# Panama Canal Benefits Analysis

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**RiverWare® Users Meeting**

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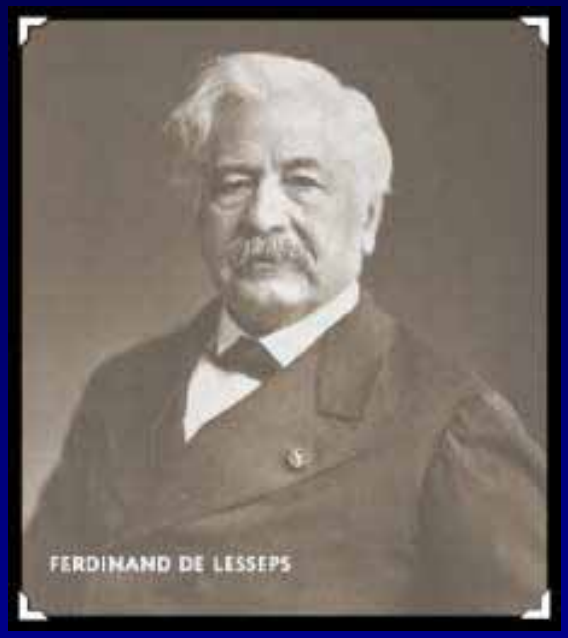
Riverside Technology, inc.

# Central America

# Panamá


Caribbean Sea
0 40 80 km
0 40 80 mi
COSTA RICA
Bocas del Toro
Golfo de los Mosquitos
Coco Solo
Cristóbal
Colón
El Porvenir
PANAMA
Panama Canal
Balboa
Vacamonte
David
Golfo de Chiriquí
Santiago
Chitré
Gulf of Panama
La Palma
Yaviza
COLOMBIA
North Pacific Ocean

# *Ferdinand de Lesseps*




- 19,000 Workers Employed at Peak
- 30 Million Cubic Yards of Earth Moved
- Culebra Cut Lowered 20 feet

# *French Disaster*

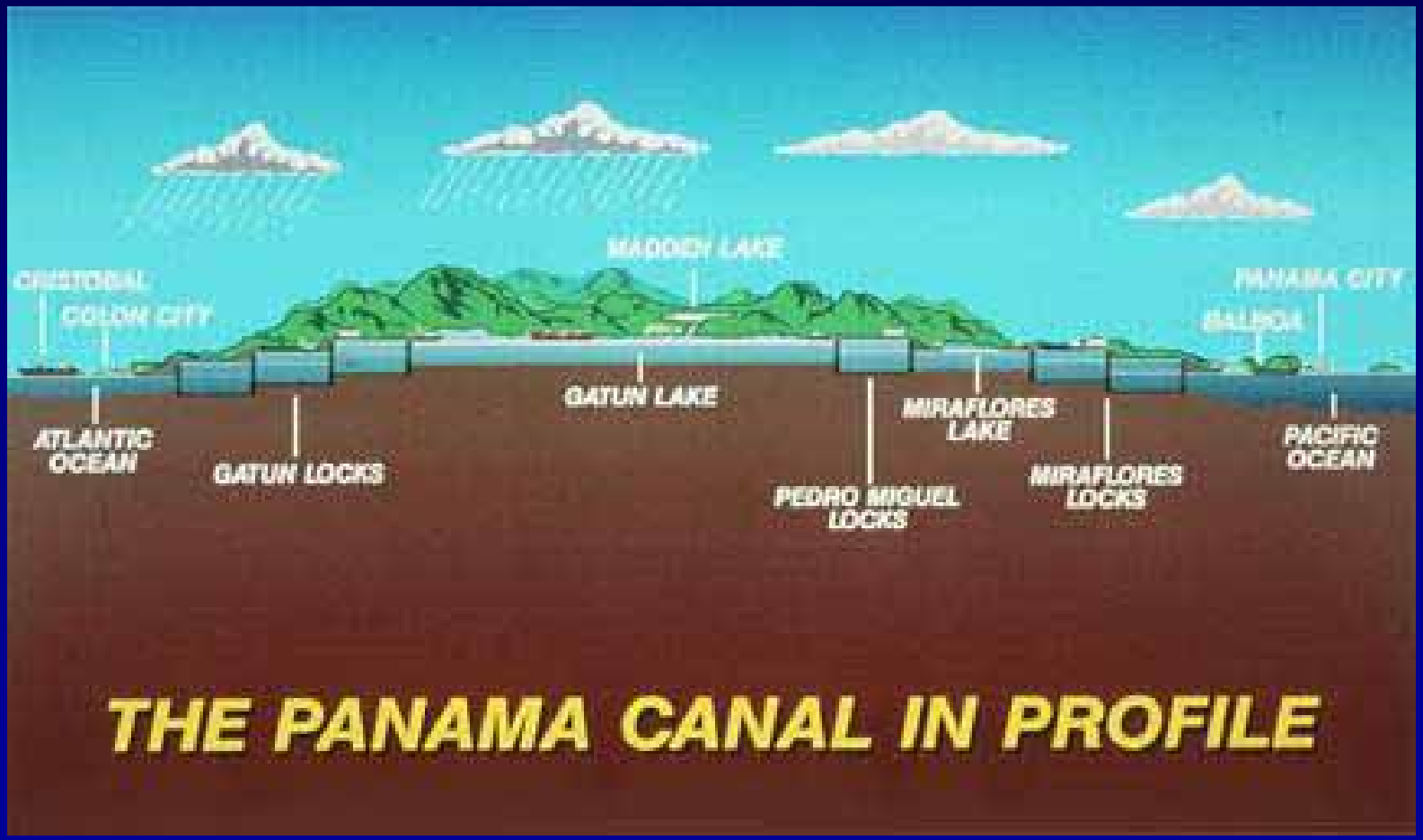
- Underestimated Magnitude of Task
- Failure to Use Panama Railroad
- Undersized Equipment
- Yellow Fever and Malaria - 20,000 Dead
- Work Stopped - May 1889

