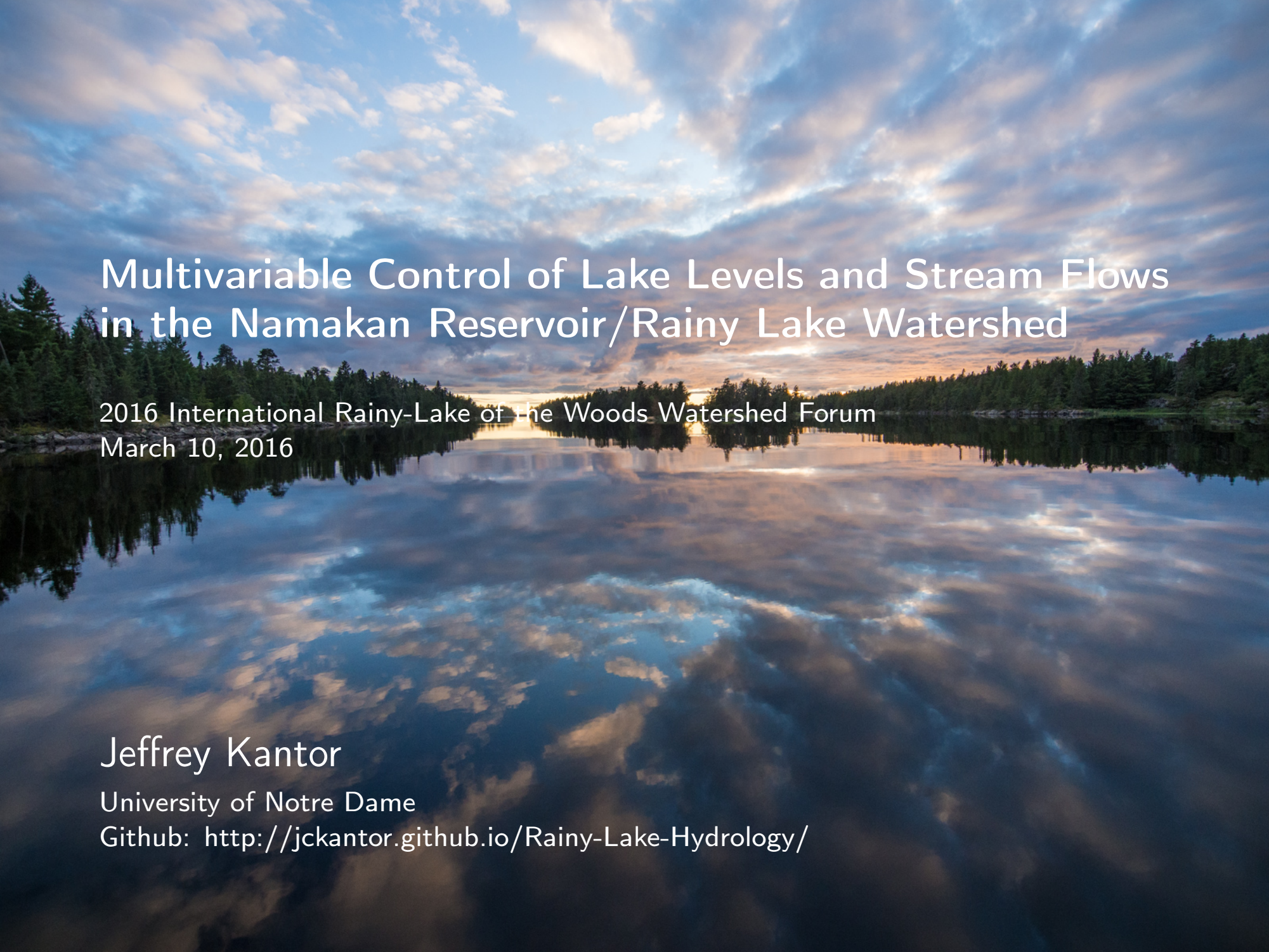


Multivariable Control of Lake Levels and Stream Flows in the Namakan Reservoir/Rainy Lake Watershed

2016 International Rainy-Lake of the Woods Watershed Forum
March 10, 2016

Jeffrey Kantor
University of Notre Dame
Github: http://jckantor.github.io/Rainy-Lake-Hydrology/

OVERVIEW

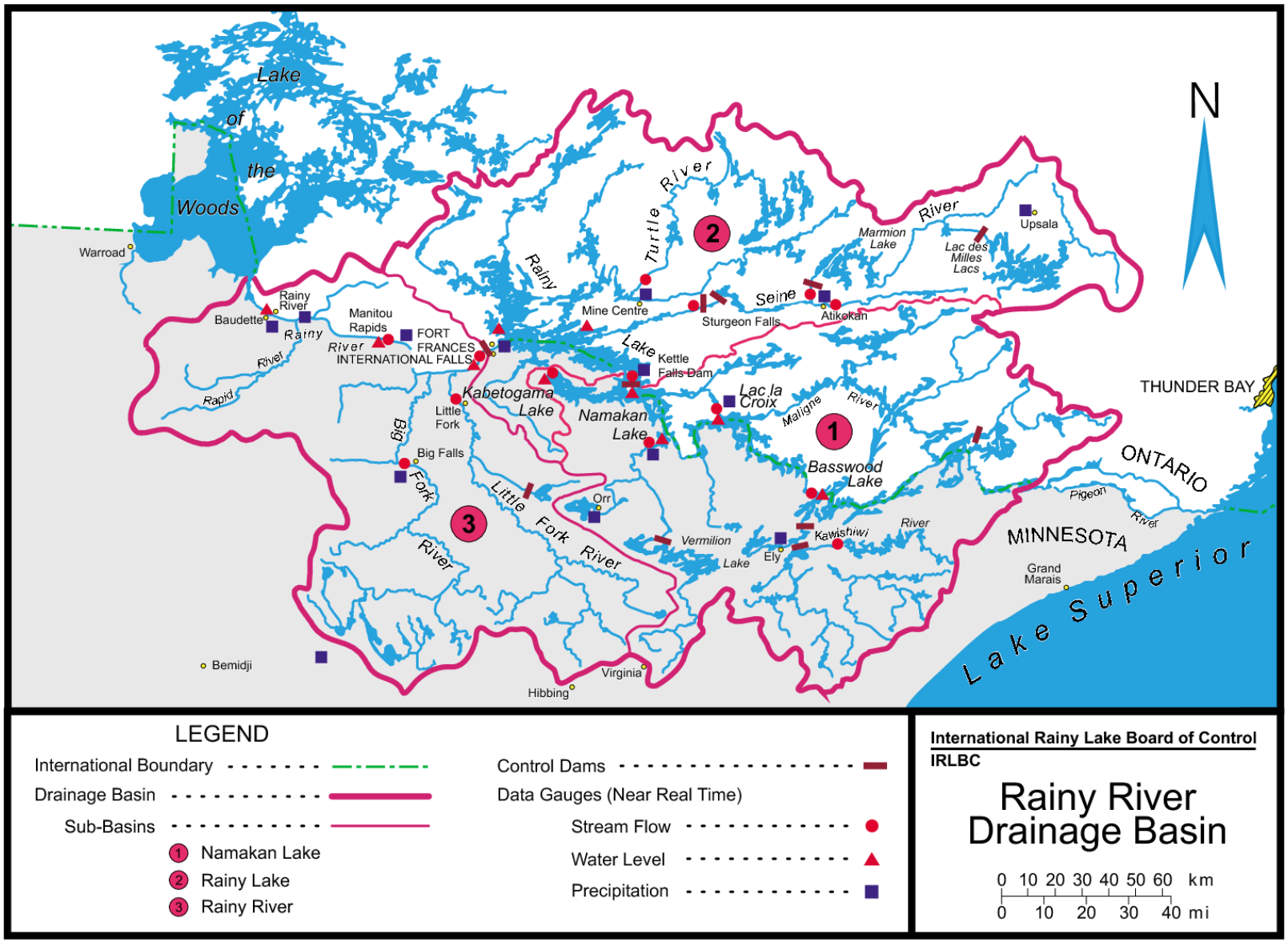
1. Why is Control so Difficult?

2. Implementing Rule Curves with Model Predictive Control

3. Assessment and Implications for Rule Curve Review


WHY IS CONTROL SO DIFFICULT?

RAINY RIVER DRAINAGE BASIN



Source: International Rainy Lake Board of Control (now IRLWWB)

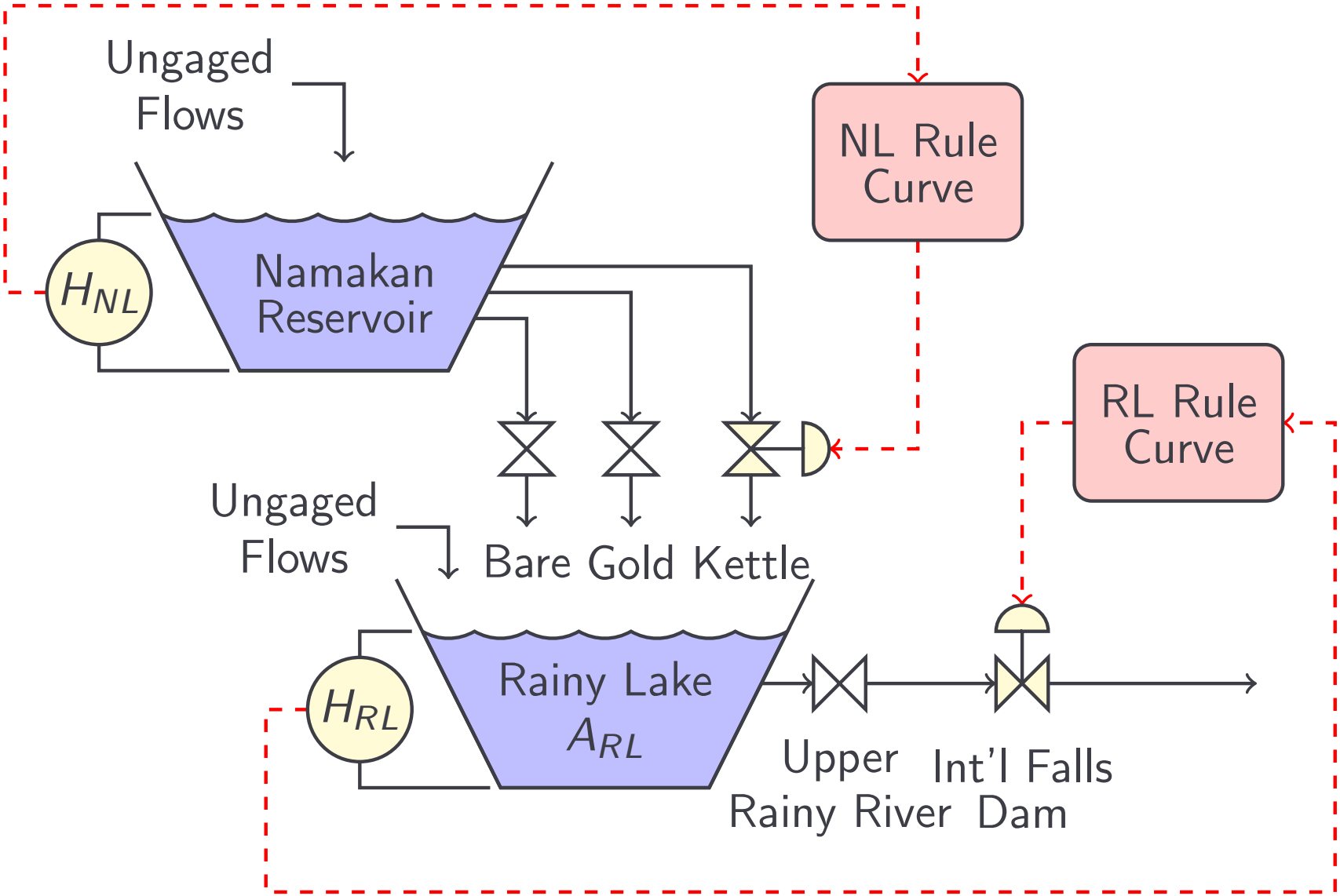
1993 FINAL REPORT AND RECOMMENDATIONS

"To offset the potential for the proposed rule curve modifications to increase the frequency of spring flood events, the IJC should enforce the provision of its 1970 Supplemental Order requiring the dam operators to anticipate inflows and maximize the discharge capabilities of the dams to prevent emergency water levels.

