

# **Ensemble Optimization Procedures (EOP) Reservoir & Hydroelectric Operations**

**By  
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**Weather  
Ensemble Forecast**



**Hydrology  
Ensemble River  
Forecast**



**EOP Decision  
Ensemble Reservoir  
Optimization**



**€, £, \$**




# **Hydrologic Ensemble**

- **Generated statistically**
- **Underlying frequency distributions are the same for each sequence**
- **Serial correlations are the same for each sequence.**
- **Eight (8) Members in the Ensemble**

[illegible]

# Reservoir Operation Objective

- **Maximize Benefits** 
- **Considering all of the possible futures in the Ensemble Forecasts**
- **How much water should be released from storage?**

# Ensemble Optimization Procedures for Reservoir Management

**1.OPTRISK**



**2.OPTSEQ**

**3.OPTNOW**

## **OPTRISK**

**Monte Carlo Simulation at each  
Mathematical Programming Iteration**

## **OPTSEQ**

**Optimize Each Member of the Ensemble  
Individually**

## **OPTNOW**

**Globally Optimize Over the Entire Ensemble**

# **PLANNING with Ensembles**

## **OPTRISK:**

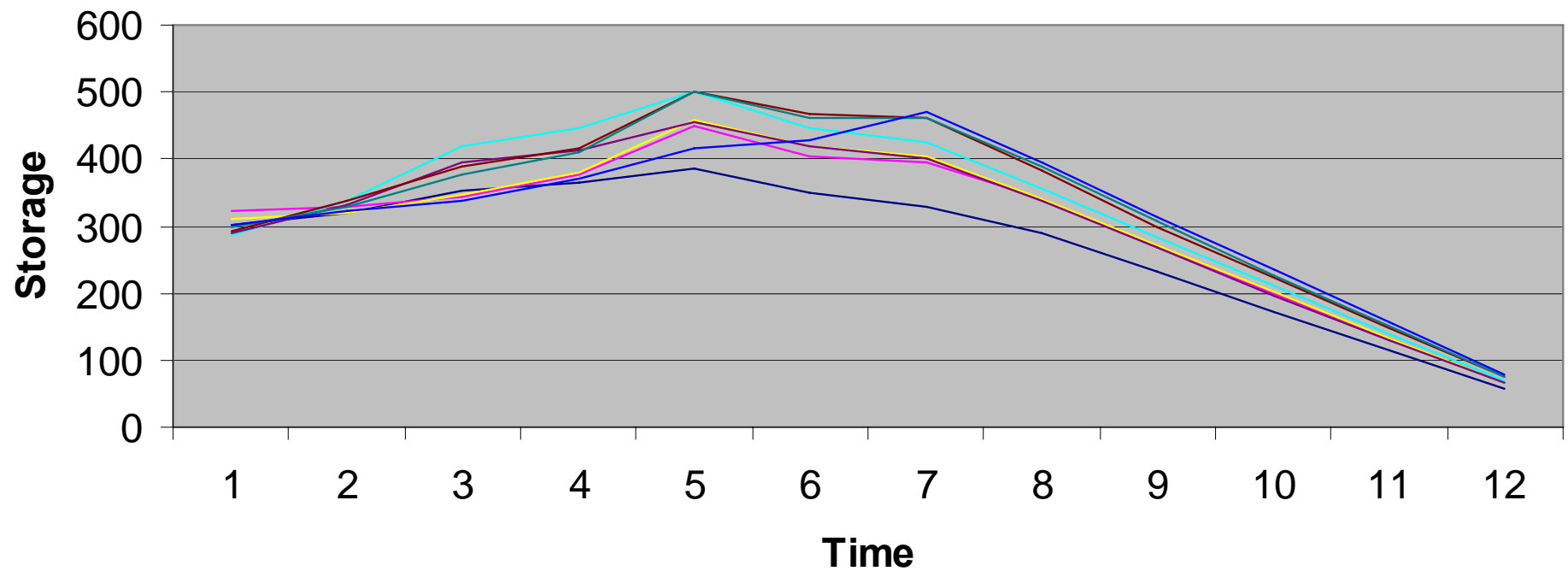
- **Develop the optimum fixed plan of operation over the entire time horizon.**
- **Consider risks inherent in the ensemble**
- **Display the risks for following that plan.**
- **Used to make agreements for future deliveries of water and power.**

# **OPERATING with Ensembles**

## **OPTSEQ & OPTNOW:**

- **Determine a single optimum decision.**
- **Consider all possible future outcomes.**
- **Display the optimum probability distributions of future decisions.**
- **Used to keep operations on the PLAN as new ensemble forecasts arrive.**