# *Panama Canal*

- Rights purchased from the French
- “Supported” Panamanian independence
- Started 1904 / first official transit August 15, 1914
- Completed under budget and on-time
- Self-sufficient / tolls support maintenance
- Gravity fed lakes and locks
- Hydropower runs operations (manual backups)
- 90 - 155 inches of rain /  year

# Panama Canal Overview

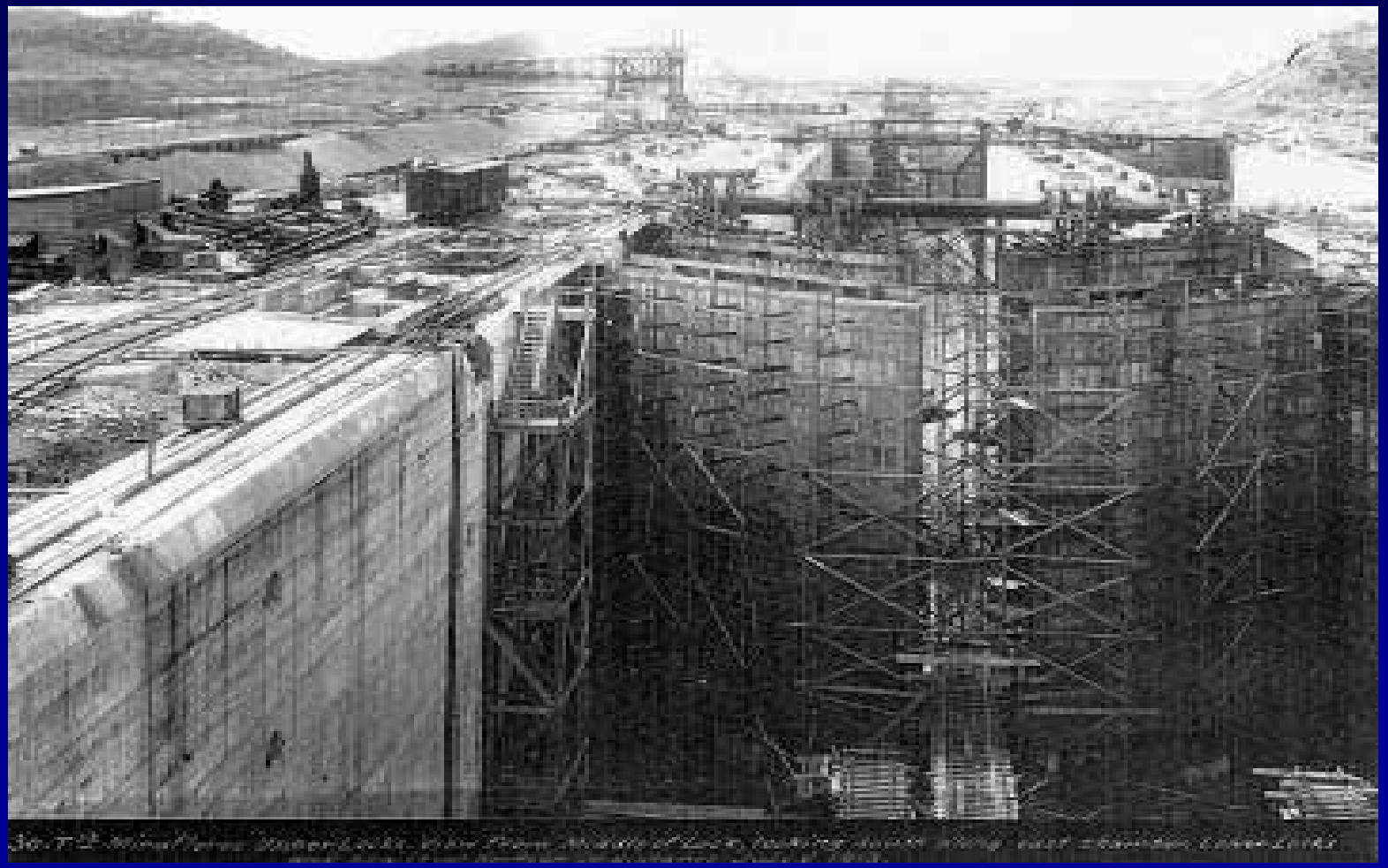
# Profile


MADDEN LAKE
CRISTOBAL
COLON CITY
PANAMA CITY
BALBOA
GATUN LAKE
ATLANTIC OCEAN
GATUN LOCKS
MIRAFLORES LAKE
PEDRO MIGUEL LOCKS
MIRAFLORES LOCKS
PACIFIC OCEAN
THE PANAMA CANAL IN PROFILE

