Appendix C-6: Alternative 310

Minimum Flows

HEC-ResSim Alternative Assessment

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1. Alternative Description & Objective

This alternative is a continuation of Phase 2 Alternative 5, further analyzing the implementation of consistent, year-round minimum flows of 4, 10, and 15 cfs (0.1, 0.3, and 0.4 cms) throughout the basin to reduce fish kills and improve water quality. In Alternative 310, Rafferty and Grant Devine were set to only maintain minimum flows if their pool elevations were above a given threshold. If the reservoirs dropped too low, the minimum flow would no longer be maintained. At Lake Darling, there was no threshold at which the minimum flow rule was “turned off.” Results derived to reflect the suggested alternative were compared to the baseline model results for low and normal starting pool elevations for the period 1930-2017.

1.1 Alternative Development

In Phase 2 Alternative 5, consistent minimum flows of 20 cfs (0.6 cms) throughout the basin were modeled, and although performance indicator (PI) results showed improvements from the baseline in terms of fish and wildlife habitat, the model showed significant risks to water supply. Since increased minimum flows are a popular concern among residents of the basin, the Plan Formulation Committee decided to further explore Alternative 5 by looking at a range of minimum flows, taking into consideration reservoir pool elevation at Rafferty and Grant Devine.

For Alternative 310, minimum flows rules were set at seven different locations (upstream of the confluence of the Souris River with Moose Mountain Creek, Sherwood, Minot, Verendrye, Bantry, and Westhope) and take into consideration minimum pool elevations for Rafferty and Grant Devine. At the time this alternative was being developed, there was no information available regarding environmental PIs for the Saskatchewan reservoirs; therefore, the dam safety PI was used to determine Rafferty’s minimum elevation threshold (1790 ft, 545.6 m), and the recreational PI was used to determine Grant Devine’s minimum elevation threshold (1811 ft, 552.0 m). When the reservoirs dropped below these thresholds, they were no longer required to maintain minimum flows.

If all the minimum flows are applied in the same simulation, there is an inaccurate representation of their effect the Saskatchewan reservoirs. The reason being that Lake Darling does not have a minimum pool elevation in place to prevent it from being drawn dry. The unrealistic drawdown of the reservoir leads to apportionment ratio shift. As stipulated in Annex B, the apportionment shifts from a 50/50 split to a 40/60 split based on either the natural flow volume at Sherwood, or on the elevation of Lake Darling. For this reason, when Lake Darling is drawn down exceptionally low, the model shifts the apportionment from a 40/60 split in the baseline to a 50/50 split based on the elevation of Lake Darling. Thus, when the apportionment ratio shifts, Grant Devine must release more water to meet the new apportionment requirements. This in turn causes Grant Devine to be drawn down unrealistically. For this reason, the study team decided to model the Saskatchewan reservoirs (Rafferty Reservoir and Grant Devine Lake) separately from the North Dakota reservoirs (Lake Darling and the J. Clark Salyer).

1.2 HEC-ResSim Nomenclature

Within HEC-ResSim, a new network, alternative and simulation run was generated to reflect each proposed scenario. To generate the alternative network, a copy of the base network was made and modified to reflect the proposed scenario. In order to carry out this scenario with the different minimum flows, a new operation set for each of the reservoirs and J. Clark Salyer was created. A table indicating the nomenclature associated with the ResSim networks, alternatives and simulations used to model both baseline and this scenarios' operations for the various index events are listed in

Scenario	Time Window	ResSim Model Name	Network Name	Alternative Name	Simulation Name
Baseline (low pool)	1930-1960	SourisRiverPoS	Base	BL_LowPool	1930-2017_MinQ
Baseline (normal pool)	1930-2017	SourisRiverPoS	Base	BL_Norm	1930-2017_MinQ _
310 - 4 cfs release (low pool)	1930-1960	SourisRiverPoS	Base_MinQ_ND	Min4Q_ND	1930-2017_MinQ
	1930-1960	SourisRiverPoS	Base_MinQ_SK	Min4Q_SK	1930-2017_MinQ
310 - 4 cfs release (normal pool)	1930-2017	SourisRiverPoS	Base_MinQ_ND	Min4Q_ND	1930-2017_MinQ
	1930-2017	SourisRiverPoS	Base_MinQ_SK	Min4Q_SK	1930-2017_MinQ
310 - 10 cfs release (low pool)	1930-1960	SourisRiverPoS	Base_MinQ10_ND	Min10Q_ND	1930-2017_MinQ
	1930-1960	SourisRiverPoS	Base_MinQ10_SK	Min10Q_SK	1930-2017_MinQ
310 - 10 cfs release (normal pool)	1930-2017	SourisRiverPoS	Base_MinQ10_ND	Min10Q_ND	1930-2017_MinQ
	1930-2017	SourisRiverPoS	Base_MinQ10_SK	Min10Q_SK	1930-2017_MinQ
310 - 15 cfs release (low pool)	1930-1960	SourisRiverPoS	Base_MinQ15_ND	Min15Q_ND	1930-2017_MinQ
	1930-1960	SourisRiverPoS	Base_MinQ15_SK	Min15Q_SK	1930-2017_MinQ
310 - 15 cfs release (normal pool)	1930-2017	SourisRiverPoS	Base_MinQ15_ND	Min15Q_ND	1930-2017_MinQ
	1930-2017	SourisRiverPoS	Base_MinQ15_SK	Min15Q_SK	1930-2017_MinQ

