Issues related to River Basin Modeling

1. Introduction
2. Some Notes on Stochastic Hydrology
3. Unresolved Issues in River Basin Optimization:
   - Time Step Length
   - Hydrologic River Routing
   - Outflow Constraints on two or more outlets
   - Defining Objective Function
   - Multiple vs Single Time step Solutions
3. Final Comments

Stochastic Generation of Natural Flows

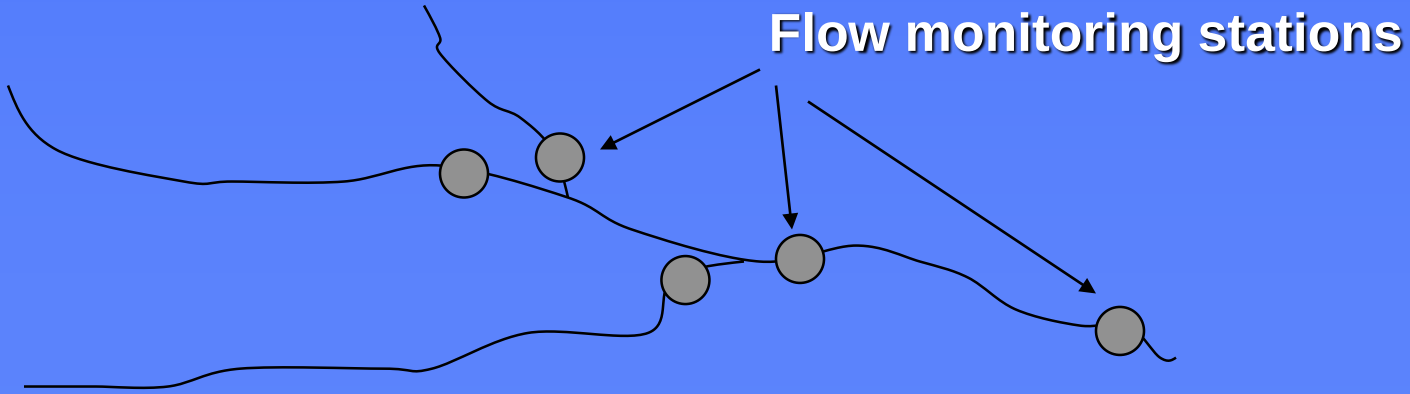
Goal: Computer generated random series of natural flows that art statistically similar to historic.

The Ultimate model:

- Works for any time step length (days, weeks or months);

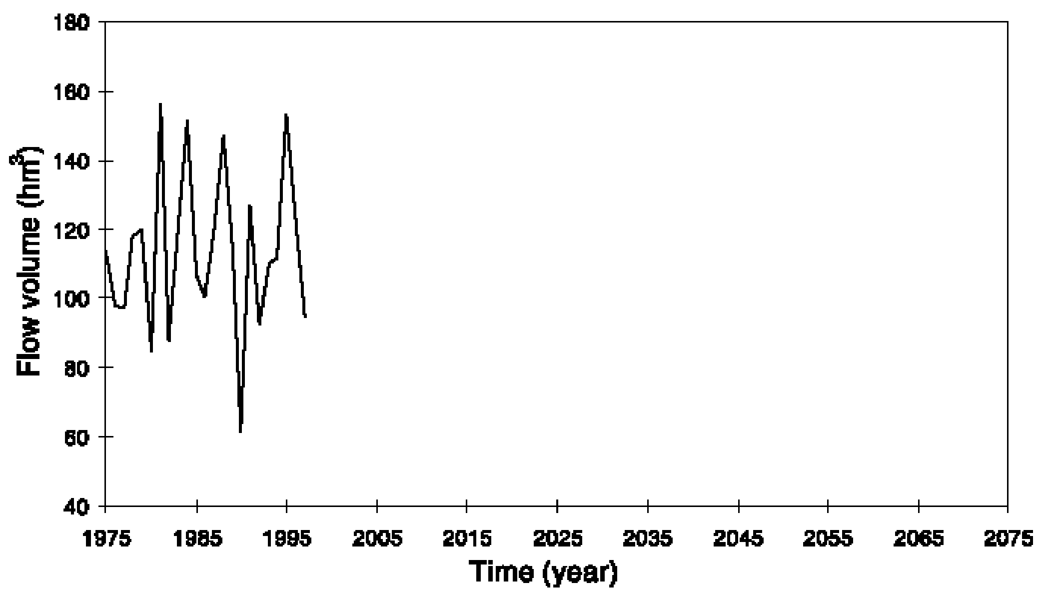
- Works with any combination of continuious and intermittent data series;

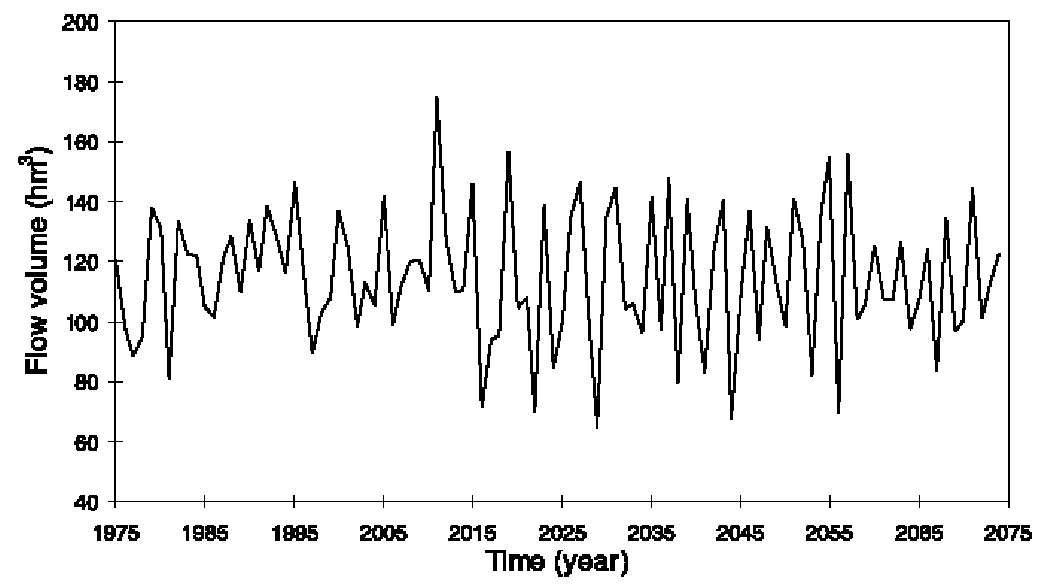
- Works for large number of stations (50 or more)



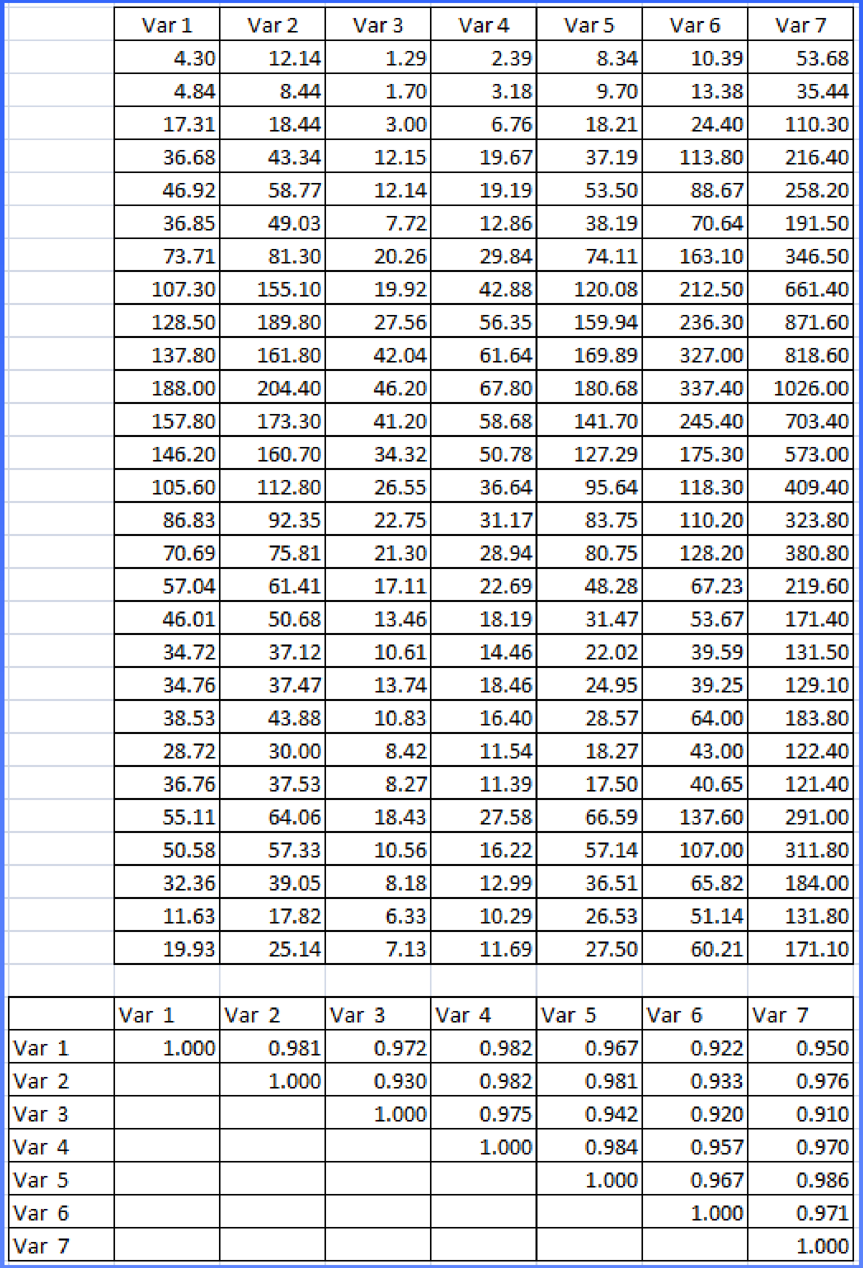
Flow monitoring stations

Significance of Stochastic Natural Flows





Recent Development in Statistical Science



Var 1	Var 2	Var 3	Var 4	Var 5	Var 6	Var 7
4.30	12.14	1.29	2.39	8.34	10.39	53.68
4.84	8.44	1.70	3.18	9.70	13.38	35.44
17.31	18.44	3.00	6.76	18.21	24.40	110.30
36.68	43.34	12.15	19.67	37.19	113.80	216.40
46.92	58.77	12.14	19.19	53.50	88.67	258.20
36.85	49.03	7.72	12.86	38.19	70.64	191.50
73.71	81.30	20.26	29.84	74.11	163.10	346.50
107.30	155.10	19.92	42.88	120.08	212.50	661.40
128.50	189.80	27.56	56.35	159.94	236.30	871.60
137.80	161.80	42.04	61.64	169.89	327.00	818.60
188.00	204.40	46.20	67.80	180.68	337.40	1026.00
157.80	173.30	41.20	58.68	141.70	245.40	703.40
146.20	160.70	34.32	50.78	127.29	175.30	573.00
105.60	112.80	26.55	36.64	95.64	118.30	409.40
86.83	92.35	22.75	31.17	83.75	110.20	323.80
70.69	75.81	21.30	28.94	80.75	128.20	380.80
57.04	61.41	17.11	22.69	48.28	67.23	219.60
46.01	50.68	13.46	18.19	31.47	53.67	171.40
34.72	37.12	10.61	14.46	22.02	39.59	131.50
34.76	37.47	13.74	18.46	24.95	39.25	129.10
38.53	43.88	10.83	16.40	28.57	64.00	183.80
28.72	30.00	8.42	11.54	18.27	43.00	122.40
36.76	37.53	8.27	11.39	17.50	40.65	121.40
55.11	64.06	18.43	27.58	66.59	137.60	291.00
50.58	57.33	10.56	16.22	57.14	107.00	311.80
32.36	39.05	8.18	12.99	36.51	65.82	184.00
11.63	17.82	6.33	10.29	26.53	51.14	131.80
19.93	25.14	7.13	11.69	27.50	60.21	171.10

