South Carolina Electric & Gas Saluda Project

Reservoir Operations Modeling Using:

Army Corps of Engineers

HEC-ResSim

Kleinschmidt
Energy & Water Resource Consultants

Saluda HYDRO RELICENSING

Afternoon Schedule

- Model Development & Calibration (1st hour)
- Break (20 minutes)
- Future Developments & Potential Results (2nd hour)
- Questions (30 minutes)

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RELICENSING

Mission Statement

"…establish a baseline of current hydrologic, hydraulic and operational conditions, and aid in analyzing and understanding the potential upstream and downstream effects of potential changes to project operation…."

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Model Objectives

- Assess impact of various environmental constraints on project operation
- Assess various project operation schemes for feasibility
- Determine "realistic" plan for future operations

Selected Model – HEC-ResSim

- Publicly available Army Corp of Engineers software (HEC-5)
- Specifically created for reservoir modeling and management
- Flexibility in managing large datasets
- Rule based decisions on daily timesteps
- Application of seasonal rules
- Ability to prioritize rules

US Army Corps of Engineers ®

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Model Development

- Model Area
  - Includes *Virtual Inflow* from entire watershed
  - Inputs located directly upstream and downstream of Lake Murray
- Input data
  - Reservoir stage/storage data
  - Historic dam releases (Outflow Hydrograph)
  - Historic water levels (Stage data)

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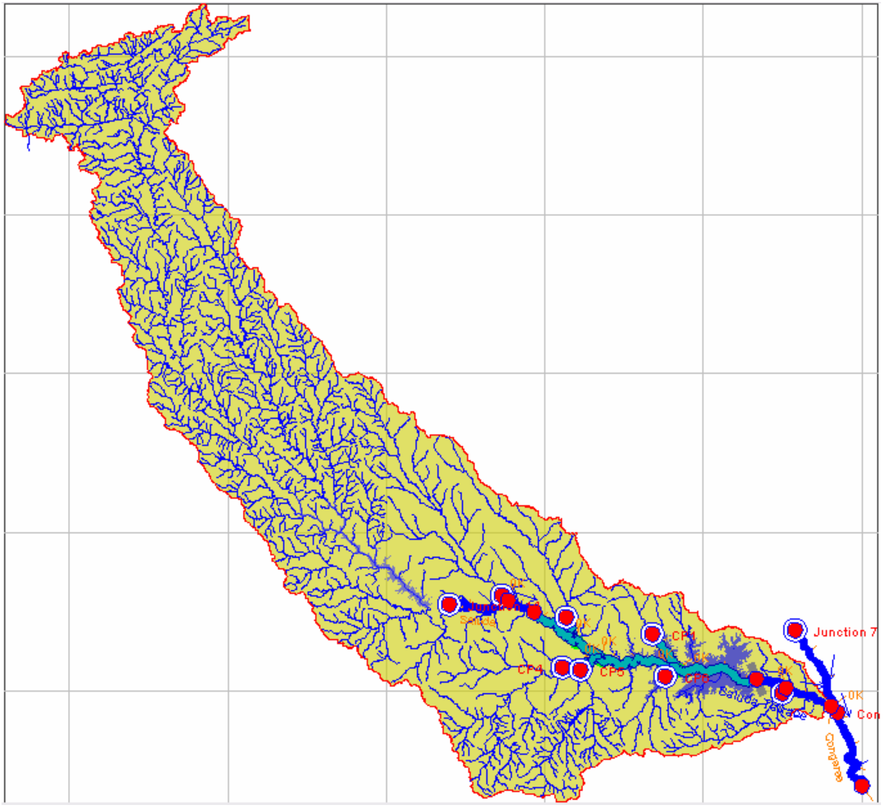
Model Development (cont)

- Components
  - Upstream Inflows
  - Lake Murray
  - Downstream Gages
  - Broad & Congaree River Gages



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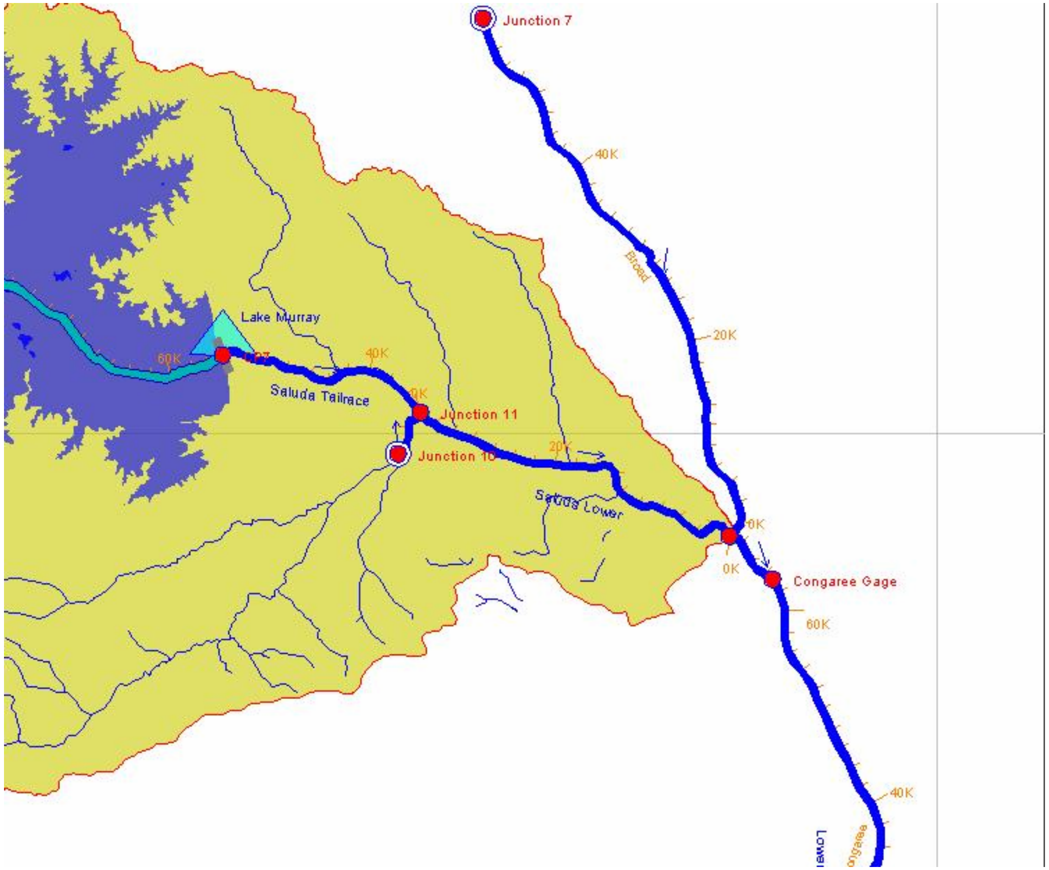
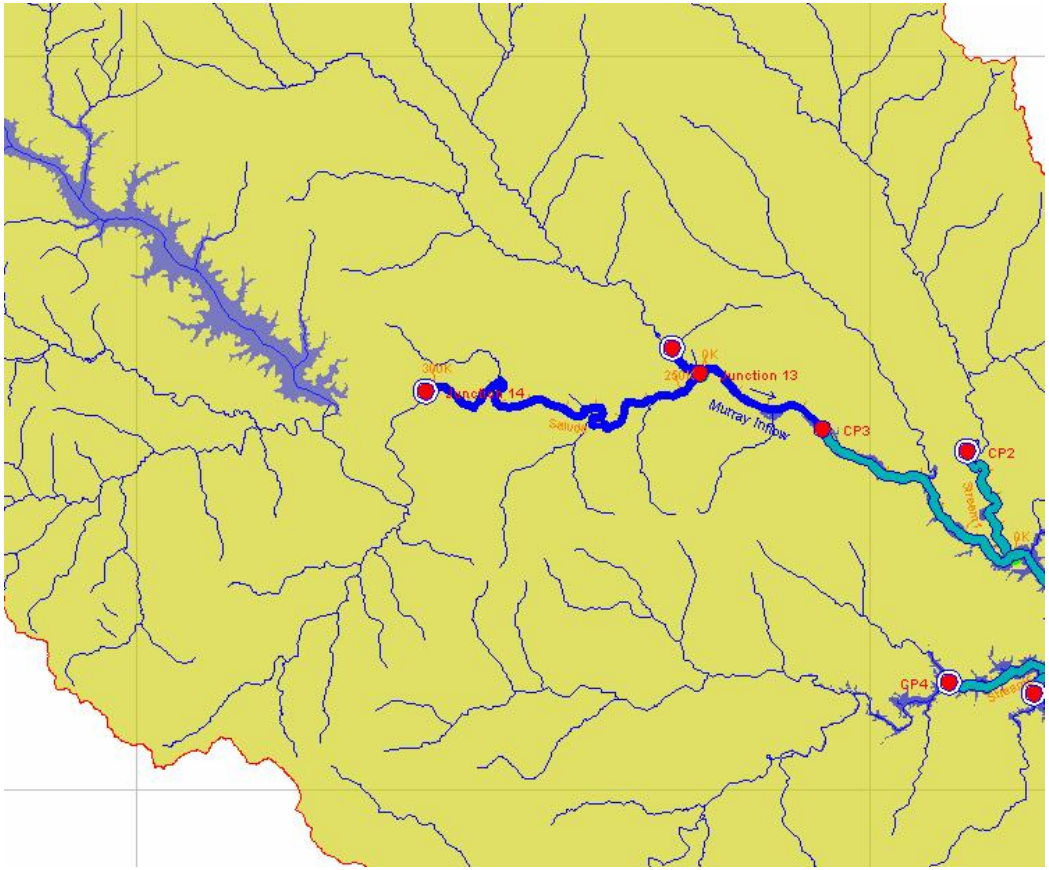
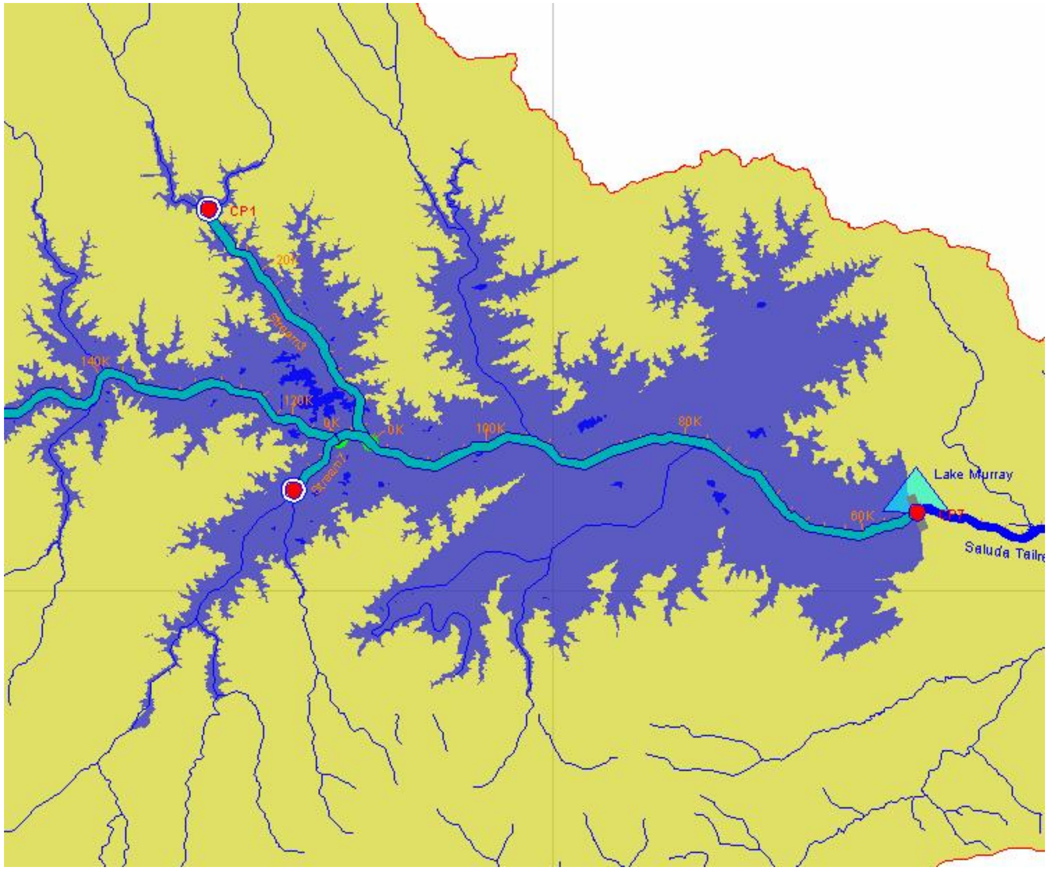
Data Layout - Downstream



Data Layout - Upstream



Data Layout – Lake Murray



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Available Data Sources

- Operations Data
  - Generation MWh (SCE&G)
  - Lake Level (USGS)
  - Downstream Flows (USGS)
- NWS – Precipitation data
- USGS – Flow Data
  - Flow Model Hydrology output

Available Data Sources (cont.)

- USGS gages
  - Saluda River at Chappells
    - 1360 sq. miles,1926-Present
  - Bush River near Prosperity
    - 115 sq. miles, 1990-Present
  - Little River near Silverstreet
    - 230 sq. miles, 1990-Present
  - Saluda River downstream of Lake Murray
    - 2420 sq. miles, 1988-present
  - Saluda River at Columbia
    - 2520 sq. miles, 1925-Present

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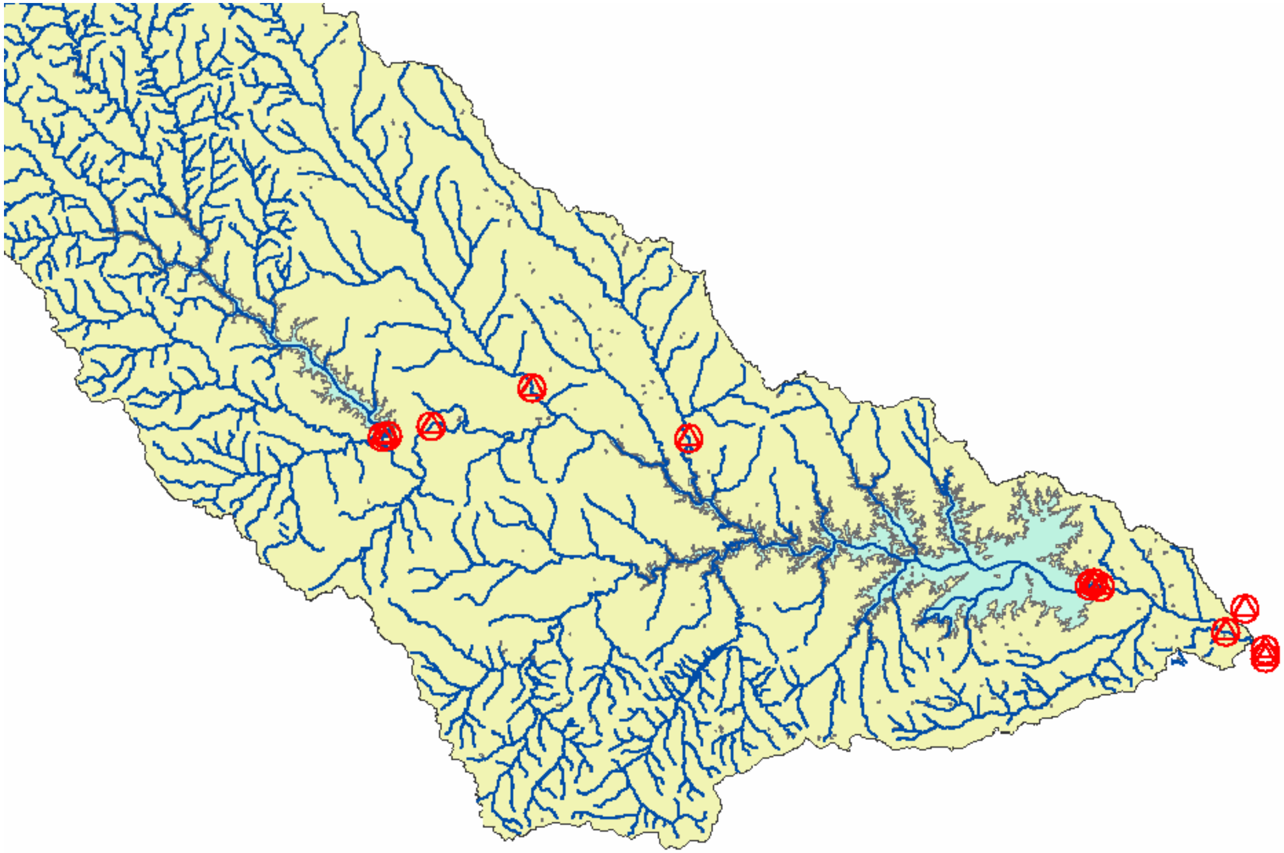
USGS Gage Locations



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Model Process

- Develop model of watershed system
- Calibrate to historical conditions
  - Historical model used to derive system inflows
- Using derived inflows, run simulations using proposed constraints to assess impacts on the Project

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Model Process

- Two Methods Tested for Developing Inflow Data:
  - 1) Upstream Gage Rating
    - Utilize available USGS gage data and adjust for ungaged areas
  - 2) Mass Balance
    - Hindcast from outflow and lake level data historical lake level data