.

Table 1. Model nomenclature

Scenario	Time Window	ResSim Model Name	Network Name	Alternative Name	Simulation Name
Baseline (low pool)	1930-1960	SourisRiverPoS	Base	BL_LowPool	1930-2017_MinQ
Baseline (normal pool)	1930-2017	SourisRiverPoS	Base	BL_Norm	1930-2017_MinQ _

310 - 4 cfs release (low pool)	1930-1960	SourisRiverPoS	Base_MinQ_ND	Min4Q_ND	1930-2017_MinQ
	1930-1960	SourisRiverPoS	Base_MinQ_SK	Min4Q_SK	1930-2017_MinQ
310 - 4 cfs release (normal pool)	1930-2017	SourisRiverPoS	Base_MinQ_ND	Min4Q_ND	1930-2017_MinQ
	1930-2017	SourisRiverPoS	Base_MinQ_SK	Min4Q_SK	1930-2017_MinQ
310 - 10 cfs release (low pool)	1930-1960	SourisRiverPoS	Base_MinQ10_ND	Min10Q_ND	1930-2017_MinQ
	1930-1960	SourisRiverPoS	Base_MinQ10_SK	Min10Q_SK	1930-2017_MinQ
310 - 10 cfs release (normal pool)	1930-2017	SourisRiverPoS	Base_MinQ10_ND	Min10Q_ND	1930-2017_MinQ
	1930-2017	SourisRiverPoS	Base_MinQ10_SK	Min10Q_SK	1930-2017_MinQ
310 - 15 cfs release (low pool)	1930-1960	SourisRiverPoS	Base_MinQ15_ND	Min15Q_ND	1930-2017_MinQ
	1930-1960	SourisRiverPoS	Base_MinQ15_SK	Min15Q_SK	1930-2017_MinQ
310 - 15 cfs release (normal pool)	1930-2017	SourisRiverPoS	Base_MinQ15_ND	Min15Q_ND	1930-2017_MinQ
	1930-2017	SourisRiverPoS	Base_MinQ15_SK	Min15Q_SK	1930-2017_MinQ

2. Operational Rules

Table 2 presents the operational rules that were added to the base HEC-ResSim model alternative to specifically reflect the changes required in support of Alternative 310.

Table 2. Operation rules added that are specific to the alternative

Name of Dam	Network	Name of Rule, Outlet or IF Statement or State Variable Element	Rule Description
Rafferty Reservoir	Base_MinQ_SK	UMMCMinQ_4cfs*	Minimum flow 4 cfs upstream Moose Mountain Creek
		SherMinQ_4cfs*	Minimum flow 4 cfs at Sherwood
	Base_Min10Q_SK	UMMCMinQ_10cfs*	Minimum flow 10 cfs upstream Moose Mountain Creek
		SherMinQ_10cfs*	Minimum flow 10 cfs at Sherwood

