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)

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…."

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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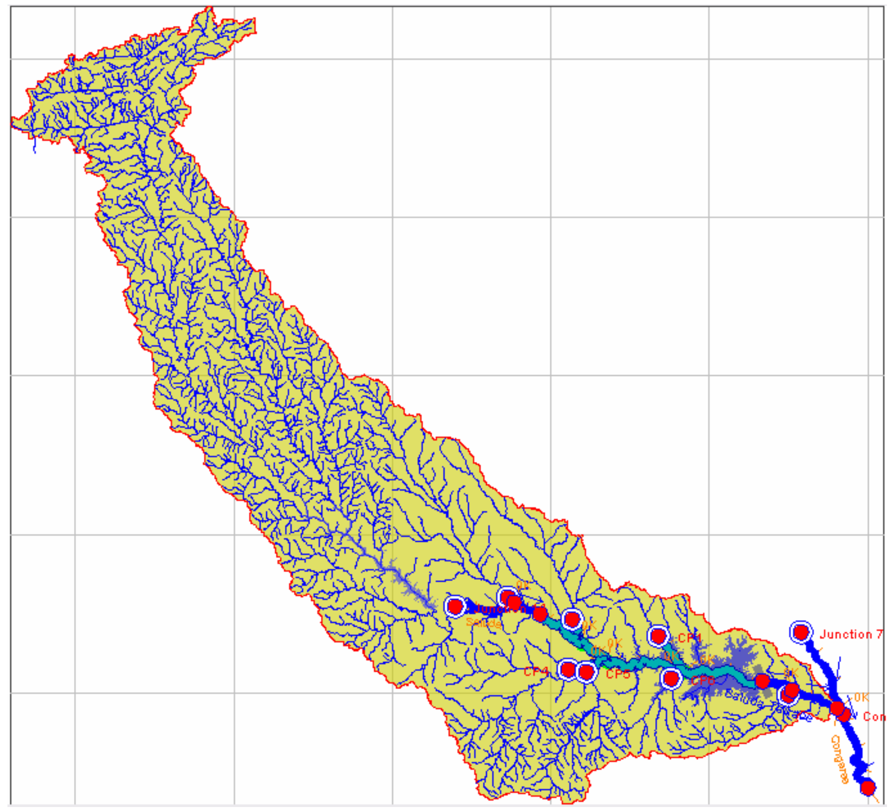
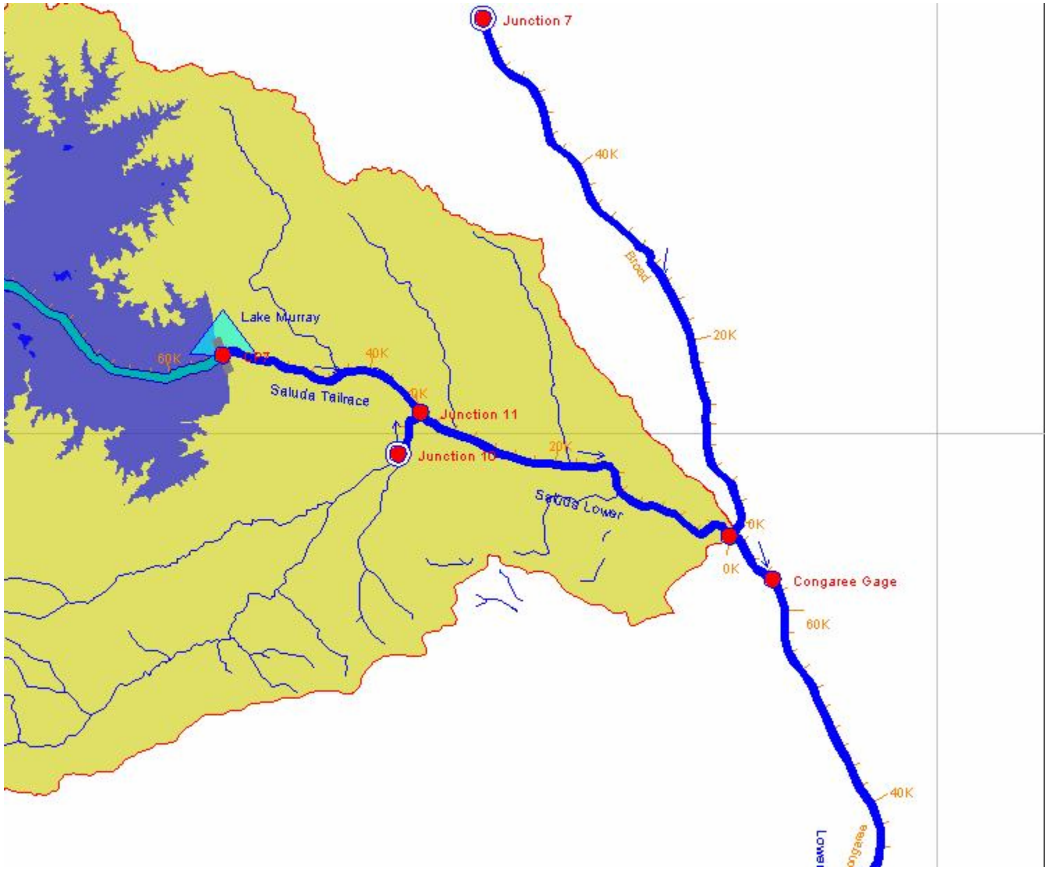
Model Development (cont)