# Culebra Cut

# Culebra Cut

# Locks Construction



# First Lockage

# Gatun Locks

# Mira Flores Locks

# Pedro Miguel Locks

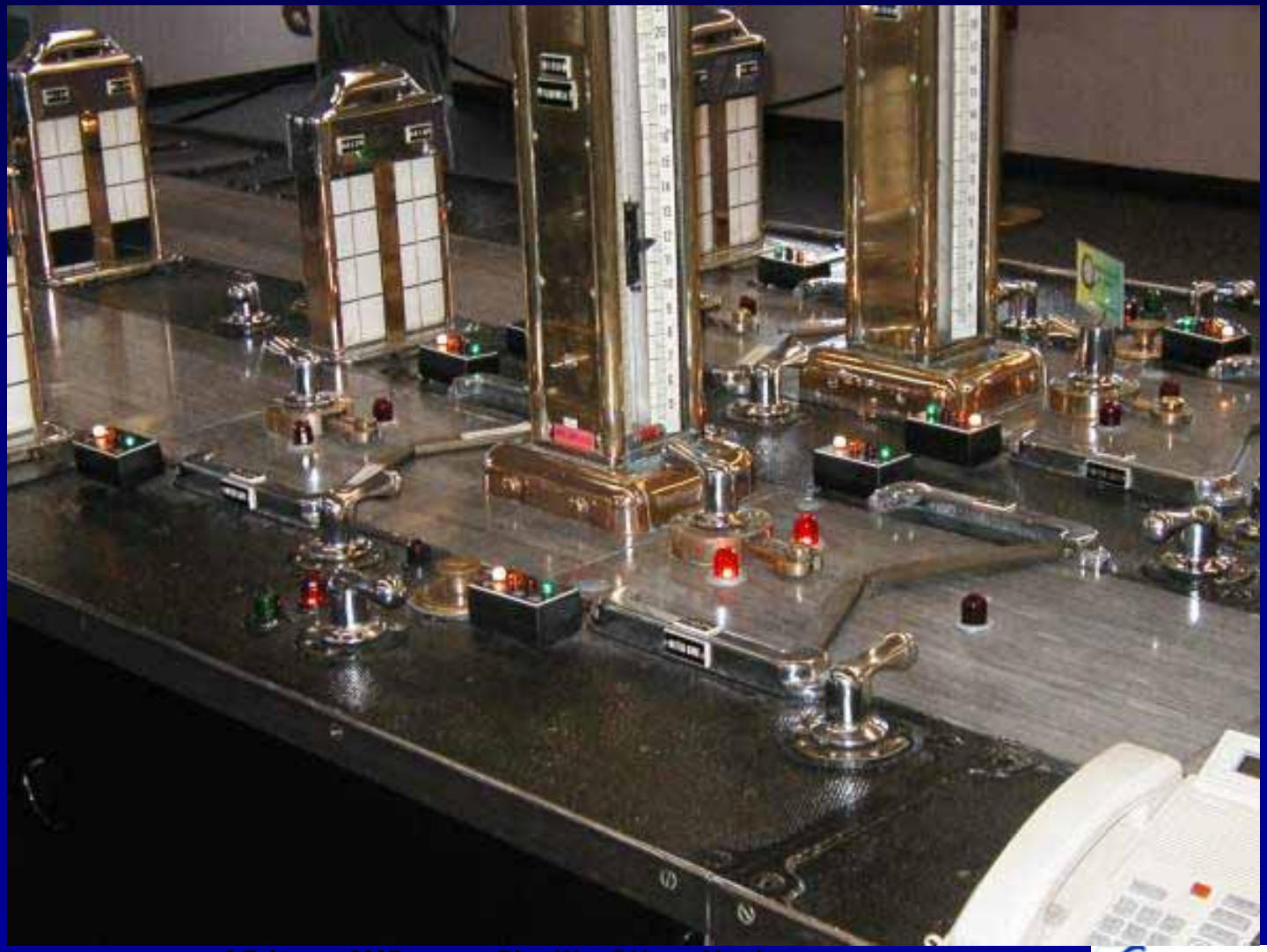
# Gatun Dam

# Gamboa

# From the Control House

# From the Control House

# Control board



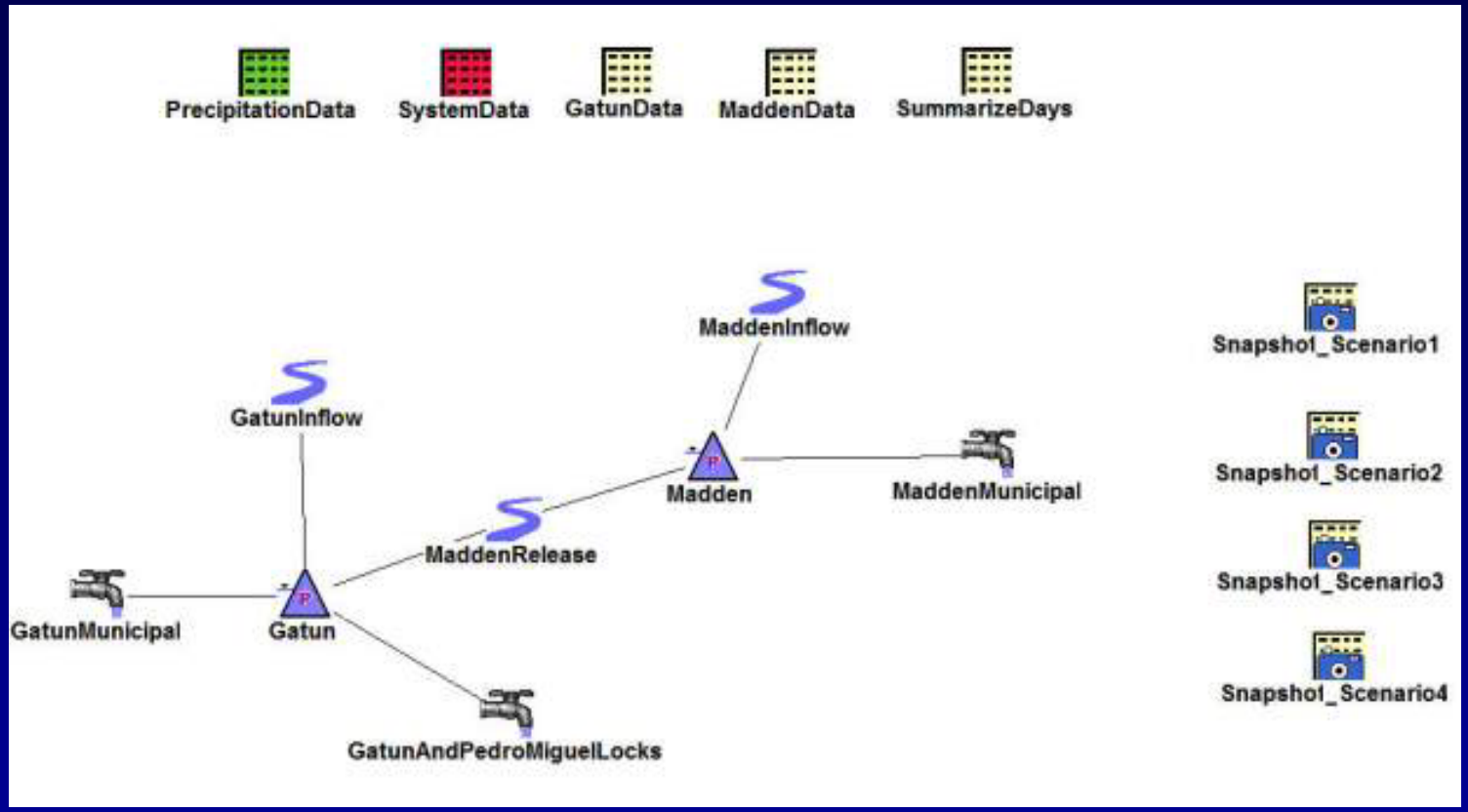
# *Project Goals – Four scenarios*

- Scenario 4
  - Use PANFCST system inflows to predict inflows and future conditions
  - Use 24 or 48 hours of predicted inflows
- Scenario 3
  - Use predicted “rain on ground” to predict inflows and future conditions
  - Define operation using 12 hours of predicted radar data

# *Project Goals – Four scenarios*

- Scenario 2
  - Follow the rule curve defined by Panama Met & Hyd group
  - Generate hydropower when above rule curve
  - Spill water to avoid top of gates operation
- Scenario 1
  - Operate without forecast information
  - Fill to top of gates
  - Generate hydropower when pool is above rule curve

# RiverWare® Layout




1972 – 2005 Hourly

# *Rules of Operation*

- Requested operational rules from Panama staff
- Panama staff provided 14 rules, like:

  If  Madden pool > RuleCurve and

  Gatun pool < RuleCurve then

  Withdraw water for municipal use from Madden, balance the reservoirs storage with hydropower from Madden and withdraw water for municipal use + lockages from Gatun.
- Analyzed rules, filling gaps with additional rules

# Rules of Operation

- Collapsed rules into a table (Madden):

