



Implementing Soft Constraints in Hydroelectric Decision Support Systems

Hong Gao

Powel-MiniMax, Inc.

Water Management Decision-Support Software
Workshop

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Powel-MiniMax

- Powel-MiniMax is a US-based energy software and services provider of stand-alone and integrated energy solutions.
- Powel has more than 250 employees based in Europe, USA, and Canada.
- Over 35 software modules used by more than 1000 customers worldwide covering
 - Transmission and Distribution Management
 - Trade and Risk Management
 - Customer Management
 - Geographic Information Systems (GIS)
 - Generation and Water Management
- Over 25 years of water management experience ranging from hydrological analysis and forecasting, water quality modeling, hydro systems, planning and operational analysis.



Agenda

- **Introduction**
 - What is a soft constraint?
 - Why are soft constraints needed?
 - How are soft constraints modeled in DSS?
 - A few soft constraint examples in HYDROPS™
 - Implementation Issues
 - Conclusions and Future Developments



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Introduction

- **Constraint Satisfaction Problems (CSP)**
 - ┆ Hydroelectric DSS Model
 - ┆ Sample Schematic of a Two Reservoir System



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Introduction

Constraint Satisfaction Problems (CSP)

$$\text{Maximize } f(x_1, x_2, \dots, x_n)$$

$$\text{Subject to } C_1 : g_1(x_1, x_2, \dots, x_n) \cong 0$$

$$C_2 : g_2(x_1, x_2, \dots, x_n) \cong 0$$

.....

$$C_m : g_m(x_1, x_2, \dots, x_n) \cong 0$$

$$x_i \in D_i \quad i = 1, 2, \dots, n$$

Where \cong means \geq, \leq or $=$

Introduction

Hydroelectric DSS Model

(Nonlinear Objective Function with Linear Constraints)

$$\text{Maximize} \quad f(x_1, x_2, \dots, x_n)$$

$$\text{Subject to} \quad a_{11}x_1 + \dots + a_{1n}x_n \cong b_1$$

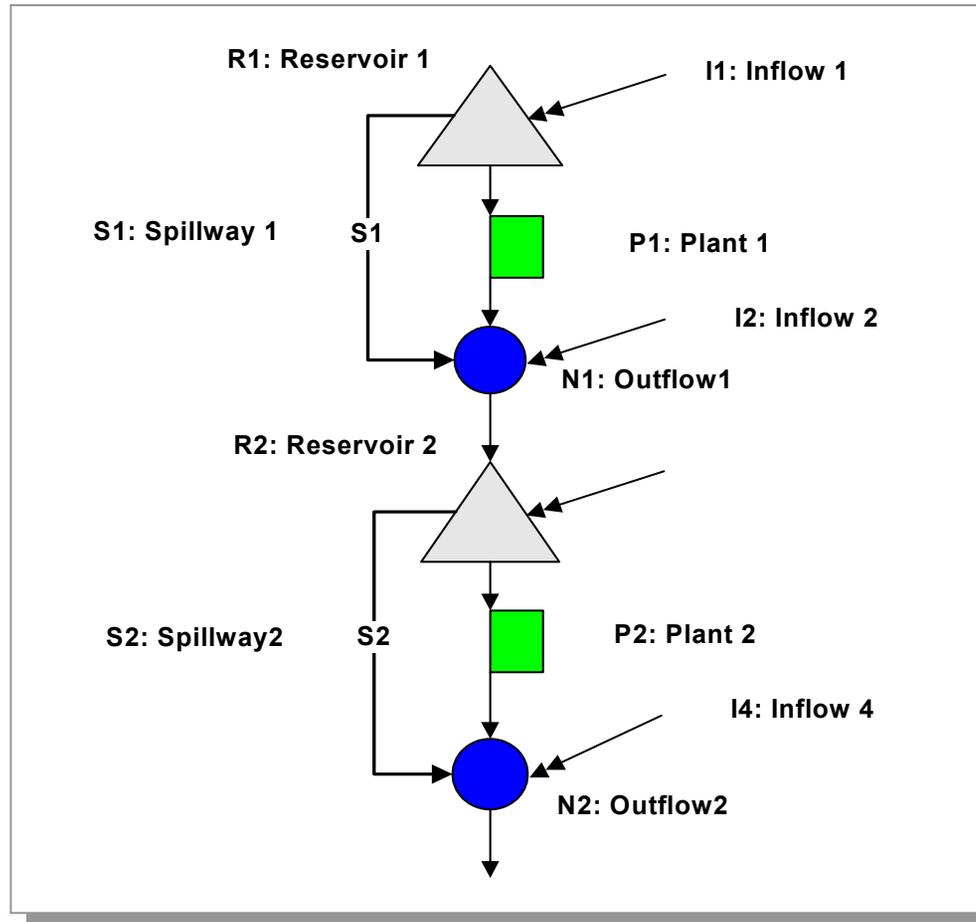
$$a_{21}x_1 + \dots + a_{2n}x_n \cong b_2$$

