

# Decision Support for Dam Operations



## Arnold Engelmann

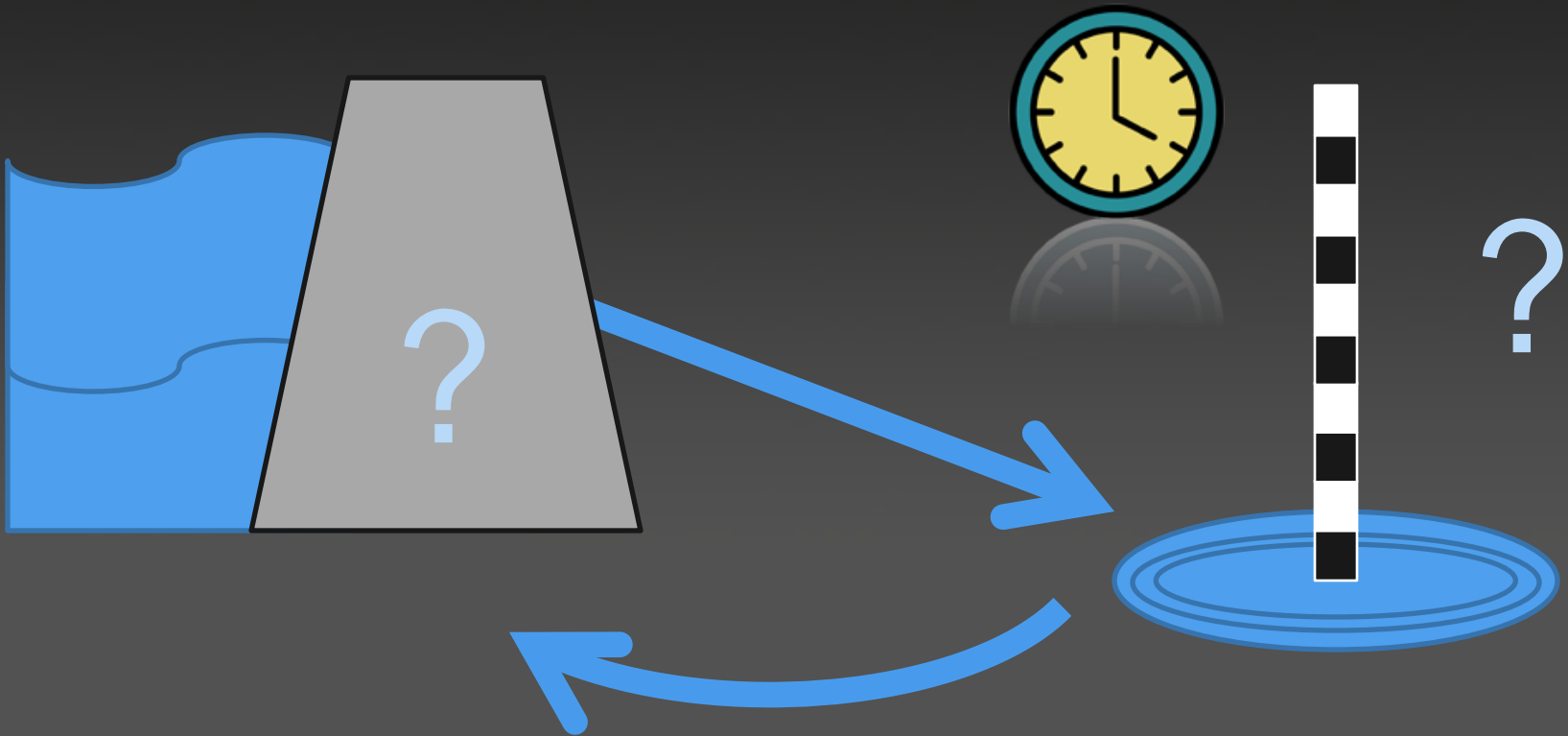
Senior Developer, Solutions Software, DHI Portland

Carter Borden, Senior Hydrologist, DHI Boise

Ryan Kilgren, Water Resource Engineer, DHI Portland

Dylan Kime, Developer, DHI South Africa

# Problem

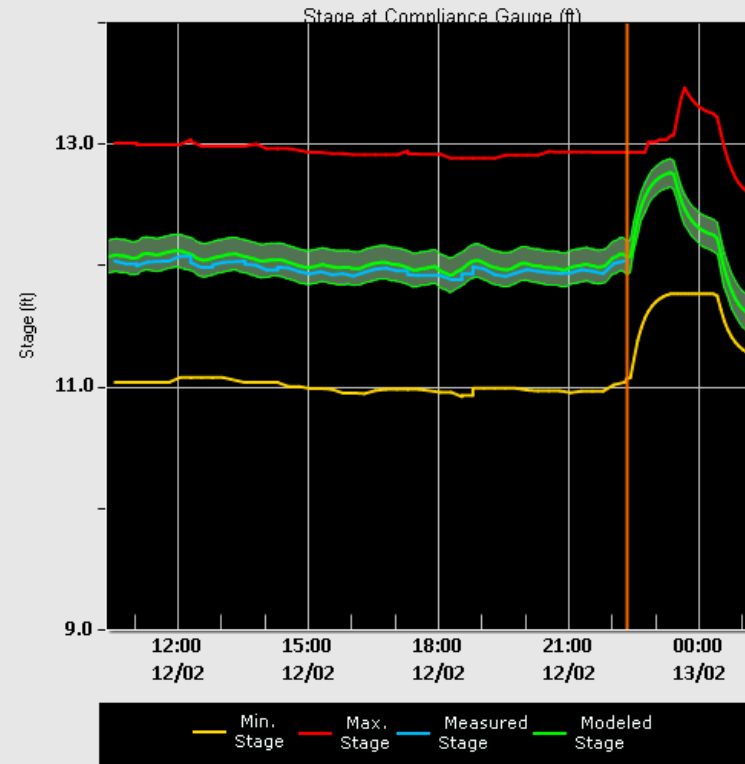
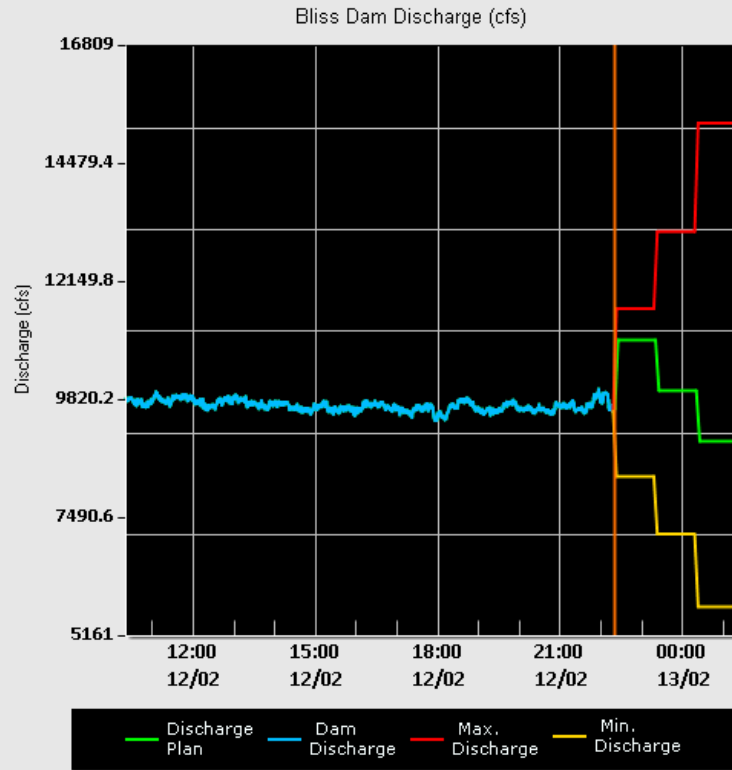


# Solution: Bliss Dam DSS



## Bliss Dam Decision Support System

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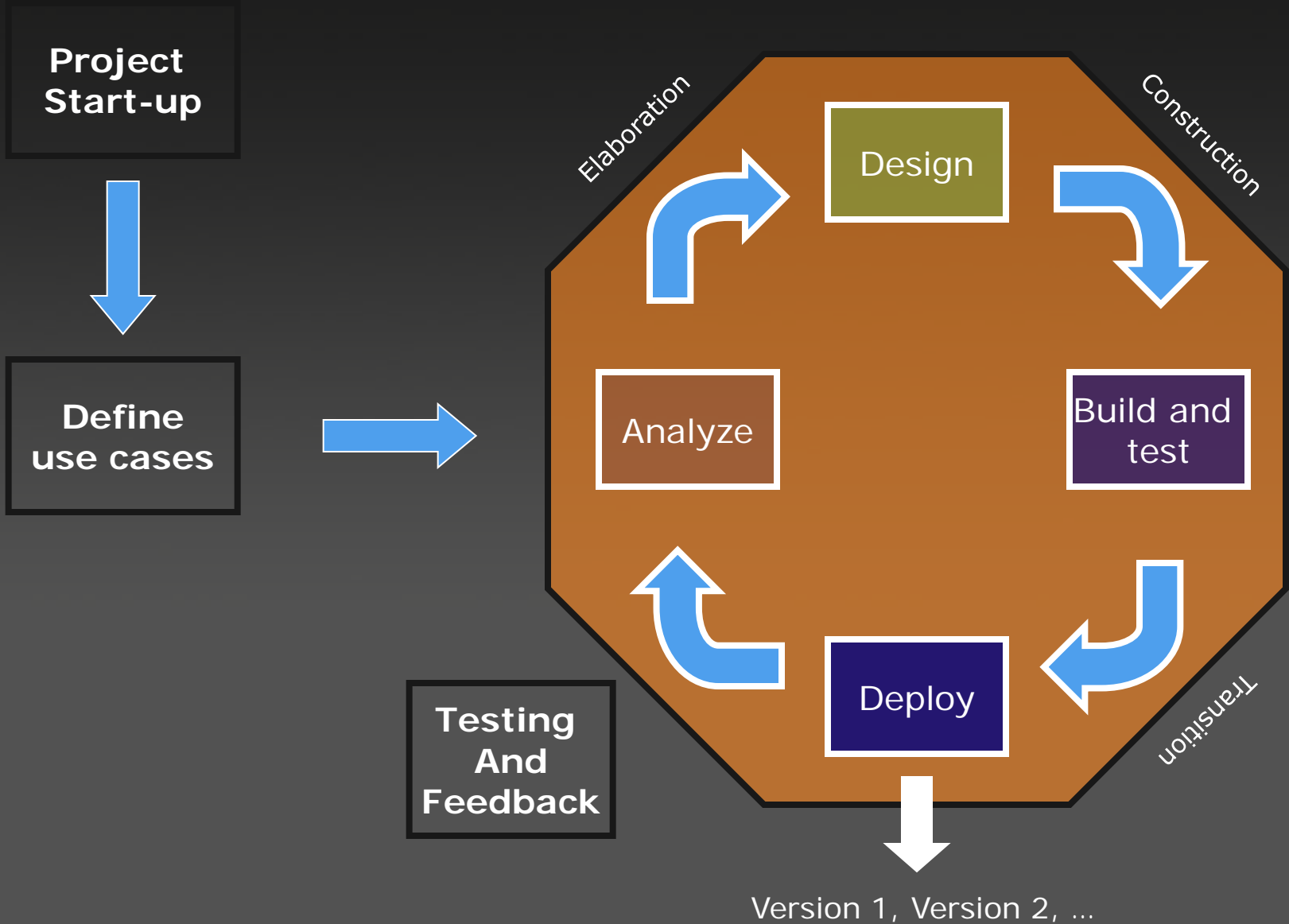
Max. Discharge Limit		Min. Discharge Limit		Input Data Quality	
Time	Value	Time	Value	Data Source	Quality
0	9,593	0	9,593	Turbine:	●
+5	11,618	+5	8,308	USGS Gauge:	●
+60	11,618	+60	8,308	<a href="#">Data Quality Metadata</a>	
+65	13,137	+65	7,168	Compliance Mode:	
+120	13,137	+120	7,168	Run of River	
+125	15,281	+125	5,735	Spill detected:	●
+180	15,281	+180	5,735		

### Discharge Plan:

Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

**Save and Simulate**

# Workflow Analysis



# Iterative Design Process



Idaho Power Bliss Dam Decision Support Tool - Windows Internet Explorer

http://d0100718/DSS/DashboardEngine.aspx?DashboardID=IdahoPower\BlissDSS

File Edit View Favorites Tools Help

Idaho Power Bliss Dam Decision Support Tool

Administration Metadata Log Off

### Bliss Dam Decision Support System

Bliss Dam Discharge (cfs)

Discharge (cfs)

17933  
15552.4  
13171.8  
10791.2  
8410.6  
6030

06:00 09:00 12:00 15:00 18:00  
21/12 21/12 21/12 21/12 21/12

— Discharge Plan — Dam Discharge — Max. Discharge — Min. Discharge

Stage at Compliance Gauge (ft)

Stage (ft)

14.0  
12.0  
10.0  
8.0

06:00 09:00 12:00 15:00 18:00  
21/12 21/12 21/12 21/12 21/12

Modeled Stage : 12.93  
Measured Stage : 12.83  
Max. Stage : 13.8  
Min. Stage : 11.85  
Date: 2011-12-21 06:32

— Min. Stage — Max. Stage — Measured Stage — Modeled Stage

Max. Discharge Limit		Min. Discharge Limit		Input Data Quality	
Time	Value	Time	Value	Data Source	Quality
0	10,412	0	10,412	Turbine:	
+5	12,290	+5	8,847	USGS Gauge:	
+60	12,290	+60	8,847	Data Quality:	
+65	14,492	+65	8,378	Compliance:	
+120	14,492	+120	8,378	Run of River:	
+125	16,303	+125	7,019	Spill detected:	
+180	16,303	+180	7,019		