	Base_Min15Q_SK	UMMCMinQ_15cfs*	Minimum flow 15 cfs upstream Moose Mountain Creek
		SherMinQ_15cfs*	Minimum flow 15 cfs at Sherwood
Boundary Reservoir	NONE	NONE	NONE
Grant Devine Lake	Base_MinQ_SK	SherMnQ_4cfs*	Minimum flow 4 cfs at Sherwood
	Base_Min10Q_SK	SherMinQ_10cfs*	Minimum flow 10 cfs at Sherwood
	Base_Min15Q_SK	SherMinQ_15cfs*	Minimum flow 15 cfs at Sherwood
Lake Darling	Base_MinQ_ND	MinMinQ_4cfs	Minimum flow 4 cfs at Minot
		VerMinQ_4cfs	Minimum flow 4 cfs at Verendrye
		BanMinQ_4cfs	Minimum flow 4 cfs at Bantry
	Base_Min10Q_ND	MinMinQ_10cfs	Minimum flow 10 cfs at Minot
		VerMinQ_10cfs	Minimum flow 10 cfs at Verendrye
		BanMinQ_10cfs	Minimum flow 10 cfs at Bantry
	Base_Min15Q_ND	MinMinQ_15cfs	Minimum flow 15 cfs at Minot
		VerMinQ_15cfs	Minimum flow 15 cfs at Verendrye
		BanMinQ_15cfs	Minimum flow 15 cfs at Bantry
Dam 357	Base_MinQ_ND	MinWesQ4cfs	Minimum flow 4 cfs at Westhope
	Base_Min10Q_ND	MinWesQ10cfs	Minimum flow 10 cfs at Westhope
	Base_Min15Q_ND	MinWesQ15cfs	Minimum flow 15 cfs at Weshope
Dam 341	Base_MinQ_ND	D341MinQ_4cfs	Minimum release 4 cfs
	Base_Min10Q_ND	D341MinQ_10cfs	Minimum release 10 cfs
	Base_Min15Q_ND	D341MinQ_15cfs	Minimum release 15 cfs
Dam 332	Base_MinQ_ND	D332MinQ_4cfs	Minimum release 4 cfs
	Base_Min10Q_ND	D332MinQ_10cfs	Minimum release 10 cfs
	Base_Min15Q_ND	D332MinQ_15cfs	Minimum release 15 cfs
Dam 326	Base_MinQ_ND	D326MinQ_4cfs	Minimum release 4 cfs
	Base_Min10Q_ND	D326MinQ_10cfs	Minimum release 10 cfs
	Base_Min15Q_ND	D326MinQ_15cfs	Minimum release 15 cfs
Dam 320	Base_MinQ_ND	D320MinQ_4cfs	Minimum release 4 cfs
	Base_Min10Q_ND	D320MinQ_10cfs	Minimum release 10 cfs
	Base_Min15Q_ND	D320MinQ_15cfs	Minimum release 15 cfs

*Minimum flow rules for Rafferty and Grant Devine were applied using the “RafLimQxx” and “MinQxxGranLim” IF blocks, respectively. These IF blocks apply the minimum flow rules whenever the reservoirs are above their minimum flow thresholds (Rafferty = 1790 ft, Grant Devine = 1811 ft).