## Optimized Equally Likely Water in Storage



# 1.OPTRISK distributions

**Optimum powerflow at time Now is 57.9**

Expected value of objective over all distributions from 1000 simulations \$94,361

Last simulation shown on screen: current value of the objective \$93,320

Optimization Over All Timesteps and Streamflow Distributions									
Streamflow Analysis				Probabilistic	Deterministic		Probabilistic		
timestep	avg	stdev	SerialCorrelations	inflow	powerflow	spill	storage	power	Pricing
<b>NOW</b>	100.27	10.148	deterministic	104.30	<b>57.9</b>	0.0	296.39	171.6	100
2	94.44	31.258	0.19	89.00	68.0	0.0	317.42	215.8	75
3	68.55	22.401	0.03	69.66	47.2	0.0	339.83	160.6	55
4	29.44	2.986	0.59	37.04	12.2	0.0	364.62	44.6	45
5	96.66	40.713	0.40	95.03	69.8	0.0	389.88	272.0	40
6	82.54	18.942	0.69	84.97	104.2	0.0	370.67	386.2	38
7	68.63	36.031	0.01	69.92	64.1	0.0	376.50	241.3	27
8	29.08	5.279	-0.72	28.41	82.0	0.0	322.93	264.8	26
9	14.37	2.409	0.48	12.34	76.2	0.0	259.11	197.3	24
10	3.88	0.783	0.24	2.98	63.5	0.0	198.61	126.1	22
11	1.83	0.437	0.31	0.75	58.5	0.0	140.82	82.4	21
12	0.50	0.040	-0.39	0.03	54.3	0.0	86.54	47.0	20
				ProbabilisticData	Decision Variables		Current Values		
				Upper Bound	150		500	Initial storage	
				Lower Bound	0		0		
							250		

# 1. OPTRISK Simulations

**Optimum powerflow at time Now is**

**57.9**

Expected value of objective over all distributions from 1000 simulations

\$94,361

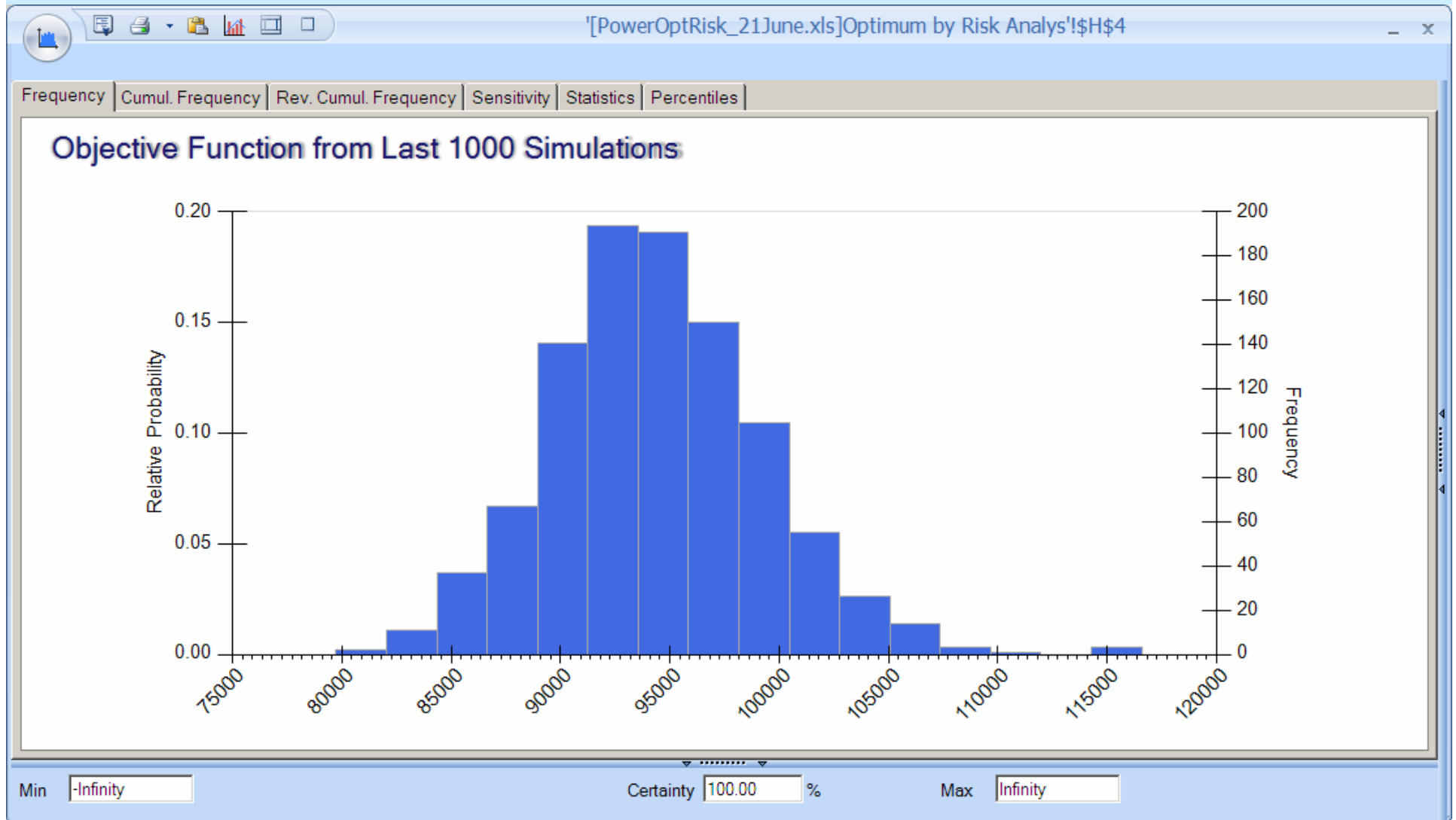
Last simulation shown on screen: current value of the objective