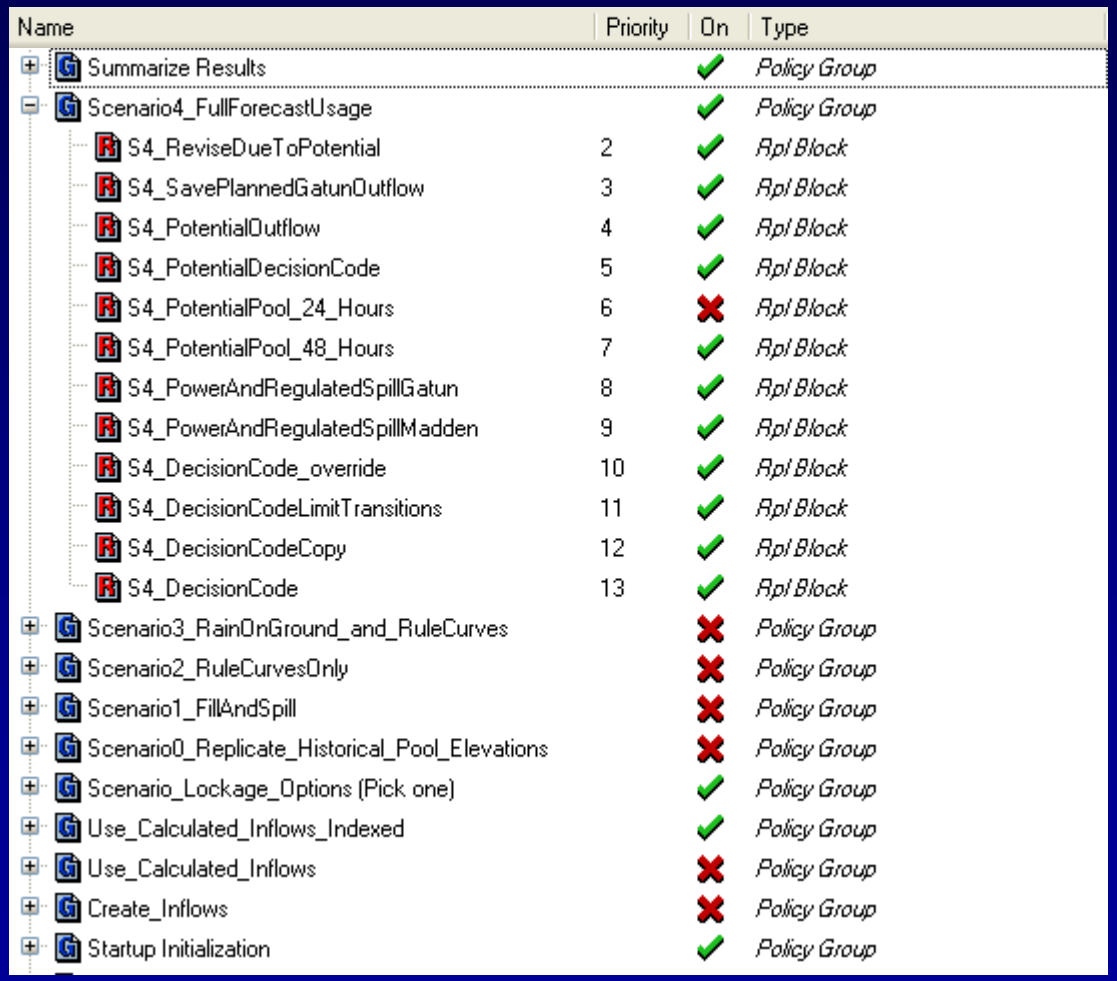
| Decision Code | Madden Pool Elevation (MP) | Gatun Pool Elevation (GP) | Date Range | Municipal | Hydro | Balance Hydro | Full Hydro | Spill | 75000 spill |
|---|---|---|---|---|---|---|---|---|---|
| 1 | MP < 205 | GP < 81.5 | | X | | | | | |
| 2 | MP > 205 | GP < 81.5 | | X | X | | | | |
| 3 | MP < 205 | GP > 81.5 | | X | | | | | |
| 4 | 205 < MP < Rcurve | 81.5 < GP < Rcurve | | X | | X | | | |
| 5 | MP > Rcurve | GP < Rcurve | | X | | X | | | |
| 6 | MP < Rcurve | GP > Rcurve | | X | | | | | |
| 7 | MP < Rcurve | GP > Rcurve + 0.25 | 5/1-12/31 | X | | | | | |
| 8 | Rcurve < MP < Fcurve | Rcurve < GP < Fcurve | 1/1-4/1 | X | X | | | | |
| 9 | Rcurve < MP < Fcurve | Rcurve < GP < Fcurve | 4/1-12/31 | X | | X | | | |
| 10 | Fcurve < MP < Fcritical | Fcurve < GP < Fcritical | | X | | | X | X | |
| 11 | Rcurve < MP < Fcurve | Fcurve < GP < Fcritical | | X | | | X | | |
| 12 | Rcurve < MP < Fcurve | GP > Fcritical | | X | | X | | | |
| 13 | MP > Fcritical | Fcurve < GP < Fcritical | | X | | | X | | X |
| 14 | MP > Fcritical | GP > Fcritical | | X | | | X | | X |
| 15 | MP < Rcurve | Fcurve - 0.25 < GP | | X | | | | | |
| 16 | MP < Rcurve | Fcurve < GP < Fcritical | | X | | | | | |
| 17 | MP < Rcurve | GP > Fcritical | | X | | | | | |
| 18 | Fcurve < MP < Fcritical | GP > Fcritical | | X | | | X | | |
| 19 | MP > Fcurve | GP < Rcurve | | X | | | X | X | |

# Rules of Operation

- Collapsed rules into a table (Gatun):

