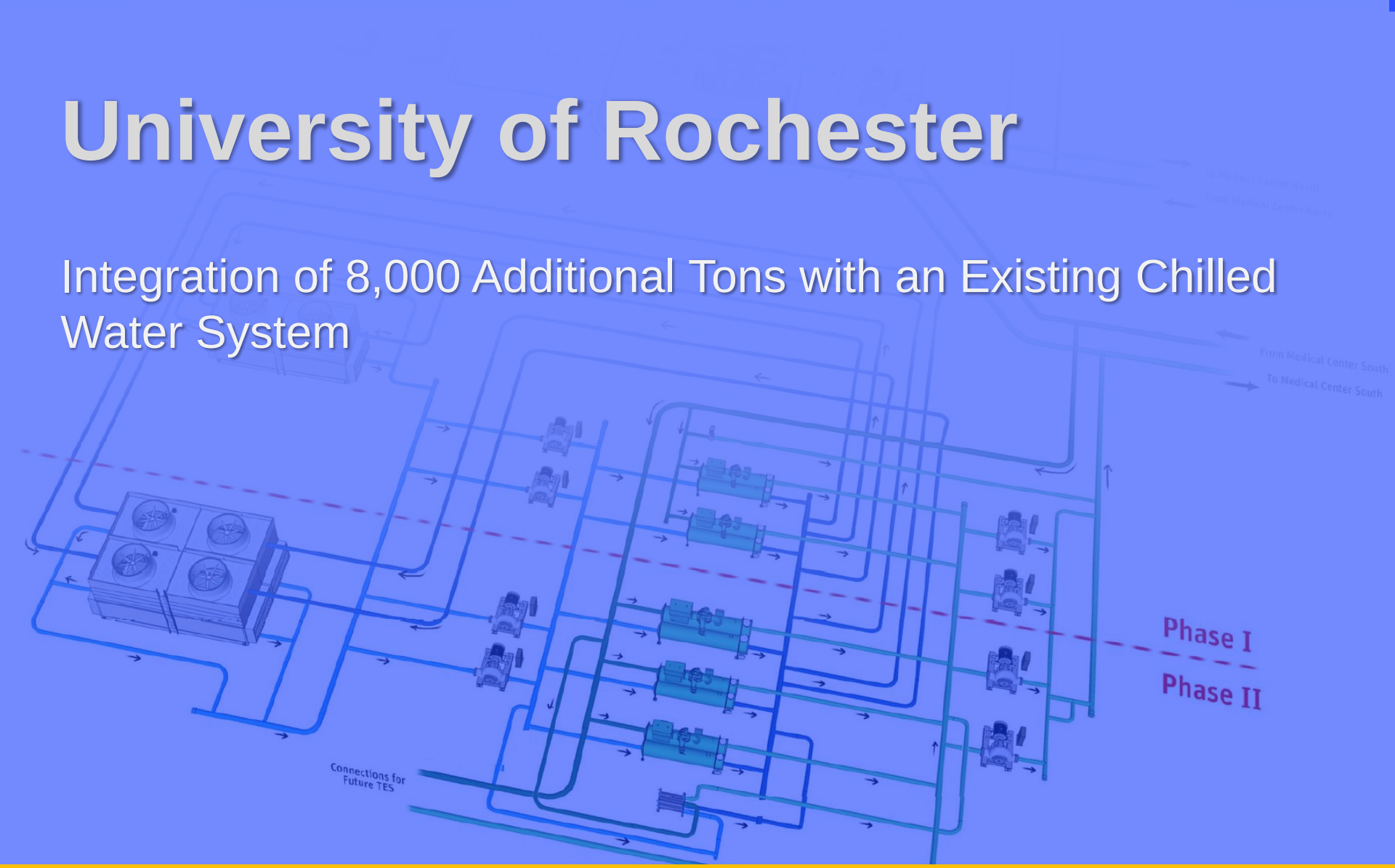
University of Rochester

Integration of 8,000 Additional Tons with an Existing Chilled Water System



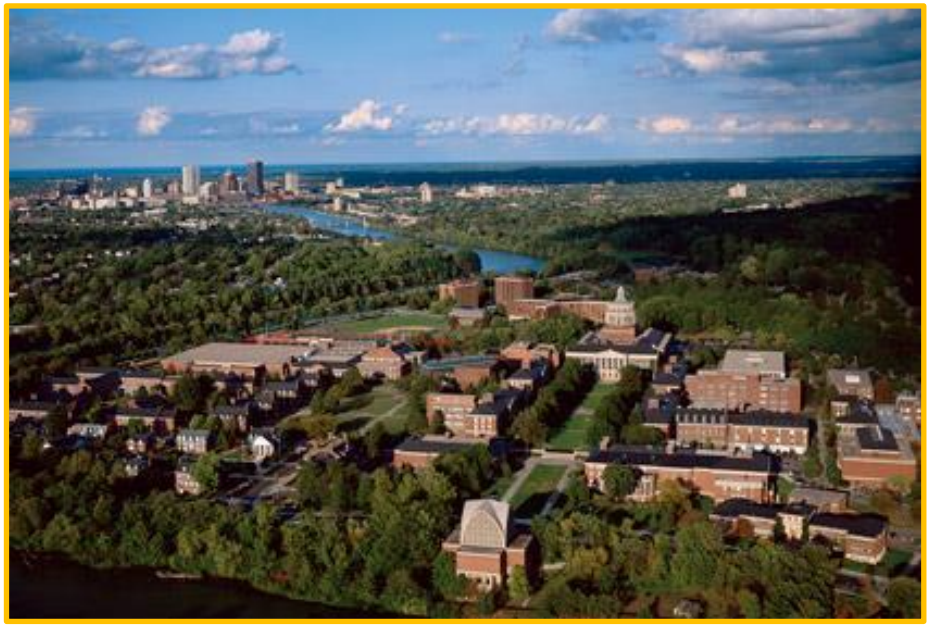
February 10, 2016

UNIVERSITY of ROCHESTER

Affiliated Engineers

University of Rochester

- Located in Rochester, NY
- Founded in 1854, Private University
- 158 Buildings, over 12 MM gross square feet of building space
- 10,500 students (graduate and undergraduate)
- 800 bed hospital, regional trauma center
- 7,177,104 gross square feet on central chilled water system
- Steam and medium temperature hot water systems, 25 MW cogen
- $54 MM Annual Utilities Budget



District Cooling History at Rochester

- 1924 - Central Boiler Plant Built (Steam Only)
- 1967 to 1972 – Central Chilled Water Plant Added with Four (4) Steam Driven Chillers & River Water Condensing System - 15,000 Tons Capacity
- 1999 - Added 6,300 Ton Steam Driven Chiller #5 and Dedicated Cooling Towers
- 2005 - Chilled Water Master Plan
- 2008 – Middle Campus Chiller Plant (MCCP) - 4,000 Tons of Chiller Capacity