.....

$$a_{m1}x_1 + \dots + a_{mn}x_n \cong b_m$$

$$l_i \leq x_i \leq u_i \quad i = 1, \dots, n$$

Schematic of a Two Reservoir System



Formula of a Two Reservoir System

Maximize Generation

$$\text{Subject to } Q_1^1 + S_1^1 + V_1^1 = I_1^1 + V_0^1 \quad t = 1$$

$$-Q_1^1 - S_1^1 + N_1^1 = I_1^2$$

$$-N_1^1 + Q_1^2 + S_1^2 + V_2^1 = I_1^3 + V_0^2$$

$$-Q_1^2 - S_1^2 + N_1^2 = I_1^4$$

$$-N_t^1 + Q_t^1 + S_t^1 + V_t^1 - V_{t-1}^1 = I_t^1 \quad t > 1$$

$$-Q_t^1 - S_t^1 + N_t^1 = I_t^2$$

$$-N_t^2 + Q_t^2 + S_t^2 + V_t^1 + V_{t-1}^2 = I_t^3$$

$$-Q_t^2 - S_t^2 + N_t^2 = I_t^4$$

Where Q_t^1 = discharge; S_t^1 = Spill; N_t^1 = outflow

V_t^1 = storage; I_t^1 = inflow

Formula of a Two Reservoir System (Concluded)

$$\underline{Q}_t^k \leq Q_t^k \leq \overline{Q}_t^k;$$

$$\underline{S}_t^k \leq S_t^k \leq \overline{S}_t^k;$$

$$\underline{N}_t^k \leq N_t^k \leq \overline{N}_t^k;$$

$$\underline{V}_t^k \leq V_t^k \leq \overline{V}_t^k; \quad \text{and}$$

$$V_n^k = \text{ending storage};$$

$$t = 1, \dots, n \quad k = 1, 2$$

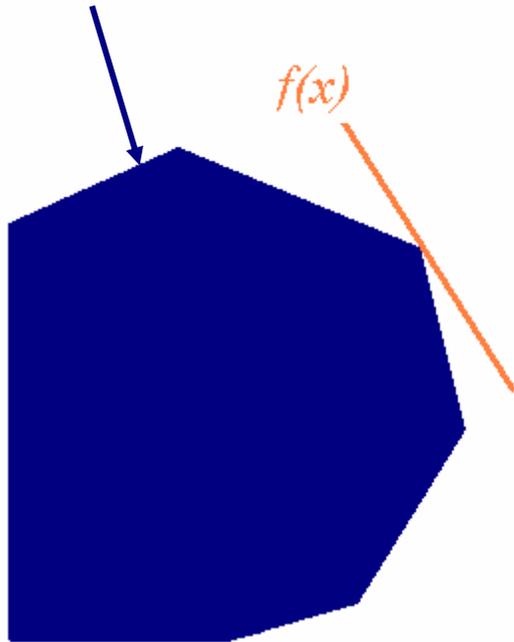


What is a Soft Constraint?

