



TVA Hydro Plant Monitoring & Optimization System

WaterView

1

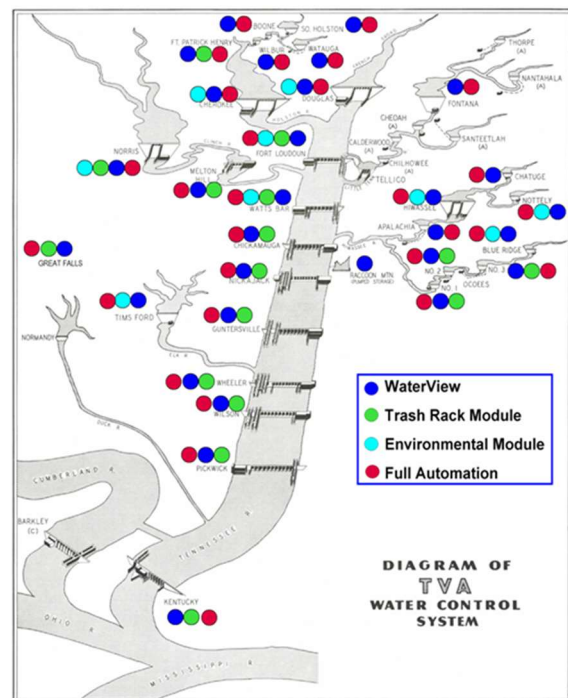
TVA Hydro Power System and WaterView Installations

TVA Hydro Power System

- 30 Hydro Power Projects
 - 20 Tributary Plants
 - 9 Main River Plants
 - 1 Pumped Storage Plant
- 113 Total Units
- 5,500 MW of Capacity
- 15,000 GWh of Energy

WaterView Installations

- 30 WaterView Systems
 - 29 Plants Fully Automated and Optimized
 - 14 Plants with Trash Rack Monitoring
 - 9 Plants with Environmental Monitoring & Control



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Hydro System Tools and Their Integration

System Level Optimization

1. Riverware (System Level Optimization & Scheduling)

Plant Level Optimization

1. WaterView Hydro Plant Monitoring and Optimization System (plant level optimization)
2. MEL/MSL Calculator Tool (spreadsheet of unit power and efficiency data over the entire range of operating heads)
3. HYPAS - Hydroturbine Performance Assessment System (automate process for generating new operating characteristics)
4. DataWolff Fleetwide Data Analysis System (fleetwide analysis for correlating measured and expected efficiencies for troubleshooting and setting testing priorities)

Troubleshooting Tools

1. DatAWare Data Historian Client Tool (applications for trending, dashboards, analytics, and ad-hoc troubleshooting)
2. PRiSM (advanced pattern recognition system for anomaly detection)
3. River Forecast Center WaterView Alarm Summary



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WaterView

TVA's Hydro plant monitoring and optimization system designed to...

- Increase efficiency, generation, and revenue
- Improve operating reliability
- Improve environmental compliance
- Reduce intake fouling losses
- Reduce maintenance costs
- Provide data for analysis, forecasting, and scheduling
- Improve business performance indicators

WaterView System Summary

WaterView - [TVASystem Main Summary]

File Views Options Tools Window Help

Data Re Opt

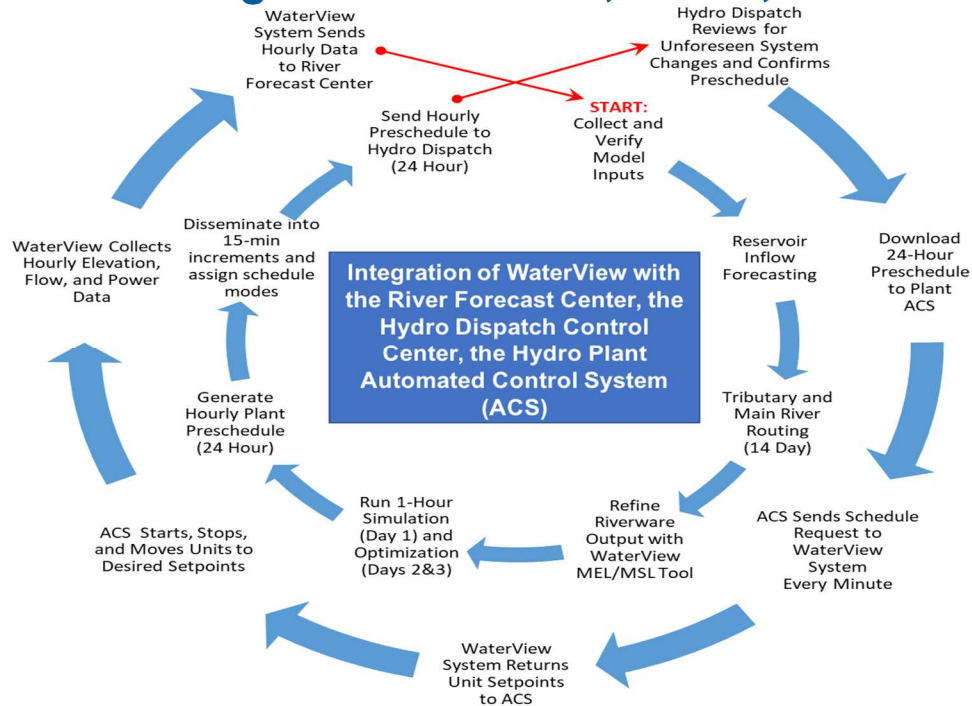
Total Hydro Generation (MW)	2,100		Total Hydro Spinning Reserve (MW)	367											
	South Holston	Watauga	Wilbur	Boone	Ft Patrick Henry	Cherokee	Douglas	Fontana	Chatuge	Nettely					
	12:44:46	12:44:46	12:44:46	12:44:45	12:44:45	12:44:49	12:44:47	12:44:47	12:44:45	12:44:45					
Headwater (ft)	1,719.20	1,951.66	1,648.58	1,353.08	1,261.11	1,057.53	982.17	1,688.86	1,921.51	1,768.83					
Aux Headwater (ft)	1,719.27	1,951.84	1,648.58	1,353.02	1,261.06	1,057.23	982.17	1,688.76	1,921.36	1,768.54					
Tailwater (ft)	1,487.59	1,648.73	1,583.15	1,261.18	1,186.59	923.84	875.11	1,279.56	1,802.99	1,611.46					
Gross Head (ft)	231.6	302.9	65.4	91.9	74.5	133.7	107.1	409.3	118.5	157.2					
Power (MW)	0.0	-1.9	0.0	-0.6	-0.3	34.4	110.0	193.7	-0.3	15.8					
Flowrate (cfs)	0	0	0	0	0	3,697	13,921	6,161	0	1,384					
Spill Flow (cfs)	1,200	0	245	0	0	0	0	0	0	0					
Spinning Reserve (MW)	0.0	39.2	0.0	28.1	22.4	0.0	21.6	2.2	14.5	3.2					
	Hiwassee	Apalachia	Blue Ridge	Ocoee 3	Ocoee 2	Ocoee 1	Norris	Melton Hill	Fort Loudoun	Watts Bar					
	12:44:45	12:44:45	12:44:47	12:44:47	12:44:45	12:44:45	12:44:45	12:44:46	12:44:41	12:44:48					
Headwater (ft)	1,506.96	1,275.65	1,679.51	1,433.11	1,096.17	828.36	1,007.66	793.31	812.90	740.61					
Aux Headwater (ft)	1,506.97	1,275.16	1,679.58	1,433.01	N/A	828.45	1,007.35	793.29	812.90	740.80					
Tailwater (ft)	1,276.95	840.55	1,540.65	1,118.49	834.66	714.86	826.83	740.70	742.58	682.61					
Gross Head (ft)	230.0	435.1	138.9	314.6	261.5	113.5	180.8	52.6	70.3	58.0					
Power (MW)	142.5	75.6	0.6	22.8	16.5	5.1	93.6	0.0	151.1	113.3					
Flowrate (cfs)	8,139	2,810	152	1,039	852	669	6,705	0	29,187	25,106					
Spill Flow (cfs)	0	25	0	0	564	0	0	3,530	0	0					
Spinning Reserve (MW)	19.7	9.4	17.5	6.1	6.9	0.0	18.4	0.0	0.1	85.2					
	Chickamauga	Raccoon Mountain	Nickajack	Guntersville	Tims Ford	Wheeler	Wilson	Pickwick	Kentucky	Great Falls					
	12:44:44	12:46:53	12:44:46	12:44:45	12:44:44	12:44:48	12:44:45	12:44:46	12:44:46	12:44:44					
Headwater (ft)	681.42	1,660.59	632.86	594.49	888.06	554.79	507.19	412.63	355.32	800.33					
Aux Headwater (ft)	681.41		632.85	594.46	888.09	554.69	507.33	412.51	355.24	800.17					
Tailwater (ft)	635.74	633.36	596.53	557.26	745.52	507.20	415.63	358.77	302.81	652.91					
Gross Head (ft)	45.7	1,027.2	36.3	37.2	142.5	47.6	91.6	53.9	52.5	147.4					
Power (MW)	111.2	819.0	90.5	94.6	0.0	142.1	343.3	224.4	122.1	-0.3					
Flowrate (cfs)	35,479	10,387	35,269	34,591	0	42,033	47,885	61,127	31,323	0					
Spill Flow (cfs)	0	0	0	0	850	0	0	0	0	0					
Spinning Reserve (MW)	0.2	0.0	12.7	0.4	0.0	3.8	7.5	0.9	47.3	0.0					

Datagram Main 9:18:2017 12:46:53 1 Unit

Data received 13:44:50. Waiting for data...