**Discharge Plan:**

Duration:  1 hour  15 minutes

Scheduled Discharge:

00:00	9000
01:00	8000
02:00	6700

Save and Simulate

Discharge Limits Updated 2 Minutes Ago

Page Loaded: 21-12-2011 16:53:14

Scheduled Discharge Updated 149 Minutes Ago

Stage (ft)

01/06/09 06:00 AM

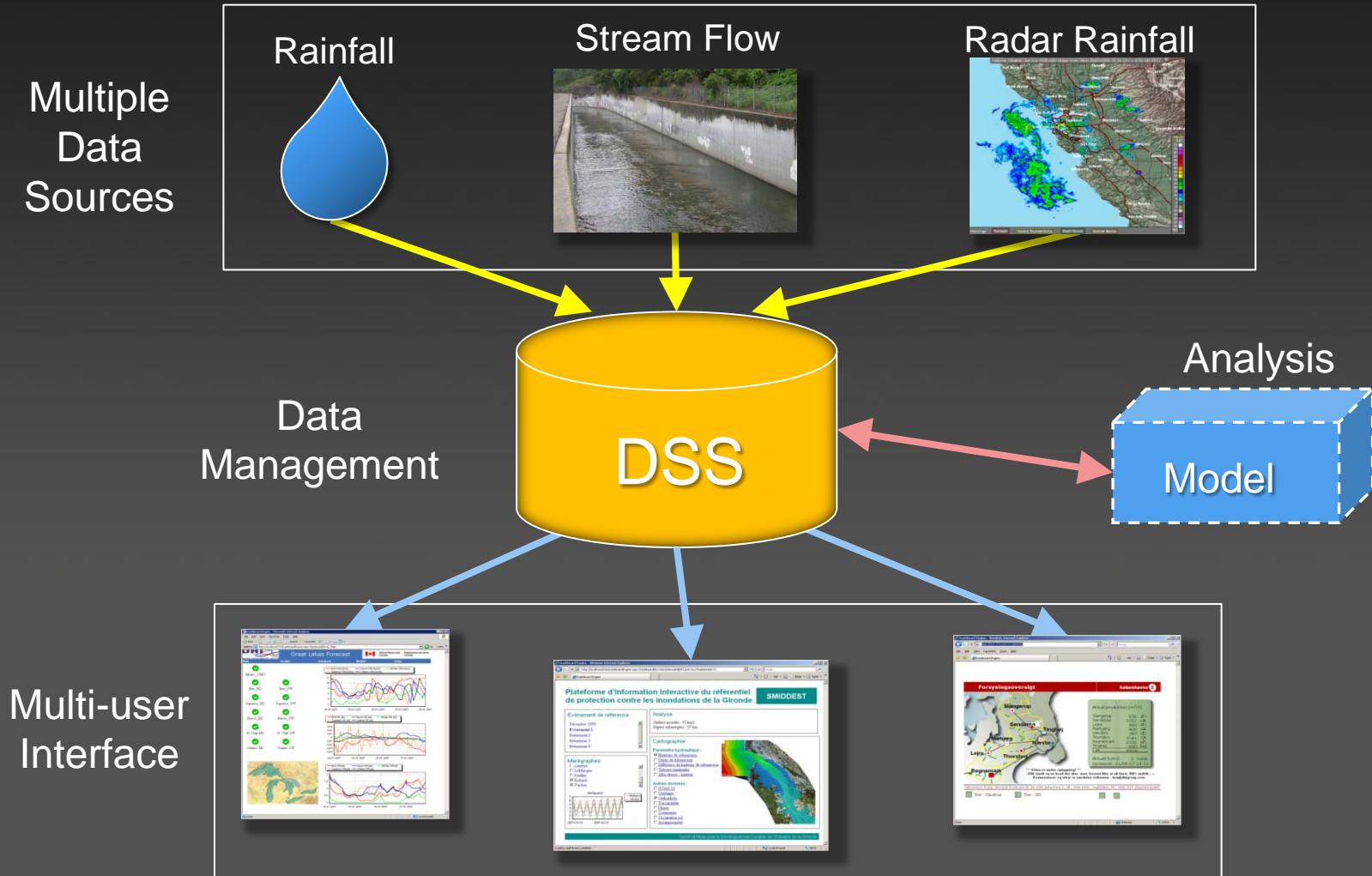
06/09 06:00 PM

— Min. Stage

Minutes Ago

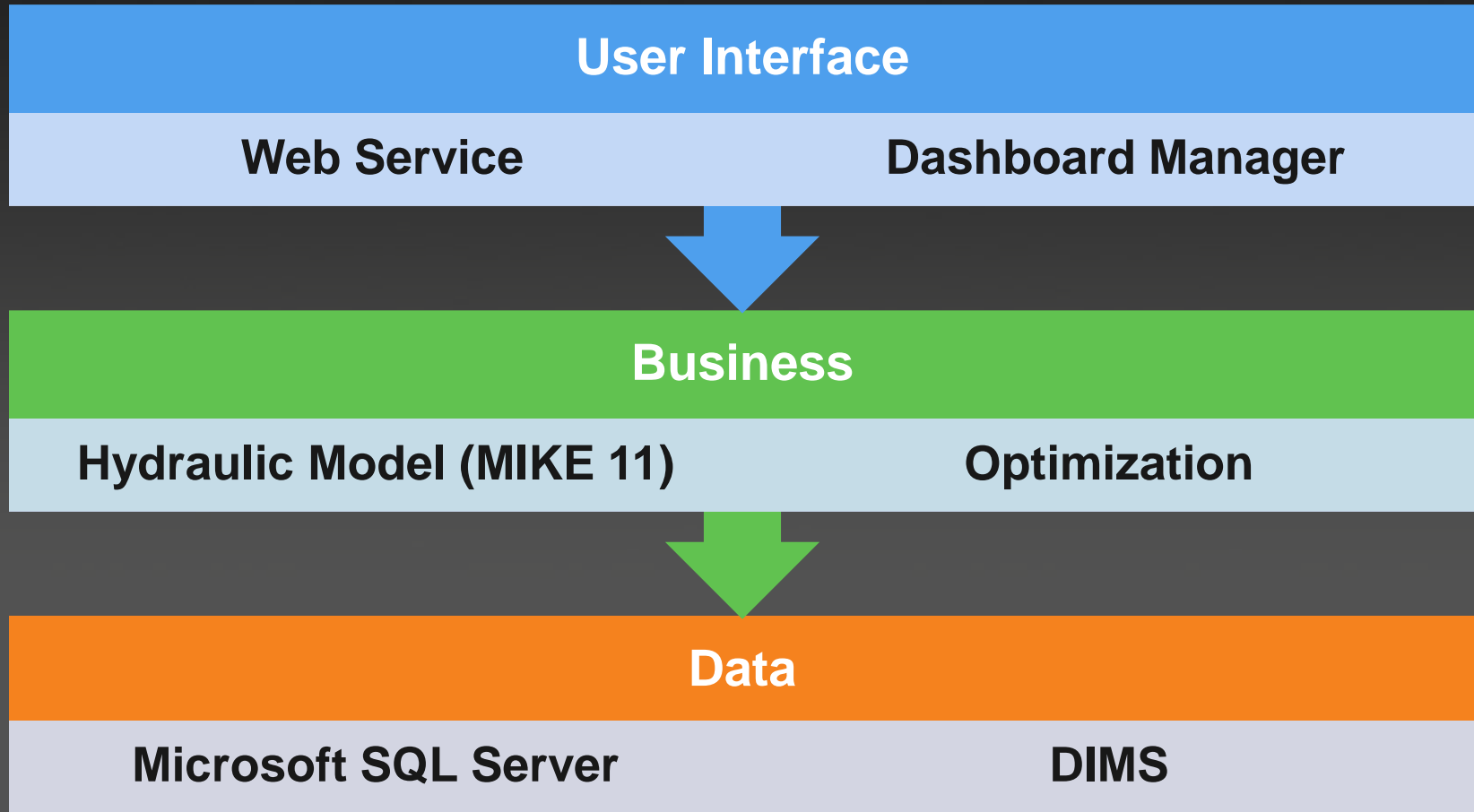
Time	Value
6:09 PM	6,464
6:14 PM	4,501
6:17:09 PM	4,501
6:17:14 PM	4,508
6:18:09 PM	4,508
6:18:14 PM	4,511
6:19:09 PM	4,511

# Decision Support Systems (DSS)



# Solution

- 3-Tier Architecture



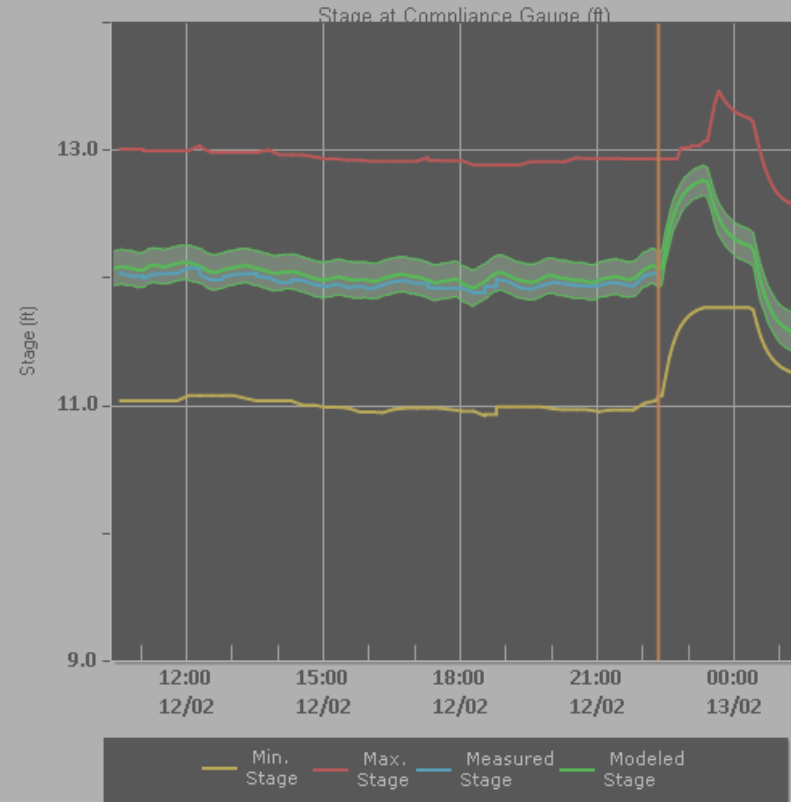
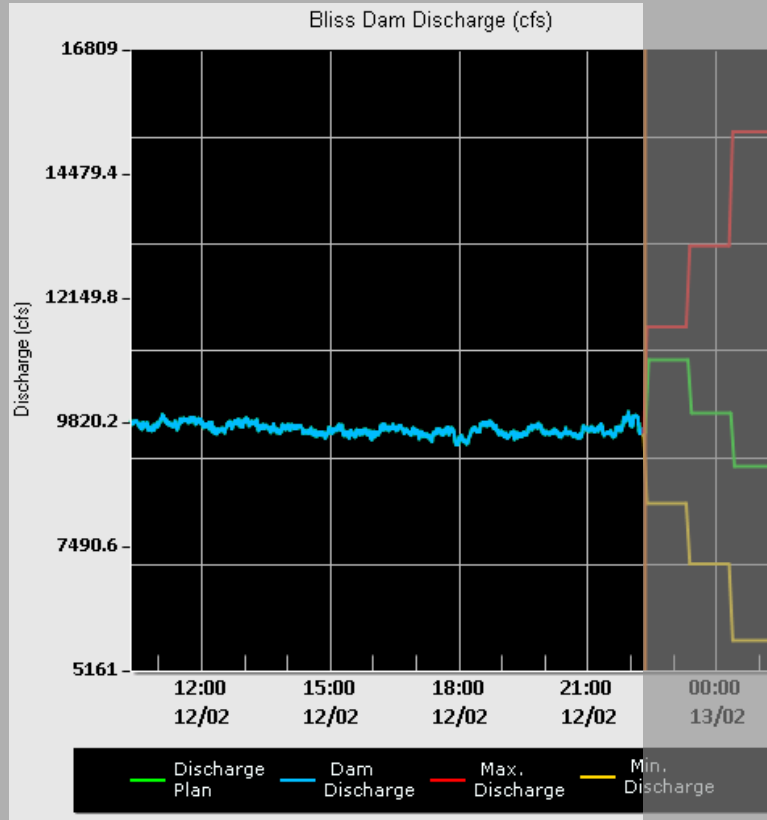
- Monitoring and Notification

# Data Sources and Management



## Bliss Dam Decision Support System

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Max. Discharge Limit		Min. Discharge Limit	
Time	Value	Time	Value
0	9,593	0	9,593
+5	11,618	+5	8,308
+60	11,618	+60	8,308
+65	13,137	+65	7,168
+120	13,137	+120	7,168
+125	15,281	+125	5,735
+180	15,281	+180	5,735

Input Data Quality	
Data Source	Quality
Turbine:	<span style="color: green;">●</span>
USGS Gauge:	<span style="color: green;">●</span>
<a href="#">Data Quality Metadata</a>	
Compliance Mode:	Run of River
Spill detected:	<span style="color: blue;">●</span>