| Decision Code | Madden Pool Elevation (MP) | Gatun Pool Elevation (GP) | Date Range | Municipal | Draft Restricted Lockages | Lockages | Hydro | Full Hydro | 4 Gates Spill | 14 Gates Spill | Culverts Spill through Locks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MP < 205 | GP < 81.5 | | X | X | | | | | | |
| 2 | MP > 205 | GP < 81.5 | | X | X | | | | | | |
| 3 | MP < 205 | GP > 81.5 | | X | | X | | | | | |
| 4 | 205 < MP < Rcurve | 81.5 < GP < Rcurve | | X | | X | | | | | |
| 5 | MP > Rcurve | GP < Rcurve | | X | | X | | | | | |
| 6 | MP < Rcurve | GP > Rcurve | | X | | X | | | | | |
| 7 | MP < Rcurve | GP > Rcurve + 0.25 | 5/1-12/31 | X | | X | X | | | | |
| 8 | Rcurve < MP < Fcurve | Rcurve < GP < Fcurve | 1/1-4/1 | X | | X | | | | | |
| 9 | Rcurve < MP < Fcurve | Rcurve < GP < Fcurve | 4/1-12/31 | X | | X | X | | | | |
| 10 | Fcurve < MP < Fcritical | Fcurve < GP < Fcritical | | X | | X | | X | X | | |
| 11 | Rcurve < MP < Fcurve | Fcurve < GP < Fcritical | | X | | X | | X | X | | |
| 12 | Rcurve < MP < Fcurve | GP > Fcritical | | X | | X | | | | X | |
| 13 | MP > Fcritical | Fcurve < GP < Fcritical | | X | | | | | X | | |
| 14 | MP > Fcritical | GP > Fcritical | | X | | | | | | X | X |
| 15 | MP < Rcurve | Fcurve - 0.25 < GP | | X | | X | | X | | | |
| 16 | MP < Rcurve | Fcurve < GP < Fcritical | | X | | X | | X | X | | |
| 17 | MP < Rcurve | GP > Fcritical | | X | | X | | | | X | |
| 18 | Fcurve < MP < Fcritical | GP > Fcritical | | X | | X | | | | X | X |
| 19 | MP > Fcurve | GP < Rcurve | | X | | X | | | | | |