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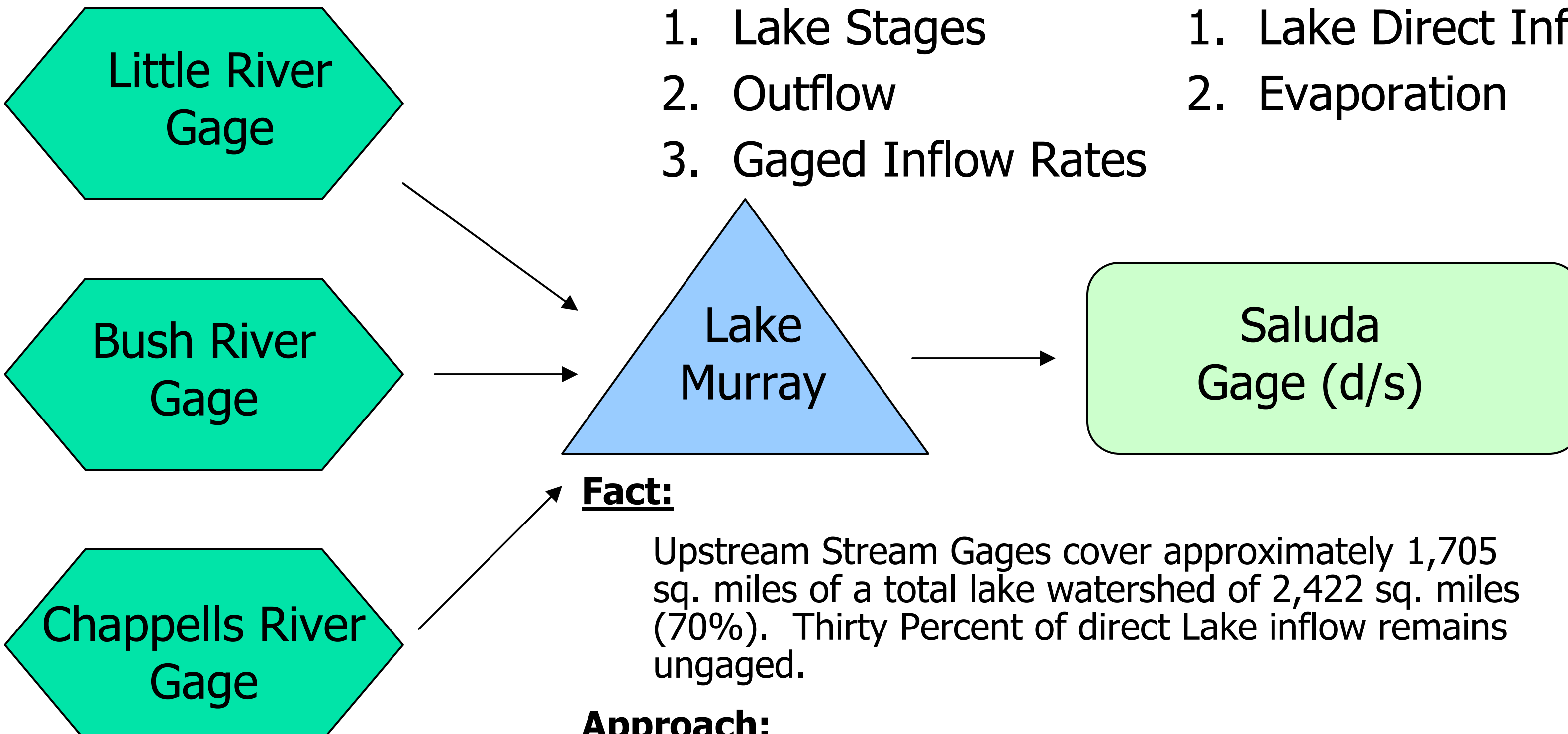
Method 1 - Gage Rating

<u>Known:</u>

1. Lake Stages
2. Outflow
3. Gaged Inflow Rates

<u>Unknown:</u>

1. Lake Direct Inflow
2. Evaporation



<u>Fact:</u>

Upstream Stream Gages cover approximately 1,705 sq. miles of a total lake watershed of 2,422 sq. miles (70%). Thirty Percent of direct Lake inflow remains ungaged.

<u>Approach:</u>

Increase upstream gages by a factor to account for any ungaged areas.

Saluda Hydro Relicensing

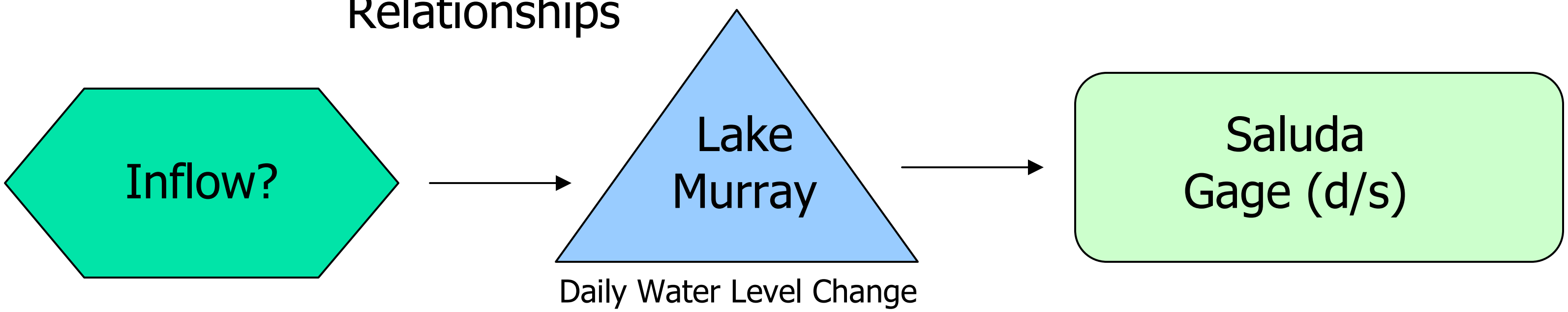
Method 2 - Mass Balance

Known:

1. Lake Stages
2. Outflow
3. Stage-Volume Relationships

Unknown:

1. Inflow



Fact:

Inflow = Change in Storage (Water Level) + Outflow

Approach:

Back calculate inflow using smoothed lake level data and gaged outflows

Calibration Procedure

1. Develop inflow hydrograph
2. Have model follow stage hydrograph by automatically adjusting discharge
   - Depends on how much flow is entering to decide how much to release
   - Must follow historically observed water levels (stage)
3. Compare calculated stage to observed stage
4. Compare correlation between calculated outflows and observed outflows (USGS gage)
5. Inflow that produces a 'good' fit would be considered calibrated
   - Both Methods were tested with this procedure

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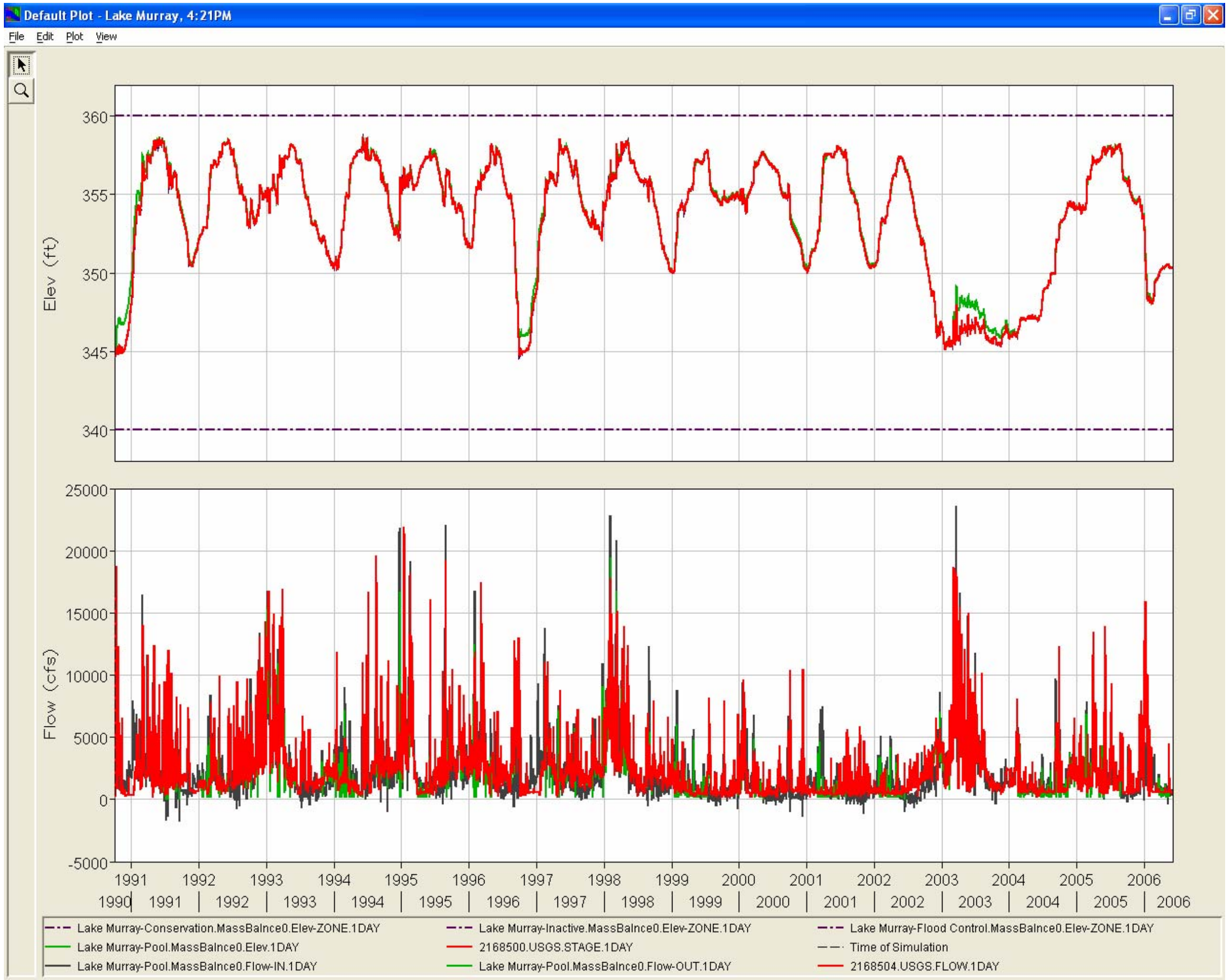
Calibration Results

Stage

Discharge



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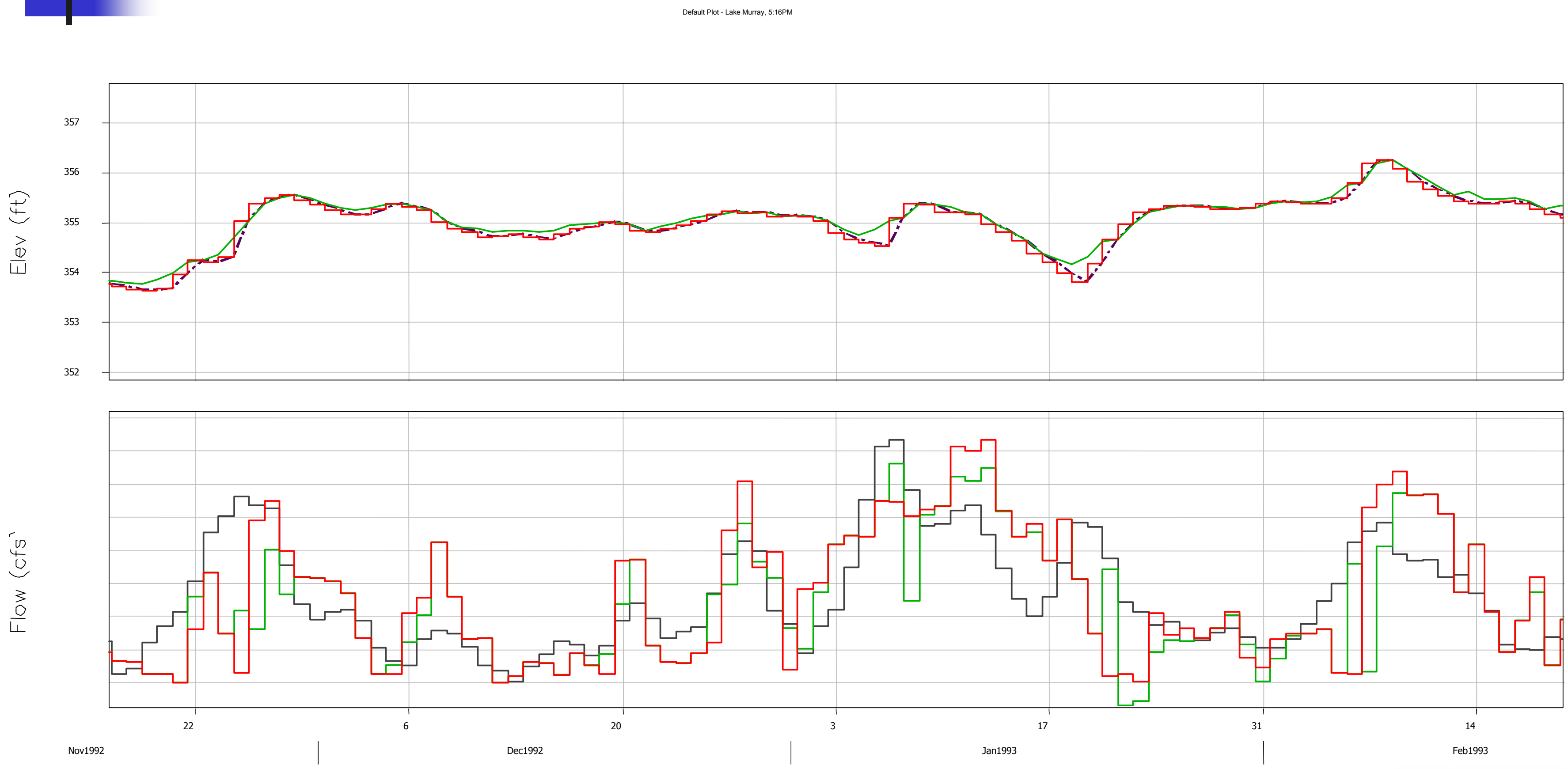
Calibration Results (cont)



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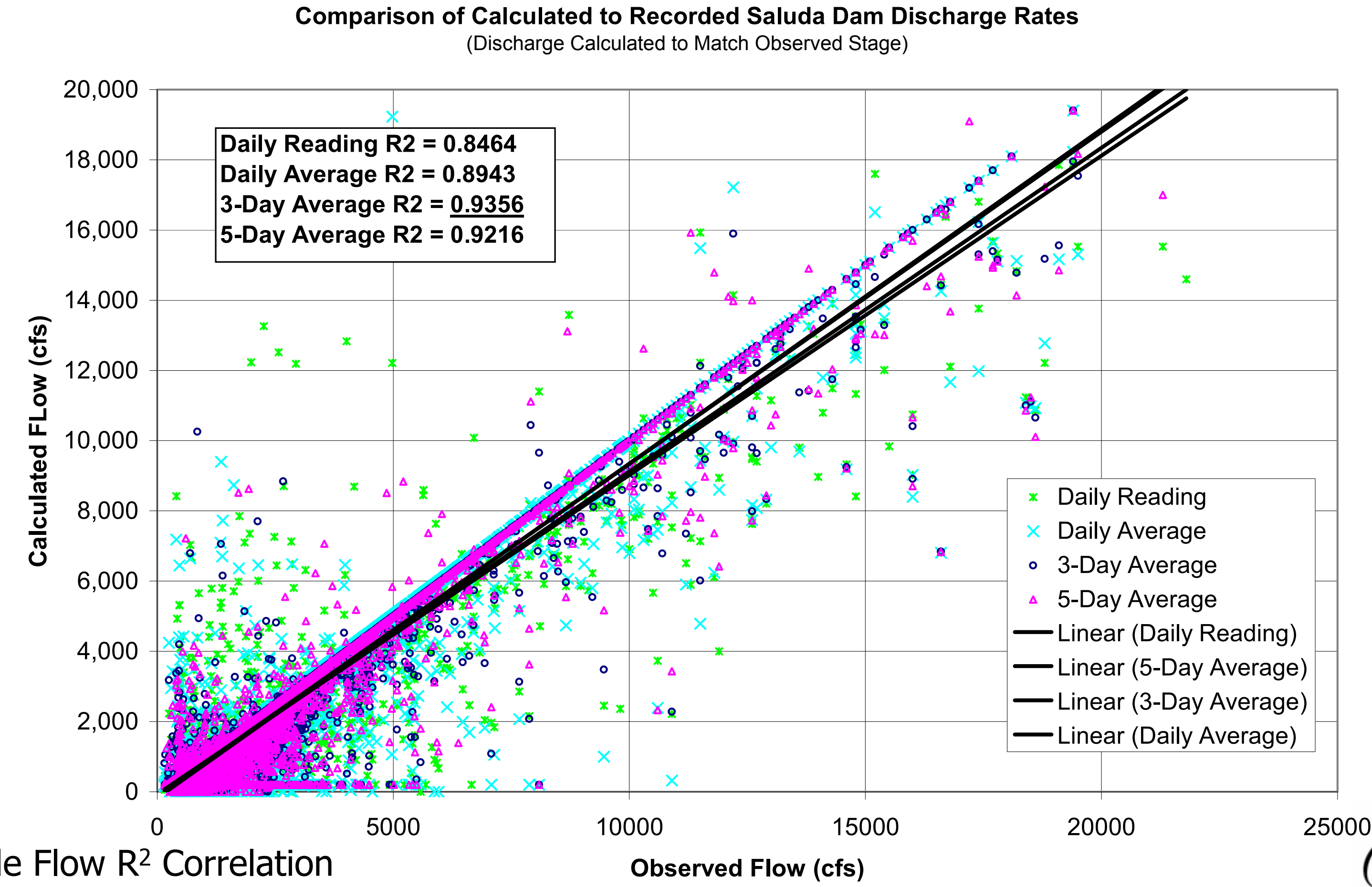
Calibration Results (cont)



*Sample Flow R^2 Correlation

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Calibration Discussion

- Lake level measurements
  - 0.1 feet of variation ~ 2200 cfs on a daily basis. SCE&G notes 0.06 feet is typical "noise" in lake level readings
  - Can result in excessive negative inflows (common problem with hindcast modeling)
  - Lake level data needed to be "smoothed" for mass balance method

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Calibration Discussion

- Accuracy of gages downstream of Lake Murray are suspect due to variations in volume
- Gages upstream have limited common period of record (1990-present)
- Low stage periods have poor correlation (result of drawdowns, accuracy of stage storage data)

Calibration Conclusion

- Mass balance method produced best correlation between both lake levels and outflows.
- **Mass balance method produced a highly correlated inflow hydrograph which is now ready for constraint analysis**

Break

- 20 minutes
- Calibration Questions?