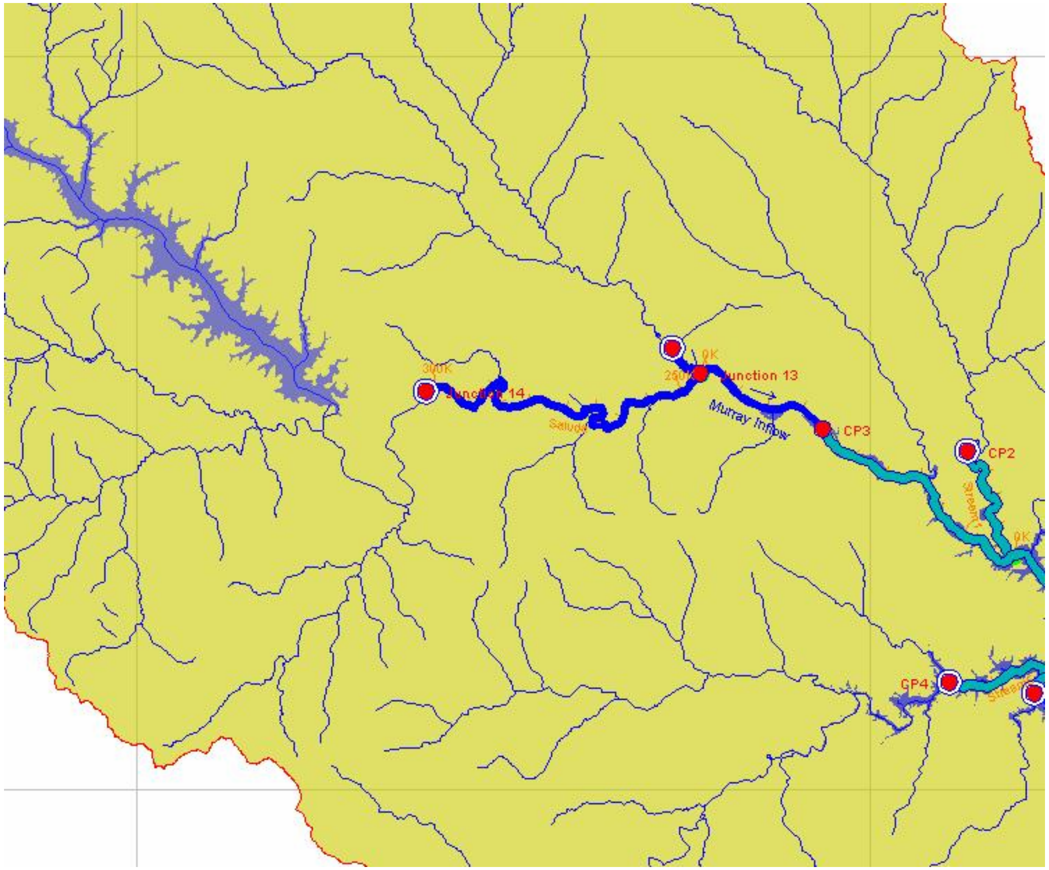
- Components
  - Upstream Inflows
  - Lake Murray
  - Downstream Gages
  - Broad & Congaree River Gages



