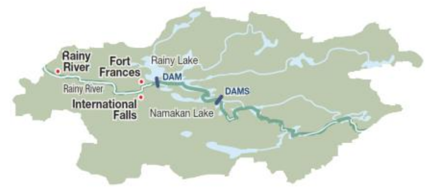
International Rainy and Namakan Lakes Adaptive Rule Curve Committee Newsletter



Issue #2 - October 20, 2016

This is the second newsletter of the Adaptive Rule Curve Committee under the Rainy-Namakan Lakes Rule Curves Study Board. The plan was to put one newsletter out twice a month or so; we hope to have one more before the practice workshop on November 2nd.

This newsletter will focus on flood damage reduction strategies. The next newsletter will consider some annual (as opposed to multi-year) environmental indicators.

An Adaptive Rule Curve

The SVM webinar on September 26th included a discussion of Matt DeWolfe's research. He found that wet and dry years were strongly, but not perfectly correlated with cool and warm ENSO's (El Niño–Southern Oscillation ocean surface temperatures) measured over the December-January-February preceding the potential flood and tourism season. As Figure 1 shows, a cool D-J-F ENSO has never preceded a year with low maximum unregulated levels; levels in cool ENSO years have been average or high water level years. A few wet years have been preceded by a warm D-J-F ENSO, but in only two years, 1954 and 1966 (Figure 2), did a warm ENSO precede significant flooding (over a million dollars' damage in both basins). ENSO is the most promising forecasting indicator we know of, far more predictive than antecedent rainfall or snowpack.

The adaptive rule curve alternatives are labeled "RC-7" in the SVM. There are seven options:

1. Perfect one-year forecast
2. Perfect two-year forecast
3. ENSO flood lower rule curve
4. ENSO flood drought line rule curve
5. ENSO flood lower rule curve + drought upper curve
6. ENSO flood drought line rule curve+ drought upper curve
7. A perfect forecast of flood damages (gets all 10 big floods right)

The first two and the last are impossible to implement because there is no such thing as a perfect forecast, but they allow us to estimate when and how much we could reduce flooding if we could foretell the future. This becomes a boundary condition for gaging the effectiveness of remaining four imperfect forecast options.

