Using Improved Climate Forecasting and the Flexibility of RiverWare to Develop Operational Policies for Increasing Efficiency for the Tarrant Regional Water District

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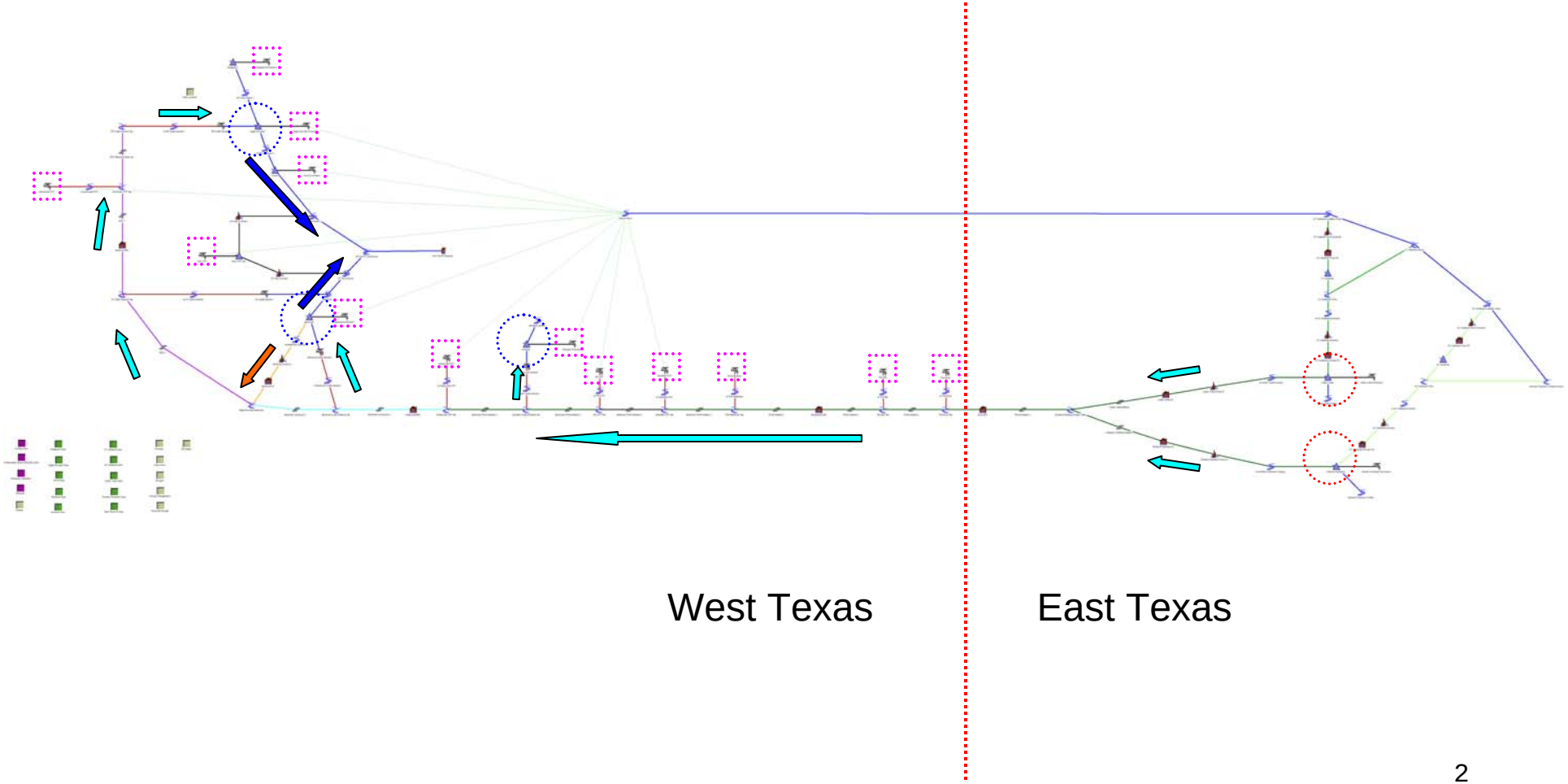
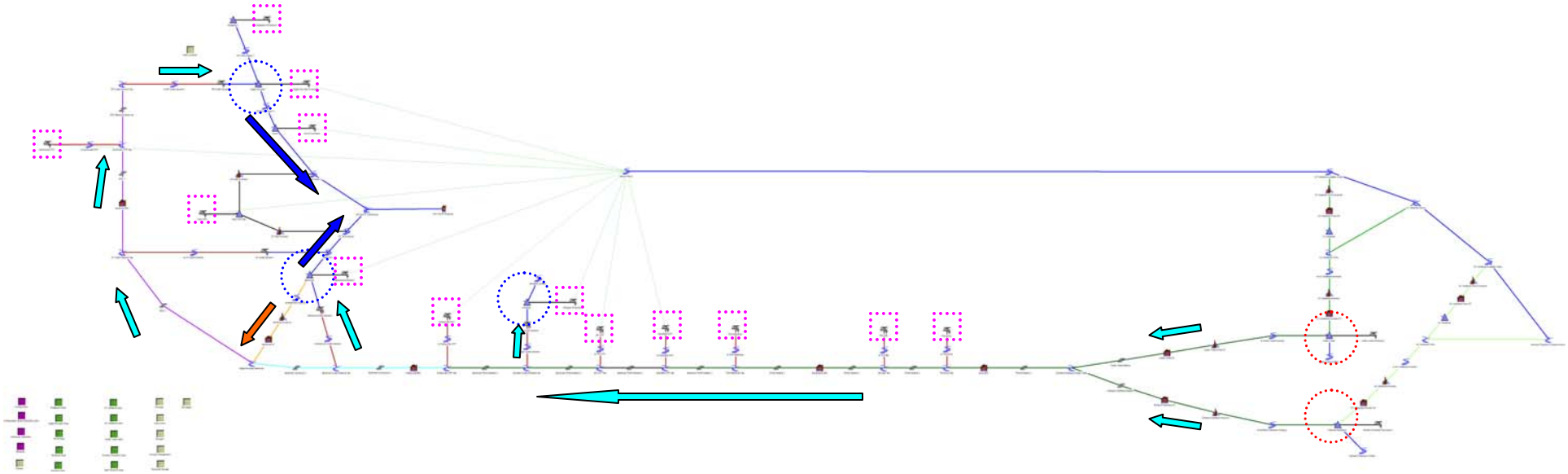
TRWD Model