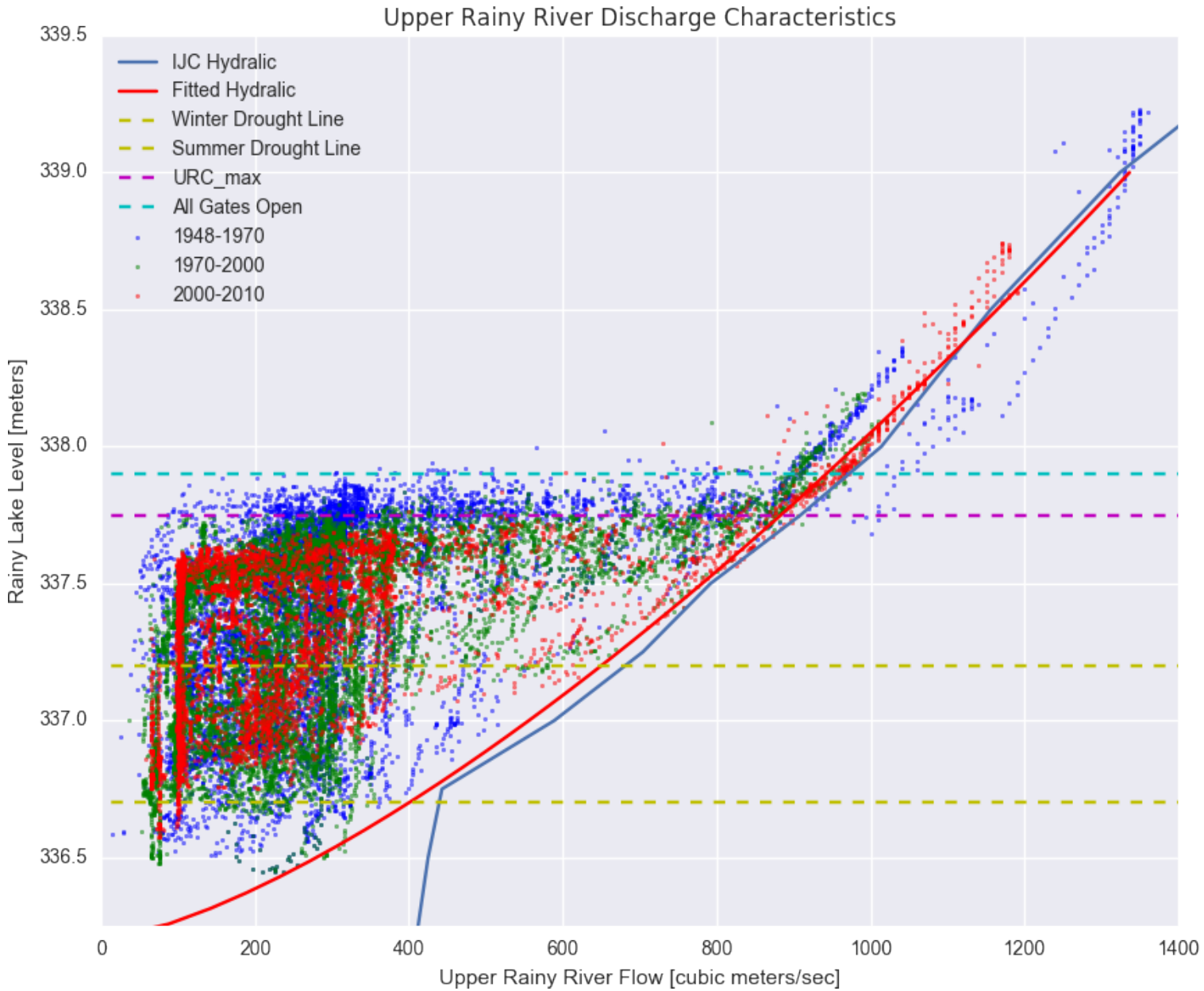
"The Steering Committee believes that diligent use of the existing network of upstream lake level gauges and currently available hydrologic models can make this IJC mandate a reality and improve the accuracy and reliability of reservoir level control."

Source: Rainy Lake & Namakan Reservoir Water Level International Steering Committee, Final Report and Recommendations, November, 1993.

CURRENT PRACTICE

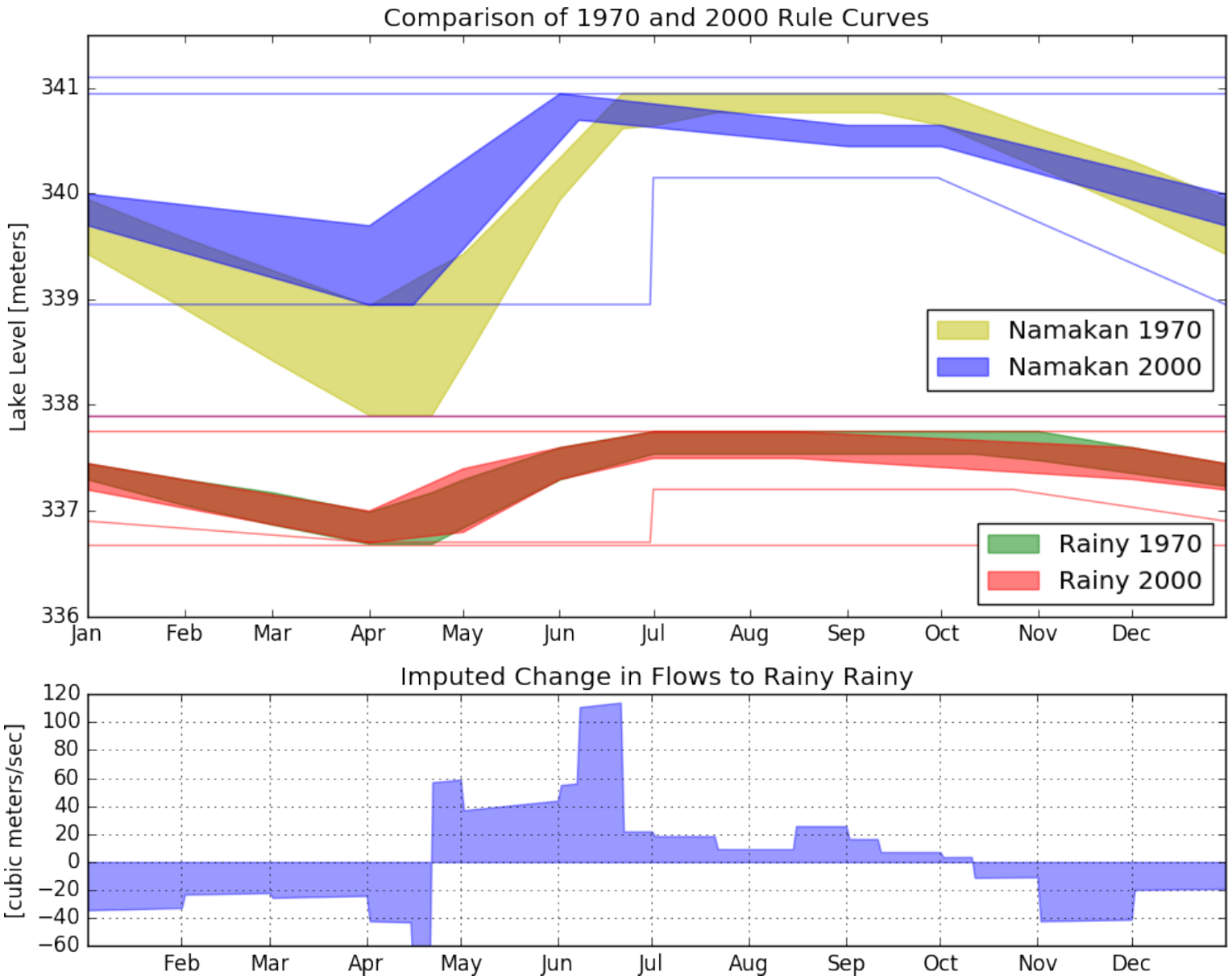


UPPER RAINY RIVER DISCHARGE CHARACTERISTICS



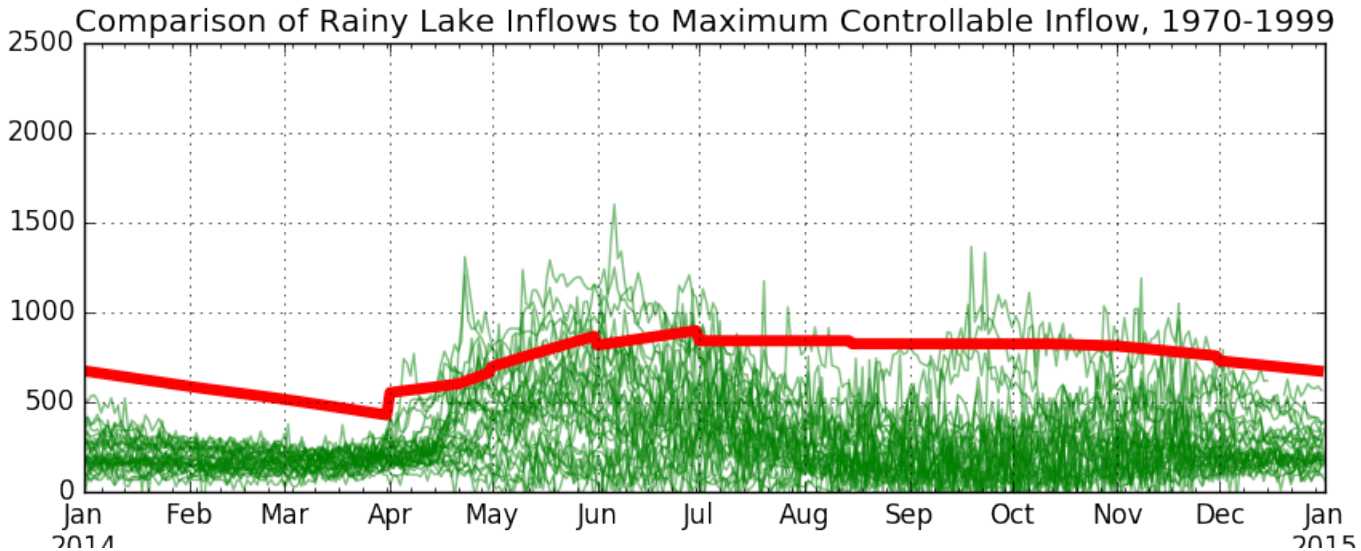
Source: Github Repository for this paper.