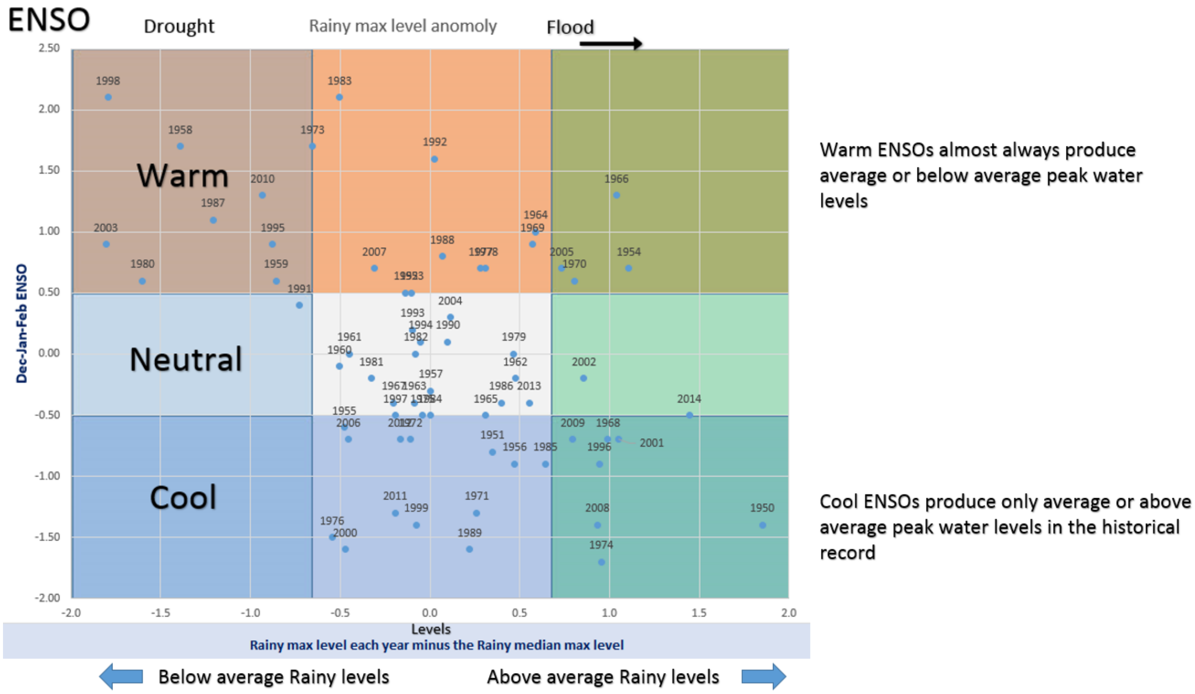


Figure 1 Cool D-J-F ENSOs have meant normal or above normal levels for Rainy

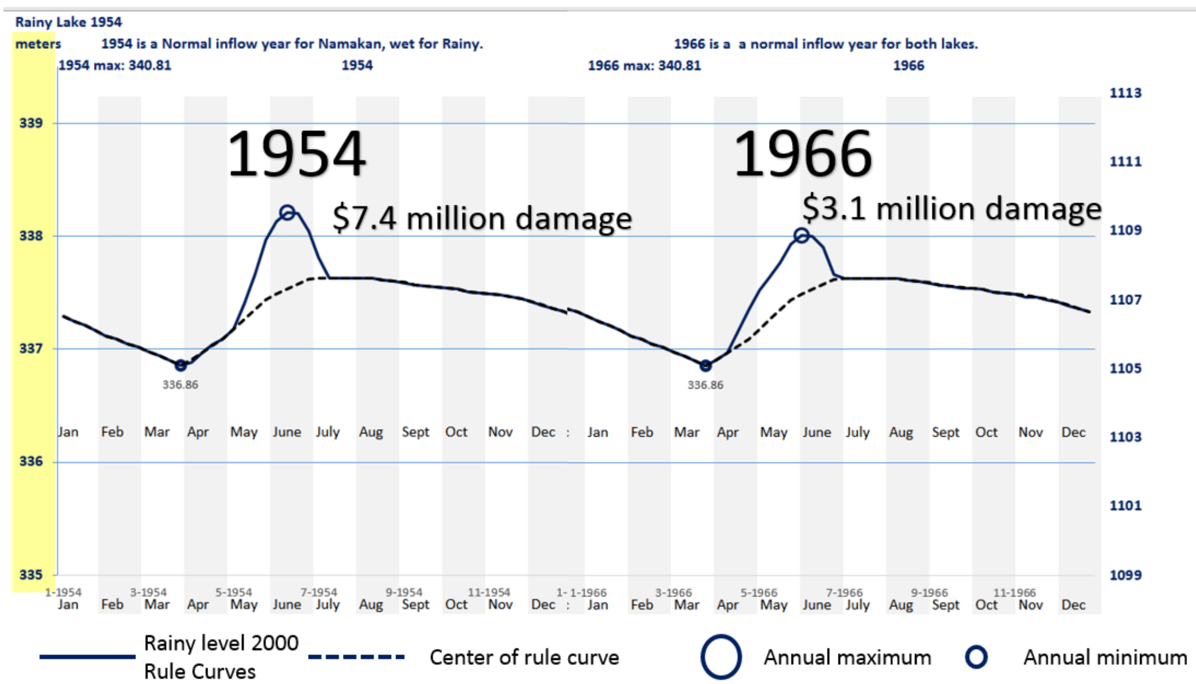


Figure 2 Flooding in two years following warn ENSOs

Perfect forecast plans RC7-1, RC7-2 and RC7-7

Table 1 Average annual damages and reduction in average annual flooding damages with RC7-1, one-year perfect forecast

Average Annual Damages for RC7-1			
	Damages	$ change	% change
Namakan	$282,463	$23,225	-7.6%
Rainy	$830,324	$338,801	-29.0%
U.S.	$681,564	$187,686	-21.6%
Canada	$431,222	$174,340	-28.8%
	# structures	# change	Percent change
Namakan	125	-2	-2%
Rainy	224	-47	-17%
U.S.	222	-23	-9%
Canada	127	-26	-17%

Table 2 Average annual damages and reduction in average annual flooding damages with RC7-2, two-year perfect forecast

Average Annual Damages for RC7-2			
	Damages	$ change	% change
Namakan	$282,463	$23,225	-7.6%
Rainy	$823,431	$345,693	-29.6%
U.S.	$677,474	$191,776	-22.1%
Canada	$428,420	$177,142	-29.3%
	# structures	# change	Percent change
Namakan	125	-2	-2%
Rainy	220	-51	-19%
U.S.	220	-25	-10%
Canada	125	-28	-18%

The "perfect forecast" options use a specific forecast of peak annual inflows. The perfect part is based on the fact that at the beginning of each year the SVM looks at inflow data for the next 12 or 24 months and if the peak inflows are high, the SVM makes the largest possible release each quarter month for the rest of the year.

Even these forecasts are imperfect in the sense that peak inflow is not always the best indicator of flooding damage. Nonetheless, average annual damages could be reduced by about a quarter with this perfect foreknowledge.

For the practice design workshop, **a third perfect forecast** alternative was designed. In this case, the forecast is of flood **damages** (now that the SVM can calculate those). In the ten years of the 1950-2014 simulation with a million or more dollars in flood damage, the SVM switches to maximum releases as it does with the other two perfect forecasts. This RC7-7 plan reduces levels in all the big flood years, unlike the other two, and reduces overall damages by much more, about 40 versus 25%.

Table 3 Average annual damages and reduction in average annual flooding damages with RC7-1, using perfect forecasts of flood damage.

Average Annual Damages for RC7-7

	Damages	$ change	% change
Namakan	$259,834	$45,854	-15.0%
Rainy	$638,138	$530,987	-45.4%
U.S.	$558,909	$310,342	-35.7%
Canada	$339,063	$266,499	-44.0%

	# structures	# change	Percent change
Namakan	123	-4	-3%
Rainy	153	-118	-43%
U.S.	187	-58	-24%
Canada	90	-64	-41%

Table 4 Flood damage reduction in ten biggest flood damage years using perfect forecast of damages

	RC1-1	RC7-7	Savings	% reduction
1950	$37,610,724	$30,441,925	$7,168,800	19%
1954	$7,384,708	$2,408,240	$4,976,468	67%
1966	$3,054,189	$1,717,681	$1,336,508	44%
1968	$4,708,433	$1,695,678	$3,012,754	64%
1974	$2,147,154	$227,153	$1,920,001	89%
1996	$2,820,444	$256,021	$2,564,422	91%
2001	$6,285,350	$3,644,836	$2,640,514	42%
2002	$10,799,343	$85,548	$10,713,795	99%
2008	$2,408,240	$836,169	$1,572,071	65%
2014	$16,311,532	$11,470,279	$4,841,253	30%

Under RC7-7, 1950 damages are reduced from $37.6 to $30.4 million; 2014 damages from $16.3 to $11.5 million. And because we have the list of flood years in advance, this plan never makes a mistake and lowers the lake in a normal or dry year.

What else does this impossible, perfect plan reveal? It shows that being perfectly sure that there will be a flood helps much more in some floods than others. In the ten biggest floods in the historical record, knowing there will be a flood generally makes much more difference in the precent reduction **when the floods are smaller.**

An exception to that generalization is the 2002 flood. This plan works really well in 2002, almost eliminating damages in what would otherwise be the third worst flood on record. At first glance, one might think it was because this plan lowers the lakes in 2001, an otherwise significant flood year, and keeps it low long after the flood threat is gone. At the end of 2001, Rainy Lake is five feet below the center of the rule curve (Figure 3). But actually, that doesn't make any difference. You can see that by the end of April the perfect plan has drawn Rainy down to about the same level in 2014 as it was in 2002.