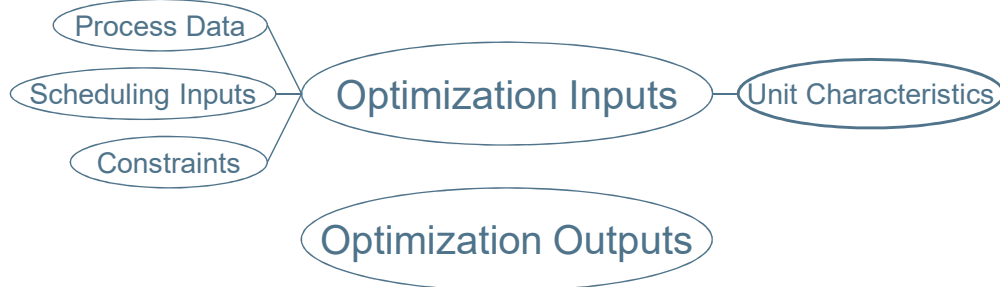
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WaterView Integration with RFC, HDCC, and Plant ACS



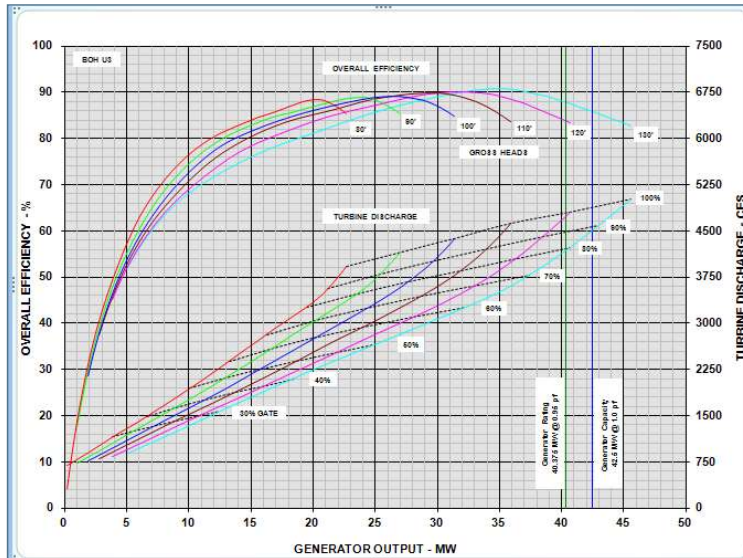
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WaterView Real-Time Plant Optimization



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WaterView Real-Time Plant Optimization



Unit Characteristics



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WaterView Real-Time Plant Optimization

Process Data

Plant and Unit Operating Data

- Headwater
- Tailwater
- Unit Power
- Unit Flow
- Unit Running Status
- Others

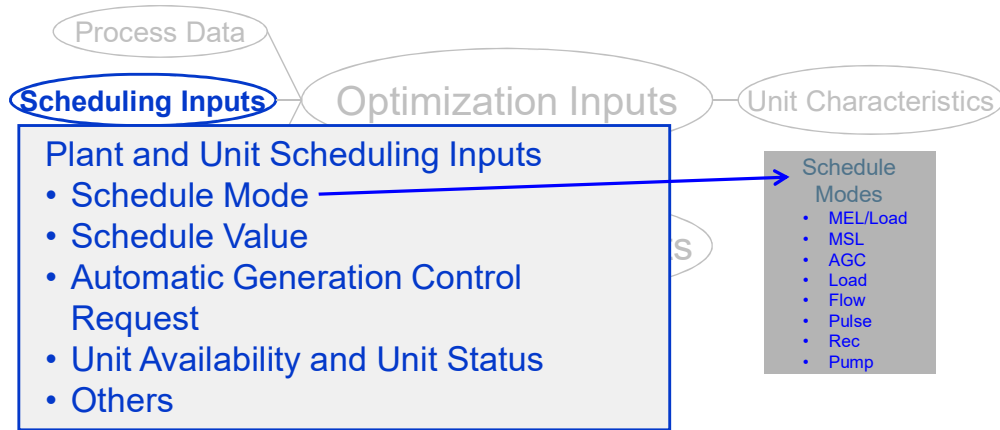
Plant Elevations				Plant Totals	
HeadWater (ft)	1,006.61	Power (MW)		94.6	
Aux HeadWater (ft)	1,006.56	Flowrate (cfs)		6,880	
TailWater (ft)	826.84	Plant Efficiency (%)		92.51	
Gross Head (ft)	179.77	Plant Reactive (MVAR)		-23.8	
Gross Head Avg (ft)	N/A	Station Service (MW)		0.14	
		Unit 1	Unit 2		
Gate Opening (%)		64.9	66.7		
Flowrate (cfs)		3,452	3,428		
Power (MW)		47.8	46.8		
Reactive Power (MVAR)		-11.4	-12.4		
Exciter Current (Amp)		491	476		
Measured Efficiency (%)		91.3	89.9		
Unit Char. Efficiency (%)		93.3	91.7		
Peak Efficiency Power (MW)		47.0	46.6		
Off-Peak Eff Loss (%)		0.0	0.0		
Off-Peak Eff Cost (\$/mo)		100	0		
Spinning Reserve (MW)		11.4	11.2		
WG Servo Pressure (psi)		73.8	155.1		
Water Temperature (C)		9.1	8.6		
AE Cavitation Level (mV)		0	0		
GG Bearing VibX US (mils)		5.3	3.5		
GG Bearing VibY I (mils)		5.5	2.9		
TG Bearing VibX US (mils)		2.8	3.8		
TG Bearing VibY I (mils)		2.7	3.3		

Diagram Main 10-16-2012 10:12:50 1 2 Unit
Data received 11:12:54. Waiting for data...



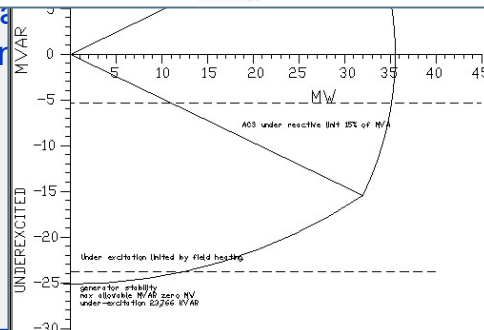
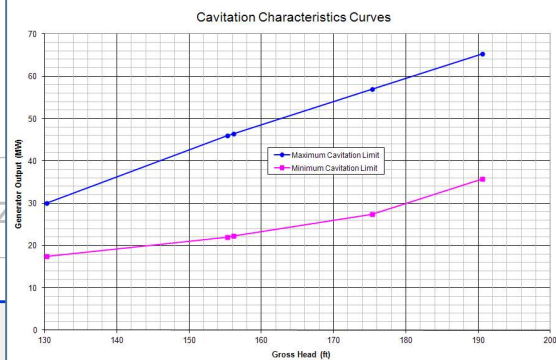
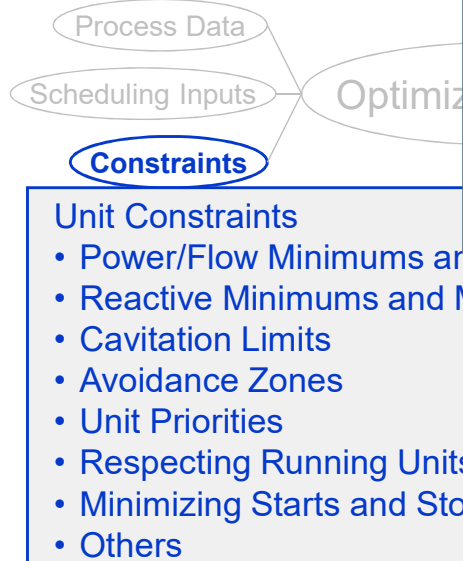
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WaterView Real-Time Plant Optimization



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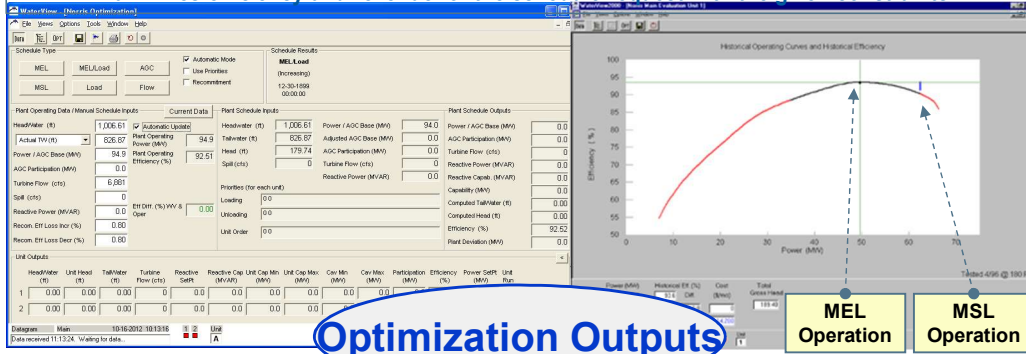
WaterView Real-Time Plant Optimization



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WaterView Real-Time Plant Optimization

Maximizes efficiency and revenue for the schedule request with the given constraints.