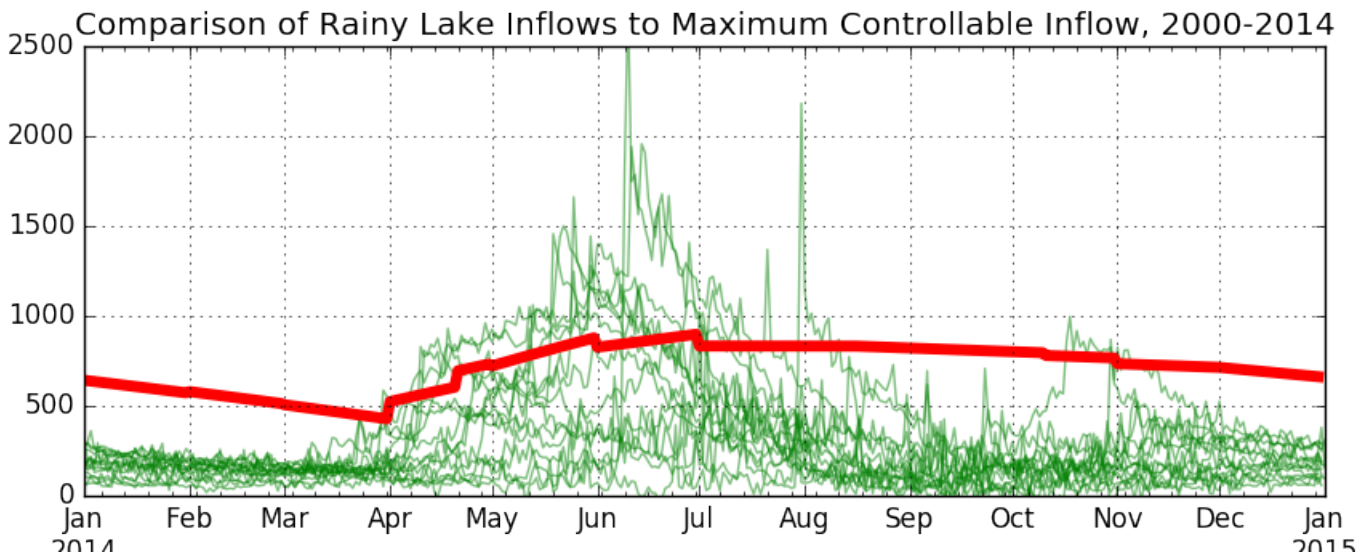
RULE CURVE CHANGES IN 2000



Source: Github Repository for this paper.

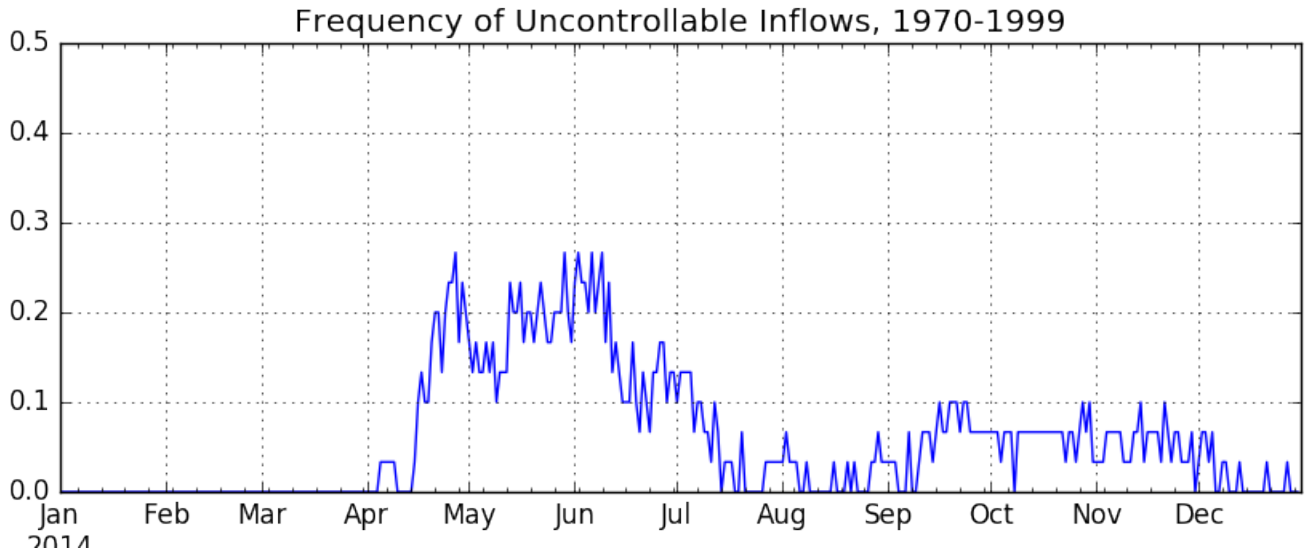
MAXIMUM CONTROLLABLE INFLOWS

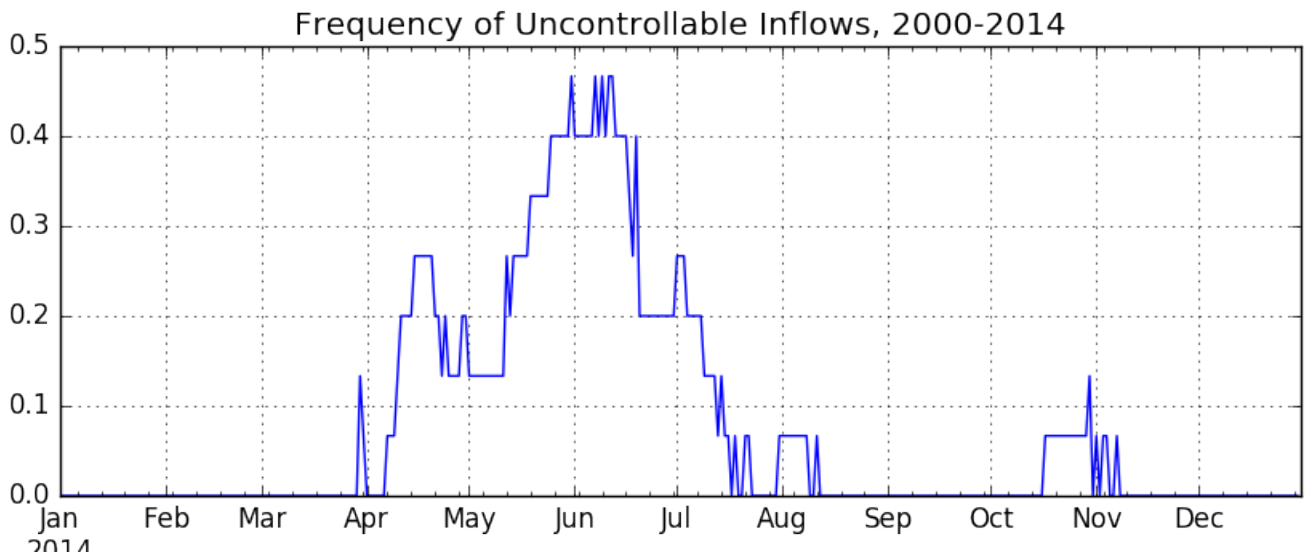




Source: Github Repository for this paper.