2008 MCCP Design Criteria

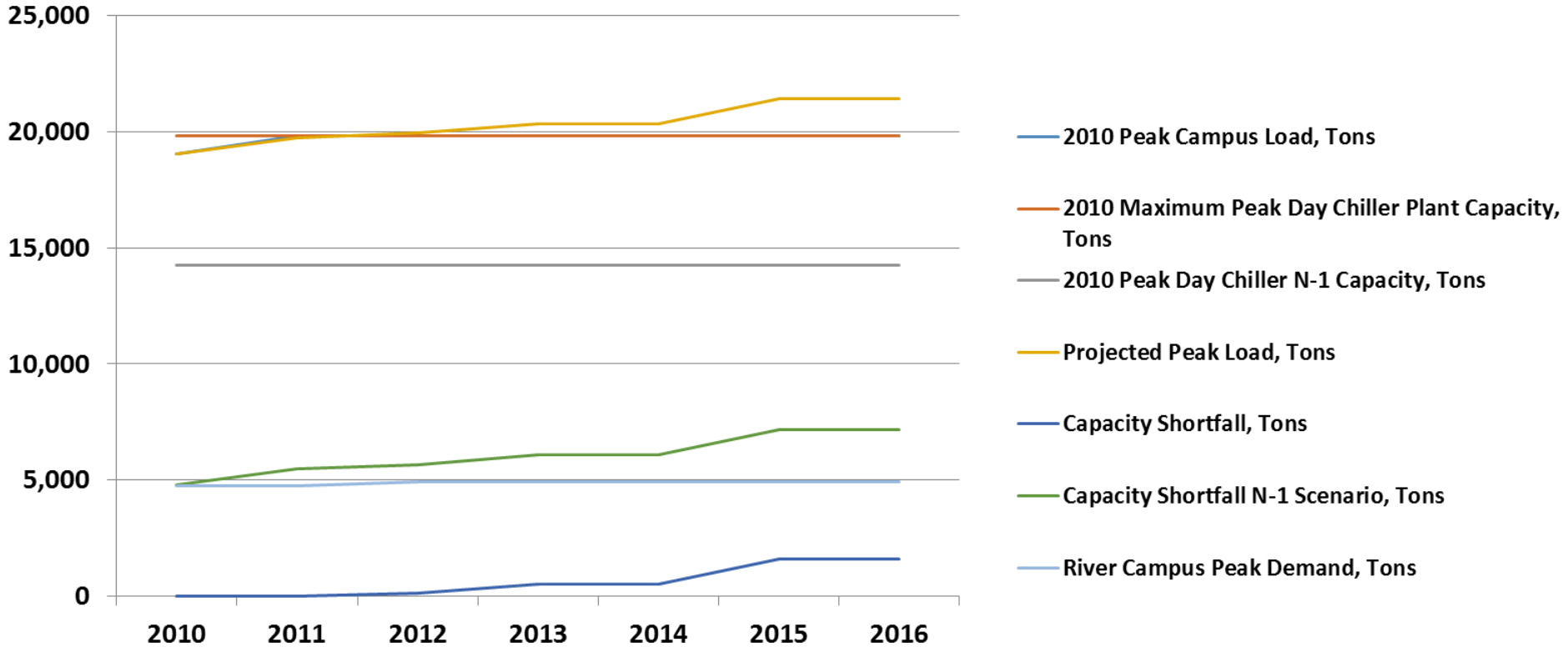
- Locate Plant Closer to Medical Center and Hospital due to Growing Cooling Loads
- Two 4,160 Volt, Electric Driven Chillers Selected for Diversity and Reliability
  - One Chiller Provided with Medium Voltage VFD
- Roof Top Cooling Towers to Reduce Dependence on River Water for Condenser Cooling
- Dedicated 34.5 KV Electric Service from Utility for Redundancy
- Designed to Allow for Future Expansion

2011 Chilled Water Peak Forecast

In August 2011 the Largest Chiller Drive Fails (6,300 Tons) Resulting in Curtailments and Rental Chillers Being Brought on Site:

	2011	2012	2013	2014	2015
2010 Summer Peak Campus Load (Tons)	19,045	19,045	19,045	19,045	19,045
2010 Maximum Peak Day Chiller Plant Capacity	19,830	19,830	19,830	19,830	19,830
2010 Peak Day Chiller N-1 Capacity	14,265	14,265	14,265	14,265	14,265
Projected Peak Load	19,045	19,735	19,942	20,335	21,413
Saunders Research Building Added Demand		690	690	690	690
Warner School of Education Building Added Demand			207	207	207
Wilmot Cancer Center Expansion Added Demand				393	393
Golisano Pediatric Hospital Demand					1,078
Capacity Shortfall @ Peak	0	0	111	504	504
Capacity Shortfall N-1 Scenario	4,780	5,470	5,676	6,069	7,148