	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6	Var 7
Var 1	1.000	0.981	0.972	0.982	0.967	0.922	0.950
Var 2		1.000	0.930	0.982	0.981	0.933	0.976
Var 3			1.000	0.975	0.942	0.920	0.910
Var 4				1.000	0.984	0.957	0.970
Var 5					1.000	0.967	0.986
Var 6						1.000	0.971
Var 7							1.000

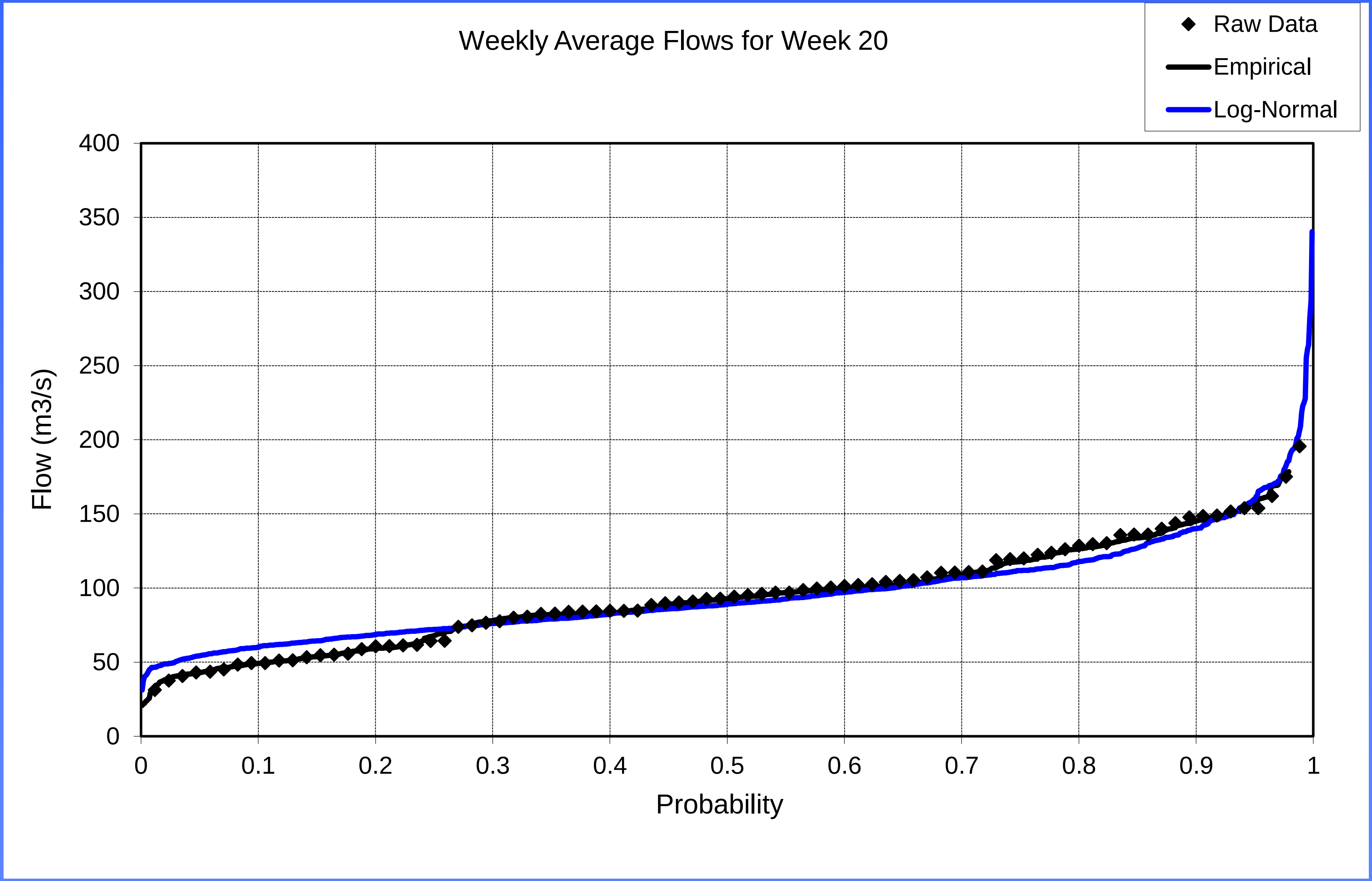
Stochastic Generation of Natural Flows

The relevant *weekly* statistics to be preserved are:

- Weekly probability distribution functions;
- Weekly mean, standard deviation and skew;
- Annual mean, standard deviation, skew;
- Annual auto correlation;
- Annual cross-correlation between various stations;
- Weekly auto correlation; and,
- Weekly cross-correlation between various stations.

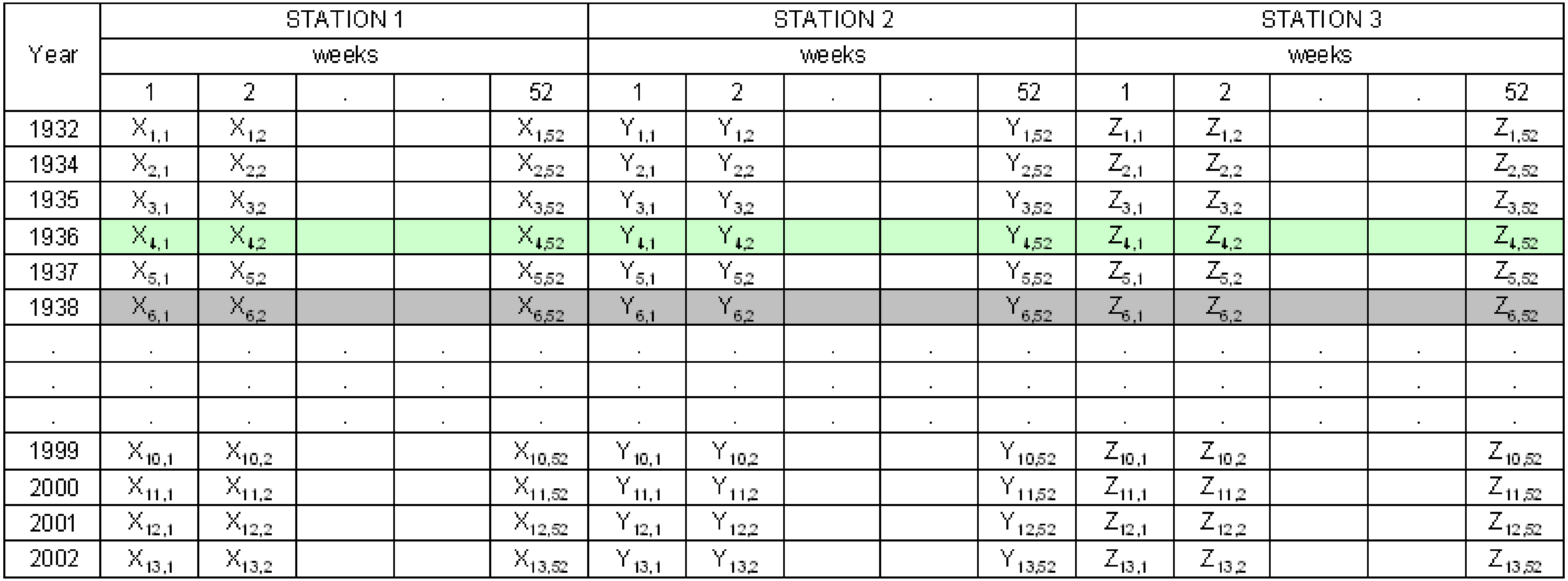
Proposed Methodology

Step 1: Generate 1000 years of data for each week using an Empirical Kernel-type distribution



Stochastic Generation of Natural Flows

Step 3 consists of re-ordering of the entire rows in a systematic way until the desired annual lag correlations and the lag correlations between ending weeks of year *i-1* and starting weeks of year *i* are preserved.