Purpose

- If we had better predictions of runoff based on improved climate forecasting, how could we improve efficiency?
- What policies should we adjust based on climate state?
  - “Hard” Targets vs. “Soft” Targets
- What are the costs vs. benefits of modifications?



Climate States

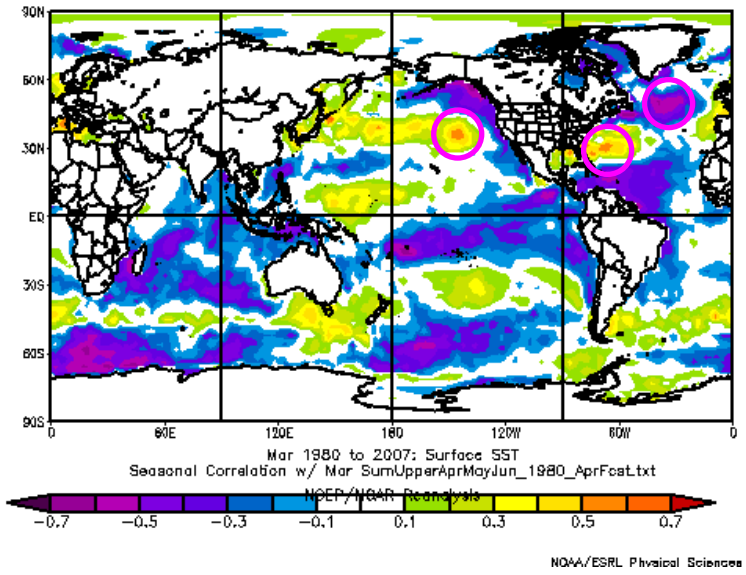
Historical Data (1941-2008)

- 1 – “Wet”
- 2 – “Average”
- 3 – “Dry”

Transition Type		Seasonal Probabilities			
		1 to 2	2 to 3	3 to 4	4 to 1
Dry to Dry	11	54.5%	55%	43%	55%
Dry to Avg	12	40.9%	32%	35%	23%
Dry to Wet	13	4.5%	14%	22%	23%
Avg to Dry	21	22%	42%	26%	22%
Avg to Avg	22	35%	25%	43%	35%
Avg to Wet	23	43%	33%	30%	43%
Wet to Dry	31	22%	5%	32%	23%
Wet to Avg	32	30%	45%	23%	45%
Wet to Wet	33	48%	50%	45%	32%

Transition Type		Monthly Probabilities											
		1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 1
Dry to Dry	11	70%	70%	61%	70%	48%	39%	39%	48%	45%	57%	61%	59%
Dry to Avg	12	22%	17%	17%	17%	26%	48%	35%	22%	36%	35%	30%	23%
Dry to Wet	13	9%	13%	22%	13%	26%	13%	26%	30%	18%	9%	9%	18%
Avg to Dry	21	23%	23%	36%	27%	41%	41%	45%	32%	43%	32%	32%	27%
Avg to Avg	22	41%	36%	45%	41%	41%	36%	36%	41%	35%	27%	32%	45%
Avg to Wet	23	36%	41%	18%	32%	18%	23%	18%	27%	22%	41%	36%	27%
Wet to Dry	31	9%	9%	4%	4%	13%	22%	17%	17%	13%	13%	9%	17%
Wet to Avg	32	35%	43%	36%	41%	30%	13%	26%	39%	26%	35%	35%	26%
Wet to Wet	33	57%	48%	59%	59%	57%	65%	57%	43%	61%	52%	57%	57%

- “Perfect Knowledge”
- Forecasting
  - Transition Probabilities
    - Quarterly
    - Monthly
  - Downscaled Climate Variables