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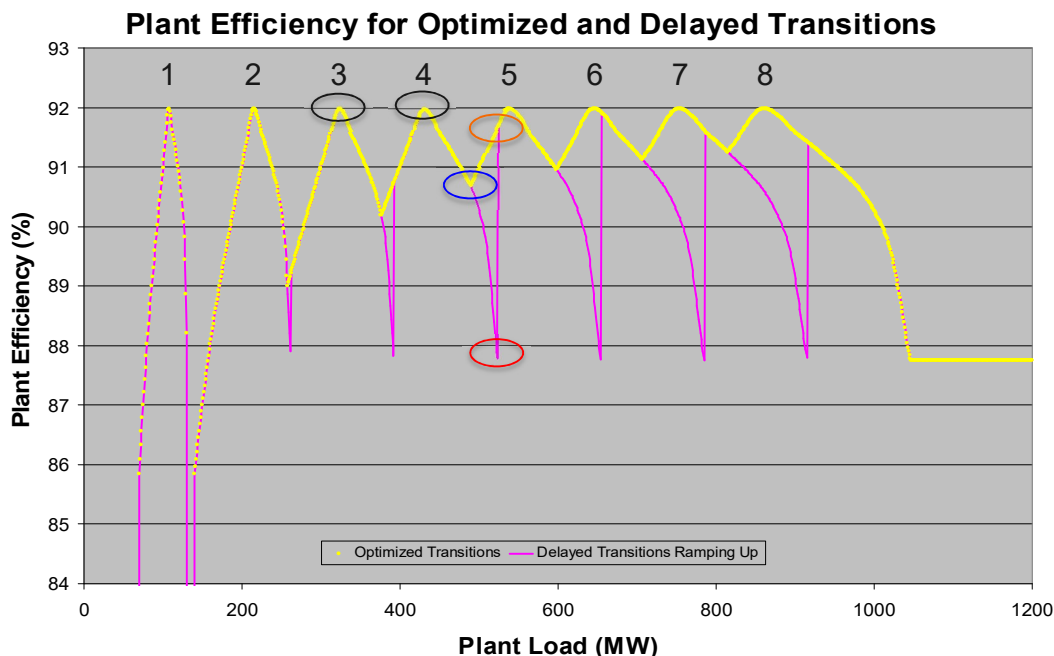
MEL/MSL Calculator for Refining Preschedule

TVA Hydro Plant MEL & MSL Calculator										FOR INTERNAL TVA USE ONLY										HT-CHH		HT-GUH										
Refresh																								Preschedule								
		09/18/2017 12:00:39				Unit Availability: 1 = Available 0 = Unavailable																										
Plant	Max Cap	Gross Head	Head	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	MEL	MSL	MSL Flow	MEL	MSL	Plant		
APH	85.3	437.5	356.0	1	1																				76.4	88.8	3394	75	78	APH		
BOH	55.3	89.3	89.0	0	1	1																			47.1	52.4	8116	44	55	BOH		
BRH	16.9	129.4	129.0	1																					13.7	15.0	1717	14	15	BRH		
CHH	112.7	43.7	43.5	1	1	1	1																		84.0	142.4	46845	82	124	CHH		
CRH	108.0	123.5	123.0	1	1	1	1																		112.3	114.1	13249	108	112	CRH		
CTH	14.1	114.9	114.5	1																					11.5	13.6	1415	11	13	CTH		
DGH	178.0	86.0	85.0	1	1	1	1	1																	109.4	123.7	21917	109	124	DGH		
FLH	150.0	72.1	72.0	1	1	1	1	1																	124.4	152.2	28287	120	152	FLH		
FNH	294.0	380.5	380.0	1	1	1																			266.2	309.0	10533	261	294	FNH		
FPH	44.2	67.4	67.0	1	1																				27.1	43.9	9237	33	431	FPH		
GFH	14.1	132.9	132.5	1	1																				26.3	30.7	3599	26	29	GFH		
GUH	94.9	40.9	40.5	1	1	1	1	0																	56.8	101.6	34980	77	127	GUH		
HIH	163.3	208.2	208.0	1	1																				124.8	139.2	9008	124	138	HIH		
KYH	211.5	54.6	54.0	1	1	1	1	1	1																142.5	226.0	58904	84	126	KYH		
MHH	0.0	54.1	54.0	0	0																				0.0	0.0	0	23	40	MHH		
NJH	105.7	39.0	38.5	1	1	1	1	1																	89.2	113.8	41127	86	113	NJH		
NOH	113.5	175.5	175.0	1	1																				90.8	111.2	8417	90	109	NOH		
NTH	19.0	154.8	154.0	1																					15.3	19.0	1746	15	19	NTH		
O1H	25.4	115.6	115.5	1	1	1	1	1	1																27.0	27.0	3505	24	25	O1H		
O2H	23.4	262.5	260.0	1	1																				20.3	23.4	1232	20	23	O2H		
O3H	28.8	315.9	315.5	1																					22.7	29.0	1483	0	0	O3H		
PKH	225.0	53.7	53.0	1	1	0	1	1	1	1															185.5	225.0	58423	201	224	PKH		
RPS	0.0	1020.8	1020.0	1	1	1	1	1																	1577.3	1660.8	20991			RPS		
SHH	0.0	224.0	224.0	0																					0.0	0.0	0	41	42	SHH		
TFH	40.8	134.8	134.0	1																					38.2	38.6	3812	37	38	TFH		
WBH	198.9	58.6	58.5	1	1	1	1	1	1																115.0	204.5	47250	112	186	WBH		
WEH	321.9	45.8	45.5	1	1	1	0	1	1	1	1	1	1	1	1										335.6	349.5	112799	331	336	WEH		
WIH	7.8	65.8	65.5	0	0	0	1																		7.3	7.8	1656	7	8	WIH		
WLH	472.2	93.4	93.0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	472.0	475.1	68013	464	503	WLH	
WTH	66.2	304.5	296.0	1	1																				60.3	66.3	2942	30	31	WTH		
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21								
Notes																														AGC		



12

Optimized for Peak Efficiency and Unit Transitions



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7 Types of Optimization

Optimized for:

1. Plant Schedule Requests (knowing the best plant loads to request to operate at peaks instead of in valleys) *O1*
2. Unit Selection (selection of more efficient units) *O2*
3. Unit Setpoints (plant level optimization using direct search, reduced gradient, and heuristic methodologies) *O3*
4. Continuous Head Changes (re-optimize on a 1-minute basis) *O4*
5. Unit Transitions (ideal unit loading and unloading transitions) *O5*
6. Reduced Damage (operating within safe limits to minimize mechanical and electrical damage to units) *O6*
7. Reduced Wear and Tear (minimizing starts/stops by respecting running units and utilizing unit priorities)

Result:

Increased plant efficiency, generation, revenue, and reliability.

Reduced maintenance cost and wear & tear on the units.



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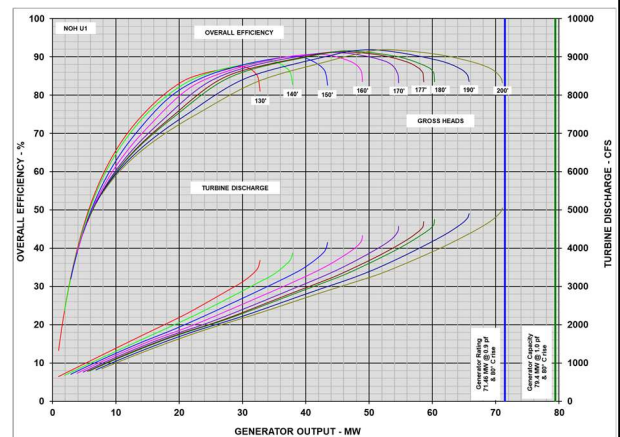
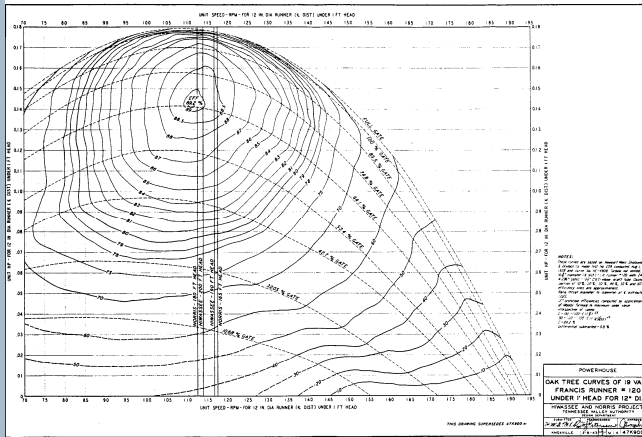
Hydroturbine Performance Assessment System

- Excel-based automated curve generation system
- Scales up physical model data from turbine manufacturer to prototype curves
- Adjusts prototype curves to reflect performance test results
- Defines true performance of the hydroturbine over the full range of operating heads

Physical Model Data



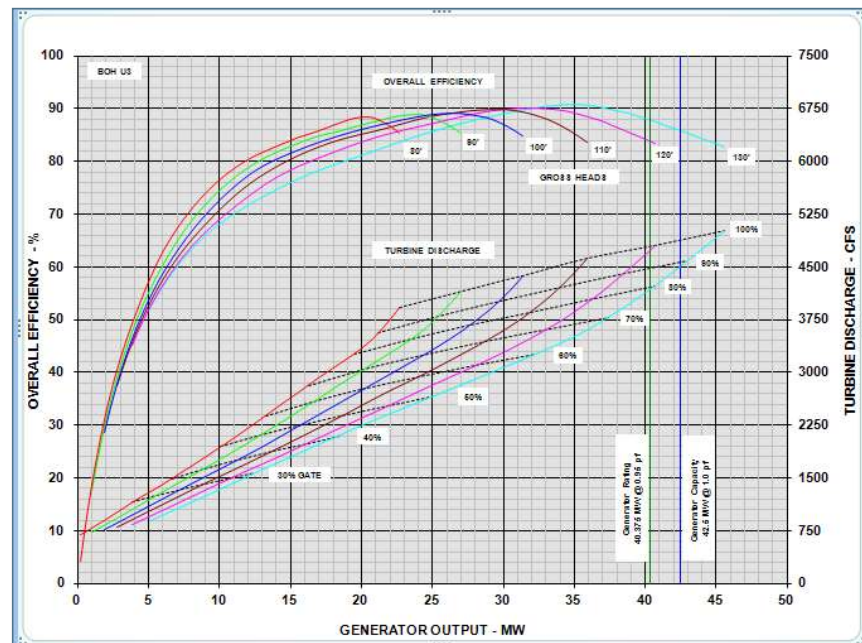
Test-Adjusted Characteristics



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Individual Unit Operating Characteristics for WaterView Optimization