Future Developments & Potential Results

- With a calibrated model… (i.e. we know inflow)
  - Evaluate Environmental Constraints
    - Temporal Stage Impacts
    - Temporal Discharge Impacts
  - Determine frequencies that constraints may be violated
- Further Evaluations
  - Downstream flow routing (confluence with Broad R.)
  - Flood Frequency Evaluation

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Sample Constraints

- Flow
  - Minimum flow between June 1st and August 1st and should be a minimum of 20,000 cfs for extreme whitewater course
- Stage
  - Maintain Lake Murray at elevation 380.0’ year-round

Constraint Requests

- Provide
  - Specific Elevations
  - Specific Flows

Extreme Example Application

- Extreme Flow Releases during Summer Months
- Information Provided
  - Operate during June, July & August
  - Minimum flow of 30,000 cfs
  - Not required on Mondays or Tuesdays

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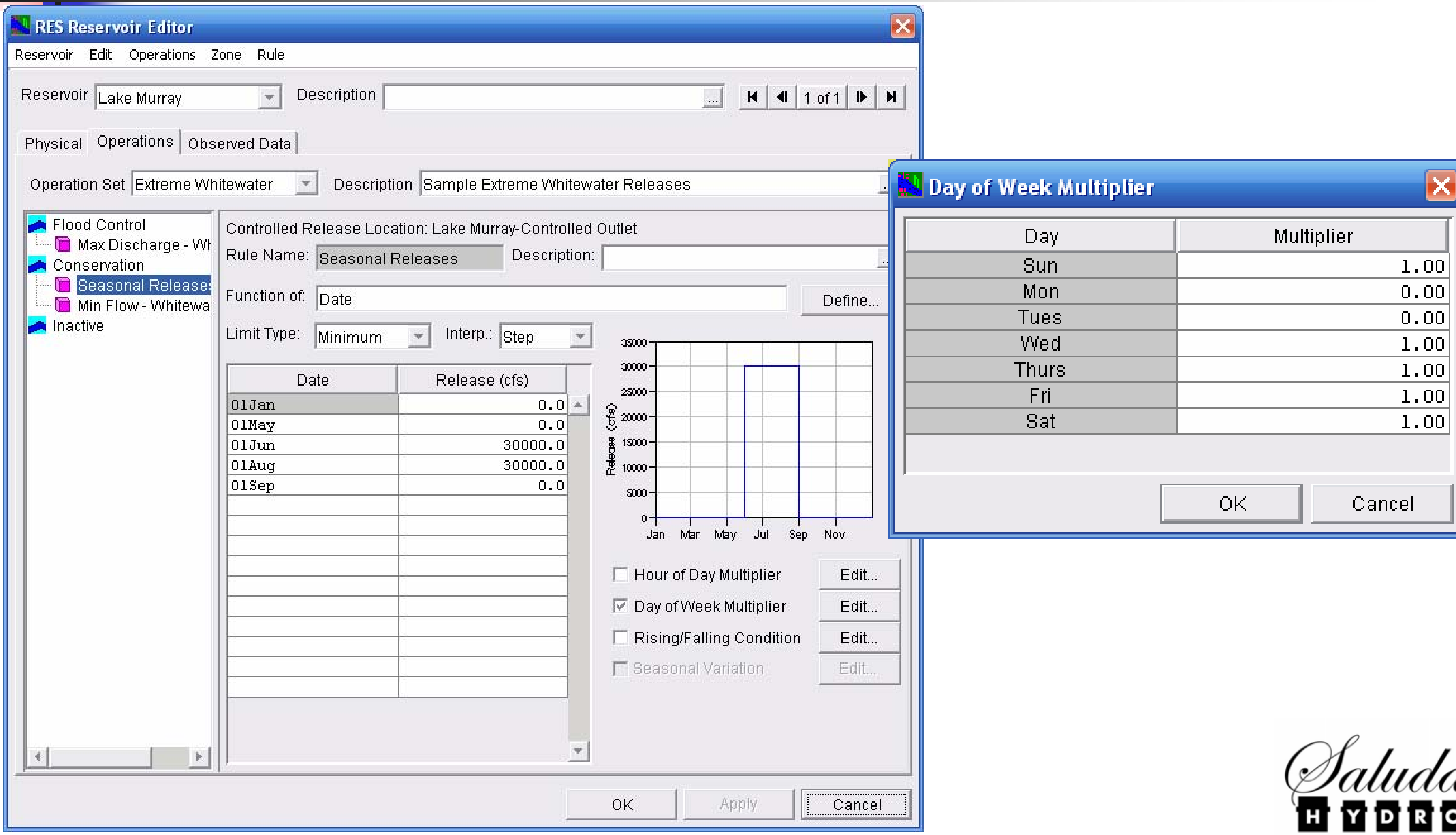
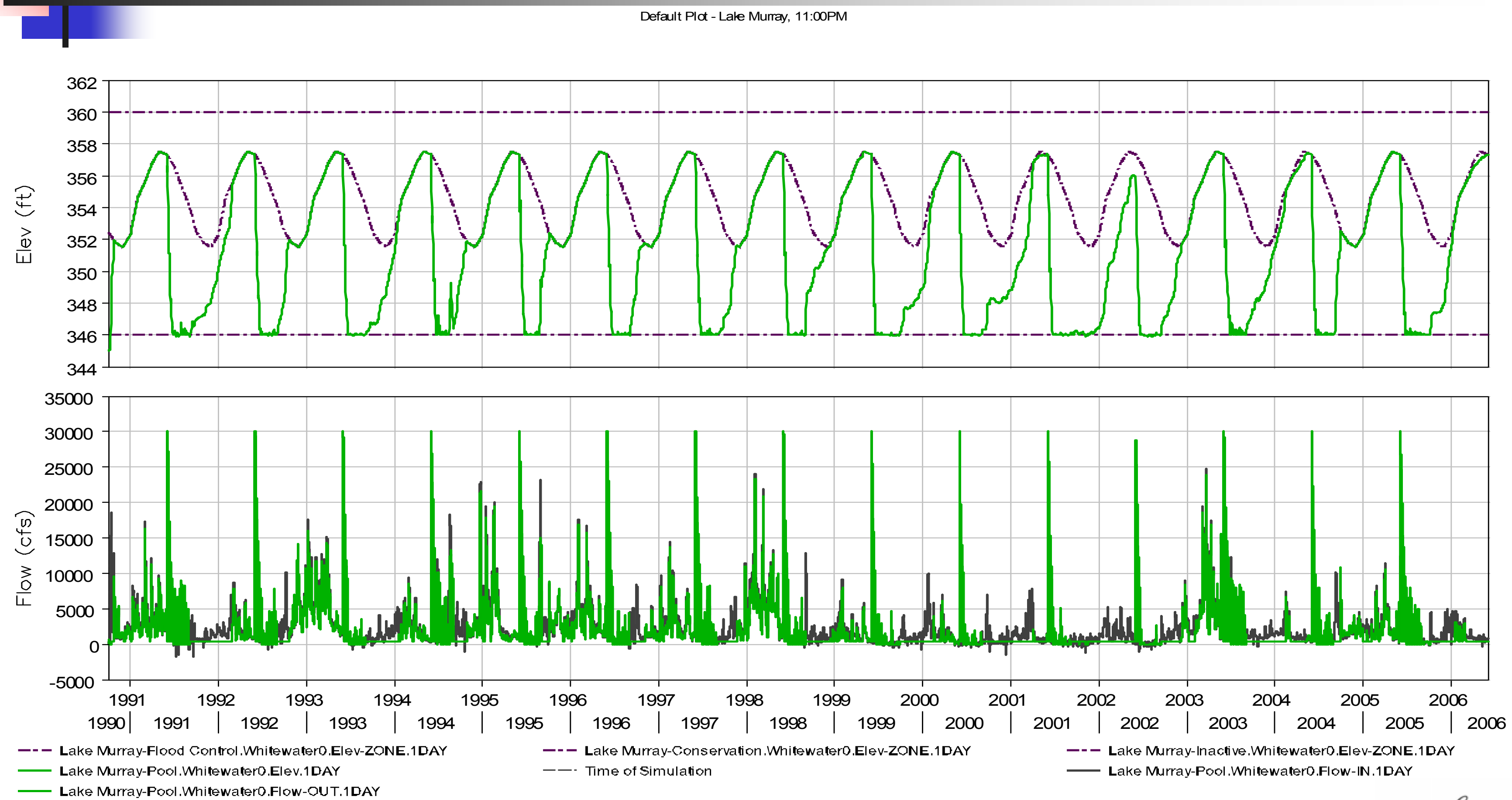
Constraint Setup Example



Saluda HYDRO RELICENSING

Extreme Example Output



Saluda HYDRO RELICENSING

Extreme Example Tables

//LAKE MURRAY-FLOOD CONTROL/ELEV-ZONE/01OCT1990/1DAY/WHITEWATER0/

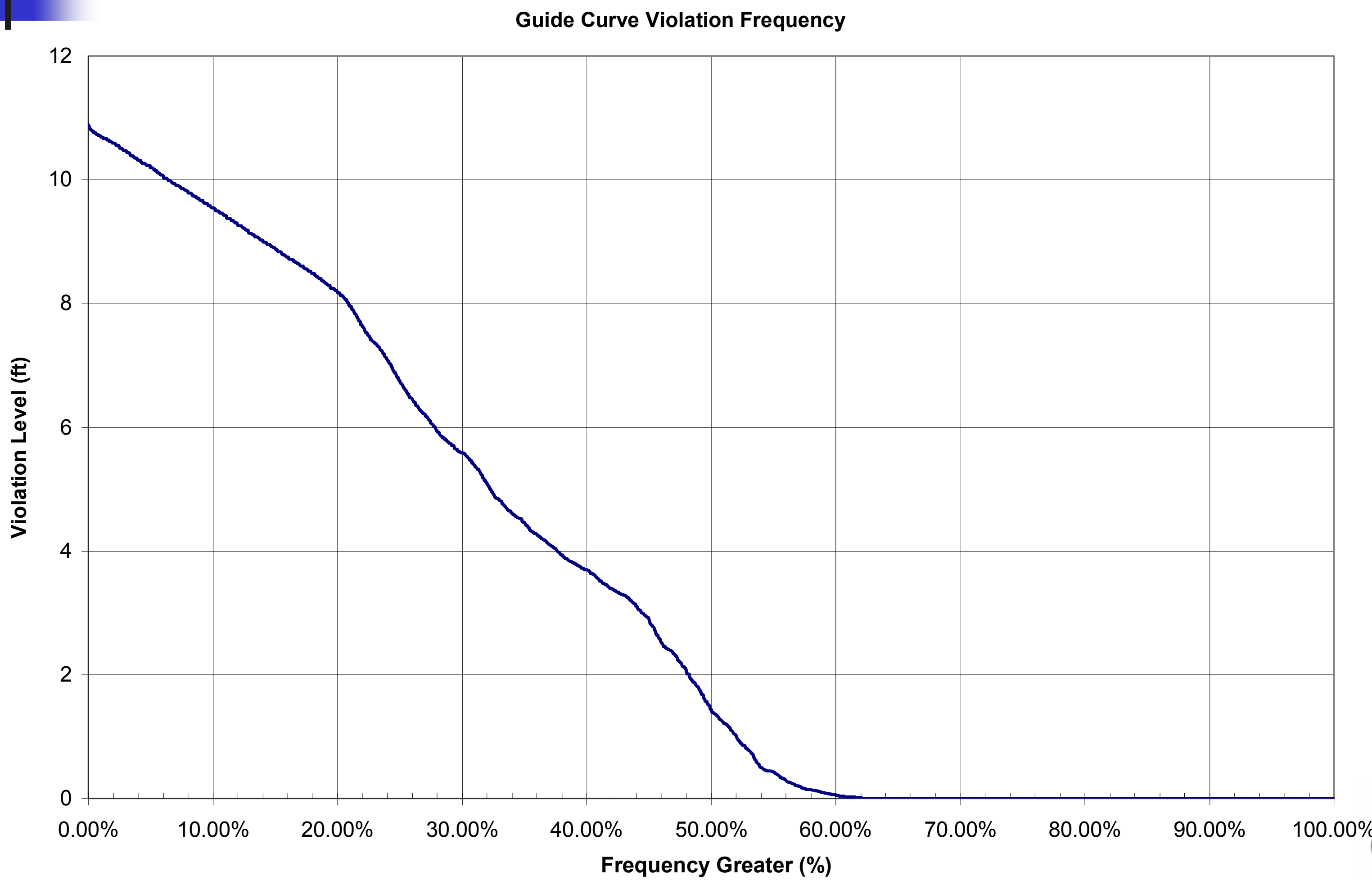
File Edit View

Ordinate	Date / Time	LAKE MURRA... ELEV-ZONE WHITEWATER0	LAKE MURRA... ELEV-ZONE WHITEWATER0	LAKE MURRA... ELEV-ZONE WHITEWATER0	LAKE MURRA... ELEV WHITEWATER0	LAKE MURRA... FLOW-IN WHITEWATER0	LAKE MURRA... FLOW-OUT WHITEWATER0
239	27 May 91 22:...	360.00	357.36	346.00	357.36	2,723	2,861
240	28 May 91 22:...	360.00	357.35	346.00	357.35	3,392	3,529
241	29 May 91 22:...	360.00	357.35	346.00	357.35	3,497	3,635
242	30 May 91 22:...	360.00	357.34	346.00	357.34	4,006	4,143
243	31 May 91 22:...	360.00	357.34	346.00	357.34	4,354	4,492
244	01 Jun 91 22:...	360.00	357.33	346.00	357.33	4,829	4,966
245	02 Jun 91 22:...	360.00	357.31	346.00	356.23	5,285	30,000
246	03 Jun 91 22:...	360.00	357.28	346.00	356.43	4,894	400
247	04 Jun 91 22:...	360.00	357.26	346.00	356.59	4,044	400
248	05 Jun 91 22:...	360.00	357.23	346.00	355.32	1,645	30,000
249	06 Jun 91 22:...	360.00	357.21	346.00	354.08	916	27,136
250	07 Jun 91 22:...	360.00	357.18	346.00	352.96	1,106	23,957
251	08 Jun 91 22:...	360.00	357.16	346.00	351.98	932	21,153
252	09 Jun 91 22:...	360.00	357.13	346.00	351.09	721	19,006
253	10 Jun 91 22:...	360.00	357.11	346.00	351.10	474	400
254	11 Jun 91 22:...	360.00	357.08	346.00	351.13	1,073	400
255	12 Jun 91 22:...	360.00	357.06	346.00	350.37	1,618	17,257
256	13 Jun 91 22:...	360.00	357.03	346.00	349.69	2,317	15,626
257	14 Jun 91 22:...	360.00	357.01	346.00	349.06	2,337	14,106
258	15 Jun 91 22:...	360.00	356.98	346.00	348.49	1,985	12,720
259	16 Jun 91 22:...	360.00	356.96	346.00	347.98	2,043	11,507
260	17 Jun 91 22:...	360.00	356.94	346.00	348.11	2,827	400
261	18 Jun 91 22:...	360.00	356.91	346.00	348.26	3,091	400
262	19 Jun 91 22:...	360.00	356.89	346.00	347.83	3,261	11,223
263	20 Jun 91 22:...	360.00	356.86	346.00	347.45	3,397	10,513
264	21 Jun 91 22:...	360.00	356.84	346.00	347.13	4,024	9,925
265	22 Jun 91 22:...	360.00	356.81	346.00	346.80	3,150	9,310
266	23 Jun 91 22:...	360.00	356.79	346.00	346.44	1,879	8,636
267	24 Jun 91 22:...	360.00	356.76	346.00	346.48	1,059	400
268	25 Jun 91 22:...	360.00	356.74	346.00	346.51	940	400

Interpretation of Example Results

- Interpretation of Results
  - Operation following this constraint visually drains the reservoir to a minimum of 346.0′
  - Dry years may not have sufficient inflow to return to Guide Curve
  - 50% of the days have greater than a 1.7′ reduction from the Guide Curve

Example Guide Curve Violation Frequency & Magnitude



Constraint Compilation

- Assemble all stage & flow constraints into HEC-ResSim model
- Evaluate various constraints to determine reasonableness

Next Steps

- Develop resource constraints in terms of *FLOW* and *ELEVATION* for model input and analysis
- Run model simulations using constraint inputs
- Determine impact of constraints on:
  - Project Operations
  - Project Generation
  - Downstream flows
  - Flood Frequencies

Questions?

Saluda HYDRO RELICENSING

ALTERNATIVE GENERATION EVALUATION

FOR

SALUDA HYDRO

SALUDA HYDRO

SALUDA HYDRO

- TOTAL GENERATION 206 MW

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.
- UNIT 5 70 MW

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.
- UNIT 5 70 MW
- START TIME <15 MIN.

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.
- UNIT 5 70 MW
- START TIME <15 MIN.
- RELIABILITY >95%

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.
- UNIT 5 70 MW
- START TIME <15 MIN.
- RELIABILITY >95%
- QUICK START RESERVE 206 MW

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.
- UNIT 5 70 MW
- START TIME <15 MIN.
- RELIABILITY >95%
- QUICK START RESERVE 206 MW
- BLACKSTART VC SUMMER

SALUDA HYDRO

- TOTAL GENERATION 206 MW
- UNITS 1-4 34 MW EA.
- UNIT 5 70MW
- START TIME <15 MIN.
- RELIABILITY >95%
- QUICK START RESERVE 206 MW
- BLACKSTART VC SUMMER
- LAKE LEVEL MANAGEMENT

ALTERNATIVE GENERATION TO SALUDA HYDRO

EVALUATION OF VIABLE OPTIONS

EVALUATION CONSIDERATIONS

EVALUATION CONSIDERATIONS

- ELECTRIC GENERATING EQUIPMENT

EVALUATION CONSIDERATIONS

- ELECTRIC GENERATING EQUIPMENT
- PLANT SITING

EVALUATION CONSIDERATIONS

- ELECTRIC GENERATING EQUIPMENT
- PLANT SITING
- CAPITAL AND O&M DOLLARS

EQUIPMENT EVALUATION

EQUIPMENT EVALUATION

- CAPACITY 200 MW

EQUIPMENT EVALUATION

- CAPACITY 200 MW
- START TIME <15 MIN.