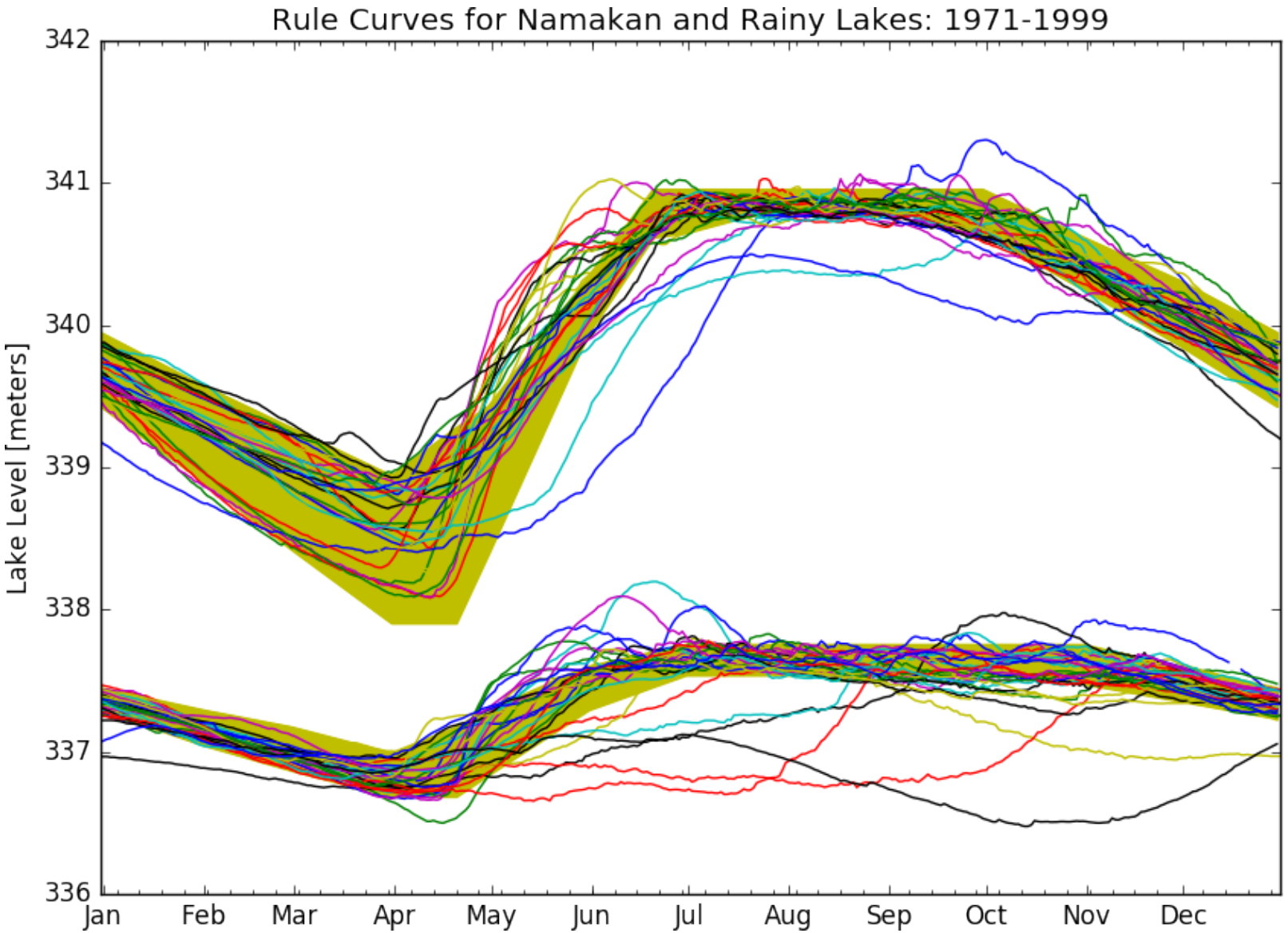
UNCONTROLLABLE INFLOW FREQUENCY





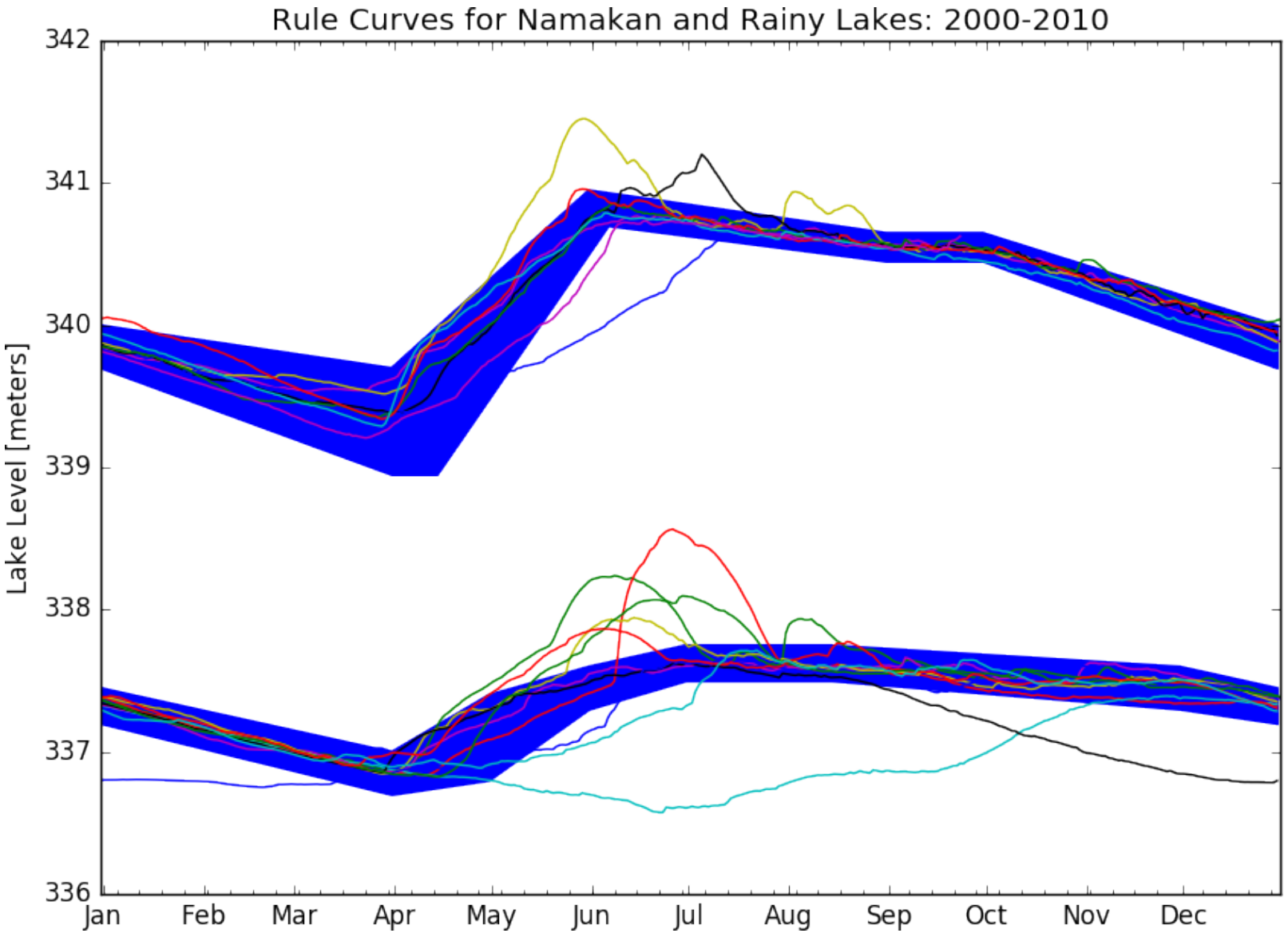
Source: Github Repository for this paper.

RULE CURVE PERFORMANCE 1970–1999



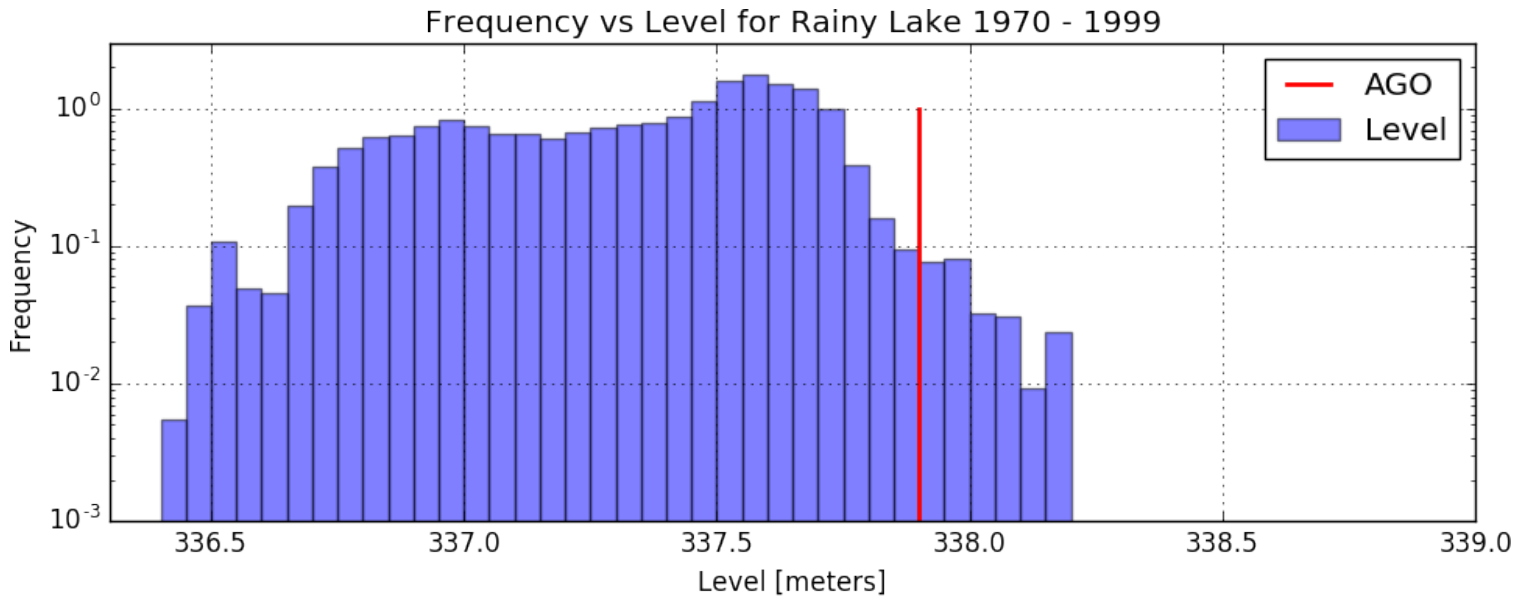
Source: Github Repository for this paper.

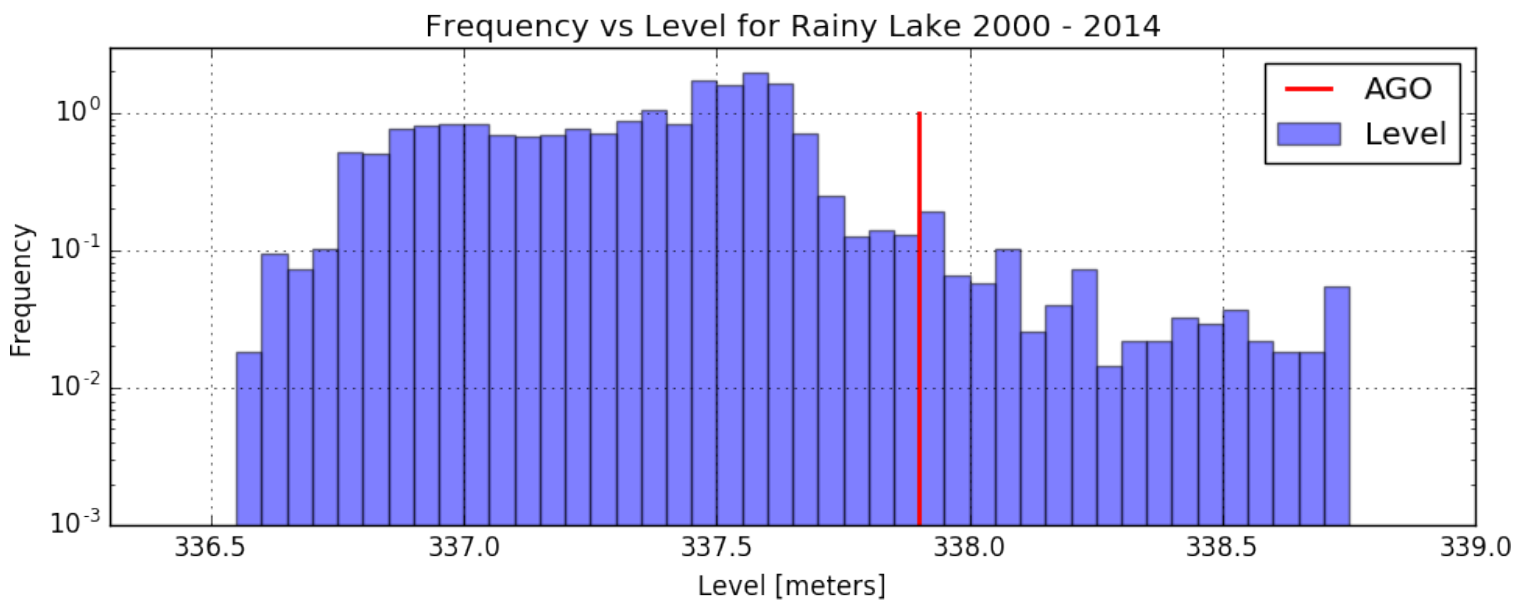
RULE CURVE PERFORMANCE 2000–2014



Source: Github Repository for this paper.