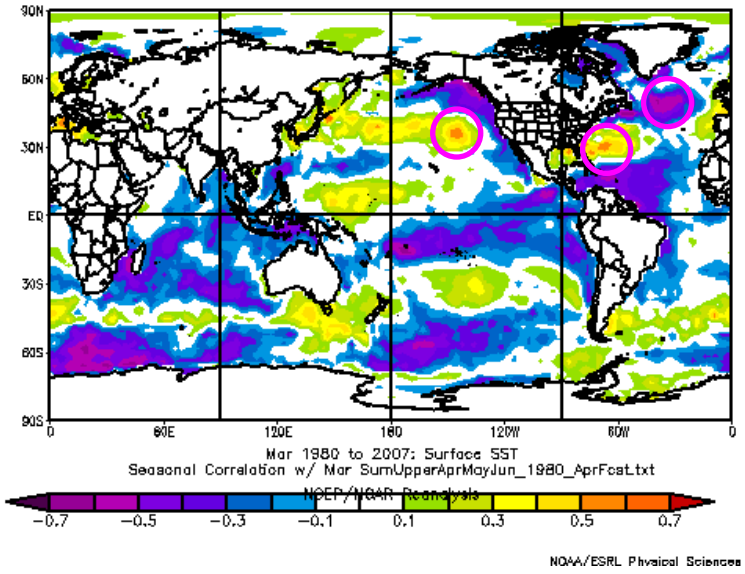


Climate-based Forecasting

- **Are there climate signals that correspond to flows?**
  - **Total Inflow to West Texas Reservoirs**
  - **A significant correlation for this data set is greater than 0.37**
  - **Q2 has skill for both Wet and Dry Forecasts**
  - **Q3 only has skill for Wet Forecasts**

Q2 Forecast Variables:
1) Sea Surface Temperature
2) 500mb Zonal Wind
3) 500mb Meridional Wind
4) 500mb Geopotential Height
5) Palmer Drought Severity Index Division 3
6) 925mb Zonal Wind
7) 925mb Meridional Wind
8) 200mb Geopoential Height

Q3 Forecast Variables:
1) Sea Surface Temperature
2) Palmer Drought Severity Index Division 3
3) 925mb Zonal Wind
4) 925mb Meridional Wind
8) 200mb Geopoential Height
9) June Flow

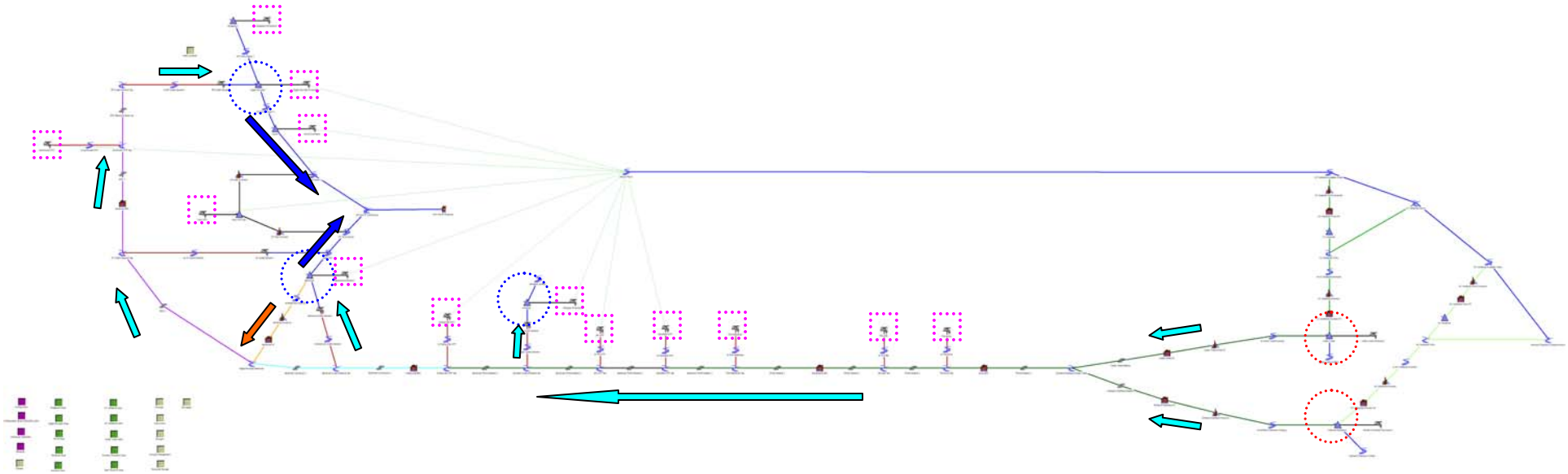


Time Series of Climate States

	Baseline	Actual Quarterly (Perfect knowledge)	Monthly Transition Prob. Only	Forecast Monthly	Forecast Quarterly
1/1941	2	1	2	2	1
2/1941	2	1	2	1	1
3/1941	2	1	2	2	1
4/1941	2	2	1	1	2
5/1941	2	2	1	1	2
6/1941	2	2	2	2	2
7/1941	2	1	2	2	3
8/1941	2	1	2	2	3