UR 2011 Capacity Shortfall Diagram



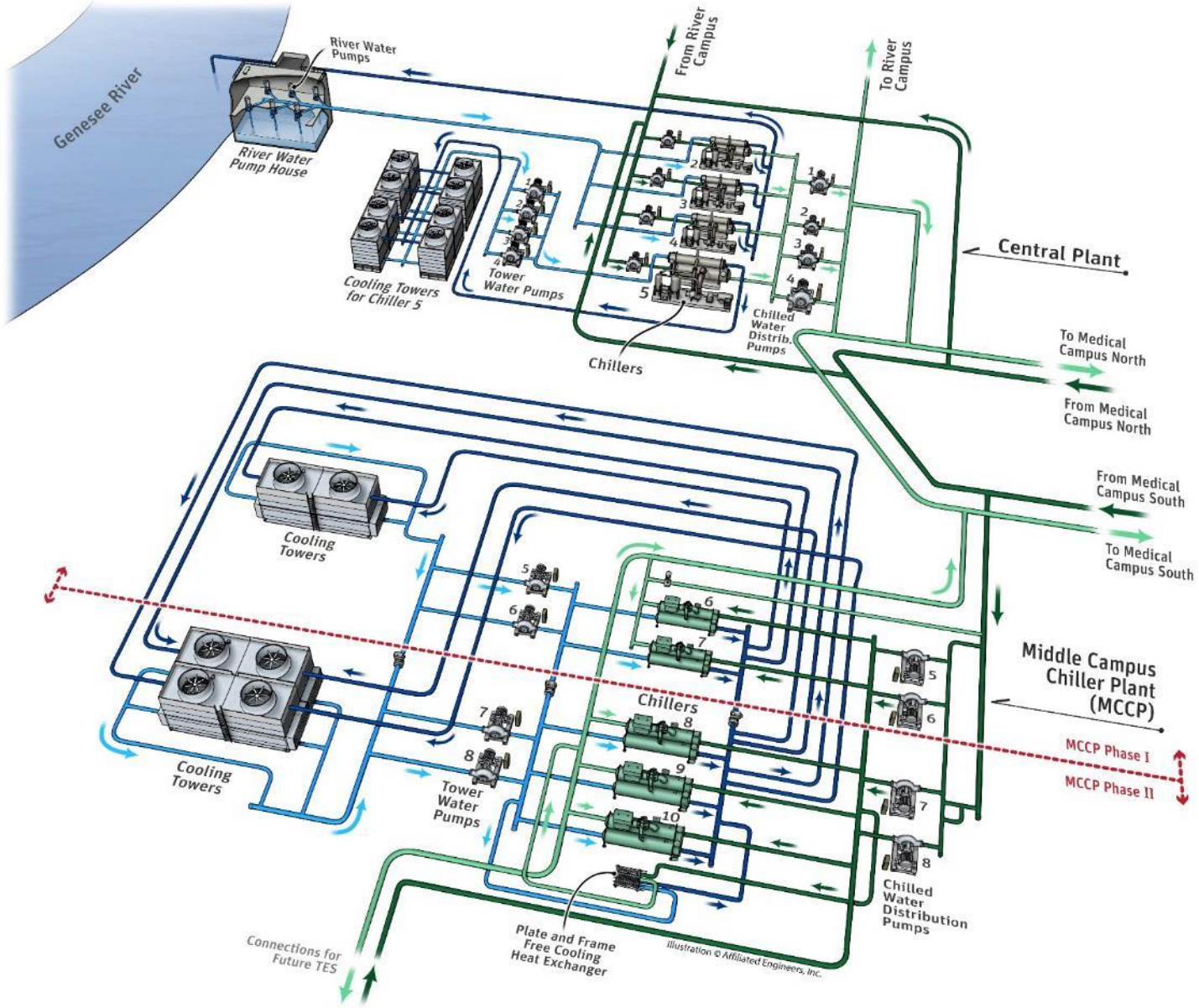
Chilled Water System Upgrades

- Upgrade 1971 Steam Driven Chillers # 2 and 3 to R-134A, Repower Steam Turbine Drives, Increase Nameplate Capacity to 5,200 Tons each
- Replace River Water Pump House Intake Screens, Electrical Transformers and Switches
- New 70 MVA Electrical Substation (New 11.5 kV loop feeder service to Mid Campus Chiller Plant)
- Replace Original Central Plant Chilled Water Distribution Pumps and Add 480 Volt VSDs
- Add 8,000 Tons of Additional Electric Chillers at Mid Campus Plant for N+1 Reliability

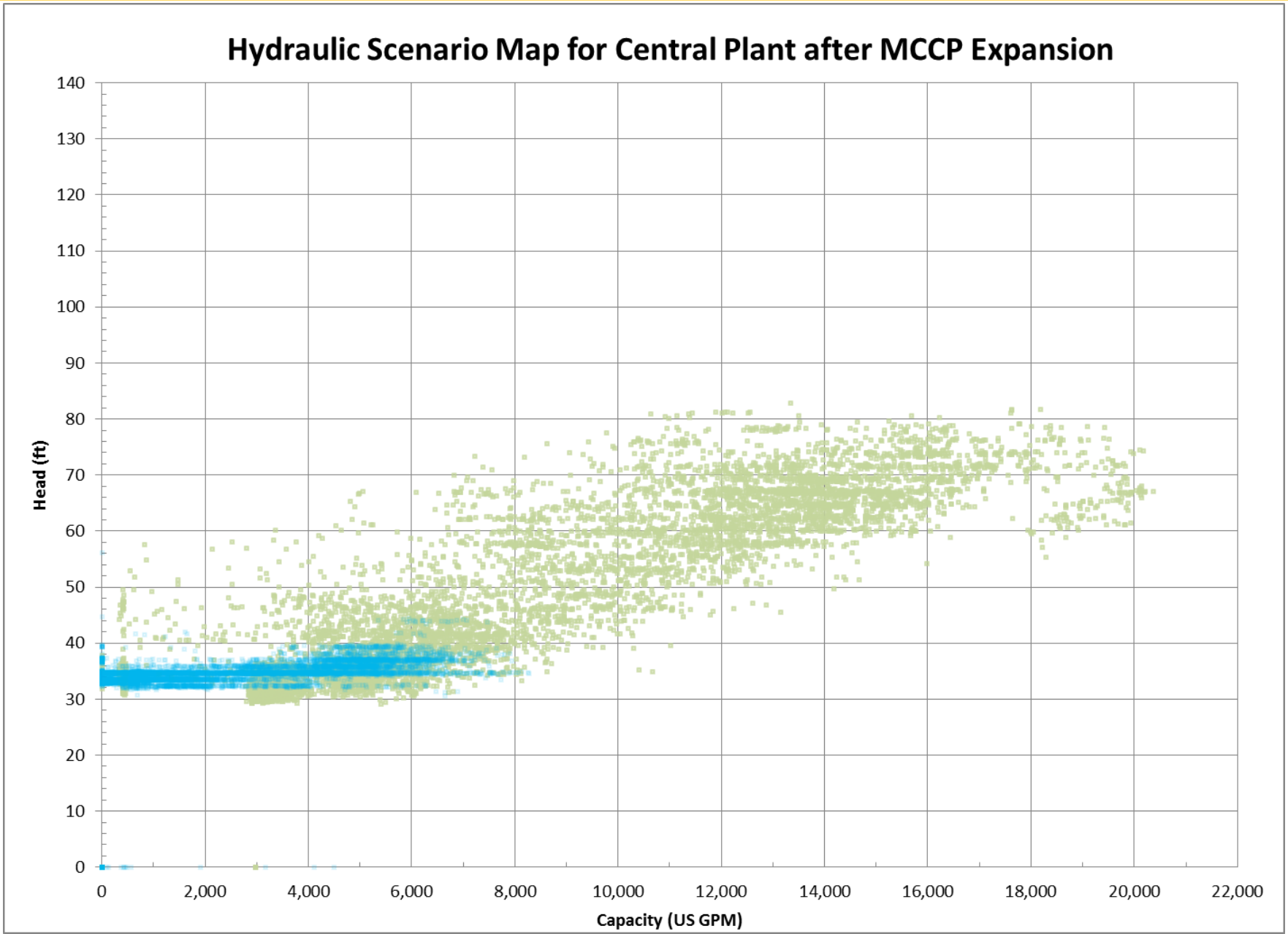
2012 Master Plan Budget

- 2012 & 2014 -Upgraded Old R-12 Steam Driven Chillers # 3 and 4 to R-134A, Increase Capacity to 5,200 Tons each - $6.6 MM
- 2013 - Replaced Original 1970's Central Plant Chilled Water Distribution Pumps and Add VSDs -$1 MM
- 2013 - Replaced River Water Pump House Intake Screens, New Electrical Transformers and Switches $1.1 MM
- 2014 - New 70 MVA Electric Substation $23MM
- 2015 - Added 8,000 Tons of Additional Electric Chillers at Mid Campus Plant - $16 MM
- New Central Plant Cooling Tower $5 MM (Future)
- New Thermal Storage Tank $5 MM (Future)
- Upgrade 1971 Chiller #4 Steam Turbine Drive $3.3 MM (Future)