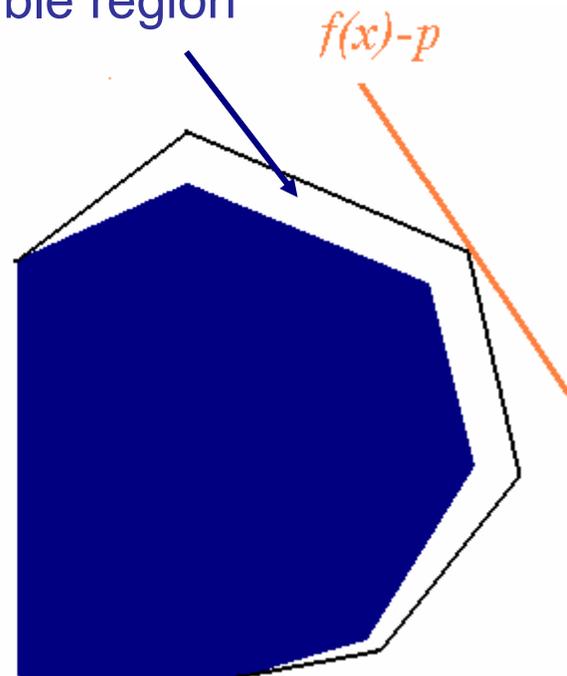
- Soft constraint is a term used in Constraint Satisfaction Problems (CSP) that allows constraints to be partially satisfied without making a solution unacceptable.

Soft Constraint: Geometry

Feasible Region



Enlarged feasible region





Why are Soft Constraints Needed?

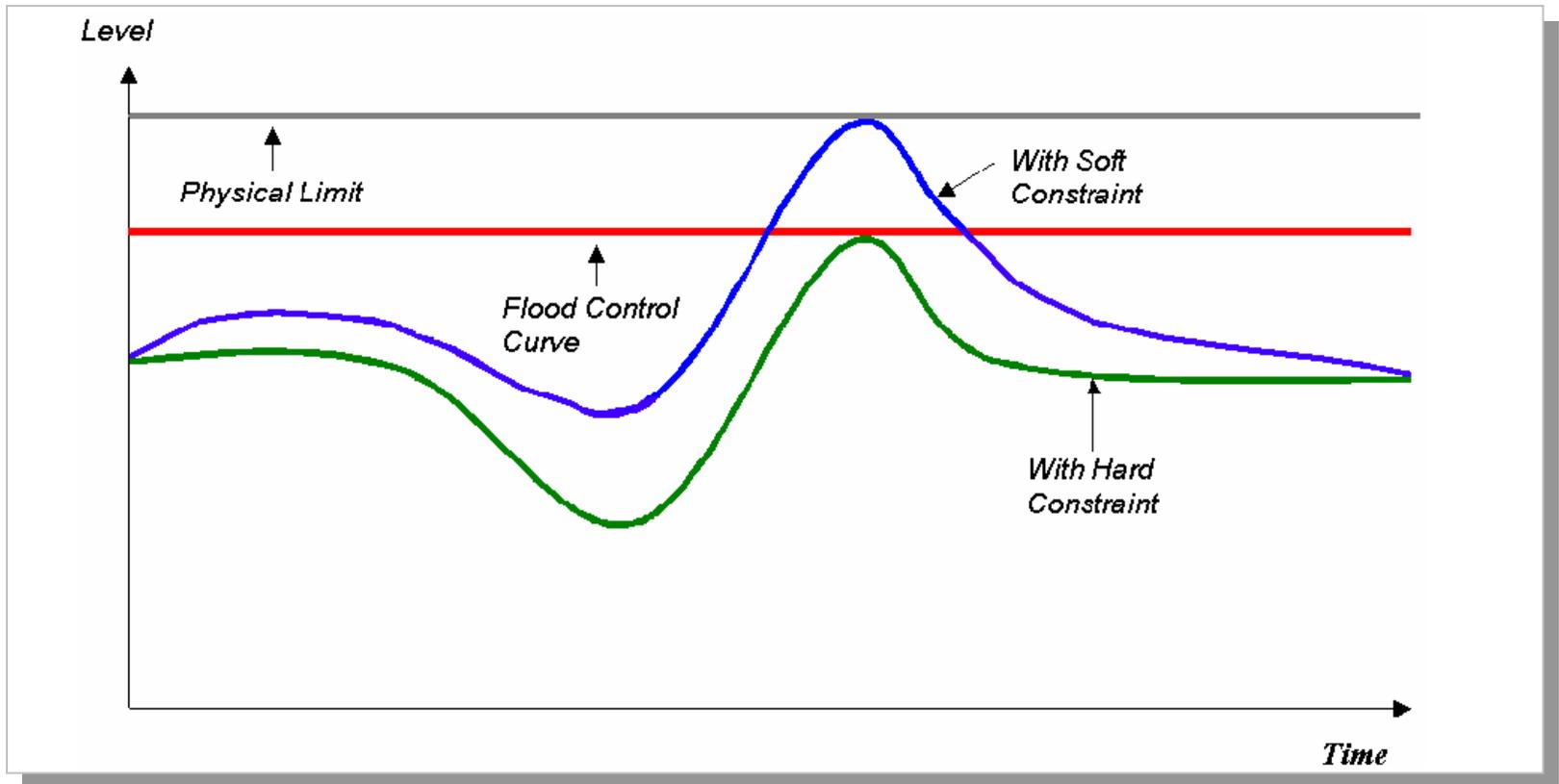
- Soft constraints represent the real-world operations better than traditional hard constraints.
- Given higher flexibility to the DSS model and Solve infeasible issues in optimization computations