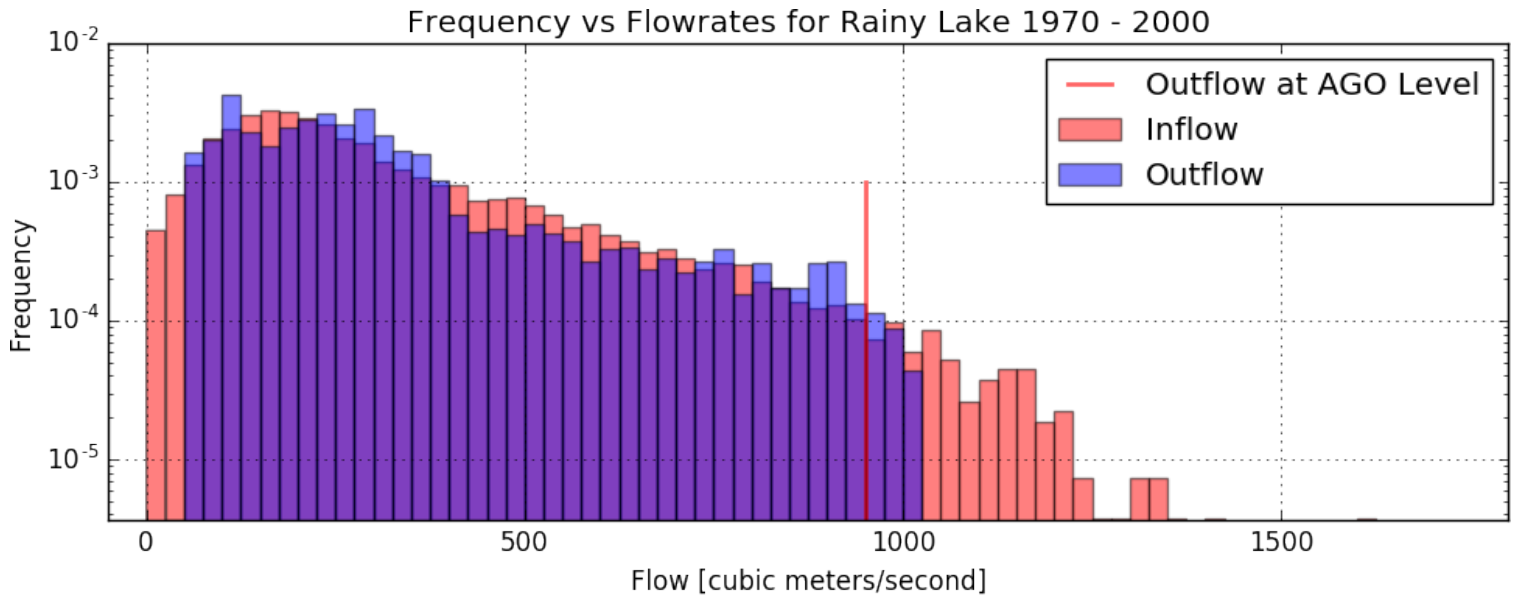
RULE CURVE PERFORMANCE - RAINY LAKE LEVELS

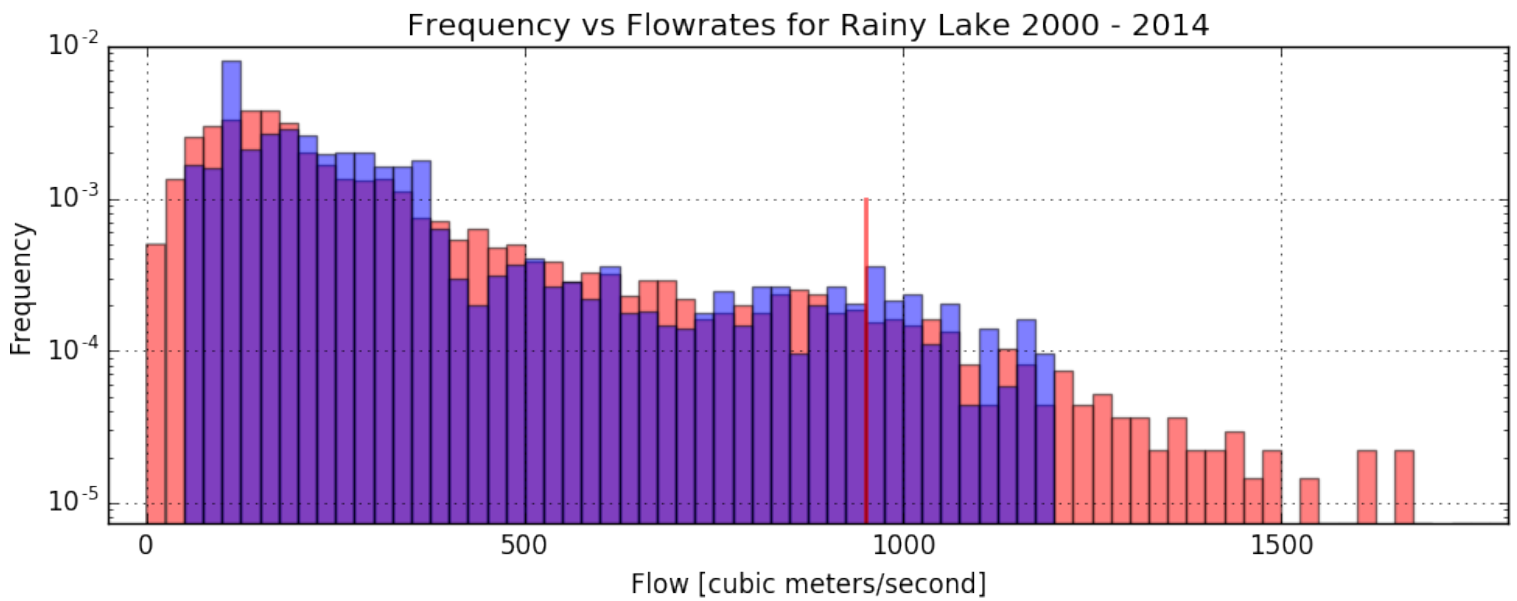




Source: Github Repository for this paper.

RULE CURVE PERFORMANCE - INFLOWS AND OUTFLOWS

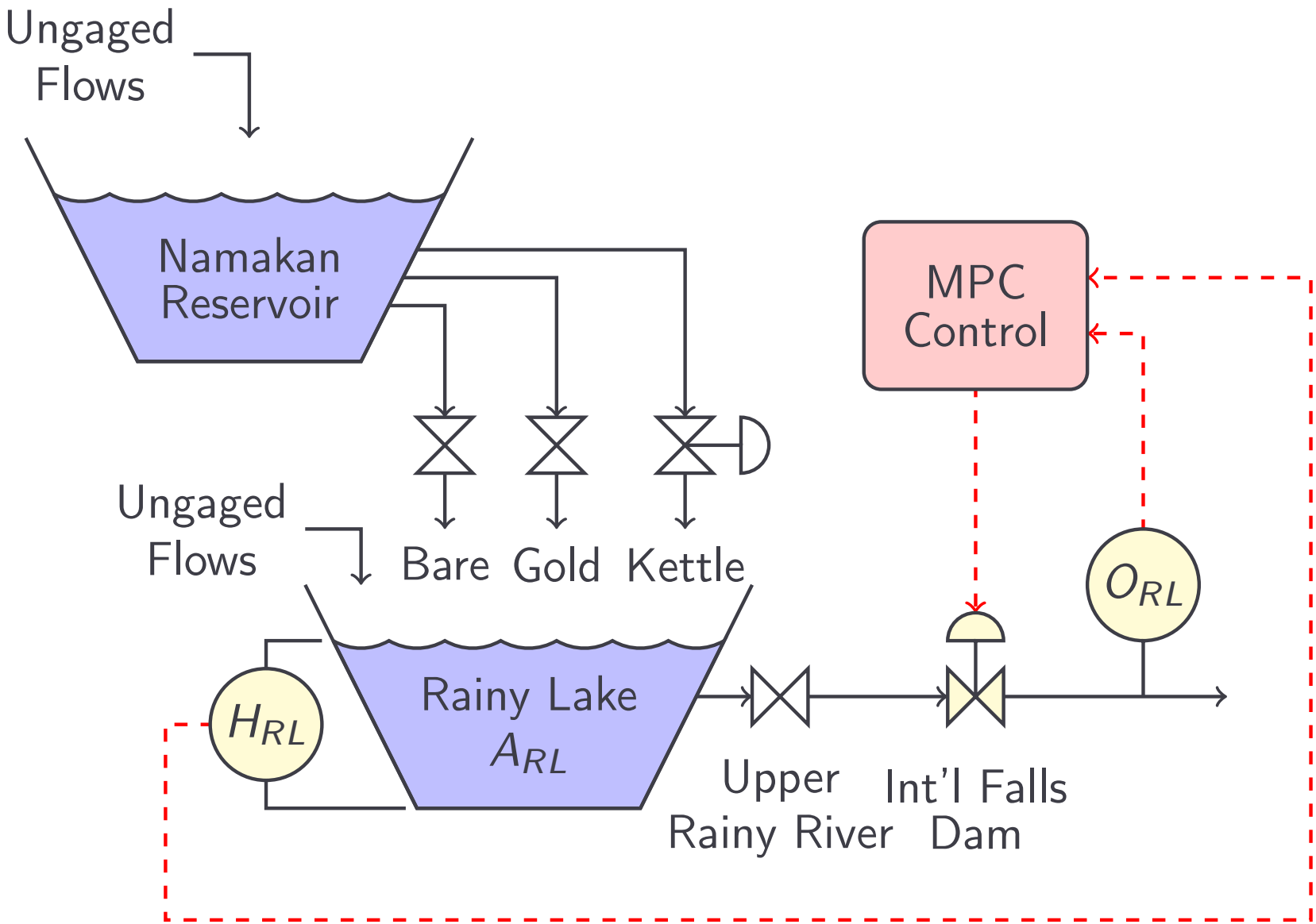




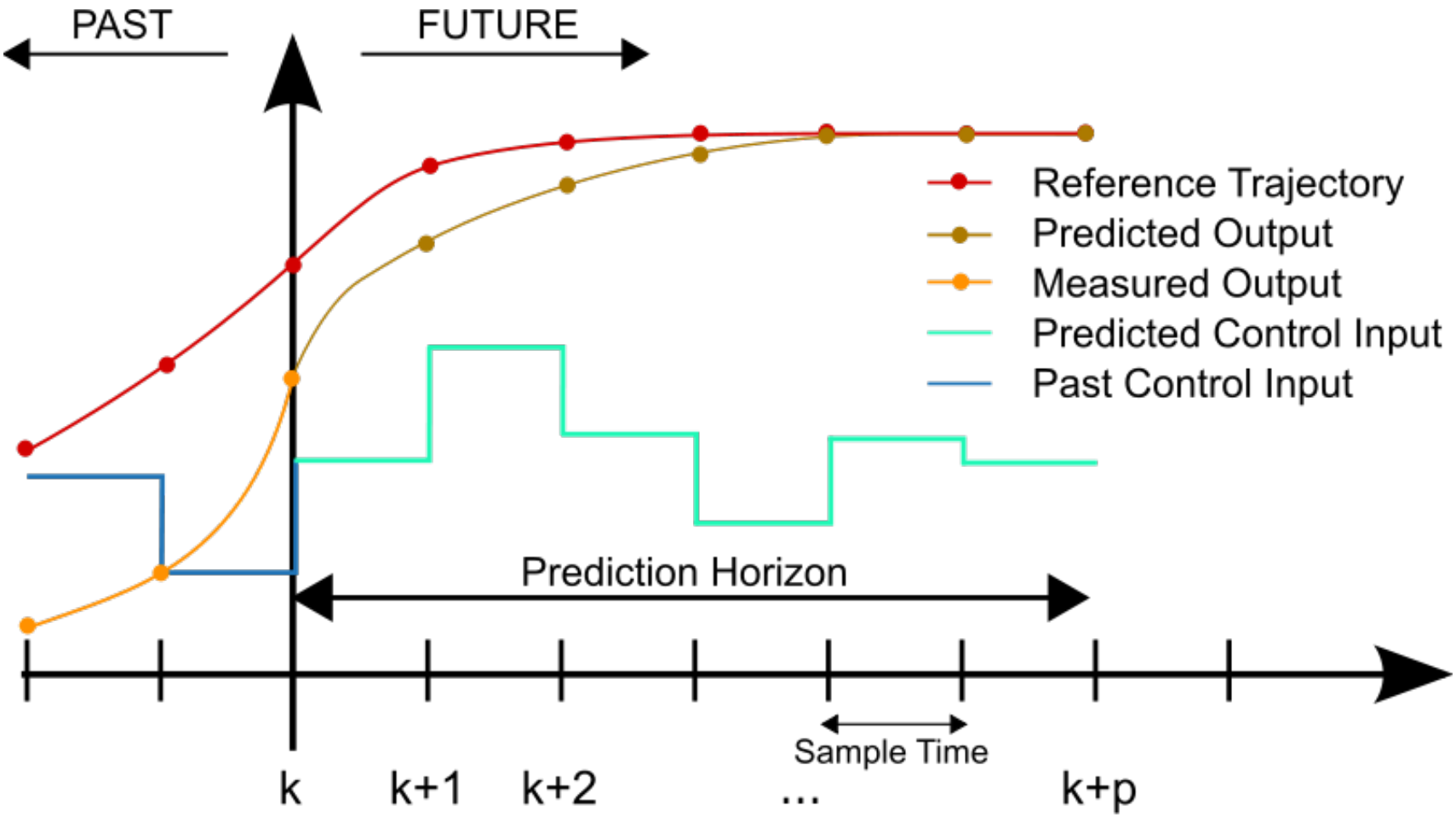
Source: Github Repository for this paper.