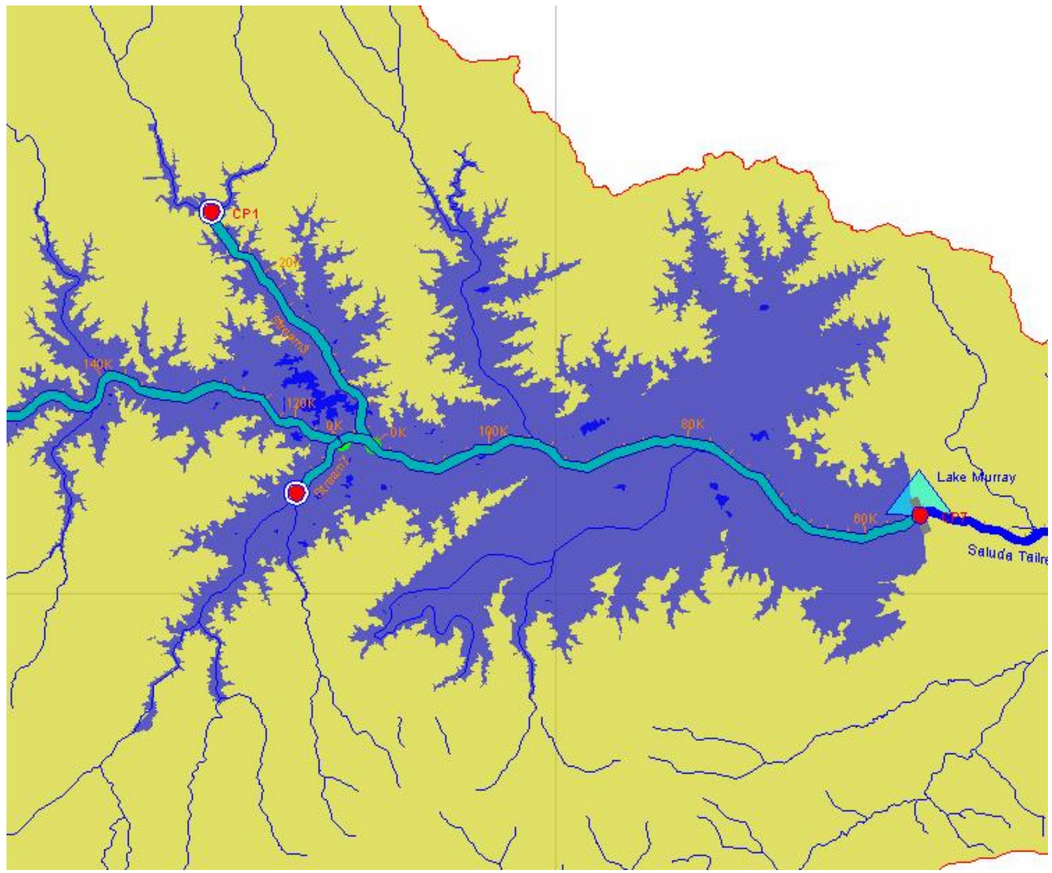
Data Layout - Downstream



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

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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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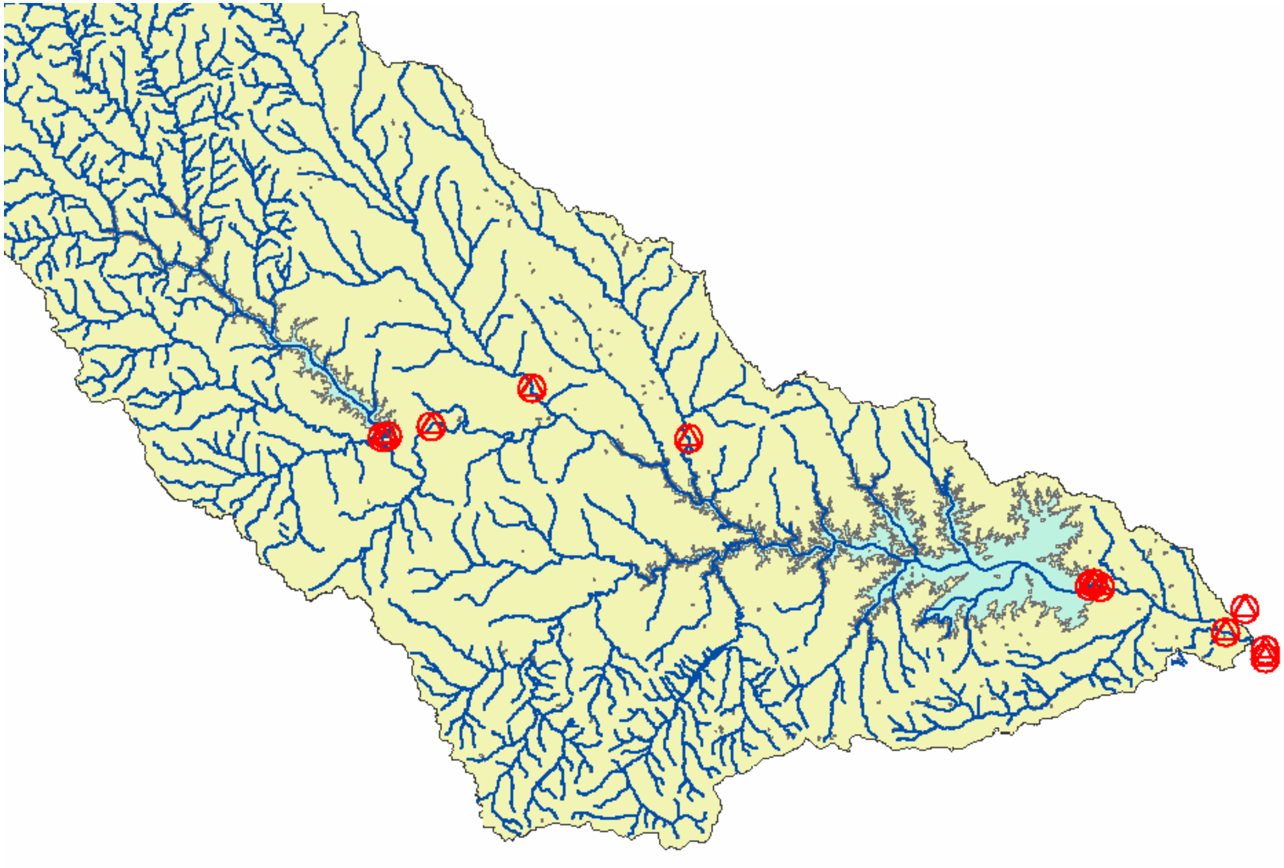
USGS Gage Locations



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

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

Unknown:
1. Lake Direct Inflow
2. Evaporation

Little River Gage

Bush River Gage

Chappells River Gage

Lake Murray

Saluda Gage (d/s)

Fact:

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.