Chilled Water System Hydraulics



Chilled Water System Hydraulics



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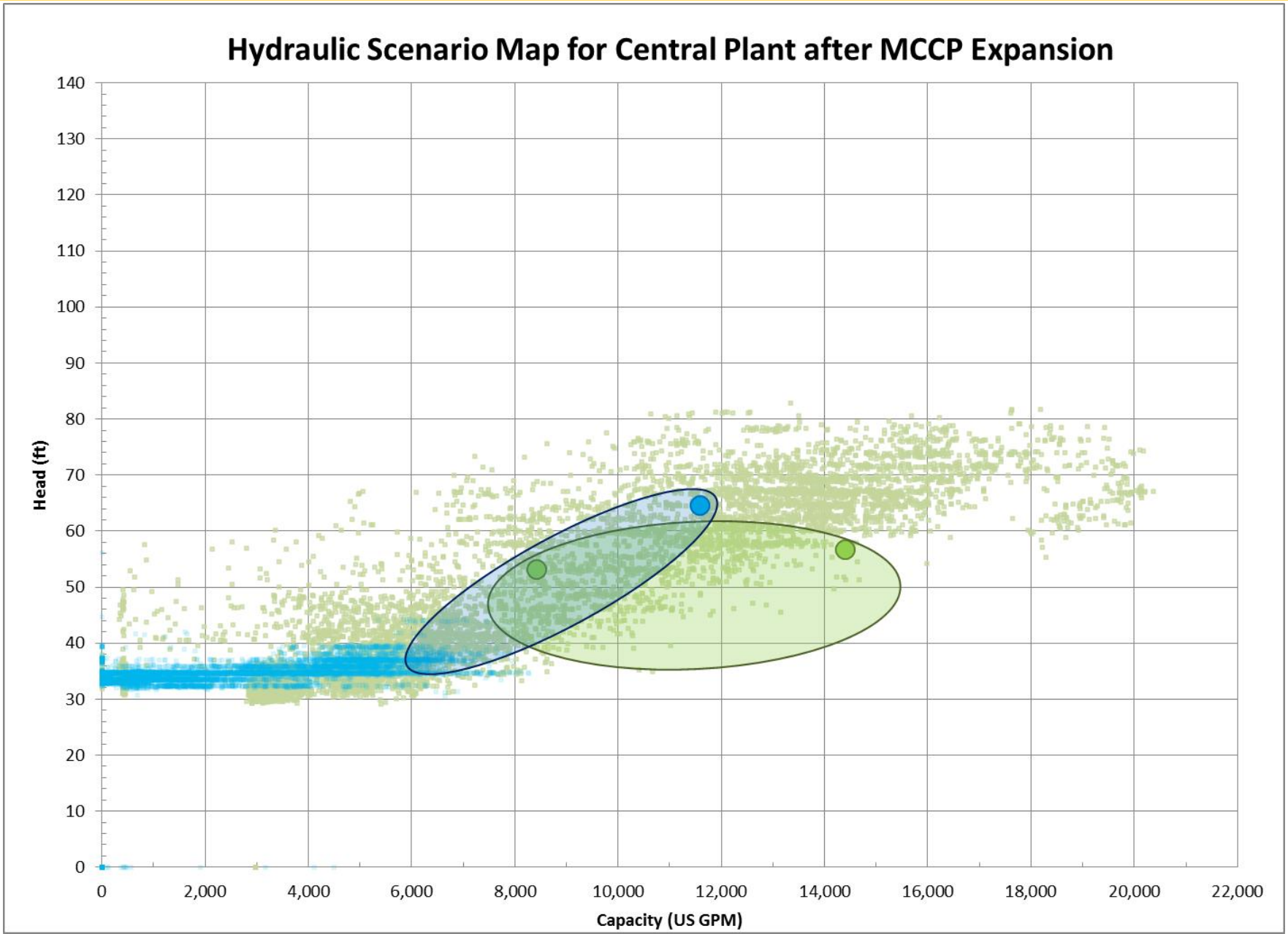

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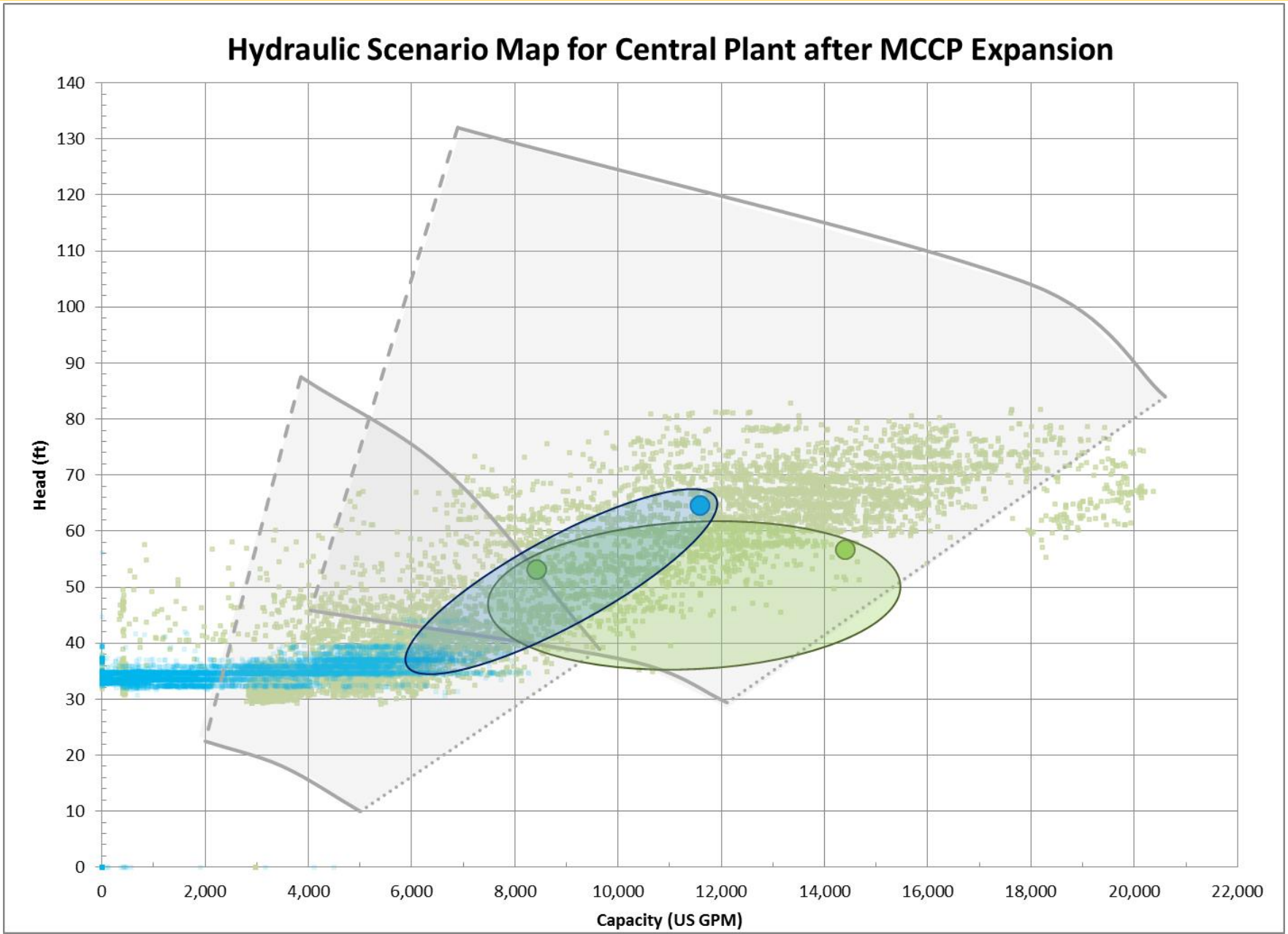