The difference in the inflows in 2002 and 2014 is what makes the perfect forecast plan effective. The 2002 flood inflows were intense but short lived; the 1950 and 2014 floods had high inflows for a much longer duration (Figure 4). The 2002 rise starts in June, the 2014 rise in May, both peaking around the beginning of July.

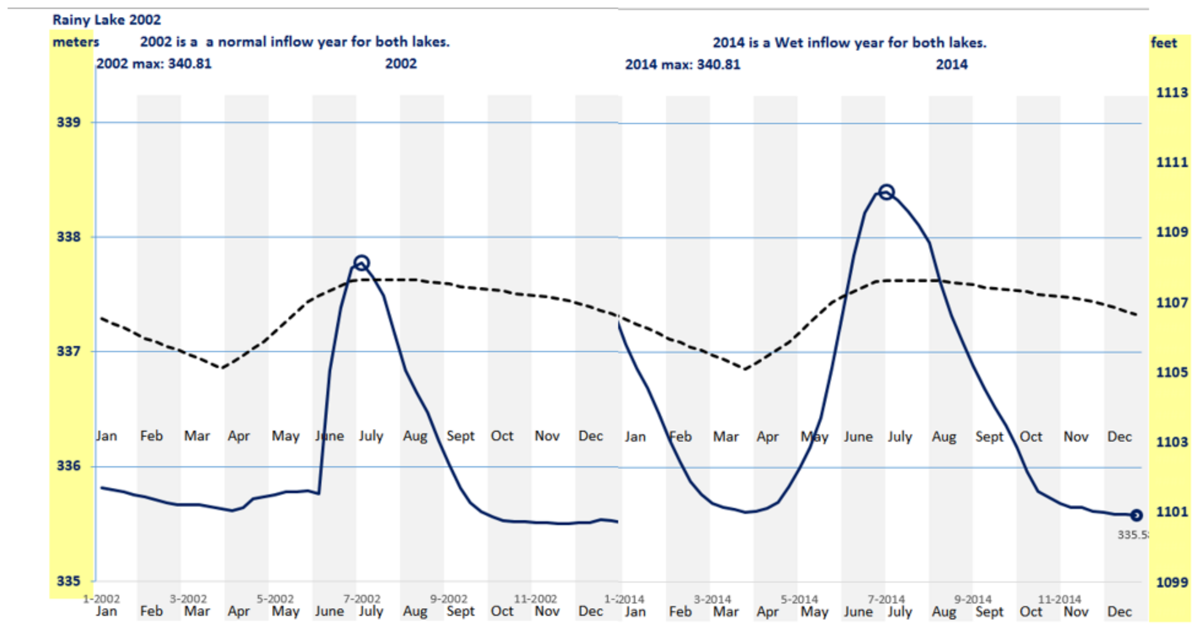


Figure 3 Comparison of 2002 and 2014 Rainy Lake levels using the perfect flood damage forecast plan

Figure 4 Comparison of Rainy Inflows, 3 biggest flood years

Realistic forecast plans

The perfect plan gives us a sense of the maximum reduction in flood damage we can hope for from forecasts. Realistic plans not only do not provide the same reduction (because not all floods are forecast); they can also create non-flood impacts because of the actions they mistakenly invoke.

RC-7 has four options for applying ENSO forecasts. The first two (RC7-3 and RC7-4) shift the rule curve target lower (lower in RC7-4 than in 3), during April, May and the first quarter of June in years with a cool ENSO. The other two options (RC7-5, RC7-6) do that but also raise the rule curve target when the D-J-F ENSO is warm. The last two will help keep the lakes higher in dry years, but would keep the lakes higher in 1954 and 1966 as well. In the historical record, we know that the 1954 and 1966 floods followed warm ENSOs, each estimated to cause millions of dollars of damage given today's development.

Table 5 Possible outcomes from an ENSO forecast

	Flood	No Flood
Cool ENSO	True positive	False positive
Warm or neutral ENSO	False negative	True negative

Any indicator such as our D-J-F ENSO, can produce four kinds of results (Table 5), characterized by whether the indicator indicates true or false and whether the state indicated happens (positive) or not (negative). The four adjectives describing the indicator in those cases are:

1. The cool ENSO forecast could be followed by a flood (true-positive indicator -it says true to the question is a flood coming, and the flood comes).
2. A warm or neutral ENSO could be followed by a flood (false-negative indicator),
3. A cool ENSO could be followed by low or normal inflows (false-positive – a false alarm) or
4. A warm or neutral ENSO could be followed by low or normal inflows (true-negative).

1. Cases when the ENSO indicator reduces flood damage (true-positives)

In eight of the ten big flood years, the D-J-F ENSO is cool and so triggers the use of lower rule curve levels for nine quarter-months in the spring. Table 7 shows how damages change. Depending on the nature of the inflows, there might be no reduction in flood damage or as much as a 38.8% decrease (1996) or $2.5 million damage reduction (1950). The reduction in damage is almost as large in 2014 ($1.8 million). RC7-3 and RC7-4 have no impact on damages in three years, and in 2008, RC7-3 reduces damages by $36,000 more than RC7-4, despite RC7-4 using the lower targets. As Figure 6 shows, in 2008 the more aggressive RC7-4 plan lowers Namakan by 2 cm rather than 1cm, and in this one case the timing of local inflows into Rainy and the larger releases from Namakan means that RC7-4 reduces Rainy levels by 3cm, not four. A centimeter difference in water levels is about the width of a little finger.

The drought versions (RC7-5 and 6) produce the same flood damage reduction results in the eight true positive year as the non-drought versions; RC7-3 and RC7-5 match and RC7-4 and RC7-6 match because in those 8 years the paired plans make exactly the same releases. It's a different story in the two false-negative years (1954 and 1966), when floods are preceded by a warm ENSO. More on that in the next section.

2. Cases when the ENSO indicator increases flood damage (false-negative)

RC7-3 and 4 do not change releasers unless the ENSO is cool, so the '54 and '66 floods are exactly the same as they would be under the 2000 rule curves. But RC7-5 and 6 react to the warm ENSO and use the top of the rule curve band as the new target, raising water levels before the flood comes. This increases damages by a third in 1954 and by a quarter in 1966.