Approach:

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

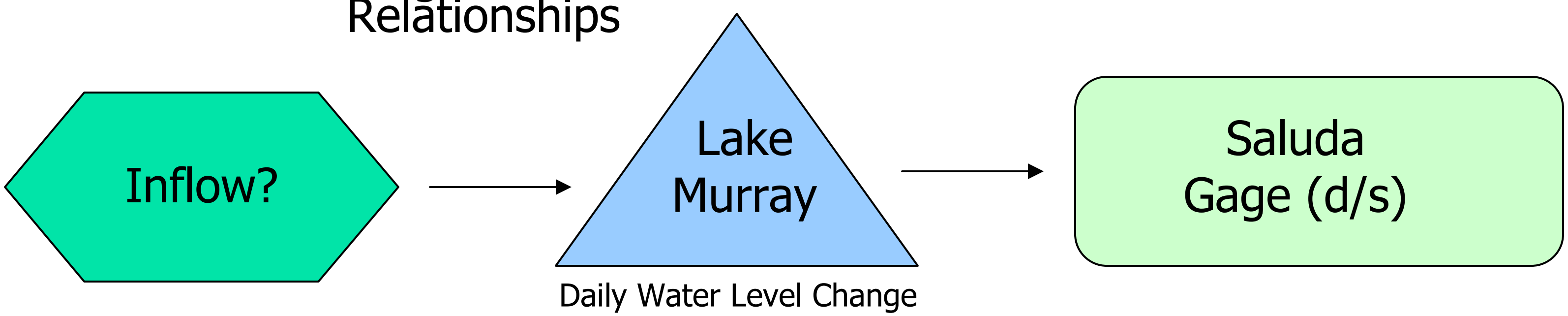
Method 2 - Mass Balance

<u>Known:</u>

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

<u>Unknown:</u>

1. Inflow



<u>Fact:</u>