EQUIPMENT EVALUATION

- CAPACITY 200 MW
- START TIME <15 MIN.
- EFFICIENCY

EQUIPMENT EVALUATION

- CAPACITY 200 MW
- START TIME <15 MIN.
- EFFICIENCY
- RELIABILITY

EQUIPMENT EVALUATION

- CAPACITY 200 MW
- START TIME <15 MIN.
- EFFICIENCY
- RELIABILITY
- PROVEN TECHNOLOGY

EQUIPMENT ALTERNATIVES

EQUIPMENT ALTERNATIVES

- DIESEL GENERATORS

EQUIPMENT ALTERNATIVES

- DIESEL GENERATORS
- GAS TURBINES (AERO DERIVED)

DIESEL GENERATORS

DIESEL GENERATORS

- SIZE 2 – 2 1/2 MW

DIESEL GENERATORS

- SIZE 2 – 2 1/2 MW
- GENSET

DIESEL GENERATORS

- SIZE 2 – 2 1/2 MW
- GENSET
- 80-100 UNITS

DIESEL GENERATORS

- SIZE 2 – 2 1/2 MW
- GENSET
- 83-100 UNITS
- START TIME 10 MIN.

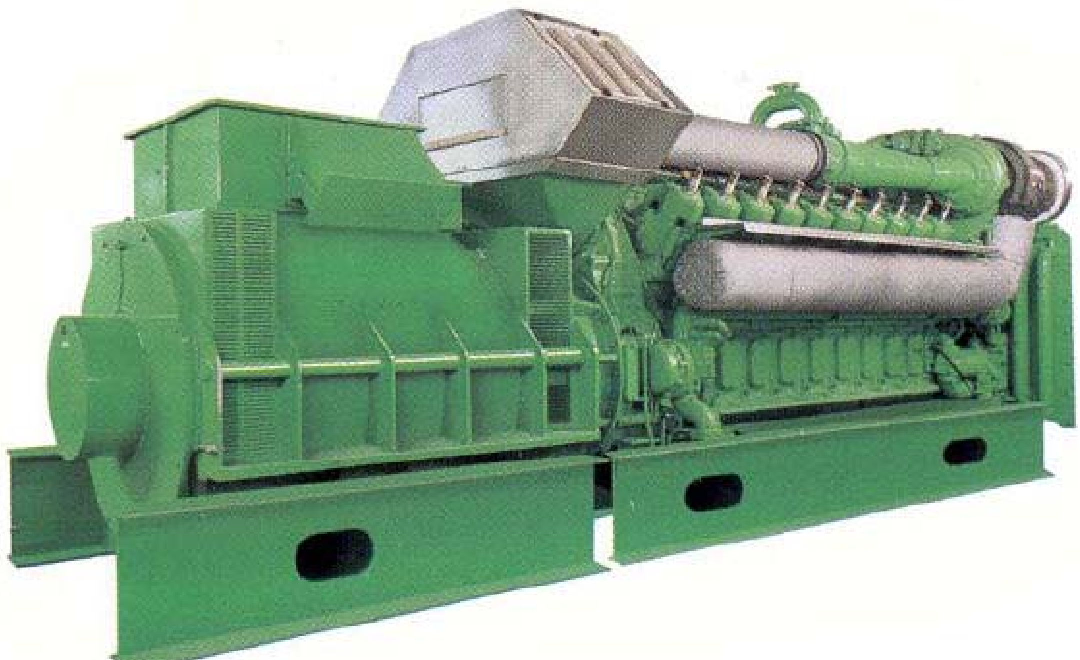
DIESEL GENERATORS

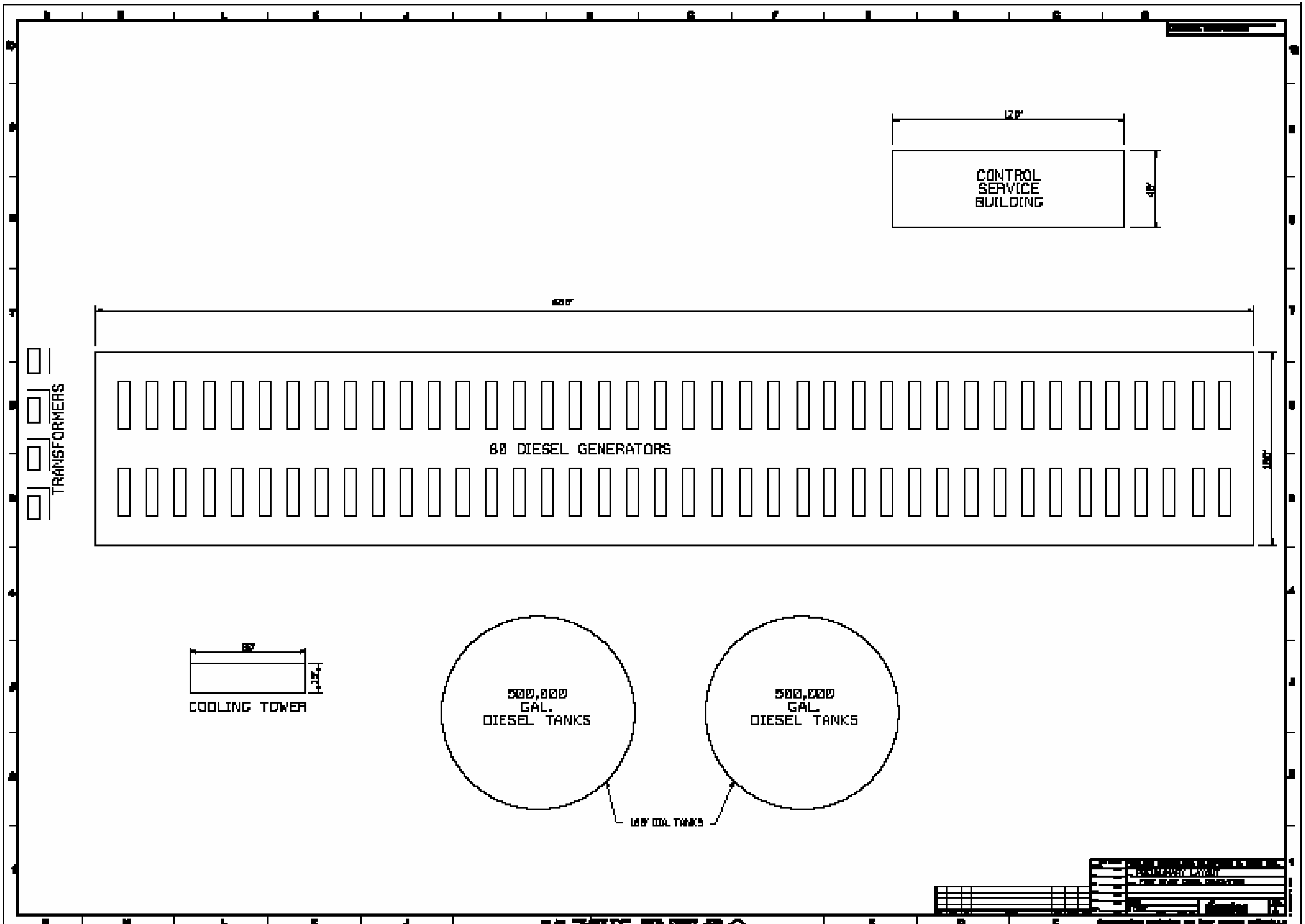
- SIZE 2 – 2 1/2 MW
- GENSET
- 83-100 UNITS
- START TIME 10 MIN.
- EFFICIENCY 37%

DIESEL GENERATORS

- SIZE 2 – 2 1/2 MW
- GENSET
- 83-100 UNITS
- START TIME 10 MIN.
- EFFICIENCY 37%
- RELIABILITY 90%

DIESEL GENSET





120'
CONTROL
SERVICE
BUILDING
TRANSFORMERS
60 DIESEL GENERATORS
COOLING TOWER
500,000
GAL.
DIESEL TANKS
500,000
GAL.
DIESEL TANKS
100' DIA. TANKS

GAS TURBINES(AERO DERIVED)

GAS TURBINES(AERO DERIVED)

- SIZE 50 MW

GAS TURBINES(AERO DERIVED)

- SIZE 50 MW
- GENERAL ELECTRIC LM6000

GAS TURBINES(AERO DERIVED)

- SIZE 50 MW
- GENERAL ELECTRIC LM6000
- 4 UNITS

GAS TURBINES(AERO DERIVED)

- SIZE 50 MW
- GENERAL ELECTRIC LM6000
- 4 UNITS
- START TIME 10 MIN.

GAS TURBINES(AERO DERIVED)

- SIZE 50 MW
- GENERAL ELECTRIC LM6000
- 4 UNITS
- START TIME 10 MIN.
- EFFICIENCY 40%

GAS TURBINES(AERO DERIVED)

- SIZE 50 MW
- GENERAL ELECTRIC LM6000
- 4 UNITS
- START TIME 10 MIN.
- EFFICIENCY 40%
- RELIABILITY 90%

PLANT SITING EVALUATION

PLANT SITING EVALUATION

- PERMITTING

PLANT SITING EVALUATION

- PERMITTING
- WATER AVAILABLITY

PLANT SITING EVALUATION

- PERMITTING
- WATER AVAILABLITY
- INTERCONNECTIONS

PLANT SITING EVALUATION

- PERMITTING
- WATER AVAILABLITY
- INTERCONNECTIONS
- PLANT LAYOUT /CONSTRUCTABILITY

PLANT SITING EVALUATION

- PERMITTING
- WATER AVAILABLITY
- INTERCONNECTIONS
- PLANT LAYOUT /CONSTRUCTABILITY
- LAND AVAILABILITY

PLANT SITING EVALUATION

- PERMITTING
- WATER AVAILABLITY
- INTERCONNECTIONS
- PLANT LAYOUT /CONSTRUCTABILITY
- LAND AVAILABILITY
- PSC APPROVAL

PERMITTING

PERMITTING

- AIR EMISSIONS

PERMITTING

- AIR EMISSIONS
- WATER INTAKE

PERMITTING

- AIR EMISSIONS
- WATER INTAKE
- WATER DISCHARGE

PERMITTING

- AIR EMISSIONS
- WATER INTAKE
- WATER DISCHARGE
- STORM WATER CONTROL

PERMITTING

- AIR EMISSIONS
- WATER INTAKE
- WATER DISCHARGE
- STORM WATER CONTROL
- WETLANDS

PERMITTING

- AIR EMISSIONS
- WATER INTAKE
- WATER DISCHARGE
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- WETLANDS
- COUNTY REGULATIONS

PERMITTING

- AIR EMISSIONS
- WATER INTAKE
- WATER DISCHARGE
- STORM WATER CONTROL
- WETLANDS
- COUNTY REGULATIONS
- SCHEDULE IMPACT 1-2 YEARS

DOLLARS EVALUATION

DOLLARS EVALUATION

- CAPITAL COST

DOLLARS EVALUATION

- CAPITAL COST
- LIFE CYCLE COST 30 YRS

COST OF:

COST OF:

- LAND

COST OF:

- LAND
- PERMITTING

COST OF:

- LAND
- PERMITTING
- GENERATING EQUIPMENT

COST OF:

- LAND
- PERMITTING
- GENERATING EQUIPMENT
- BALANCE OF PLANT

COST OF:

- LAND
- PERMITTING
- GENERATING EQUIPMENT
- BALANCE OF PLANT
- ENGINEERING

COST OF:

- LAND
- PERMITTING
- GENERATING EQUIPMENT
- BALANCE OF PLANT
- ENGINEERING
- CONSTRUCTION

COST OF:

- LAND
- PERMITTING
- GENERATING EQUIPMENT
- BALANCE OF PLANT
- ENGINEERING
- CONSTRUCTION
- START-UP

COST OF:

- LAND
- PERMITTING
- GENERATING EQUIPMENT
- BALANCE OF PLANT
- ENGINEERING
- CONSTRUCTION
- START-UP
- PROJECT MANAGEMENT

PARAMETERS / ASSUMPTIONS

PARAMETERS / ASSUMPTIONS

- ORDER OF MAGNITUDE ESTIMATE

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- +25% / -10% ACCURACY

PARAMETERS / ASSUMPTIONS

- ORDER OF MAGNITUDE ESTIMATE
- +25% / -10% ACCURACY
- 2006 DOLLARS FOR CAPITAL $
- 2010 DOLLARS FOR LIFE CYCLE $

PARAMETERS / ASSUMPTIONS

- ORDER OF MAGNITUDE ESTIMATE
- +25% / -10% ACCURACY
- 2006 DOLLARS FOR CAPITAL $
- 2010 DOLLARS FOR LIFE CYCLE $
- ESCALATION EXCLUDED

PARAMETERS / ASSUMPTIONS

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- 2010 DOLLARS FOR LIFE CYCLE $
- ESCALATION EXCLUDED
- COST OF MONEY EXCLUDED

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- COST OF MONEY EXCLUDED
- PROVEN GENERATION TECHNOLOGY

PARAMETERS / ASSUMPTIONS

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- 2006 DOLLARS FOR CAPTIAL $
- 2010 DOLLARS FOR LIFE CYCLE $
- ESCALATION EXCLUDED
- COST OF MONEY EXCLUDED
- PROVEN GENERATION TECHNOLOGY
- NEW PLANT SITE

PARAMETERS / ASSUMPTIONS

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- +25% / -10% ACCURACY
- 2006 DOLLARS FOR CAPITAL $
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- COST OF MONEY EXCLUDED
- PROVEN GENERATION TECHNOLOGY
- NEW PLANT SITE
- NATURAL GAS AVAILABLE

PARAMETERS / ASSUMPTIONS

- ORDER OF MAGNITUDE ESTIMATE
- +25% / -10% ACCURACY
- 2006 DOLLARS FOR CAPITAL $
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- ESCALATION EXCLUDED
- COST OF MONEY EXCLUDED
- PROVEN GENERATION TECHNOLOGY
- NEW PLANT SITE
- NATURAL GAS AVAILABLE
- TRANSMISSION CONNECTION AVAILABLE

PARAMETERS / ASSUMPTIONS

- ORDER OF MAGNITUDE ESTIMATE
- +25% / -10% ACCURACY
- 2006 DOLLARS FOR CAPITAL $
- 2010 DOLLARS FOR LIFE CYCLE $
- ESCALATION EXCLUDED
- COST OF MONEY EXCLUDED
- PROVEN GENERATION TECHNOLOGY
- NEW PLANT SITE
- NATURAL GAS AVAILABLE
- TRANSMISSION CONNECTION AVAILABLE
- WATER AVAILABLE

CAPTITAL COST DIESEL GEN

LAND	$100,000
PERMITTING	$160,000
EQUIPMENT	$40,500,000
BALANCE OF PLANT	$38,000,000
ENGINEERING	$500,000
CONSTRUCTION	$7,000,000
START-UP	$250,000
PROJECT MGMT	$250,000
TOTAL	$86,850,000

CAPITAL COST GAS TURBINES

LAND	$100,000
PERMITTING	$160,000
EQUIPMENT	$58,800,000
BALANCE OF PLANT	$18,780,000
ENGINEERING	$600,000
CONSTRUCTION	$11,400,000
START-UP	$200,000
PROJECT MGMT	$300,000
TOTAL	$90,390,000

CAPITAL COST SALUDA HYDRO

LAND	NA
RE-LICENSING	<$12 MILLION
EQUIPMENT	$20,000,000
BALANCE OF PLANT	In- above
ENGINEERING	In-above
CONSTRUCTION	In-above
START-UP	In-above
PROJECT MGMT	In-above
TOTAL	$32,000,000

LIFE CYCLE COSTS 30 YEARS (includes capital, O&M, fuel)

SALUDA	$174,000,000
GAS TURBINES	$508,230,000
DIESEL GEN'S	$705,000,000

SALUDA ADVANTAGES

SALUDA ADVANTAGES

- LOWER LIFE CYCLE COST

SALUDA ADVANTAGES

- LOWER LIFE CYCLE COST
- BETTER RELIABILITY

SALUDA ADVANTAGES

- LOWER LIFE CYCLE COST
- BETTER RELIABILITY
- NO AIR EMISSIONS

SALUDA ADVANTAGES

- LOWER LIFE CYCLE COST
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- NO AIR EMISSIONS
- NO NEW PLANT SITING IMPACT

SALUDA ADVANTAGES

- LOWER LIFE CYCLE COST
- BETTER RELIABILITY
- NO AIR EMISSIONS
- NO NEW PLANT SITING IMPACT
- AVAILABLE QUICK START RESERVE

SALUDA ADVANTAGES

- LOWER LIFE CYCLE COST
- BETTER RELIABILITY
- NO AIR EMISSIONS
- NO NEW PLANT SITING IMPACT
- AVAILABLE QUICK START RESERVE
- VCS BLACKSTART CAPABILTY

ALT GENERATION IMPACTS

ALT GENERATION IMPACTS

- HIGHER RATES FOR ELECTRICITY

ALT GENERATION IMPACTS

- HIGHER RATES FOR ELECTRICITY
- HIGHER EMISSIONS

ALT GENERATION IMPACTS

- HIGHER RATES FOR ELECTRICITY
- HIGHER EMISSIONS
- LAND USE

QUESTIONS?

South Carolina Electric & Gas Saluda Project

Reservoir Modeling

Model Objectives

- What are the objectives of the modeling work?
  - Reservoir Model
  - Watershed Model
  - Water Quality Model
  - Generation Model
  - System Model
  - Other

Model Objectives

- Hydrologic Model
- Hydraulic Model
- Economic Model
- Water Quality Model

- Combination of all?

Model Objectives

- Suggested objectives from 12/6 Operations Group Meeting
  - Lake levels
  - LSR or Minimum Flows
  - Inflows
  - Generation
  - Storage
  - Graphic Ability
  - Interactive Front End

Mission Statement

"…establish a baseline of current hydrologic, hydraulic and operational conditions, and aid in analyzing and understanding the potential upstream and downstream effects of potential changes to project operation…."