IMPLEMENTING RULE CURVES WITH MODEL PREDICTIVE CONTROL

MODEL PREDICTIVE CONTROL FOR RAINY LAKE

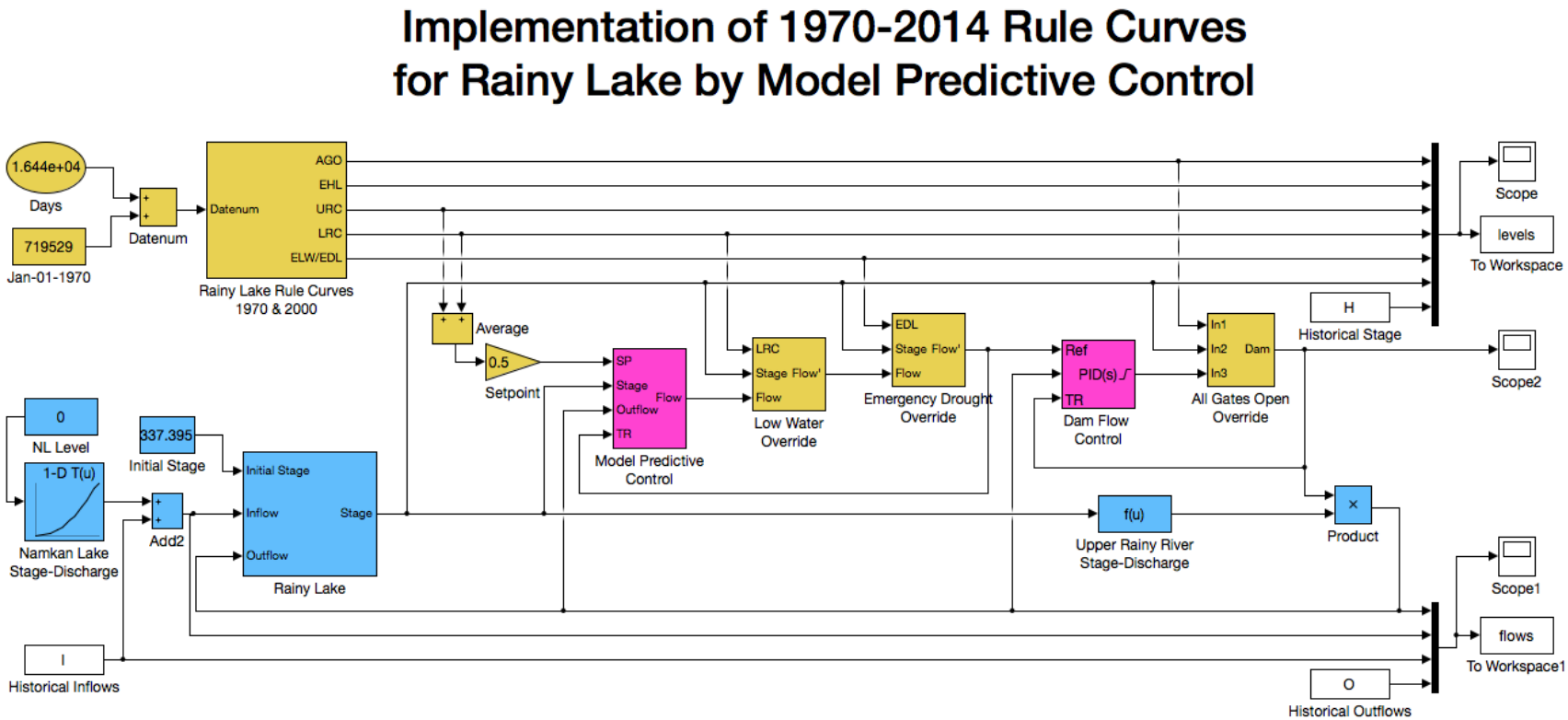


MODEL PREDICTIVE CONTROL



Source: Martin Behrendt

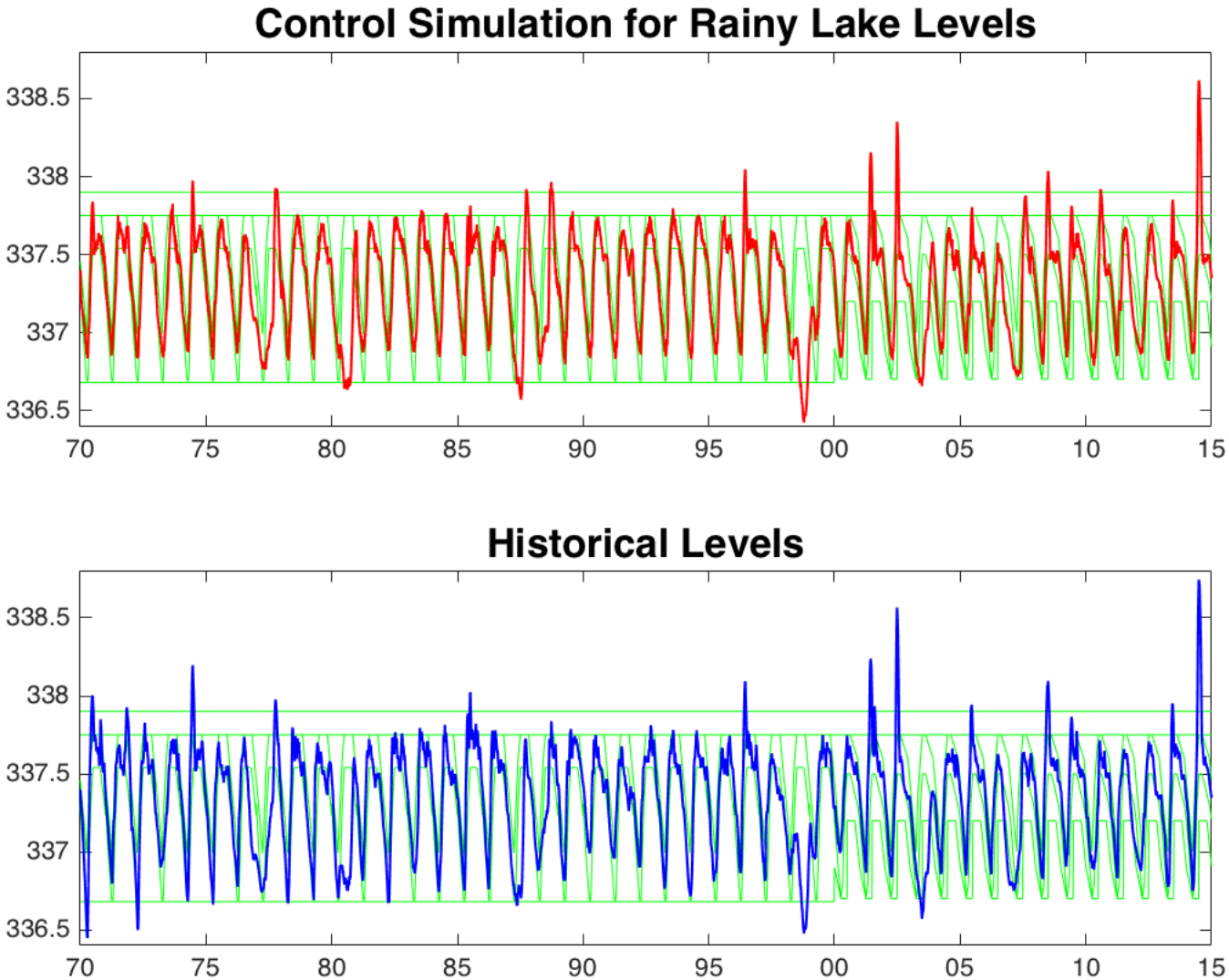
MATLAB/SIMULINK IMPLEMENTATION



Source: Github Repository for this paper.

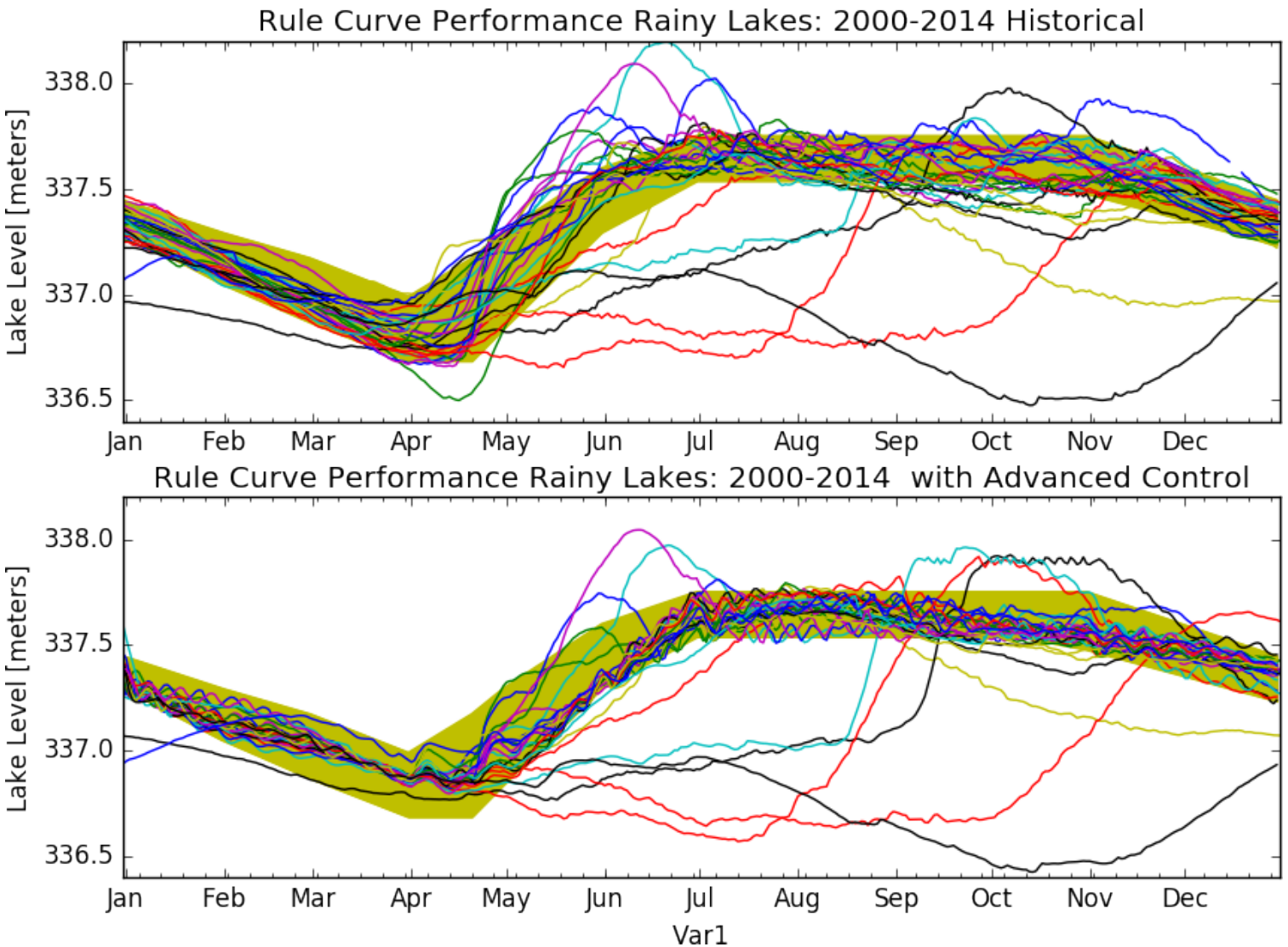
ASSESSMENT AND IMPLICATIONS FOR RULE CURVE REVIEW

SIMULATION RESULTS



Source: Github Repository for this paper.