\$88,768

Optimization Over All Timesteps and Streamflow Distributions

Streamflow Analysis				Probabilistic	Deterministic		Probabilistic		
timestep	avg	stdev	SerialCorrelations	inflow	powerflow	spill	storage	power	Pricing
<b>NOW</b>	114.33	41.907	deterministic	104.30	<b>57.9</b>	0.0	296.39	171.6	100
2	85.68	22.304	-0.14	84.03	68.0	0.0	312.45	212.4	75
3	77.05	18.209	-0.24	74.92	47.2	0.0	340.11	160.7	55
4	29.49	7.438	0.09	21.13	12.2	0.0	349.00	42.7	45
5	78.33	16.069	-0.40	73.77	69.8	0.0	353.01	246.3	40
6	86.43	16.255	-0.22	93.37	104.2	0.0	342.19	356.5	38
7	69.52	12.203	0.18	65.12	64.1	0.0	343.24	220.0	27
8	29.30	2.537	-0.37	37.11	82.0	0.0	298.36	244.6	26
9	14.68	3.098	-0.76	19.53	76.2	0.0	241.73	184.1	24
10	4.89	0.747	0.13	2.43	63.5	0.0	180.68	114.7	22
11	1.94	0.133	-0.42	0.01	58.5	0.0	122.15	71.5	21
12	0.57	0.210	0.57	3.27	54.3	0.0	71.11	38.6	20
				ProbabilisticData	Decision Variables		Current Values		
				Upper Bound	150		500		
				Lower Bound	0		0		
							250	Initial storage	