- Head, flow, power, and efficiency data for each of the 113 hydro units at TVA
- Provide the expected unit performance under any operating conditions
- Indicate the MIN and MAX safe operating limits and the peak efficiency (MEL) for any head condition
- Utilized in WaterView optimization systems
- The curves do change over time due to equipment upgrades and unit degradation
- Accuracy of the curves is continuously evaluated

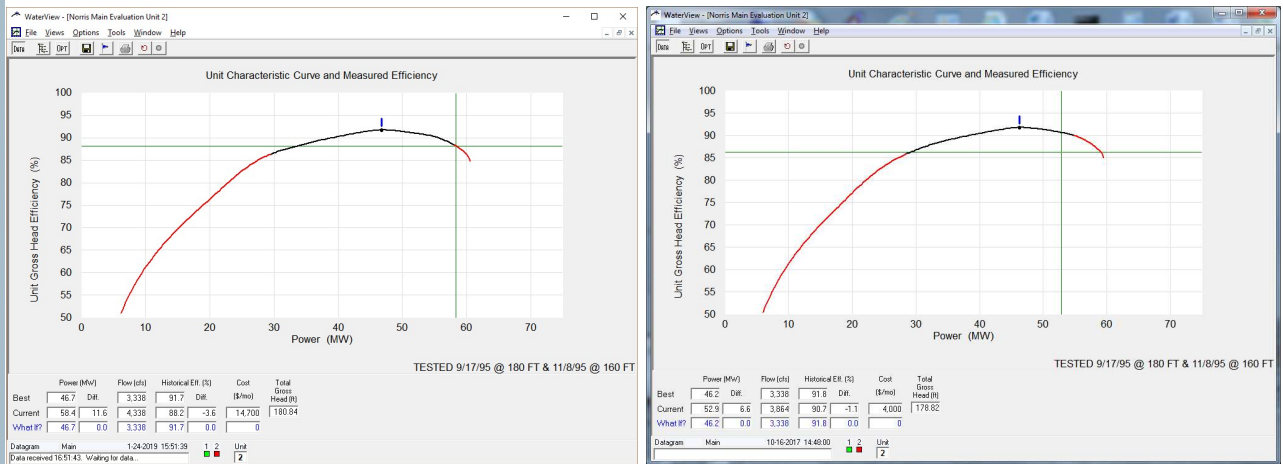


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DataWolff Efficiency Correlation Analysis System

Evaluates how well the existing operating characteristics correlate with the measured plant performance data

1. Identify measurement problems with plant instrumentation
2. Identify operational issues
3. Define testing priorities based on accuracy of the curves and energy production of the unit



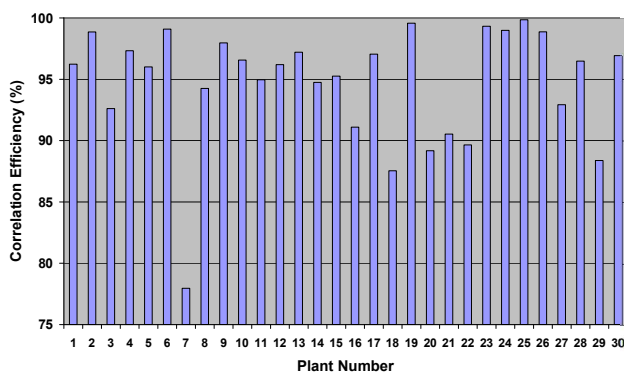
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DataWolff Efficiency Correlation Analysis System

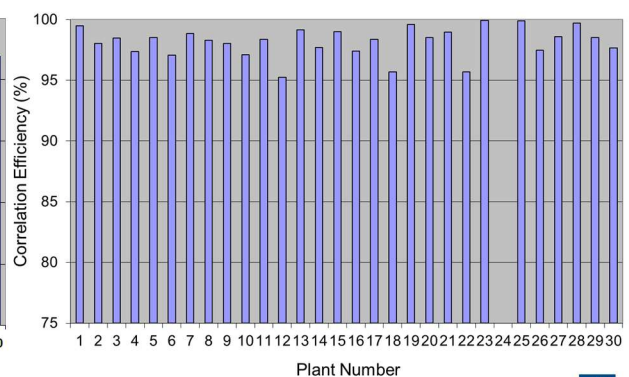
Evaluates how well the existing operating characteristics correlate with the measured plant performance data

1. Identify measurement problems with plant instrumentation
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3. Define testing priorities based on accuracy of the curves and energy production of the unit

2005 TVA System Correlation Efficiency (93.5%)

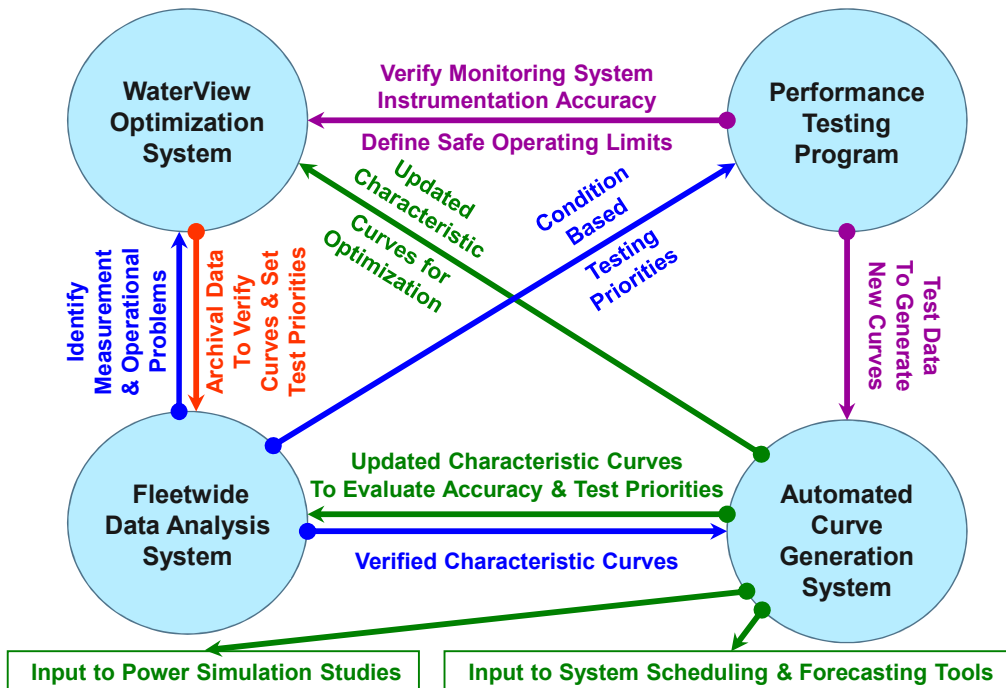


2018 TVA System Correlation Efficiency (98.14%)



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Maintaining Accurate Operating Characteristics for Optimization

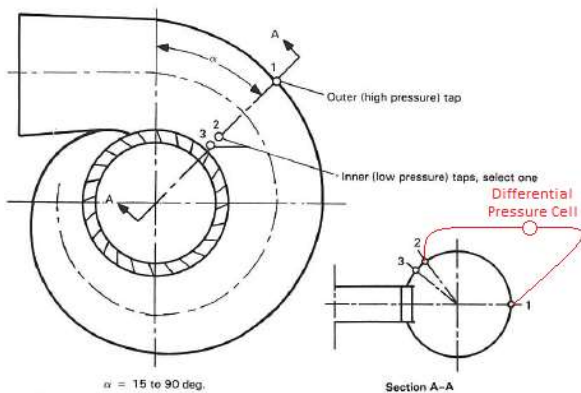


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Flow Measurement Using Winter-Kennedy Taps

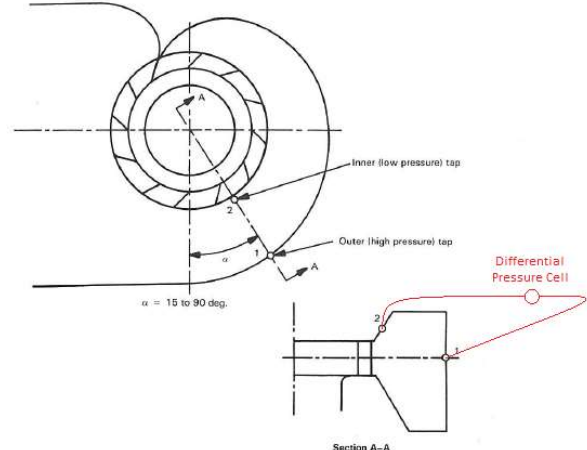
- Measured flow is a function of the differential pressure between the piezometer taps
- Accurate flow measurement depends on a uniform flow pattern
- Accurate flow is needed to measure the true performance of the hydroturbine