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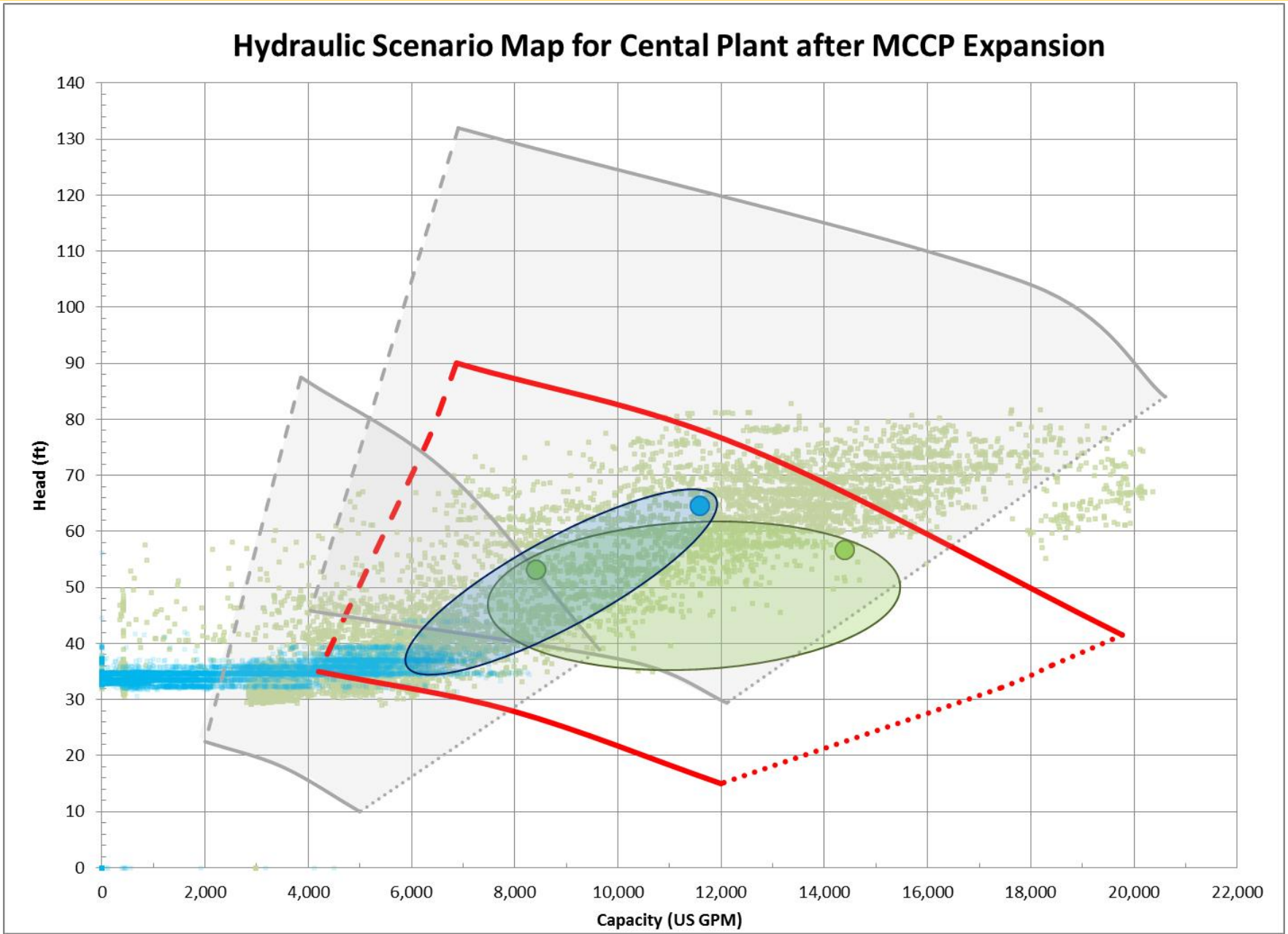
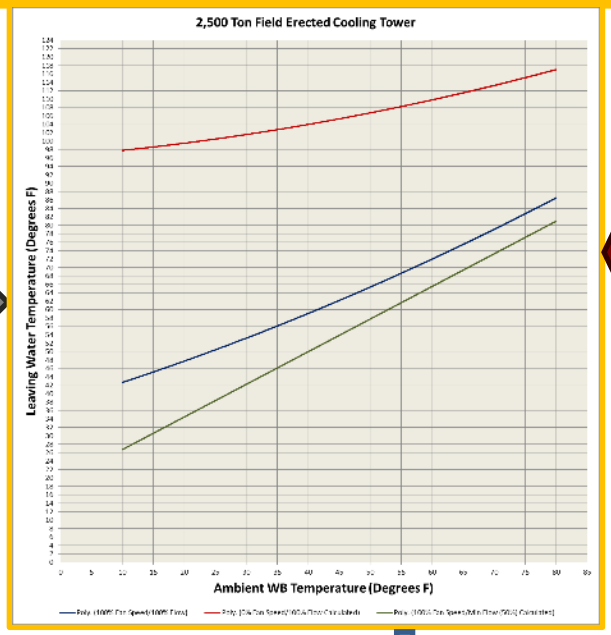


Chiller Plant Analysis – Chilled Water Model

Hourly Ambient WB Temperature Data



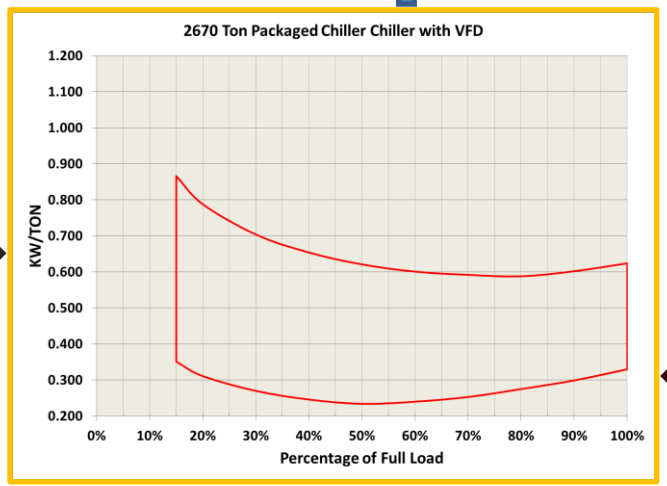
- CT Leaving Water Temperature Set Points
- VFD Driven Cooling Tower Fan / WB Following