Table 6 Changes in flood damage from ENSO forecast Adaptive Rule Curves

Flood	$ Reduction (or increase) in flood damages				% Reduction (or increase) in flood damages			
Year	RC7-3	RC7-4	RC7-5	RC7-6	RC7-3	RC7-4	RC7-5	RC7-6
1950	$1,806,744	$2,503,350	$1,806,744	$2,503,350	4.8%	6.7%	4.8%	6.7%
1954	$0	$0	-$2,293,134	-$2,293,134	0.0%	0.0%	-31.1%	-31.1%
1966	$0	$0	-$787,685	-$787,685	0.0%	0.0%	-25.8%	-25.8%
1968	$666,341	$666,341	$666,341	$666,341	14.2%	14.2%	14.2%	14.2%
1974	$683,339	$769,535	$683,339	$769,535	31.8%	35.8%	31.8%	35.8%
1996	$740,747	$1,093,936	$740,747	$1,093,936	26.3%	38.8%	26.3%	38.8%
2001	$754,455	$754,455	$754,455	$754,455	12.0%	12.0%	12.0%	12.0%
2002	$0	$0	$0	$0	0.0%	0.0%	0.0%	0.0%
2008	$345,351	$309,116	$345,351	$309,116	14.3%	12.8%	14.3%	12.8%
2014	$1,529,501	$1,803,601	$1,529,501	$1,803,601	9.4%	11.1%	9.4%	11.1%

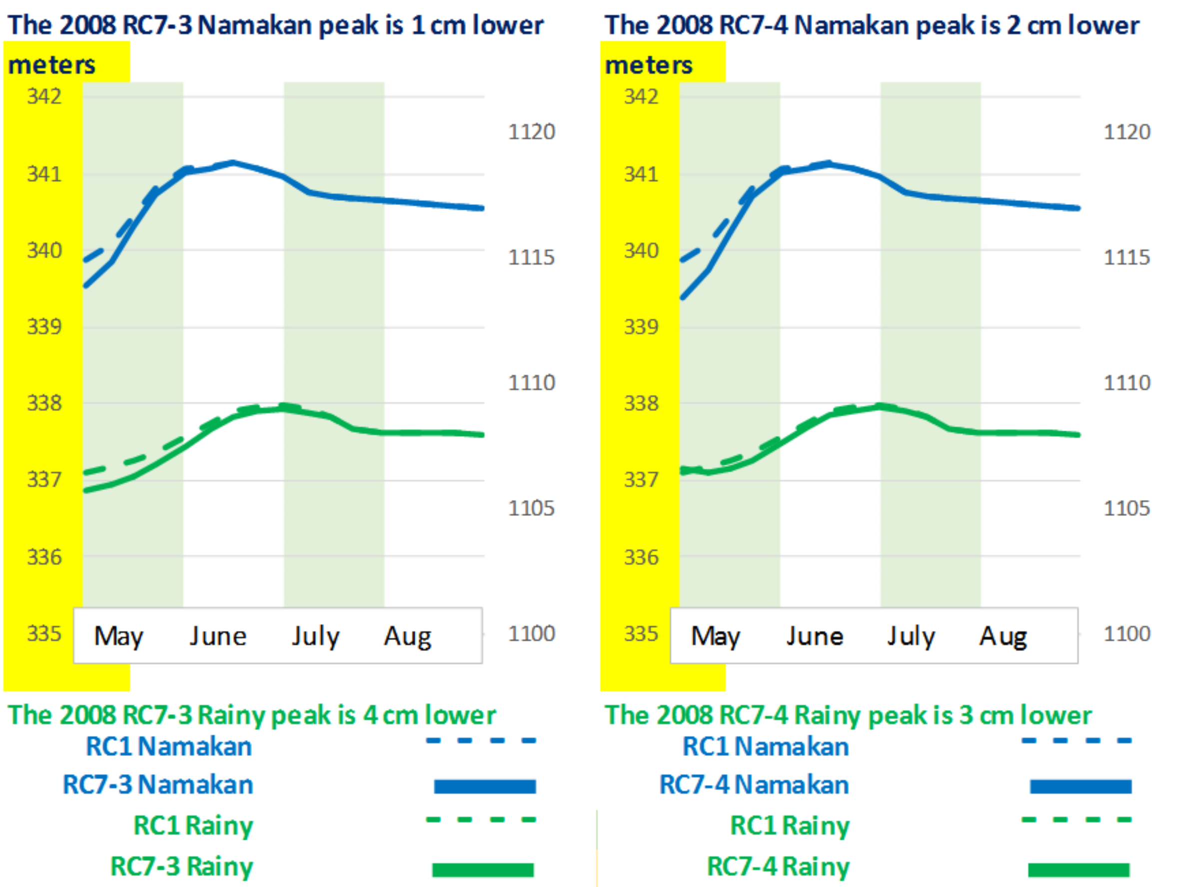


Figure 5 RC73 vs RC7-4 water levels, 2008 Flood

Table 7 Changes in flood damage from ENSO forecast Adaptive Rule Curves

Flood	$ Reduction (or increase) in flood damages				% Reduction (or increase) in flood damages			
Year	RC7-3	RC7-4	RC7-5	RC7-6	RC7-3	RC7-4	RC7-5	RC7-6
1950	$1,806,744	$2,503,350	$1,806,744	$2,503,350	4.8%	6.7%	4.8%	6.7%
1954	$0	$0	-$2,293,134	-$2,293,134	0.0%	0.0%	-31.1%	-31.1%
1966	$0	$0	-$787,685	-$787,685	0.0%	0.0%	-25.8%	-25.8%
1968	$666,341	$666,341	$666,341	$666,341	14.2%	14.2%	14.2%	14.2%
1974	$683,339	$769,535	$683,339	$769,535	31.8%	35.8%	31.8%	35.8%
1996	$740,747	$1,093,936	$740,747	$1,093,936	26.3%	38.8%	26.3%	38.8%
2001	$754,455	$754,455	$754,455	$754,455	12.0%	12.0%	12.0%	12.0%
2002	$0	$0	$0	$0	0.0%	0.0%	0.0%	0.0%
2008	$345,351	$309,116	$345,351	$309,116	14.3%	12.8%	14.3%	12.8%
2014	$1,529,501	$1,803,601	$1,529,501	$1,803,601	9.4%	11.1%	9.4%	11.1%