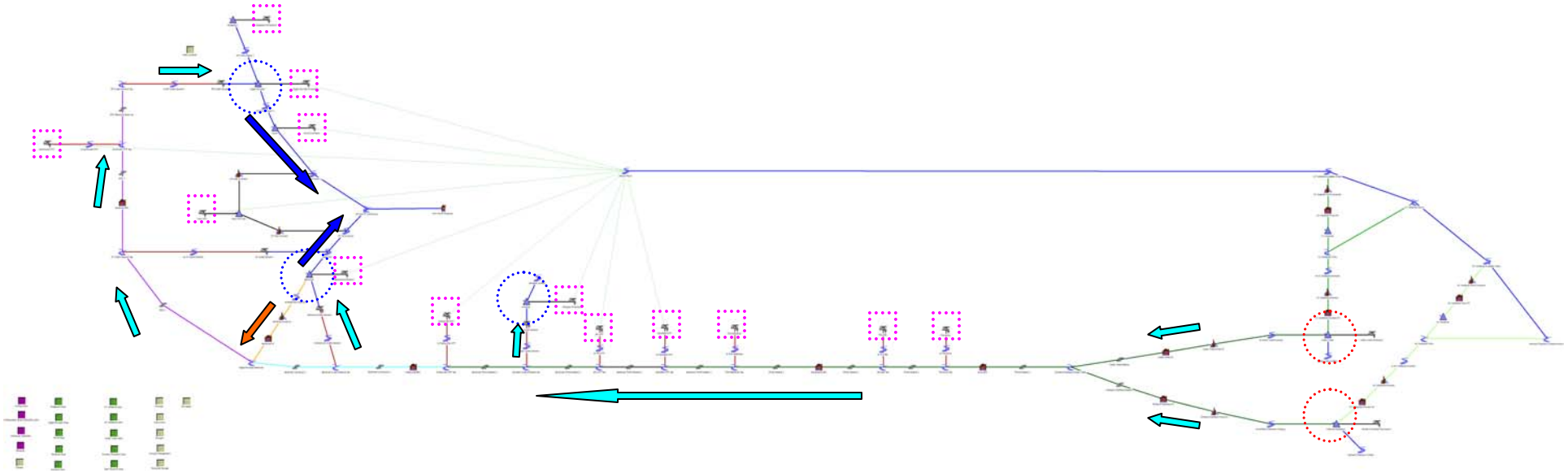
Evaluation Criteria

- Pumping Volumes
- Shortages to Water Users
- Evaporation Losses
- Spills from Reservoirs
- Pumping Costs [f(x) = {flow, timing, rate structures, etc.)