Francis Type Turbine



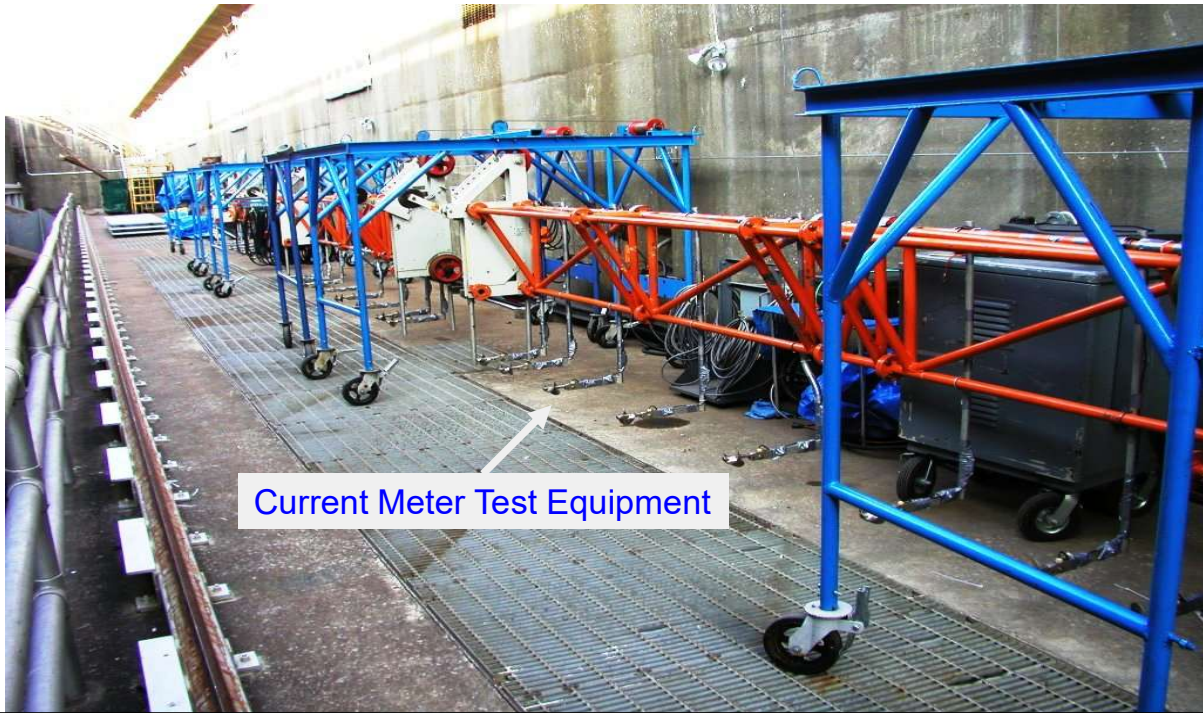
LOCATION OF WINTER-KENNEDY PRESSURE TAPS IN SPIRAL CASE

Kaplan Type Turbine



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Absolute Flow Measurement Using Current Meters



Current Meter Test Equipment



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Keys for Success

1. System level scheduling and optimization (Riverware and MEL/MSL Calculator)
2. Real-time plant optimization (WaterView)
3. Maintaining accurate operating characteristics for optimization (HYPAS and DataWolff)
4. Turbine flow measurement for tracking unit performance (calibrated W-K Taps)
5. Integration of systems and tools
6. Troubleshooting tools for detecting and resolving problems (DataWare and PRiSM)
7. Focus on continuous improvement

Questions?



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Troubleshooting Tools

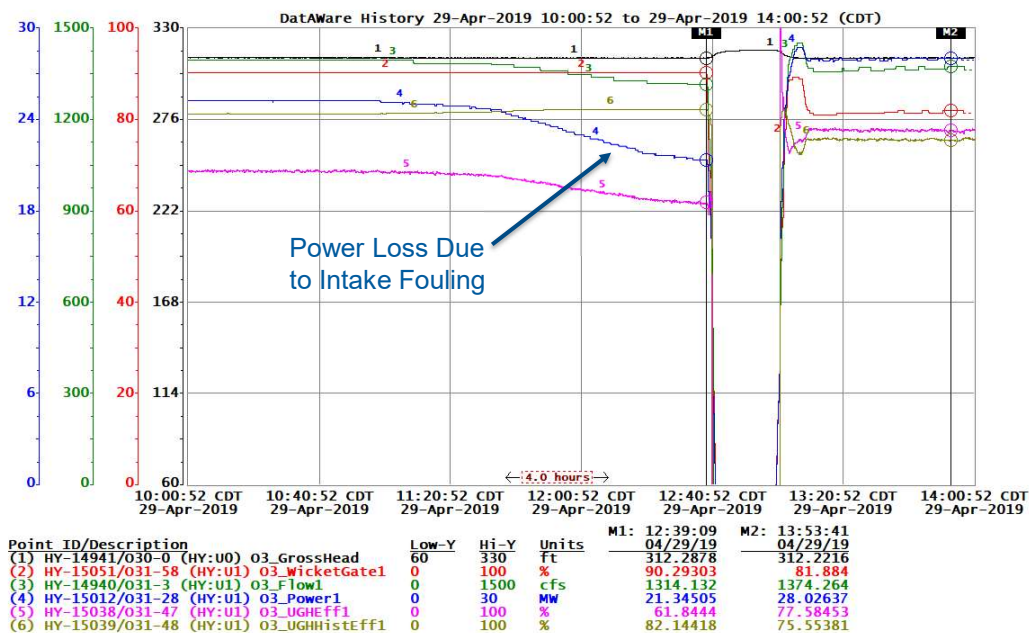
1. DatAWARE Data Historian Client Tool (applications for trending, dashboards, analytics, and ad-hoc troubleshooting) [*TT1*](#)
2. PRiSM (advanced pattern recognition system for anomaly detection) [*TT2*](#)
3. River Forecast Center WaterView Alarm Summary [*TT3*](#)



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Data Historian Client Software (DataWare)

O

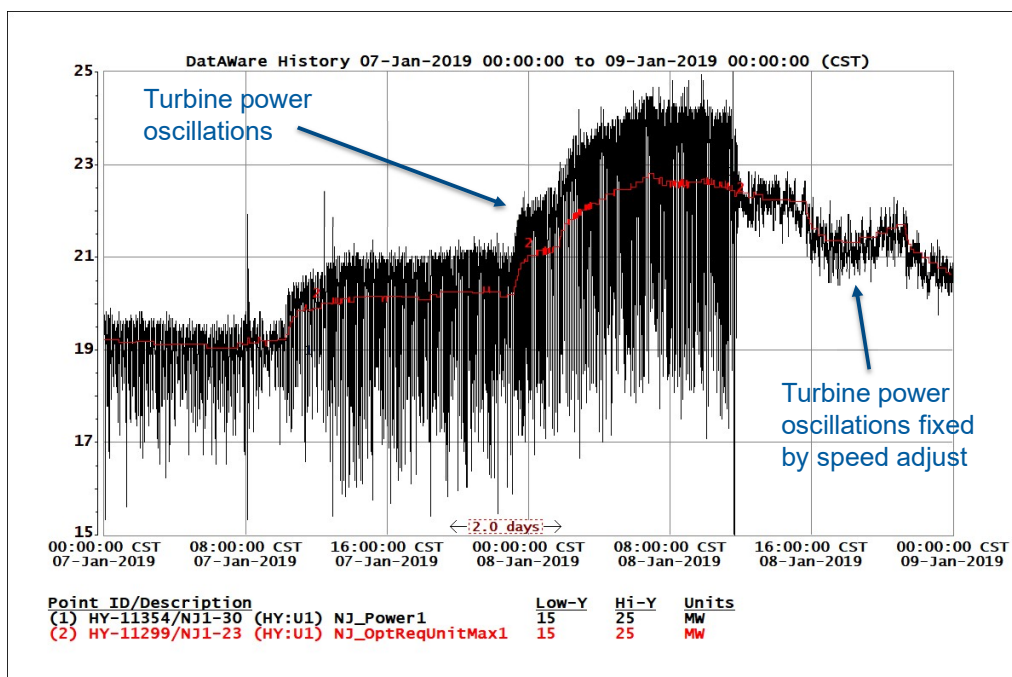


TVA

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Data Historian Client Software (DataWare)

O



TVA

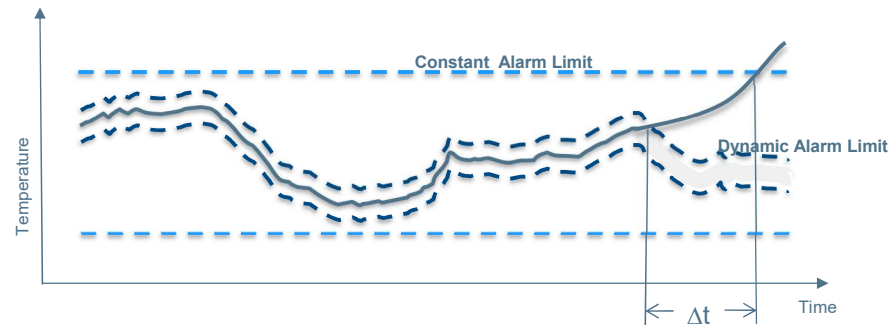
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Advanced Pattern Recognition Software (PRiSM)

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- Advance Pattern Recognition (APR) allows for **Dynamic Alarm Limits**
- Improves reliability by using advanced techniques to detect and diagnose asset anomalies more quickly