System Modeling

- Potential new model options
  - HEC-5
  - OASIS
  - CHEOPS
  - *MIKE Basins*
  - *WMS*
  - Decision Support Programs

HEC-5

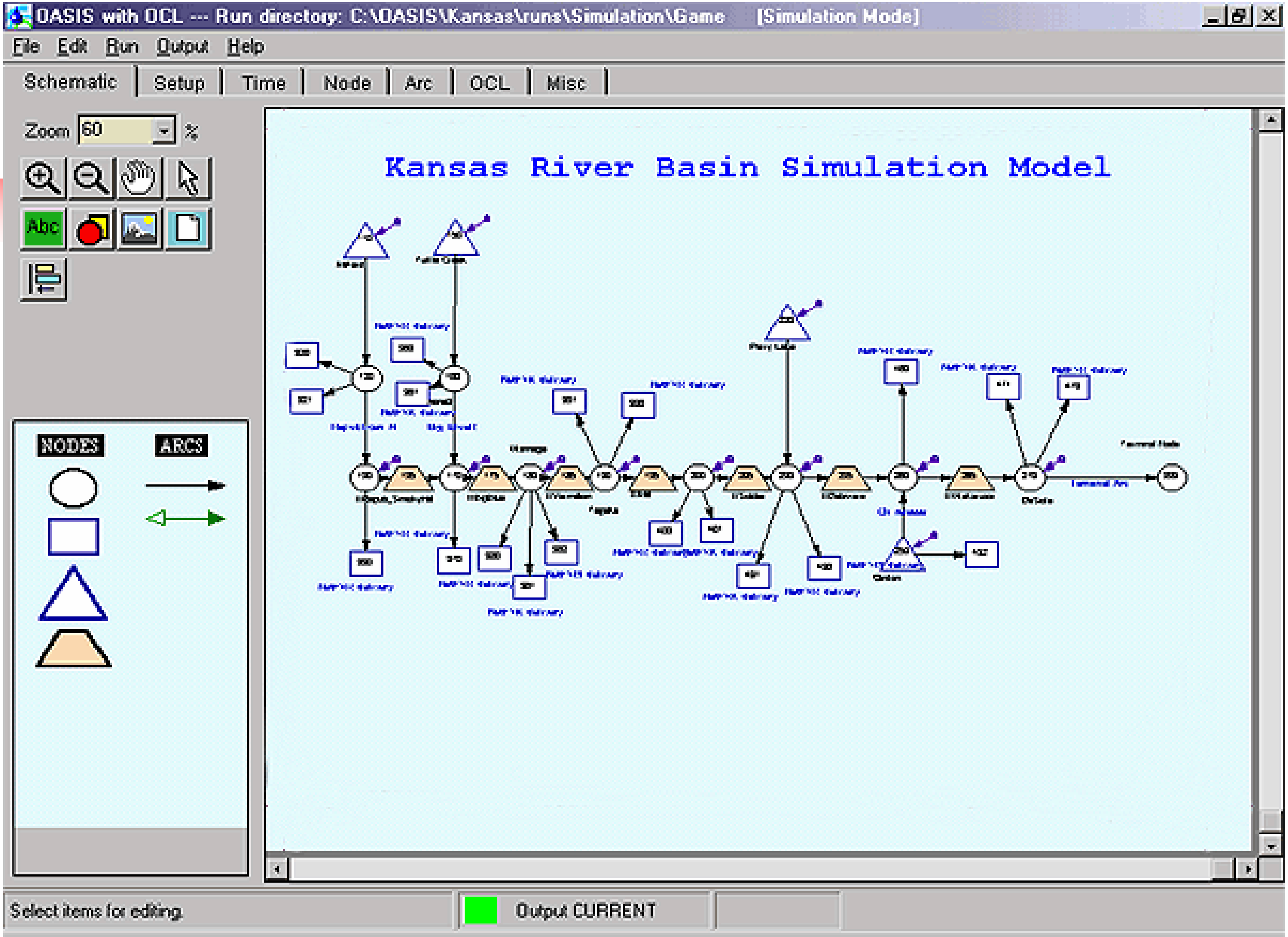
- Designed to simulate a sequential operation of a reservoir channel system
- Public domain software
- Major focus of model
  - Reservoir operations
  - Flood Control
  - Optimization of Water Supply and Hydropower operations
  - Flood Damage and reservoir economics

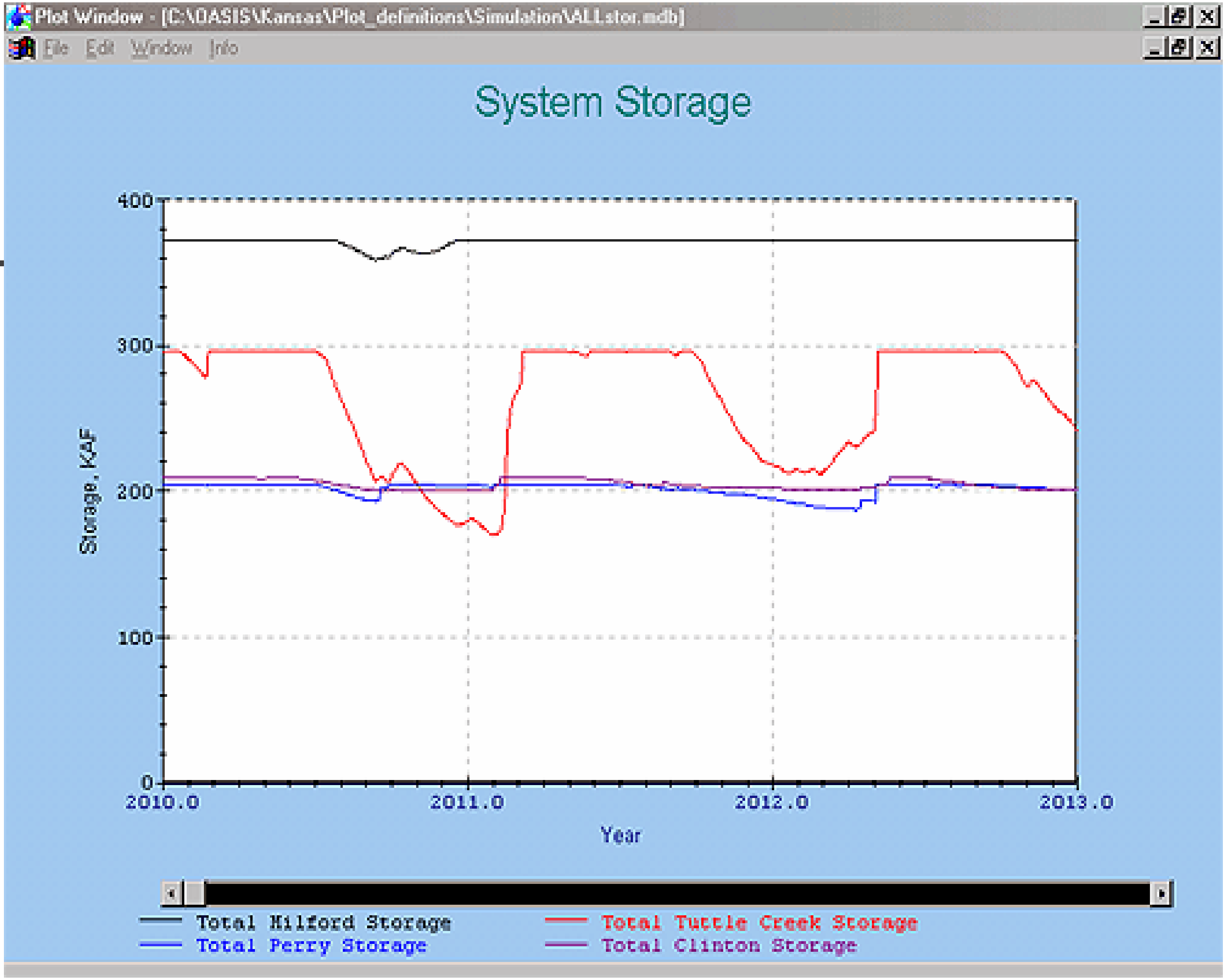
OASIS

- Routes water through a water resource system
- Extremely flexible
- Purchased Software
- Can account for both human and physical constraints on the reservoir system.
- Allows for assessment of management options, supply options, alterations due to biologic requirements or other sociologic driven demands.

OASIS

- Operates using Constraints and Goals for all decisions
- Ability to interface with a wide variety of other models.
- Can run several models simultaneously within the OASIS shell.
- Graphical Interfaces


OASIS with OCL --- Run directory: C:\OASIS\Kansas\runs\Simulation\Game [Simulation Mode]
File
Edit
Run
Output
Help
Schematic
Setup
Time
Node
Arc
OCL
Misc
Zoom
60
%
Abc
NODES
ARCS
Kansas River Basin Simulation Model
Select items for editing.
Output CURRENT


Plot Window - [C:\OASIS\Kansas\Plot_definitions\Simulation\ALLstor.mdb]
File Edit Window Info
System Storage
Storage, KAF
400
300
200
100
0
2010.0
2011.0
2012.0
2013.0
Year
Total Milford Storage
Total Tuttle Creek Storage
Total Perry Storage
Total Clinton Storage

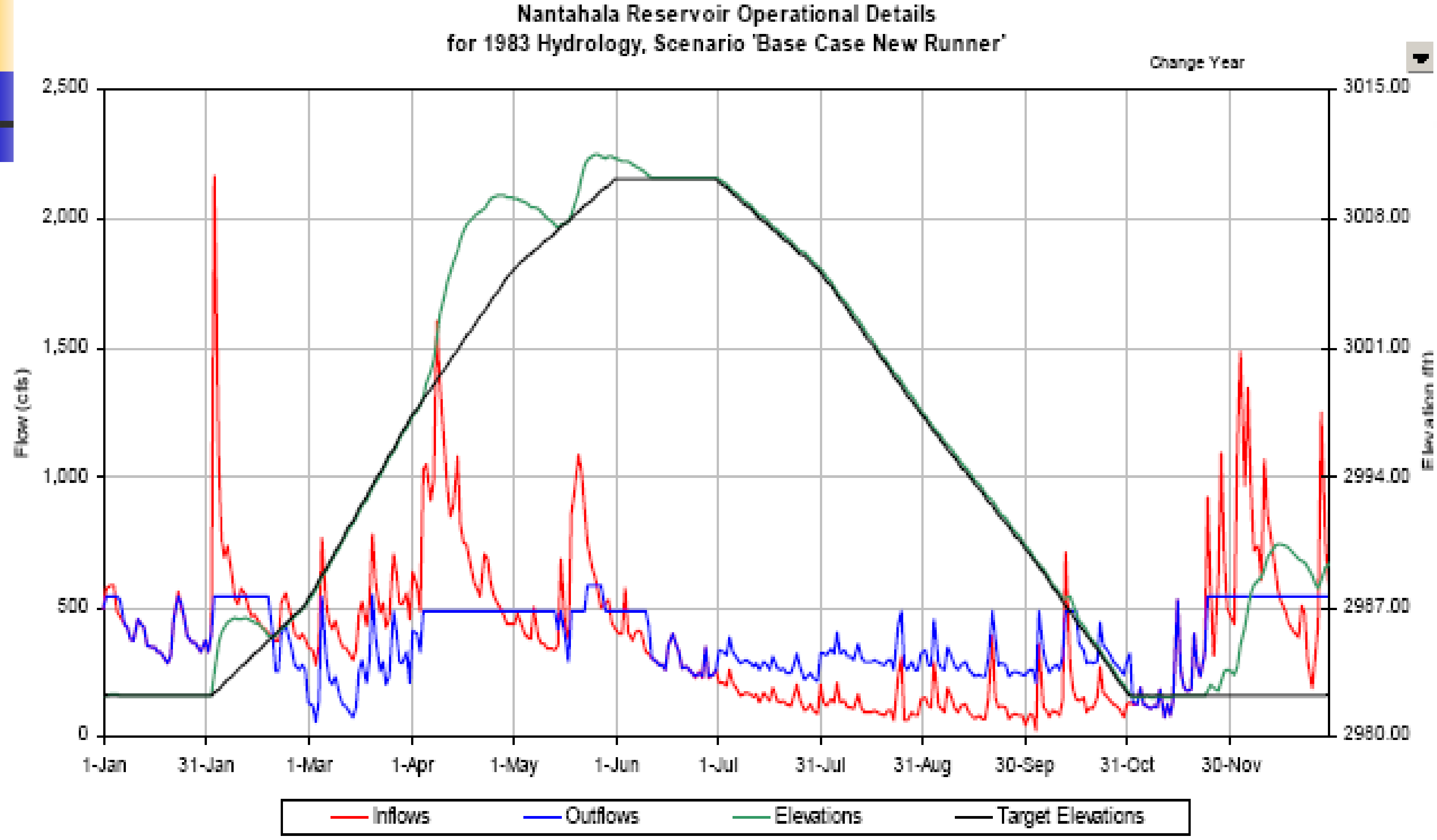
CHEOPS

- Operations and Planning Program
- Models reservoir systems
- Private domain software
- Focuses on hydroelectric optimization
- Has Graphical and Tabular Outputs
- Potential for Long Run Time

Base Case New Runner

(Normal 1983)

CHEOPS
Operations and Planning Model



Existing Models

- SCE&G Flow Forecast Model
  - Currently used to model what-if scenarios for project operations.
  - Model is calibrated to system, updated as required
  - Run daily – incorporates NWS and USGS data.
  - Encompasses entire Saluda Basin
    - Rainfall/Runoff Relationship
    - Reservoir levels
    - Inflows/Outflows
    - Minimum flows
  - Meets almost all criteria noted in minutes from 12/6 group meeting

Existing Models

- RMS 4 – Downstream water quality (DO and Temp) and simulated fish growth
- W2 model
  - Assessed water quality parameters of reservoir.
    - Phosphorous
    - DO
    - Thermal Stratification

Conclusion

- Most of the noted objectives are met with existing models
- Any additional model objectives need to be identified
- Can existing models be modified to meet all required objectives?

Data Sources

- SCE&G Operations Data
  - Generation
  - Lake Level
  - Tailwater
  - Downstream flows
- NWS – Precipitation data
- USGS – Flow Data
  - Flow Model Hydrology output

Data Sources

- Other Resources?

Output Requirements

- Water Levels
- Generation Impacts
- Downstream levels
- Economics

Model Methodology

- Use typical year
- Hold inflows constant to assess impact on changes in operation on lake levels

Saluda Hydro Operations

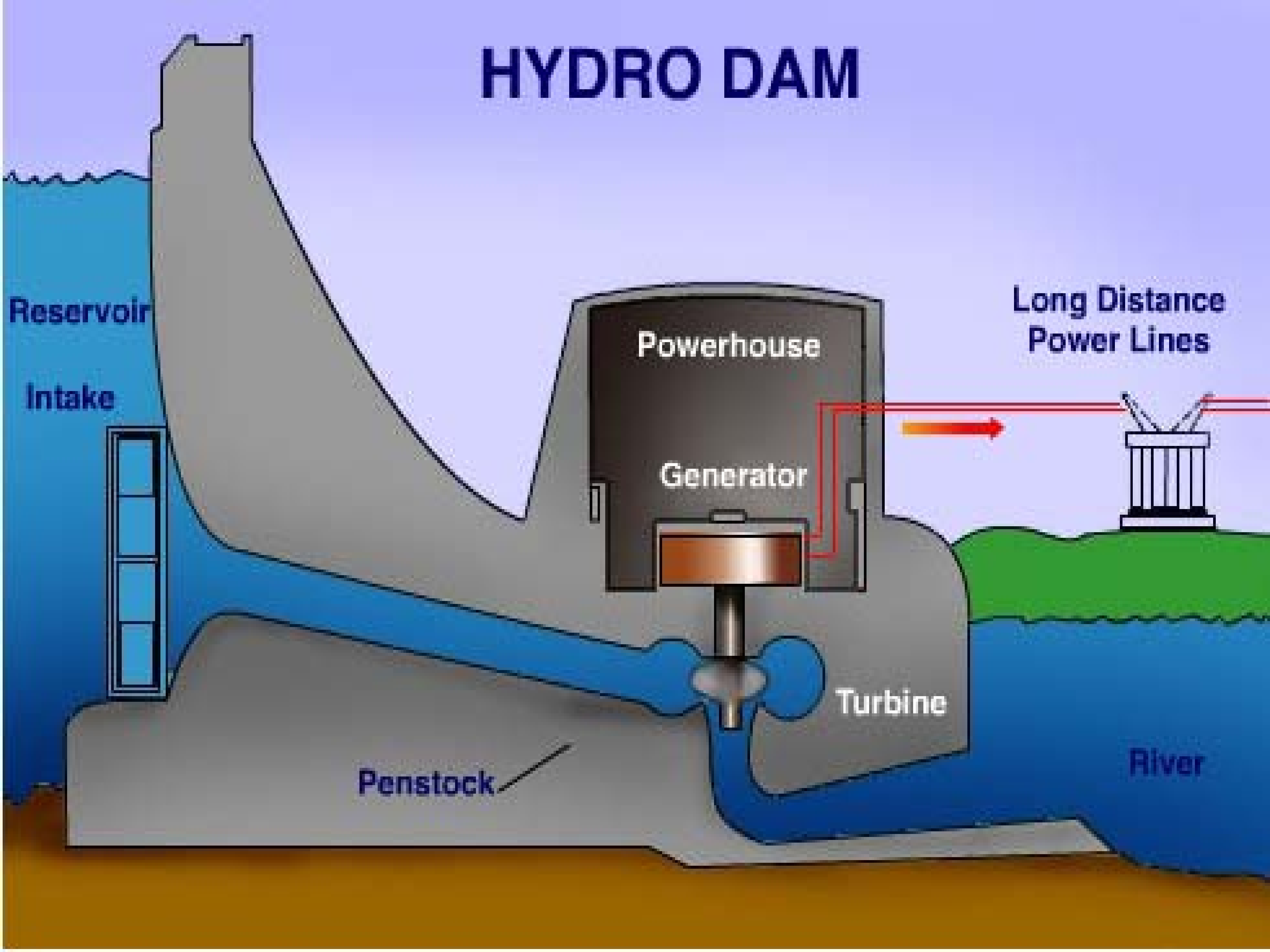
William R. Argentieri, P.E.
Fossil & Hydro Technical Services