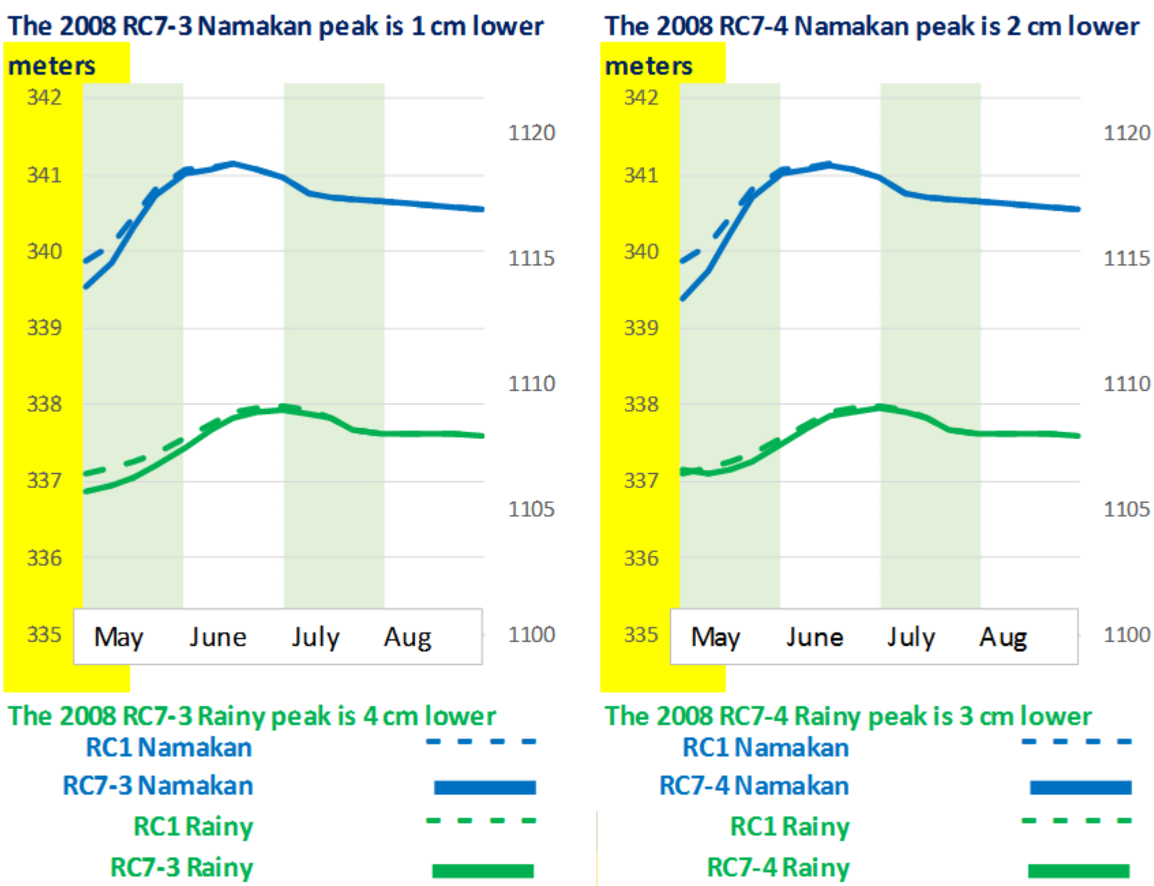


Figure 6 RC73 vs RC7-4 water levels, 2008 Flood

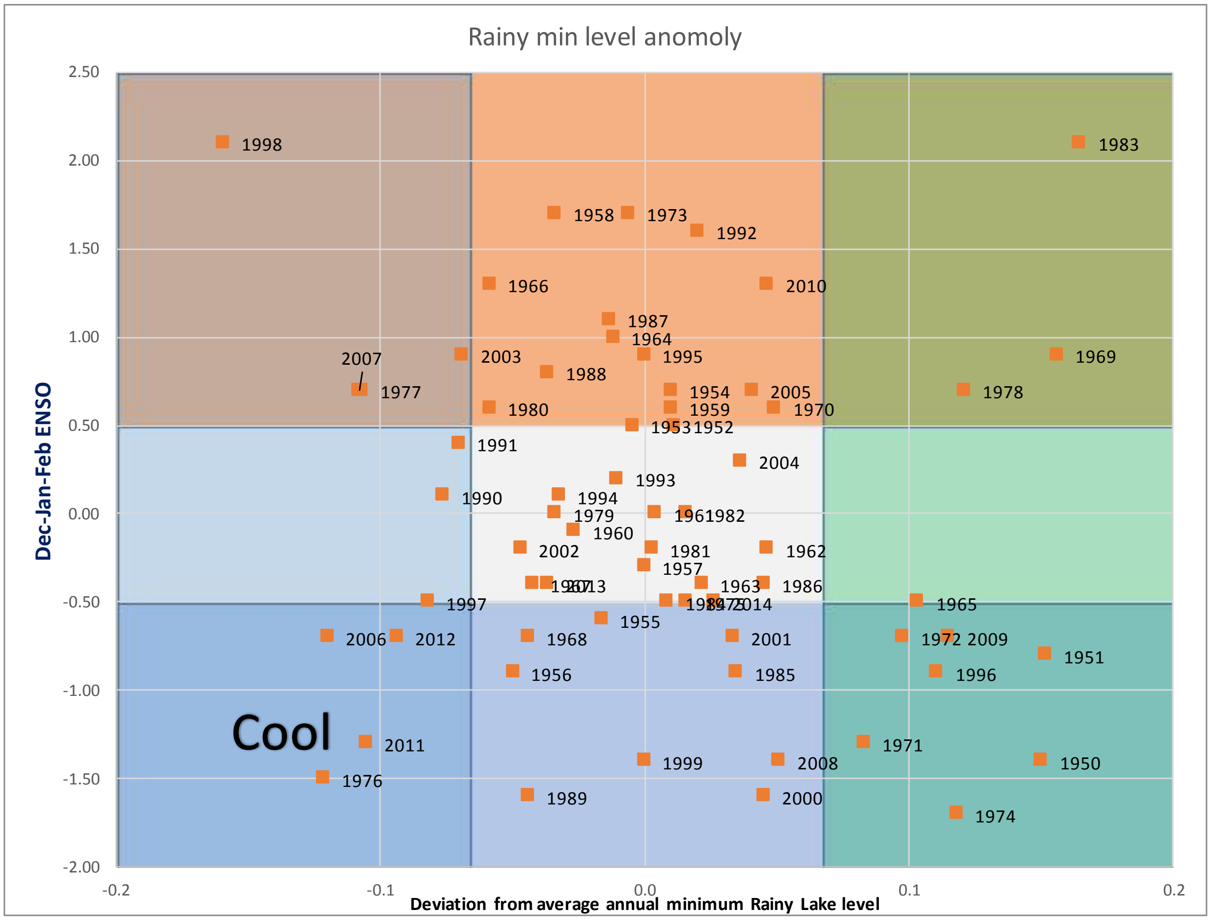


Figure 7 Deviations from average annual minimum levels for Rainy Lake without regulation, in meters

3. False alarms - cases when the ENSO indicator warns there will be a flood but inflows are normal or dry (false-positive)

False alarms do not impact flooding but are potentially important for tourism, hydropower and the environment. Figure 1 shows the correlation between peak unregulated Rainy levels and the ENSO indicator, but for false alarms and true negatives, the issue is how the ENSO adaptive rule curves would affect low levels. Figure 7 (above) shows the correlation between ENSO and unregulated Rainy minimum levels. Note that these are unregulated (state of nature) minima and those are much lower than regulated minima. Figure 