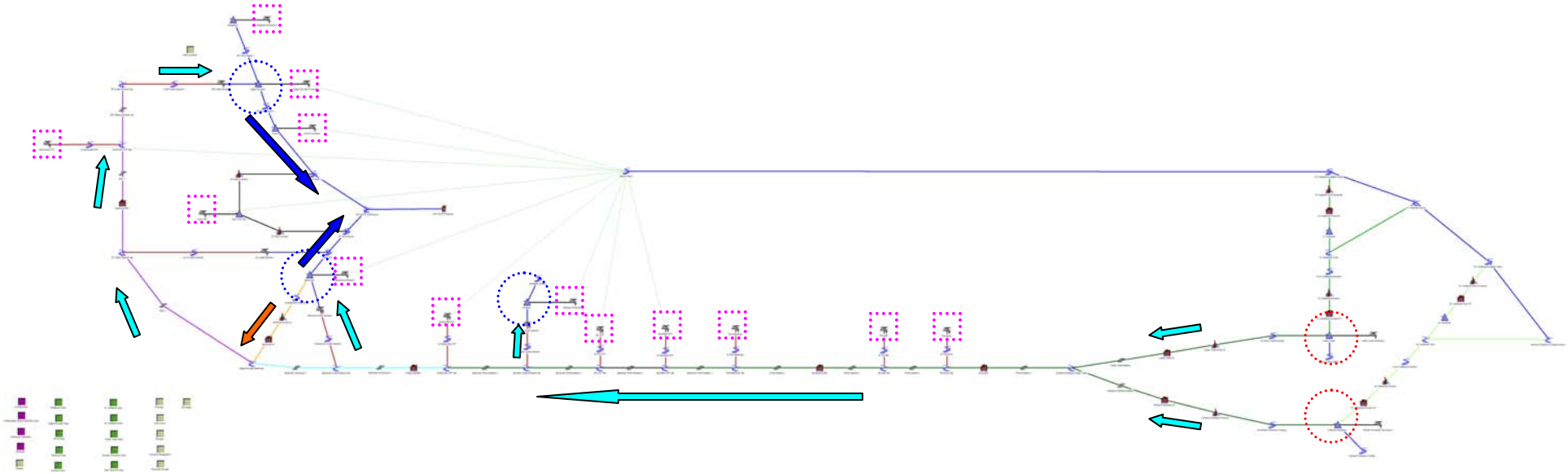
Policy Alternatives

Option #	Scenario	Purpose	Potential Risks
1	Sustain Summer Pumping	No Longer Proposed	
2	Drawdown Trigger for Pumping to Eagle Mountain	Increasing the trigger elevations for dry quarters (hence maintaining higher flows at a given elevation) will allow more pumping into Eagle Mountain Reservoir.	Spills from Eagle Mountain Reservoir, possible excessive pumping costs if local inflows to Eagle Mountain Reservoir refill.
3	Critical Path for Lake Arlington	Decreasing the Critical Path for Arlington during wet quarters will require less pumping into Arlington. Meeting the Critical path will be subject to Arlington local inflows.	Not meeting the Arlington Critical path during periods when the levels are dependent on local inflows
4	Target Path for Lake Benbrook	Decreasing the Target Elevation for Benbrook during wet quarters will require less pumping into Benbrook. Meeting the Critical path will be subject to Benbrook local inflows.	Not meeting the Target Elevation for Benbrook path during periods when the levels are dependent on local inflows
5	Operating Rule Between Bridgeport and Eagle Mountain	Decreasing the drop-down ratio (Bridgeport:Eagle Mountain) in "Zone 3" from 2 to 1 will tend to retain water in the higher reservoir (Bridgeport) during wet quarters.	Not meeting elevation requirements of Eagle Mountain and possible increased risk of spills from Bridgeport (and consequentially through Eagle Mountain).



Policy Alternatives

Option #	Scenario	Purpose	Potential Risks
6	Months of Allowable Pumping from Benbrook	Expanding the number of months that water can be pumped from Benbrook during wet quarters would allow more demands to be met through Benbrook instead of from East Texas while allowing space in Benbrook to refill with local inflows.	Reaching the 72,500 acre-feet/year maximum diversion too early in the year and not having the ability to meet needs from Benbrook and requiring excess East Texas water.
7	East Texas Pump Configuration	Fixing the East Texas Pumping configuration to a minimum of each branch pumping with three pumps (3/3 Low) during all dry quarters.	Excessive pumping costs and increased probablility of spills.
8	Trigger for Wetlands Water into ETX Reservoirs	Decreasing the recharge trigger elevation for the wetlands allows more water to be transferred to the ET reservoirs sooner, thus keeping them more full for use during dry quarters.	Loss of water due to spills from the East Texas reservoirs.
9	Flood Pump Trigger for Lake Benbrook	Reduce the elevation at which flood pumping from Benbrook to the pipeline begins during wet quarters. This will allow more local inflow water to be captured by Benbrook	Reaching the 72,500 acre-feet/year maximum diversion too early in the year and not having the ability to meet needs from Benbrook and requiring excess East Texas water.
10	Reduce Flows to Eagle Mountain Reservoir	Reduce the flows into Eagle Mountain Reservoir during all climate conditions. This will reduce total pumping to and spills from eagle Mountain and will allow Eagle Mountain to capture inflow events	Increased risk of shortages



Options Analysis

Period of Record (1941-2008)

Total Volume (acre-feet)

	Baseline	Option #2	Option #3	Option #4	Option #5	Option #6	Option #7	Option #8	Option #10
Pumping from East Texas	19,974,363	20,048,906	19,753,993	19,945,068	19,986,037	19,974,363	20,087,851	19,974,363	19,727,331
Total Evaporation from Reservoirs	15,583,306	15,585,966	15,582,996	15,581,782	15,582,703	15,583,306	15,598,924	15,646,872	15,563,165
Total Shortage	56,366	56,253	57,107	56,366	56,580	56,366	49,903	56,366	61,056
Total Spills from Terminal Storage Reservoirs	13,168,647	13,228,401	12,961,360	13,140,348	13,166,912	13,168,647	13,274,889	13,168,647	12,910,262

Change from Baseline (acre-feet)

	Baseline	Option #2	Option #3	Option #4	Option #5	Option #6	Option #7	Option #8	Option #10
Pumping from East Texas	0	74,543	-220,370	-29,296	11,674	0	113,487	0	-247,032
Total Evaporation from Reservoirs	0	2,660	-309	-1,524	-603	0	15,618	63,566	-20,141
Total Shortage	0	-113	741	0	214	0	-6,463	0	4,690
Total Spills from Terminal Storage Reservoirs	0	59,754	-207,287	-28,300	-1,735	0	106,242	0	-258,385

Percent Change from Baseline

	Baseline	Option #2	Option #3	Option #4	Option #5	Option #6	Option #7	Option #8	Option #10
Pumping from East Texas	0.0%	0.4%	-1.1%	-0.1%	0.1%	0.0%	0.6%	0.0%	-1.2%
Total Evaporation from Reservoirs	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.4%	-0.1%
Total Shortage	0.0%	-0.2%	1.3%	0.0%	0.4%	0.0%	-11.5%	0.0%	8.3%
Total Spills from Terminal Storage Reservoirs	0.0%	0.5%	-1.6%	-0.2%	0.0%	0.0%	0.8%	0.0%	-2.0%