Saluda HYDRO RELICENSING

SCE&G® A SCANA COMPANY

Hydropower Basics

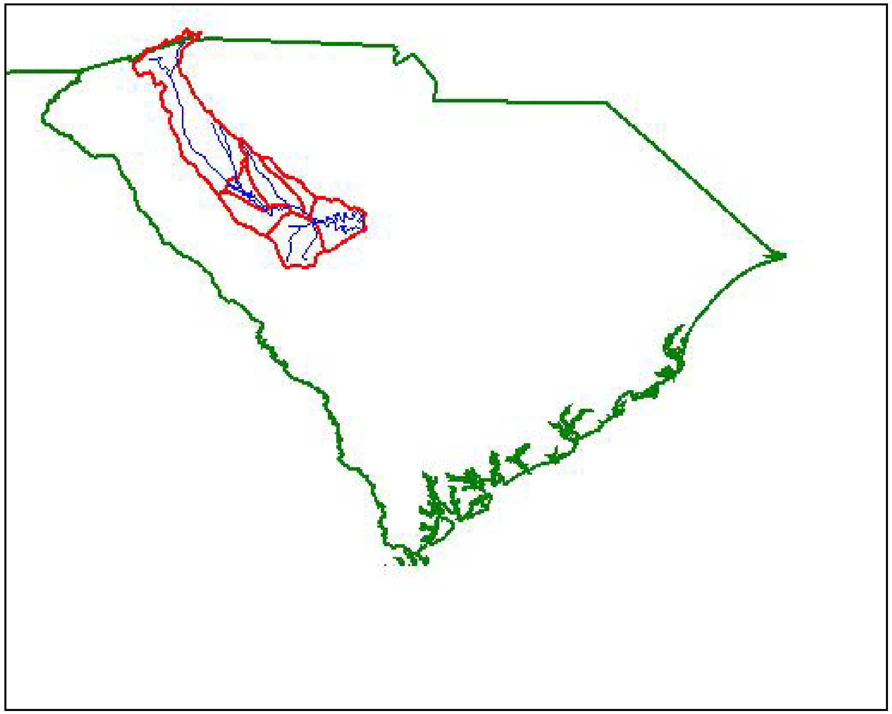
- *Hydroelectric plants convert potential energy of water into kinetic energy to drive a generator.*
- *Water flows from "headwater" elevation to "tailwater" elevation through a hydraulic turbine, which is connected to a generator.*



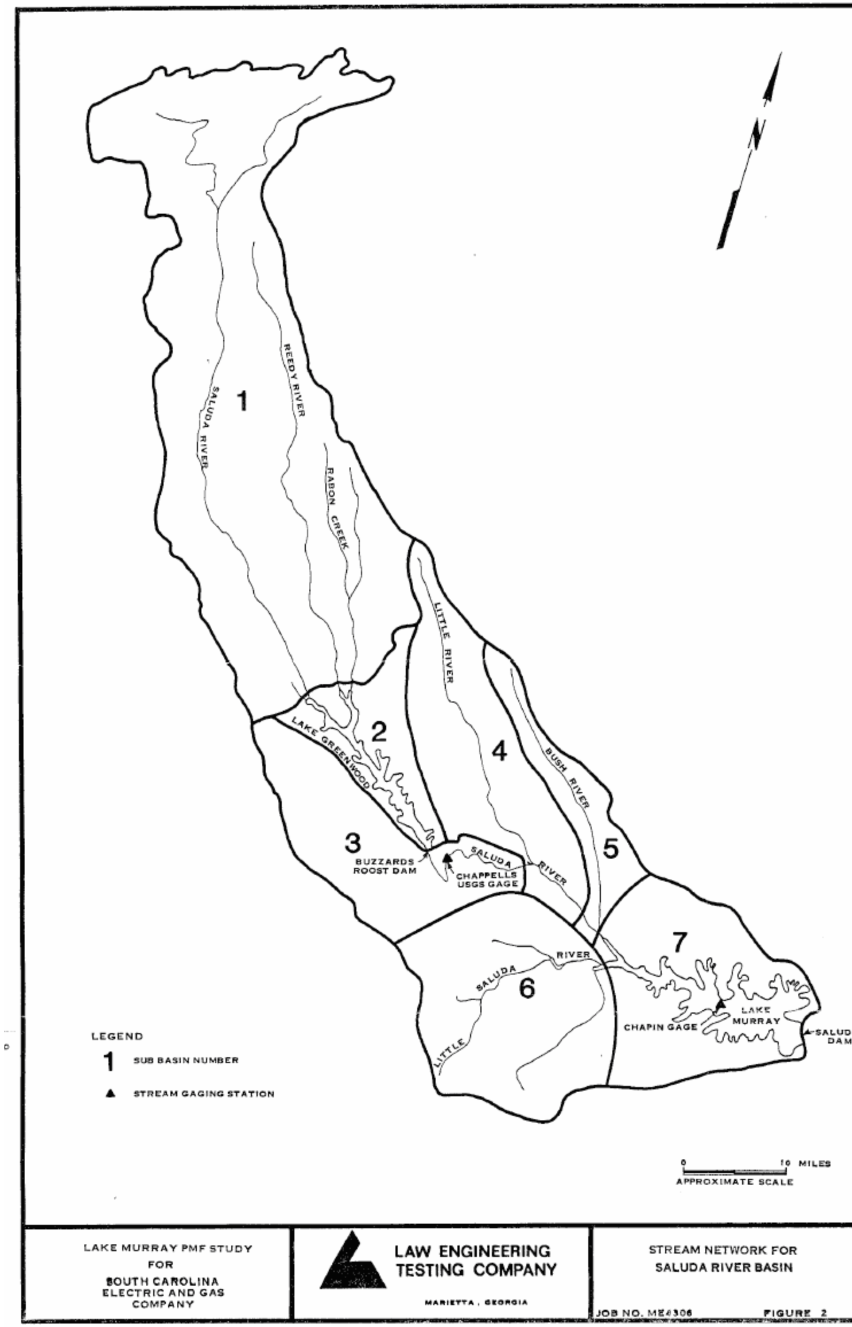
HYDRO DAM
Reservoir
Intake
Powerhouse
Generator
Long Distance
Power Lines
Turbine
Penstock
River

Saluda Hydro Basic Facts

- *Saluda Hydroelectric Project was built between 1927 and 1930.*
- *Saluda Hydro originally had four turbine-generator units installed.*
- *A fifth unit was added in 1969 - 1971.*
- *Generation capacity is 206 MW*
- *Hydraulic capacity is 18,000 CFS (8 million GPM!)*

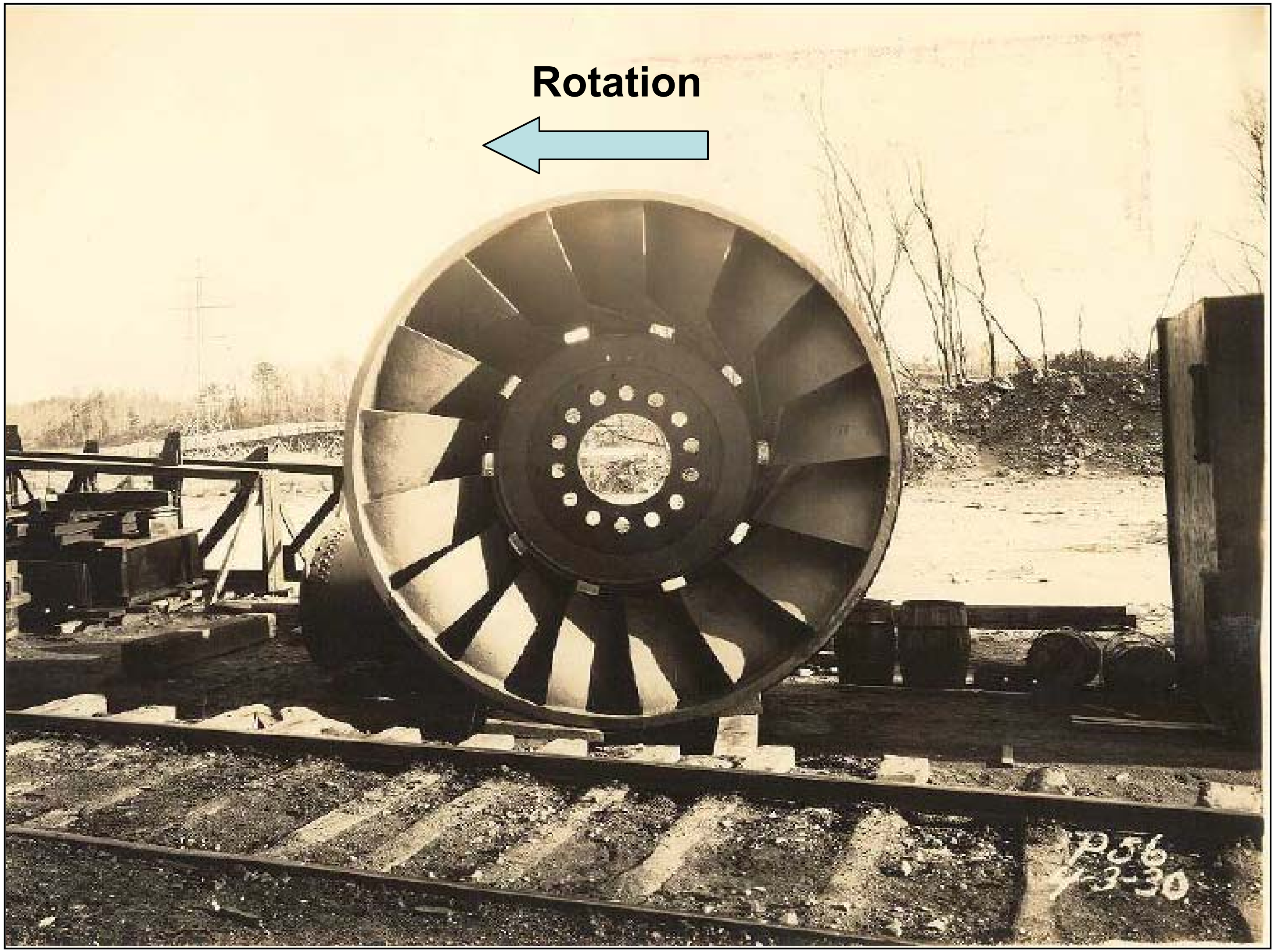


- *Drainage Basin Area 2,420 sq. mi.*
- *Reservoir surface area 50,000 acres at elev. 360.0 SPD.*
- *Reservoir capacity 1,600,000 ac-ft at elev. 360.0 SPD.*



Units 1 - 4

- *Units 1 – 4 turbines are Francis reaction type, built by S. Morgan Smith Co., and develop over 55,000 HP each at 138.5 RPM. Design head is 180 feet.*
- *Units 1 - 4 generators are Westinghouse machines operating at 13,800 VAC.*
- *Units 1, 2 & 4 generators are rated at 32.5 MW. Unit 3 was rewound in 1966 and is now rated at 42.3 MW.*

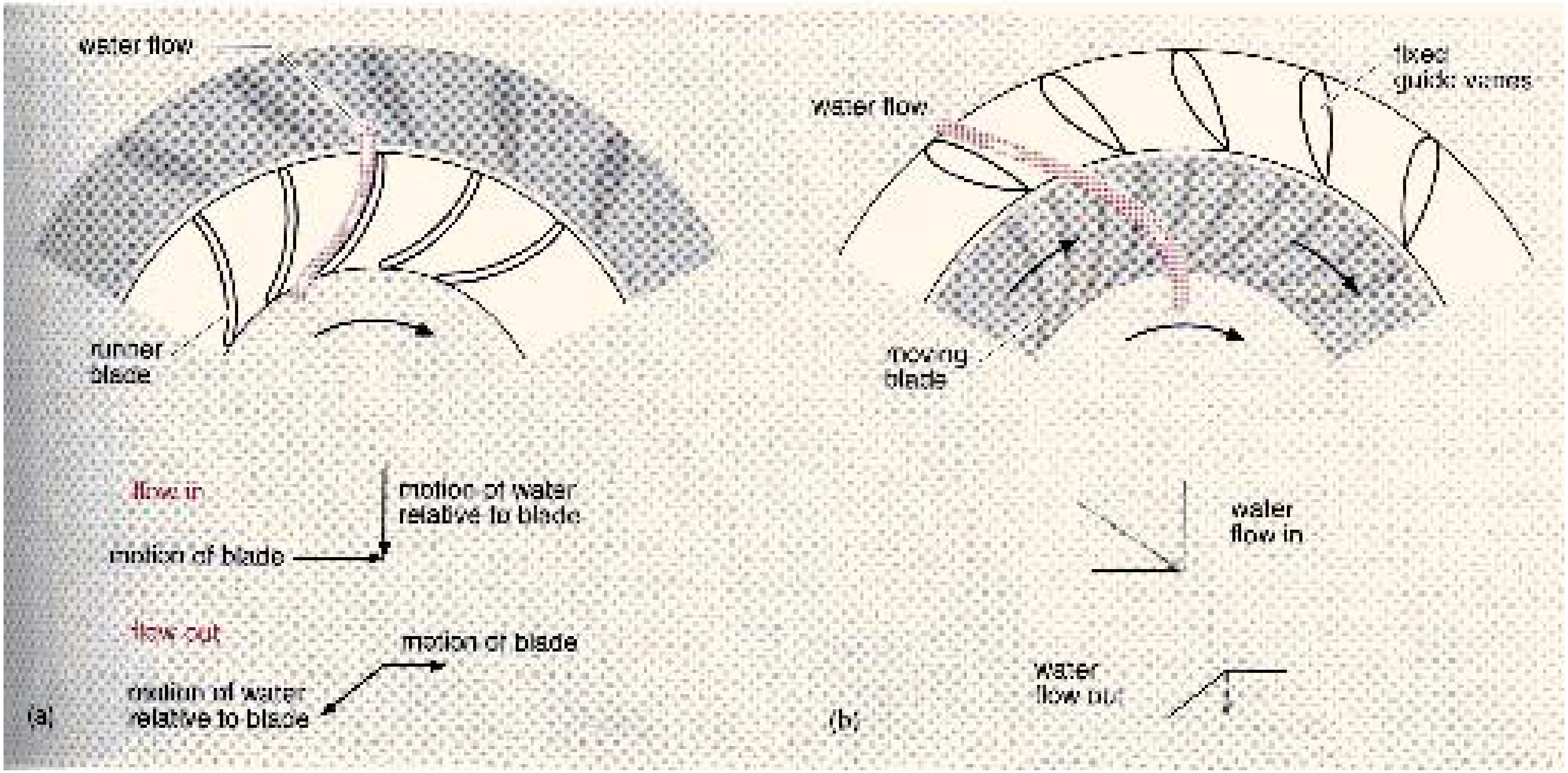


Unit 1 – 4 Turbine Runner (Bottom View)

Francis Turbine Runner Similar to Saluda 1 - 4

Water Flow in a Francis Turbine

Left: relative to turbine blades Right: true water path



Unit 5

- *Unit 5 turbine is also a Francis reaction type, built by Baldwin-Lima-Hamilton and developing 98,300 HP at 128.6 RPM.*
- *Design head is 156 feet.*
- *Unit 5 generator is a General Electric machine rated at 75 MW at 13,800 VAC.*

Intake Towers

- *Towers 1 – 4 are 30 feet in diameter and 223 feet tall.*
- *Each tower has two 9 ft. by 14 ft. Broome roller gates with sills at bottom of reservoir - elevation 160 ft. Saluda Plant Datum (SPD).*
- *Gates are operated by electric hoists in brick machine houses atop each tower.*

Intake Towers

- *Tower 5 is 60 feet in diameter and 223 feet tall.*
- *It was designed to supply two future units similar to the original four.*
- *It now supplies Unit 5, which is about twice as large as the original units.*
- *Tower 5 has six 10 ft. by 10 ft. Broome roller gates with sills at elevation 271.67 ft. SPD.*