TVA

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WaterView Alarm Summary

O

WV Data Summary

Name	Date/Time	Hw(ft)	Hw(2ft)	Tv(ft)	Turb.Q(cfs)	Spill(cfs)	Mw	Presch	Presch+1	Notes
South Holston	05/28/19 15:39	1729.00	1700.65	1486.23	0	280	0	0	0	MISMATCH? (1729.00/1700.65)
Watauga	05/28/19 15:39	1959.31	1959.48	1649.85	1285	30	REC(31)			31
Wilbur	05/28/19 15:39	1645.21	1645.21	1584.59	1520	215	7	REC(6)		0
Boone	05/28/19 15:39	1353.22	1353.18	1263.11	3583	23	AGC(19-25)			22
Fort Pat	05/28/19 15:39	1260.66	1260.62	1192.83	3562		19	18		18
Cherokee	05/28/19 15:39	1071.29	1071.21	923.83	3573		36	37		37
Douglas	05/28/19 15:39	994.49	994.64	875.21	15898		138	MSL(138)		138
Norris	05/28/19 15:39	1020.47	1020.69	824.66	3424		51	52		52
Melton Hill	05/28/19 15:39	794.04	794.04	741.09	0		0	24		24
Chaluge	05/28/19 15:39	1926.32	1926.22	1797.96	0	125	-24.0	0		0
Nottely	05/28/19 15:39	1777.08	1777.03	1607.64	4	285	0	0		0
Hiwassee	05/28/19 15:39	1530.77	1530.67	1278.58	4477		81	81		81
Apalachia	05/28/19 15:39	1277.99	1278.08	940.30	2847		75	REC(76)		76
Blue Ridge	05/28/19 15:39	1696.97	1696.95	1543.46	1598	150	16	16		16
Ocoee 3	05/28/19 15:39	1432.54	1432.48	1114.09	0		0	SCH(0)		0
Ocoee 2	05/28/19 15:39	1096.69	1109.55	832.79	0	92	0	SCH(17)		17
Ocoee 1	05/28/19 15:39	828.01	828.18	716.00	1338		10	10		15
Fontana	05/28/19 15:39	1702.94	1703.29	1277.38	3130		105	MSL(103)		103
Great Falls	05/28/19 15:39	800.01	800.23	653.44	1366		13	13		13
Tims Ford	05/28/19 15:39	887.83	887.85	744.15	0	240	0	0		0
Fort Loudoun	05/28/19 15:39	812.82	812.88	741.40	15418		81	MSL(80)		80
Watts Bar	05/28/19 15:39	740.66	740.88	684.42	47254		194	MSL(194)		194
Chickamauga	05/28/19 15:39	682.05	682.04	635.01	26919		92	91		91
Nickajack	05/28/19 15:39	633.09	633.14	596.18	31228		80	AGC(72-84)		78
Guntersville	05/28/19 15:39	594.57	594.53	557.78	34535		91	MSL(91)		91
Wheeler	05/28/19 15:39	555.71	555.59	507.10	36268		120	120		120
Wilson	05/28/19 15:39	507.07	507.24	414.87	33054	460	225	AGC(225-265)		245
Pickwick	05/28/19 15:39	413.68	413.53	359.81	19535	5870	77	MSL(76)		76
Kentucky	05/28/19 15:39	358.90	358.89	314.45	39837		131	MSL(131)		131
Raccoon Mt.	05/28/19 15:39	1652.97		633.20	15454					

24 Hour 48 Hour 72 Hour
Total above Chickamauga 0.003 0.014 0.019
* through 05/28/2019 1500

Ocoee 2 Diversion Dam Flow

End

TVA

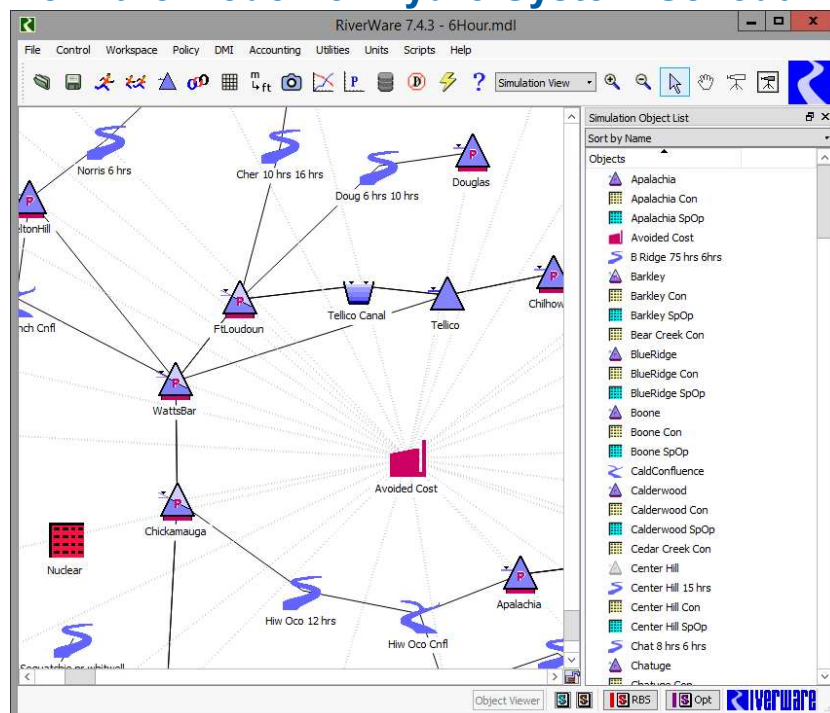
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System Level Optimization Tools



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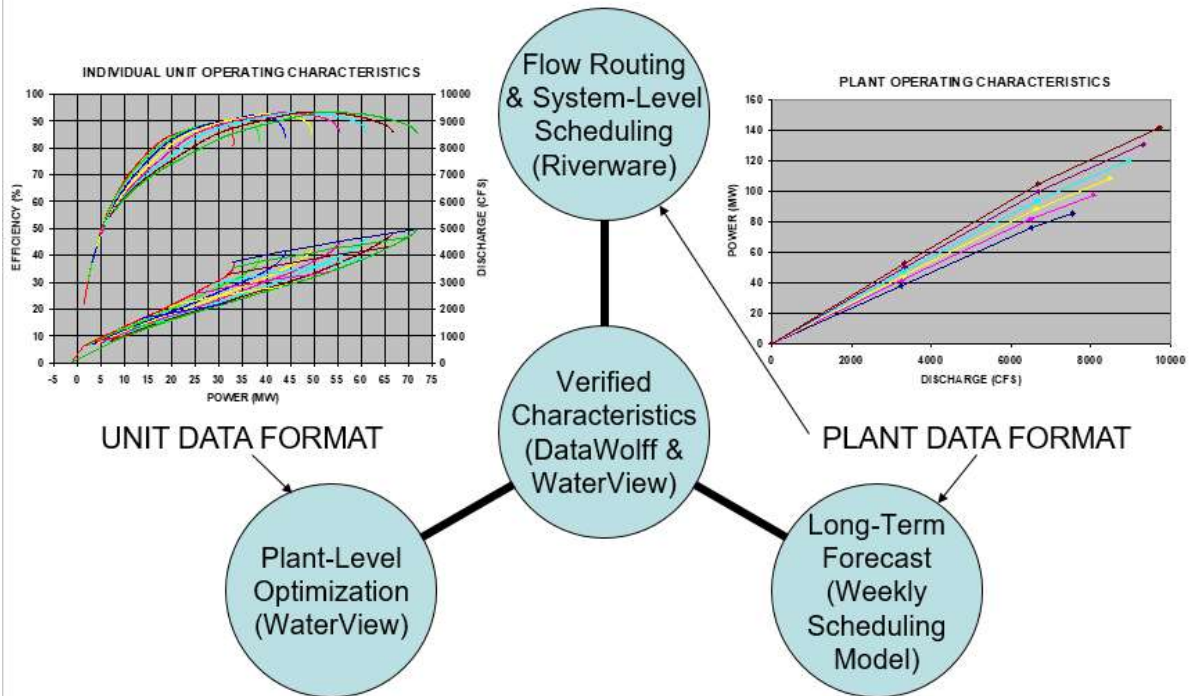
RiverWare Model for Hydro System Scheduling



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WaterView Unit and Plant Characteristics

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Plant Level Optimization Tools

TVA

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WaterView Real-Time Plant Optimization

Inputs:

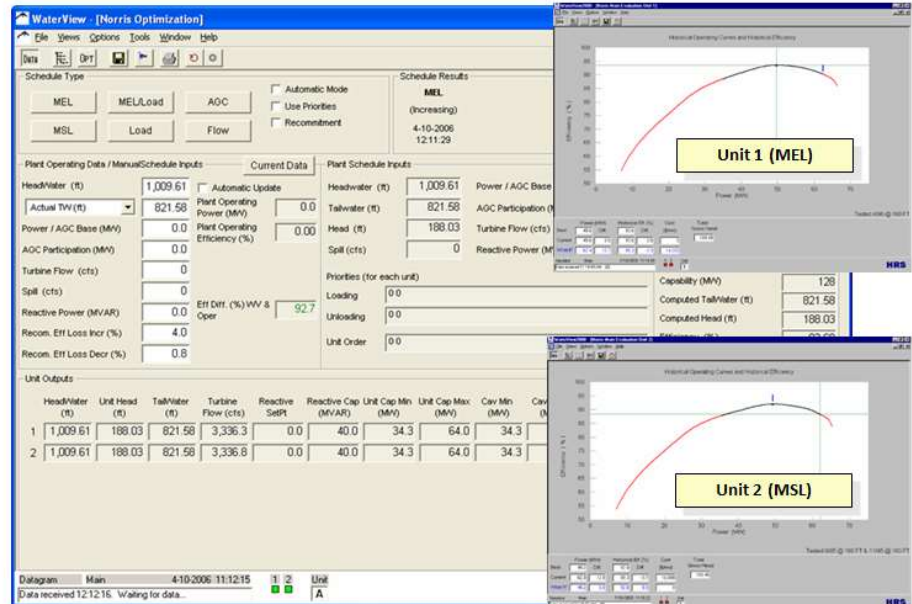
- Individual unit operating characteristics
- Process data
- Unit constraints
- Schedule request

Schedule Modes

- MEL/Load
- MSL
- AGC
- Load
- Flow
- Pulse
- Recreation
- Pump

Outputs:

- Unit selection
- Unit power setpoints
- Unit reactive setpoints
- Unit AGC setpoints & ranges
- Plant capability
- Plant efficiency



33

Economic Benefits of Optimization

Testing

- Ranking of unit efficiency for unit commitment
- Adjust to changes in efficiency and shape over time
- Identify cam adjustments to improve unit efficiency and capacity
- Identify cavitation and vibration avoidance zones
- Identify runner seal wear effects on unit performance
- Provide independent verification of ACS & WaterView instrumentation accuracy
- Identify trash effects and the impact on flow profiles
- Evaluate the effects of aeration on unit performance