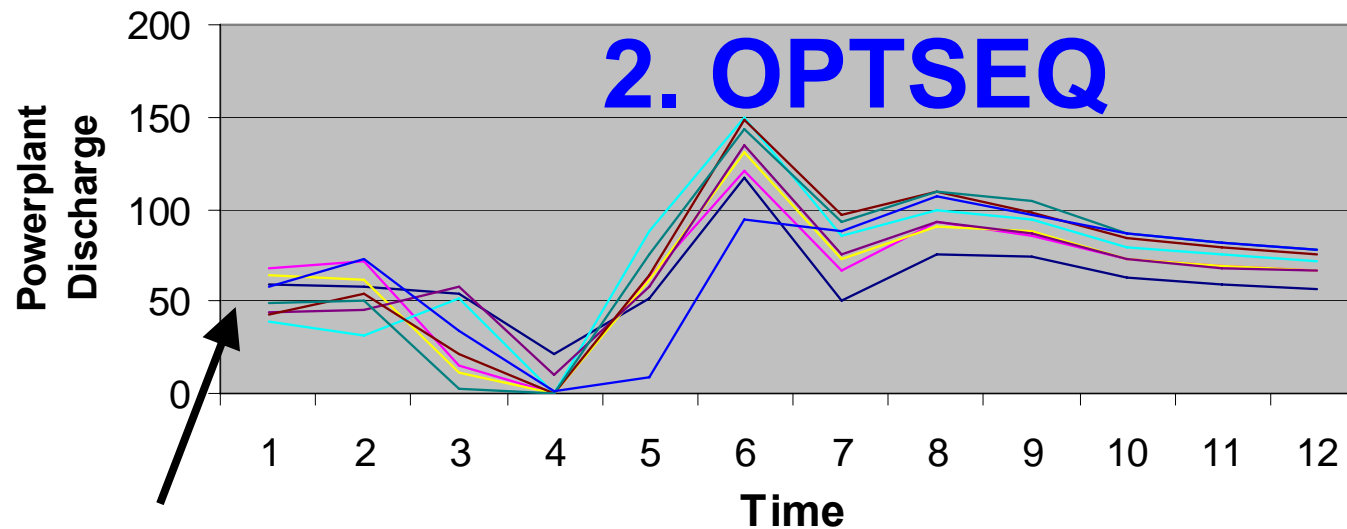
# 1. OPTRISK



## Optimized Plant Output Eight Separate QLP's

Average NOW=52.8

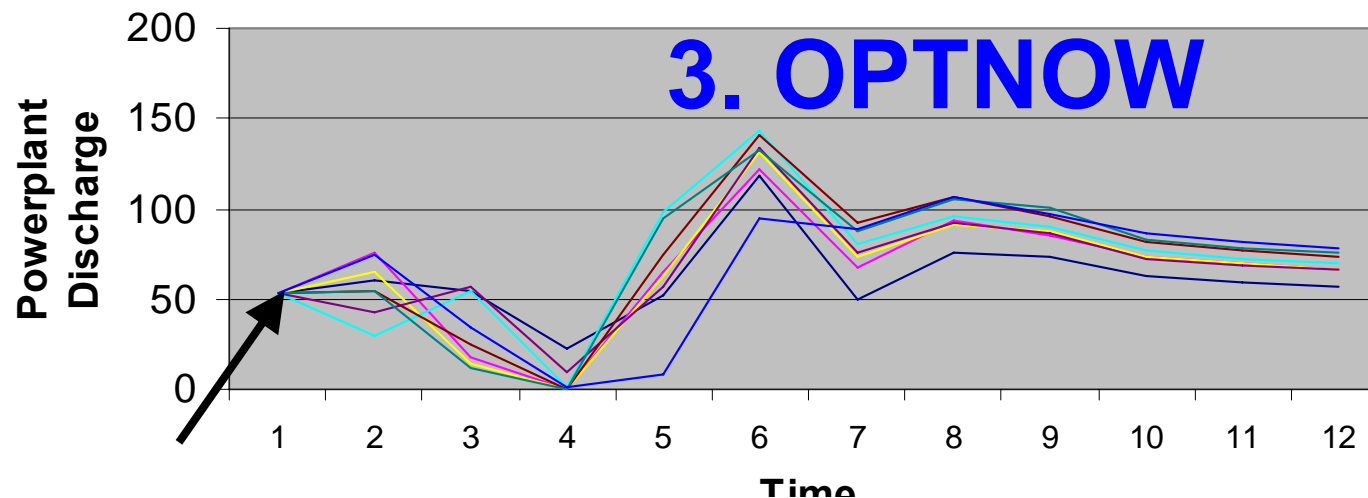
52.8



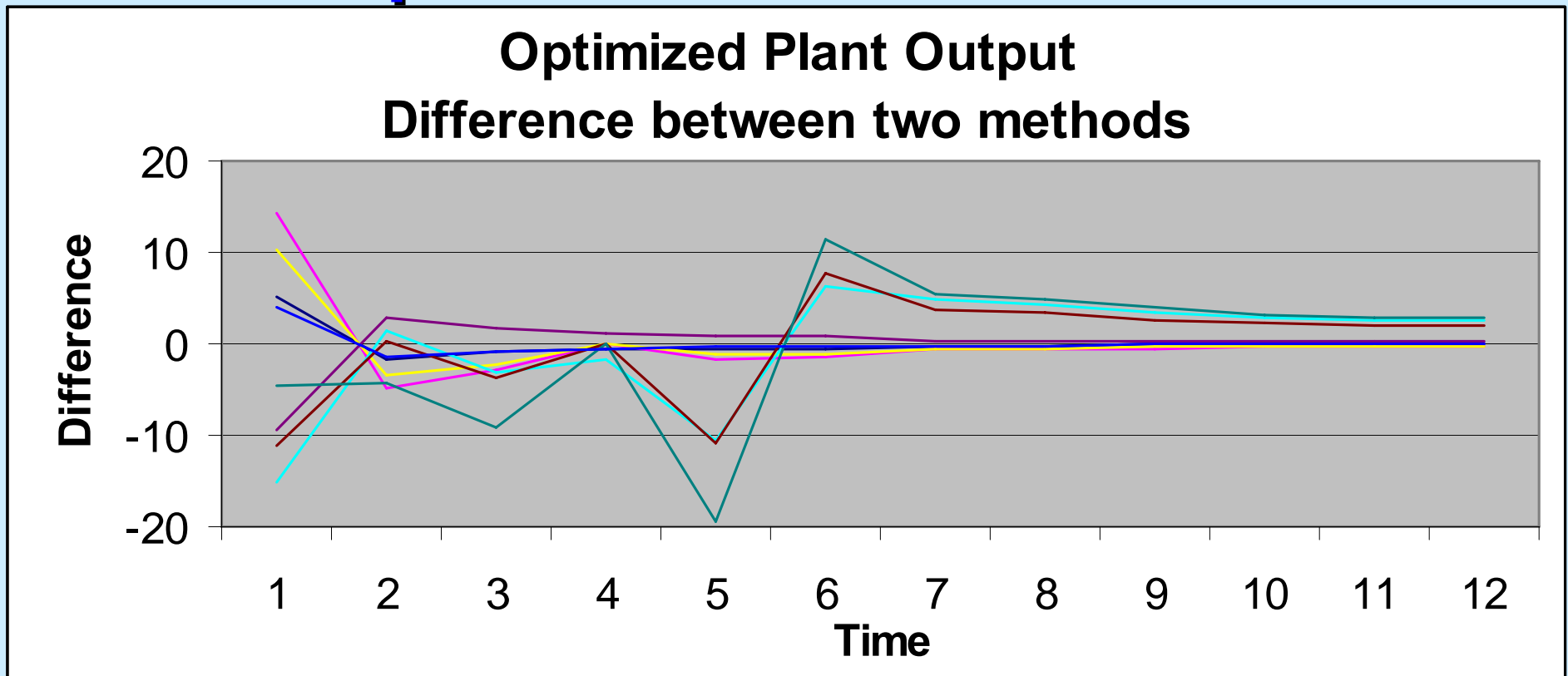
1. OPTRISK 57.9

Optimized Plant Output NOW = 53.6

53.6