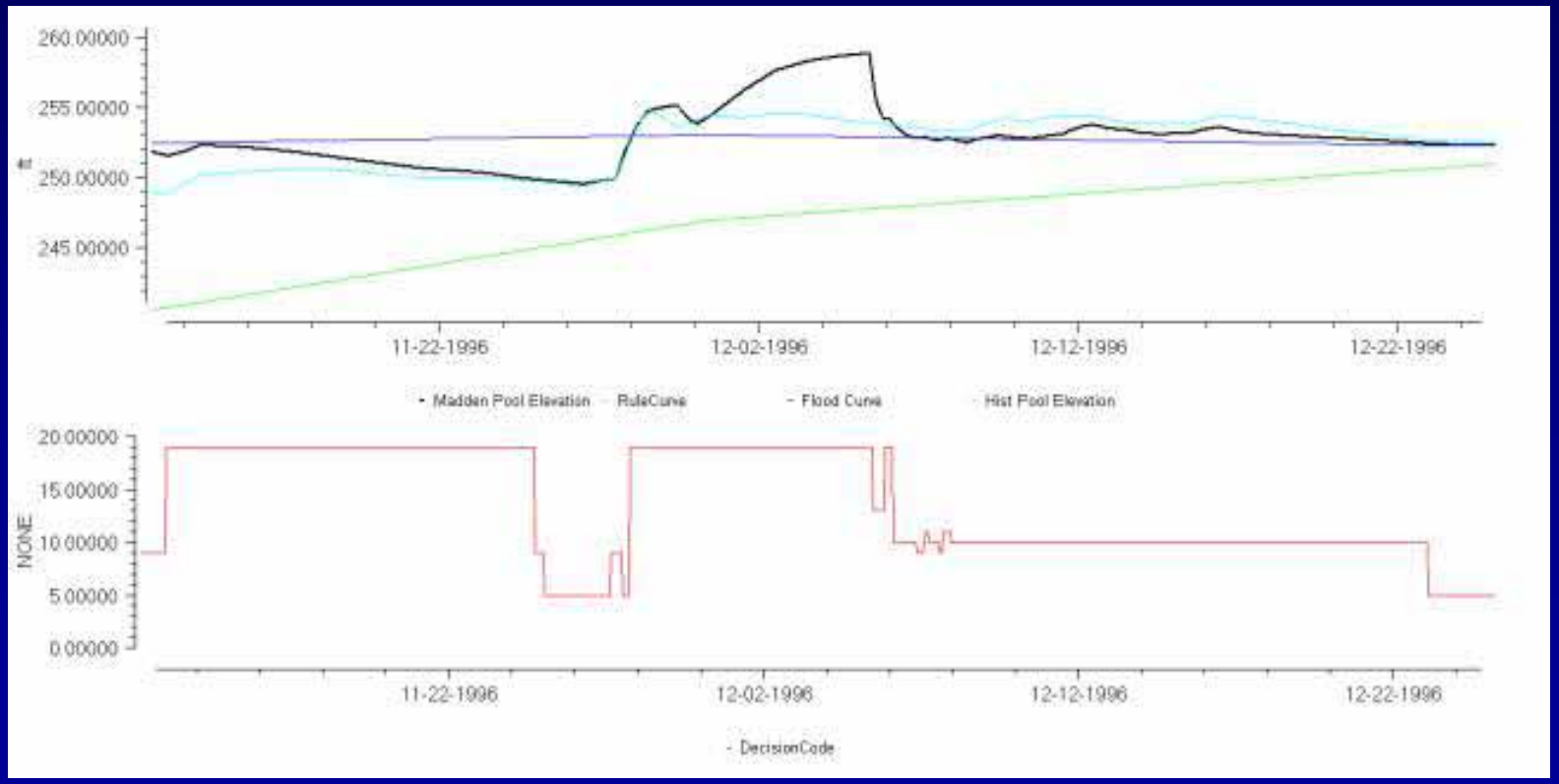
# RiverWare® Rules



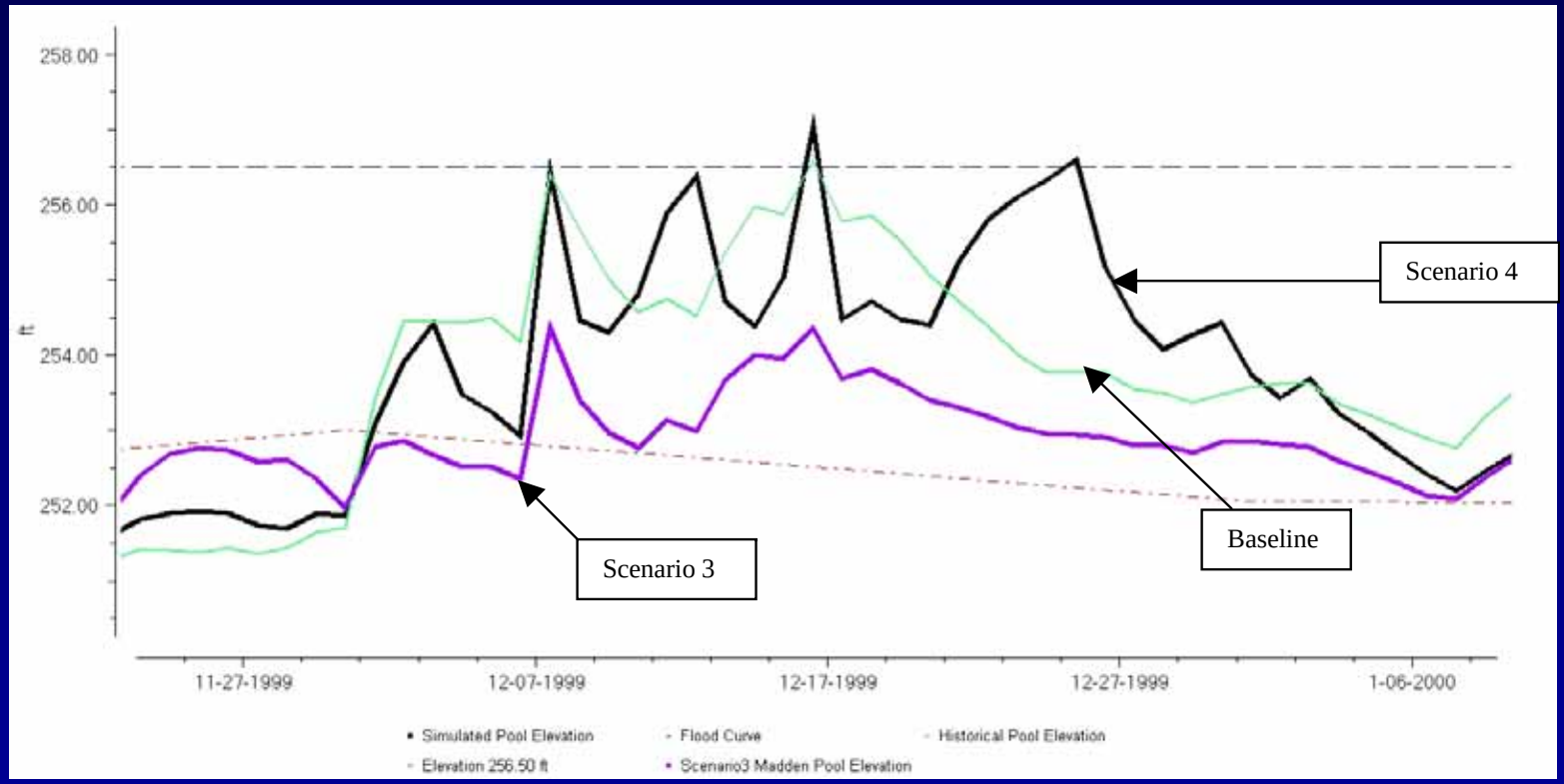
| Name | Priority | On | Type |
|---|---|---|---|
| Summarize Results | | ✓ | Policy Group |
| Scenario4_FullForecastUsage | | ✓ | Policy Group |
| S4_ReviseDueToPotential | 2 | ✓ | Rpl Block |
| S4_SavePlannedGatunOutflow | 3 | ✓ | Rpl Block |
| S4_PotentialOutflow | 4 | ✓ | Rpl Block |
| S4_PotentialDecisionCode | 5 | ✓ | Rpl Block |
| S4_PotentialPool_24_Hours | 6 | ✗ | Rpl Block |
| S4_PotentialPool_48_Hours | 7 | ✓ | Rpl Block |
| S4_PowerAndRegulatedSpillGatun | 8 | ✓ | Rpl Block |
| S4_PowerAndRegulatedSpillMadden | 9 | ✓ | Rpl Block |
| S4_DecisionCode_override | 10 | ✓ | Rpl Block |
| S4_DecisionCodeLimitTransitions | 11 | ✓ | Rpl Block |
| S4_DecisionCodeCopy | 12 | ✓ | Rpl Block |
| S4_DecisionCode | 13 | ✓ | Rpl Block |
| Scenario3_RainOnGround_and_RuleCurves | | ✗ | Policy Group |
| Scenario2_RuleCurvesOnly | | ✗ | Policy Group |
| Scenario1_FillAndSpill | | ✗ | Policy Group |
| Scenario0_Replicate_Historical_Pool_Elevations | | ✗ | Policy Group |
| Scenario_Lockage_Options (Pick one) | | ✓ | Policy Group |
| Use_Calculated_Inflows_Indexed | | ✓ | Policy Group |
| Use_Calculated_Inflows | | ✗ | Policy Group |
| Create_Inflows | | ✗ | Policy Group |
| Startup Initialization | | ✓ | Policy Group |