Chiller and Condenser Water Pump Operation

Annual Plant Electrical Energy Consumed/Cost

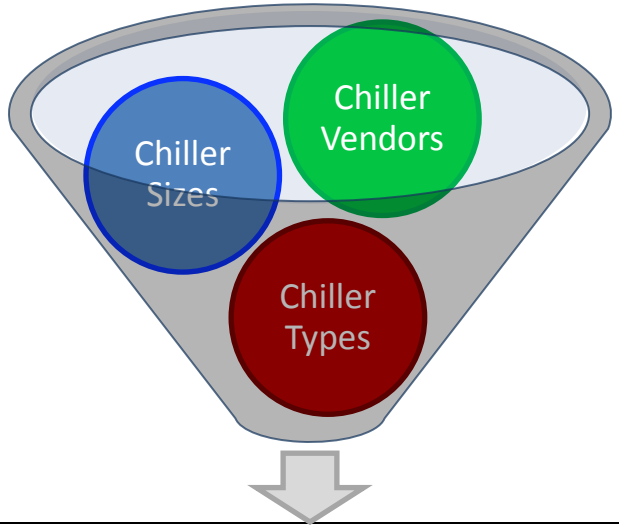
Annual Plant Water Consumption/Cost

Hourly Campus CHW Load Data



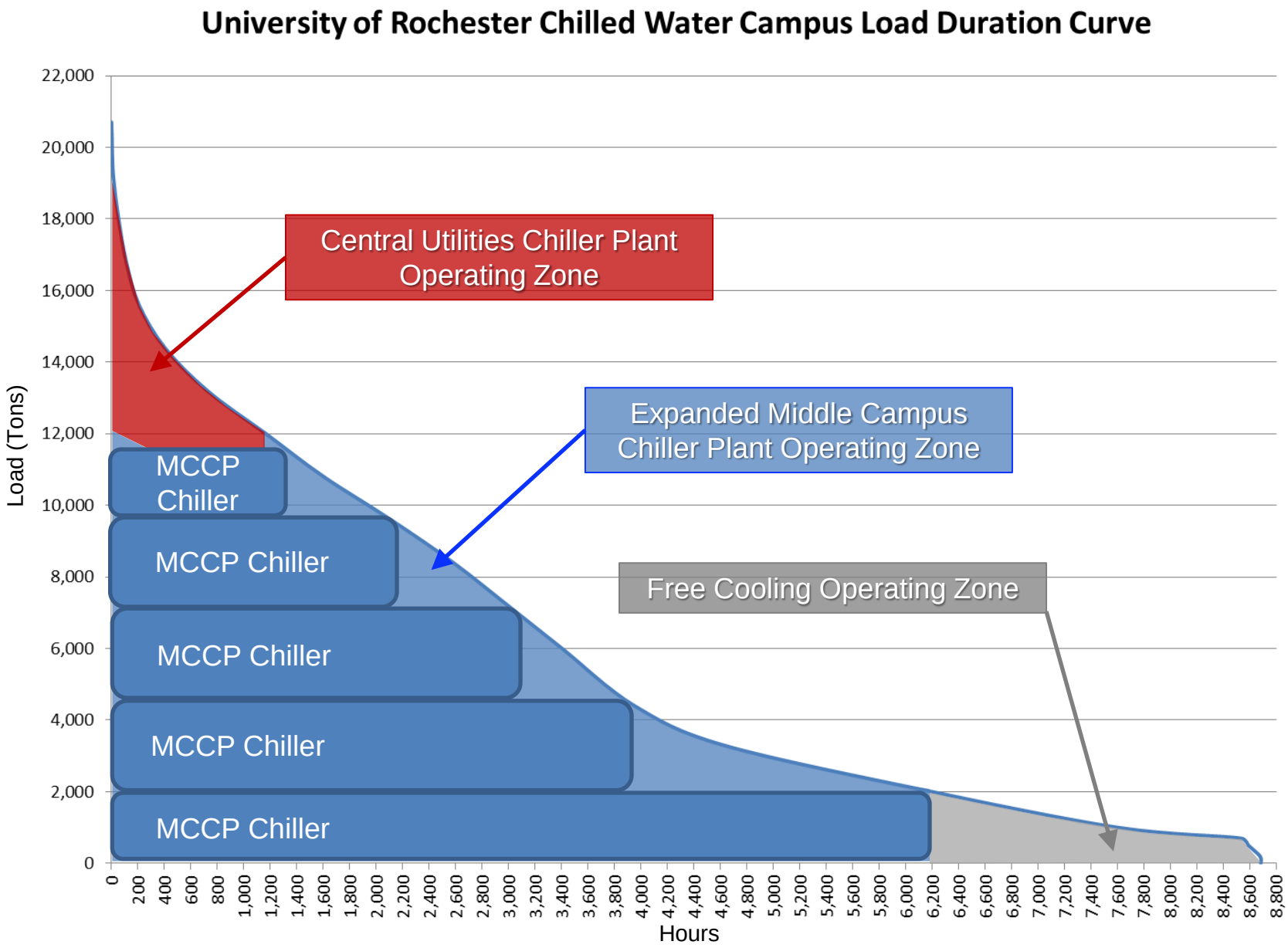
Chiller Staging

Chiller Plant Analysis - Options Analysis



Criteria	Vendor A Options								
	1	2	3	4	4A	4B	5	5A	6
Option Description	Three 2,670 Ton Chillers with Starters	Three 2,670 Ton Chillers with VFDs	Three 2,670 Ton Chillers - One Starter/Two with VFDs	Two 4,000 Ton Packaged Chillers with Starters	Two 4,000 Ton Chillers with Starters and X-CH-6 Retrofit	Two 5,00 Ton Packaged Chillers With Starters	One 5,600 Ton Packaged Chiller with Starter and One 2400 Ton Chiller wth VFD	One 5,600 Ton PackagedChiller with Starter and One 2,400 Ton Chiller VFD and X-CH-6 VFD Retrofit	Four 2,000 Ton Series Counterflow Chillers with VFDs
Number of Chillers	3	3	3	2	2	2	2	2	2(4)
Total New Chiller Tons	8,010	8,010	8,010	8,000	8,000	10,000	8,000	8,000	8,000
Total New Chiller Tons on VFD	0	8,010	5,340	0	0	0	2,400	2,400	8,000
Total Plant Firm Capacity	9,340	9,340	9,340	8,000	8,000	9,000	6,400	6,400	10,000
Total MCCP Tons on VFD	2,000	10,010	7,340	2,000	4,000	2,000	4,400	6,400	10,000
Total MCCP Tons	12,010	12,010	12,010	12,000	12,000	14,000	12,000	12,000	12,000
Relative First Cost - Mech.	$ 8,600,000	$ 9,600,000	$ 9,200,000	$ 9,200,000	$ 9,500,000	$ 10,600,000	$ 9,200,000	$ 9,500,000	$ 10,700,000
Relative First Cost - Elec. Opt A	$1,500,000	$1,500,000	$1,500,000	$1,600,000	$1,600,000	$1,500,000	$1,500,000	$1,500,000	$1,900,000
Total Relative First Cost	$ 10,100,000	$ 11,100,000	$ 10,700,000	$ 10,800,000	$ 11,100,000	$ 12,100,000	$ 10,700,000	$ 11,000,000	$ 12,600,000
Chiller Fit	Fair	Fair	Fair	Good	Good	Good	Good	Good	Poor
Option Relative Cost $/Ton	$ 1,261	$ 1,386	$ 1,336	$ 1,350	$ 1,388	$ 1,210	$ 1,338	$ 1,375	$ 1,575
Annual Energy Cost	$ 2,161,932	$ 1,964,037	$ 1,992,602	$ 2,218,769	$ 2,062,671	$ 2,446,770	$ 2,056,630	$ 2,026,942	$ 1,909,791
25 YR Net Present Cost	$46,704,229	$44,895,737	$44,827,765	$48,707,908	$46,583,337	$54,207,751	$46,085,754	$45,906,199	$46,292,261