# Compare OPTSEQ and OPTNOW

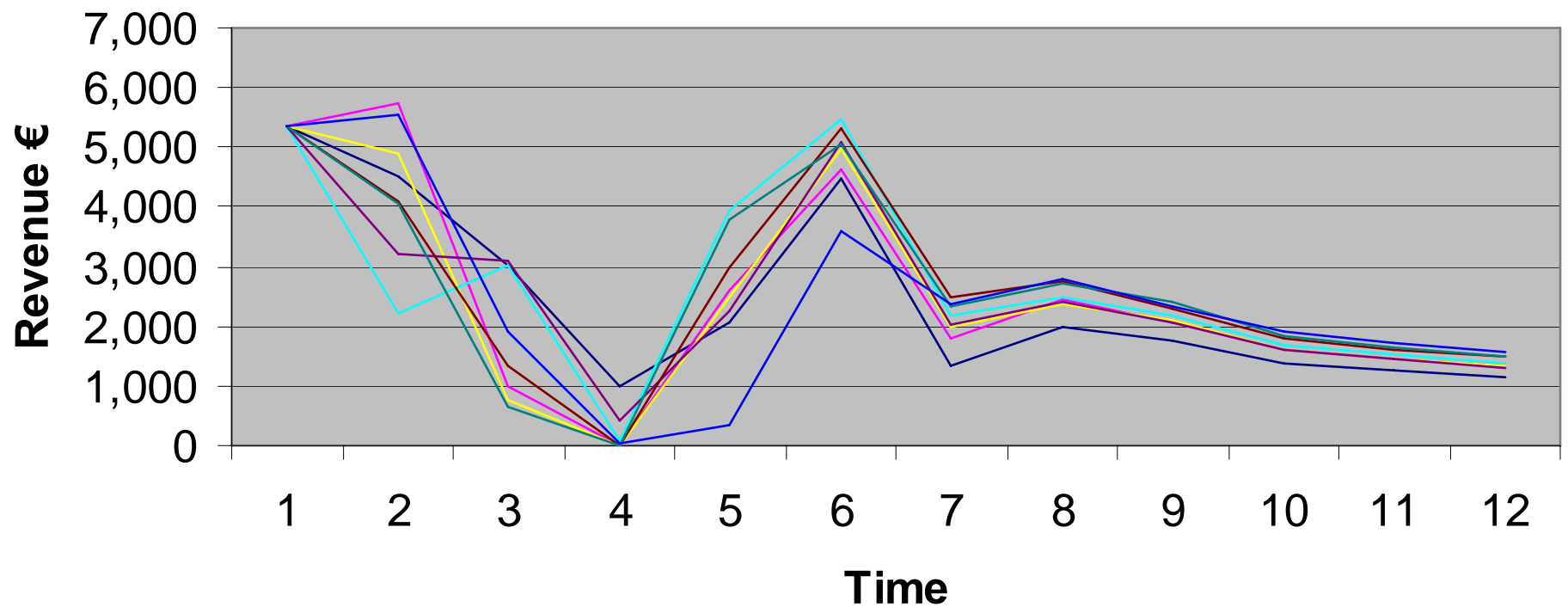


**OPTSEQ Average Decision almost same as OPTNOW.**

**High and Low recommendations tend to cancel**

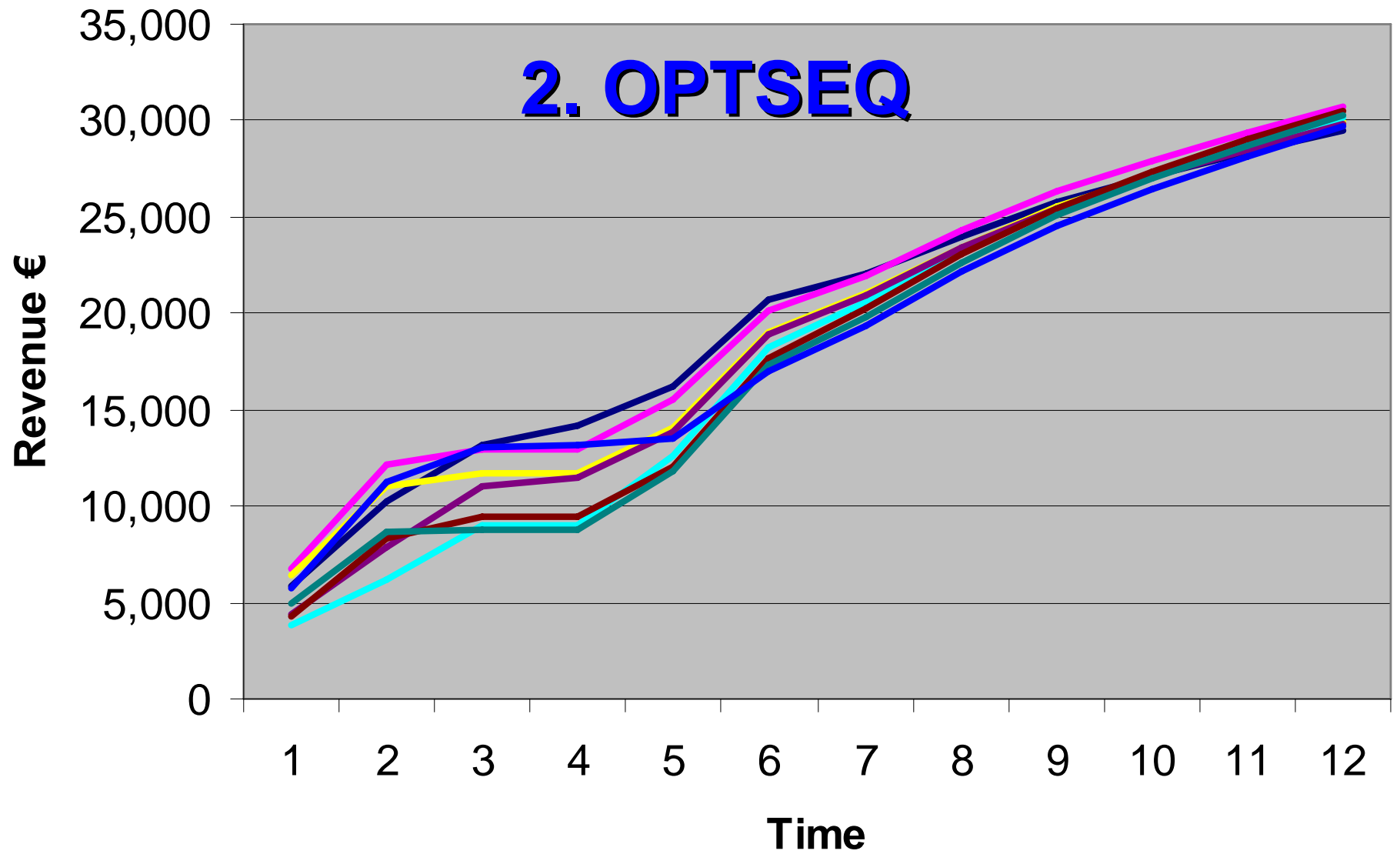
### 3. OPTNOW

#### Optimized Revenue Forecast