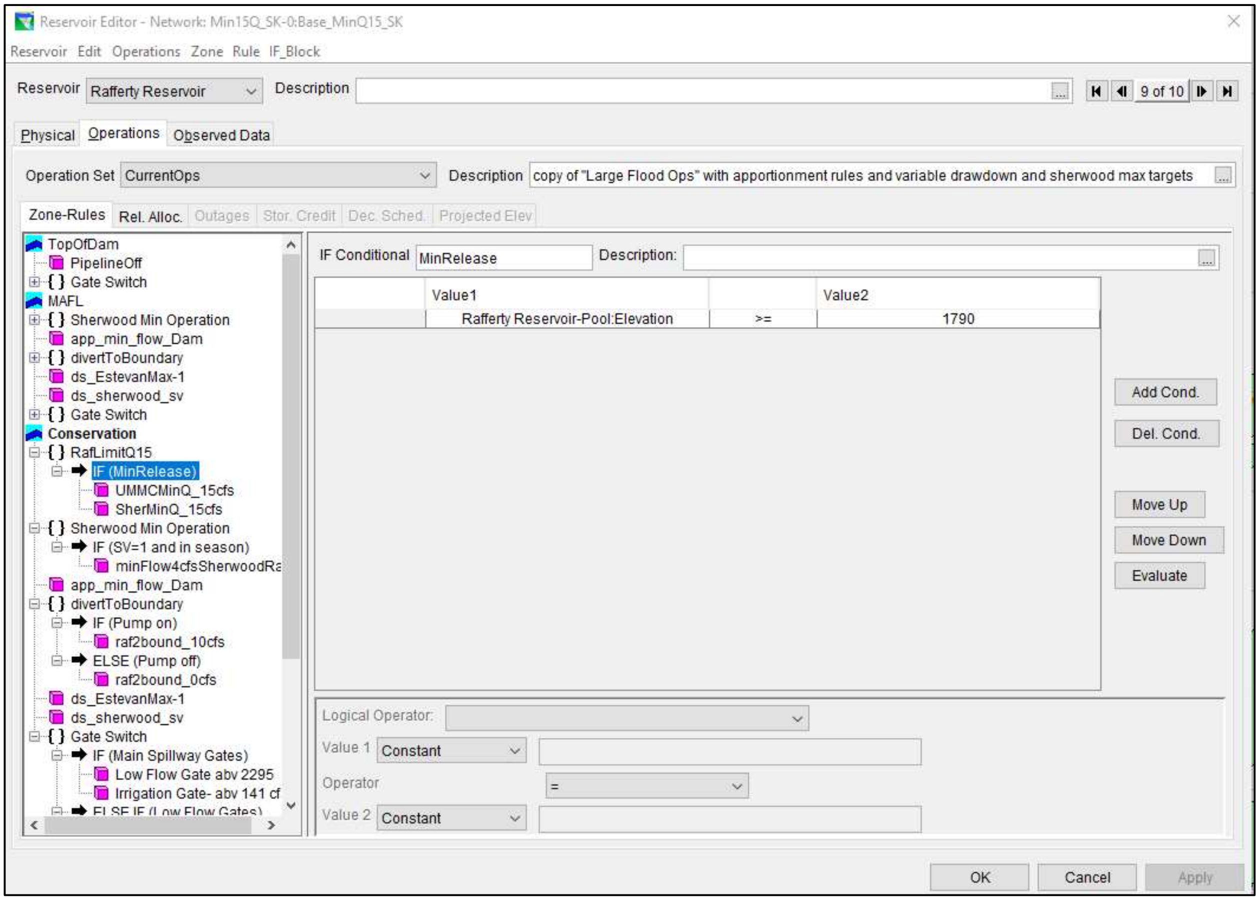


Figure 1 through **Error! Reference source not found.** display the rules added to the Rafferty, Grant Devine, Lake Darling and J. Clark Salyer operation sets. The relevant model feature is indicated by the red box.