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Reality: Flood Control vs. Generation





Flexibility: Infeasible Issues

- Infeasible means the feasible region is an empty set. In this case, no solution is possible.
- Infeasible may come from data errors, input errors, or unrealistic scenarios, etc.
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How Are Soft Constraints Modeled?

- Any constraint may be “softened.”

$$x \leq 10$$

$$x - u \leq 10 \quad u \geq 0$$

- Penalty methods.

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- Penalty methods.

$$\max \quad f(x) + \lambda u$$

$$\lambda < 0$$

Penalty Methods for Linear Constraints ($\leq \geq =$):

$$\sum_{i=1}^n a_j x_j \leq b$$

$$\sum_{i=1}^n a_j x_j - u \leq b \quad u > 0$$

Add a penalty term λu to the objective.

$$\sum_{i=1}^n a_j x_j \geq b$$

$$\sum_{i=1}^n a_j x_j + v \geq b \quad v > 0$$

Add a penalty term λv to the objective.

$$\sum_{i=1}^n a_j x_j = b$$

$$\sum_{i=1}^n a_j x_j - u + v \leq b \quad u > 0, v > 0$$

Add a penalty term $\lambda (u + v)$ to the objective.



A few examples of Soft Constraints in HYDROPS™

- Soft ending level constraints.
- Soft minimal stream flow soft constraints.
- Soft ramping constraints.
- And many more



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Example 1: Reservoir Soft Ending Constraints

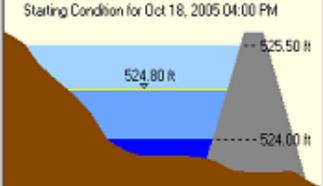
Short-Term Operations Model - [Starting and Ending Conditions]

File Options Tools Windows Help

Starting and Ending Conditions

Starting/Ending Conditions

Starting Condition for Oct 18, 2005 04:00 PM



Selected as:

- EMS Pond Level
- Long Term Average
- User Defined

Starting Level (ft) 524.80

Draw Down (ft) 0.70

Storage (cfs-day) 24,214

Percent Full (%) 51.71

Water Balance

Storage Change (cfs-day) 0

Total Inflow (cfs-day) 14330

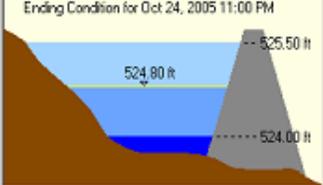
Total Release (cfs-day) 14330

Ending Level Constraint

- Hard
- Soft

Penalty - 10000

Ending Condition for Oct 24, 2005 11:00 PM



Selected as:

- Same as Starting
- Long Term Average
- User Defined

Ending Level (ft) 524.80

Draw Down (ft) 0.70

Storage (cfs-day) 24,214

Percent Full (%) 51.71

Legend

- Valid Value
- Out of Date
- Out of Range
- Out of Range & Date

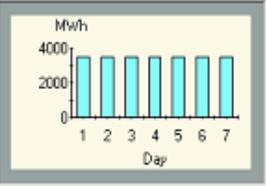
Save

Other Parameters

Item	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Pond Coef	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Num of Locks	1	1	1	1	1	1	1
Leakage (cfs)	25	25	25	25	25	25	25
Vent Opening (%)	0	0	0	0	0	0	0