Chiller Plant Analysis - Options Analysis



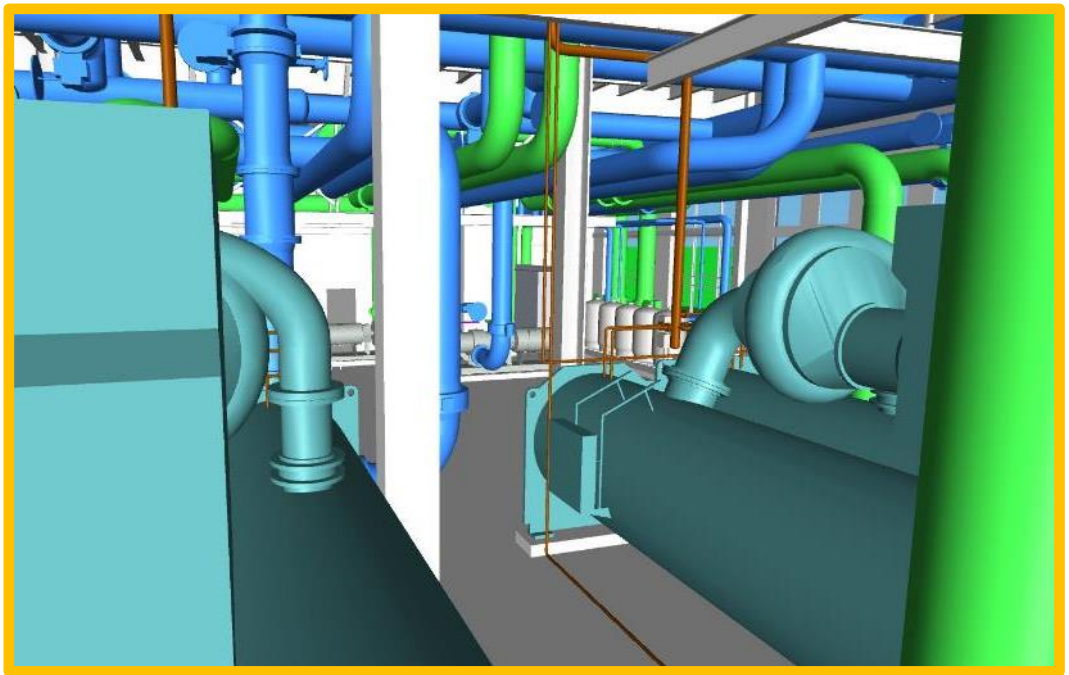
Measured Data – Comparison to System Model

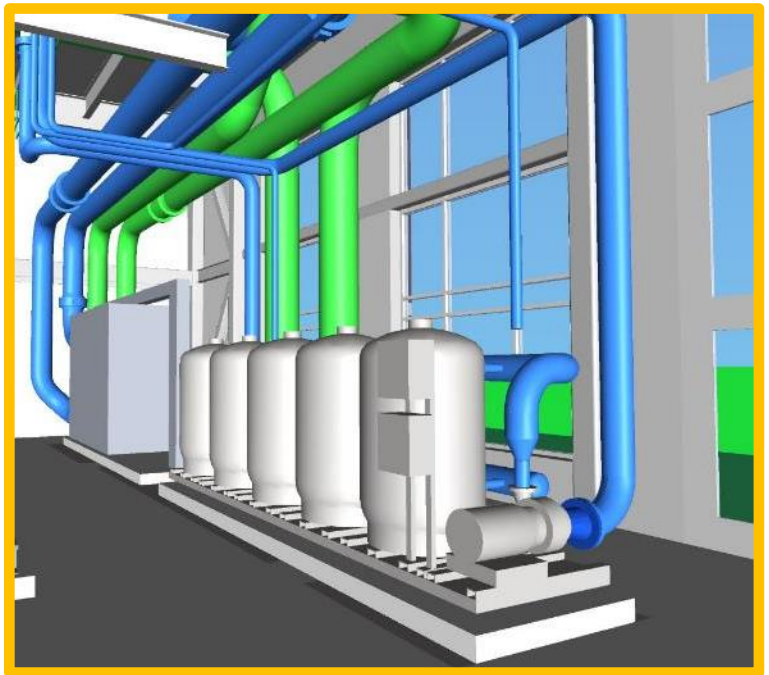
- Measured Hourly Data Started July 2015
- Model Normally Predicts Chiller kW/ton 2 - 4% Higher than Actual
  - Some conservativism in vendor provided chiller efficiencies
  - More variance with VFD driven Chillers
- Average Accuracy of Chiller operating Curves +/- 2%

MCCP Summer and Fall Operation (July 15 to Oct 31) - Measured VS Modeled						
	Chiller #8		Chiller #9		Chiller #10	
	Measured	Modeled	Measured	Modeled	Measured	Modeled
kW/ton	0.477	0.501	0.562	0.573	0.423	0.478
Deviation (kW/ton)	-0.024		-0.011		-0.055	
Deviation (%)	-5.0%		-2.0%		-13.0%	

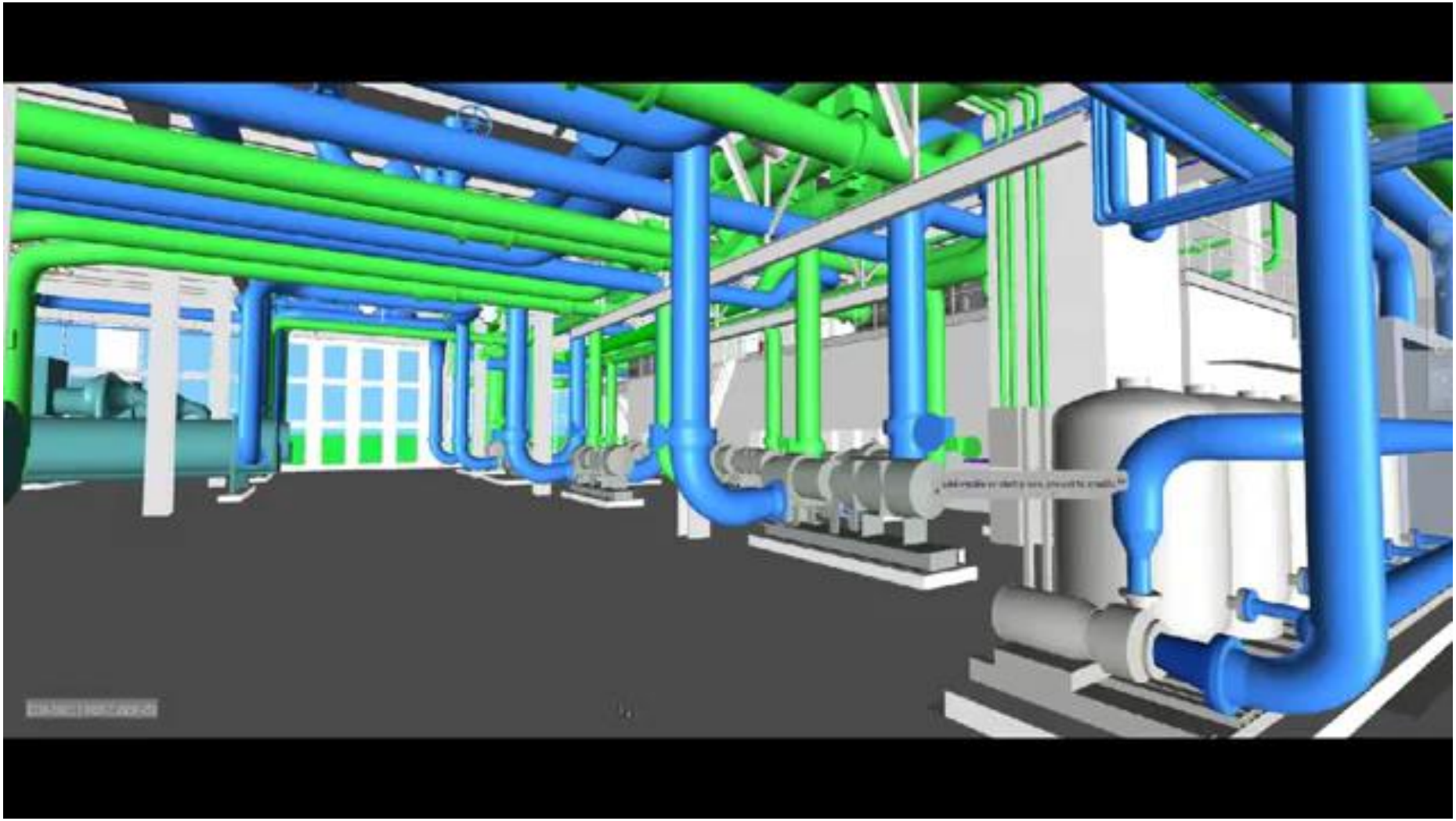
MCCP Peak Summertime Operation (Peak Day - July 28th) - Measured VS Modeled						
	Chiller #8		Chiller #9		Chiller #10	
	Measured	Modeled	Measured	Modeled	Measured	Modeled
kW/ton	N/A Not Operating		0.591	0.580	0.472	0.503
Deviation (kW/ton)			0.011		-0.031	
Deviation (%)			1.9%		-6.6%	