SIMULATION RESULTS



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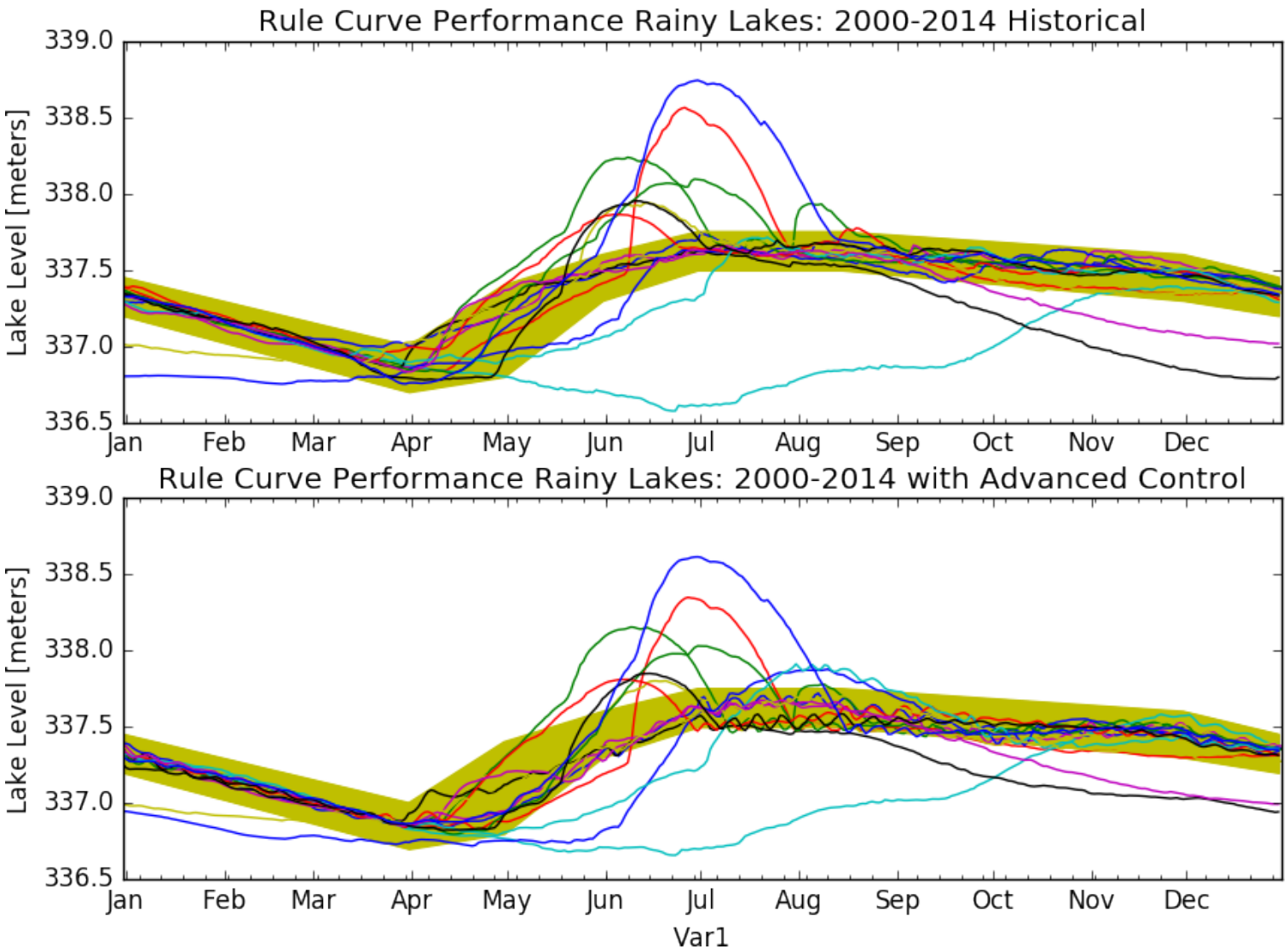
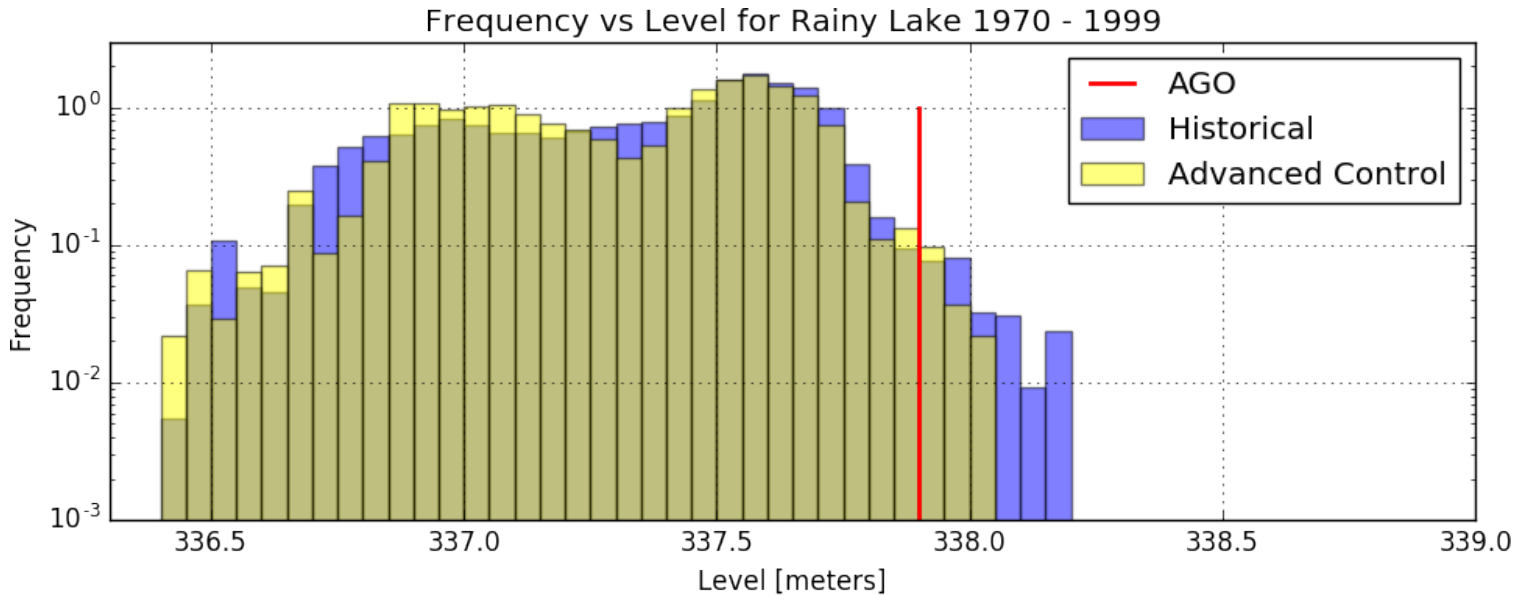
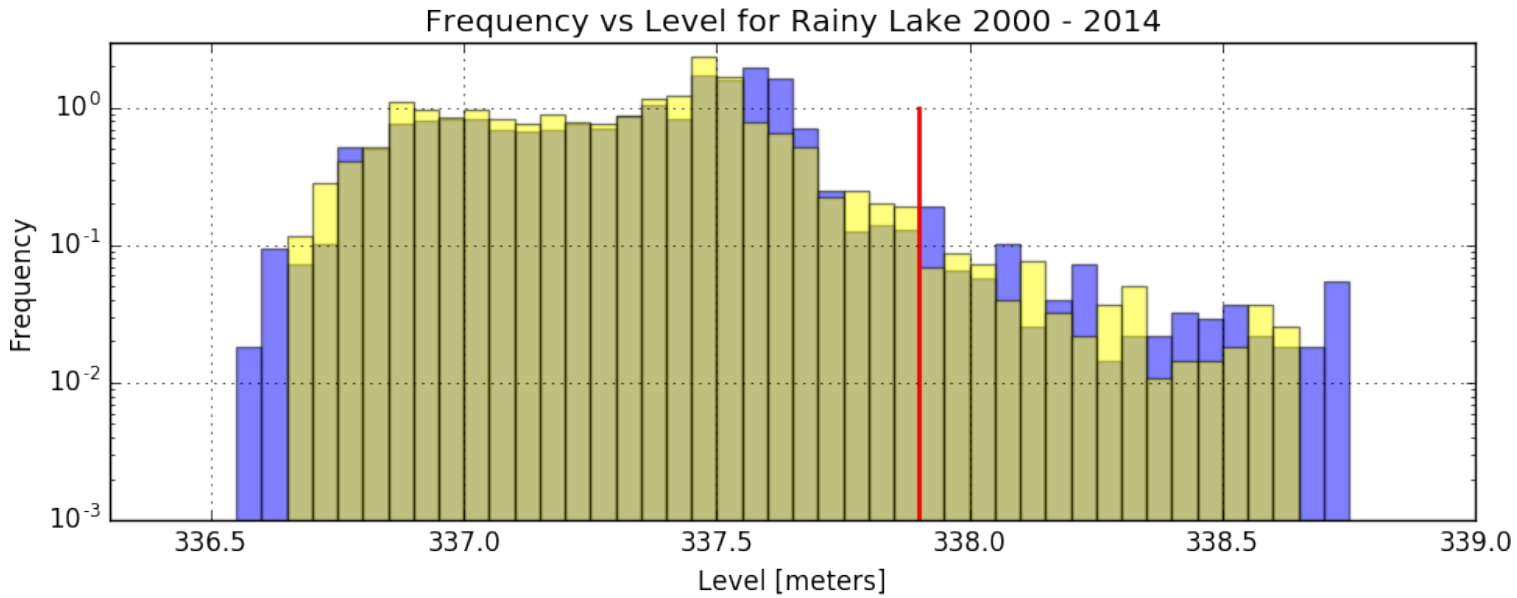
SIMULATION RESULTS



Source: Github Repository for this paper.