Year	STATION 1					STATION 2					STATION 3				
	weeks					weeks					weeks				
	1	2	.	.	52	1	2	.	.	52	1	2	.	.	52
1932	$X_{1,1}$	$X_{1,2}$			$X_{1,52}$	$Y_{1,1}$	$Y_{1,2}$			$Y_{1,52}$	$Z_{1,1}$	$Z_{1,2}$			$Z_{1,52}$
1934	$X_{2,1}$	$X_{2,2}$			$X_{2,52}$	$Y_{2,1}$	$Y_{2,2}$			$Y_{2,52}$	$Z_{2,1}$	$Z_{2,2}$			$Z_{2,52}$
1935	$X_{3,1}$	$X_{3,2}$			$X_{3,52}$	$Y_{3,1}$	$Y_{3,2}$			$Y_{3,52}$	$Z_{3,1}$	$Z_{3,2}$			$Z_{3,52}$
1936	$X_{4,1}$	$X_{4,2}$			$X_{4,52}$	$Y_{4,1}$	$Y_{4,2}$			$Y_{4,52}$	$Z_{4,1}$	$Z_{4,2}$			$Z_{4,52}$
1937	$X_{5,1}$	$X_{5,2}$			$X_{5,52}$	$Y_{5,1}$	$Y_{5,2}$			$Y_{5,52}$	$Z_{5,1}$	$Z_{5,2}$			$Z_{5,52}$
1938	$X_{6,1}$	$X_{6,2}$			$X_{6,52}$	$Y_{6,1}$	$Y_{6,2}$			$Y_{6,52}$	$Z_{6,1}$	$Z_{6,2}$			$Z_{6,52}$
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1999	$X_{10,1}$	$X_{10,2}$			$X_{10,52}$	$Y_{10,1}$	$Y_{10,2}$			$Y_{10,52}$	$Z_{10,1}$	$Z_{10,2}$			$Z_{10,52}$
2000	$X_{11,1}$	$X_{11,2}$			$X_{11,52}$	$Y_{11,1}$	$Y_{11,2}$			$Y_{11,52}$	$Z_{11,1}$	$Z_{11,2}$			$Z_{11,52}$
2001	$X_{12,1}$	$X_{12,2}$			$X_{12,52}$	$Y_{12,1}$	$Y_{12,2}$			$Y_{12,52}$	$Z_{12,1}$	$Z_{12,2}$			$Z_{12,52}$
2002	$X_{13,1}$	$X_{13,2}$			$X_{13,52}$	$Y_{13,1}$	$Y_{13,2}$			$Y_{13,52}$	$Z_{13,1}$	$Z_{13,2}$			$Z_{13,52}$

Stochastic Generation of Natural Flows

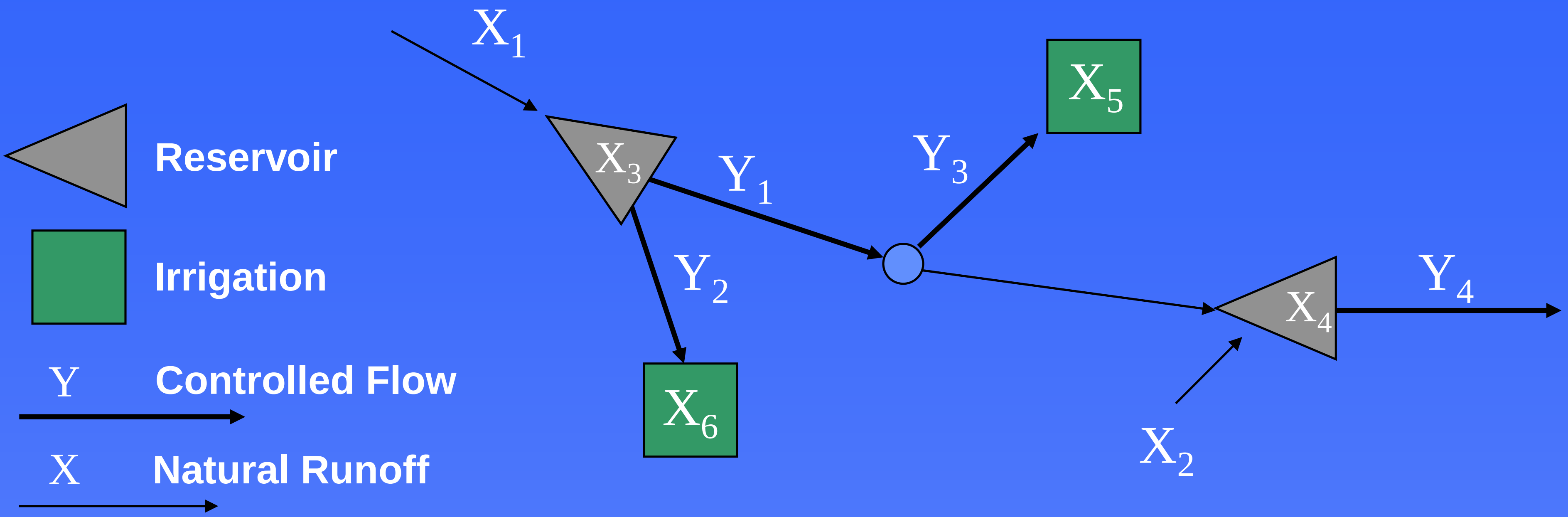
a) Step 3 has 1000! combinations

b) Current approach is based on simulated annealing

c) Success rate is acceptable for up to 17 stations

d) There are many possible solutions which are acceptable, but they are hard to find with the current algorithm.

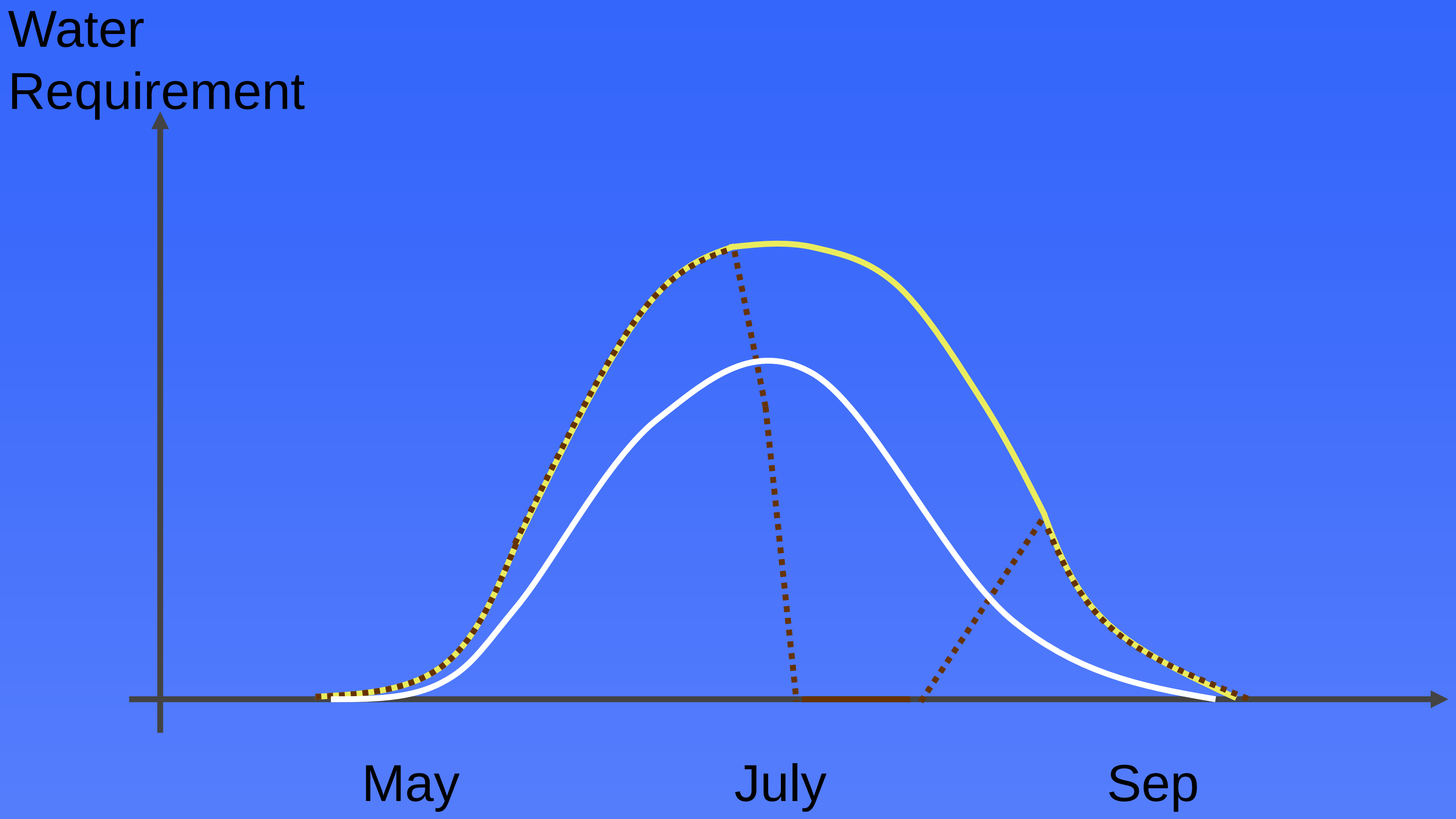
Single Time Step Optimization



Maximize $\sum Y_i C_i$ **(objective function)**

i.e. find a set of controlled releases Yi to maximize the objective function subject to physical flow constraints related to mass balance and flow limits. Factor C_i is the pay off function (benefit) for supplying a unit of flow to user *i*.

Typical Seasonal Water Demand

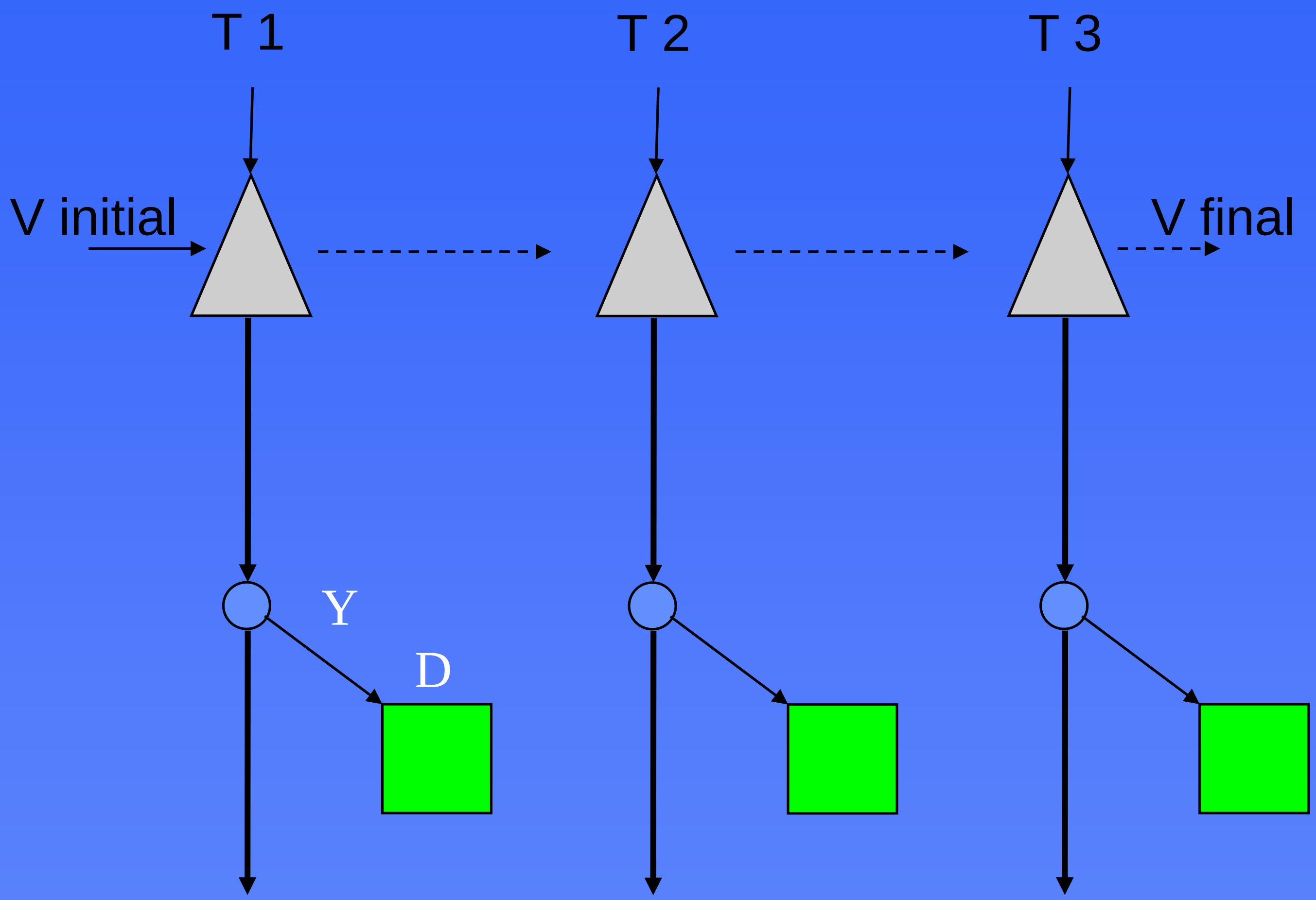


Ideal Demand

Achieved Supply (as modelled if STO mode is used)