Daily Target Setting

Day	Defined By User	Daily Target
1 (Oct 18)	<input type="checkbox"/>	n/a
2 (Oct 19)	<input type="checkbox"/>	n/a
3 (Oct 20)	<input type="checkbox"/>	n/a
4 (Oct 21)	<input type="checkbox"/>	n/a
5 (Oct 22)	<input type="checkbox"/>	n/a
6 (Oct 23)	<input type="checkbox"/>	n/a
7 (Oct 24)	<input type="checkbox"/>	n/a



Data Type: MWh CFS

Model setting range

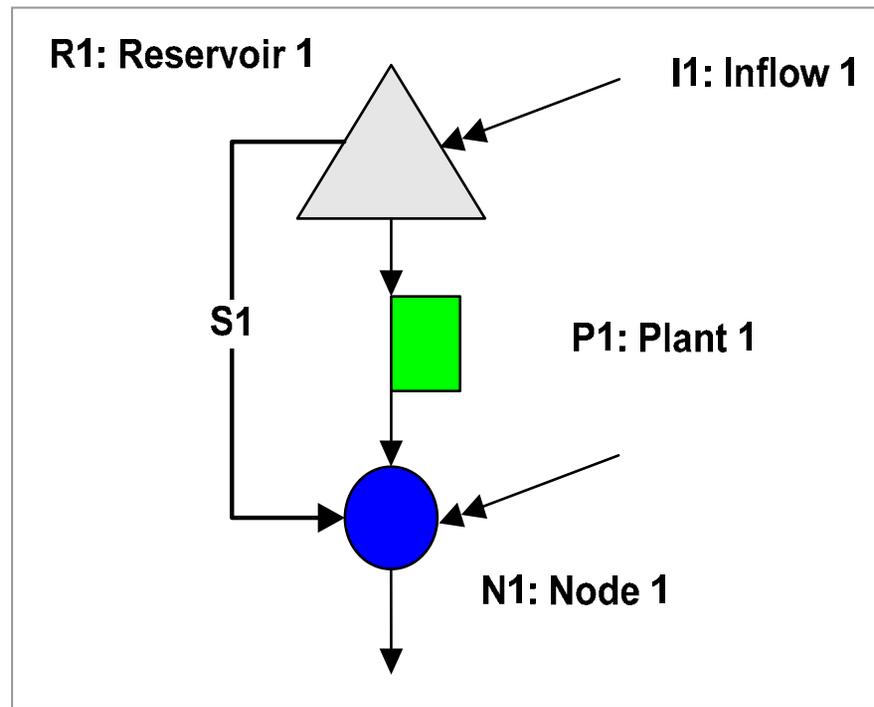
User defined target

Unused Capacity

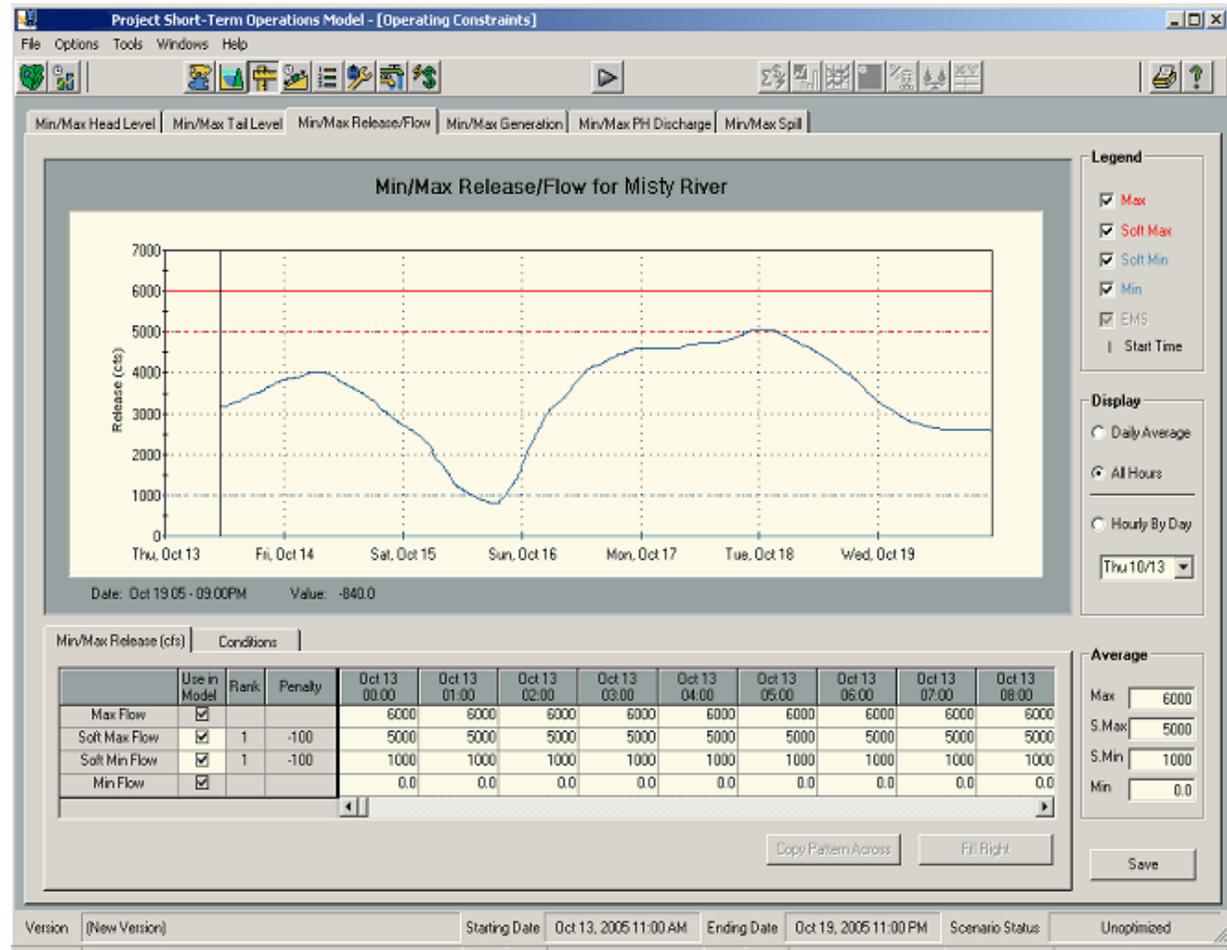
Version [New Version] Starting Date Oct 18, 2005 04:00 PM Ending Date Oct 24, 2005 11:00 PM Scenario Status Unoptimized

Implementing Soft Constraints in Hydroelectric Decision Support Systems

Example 2: Minimal Flow Soft Constraints



Example 2 : Minimal Flow Soft Constraints (concluded)



Example 3: Soft Ramping Constraints

Project Short-Term Operations Model - [Ramping Rates]

File Options Tools Windows Help

Ramping Rates

Location	Ramping On	Window		Ramping Rate				
		Start Date/Time	End Date/Time	Ramping Rate	Daily	When	Penalty	Caused By
Misty River	Flow	Jan 26, 2003 12:00 AM	Jan 01, 2006 12:00 AM	-1650 cfs /hr(s)	12:00 AM to 11:00 PM	n/a	0	

Add Remove Update Save

Ramping on Flow Ramping on Level

Location: Mississippi River

Ramping Constraint Window

Start Date/Time: January 2003