<u>Inflow = Change in Storage (Water Level) + Outflow</u>

<u>Approach:</u>

Back calculate inflow using smoothed lake level data and gaged outflows

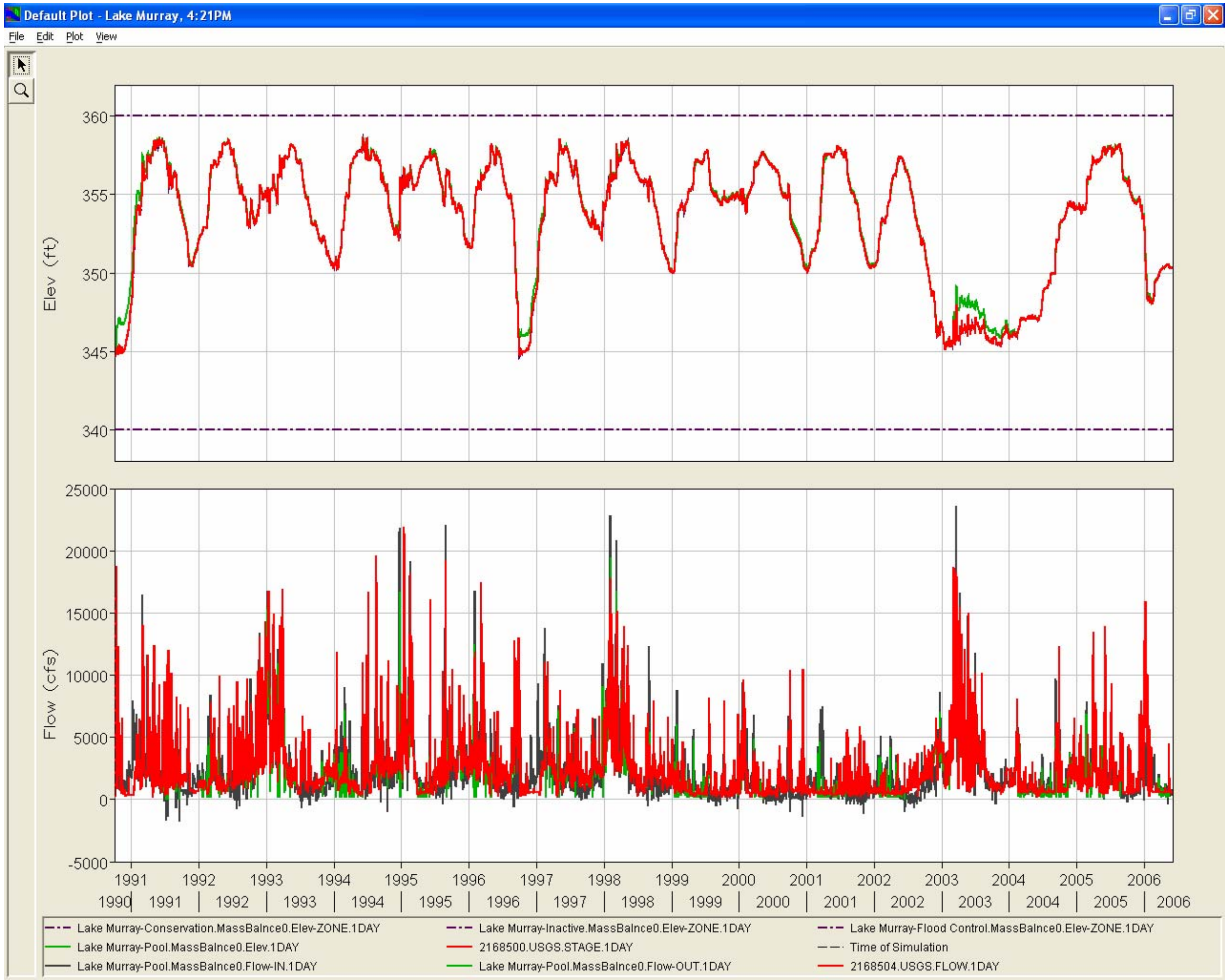
Calibration Procedure