### Discharge Plan:

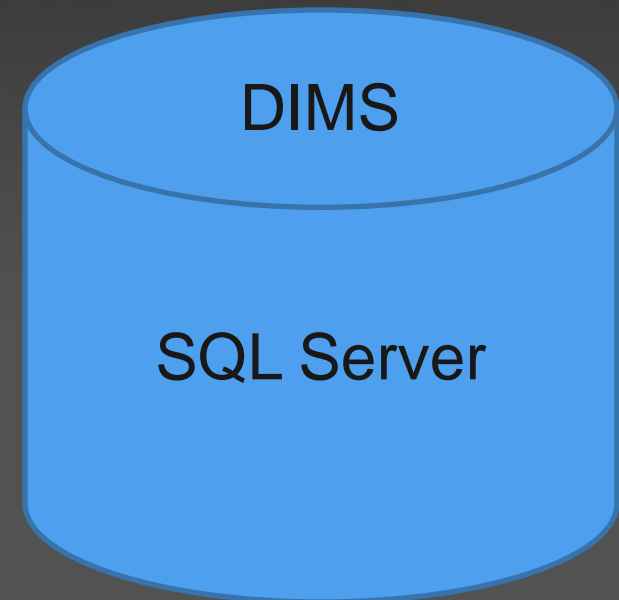
Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

**Save and Simulate**



# Data Sources and Management

- Problem: How to Manage Data
- Why a separate database?
- DIMS: Dynamic Information Management System
  - Real Time Data Management
  - Data Validation
  - Scheduled Execution
- DIMS Online vs. Offline
  - Data “pushed” to SQL Server
    - Turbine Discharge
    - Spillway Discharge (Calculated)
    - Water Levels



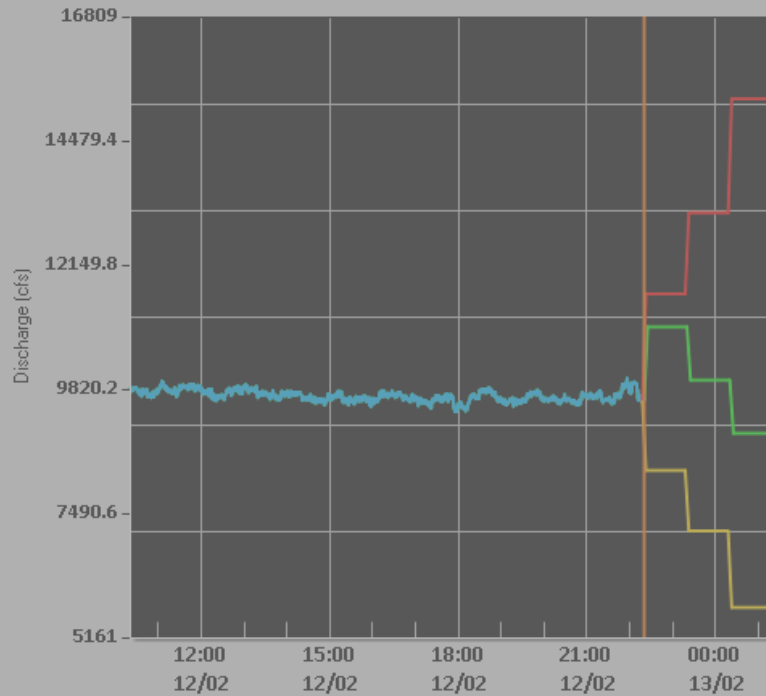
# Input Data Quality



## Bliss Dam Decision Support System

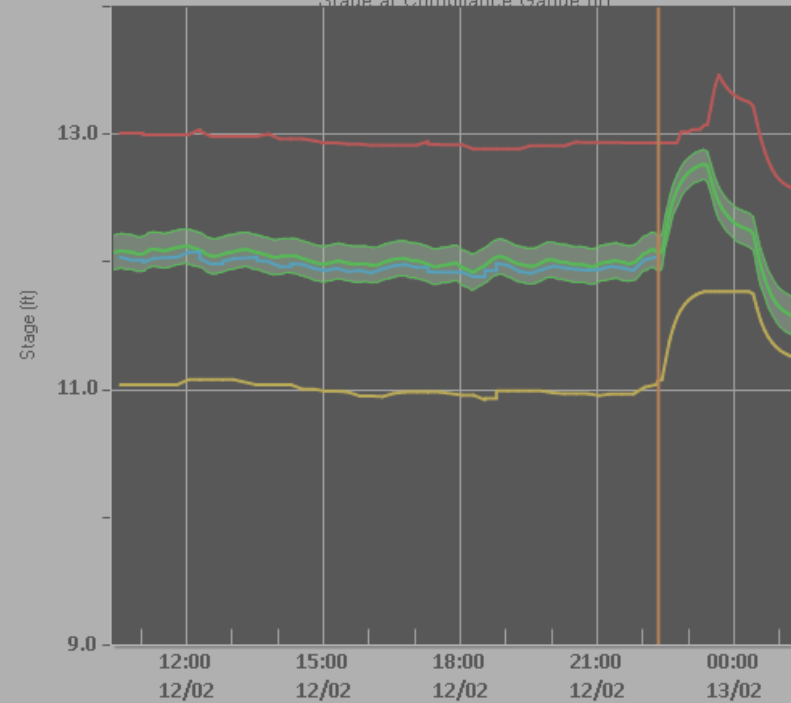
[Administration](#) [Metadata](#) [Log Off](#)

Bliss Dam Discharge (cfs)



— Discharge Plan   
 — Dam Discharge   
 — Max. Discharge   
 — Min. Discharge

Stage at Compliance Gauge (ft)



— Min. Stage   
 — Max. Stage   
 — Measured Stage   
 — Modeled Stage

Max. Discharge Limit		Min. Discharge Limit	
Time	Value	Time	Value
0	9,593	0	9,593
+5	11,618	+5	8,308
+60	11,618	+60	8,308
+65	13,137	+65	7,168
+120	13,137	+120	7,168
+125	15,281	+125	5,735
+180	15,281	+180	5,735

### Input Data Quality

**Data Source Quality**  
 Turbine: ●  
 USGS Gauge: ●  
[Data Quality Metadata](#)  
 Compliance Mode:  
 Run of River  
 Spill detected: ●

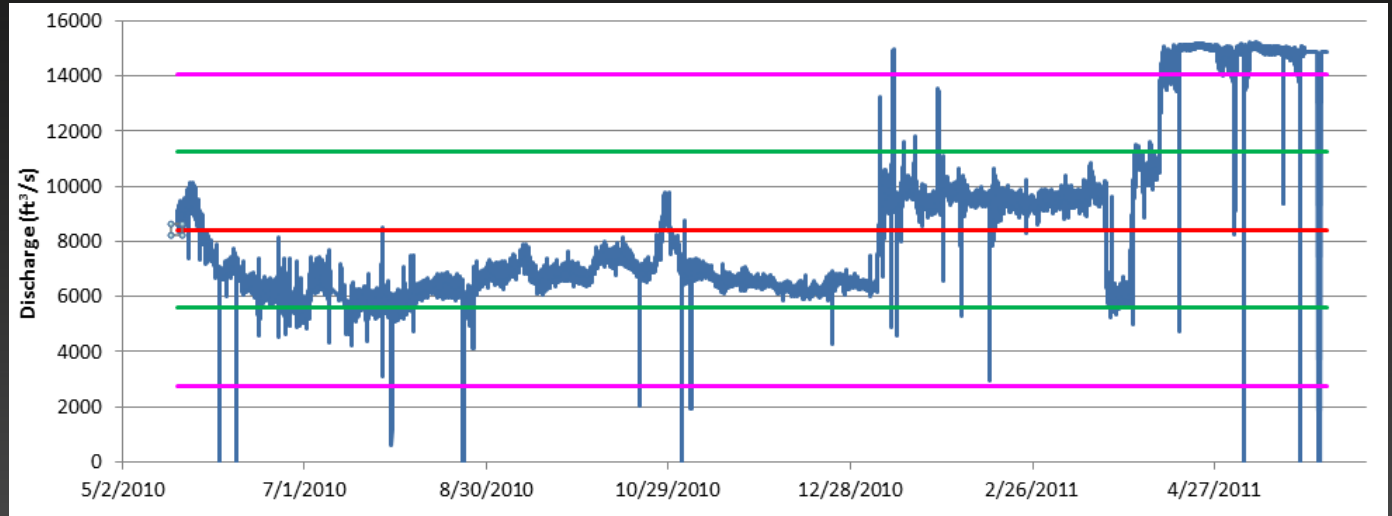
### Discharge Plan:

Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

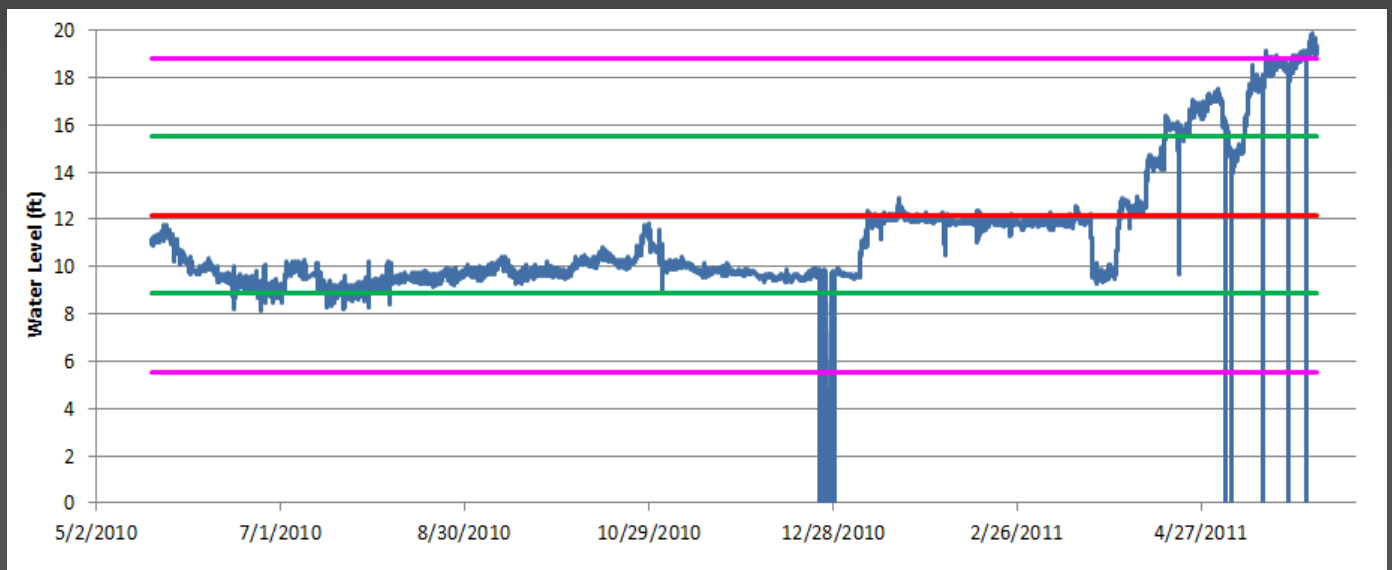
**Save and Simulate**

# Input Data Quality

- Discharge



- Water Level



# Real Time Data Validation



- Sensor data quality can be inspected, using simple but robust methods, for frequent errors, including:
  - Missing Data
  - Measurement values out of range
  - Peaks (rate of change)
  - Constant measurement values
  - Drift
- Each error type is assessed using confidence functions with physically based thresholds
- Overall confidence is determined as the minimum confidence for the error types assessed

## Citation:

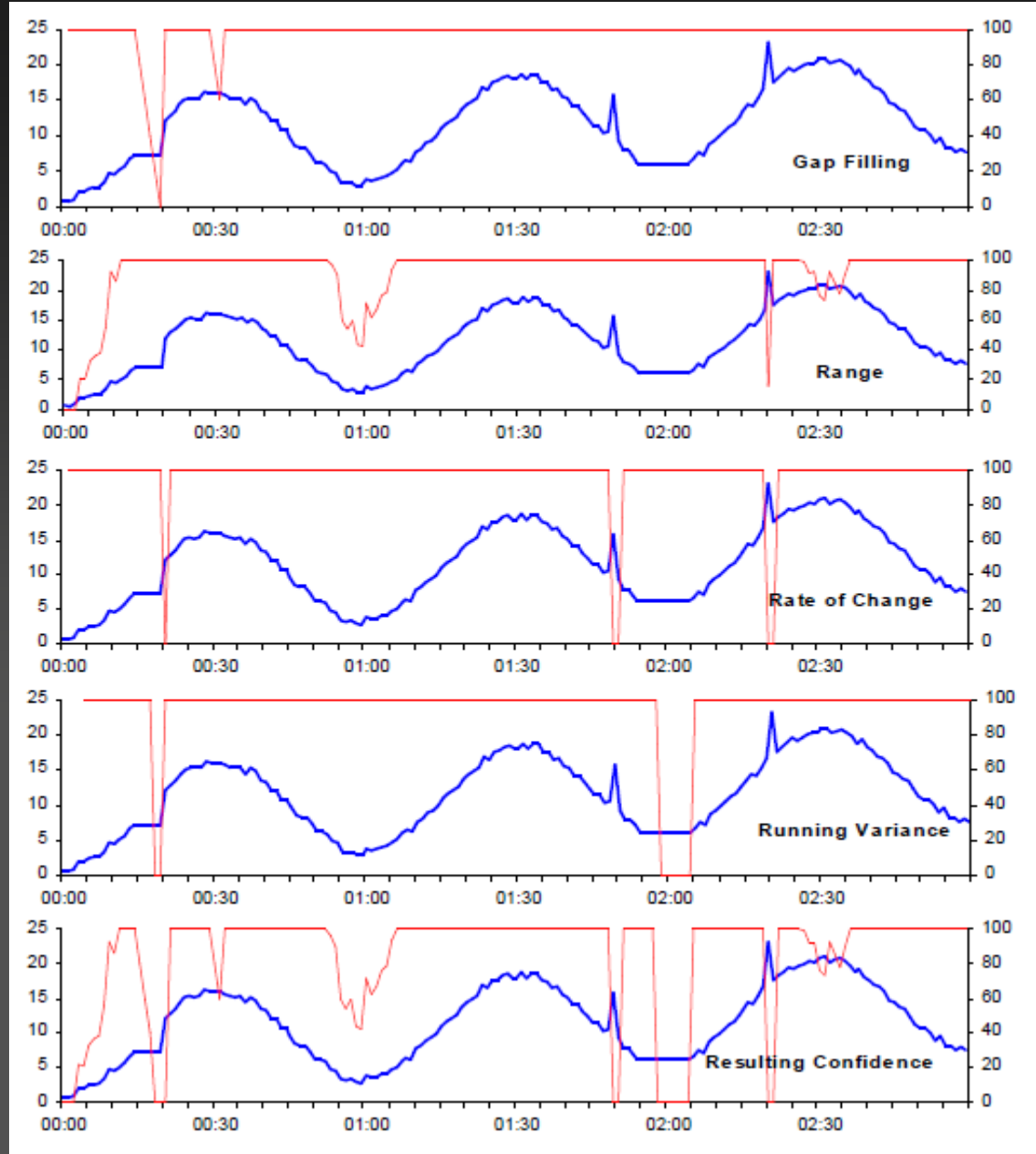
Lynggaard-Jensen, A., Frey, M.: Use and Reporting of Data - Data Handling and Validation. In Online Monitoring for Drinking Water Utilities. Published by American Water Works Association Research Foundation and CRS Proaqua (2002). ISBN 1-58321-183-7.