1 and 6 are both helpful in considering the significance of false positives. The vertical location of any year stays the same in Figure 1 and Figure 7 because the ENSO's are the same, but the left-right orientation can change dramatically. Also notice the x-axis in Figure 1 spans 4 meters, the x-axis in Figure 7 only 40 cm. The difference between the lowest simulated unregulated Rainy Lake level (1998, when Rainy Lake reaches 1101.42 ft. or 335.72 m.) and the highest minimum (1983, 1100.36 ft. or 335.39m.) is only about a foot. An important inference from Figure 7 is that if Rainy is lower than normal, it's not by much. The false alarm years, in which a cool ENSO could lower an already low Rainy Lake are 1976, 1997, 2006, 2011 and 2012.

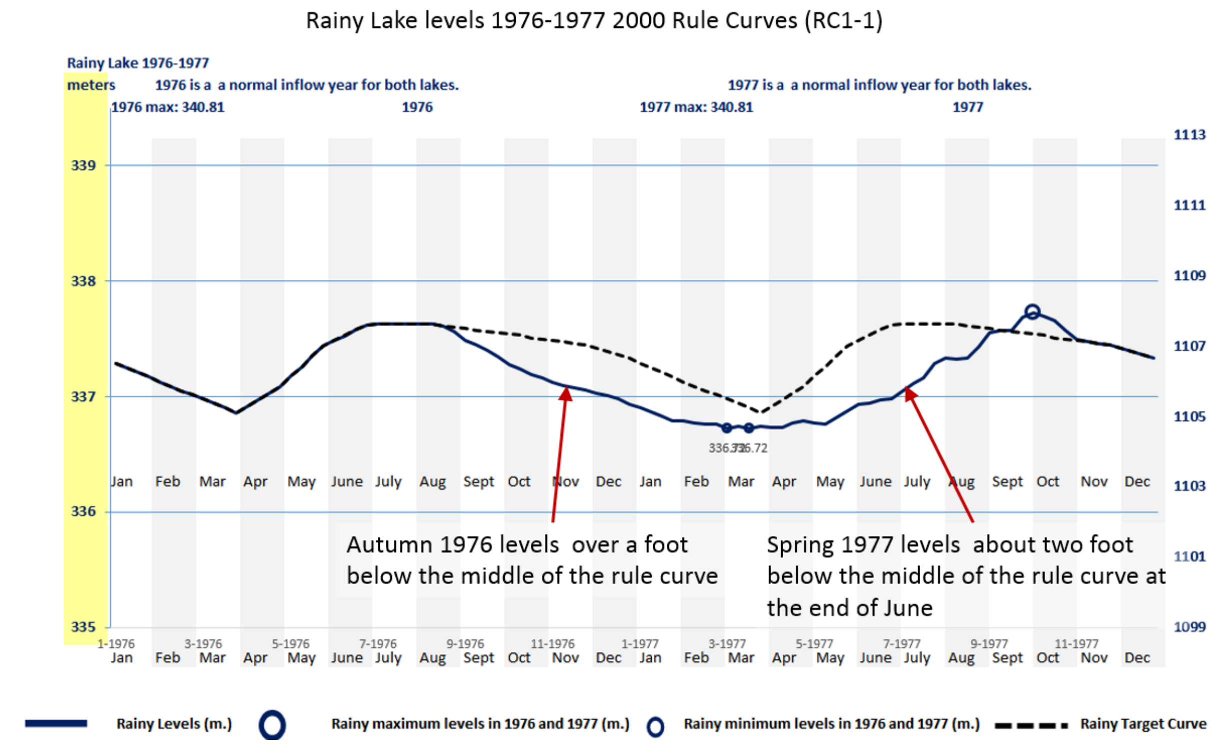


Figure 8 Rainy Lake levels in 1976 and 77 regulated under the current 2000 Rule Curves