Emergency Spillway

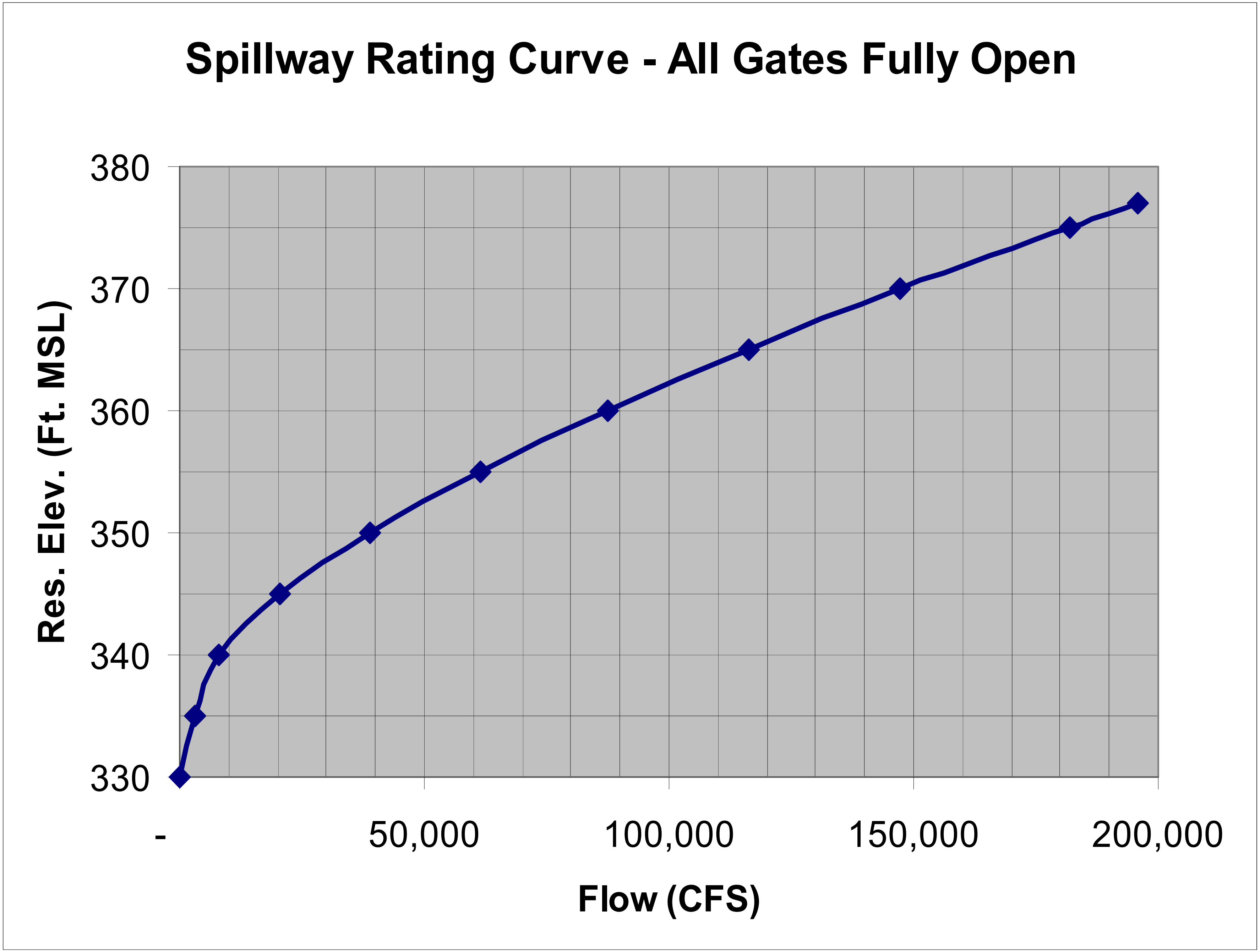
- *Emergency spillway is used to release water from reservoir in excess of what can be passed through the plant and stored in reservoir.*
- *Only used to prevent uncontrolled reservoir rise which threatens to overtop the dam.*
- *Spillway is tested each year by opening one gate fully, and raising others one foot each.*
- *Spillway is NOT the original Saluda River channel. It is a man-made channel.*

Emergency Spillway

- *Four gates 37.5 ft W x 25 ft H – original*
- *Two gates 46.5 ft W x 32 ft H – added 1946*
- *Each of the six spillway gates has its own hoist.*
- *Primary power for gate hoists is overhead electric.*
- *Backup generator is located near spillway.*
- *Gates can be operated using compressed air if electric hoist motors fail.*

Spillway Hydraulic Capacity

- *Flow through the spillway depends on number of gates opened, how far the gates are raised, and the reservoir elevation.*
- *Spillway hydraulic capacity with all gates fully open and reservoir at el. 360 SPD is about 90,000 CFS (five times powerhouse hydraulic capacity).*
- *Maximum spillway hydraulic capacity with all gates fully open and reservoir at el. 377 SPD is about 197,000 CFS.*



Spillway Rating Curve - All Gates Fully Open
380
370
360
350
340
330
Res. Elev. (Ft. MSL)
-
50,000
100,000
150,000
200,000
Flow (CFS)

Emergency Spillway

- *Spillway has been operated four times during floods – in 1936, 1964, 1965, and 1969.*
- *Installation of Unit 5 increased ability to pass flood flows through powerhouse, reducing frequency of spillway operation.*
- *Spillway operation to pass floods has not been required since 1969.*

Project Operation

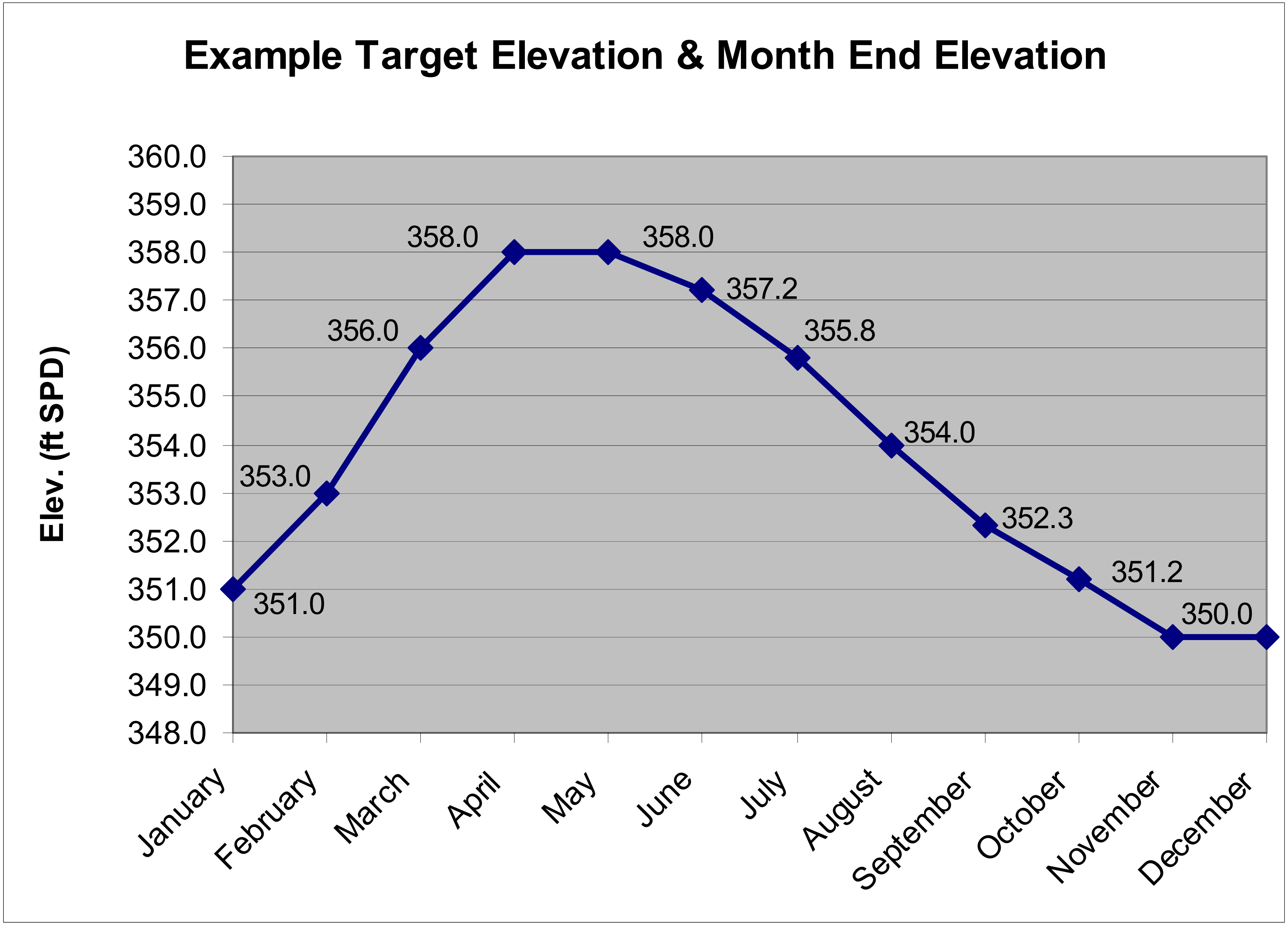
- *Saluda Hydro is normally operated as a reserve plant, to quickly replace other system generation which is offline for some reason.*
- *Saluda Hydro can respond quickly to provide generation and keep the system stable.*
- *Occasionally Saluda Hydro is used to augment other system generation at times of extremely high demand.*
- *Saluda also has "black start" capability to get system back up after catastrophic outage.*

Project Operations – Reservoir Level

- *Project License sets a minimum reservoir elevation of 345 ft. SPD, and a maximum reservoir elevation of 360 ft. SPD.*
- *SCE&G normally operates the reservoir in the range of 350 to 358 ft. SPD.*
- *Reservoir is occasionally drawn down to near el. 345 ft. SPD for vegetation control or other maintenance work.*

Project Operations – Reservoir Level

- *SCE&G sets target reservoir elevations for each month of the year, to allow for seasonal inflow variations.*
- *These target elevations may vary from year to year, depending on inflow available, maintenance activities, unit availability, etc.*
- *It is important to remember that each year is different – there is no "normal year".*
- *There is no one "Rule Curve" for reservoir operation.*


Example Target Elevation & Month End Elevation
Elev. (ft SPD)
360.0
359.0
358.0
357.0
356.0
355.0
354.0
353.0
352.0
351.0
350.0
349.0
348.0
351.0
353.0
356.0
358.0
358.0
357.2
355.8
354.0
352.3
351.2
350.0
January
February
March
April
May
June
July
August
September
October
November
December

Historical Floods

- *August 1928: 58,200 CFS (During project construction)*
- *March 1929: 53,600 CFS (During project construction)*
- ***October 1929: 67,000 CFS (During project construction, flood of record for basin)***
- *April 1936: 61,600 CFS* ***(Highest recorded lake level 361.5 SPD resulted) – 4 Gates Opened***
- *April 1964: 38,800 CFS – 2 Gates Opened*
- *June 1965: 53,200 CFS – 4 Gates Opened*
- *April 1969: 35,700 CFS – 2 Gates Opened*

Powerhouse Foundation During Flood, October 1929

Powerhouse Foundation After Flood, October 1929

Inflow Design Flood (IDF)

- *The IDF is the largest hypothetical flood which can be safely accommodated by the project.*
- *The IDF for Saluda is the Probable Maximum Flood (PMF) - the largest flood determined to be probable in the basin.*
- *The PMF results from a hypothetical storm of optimum size, shape, and orientation to produce maximum runoff in the drainage basin.*
- *The PMF inflow for Saluda Hydro is 572,300 CFS – almost 10 times the flood of record.*

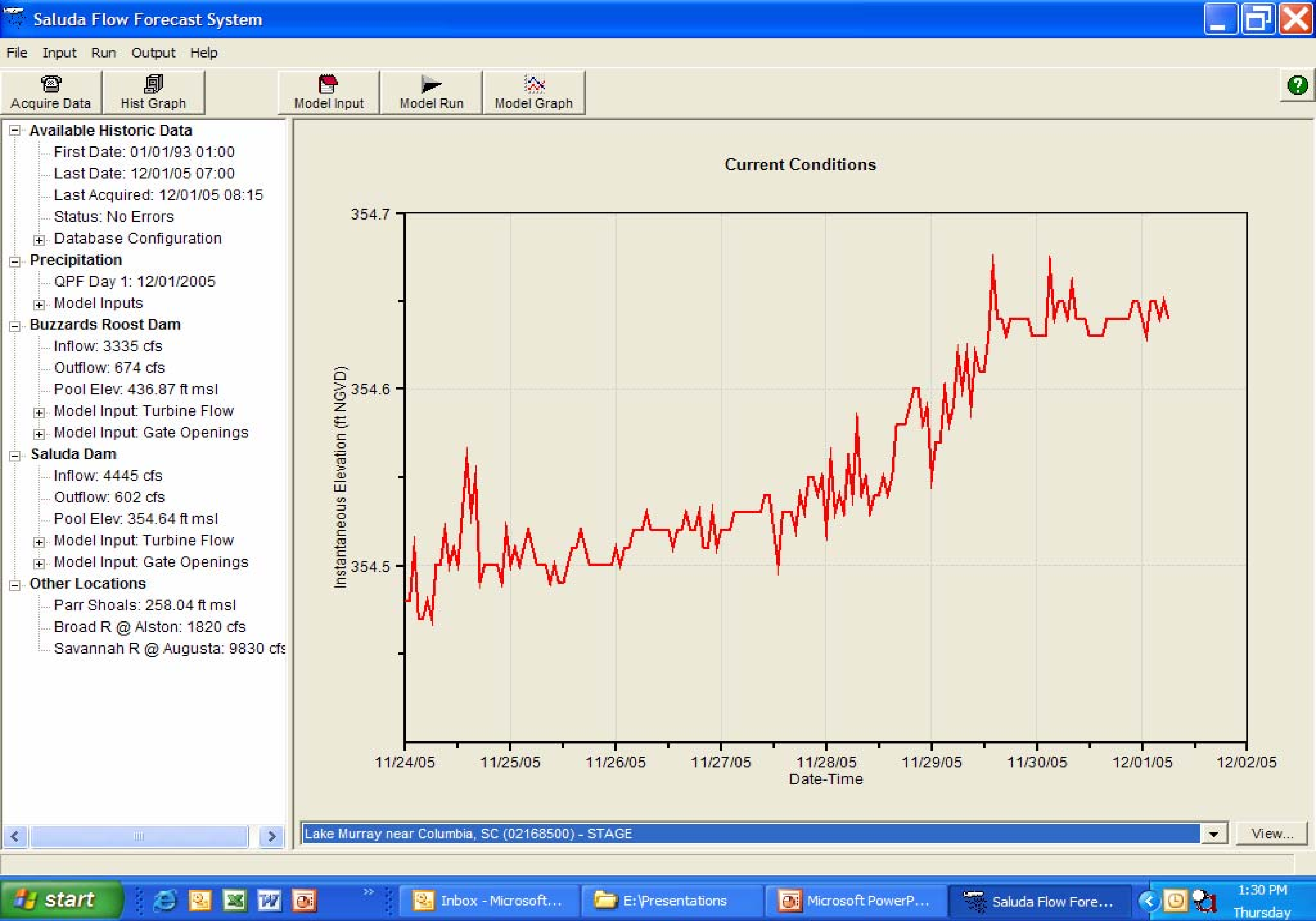
Inflow Design Flood (IDF)

- *Dam has been modified twice to accommodate updated estimates of the PMF.*
  - *1940s – Dam crest raised 3 feet to el. 375.0 SPD, two spillway gates added.*
  - *1990 – Latest PFM lake level would be 375.9 SPD. Sheet pile freeboard wall added to dam crest – top of wall el. 377.0 SPD.*
- *Flow Forecast Model was developed to predict reservoir level during floods.*

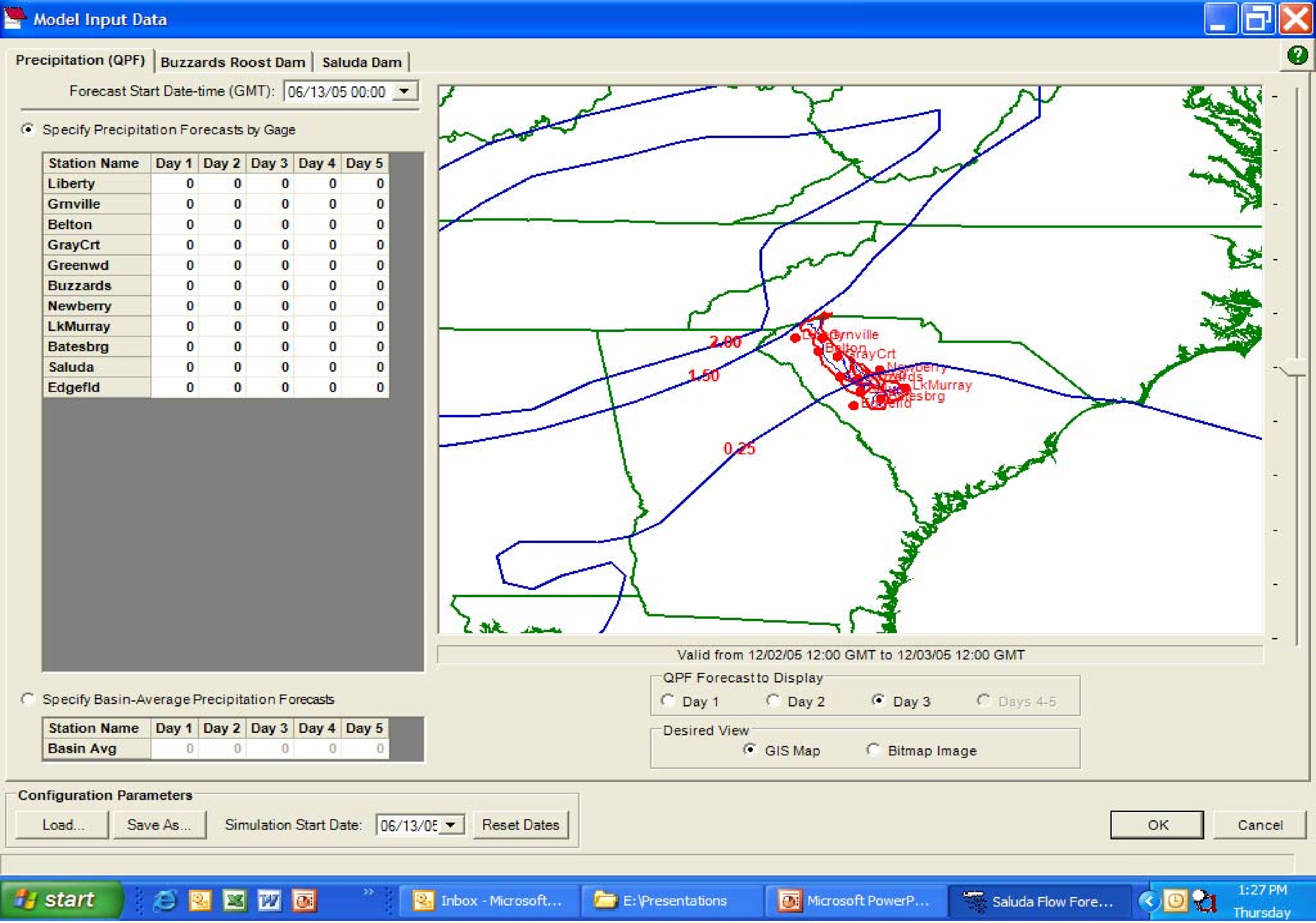
Sheet Pile Freeboard Wall Construction - 1990