 End Date/Time: January 2006

Ramp Rate:
 Up Ramp Value: 1650 Units: cfs / Duration: 1 hr(s)
 Down Violation Penalty: 0 Rank: n/a

Occurrence:
 Daily from 12:00 AM to 11:00 PM
 When Flow at Mississippi River and 18000 cts

Version (New Version) Starting Date Oct 13, 2005 12:00 PM Ending Date Oct 19, 2005 11:00 PM Scenario Status Unoptimized



Implementation Issues

- **Defining penalty coefficients.**
- When applying multiple soft constraints in a system, it's not easy to find the relationship between the penalty coefficients, especially when the variables have different units.



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Conclusions and Future Development:

- **Soft Constraints are a useful tool in Hydroelectric DSS modeling, allowing a model to more closely reflect real-world operations.**
- Soft Constraints allow operators to avoid the infeasible caused by data, operator error, etc.
- Soft Constraints are used successfully in HYDROPS™ DSS.
- Under Development: Quantify penalty co-efficiencies, especially for multiple soft constraints.



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Thank You!

Hong Gao, Powel-MiniMax, Inc.
239 Menzies Street Suite 210
Victoria, BC, Canada V8V 2G6
V: 250.385.0206 ext. 27
F: 250.385.7737
hong.gao@powelminimax.com