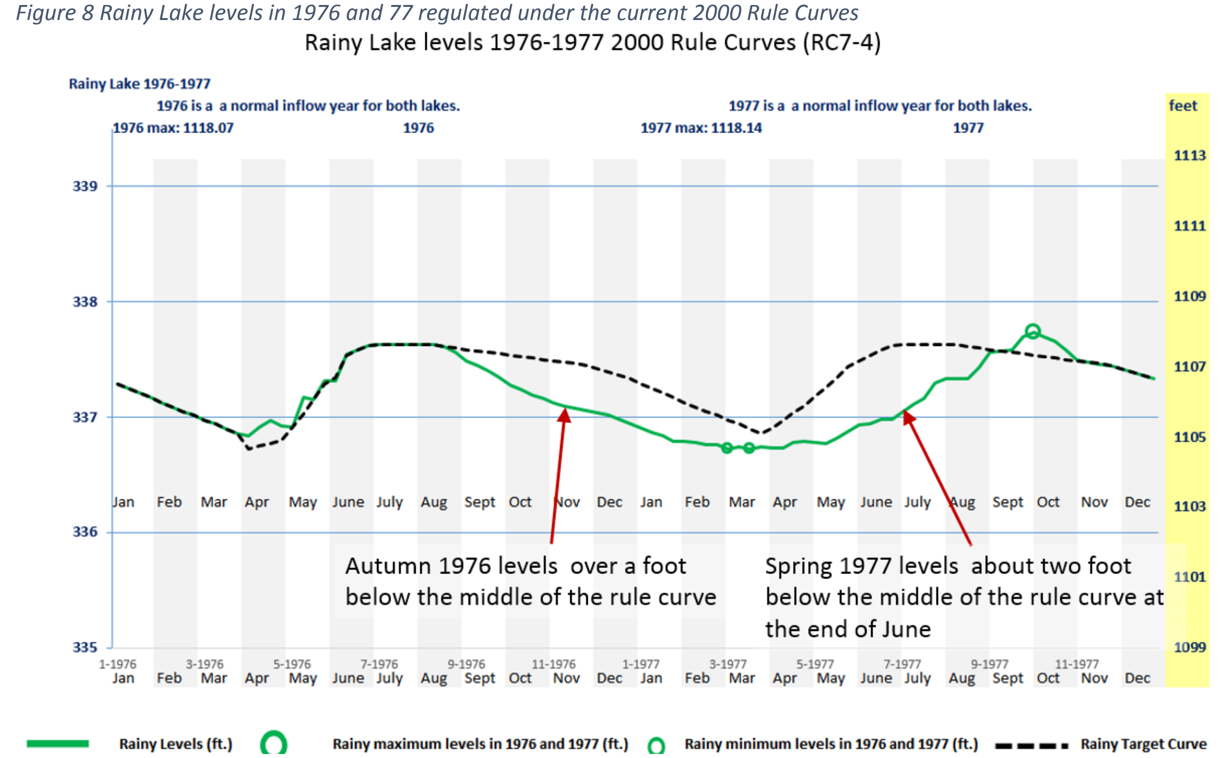


Figure 9 Rainy Lake levels in 1976-77 regulated with the ENSO adaptive rule curve alternative RC7-4

The adaptive rule curve will try to lower the lakes from the center to the bottom of the rule curve or the drought line (depending on the option) before the dry summer starts.

What happens in 1976, one of the driest years on record but one with a cool ENSO?

Under the 2000 Rule Curves, inflows to Rainy Lake are not sufficient to keep the lake in the middle of the rule curve band (**Error! Reference source not found.**). Lower levels start at the end of August and do not recover until the fall of 1978. Fall 1976 levels are a foot below normal, and the lake is about two feet below normal in June 1977.

Changing to an adaptive rule curve that considers only cool ENSOs and flooding, the results aren't much different (**Error! Reference source not found.**). The target curve (black dashed line) is dropped in April 1976 in anticipation of a flood, but the lake is not drawn down to the target because the maximum possible release at these low levels is not enough to draw the lake down to that level. The results later that year and in 1977 are essentially the same.

The results are different in 2006 and 2007. Even with the 2000 Rule Curves, water levels in Rainy fall below the target curve in the fall of 2006 (Figure 9). Under RC7-4, the cool ENSO triggers a shift to use the bottom of the rule curve in the spring (Figure 10). The flood never comes, and the peak level in 2006 is a foot lower than it would have been under the 2000 Rule Curves. 2008 levels are about the same under either plan.

The flood fighting adaptive rule curve would have lowered levels during the boating season but also produced a lower level for cattail control. Is an occasional low year a reasonable tradeoff for slightly lower flood levels in many years?