# Real Time Data Validation

- Gap Filling
- Range
- Rate of Change
- Running Variance
- Resulting Confidence

Sensor value

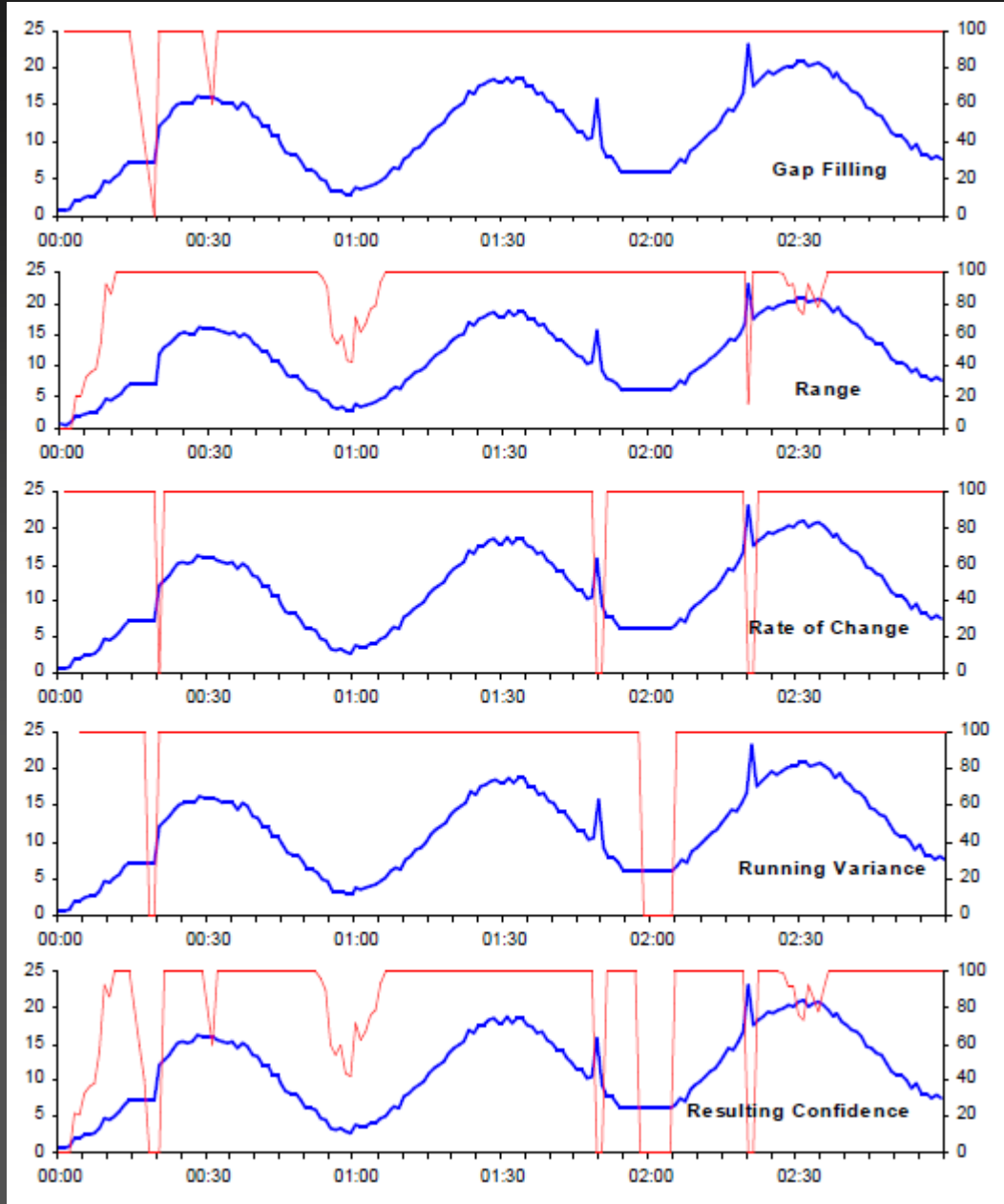
Confidence



# Real Time Data Validation

- The database archiving real time data is appended with the overall confidence at each timestep
- Quality descriptions are assigned to overall confidence ranges, such as:
  - $> 80 = \text{“Good”}$
  - $60-80 = \text{“Fair”}$
  - $< 60 = \text{“Poor”}$
- Automated warning messages and actions can be implemented based on specified confidence values

Sensor value



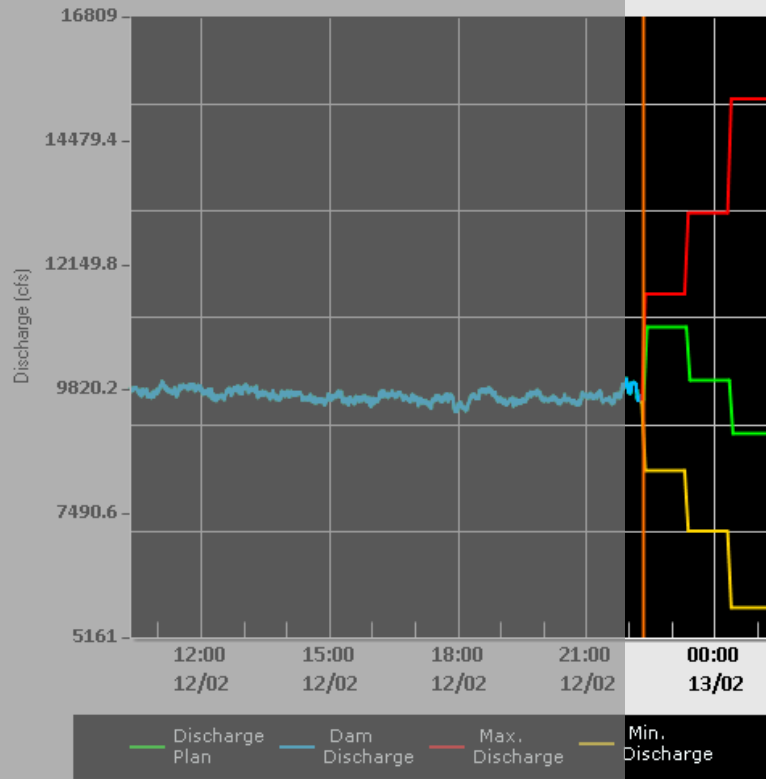
Confidence

# Discharge Planning

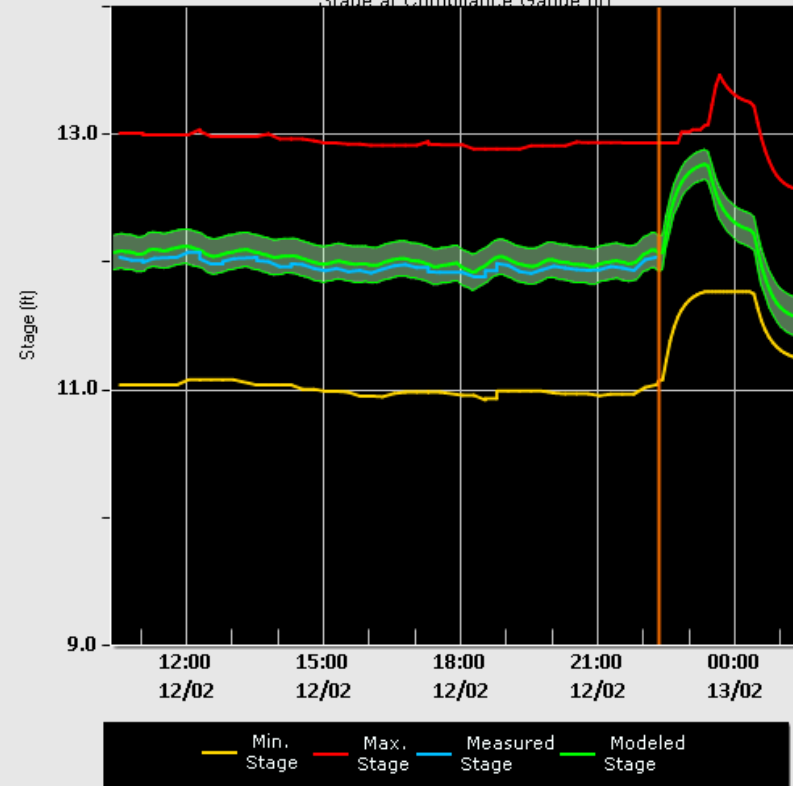
## Bliss Dam Decision Support System

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Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)



Max. Discharge Limit		Min. Discharge Limit		Input Data Quality	
Time	Value	Time	Value	Data Source	Quality
0	9,593	0	9,593	Turbine:	<span style="color: green;">●</span>
+5	11,618	+5	8,308	USGS Gauge:	<span style="color: green;">●</span>
+60	11,618	+60	8,308	<a href="#">Data Quality Metadata</a>	
+65	13,137	+65	7,168	Compliance Mode:	
+120	13,137	+120	7,168	Run of River	
+125	15,281	+125	5,735	Spill detected:	<span style="color: blue;">●</span>
+180	15,281	+180	5,735		

### Discharge Plan:

Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

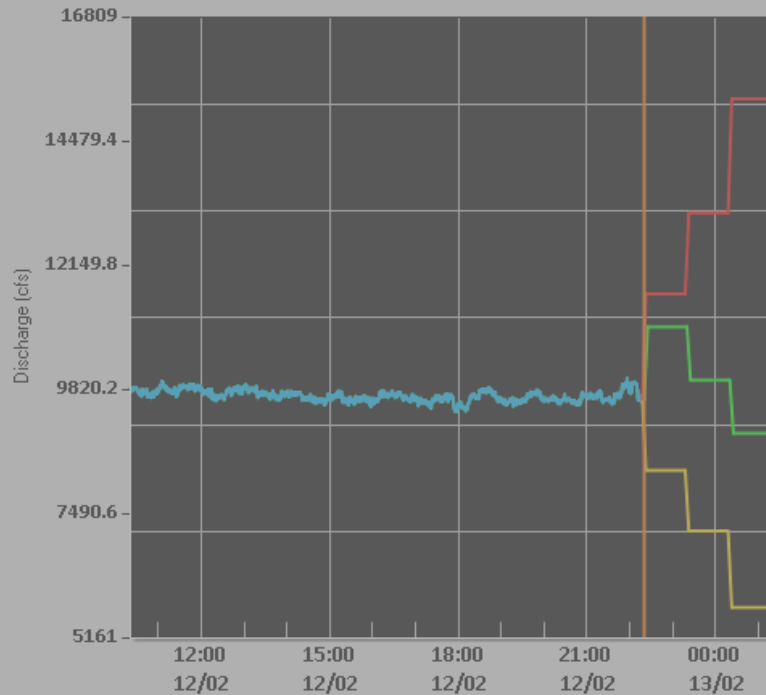
**Save and Simulate**

# Error Analysis / Uncertainty

## Bliss Dam Decision Support System

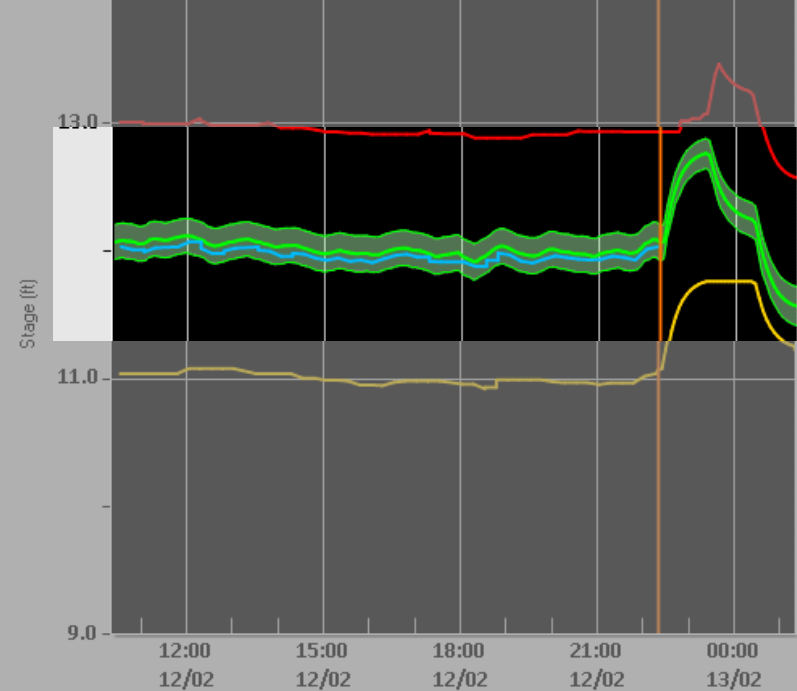
[Administration](#) [Metadata](#) [Log Off](#)