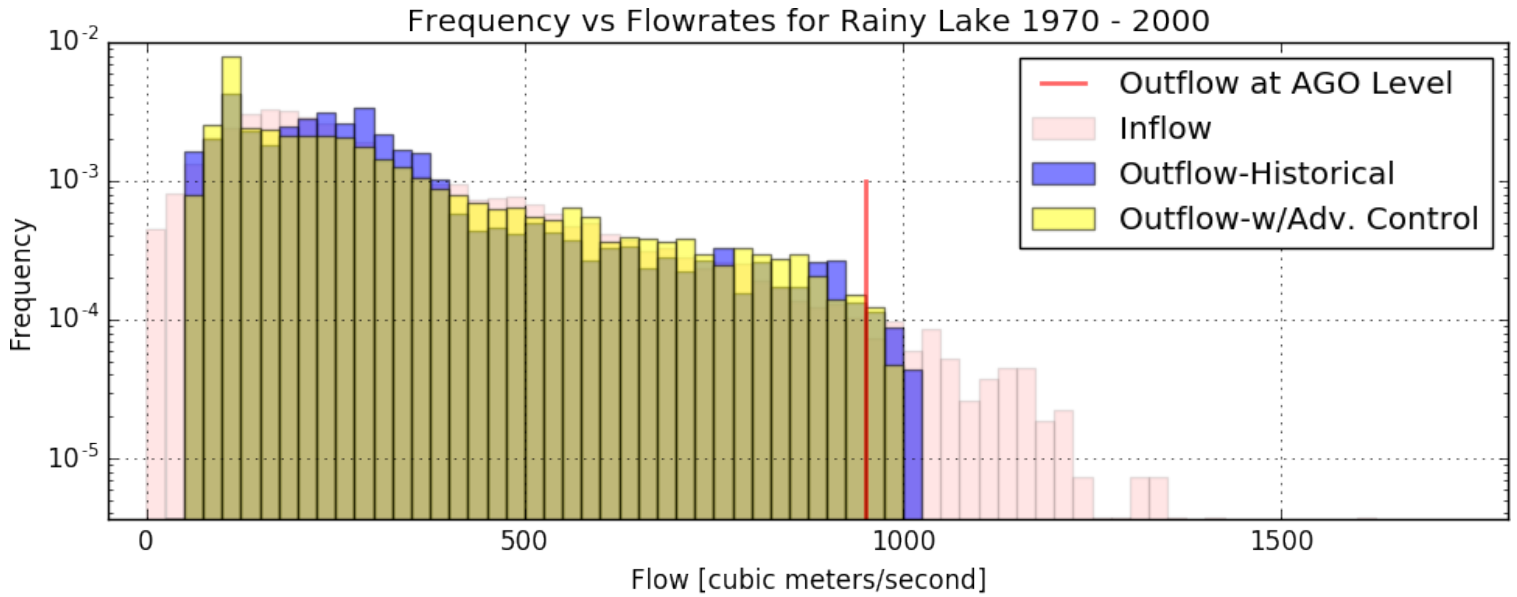
SIMULATION RESULTS - RAINY LAKE LEVELS

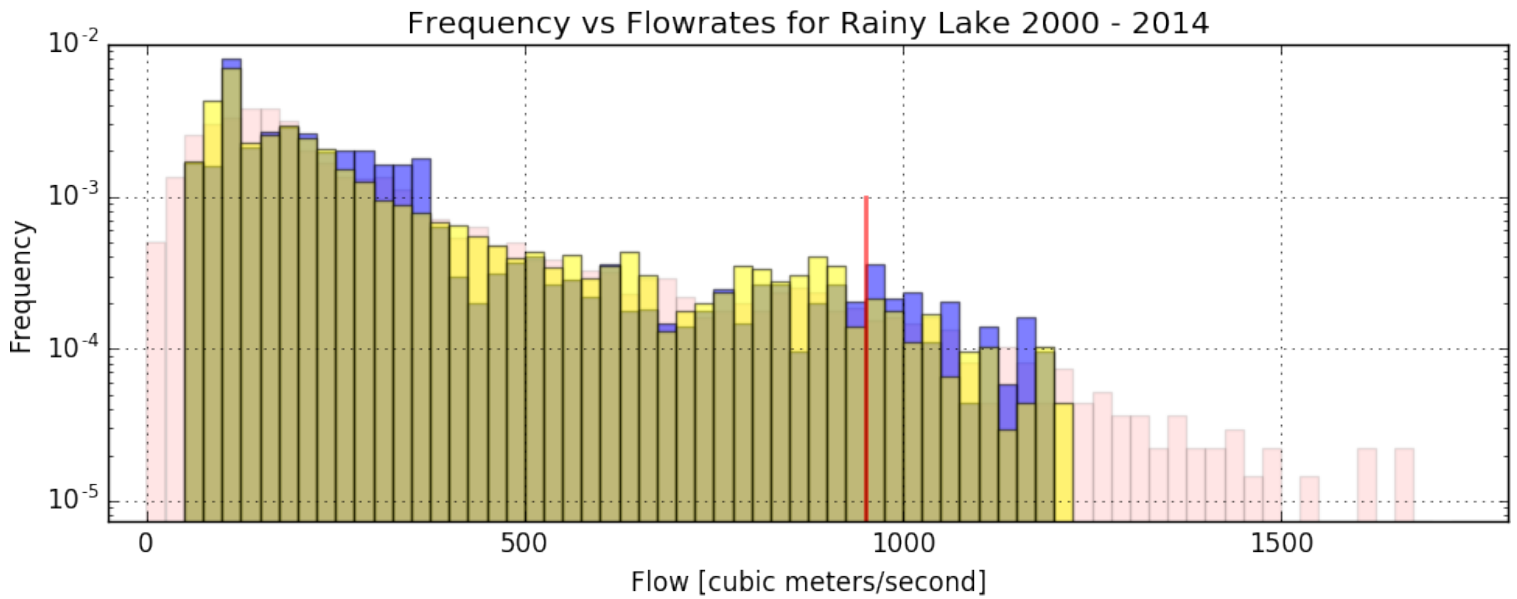




Source: Github Repository for this paper.

SIMULATION RESULTS - INFLOWS AND OUTFLOWS





Source: Github Repository for this paper.

SUMMER HIGH WATER EVENTS (MAY–SEPTEMBER), 1970-99

		Historical	w/MPC
Rule Curve Exceeded			
	Frequency	15.8%	6.5%
	Median	0.07 m	0.08 m
	95th Percentile	0.37 m	0.32 m
Emergency High Water			
	Frequency	8.3%	5.0%
	Median	0.06 m	0.07 m
	95th Percentile	0.34 m	0.25 m
All Gates Open			
	Frequency	2.4%	1.3%
	Median	0.10 m	0.06 m
	95th Percentile	0.29 m	0.14 m

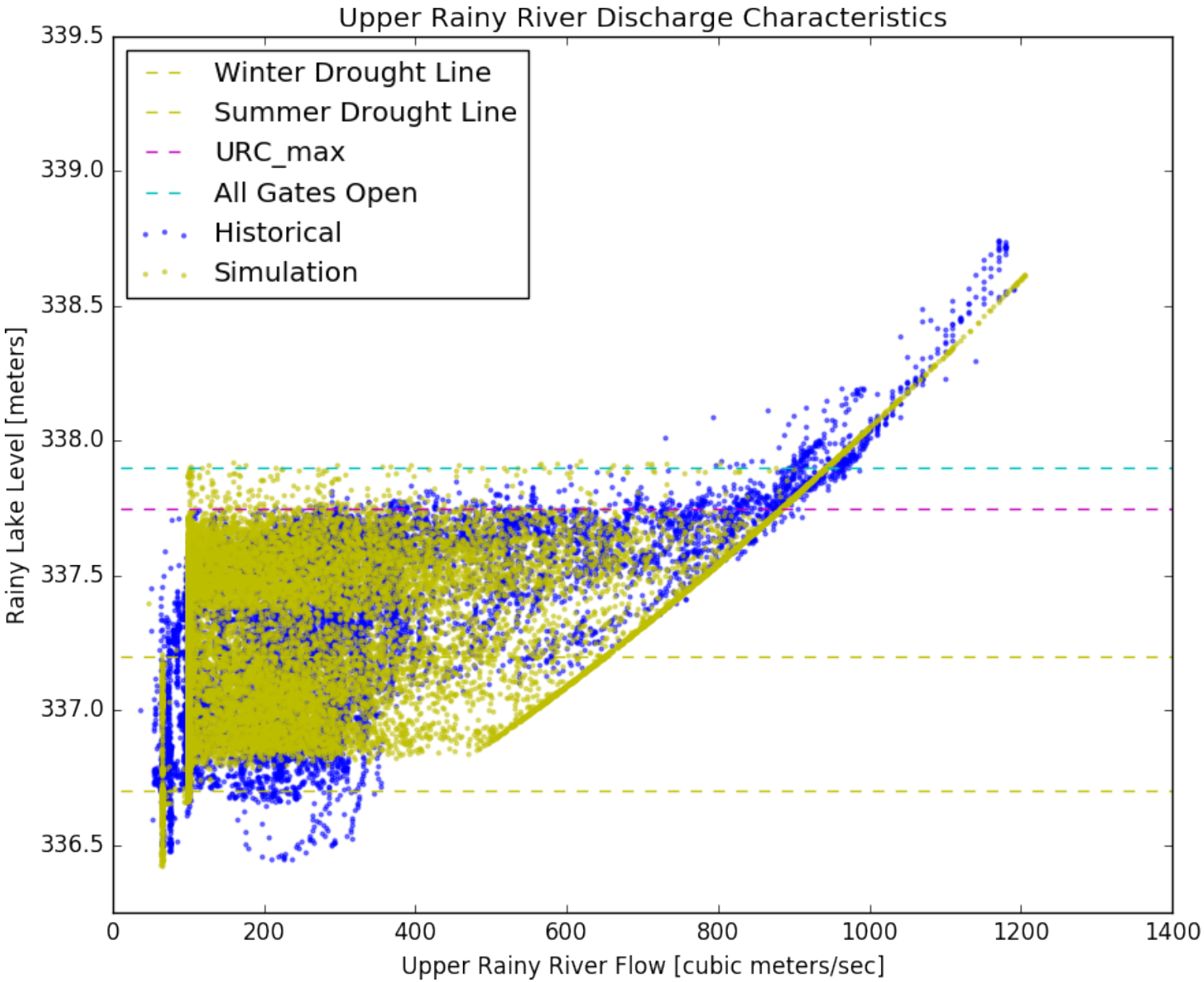
Source: Github Repository for this paper.

SUMMER HIGH WATER EVENTS (MAY–SEPTEMBER), 2000-14

		Historical	w/MPC
Rule Curve Exceeded			
	Frequency	18.0%	18.1%
	Median	0.25 m	0.15 m
	95th Percentile	0.91 m	0.78 m
Emergency High Water			
	Frequency	14.6%	15.0%
	Median	0.21 m	0.14 m
	95th Percentile	0.94 m	0.80 m
All Gates Open			
	Frequency	9.9%	7.3%
	Median	0.20 m	0.23 m
	95th Percentile	0.82 m	0.69 m

Source: Github Repository for this paper.

SIMULATION RESULTS - INFLOWS AND OUTFLOWS



Source: Github Repository for this paper.

CONCLUSIONS

The rule curve review needs to include control implementation within the scope of its work.

1. There is little evidence for "diligent use of existing network of upstream lake level gauges and currently available hydrological models can make this IJC mandate a reality and improve the accuracy and reliability of reservoir level control."
2. The 2000 rule curves are not a feasible mandate for level management on Rainy Lake. Namakan and Rainy Lake rule curves require 'harmonization'.
3. Consideration should be given to an integrated control strategy for flow control points on the Rainy-Lake of the Woods watershed coupled with significant rule curve revisions.

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  - Kirk Skallman
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