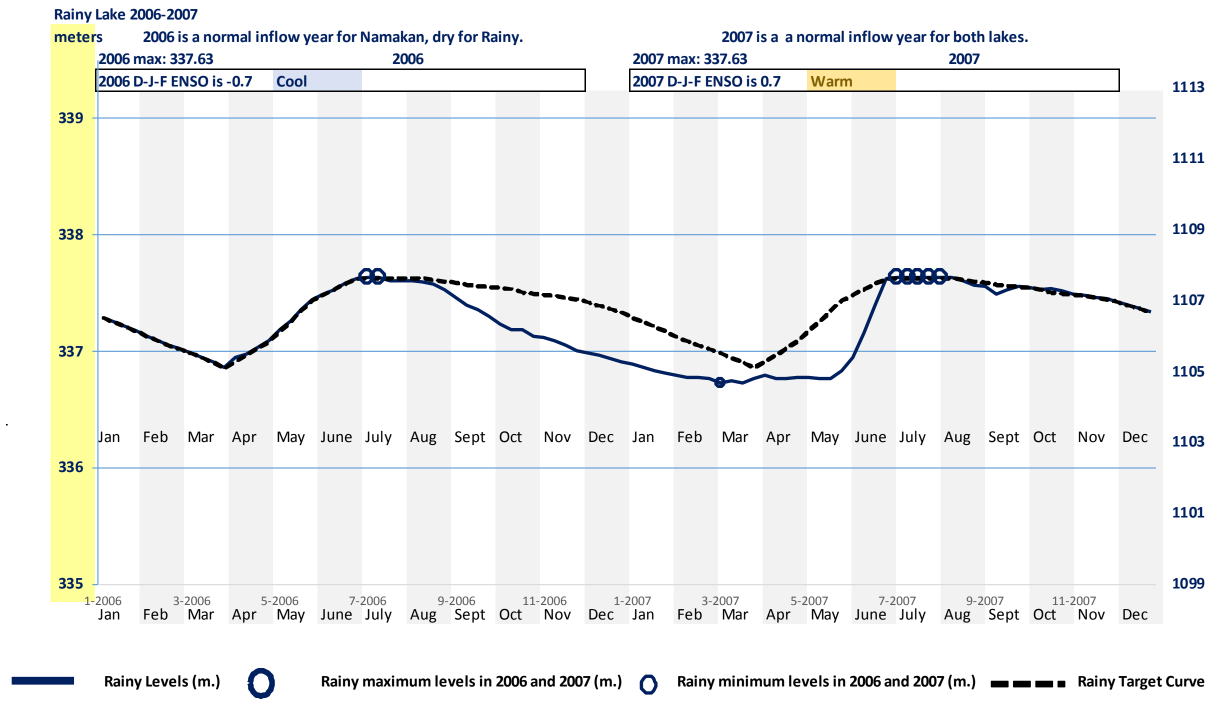


Figure 10 Rainy Lake levels 2006-2007 under the current 2000 Rule Curves (RC1-1)

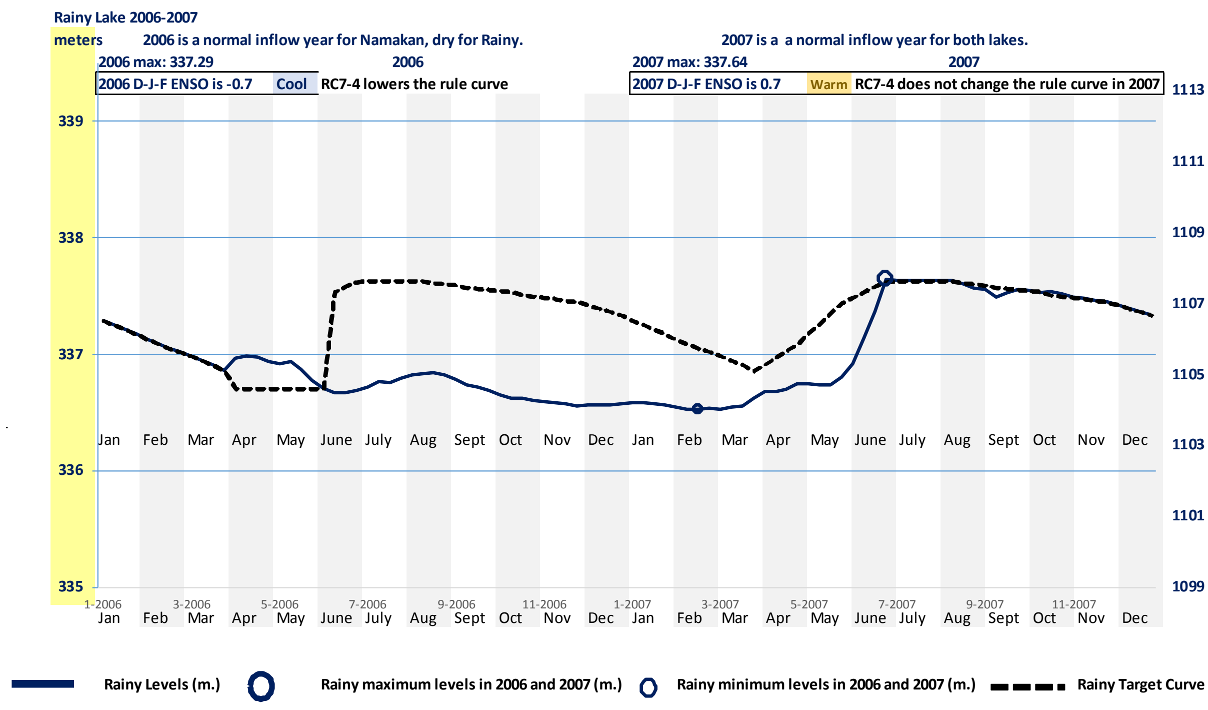


Figure 11 2006-7 Rainy Lake levels regulated by RC7-4

4. ENSO indicator warns of dry conditions that do occur (true-negative)

A warm or neutral ENSO could be followed by low or normal inflows (true-negative). The driest years on record come in pairs; 1976-77 is the driest. Also dry, 1997-98; 2006-7 and 2011-12. As can be seen in Figure 7, it is the second year that is preceded by a warm ENSO in three of these droughts (1977, 1998, and 2007). RC7-3 and RC7-4 do not respond to warm ENSOs but RC7-5 and RC7-6 do. Would they help raise water levels in those years?

It makes no difference in 1977, very little in 1998 or 2007. With conditions this dry, the releases under the 2000 Rule Curve are often the minimum 65m3/s, so setting the target higher doesn't change the releases at all.

Observations and questions

The ENSO forecast adaptive rule curve as modeled provides some flood damage reduction benefits but also carries some risks. These alternatives could be adjusted (using different ENSO cutoffs, different rule curve target levels, and different durations). Different rules could be imposed on Namakan and Rainy. **How do you feel about the tradeoffs from these alternatives?**

The warm ENSO drought indicator provides a theoretical advantage that does not seem to make much difference in water levels. And it induces damage in two flood years (1954 and 1966) when it raises lake levels based on forecasts of low water conditions. **Is there any point in pursuing an ENSO adaptive rule curve for drought?**

Next steps

There will be one more newsletter before the practice decision focusing on some 1d indicators, particularly those that score well when water levels are fairly stable. The ENSO adaptive rule curve plans may not perform as well as the 2000 Rule Curves because they trigger a rapid lowering of the lakes. And they may cause spills of water that could have otherwise been used to generate hydropower? Can there be any middle ground?