Best Possible Supply (aprox. 75% of the ideal target in the above figure; it varies from year to year)

(MTO) – Model finds demand best demand driver releases

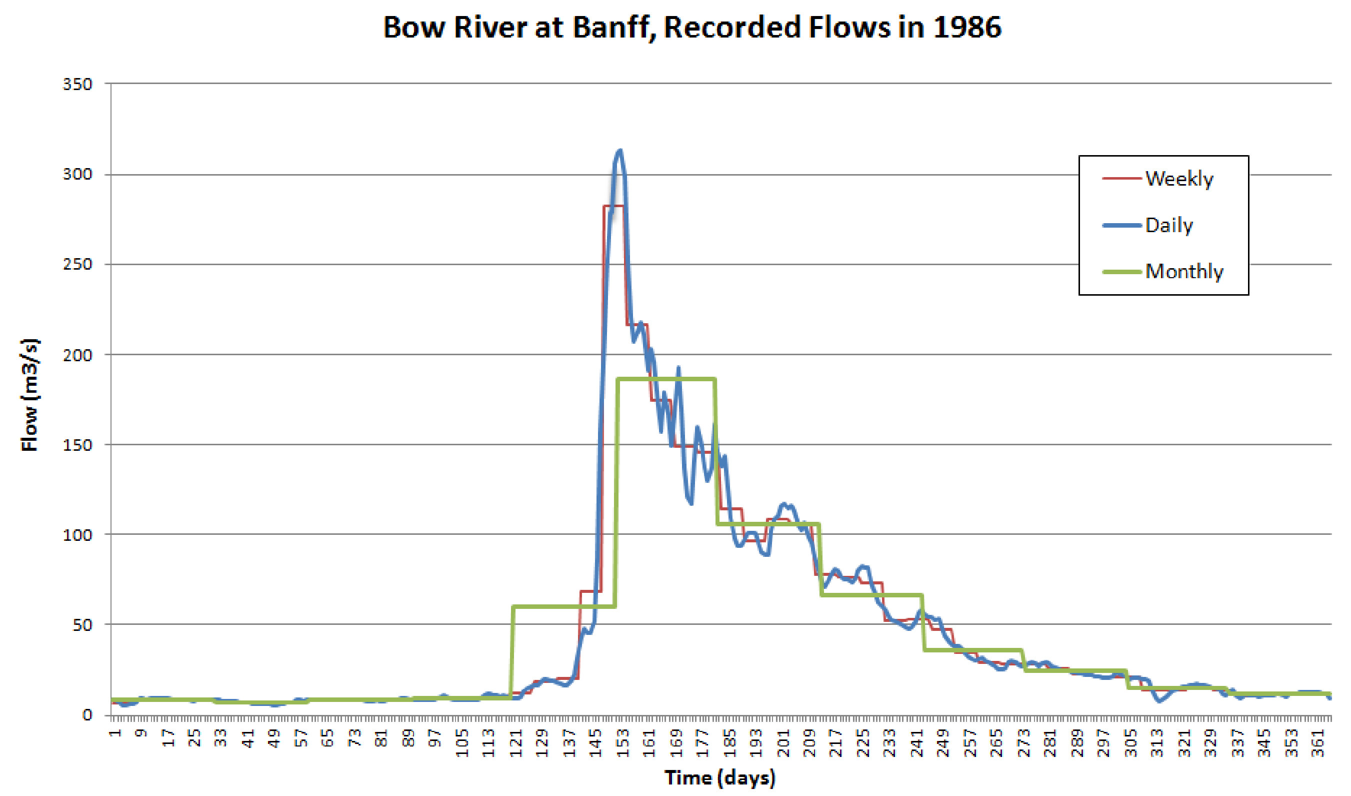


Maximize $\sum \sum Y_{i,t} C_i$

$$\frac{Y_t}{D_t} = \frac{Y_{t+1}}{D_{t+1}} \qquad for\ t = 0, n-1$$

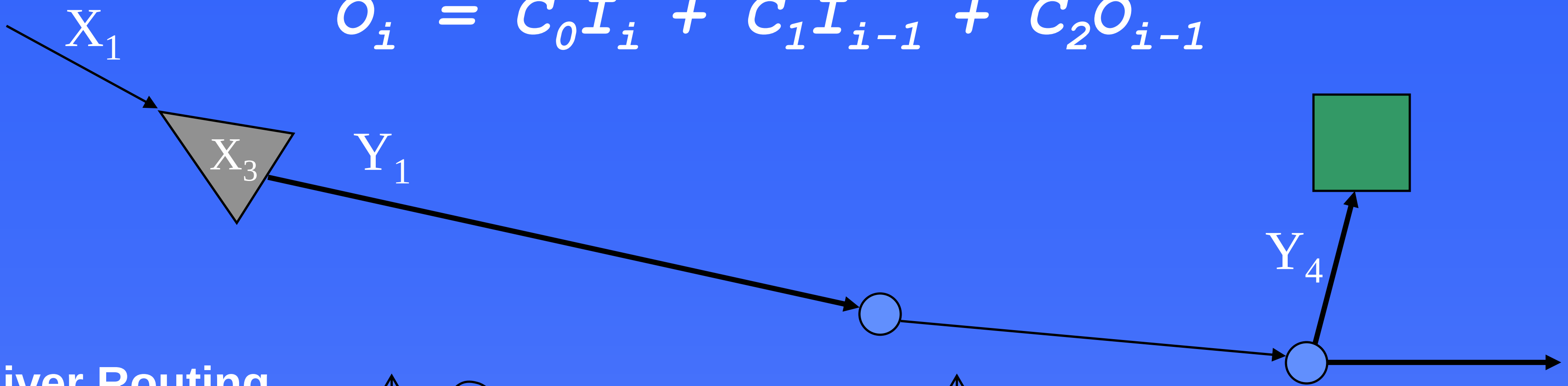
Issue 1: Time Step Length

1. **Assumption of water availability from any source to any user within a time step. This restricts modeling of large basins to monthly time steps.**
2. **Monthly inflow hydrographs are too easy to manage. <u>The same basins modeled with monthly and weekly time steps showed up to 28% difference in spills</u>.**

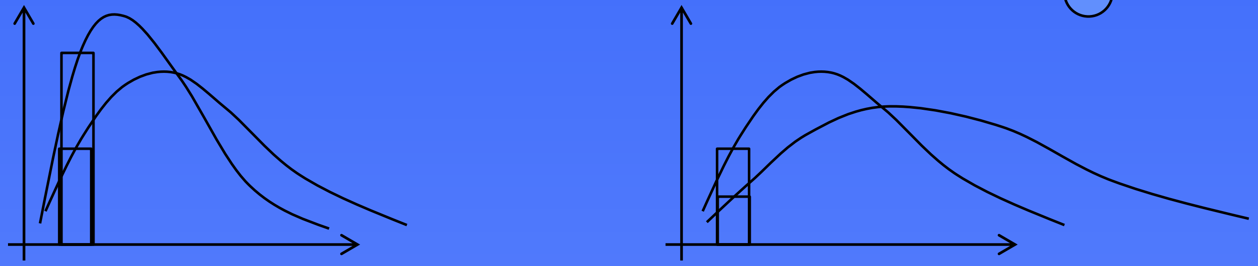


Problems with Channel Routing Constraints

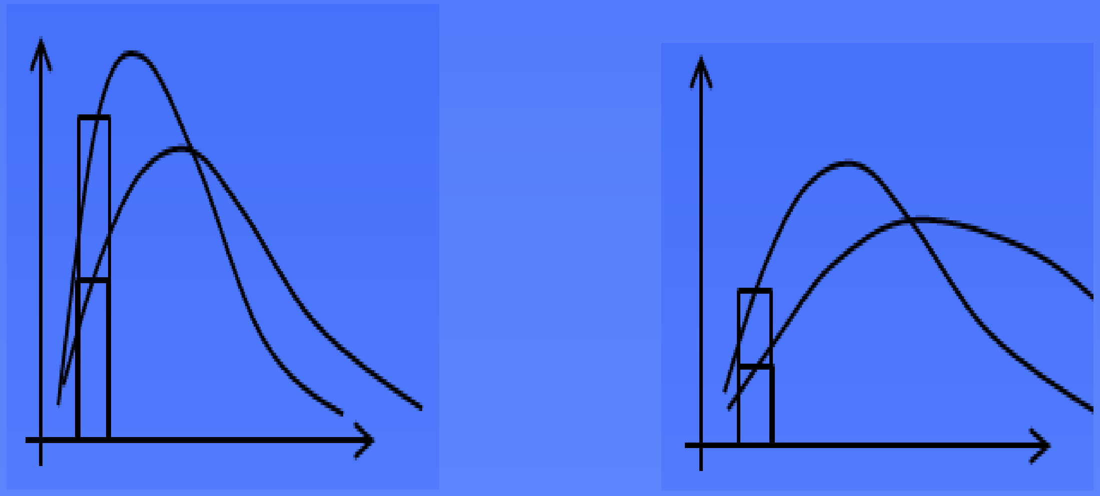
$$O_i = C_0 I_i + C_1 I_{i-1} + C_2 O_{i-1}$$



River Routing Effects under normal reservoir release:

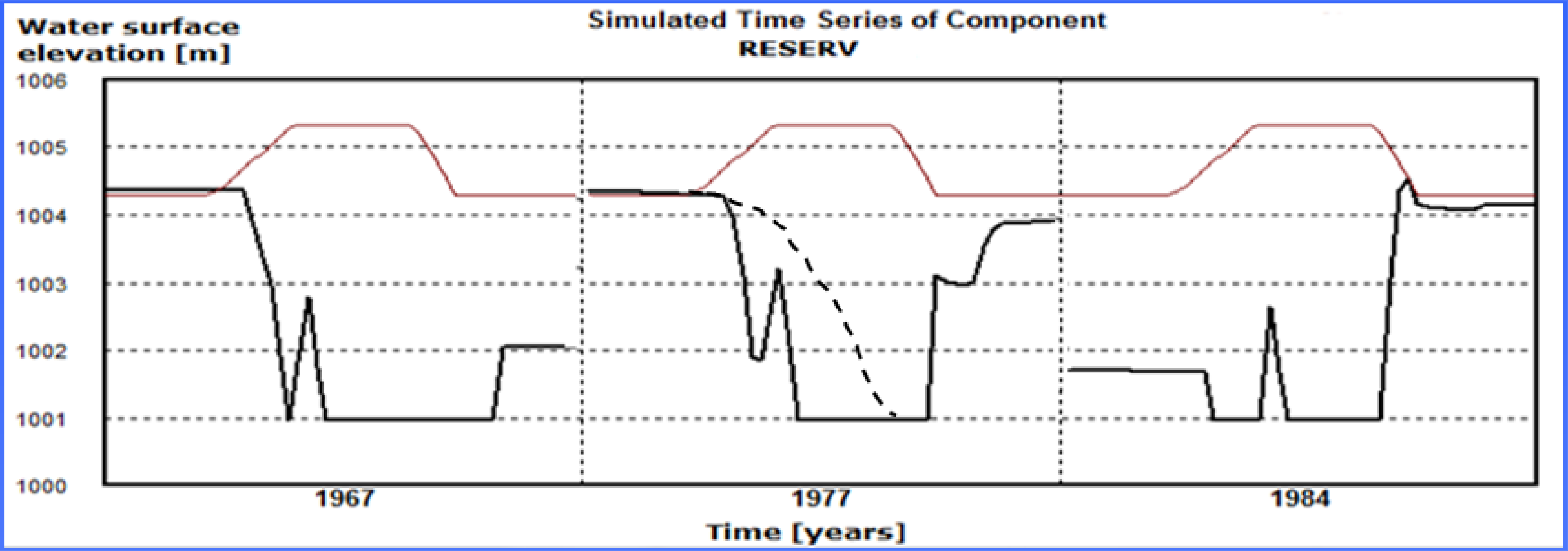


River Routing Effects under increased reservoir release:



Issue 1: Time Step Length

1. Proper routing requires daily time steps, which has its own problems:
   - model floods the river valley to reduce the time of travel and consequently downstream deficits (see the 2008 paper in WRR);
   - MTO solutions don’t resolve the problem



Ilich, N. 2008. Shortcomings of Linear Programming in Optimizing River Basin Allocation. Water Res. Research, Vol. 44.

Issue # 1: Time Step Length

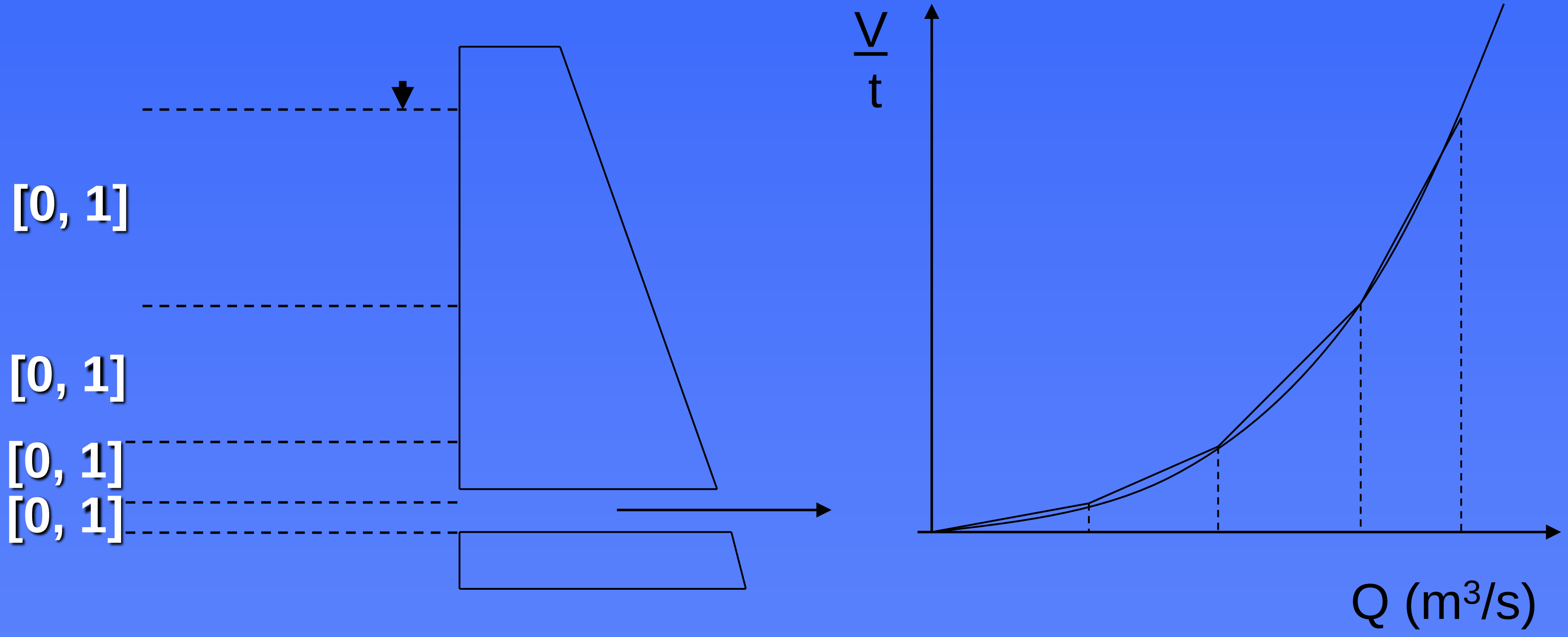
There should be guidelines on:

- establishing the proper time step length (not too long to avoid problem with the spills, not too short to avoid problems with routing);
- how to model time steps which are shorter than the total travel time through the basin; and,
- how to model hydrologic river routing within the optimization framework, can it be done within the LP framework and if so, how? The routing coefficients do change with significant flow variations over the year.

Issue #2: Modeling of Hydraulic Constraints in LP

Outflow capacity constriants are approximated with linear segments

Binary variables are required to ensure proper zone filling from bottom to top and emptying from top to bottom.

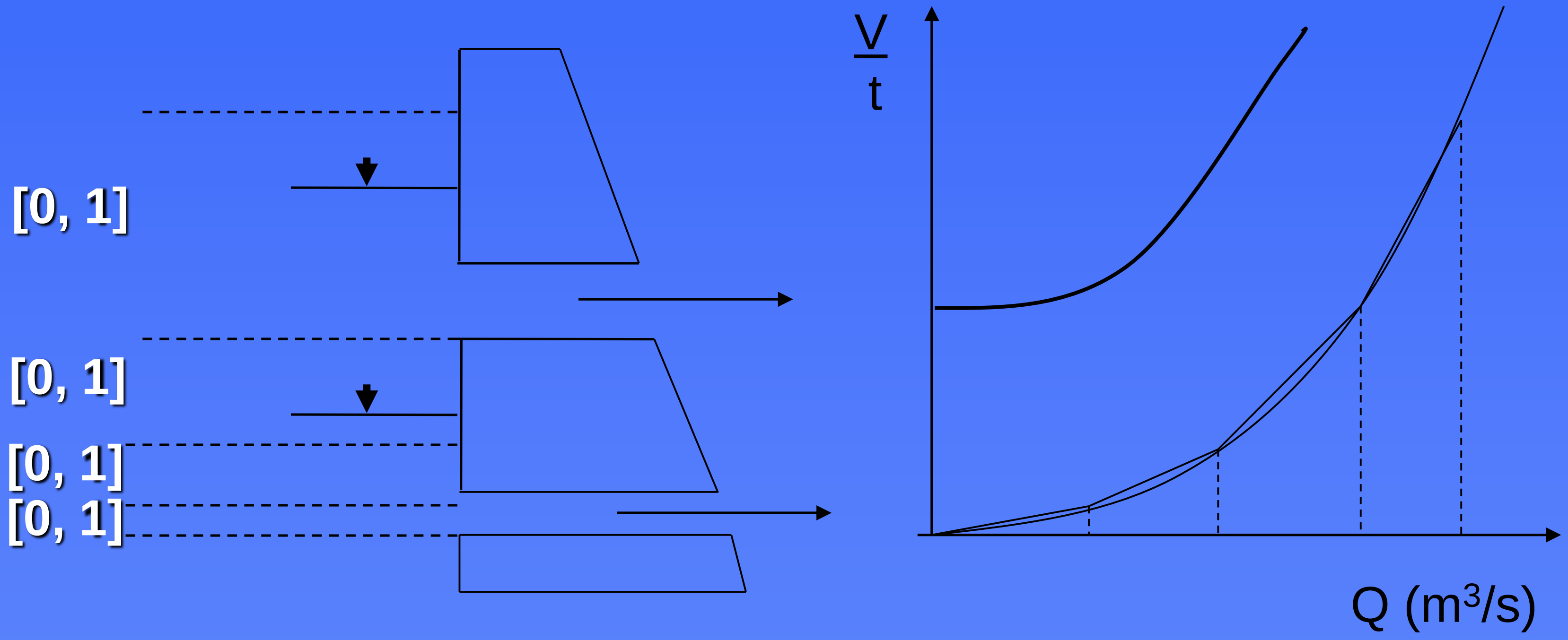


$$S = \frac{Vs - Ve}{Q1 - Q2} \cdot \frac{1}{t}$$

$$Qmax(o) = \frac{1}{S} \cdot \frac{1}{2}\left(\frac{Vs}{t} + \frac{Ve}{t}\right)$$

Binary variables significantly slow down the solution process.