Characteristics

- Develop test adjusted characteristics over the full range of operating outputs and heads
- Provide test adjusted characteristics for system-level scheduling

Monitoring

- Provide continuous data for verification of operating characteristics
- Provide remote index testing capabilities
- Utilize the accurate characteristics for optimized plant performance

Verification

- Provide for condition-based testing instead of time-based testing
- Determine the best use of testing funds through system-wide evaluation of unit efficiencies
- Rank units for testing based on both efficiency loss and energy loss
- Evaluate the accuracy of unit characteristics over the full range of operating outputs and heads
- Identify measurement problems, such as flowmeter problems
- Identify operational problems, such as blade cam problems
- Identify curves requiring extension
- Provide analysis of new characteristics before implementation



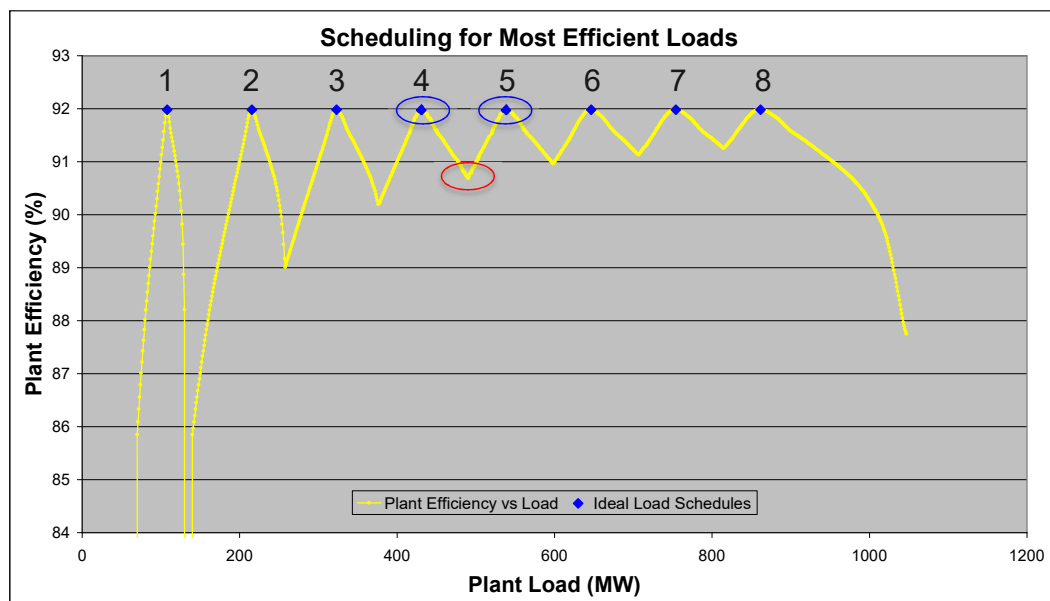
34

7 Types of Optimization



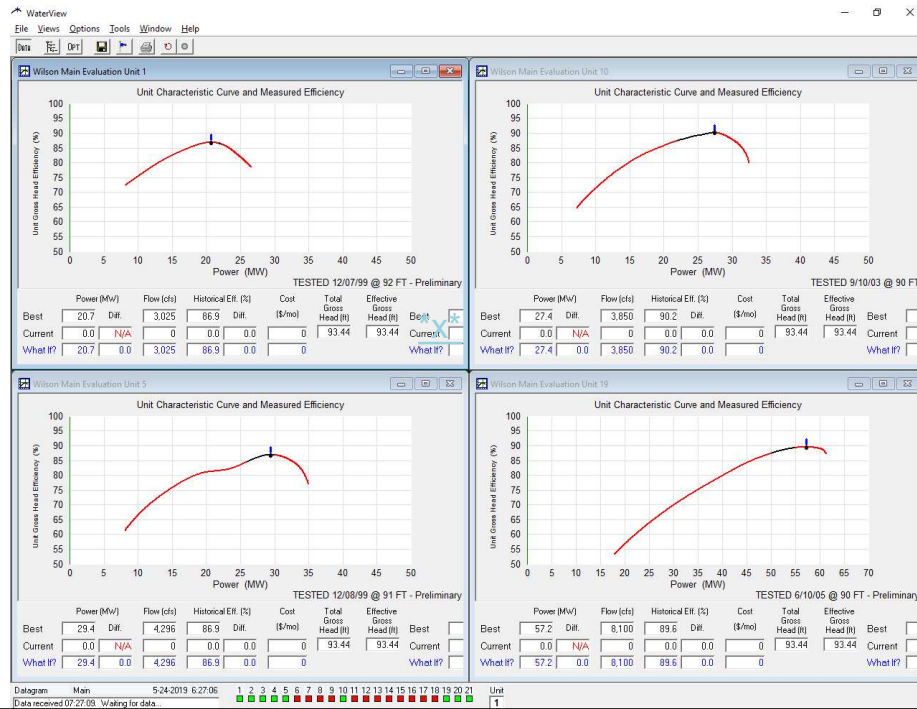
35

Optimized Plant Schedule Request (8-Unit Plant)



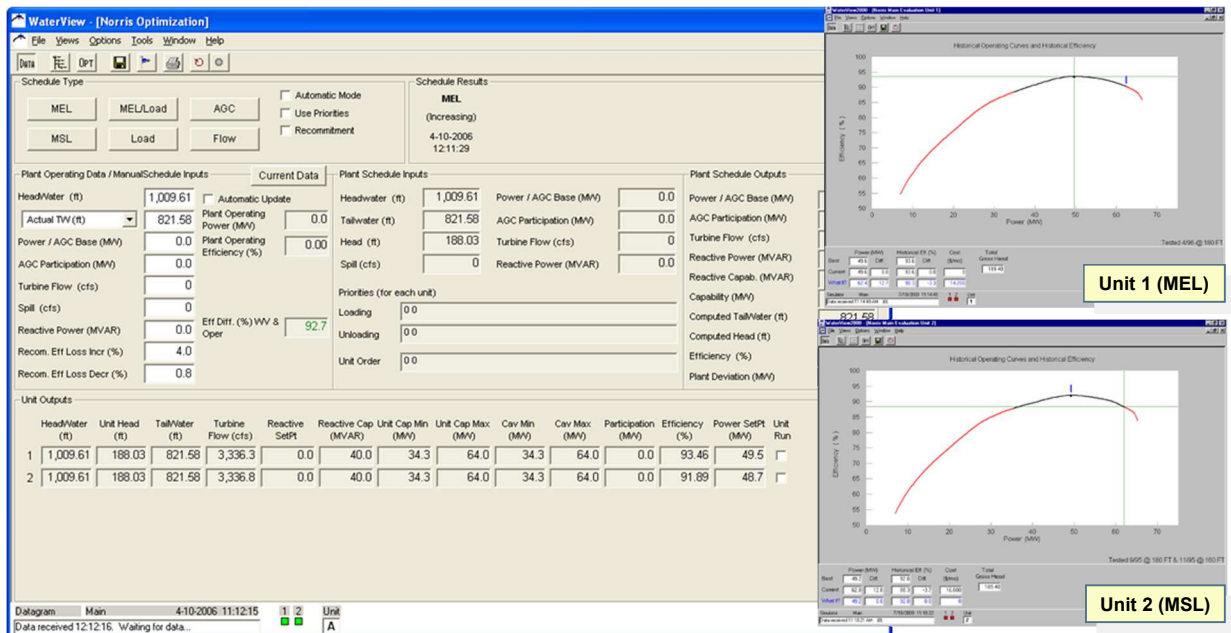
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Optimized Unit Selection (Variation in Shape & Efficiency)



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Optimized Unit Setpoints (WaterView Optimization Screen)

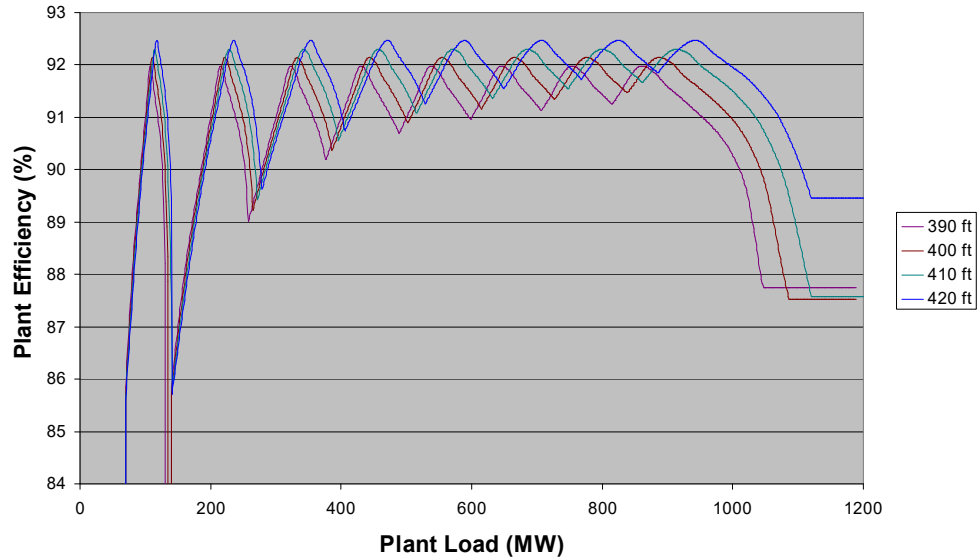


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Optimized for Continuous Head Changes

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Plant Efficiency for Optimized Transitions and Changes in Head