Combination Policy Analysis

1) **Baseline:** This policy uses the average hydrology for all climate conditions, therefore negating all policy modifications applied in the model.
2) **3-4-7 Policy:** This is a combination of 3 proposed policies including:
    1) Policies 3 & 4: Allowing Greater Flexibility in Receiving Reservoirs during wet conditions
    2) Policy 7: Setting a minimum pumping rate from East Texas during dry conditions
3) **3-4-7 Policy (Pumping Caveat):** Apply 3-4-7 Policy but **negate** policy 7 when west Texas reservoirs is greater than 80% relative to the conservation storage values (minimize any spills that may result from excess water pumped into reservoirs that are close to being full.)
4) **3-4-7-10 Policy (Pumping Caveat):** Apply 3-4-7 Policy (with pumping caveat)
    1) Policy 10 - Reducing the trigger elevations (flow requests) to Eagle Mountain Reservoir

Combination Policy Analysis

Total Volume (acre-feet)

		3-4-7 Policy				3-4-7 Policy (Pumping Caveat)				3-4-7-10 Policy (Pumping Caveat)			
	Baseline	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly
Total Pumping	19,974,363	19,810,583	19,948,247	19,964,912	20,145,721	19,783,024	19,904,577	19,854,422	19,993,329	19,313,262	19,419,102	19,404,252	19,610,757
Total Evaporation	15,583,306	15,598,023	15,591,732	15,589,063	15,586,861	15,591,384	15,587,242	15,582,496	15,584,192	15,556,687	19,419,102	15,554,720	15,556,005
Total Shortage	56,366	47,849	45,497	46,678	55,673	47,847	45,500	46,680	55,673	59,326	58,750	57,391	58,620
Total Spills	13,168,647	13,005,144	13,126,345	13,150,834	13,348,722	12,972,409	13,079,601	13,032,305	13,186,001	12,501,199	12,616,087	12,605,672	12,811,785

Change from Baseline (acre-feet)

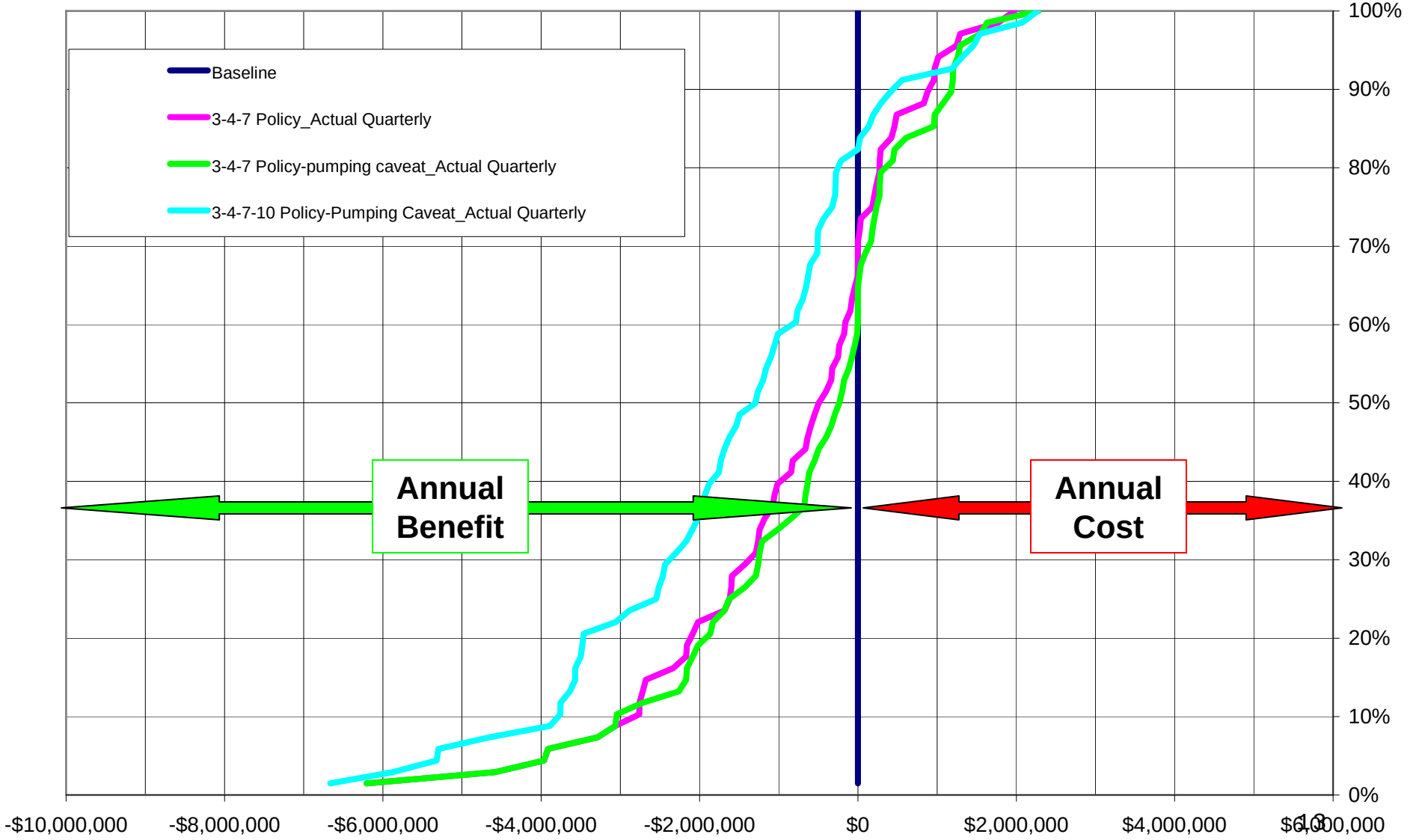
		3-4-7 Policy				3-4-7 Policy (Pumping Caveat)				3-4-7-10 Policy (Pumping Caveat)			
	Baseline	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly
Total Pumping	0	-163,781	-26,116	-9,452	171,358	-191,339	-69,786	-119,941	18,966	-661,101	-555,261	-570,112	-363,607
Total Evaporation	0	14,717	8,426	5,757	3,555	8,078	3,937	-810	886	-26,619	3,835,796	-28,585	-27,300
Total Shortage	0	-8,518	-10,870	-9,688	-694	-8,519	-10,867	-9,686	-694	-3,060	2,384	1,025	2,253
Total Spills	0	-163,503	-42,302	-17,813	180,075	-196,238	-89,046	-136,343	17,354	-667,448	-552,560	-562,975	-356,862