Issue #2: Hydraulic Constraints in LP

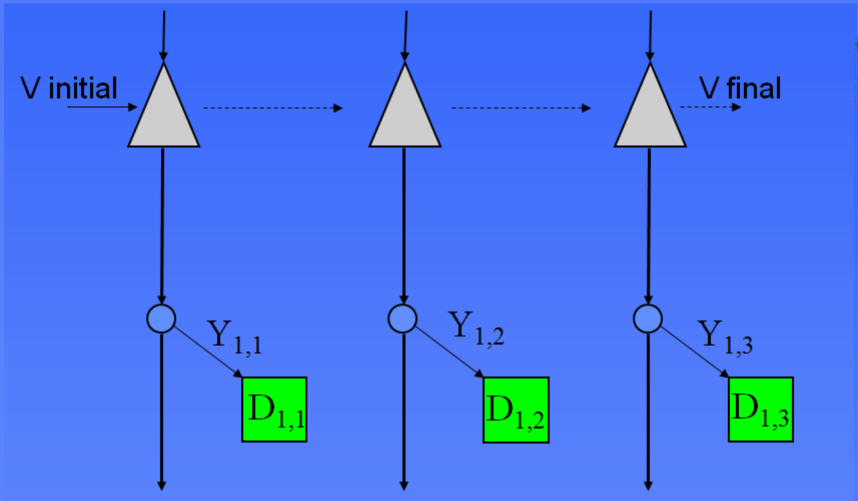


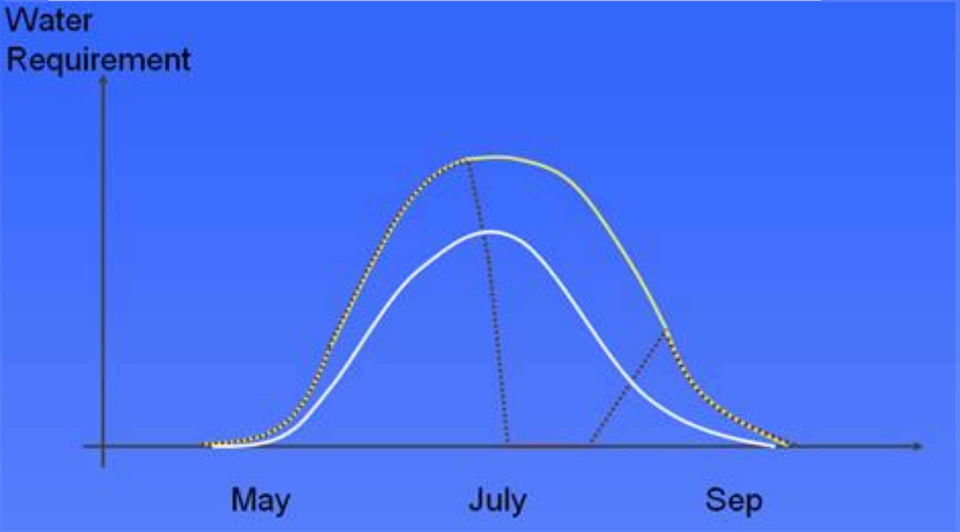
$$S = \frac{Vs - Ve}{Q1 - Q2} \cdot \frac{1}{t} \qquad Qmax(o) = \frac{1}{S} \cdot \frac{1}{2}\left(\frac{Vs}{t} + \frac{Ve}{t}\right)$$

Min Tech. Specifications: List of Constraints

- Storage outlet structure
- Diversion at a weir
- Return flow channels
- Diversion license volume limit per year
- Apportionment volume limit per year
- Channel routing (?)
- Equal deficit constraints:

$$\frac{Y_t}{D_t} = \frac{Y_{t+1}}{D_{t+1}} \qquad \mathit{for}\ t = 0,\ n-1$$



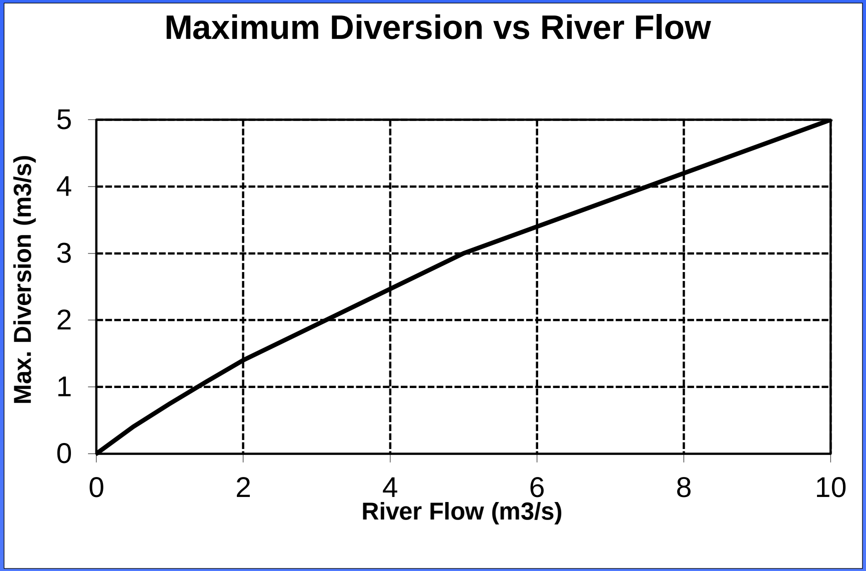


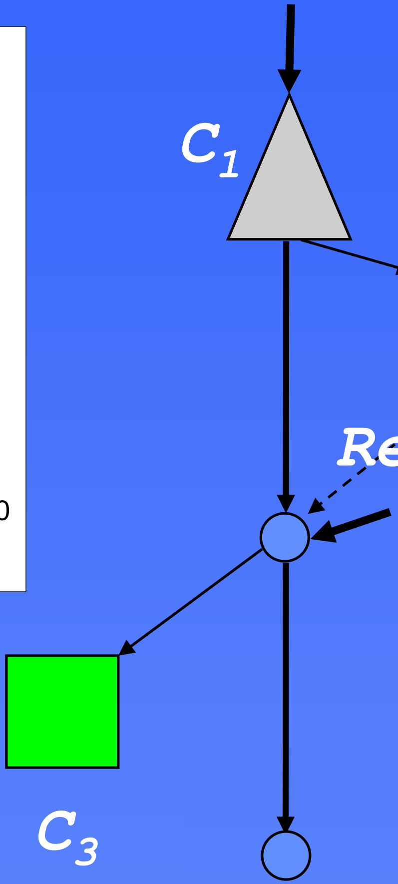
Food for thought: Constraints

There should be guidelines on:

- Establishing which constraints are important and by how much they affect the quality of solutions if they are not modeled;
- How individual constraints should be formulated and included in the model; and,
- Problems with constraints should be formulated as benchmark tests and their solutions should be published solved in such a way that every model vendor has ability to verify their model by re-running the benchmarks.

Issue # 3: Definition of Objectives



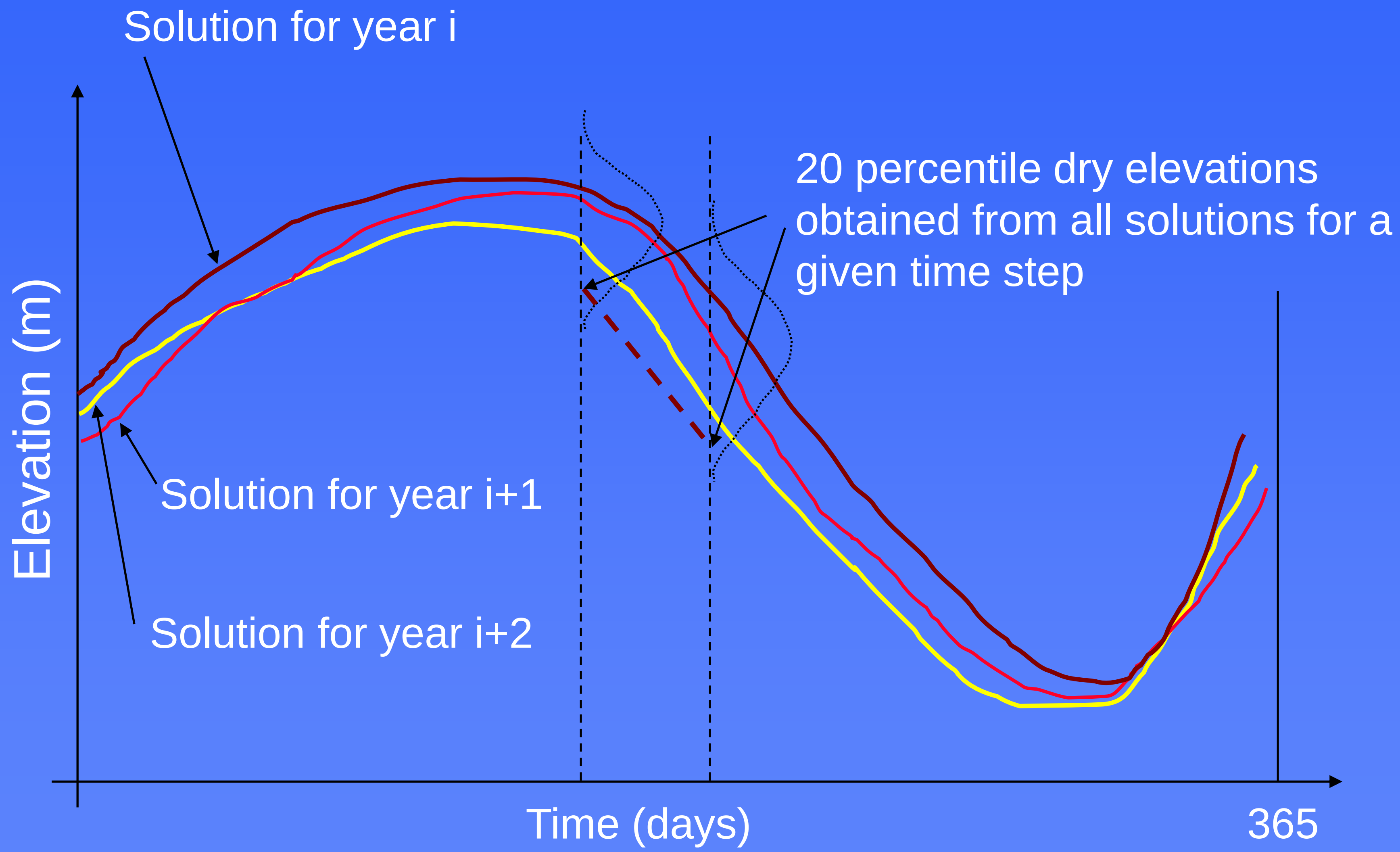


Return=0.3 Div.

$C_2 > 1.3C_1$

Israel M.S. and Lund J. 1999. Priority Preserving Unit Penalties in Network Flow Modeling. ASCE Journal of Water Resources Planning and Management, Vol. 125 (4), July /August.