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

Calibration Results

Stage

Discharge



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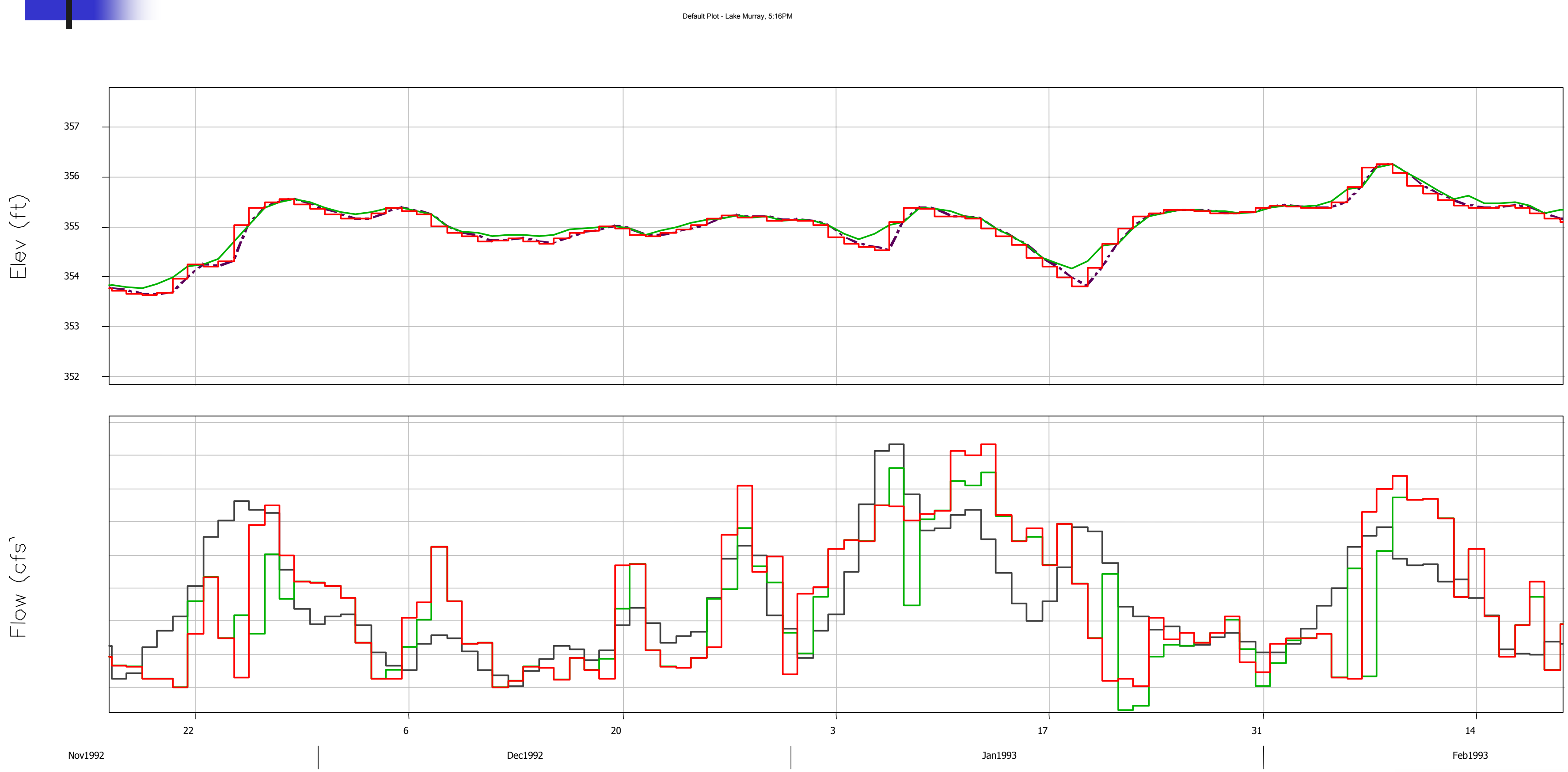
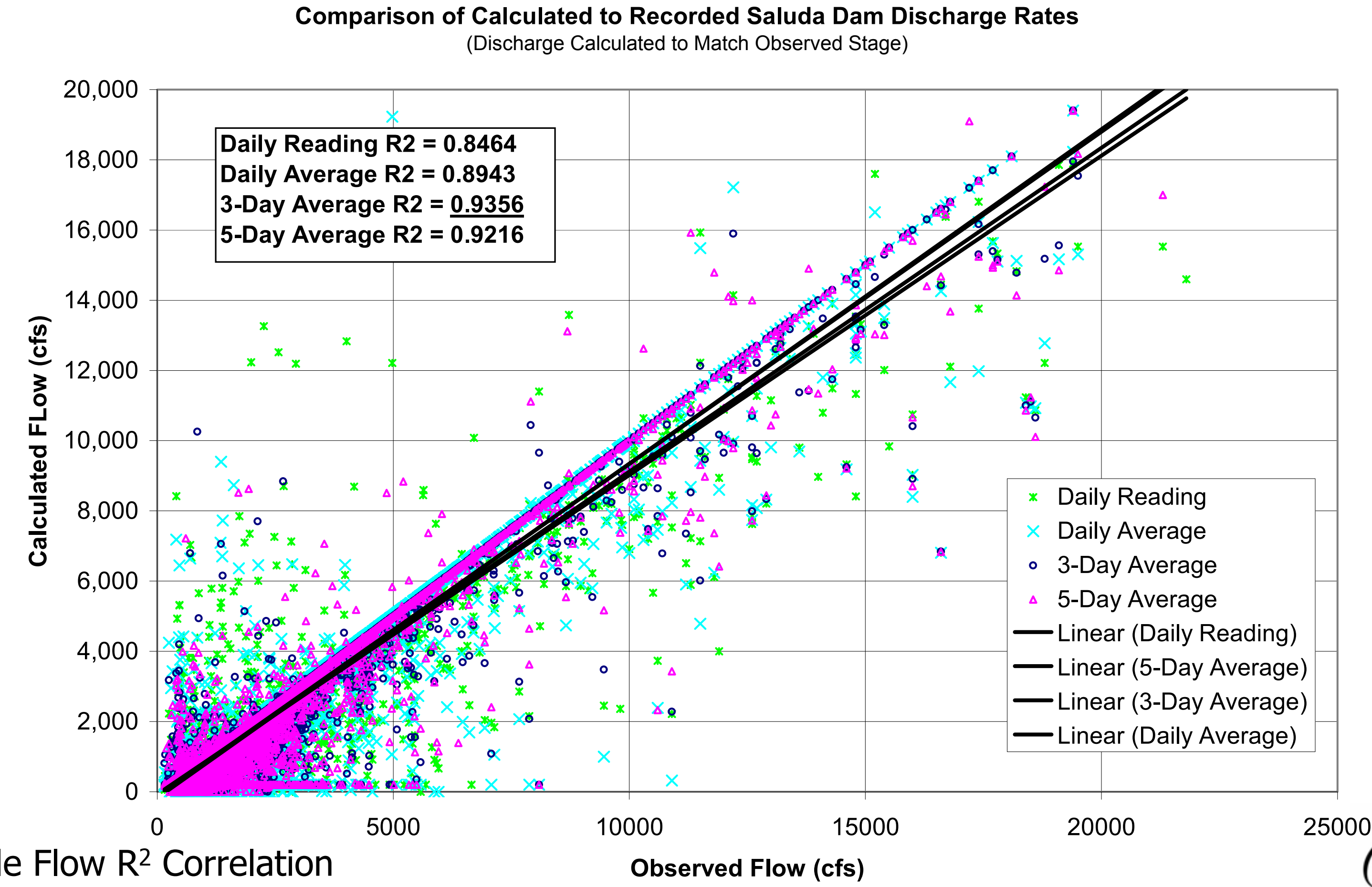
Calibration Results (cont)