Percent Change from Baseline

		3-4-7 Policy				3-4-7 Policy (Pumping Caveat)				3-4-7-10 Policy (Pumping Caveat)			
	Baseline	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly	Actual Quarterly	Transition Prob Monthly	Forecast Monthly	Forecast Quarterly
Total Pumping	0.0%	-0.8%	-0.1%	0.0%	0.9%	-1.0%	-0.3%	-0.6%	0.1%	-3.3%	-2.8%	-2.9%	-1.8%
Total Evaporation	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	-0.2%	24.6%	-0.2%	-0.2%
Total Shortage	0.0%	-15.1%	-19.3%	-17.2%	-1.2%	-15.1%	-19.3%	-17.2%	-1.2%	-5.3%	4.2%	1.8%	4.0%
Total Spills	0.0%	-1.2%	-0.3%	-0.1%	1.4%	-1.5%	-0.7%	-1.0%	0.1%	-5.1%	-4.2%	-4.3%	-2.7%

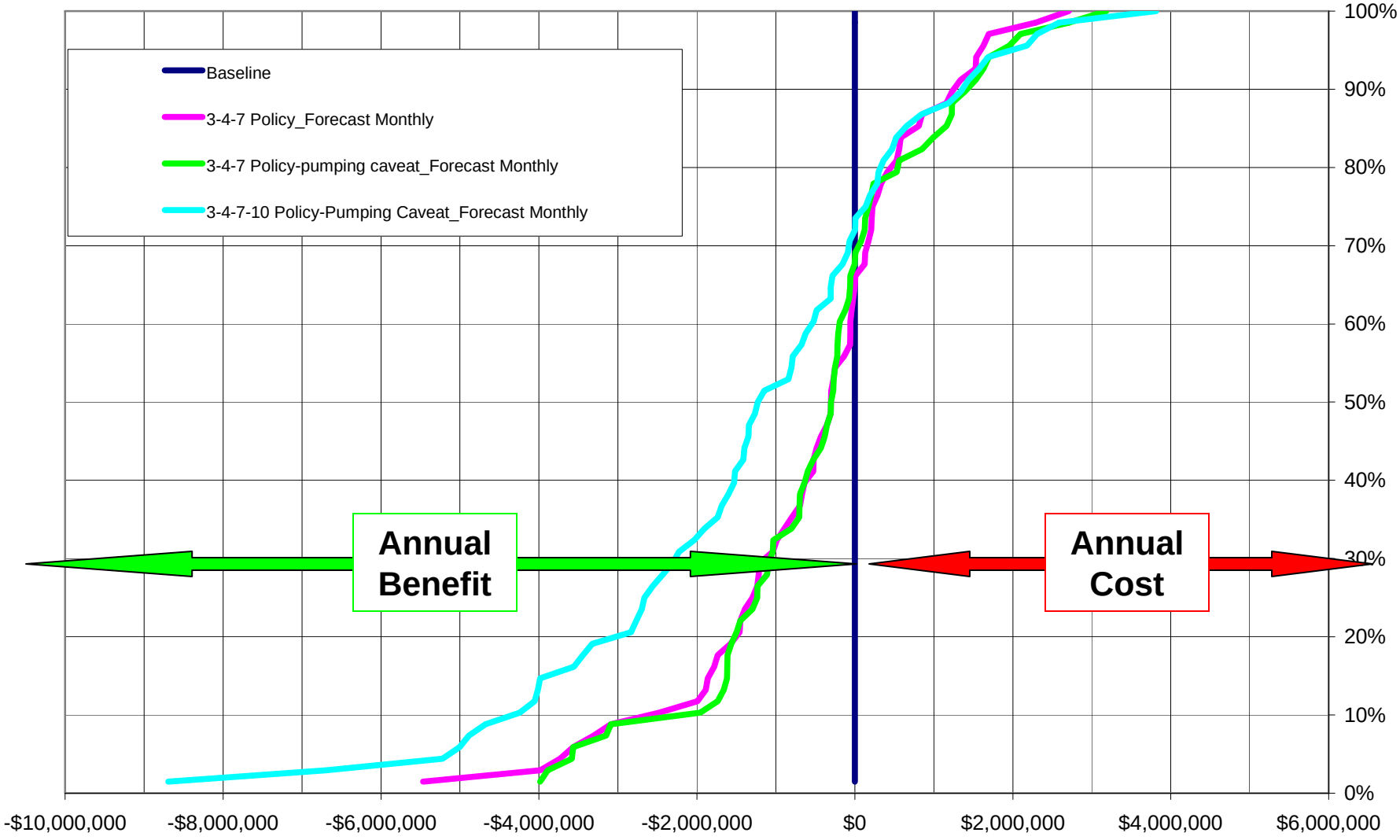
Annual Cost/Benefit Analysis --- Deviation from Baseline