Bliss Dam Discharge (cfs)



— Discharge Plan   
 — Dam Discharge   
 — Max. Discharge   
 — Min. Discharge

Stage at Compliance Gauge (ft)



— Min. Stage   
 — Max. Stage   
 — Measured Stage   
 — Modeled Stage

Max. Discharge Limit		Min. Discharge Limit	
Time	Value	Time	Value
0	9,593	0	9,593
+5	11,618	+5	8,308
+60	11,618	+60	8,308
+65	13,137	+65	7,168
+120	13,137	+120	7,168
+125	15,281	+125	5,735
+180	15,281	+180	5,735

**Input Data Quality**

Data Source    Quality

Turbine:    ●

USGS Gauge:    ●

[Data Quality Metadata](#)

Compliance Mode:  
Run of River

Spill detected:    ●

### Discharge Plan:

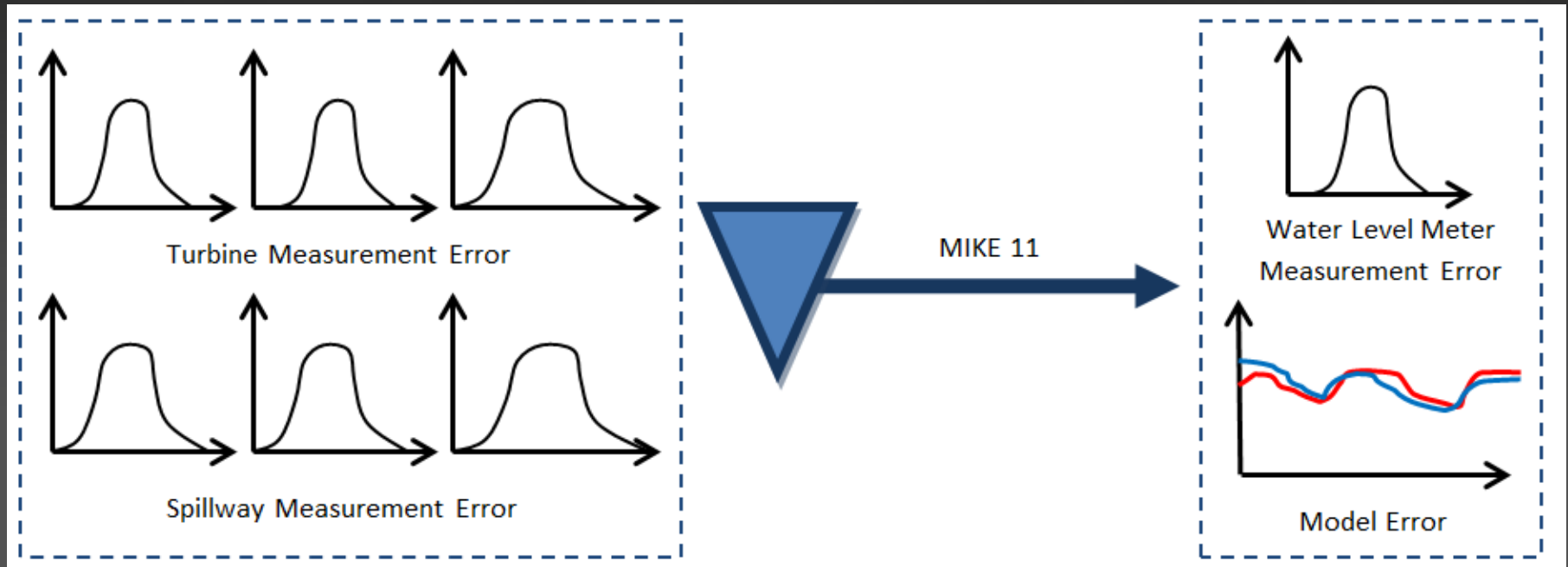
Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

**Save and Simulate**



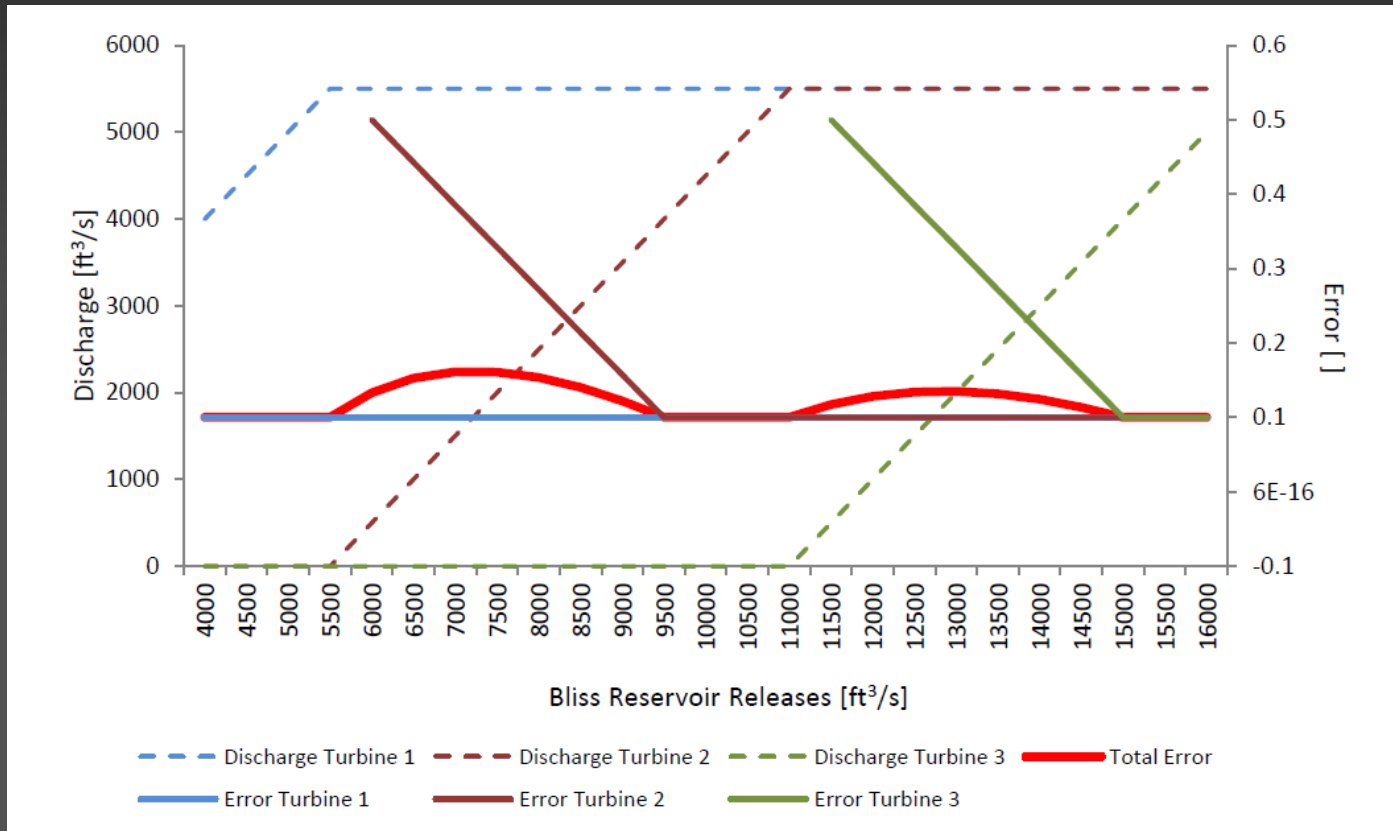
# Error Analysis / Uncertainty

- Sources of Error
  - Measurement Error
  - Modeling Error



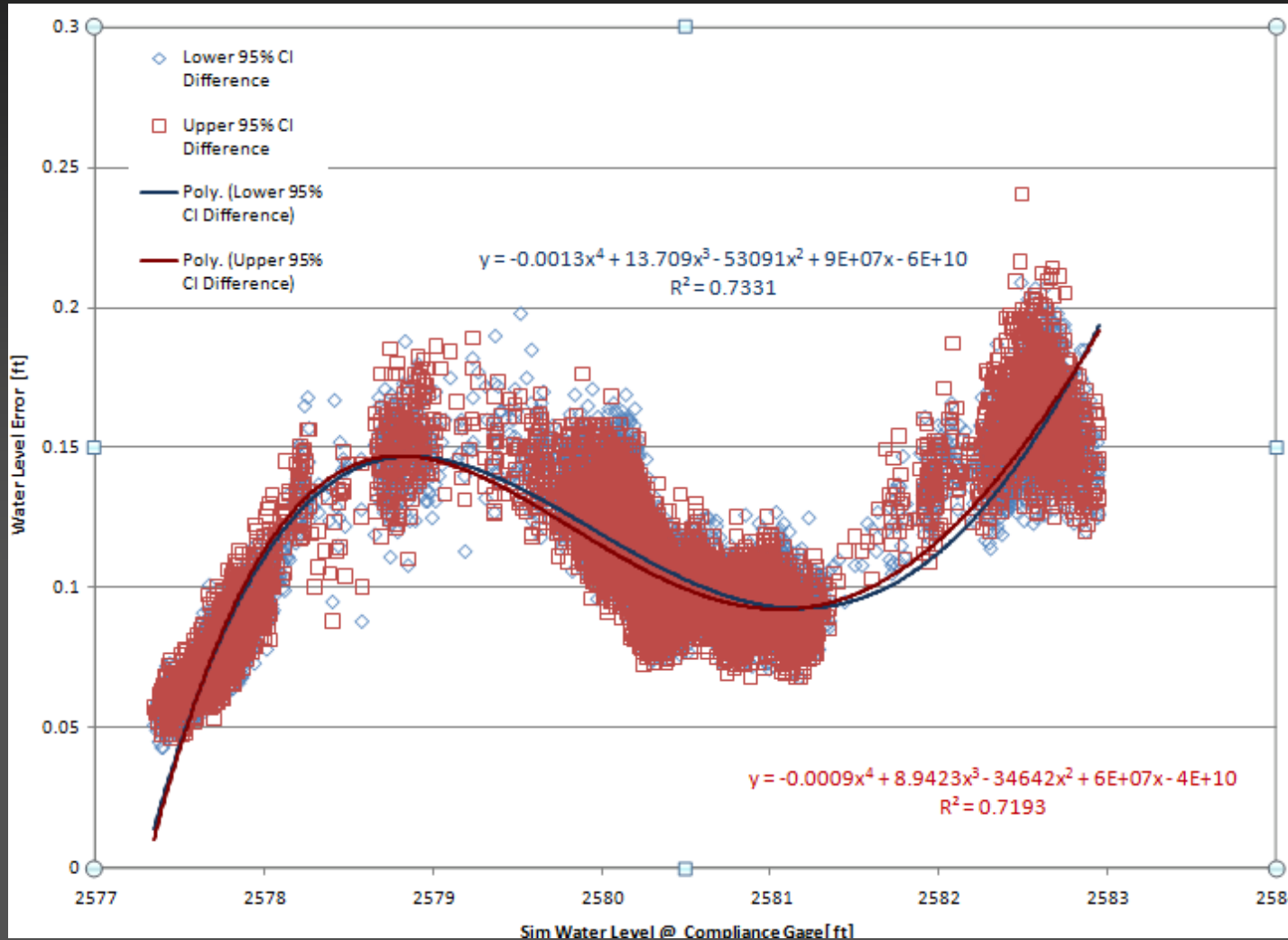
# Error Analysis / Uncertainty

- Error is highest during low discharge values on sequentially activated turbines
- Error decrease as turbines releases are increased



# Error Analysis / Uncertainty

- Monte Carlo Results

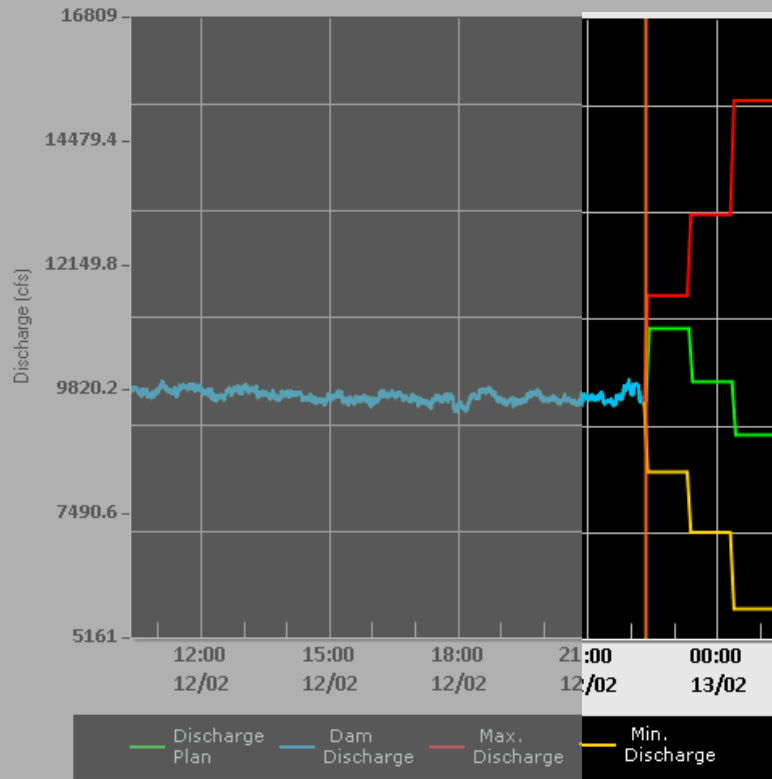


# Discharge Limits

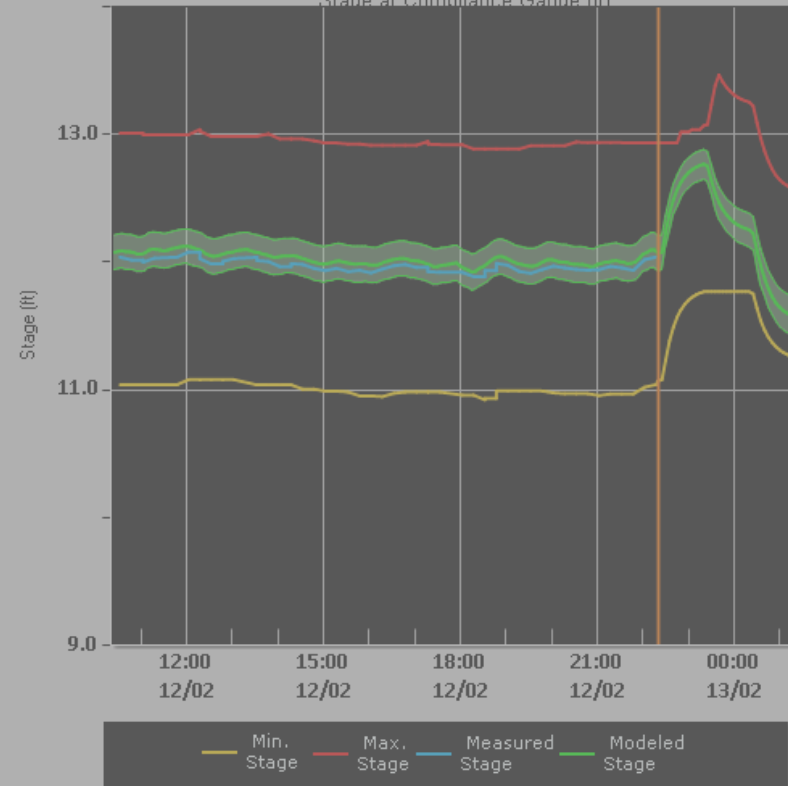
## Bliss Dam Decision Support System

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Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)