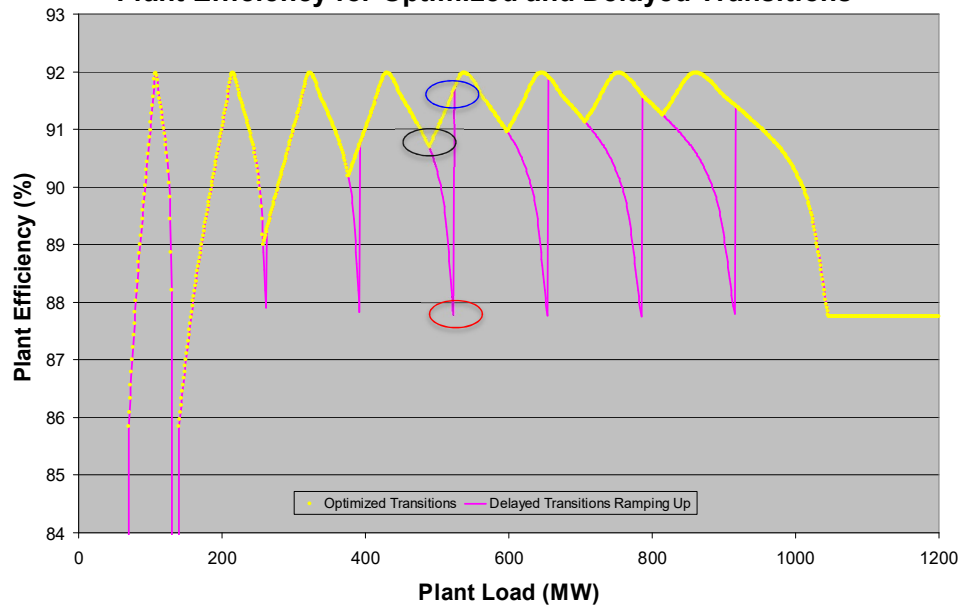
TVA

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Optimized for Unit Transitions (Loading of Units)

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Plant Efficiency for Optimized and Delayed Transitions

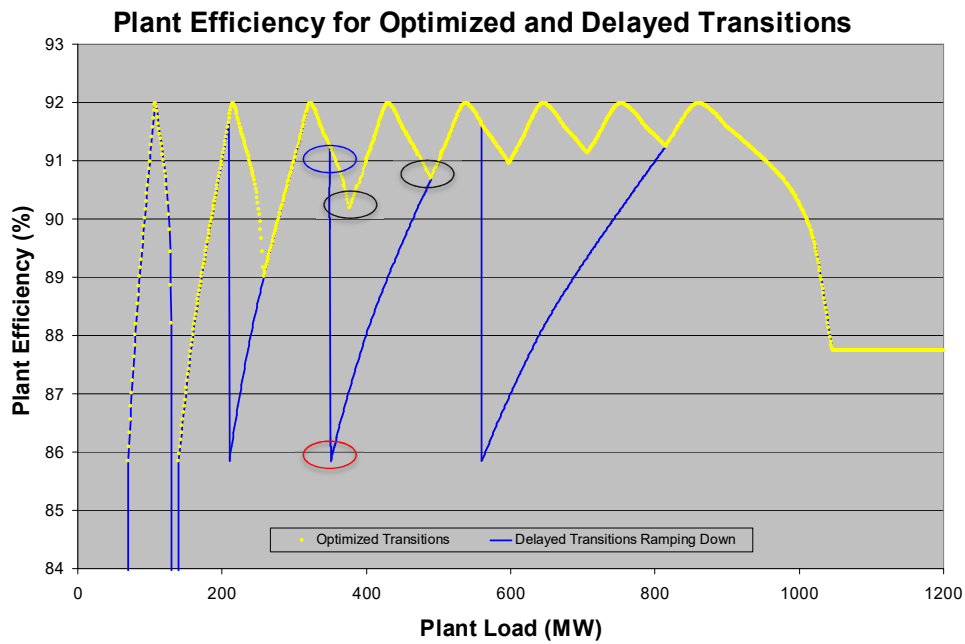


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Optimized for Unit Transitions (Unloading of Units)

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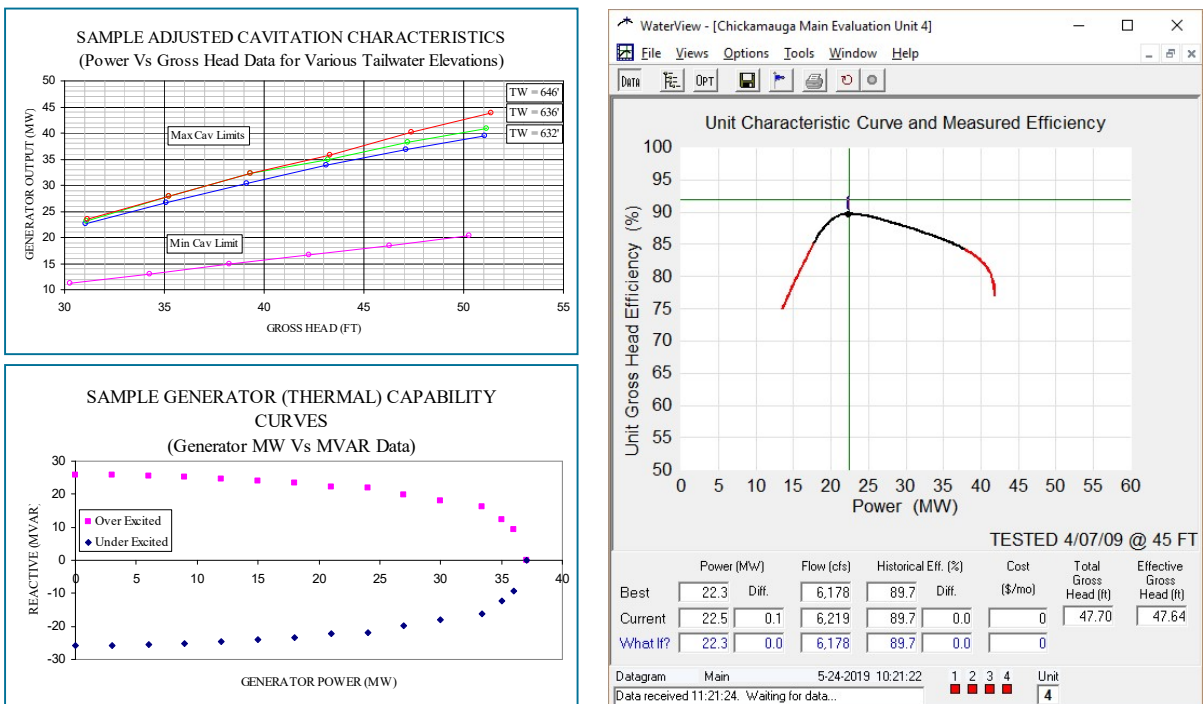


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Optimized for Reduced Damage (Operating within Constraints)

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Optimization Details



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$$\eta = \frac{P}{\rho g Q H}$$

- The WaterView optimization engine uses direct search, reduced gradient, and heuristic methodologies to determine a unit configuration maximizing plant efficiency.
- For unit commitment, WaterView methodology honors unit ramping, unit running, unit priority (and several other) constraints



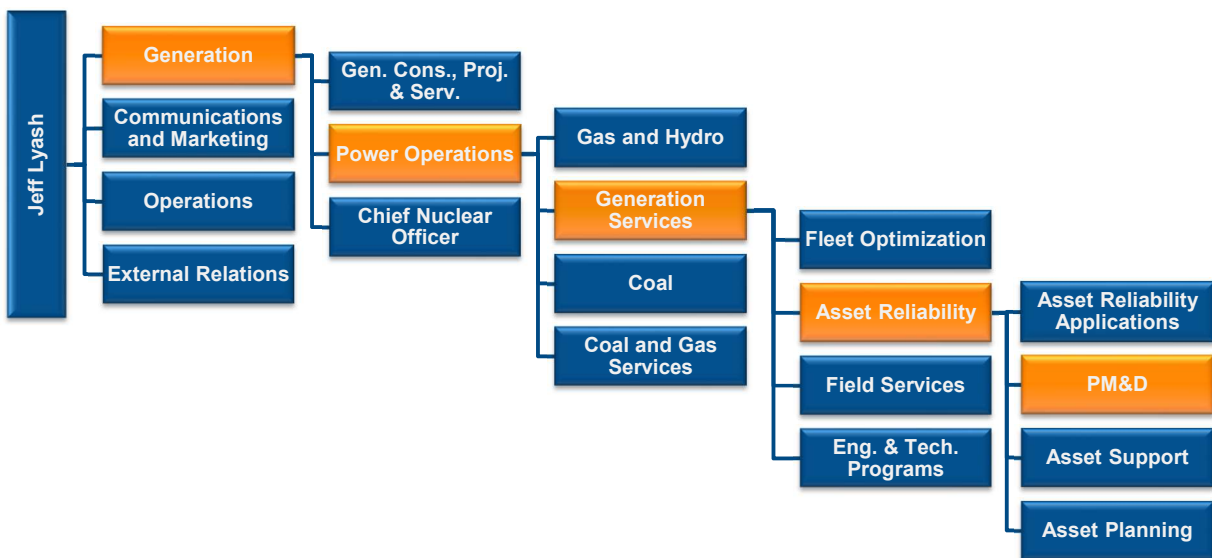
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Organization and Mission



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Where is PM&D in the TVA Organization?



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The TVA Mission

TOGETHER WE
ALIGN | ENGAGE | EXECUTE



TVA MISSION

Serve the People of the Valley.

POWER OPERATIONS

Provide low-cost, reliable coal, gas, and hydro generation while keeping our people safe and ensuring compliance with environmental regulations.

GENERATION SERVICES

Provide efficient, valuable, and sustainable core services that enable Power Operations to deliver low cost, reliable coal, gas and hydro generation while keeping our people safe and ensuring compliance with regulations.

ASSET RELIABILITY

Optimize fleet reliability by delivering comprehensive asset management services. This is achieved through effective risk management.

PM&D CENTER

Transform data into actionable information to lower cost and improve reliability.