Project Operation – Flow Forecast Model

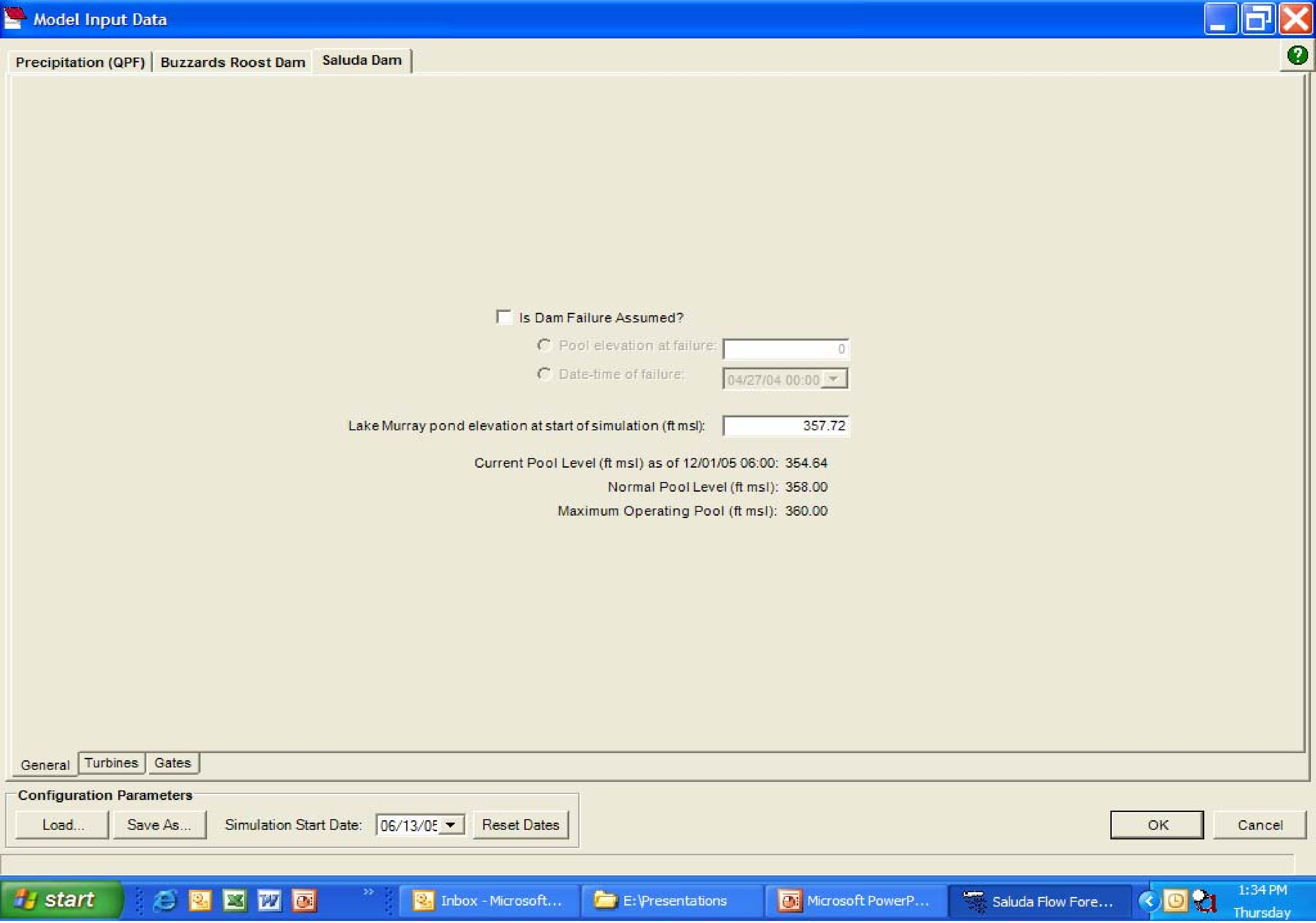
- *Flow Forecasting Model (FFM) is a computer based model used to predict inflow and reservoir rise from storm events in the basin.*
- *The FFM uses NWS forecasts and USGS rain and flow gage data as input to a hydrologic/hydraulic model which predicts runoff and stream flow.*
- *SCE&G uses the FFM to decide how much to lower the reservoir in advance of a large storm system, how much to generate to maintain the lake level, and whether spillway operation is required.*



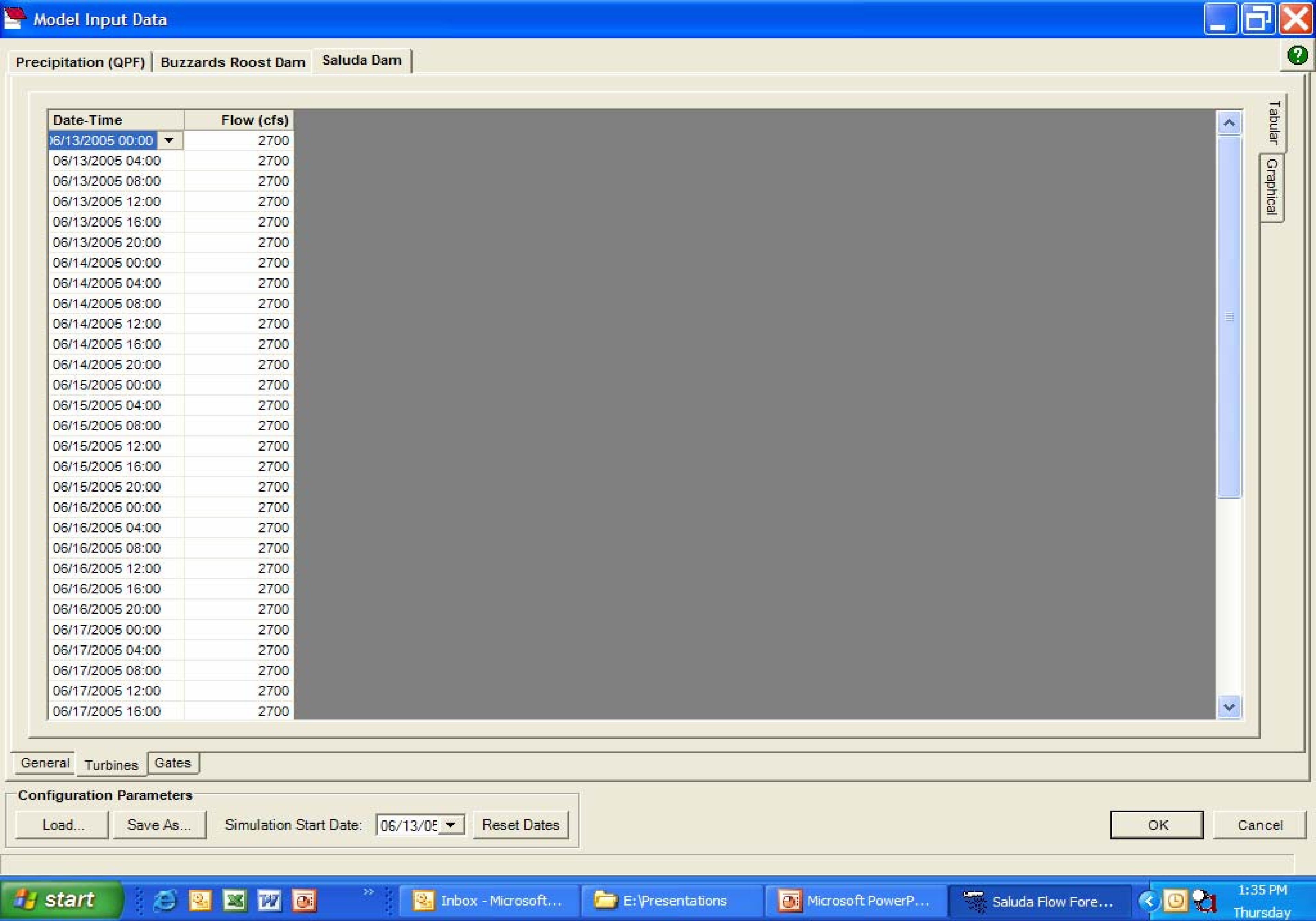
FFM Screen – Current Conditions



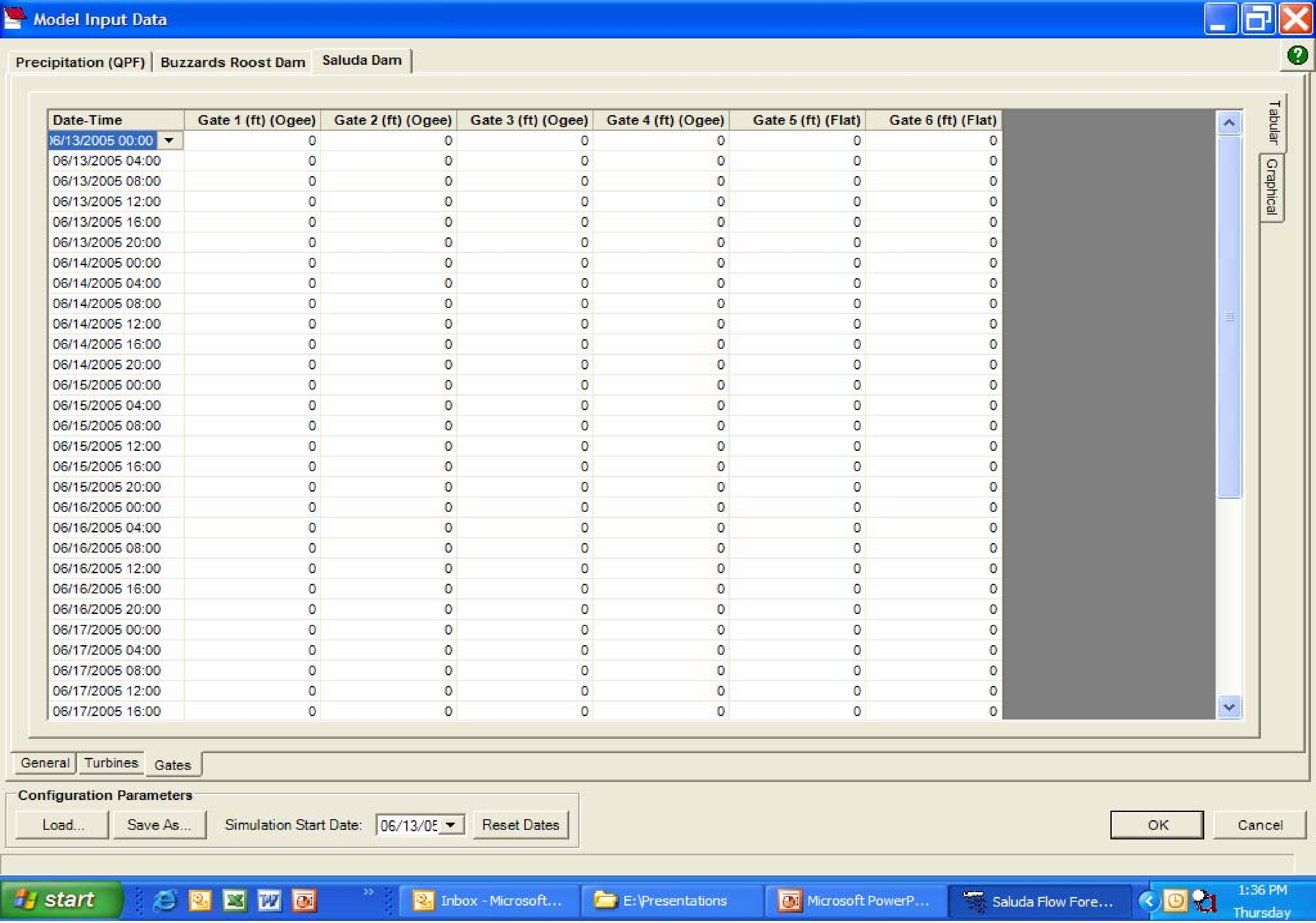
FFM Screen – NWS Precipitation Forecast



FFM Screen – Model Input Screen - General



FFM Screen – Model Input Screen - Turbines



Date-Time	Gate 1 (ft) (Ogee)	Gate 2 (ft) (Ogee)	Gate 3 (ft) (Ogee)	Gate 4 (ft) (Ogee)	Gate 5 (ft) (Flat)	Gate 6 (ft) (Flat)
6/13/2005 00:00	0	0	0	0	0	0
06/13/2005 04:00	0	0	0	0	0	0
06/13/2005 08:00	0	0	0	0	0	0
06/13/2005 12:00	0	0	0	0	0	0
06/13/2005 16:00	0	0	0	0	0	0
06/13/2005 20:00	0	0	0	0	0	0
06/14/2005 00:00	0	0	0	0	0	0
06/14/2005 04:00	0	0	0	0	0	0
06/14/2005 08:00	0	0	0	0	0	0
06/14/2005 12:00	0	0	0	0	0	0
06/14/2005 16:00	0	0	0	0	0	0
06/14/2005 20:00	0	0	0	0	0	0
06/15/2005 00:00	0	0	0	0	0	0
06/15/2005 04:00	0	0	0	0	0	0
06/15/2005 08:00	0	0	0	0	0	0
06/15/2005 12:00	0	0	0	0	0	0
06/15/2005 16:00	0	0	0	0	0	0
06/15/2005 20:00	0	0	0	0	0	0
06/16/2005 00:00	0	0	0	0	0	0
06/16/2005 04:00	0	0	0	0	0	0
06/16/2005 08:00	0	0	0	0	0	0
06/16/2005 12:00	0	0	0	0	0	0
06/16/2005 16:00	0	0	0	0	0	0
06/16/2005 20:00	0	0	0	0	0	0
06/17/2005 00:00	0	0	0	0	0	0
06/17/2005 04:00	0	0	0	0	0	0
06/17/2005 08:00	0	0	0	0	0	0
06/17/2005 12:00	0	0	0	0	0	0
06/17/2005 16:00	0	0	0	0	0	0

FFM Screen – Model Input Screen - Gates

Project Operation – Flow Forecast Model

- *The FFM can model different "what if" scenarios – various combinations of powerhouse and spillway operations can be input to determine effect on reservoir level.*
- *The FFM models conditions at Buzzards Roost (Lake Greenwood), as well as Saluda Hydro.*
- *FFM database is updated daily from USGS and NWS servers.*

Project Operation - Storms

- *Floods cause high tailwater conditions at the Saluda powerhouse, reducing generating capability due to lower effective head.*
- *High tailwater can also flood portions of the powerhouse if precautions are not taken – stop logs at work bay door, seals at ventilation louvers.*
- *Powerhouse had to be sealed during the 1965 flood – tailwater rose to almost 199 ft. SPD.*

Project Operation - Restrictions

- *Informal agreement in place with SCDHEC to maintain 180 CFS minimum flow in lower Saluda River.*
- *McMeekin Station discharges cooling water to Unit 2.*
- *McMeekin NPDES Permit requires that Saluda Hydro discharge 2,500 CFS when Unit 2 is operated, or when cooling water is bypassed to tailrace.*

Project Operation – Restrictions

- *Unit 5 operations are often restricted during summer due to fish schooling around intake tower – hydroacoustic system detects presence of fish and displays in System Control Room.*

McMeekin Cooling Water Bypass – June 2005

Project Operation – DO Issues

- *During late summer and fall, dissolved oxygen in reservoir becomes depleted below about 75 feet depth.*
- *SCE&G has installed turbine vents and hub baffles to enhance air entrainment into turbine discharges.*
- *Venting efficiency varies with load on unit – generally better venting occurs in middle third of load range.*

Project Operation – DO Issues

- *SCE&G uses Look Up Tables (LUTs) to dispatch units according to reservoir DO levels and venting capability of each unit.*
- *Attempt to optimize operations to mitigate DO impact to lower Saluda River.*
- *This usually results in having to spread load over several units during low DO season.*

Project Maintenance - Powerhouse

- *Normal preventive maintenance work is performed constantly.*
- *Periodic maintenance requiring brief unit outage is performed as required during the year.*
- *Major maintenance requiring prolonged unit outage or dewatering of a unit is scheduled for low demand time of year, if possible.*

Project Maintenance - Powerhouse

- *Dewatering of a unit requires closing butterfly valve for Units 1 – 4, or closing head gate at tower for Unit 5.*
- *Dewatering of a penstock requires closing head gate at tower.*
- *Dewatering penstock and scroll case can take as long as a week, depending on how well gates seal.*

Project Maintenance - Dam

- *Lake is occasionally drawn down to about el. 345 SPD for maintenance of dam and appurtenant structures, or for control of vegetation in reservoir.*
- *Repair of the upstream riprap armor planned for winter 2006 will require reservoir draw down to about el. 348 SPD.*

Public Safety Plan

- *Submitted as part of the license application.*
- *Provides locations of operational sirens, warning signs, strobe lights, etc.*
- *On the lake we have warning signs only at the public access locations.*
- *On the river, we have sirens, warning signs, and strobe lights at two locations, Mill Race Rapids at the Zoo and Hope Ferry Landing/ Saluda Shoals Park.*


-WARNING-
HORN SIGNAL and
FLASHING LIGHTS
INDICATE RISING WATER
-CAUTION-
ABSENCE of HORN SIGNAL or
FLASHING LIGHTS DO NOT ASSURE
CONSTANT WATER LEVEL

Dam Surveillance Program

- *SCE&G performs monthly dam surveillance in accordance with FERC regulations.*
- *Both original dam and backup dam are instrumented to monitor water level and pressure, seepage, and deformation.*
- *SCE&G technicians collect instrument data and inspect dam at least monthly, more often if unusual conditions present.*
- *Dam is surveyed semi-annually.*
- *Surveillance Report filed with FERC annually.*

Emergency Action Plan (EAP)

- *SCE&G maintains an Emergency Action Plan (EAP) detailing response to potential or actual failure of dam.*
- *EAP contains procedures used to notify local, state, and federal officials in event of dam related emergency and inundation maps showing the flood area during the Probable Maximum Precipitation and Sunny Day failure.*

Emergency Action Plan (EAP)

- *During the dam remediation we installed 10 early warning sirens that are still active today. We also published an Emergency Information Brochure to provide guidance to the public should these sirens need to be activated. This brochure is mailed to those in the inundation zone and can be found on the SCE&G website.*
- *Purpose is to allow coordination of downstream notification/evacuation if required.*

Emergency Action Plan (EAP)

- *EAP is updated annually with current contact information for response agencies.*
- *EAP tabletop and functional exercises are conducted every 5 years to test communications channels and procedures.*
- *Plant personnel attend annual EAP training session on procedures.*

Questions?