Max. Discharge Limit		Min. Discharge Limit	
Time	Value	Time	Value
0	9,593	0	9,593
+5	11,618	+5	8,308
+60	11,618	+60	8,308
+65	13,137	+65	7,168
+120	13,137	+120	7,168
+125	15,281	+125	5,735
+180	15,281	+180	5,735

Input Data Quality	
Data Source	Quality
Turbine:	<span style="color: green;">●</span>
USGS Gauge:	<span style="color: green;">●</span>
<a href="#">Data Quality Metadata</a>	
Compliance Mode:	
Run of River	
Spill detected:	<span style="color: blue;">●</span>

### Discharge Plan:

Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

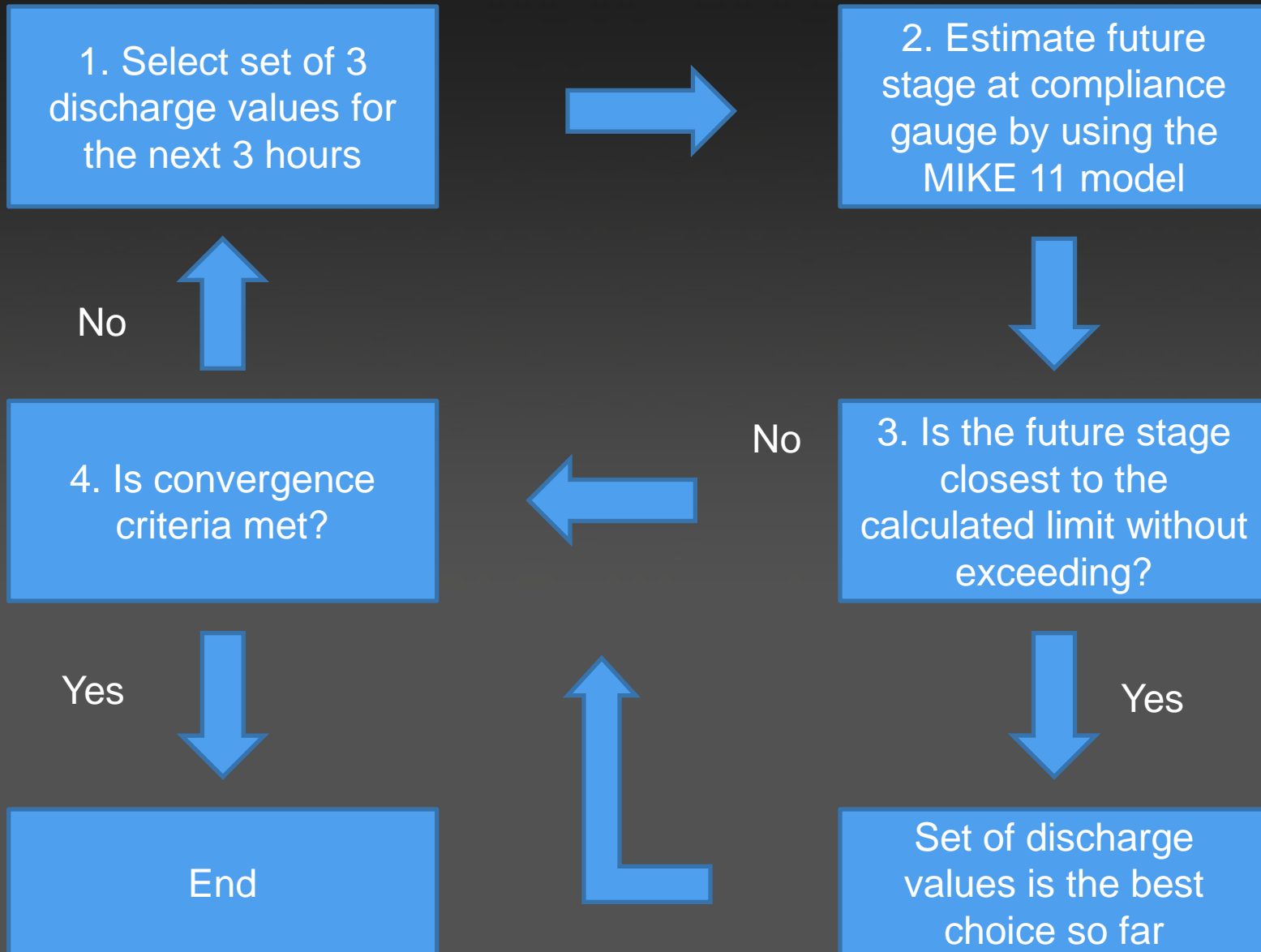
**Save and Simulate**

# Optimization Routine



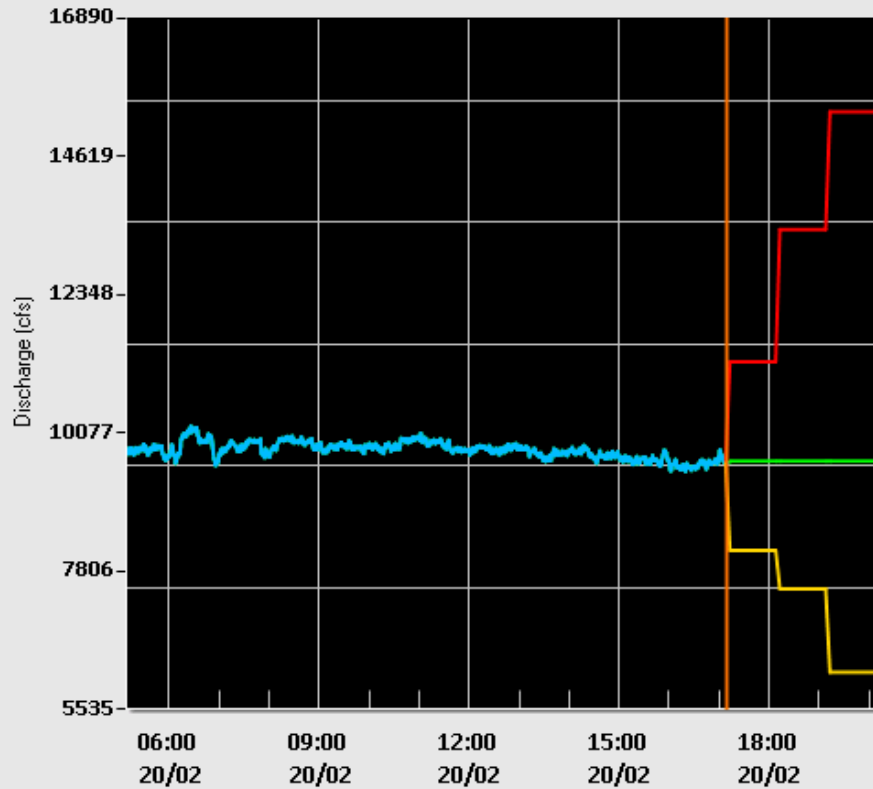
- Objective = find maximum and minimum allowable discharge operations that meet the compliance rules for downstream location
- Compliance Rules
  - Stage increases  $\pm 3$  feet / hour OR  $\pm 1$  feet / hour (continuous limit)
  - Stage increases  $\pm 6$  feet / day OR unlimited (daily limit)
  - Discharge  $\geq 4500$  cubic feet /second (provides 8.12 feet of depth at compliance location)
- Optimization steps
  1. Select a set of three discharge values, which is the proposed solution.
  2. Estimate the future stage at the compliance gauge by using the MIKE11 model.
  3. Check how the future stage at the compliance gauge compares to the calculated limit. It is considered the best choice so far when it is closest to the calculated limit without exceeding it.
  4. Evaluate a convergence criteria to stop the iteration, or to go back to guess another solution (i.e., step 1).

# Optimization Routine

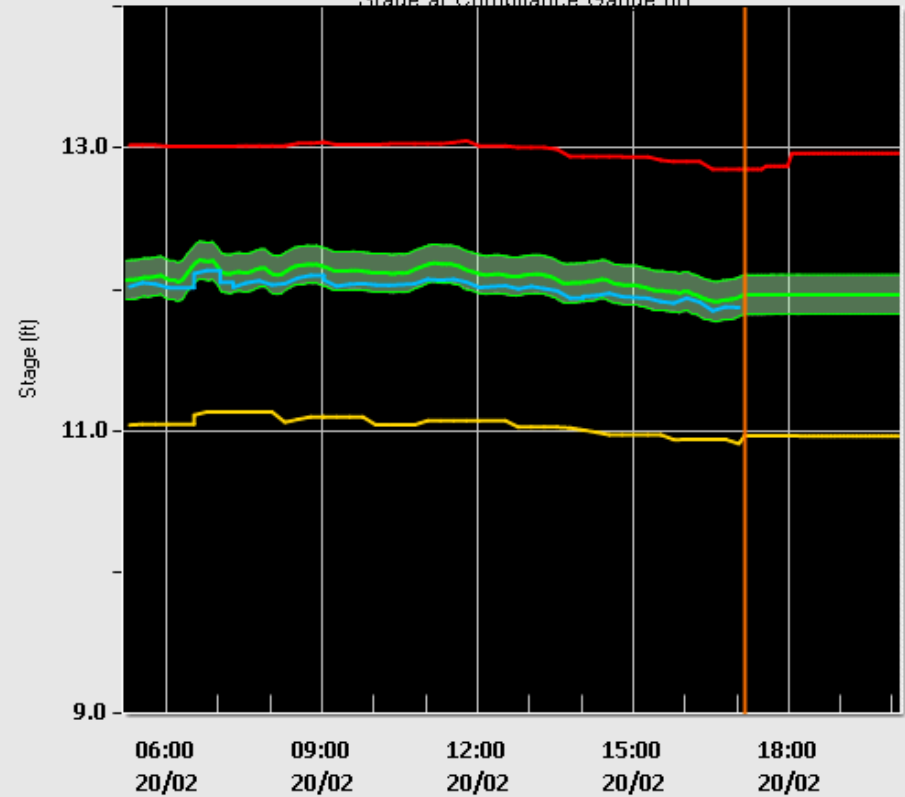


# Optimization Routine

Bliss Dam Discharge (cfs)

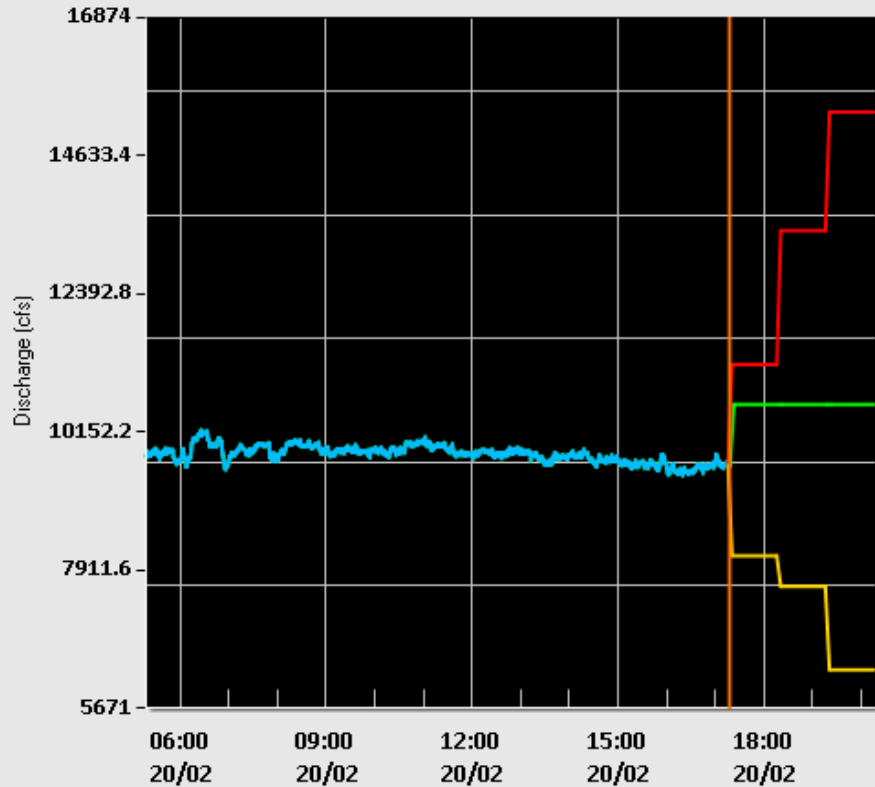


Stage at Compliance Gauge (ft)