## Cumulative Revenue Eight Separate QLP's

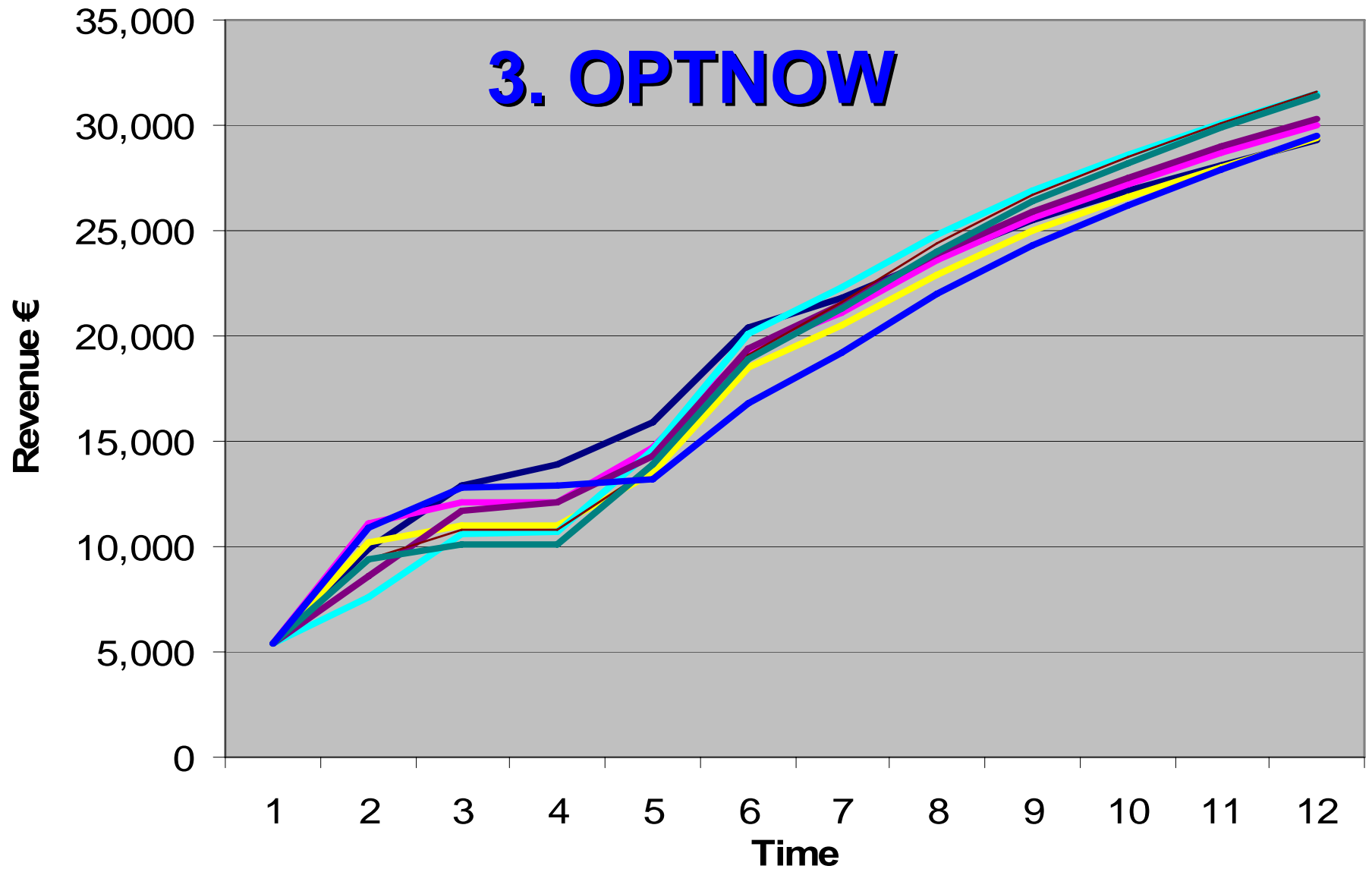
### 2. OPTSEQ



# Cumulative Revenue

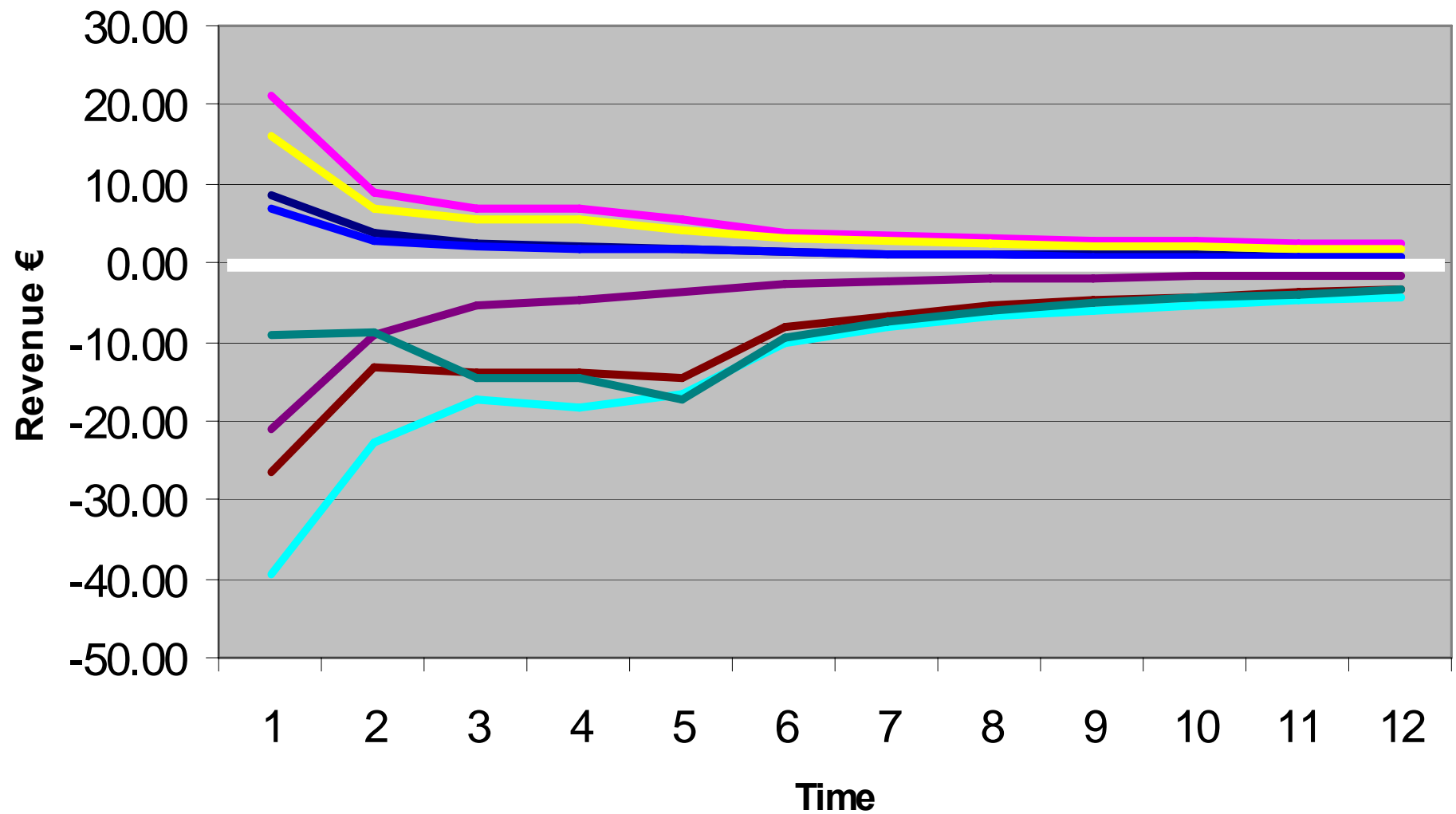
Optimized Plant Output NOW = 53.6

## 3. OPTNOW



# Optimized Cumulative Revenue

## Percentage Difference Between Two Methods



# Maximum Objective Functions

- **OPTRISK = 94,361**
  - average of 1000 values
- **OPTSEQ = 100,956**
  - average of 8 values
- **OPTNOW = 100,826**
  - single value

# Conclusions

- All three methods have about the same value for the objective function
- All recommend about the same reservoir release at time NOW.
- OPTRISK ensemble = 1000 sequences
- OPTNOW/OPTSEQ ensemble = 8 sequences

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# Thank You

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