Issue # 4: Use of MTO in Development of Rule Curves



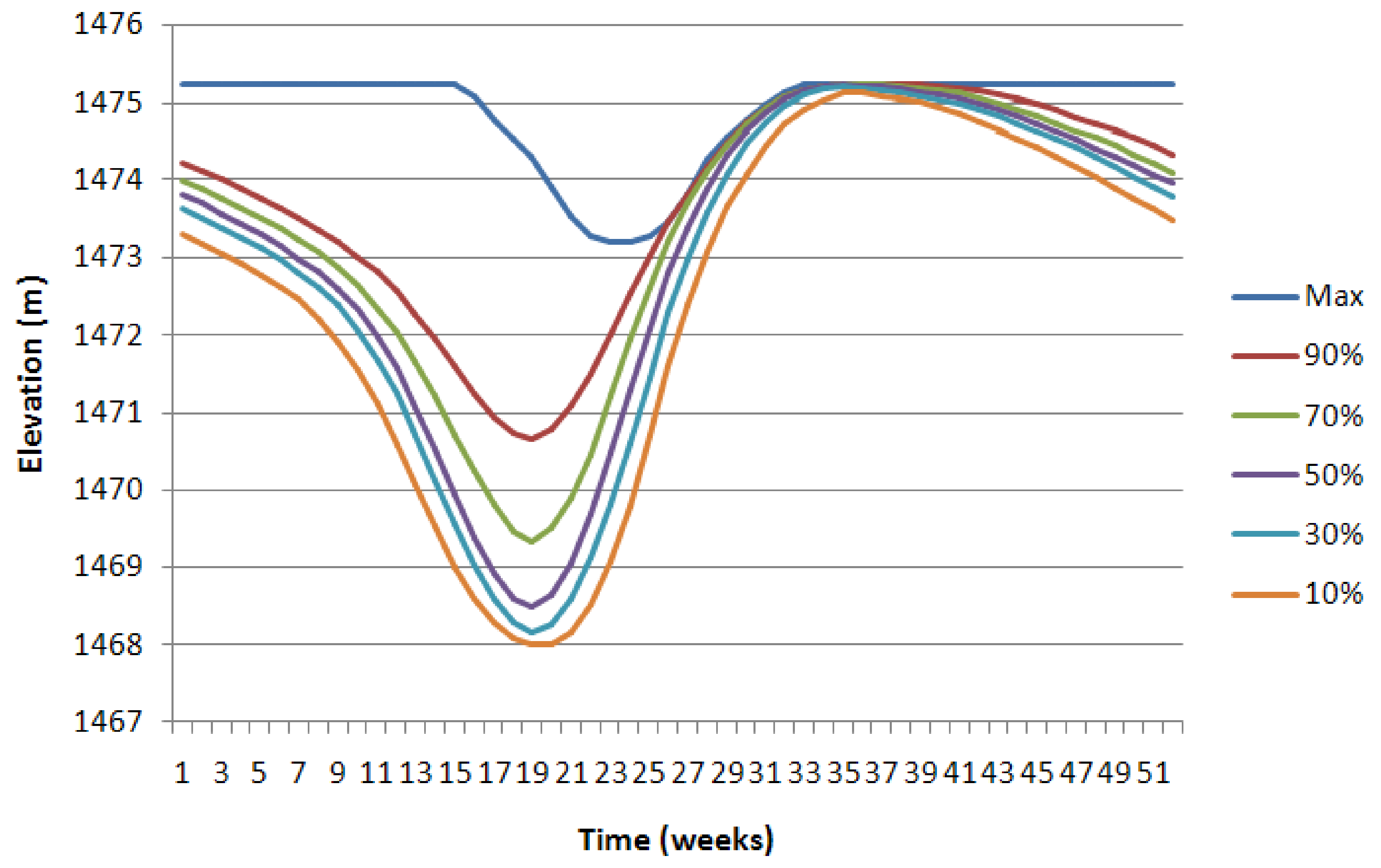
Solution for year i

20 percentile dry elevations obtained from all solutions for a given time step

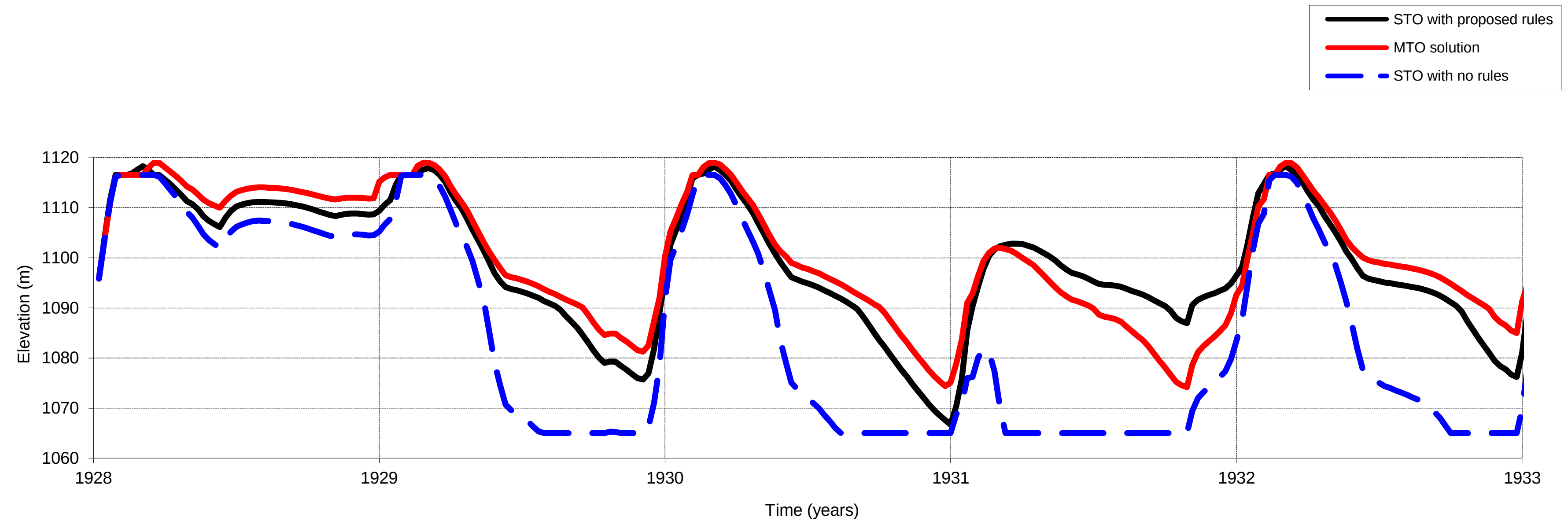
Solution for year i+1

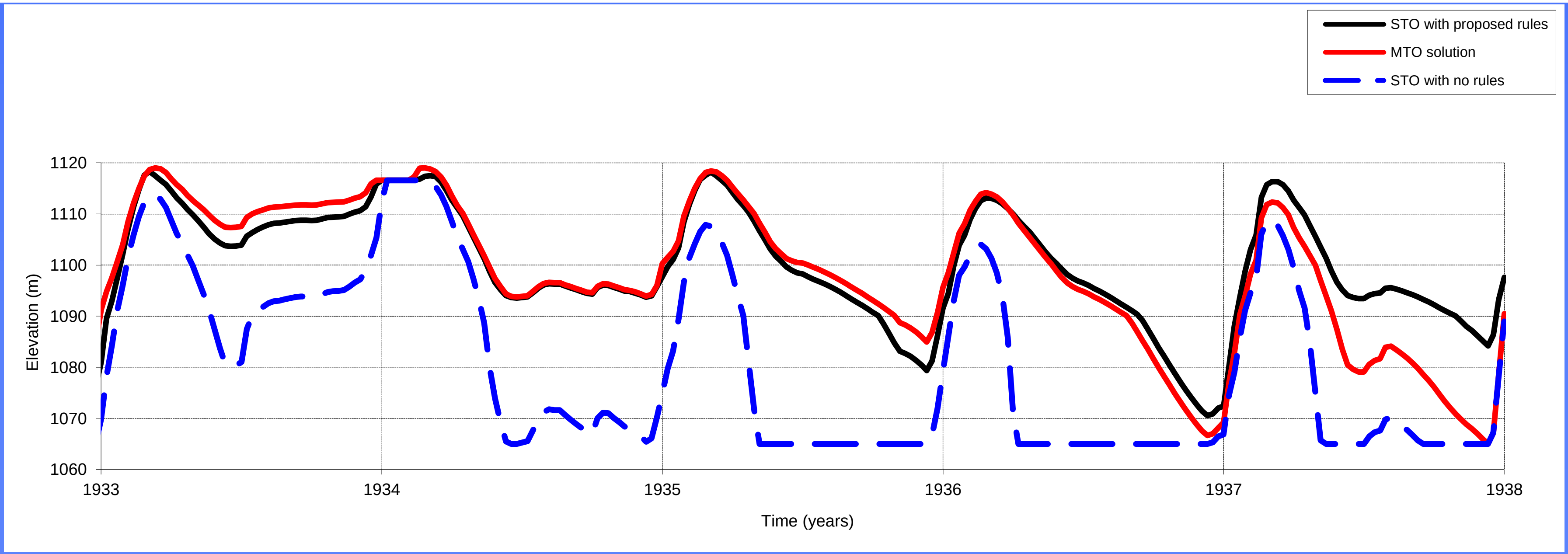
Solution for year i+2

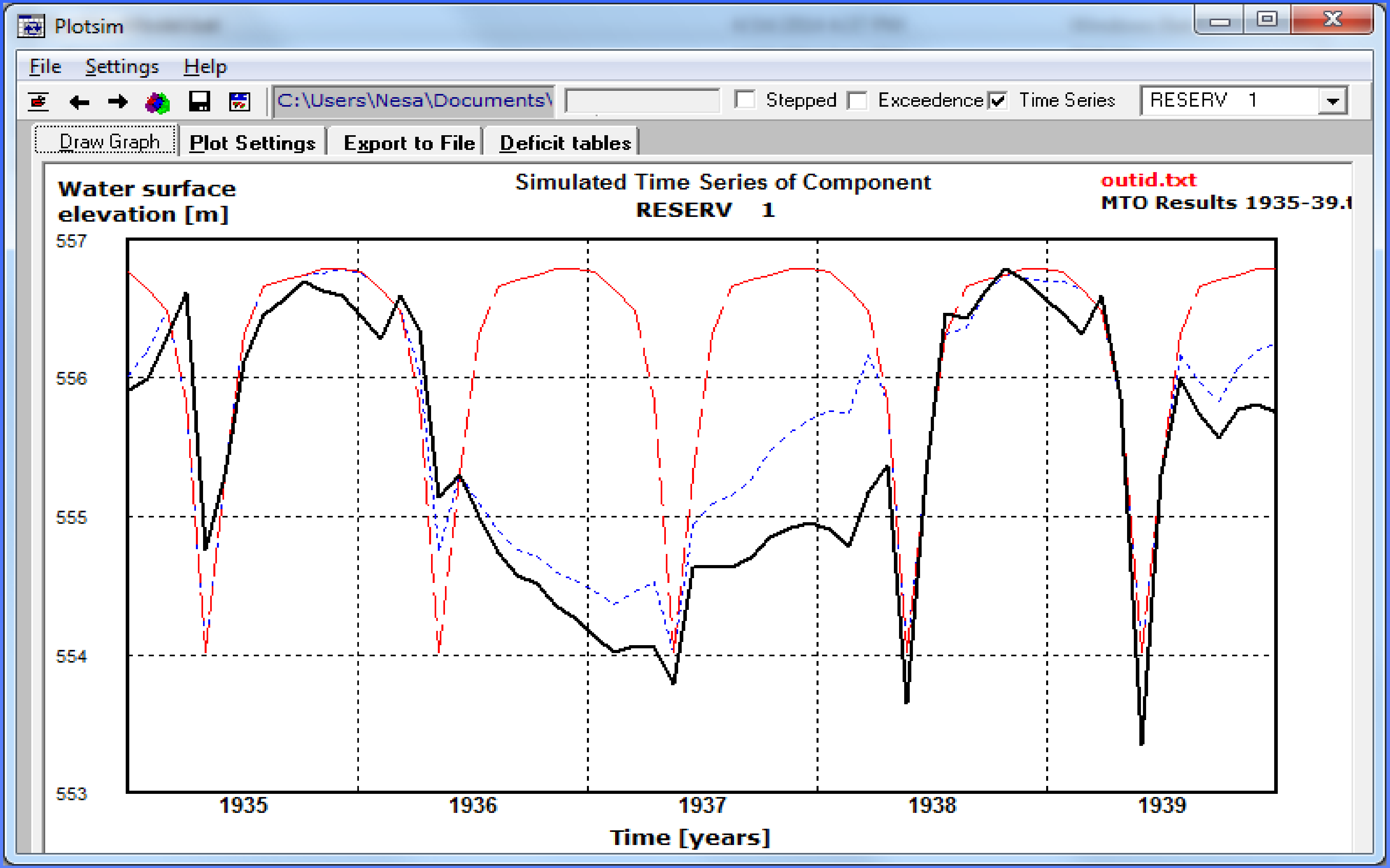
Reservoir Operating Zones -- example



Storage Levels for three Scenarios (1928-1937)







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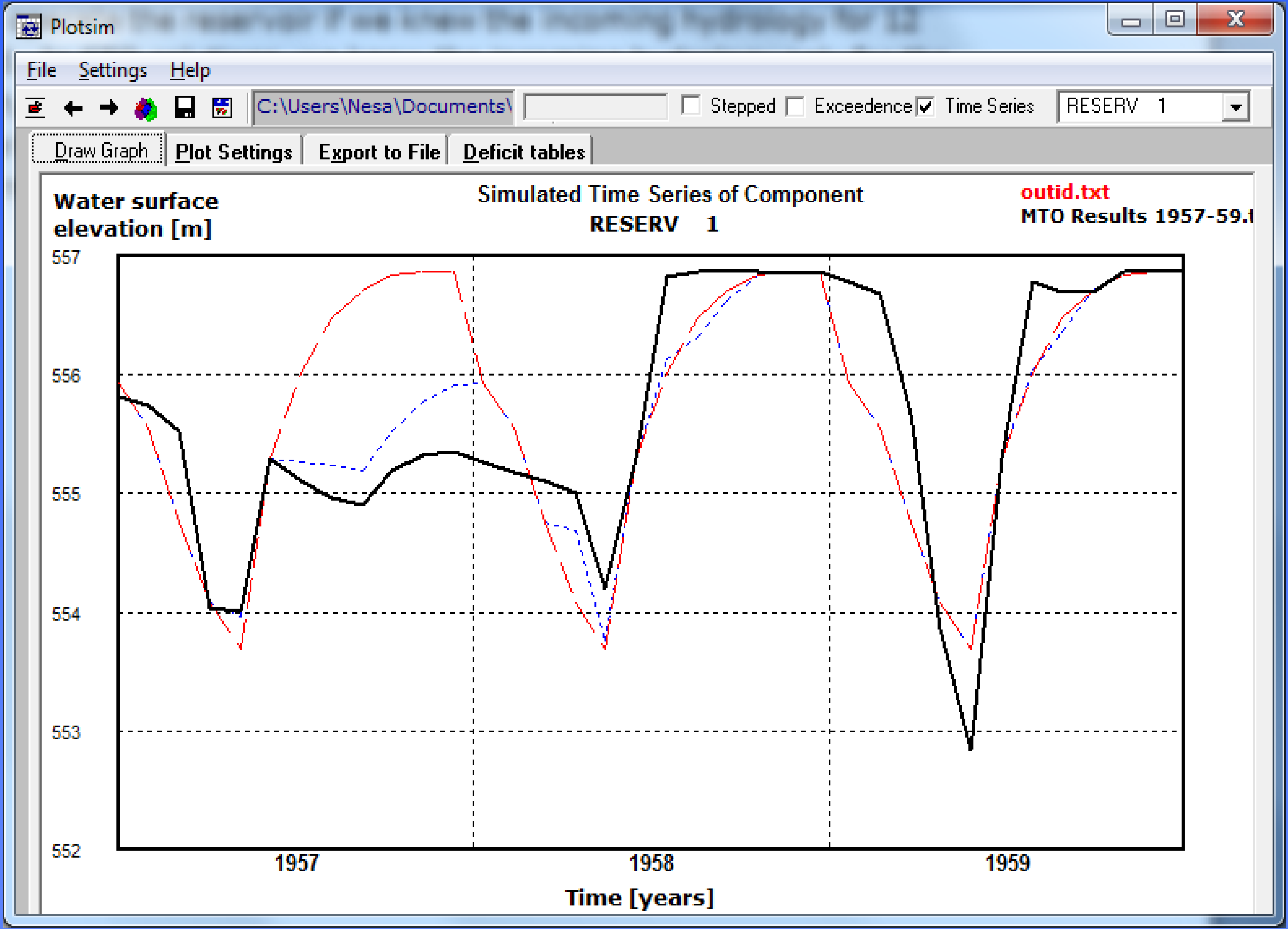
☐ Stepped ☐ Exceedence ☑ Time Series

RESERV 1



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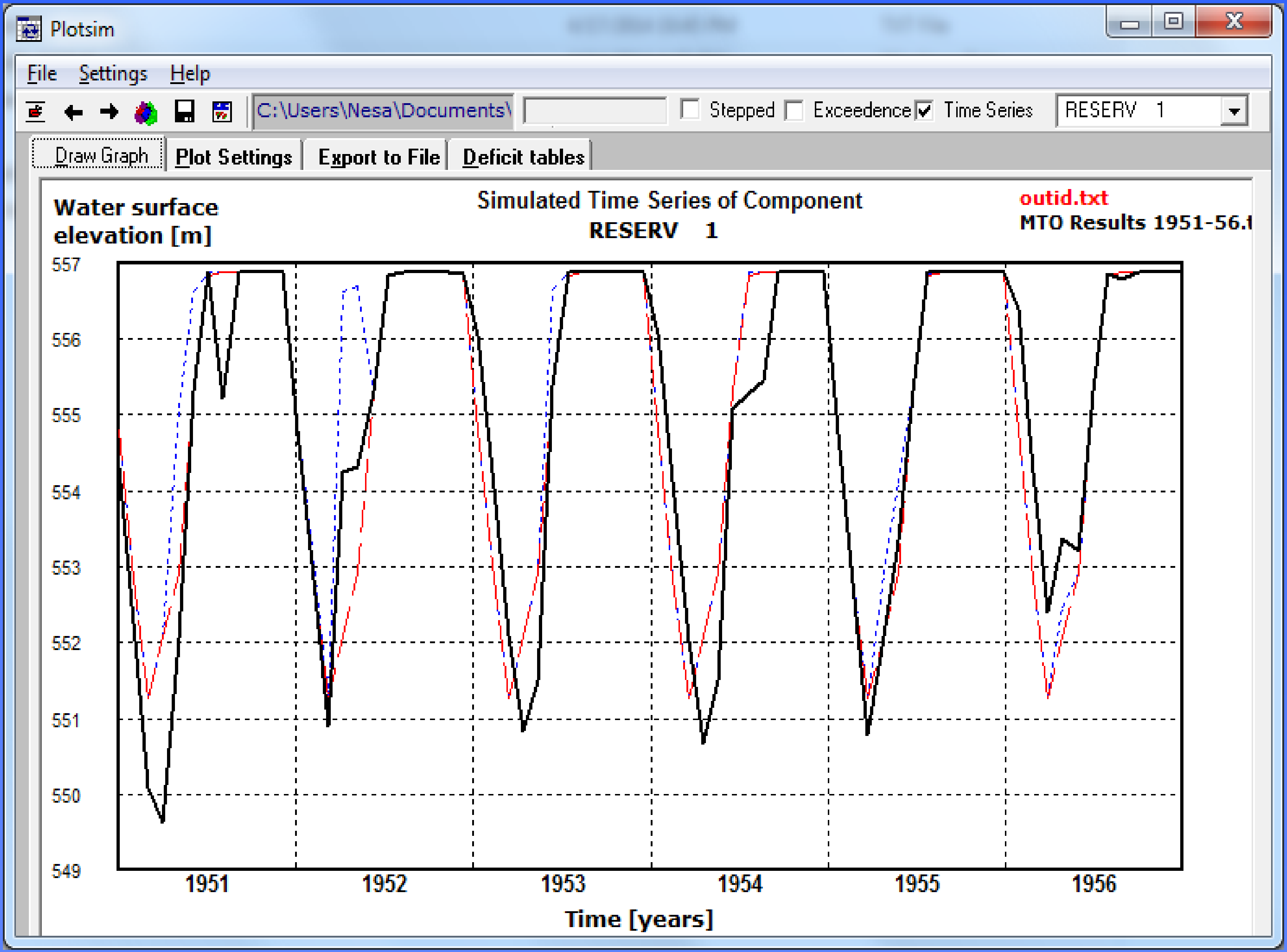
☐ Stepped ☐ Exceedence ☑ Time Series

RESERV 1



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☐ Stepped ☐ Exceedence ☑ Time Series

RESERV 1

Unsolved Issues

- Significance of Time Step Length and STO vs MTO
- Hydrologic Routing
- Reservoir outflow constraints for two or more outlets
- Finding the best set of weight factors
- Agreeing on minimum models' tech. specifications
- Establishing Benchmarks test problems that should be accepted in the industry
- Develop procedure for finding and verifying optimal reservoir operating rules for a range of hydrologic years; and,
- Develop procedures how to apply the optimal rules in real time

The End