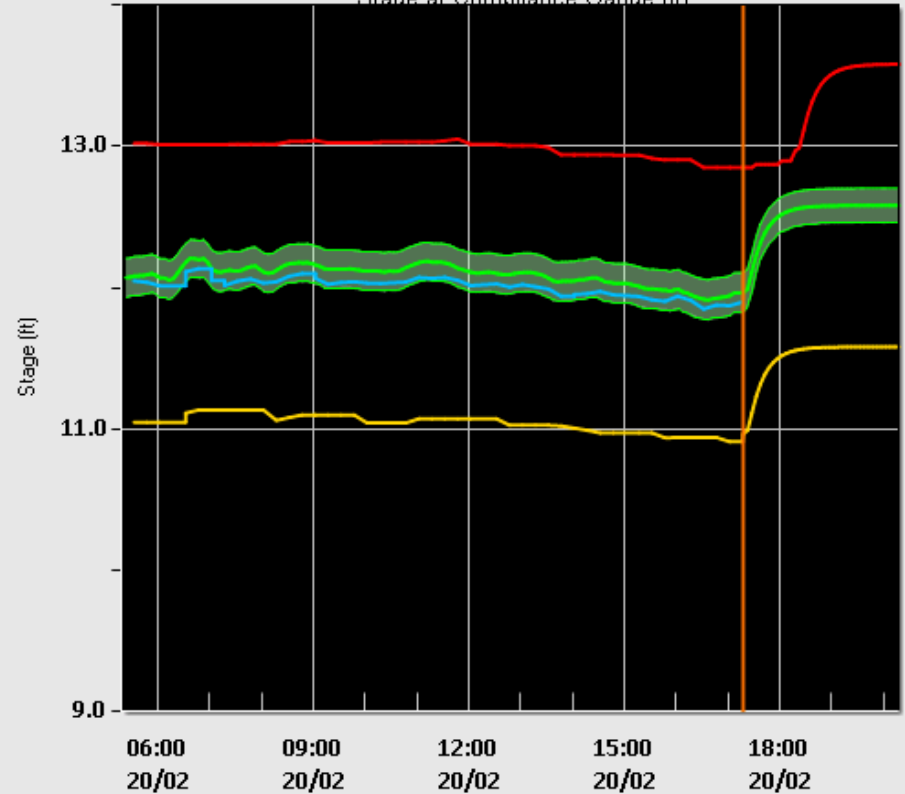


# Optimization Routine

Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)



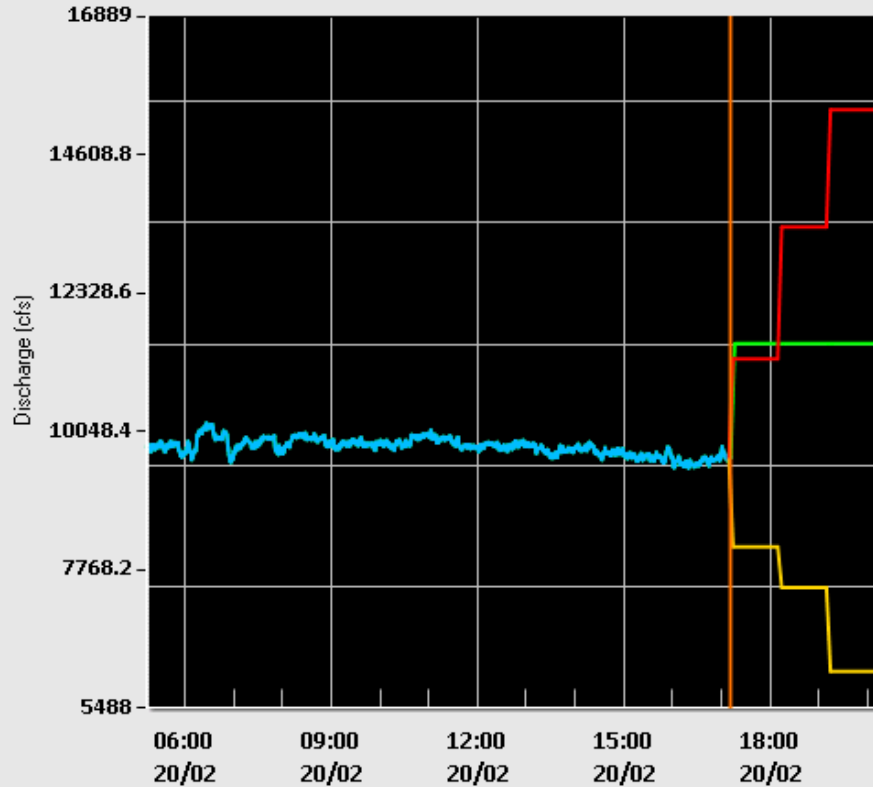
Discharge Plan Dam Discharge Max. Discharge Min. Discharge

Min. Stage Max. Stage Measured Stage Modeled Stage

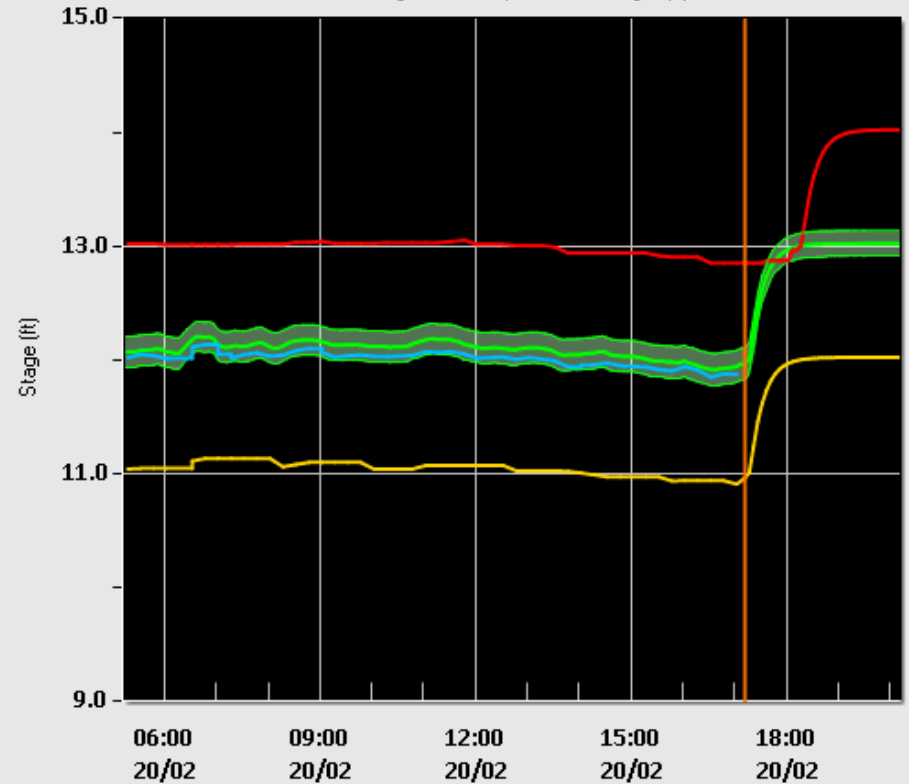


# Optimization Routine

Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)

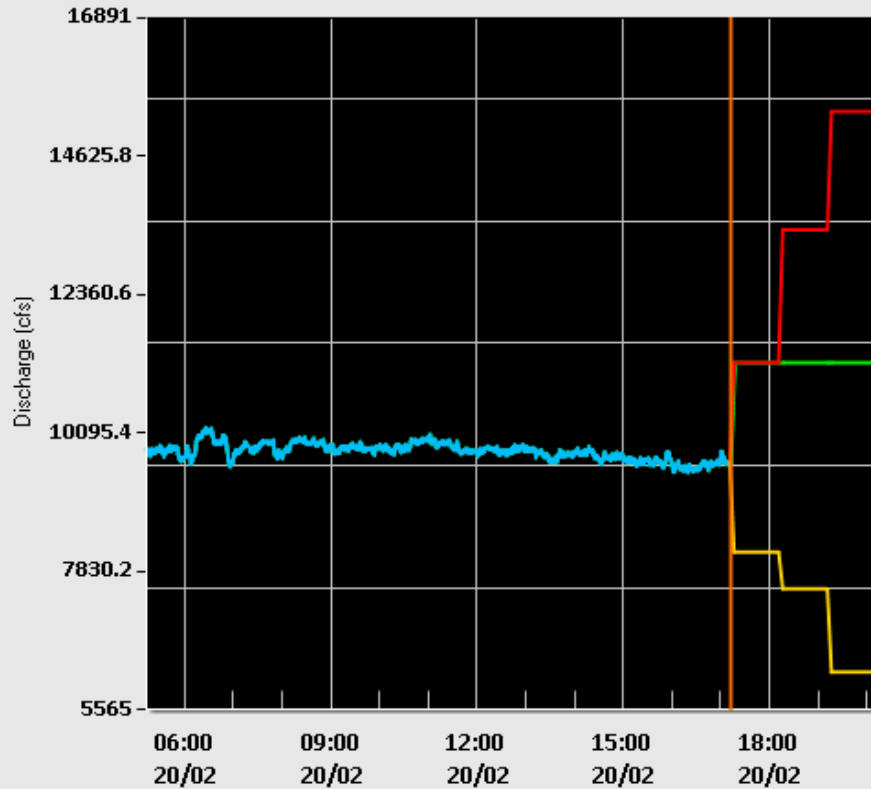


Discharge Plan Dam Discharge Max. Discharge Min. Discharge

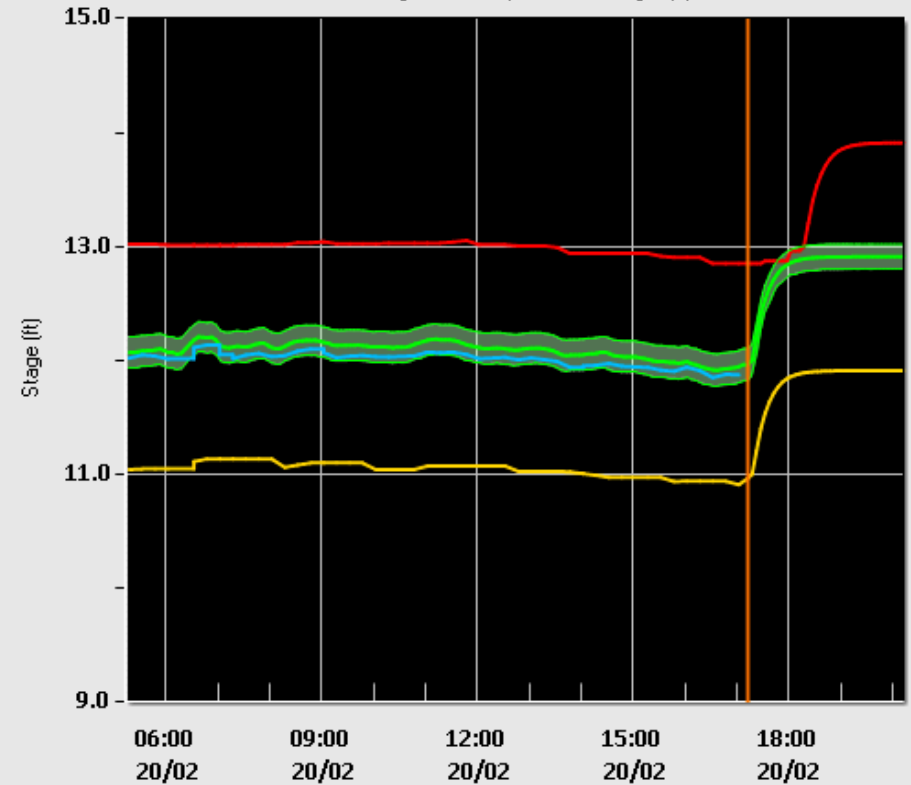
Min. Stage Max. Stage Measured Stage Modeled Stage

# Optimization Routine

Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)

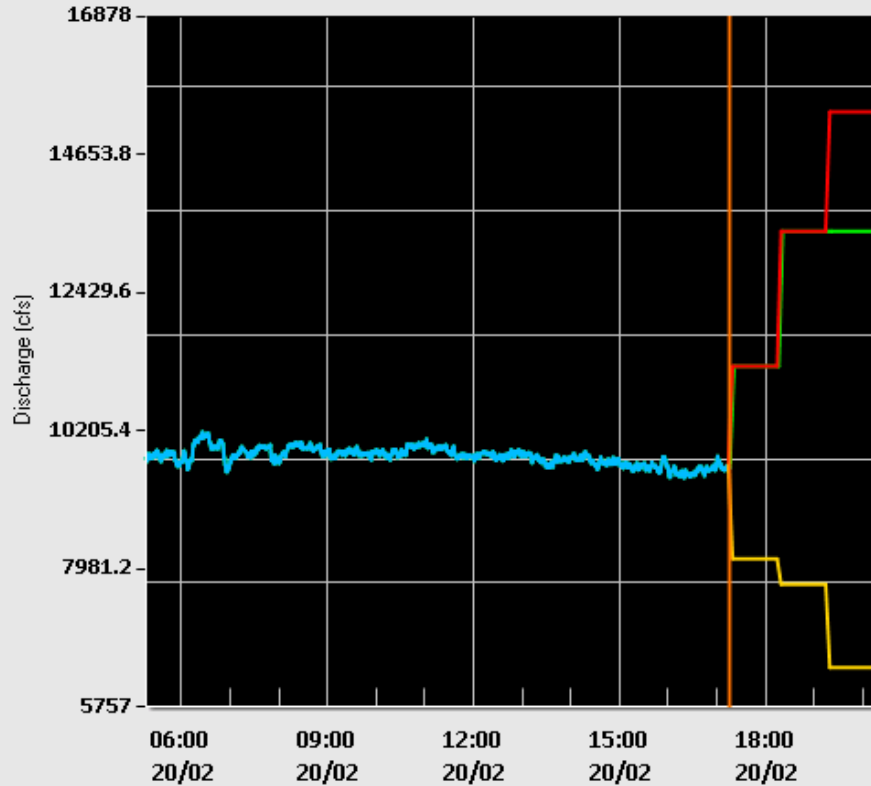


Discharge Plan (green), Dam Discharge (cyan), Max. Discharge (red), Min. Discharge (yellow)