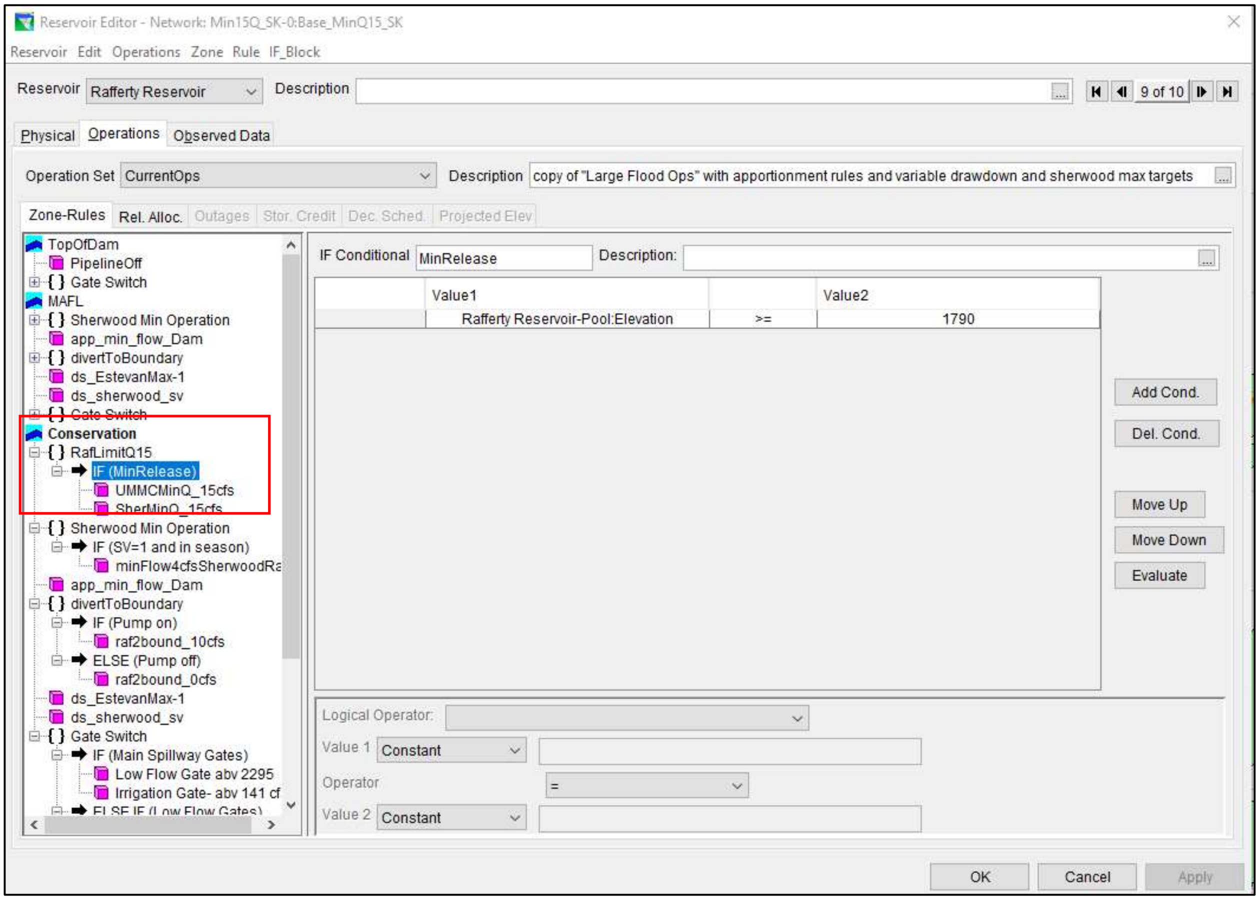


Figure 1. Modifications made to Rafferty Reservoir operations