"Perfect Knowledge"

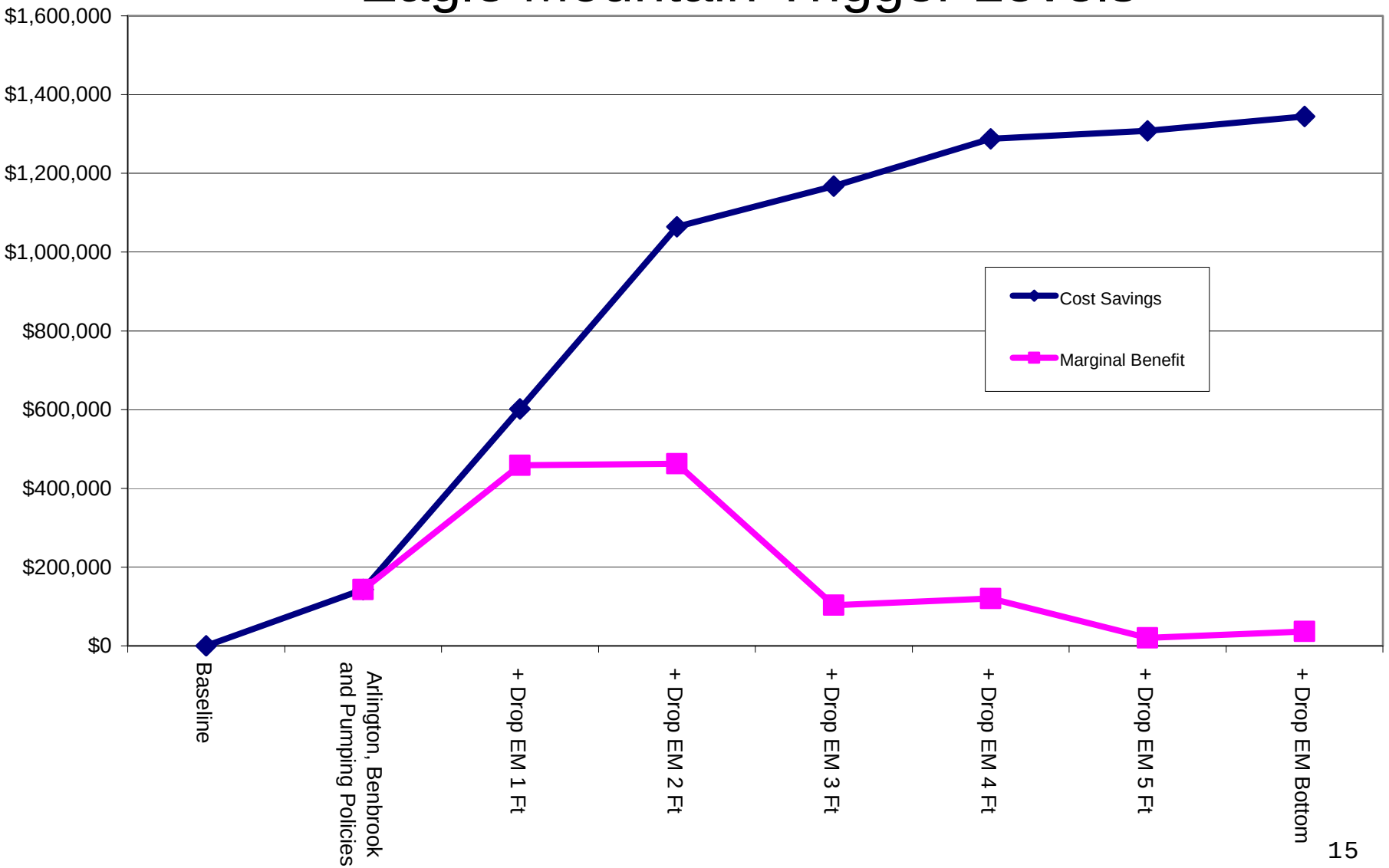


Annual Cost/Benefit Analysis --- Deviation from Baseline

"Best Forecast"



Annual Average Cost Savings
Eagle Mountain Trigger Levels



Next Steps

- Refinement of Eagle Mountain Rule (Option #10)
- Implementation in the Daily Model
  - Test Primary Alternative with Daily Inflows and Demands
- Operating in a Forecast Mode
  - 36 Month Model Run
  - 100 Traces
    - Based on Previous Month “State”
    - Monthly Transition Probabilities
    - Downscaled Climate Indicators
  - Real Time Evaluation of the Risks