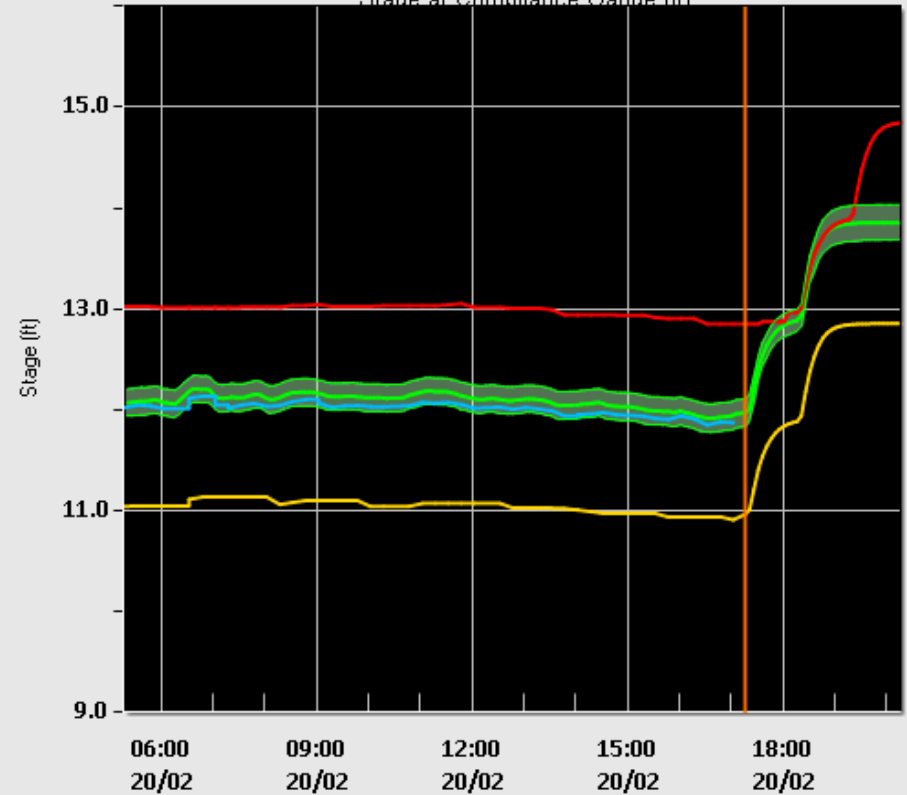
Min. Stage (yellow), Max. Stage (red), Measured Stage (cyan), Modeled Stage (green)

# Optimization Routine

Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)

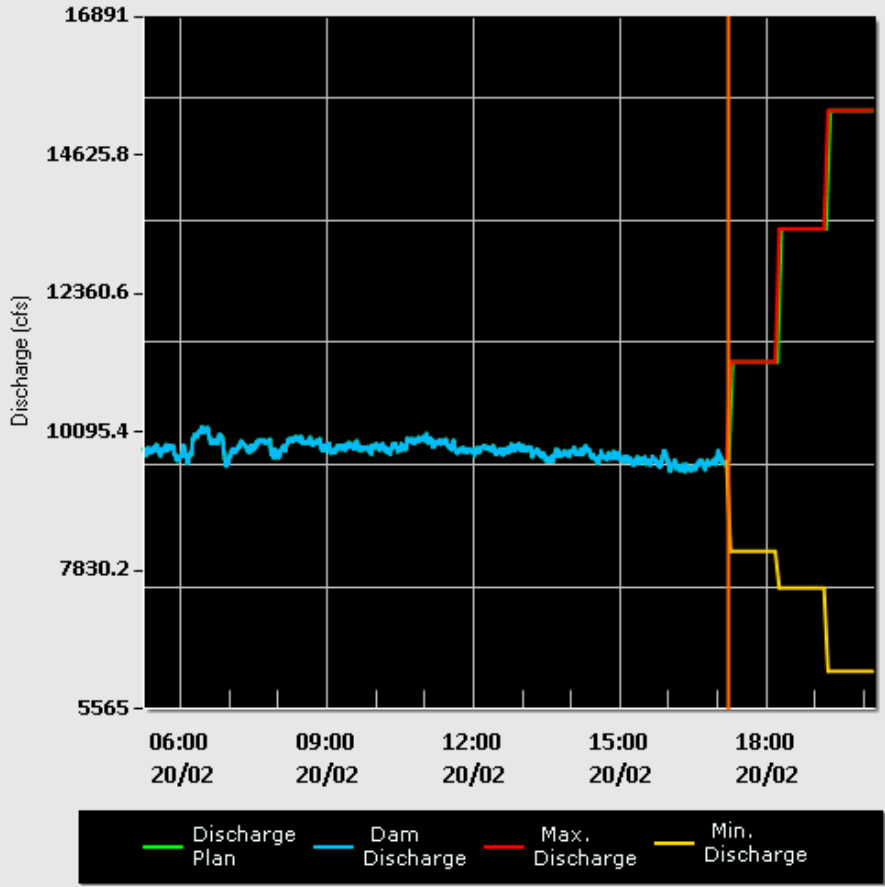


Discharge Plan Dam Discharge Max. Discharge Min. Discharge

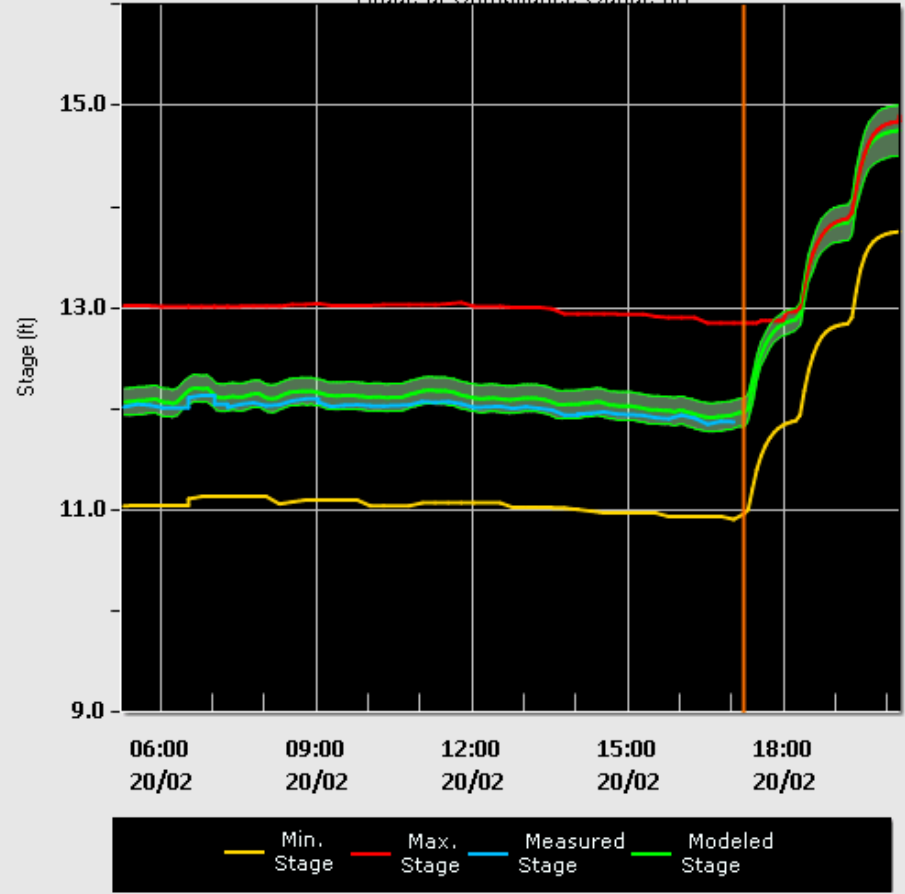
Min. Stage Max. Stage Measured Stage Modeled Stage

# Optimization Routine

Bliss Dam Discharge (cfs)



Stage at Compliance Gauge (ft)



# User Interface



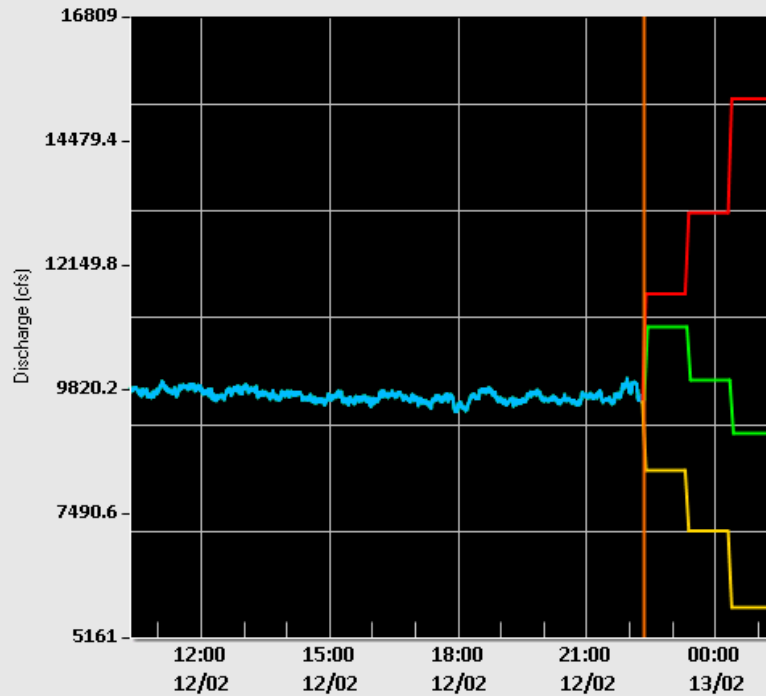
- Web Interface
  - One Screen
  - Dashboard Manager
  - Customized Components
  
- System Monitoring and Notification Application
  - Configurable
  - Web Service
  - Items Checked
    - Server Running
    - Model Service Running
    - Data Validation Running
    - Data Quality Warning
    - Gap Check
    - Age of Optimization Results

# Questions?

## Bliss Dam Decision Support System

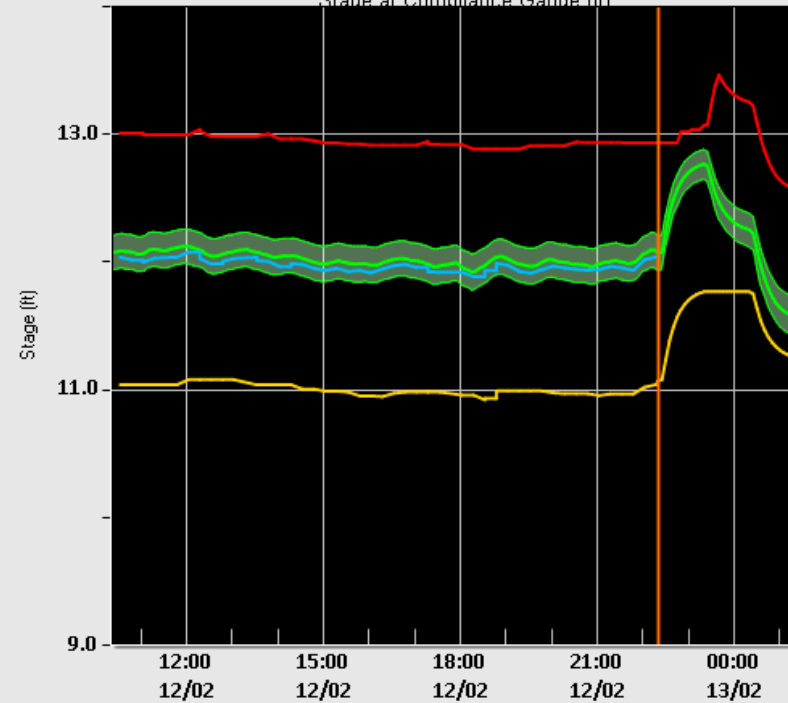
[Administration](#) [Metadata](#) [Log Off](#)

Bliss Dam Discharge (cfs)



— Discharge Plan   
 — Dam Discharge   
 — Max. Discharge   
 — Min. Discharge

Stage at Compliance Gauge (ft)



— Min. Stage   
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Max. Discharge Limit		Min. Discharge Limit	
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+120	13,137	+120	7,168
+125	15,281	+125	5,735
+180	15,281	+180	5,735

**Input Data Quality**

Data Source    Quality

Turbine:    ●

USGS Gauge:    ●

[Data Quality Metadata](#)

Compliance Mode:  
Run of River

Spill detected:    ●

### Discharge Plan:

Duration	Time Interval	Scheduled Discharge
<input type="radio"/> 1 hour	<input type="radio"/> 15 minutes	00:00 <input type="text" value="11000"/>
<input type="radio"/> 2 hours	<input type="radio"/> 30 minutes	01:00 <input type="text" value="10000"/>
<input checked="" type="radio"/> 3 hours	<input checked="" type="radio"/> 1 hour	02:00 <input type="text" value="9000"/>
	<input type="radio"/> 3 hours	

**Save and Simulate**