# Debugging Rules

- Quickly determine system state for critical events
- Find causes for oscillations (rule transitions)



# Project Results



# Project Results

- Used rules to count number of days above / below threshold values
- Summarized time series values using expression slots

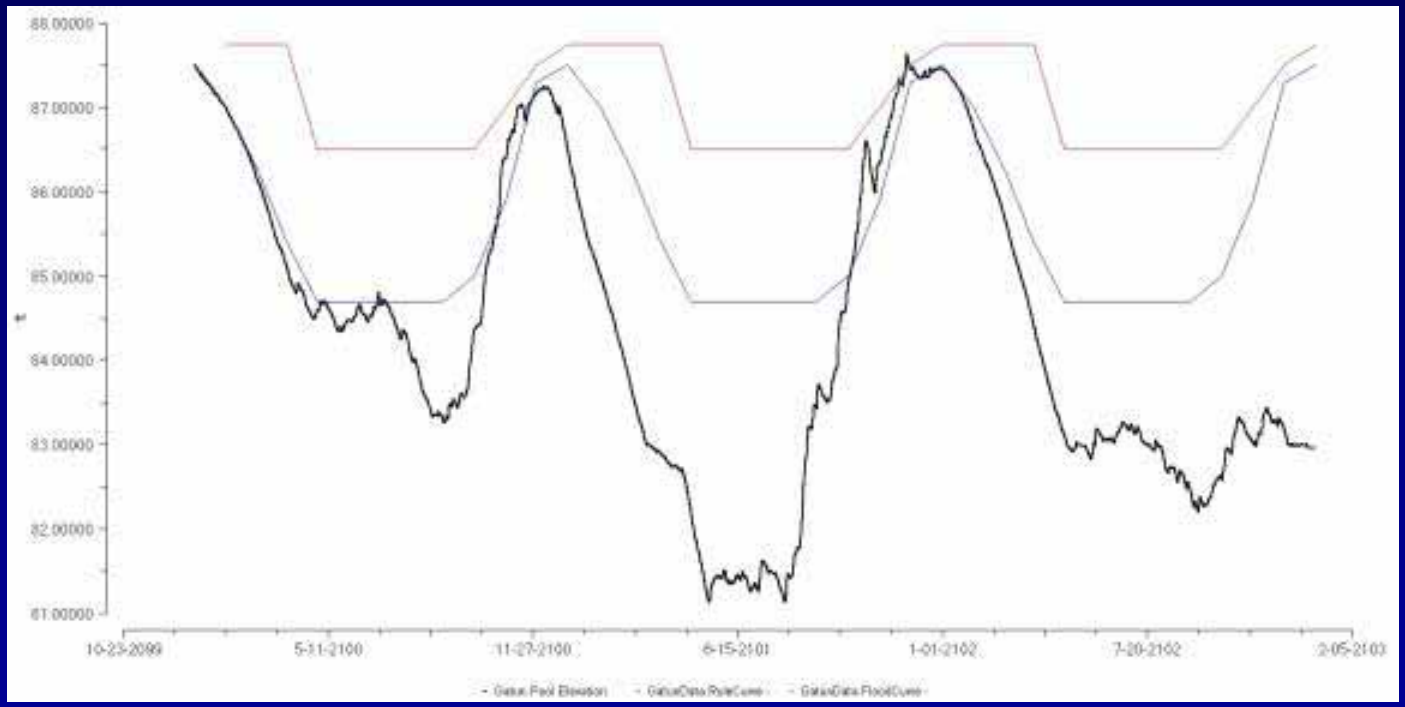
| Scenario | Madden | Gatun | | Madden # of days | | Gatun # of days | |
|---|---|---|---|---|---|---|---|
| | Average Daily Hydropower Generating Flow (cfs) | Average Daily Spill (cfs) | Average Daily Hydropower Generating Flow (cfs) | Above 256.50 ft | Below 210.00 ft | Above 92.00 ft | Below 82.00 ft |
| 1 | 2023.91 | 198.48 | 1768.09 | 0 | 0 | 19 | 675 |
| 2 | 2023.91 | 780.90 | 1187.58 | 0 | 0 | 0 | 765 |
| 3 | 1962.27 | 649.81 | 1301.58 | 3 | 608 | 0 | 242 |
| 4 | 2087.76 | 642.44 | 1310.20 | 23 | 667 | 0 | 258 |
| Baseline | 2172.67 | 452.83 | 1622.45 | 4 | 1312 | 0 | 293 |

# Drought and Number of Lockages

- Panama requested additional modeling runs, comparing the number of lockages / day during a drought sequence
  - Rules for flood control were re-used
  - Added user parameters for number of lockages / day
  - Added indexing, allowing simulation of back to back drought years

# Results Varying Lockages / Day

- Simulate Drought years 1976, 1977, and 1997



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