Chiller Plant Analysis – Equipment Layout





Chiller Plant Analysis – Equipment Layout



Chiller Plant Analysis – Equipment Layout

Chiller Plant Analysis – Equipment Layout

Additional Features at MCCP

- Plate and Frame Heat Exchanger for Winter Free Cooling - 2,000 Tons
  - Dedicated Cooling Tower Basins (4 of 6) for Free Cooling Temperatures
  - CU Chillers – Free Cooling with Vapor Migration
  - Allows for Maintenance to be Performed on CU
- Chlorine Dioxide Unit for Chilled Water System Disinfection
- Side Stream Sand Filters for Tower Water
- Added Piping Provisions for Future Chilled Water Thermal Storage (24” Dia. Supply & Return)

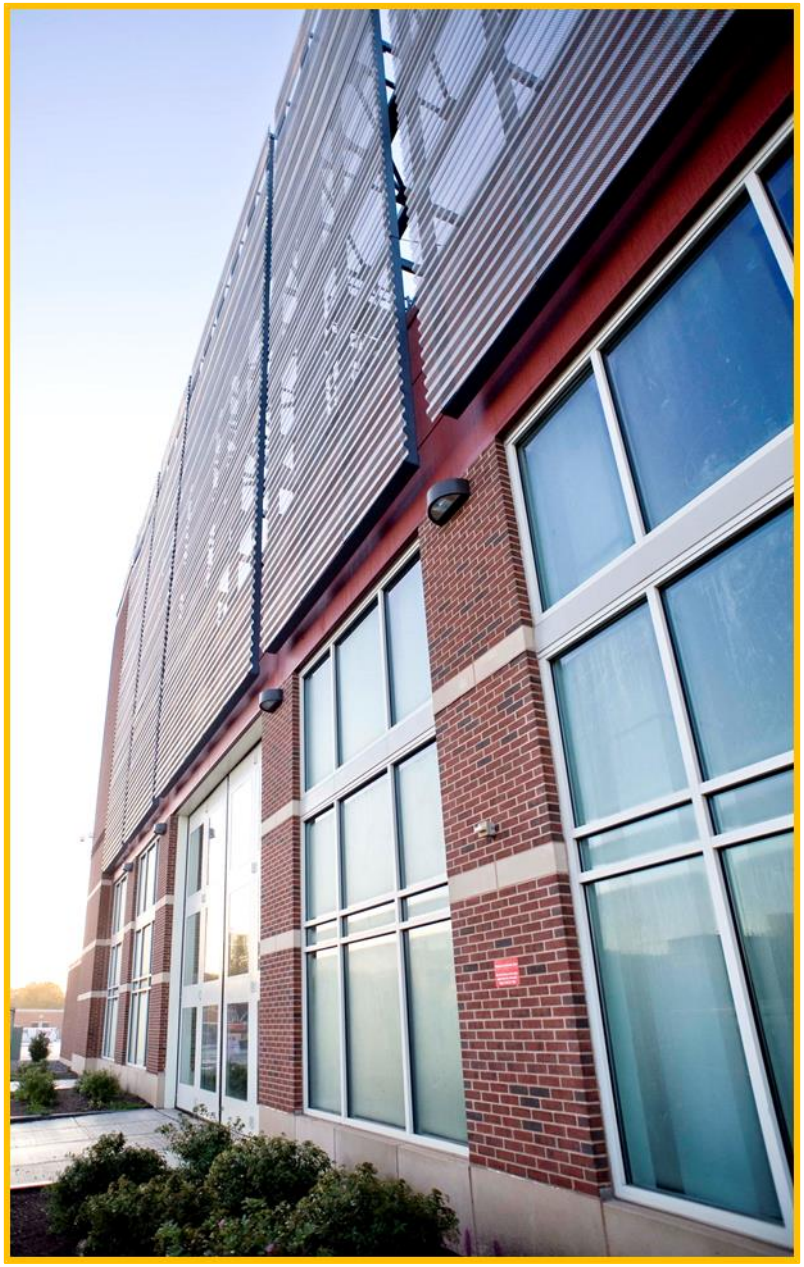
Additional Features at MCCP

Lessons Learned

- Owner Direct Procurement of New Chillers, Pumps, Drives, Electrical Switchgear saved Time and Money
- Allow for Controls System Flexibility in Dispatching Chillers
- Integration of a new Primary Pump Plant with an Existing Primary/Secondary Pump Plant
- With Primary Pumping – Controls Sequencing to Bring on Additional Chilled Water Pumps as Load/Flow Increases
- Time Frame for New Piping Chemical Cleaning and Flushing was extensive, Contractor not prepared
- Take the Required Time to Fully Commission Plant
- New 10 MVA, 11.5 KV Transformer Failed on Initial Start Up, Possible Harmonic Transients, Retrofitted with R.C. Snubber

What is Next?

- NYSERDA Rebate
  - Super Efficient Chiller Bonus
  - $605,000 Rebate Delivered
  - Additional $404,000 Expected after M&V
- Chilled Water Energy Dashboard Graphics
- Upgrade Chiller 4 Steam Turbine Drive & Controls
- New Cooling Tower at Central Plant
- Thermal Energy Storage System
  - Electrical Demand Charges Increasing



Questions?