Calibration Results (cont)



*Sample Flow R^2 Correlation

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

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**

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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

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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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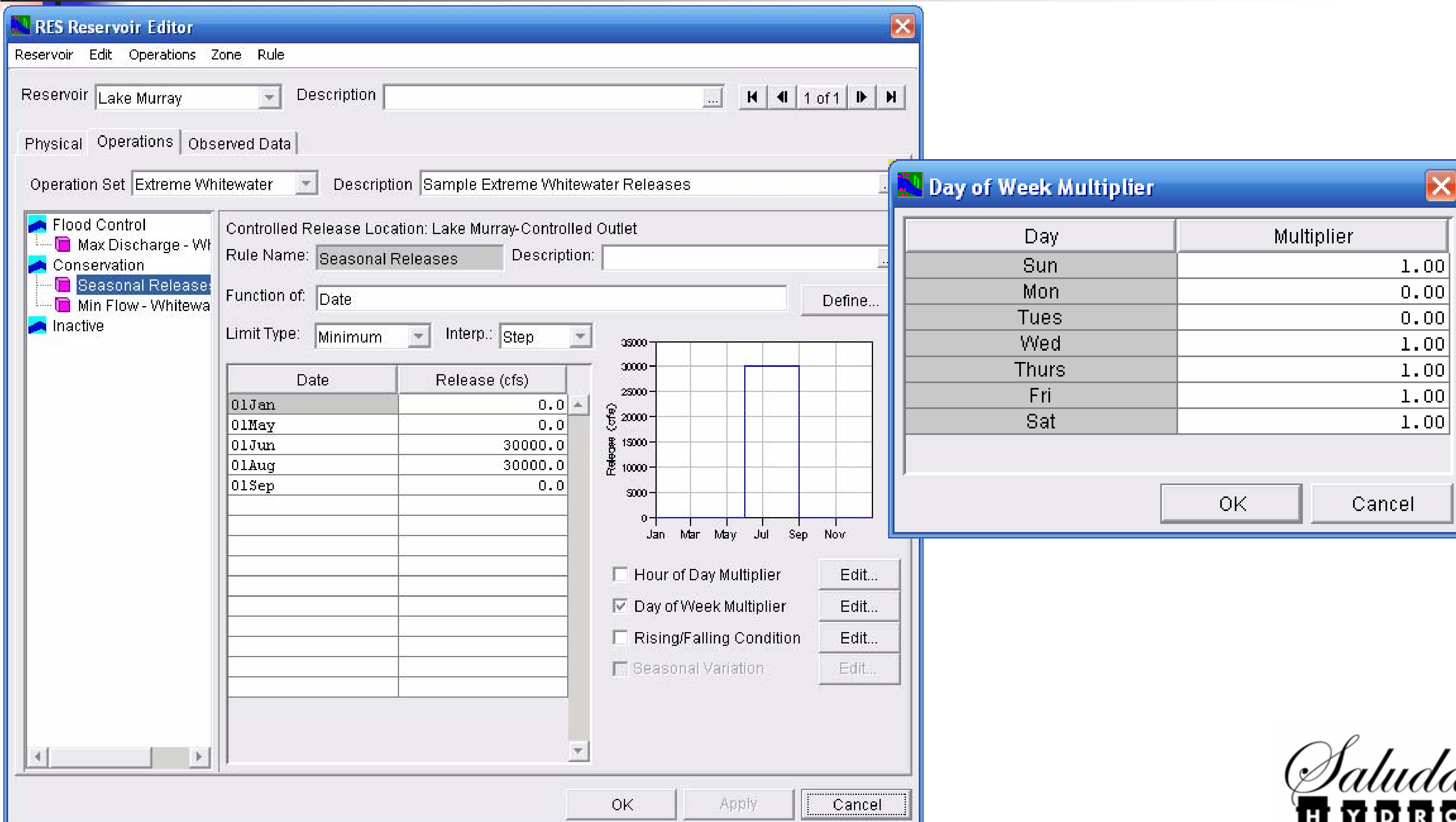
Constraint Setup Example



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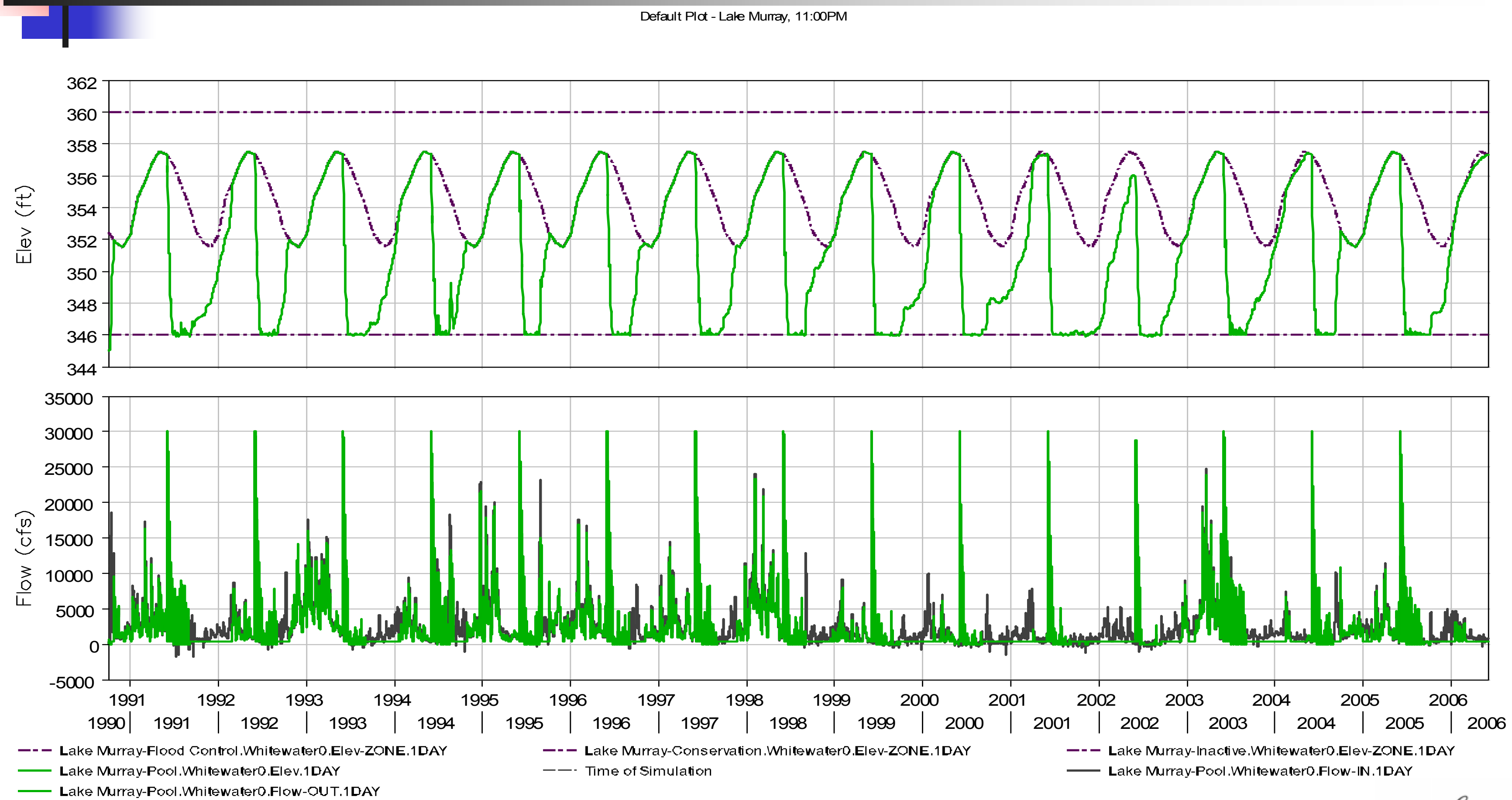
Extreme Example Output



