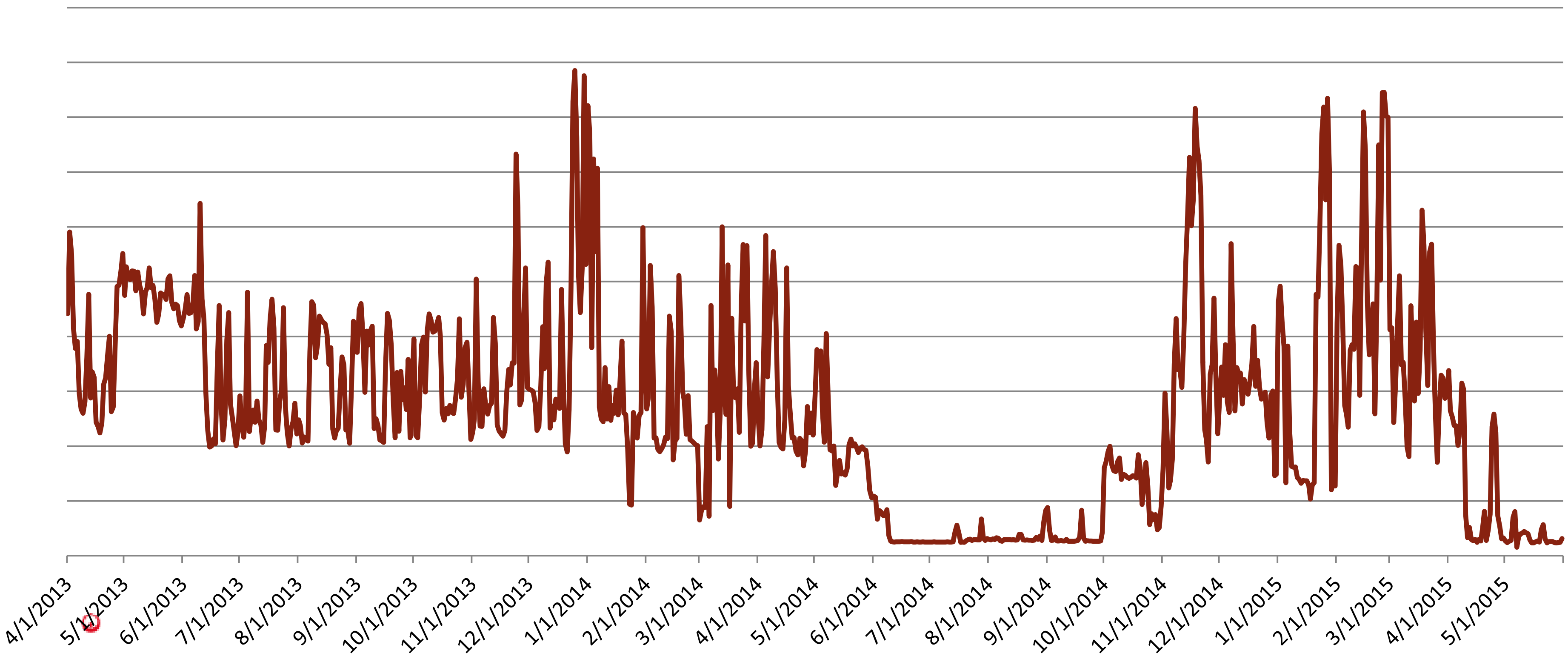
Current Arrangement

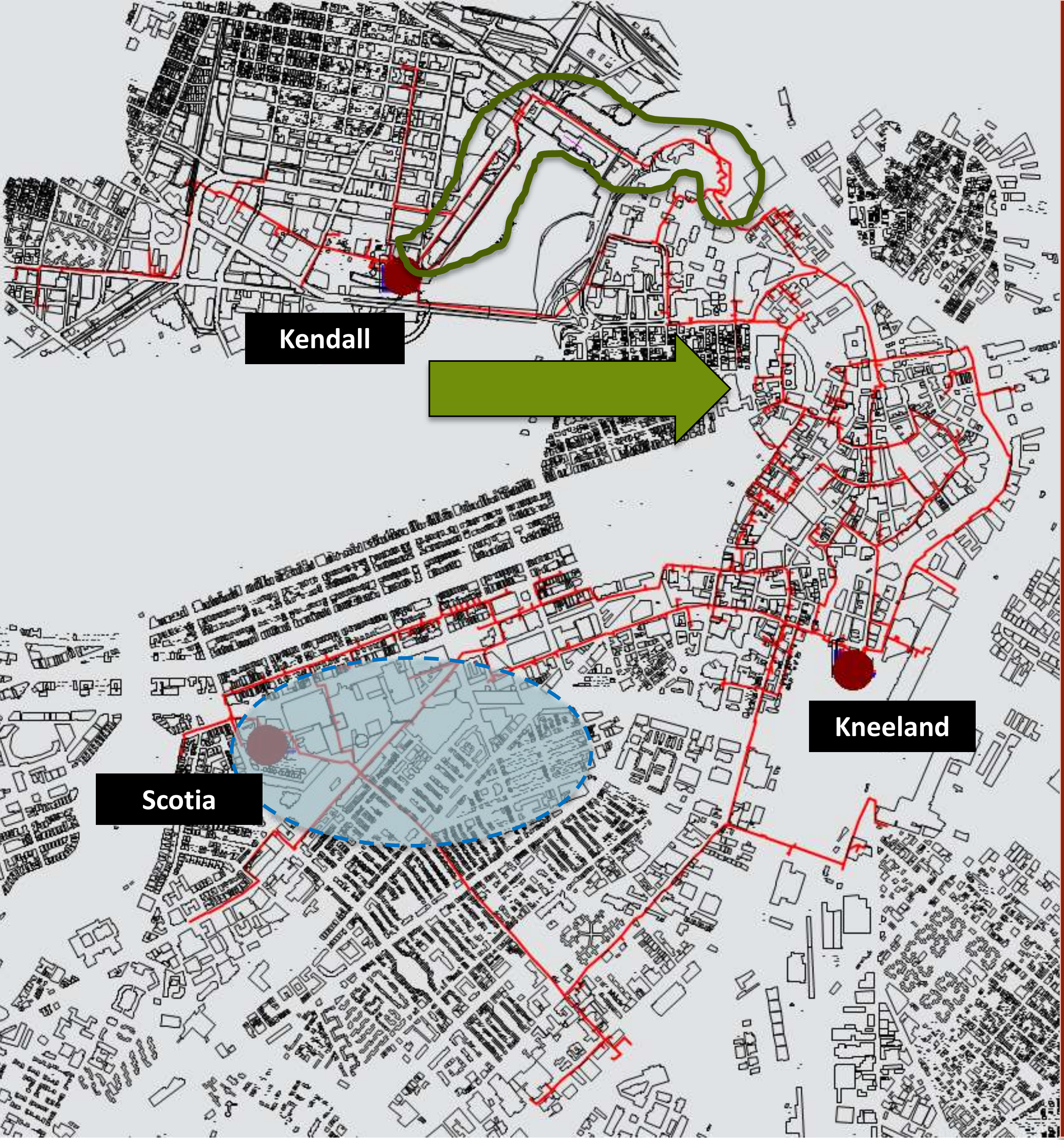
November 2013 — **Construction of Lechmere Viaduct**

February 2014 — **Acquisition of Kendall Station**

June 2014 — **Completion of Scotia single boiler gas conversion**

Summer 2014 — **Kneeland cycles off for the first time in 50+ years**
System operated on Kendall cogenerated steam with Scotia on pressure balance





Improved system cogeneration steam use from 30% to 65%

Reduced Boston GHG emissions by 475,000 tons annually.

6% reduction of non-transportation carbon emissions for both Boston and Cambridge

Reduced heat rejection to Charles River by 30%

Improved air quality by reducing NOx and SO2 emissions by 31% and 61% respectively

Conclusions

- A process that started to guide a major system transition has left us process and tools that we use to continually optimize our business
- Ultimately, the modeling efforts allows us to serve the needs of our customers better through efficient, reliable, environmentally friendly steam – which is really what it is all about

Thank you! – Contact details

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