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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

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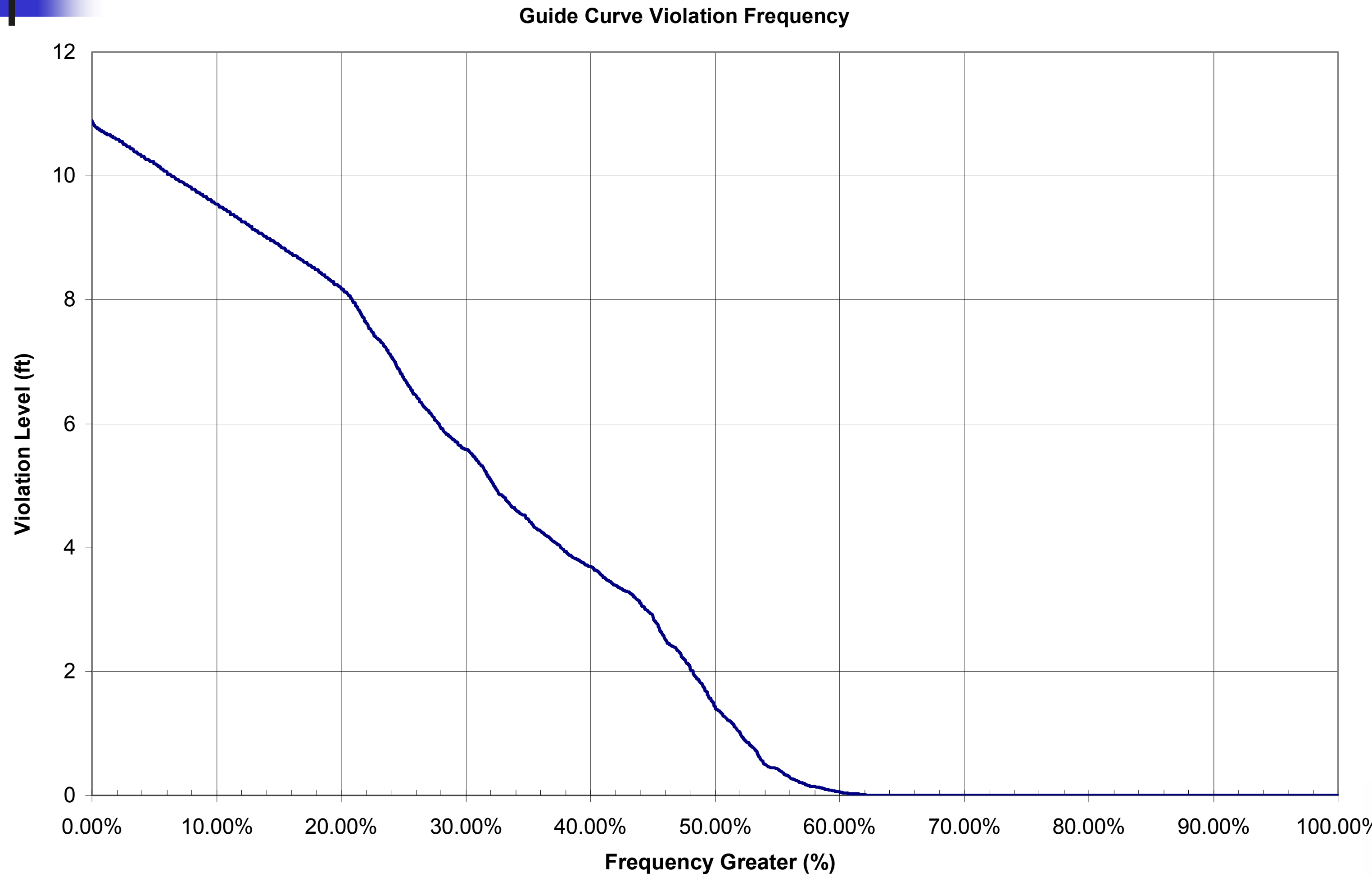
Interpretation of Example Results

- 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



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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?

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