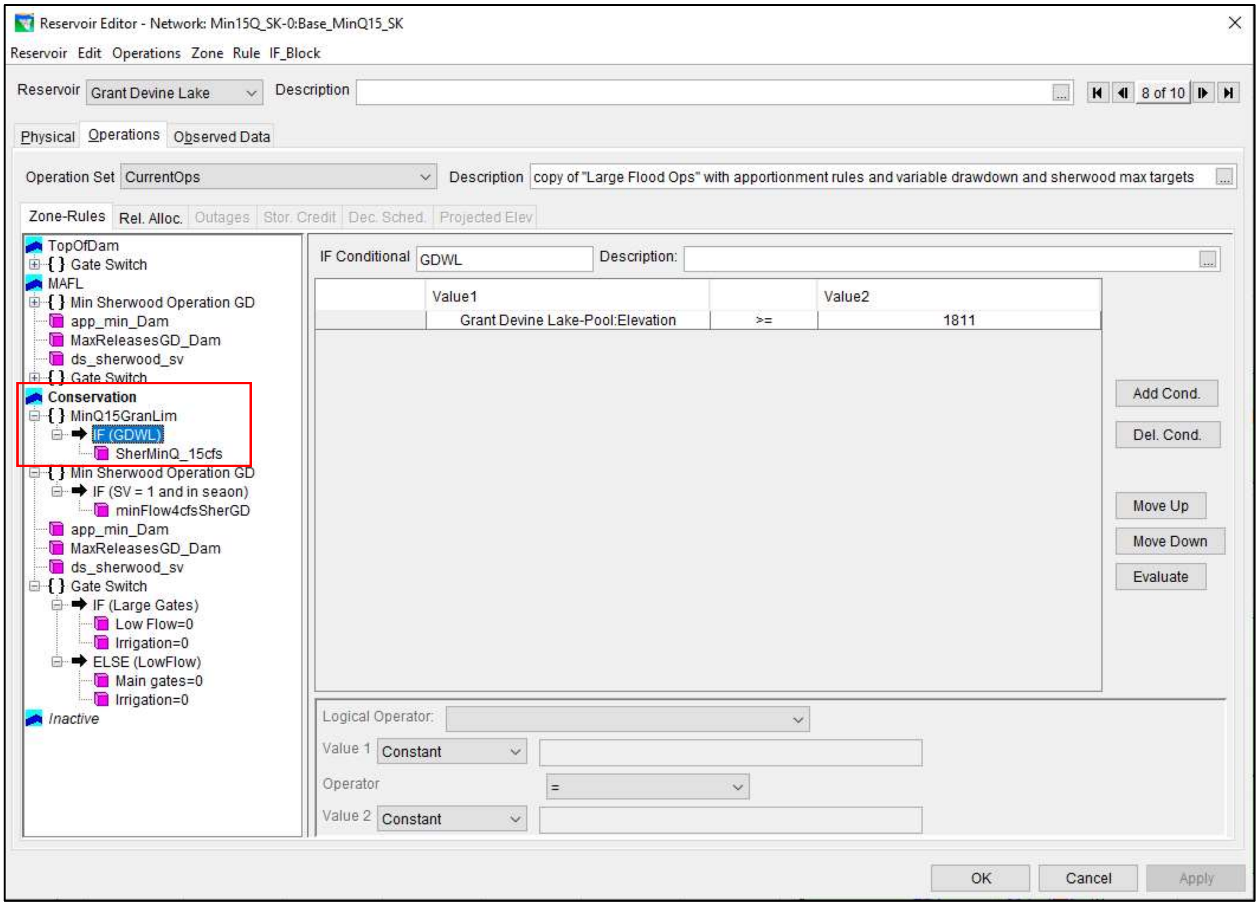


Figure 2. Modifications made to Grant Devine Lake operations

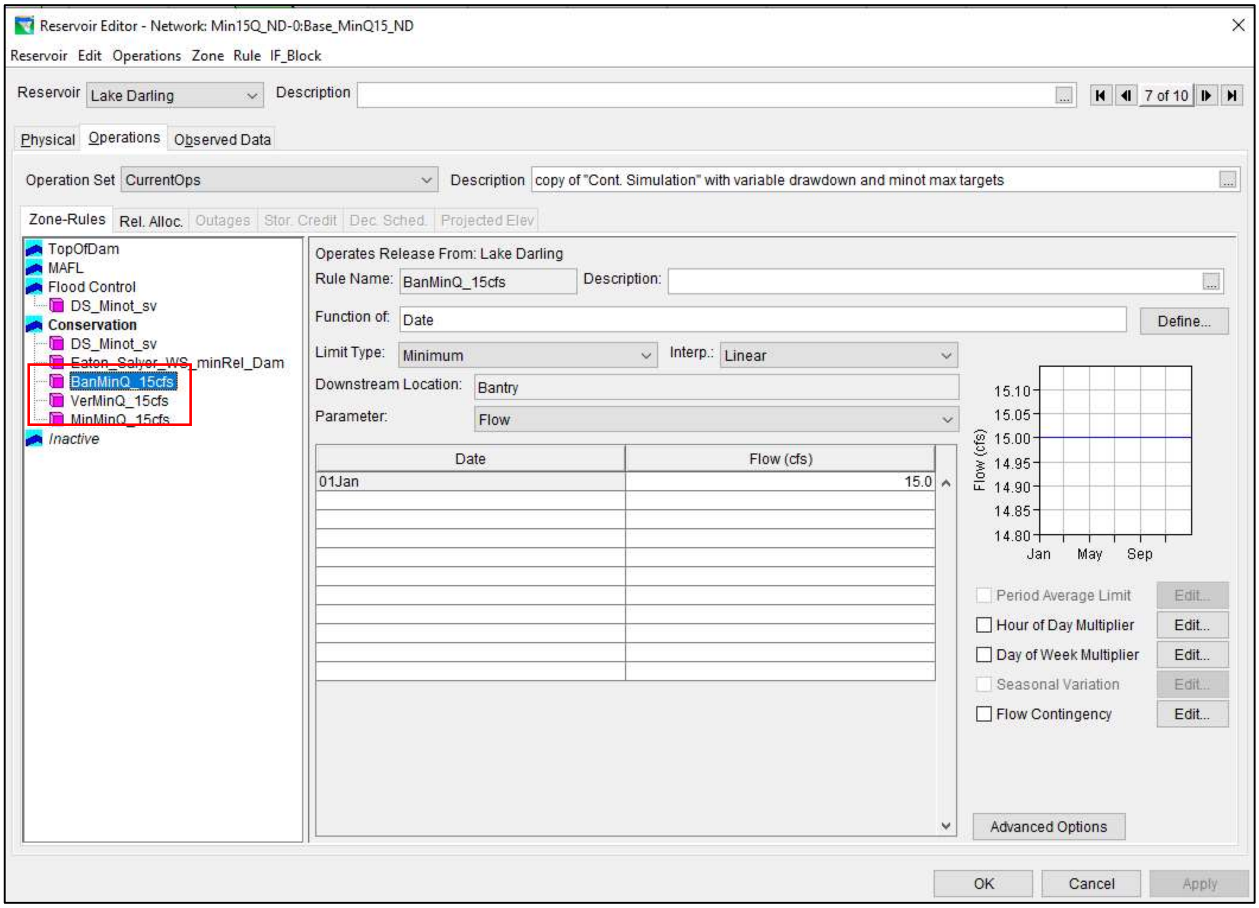
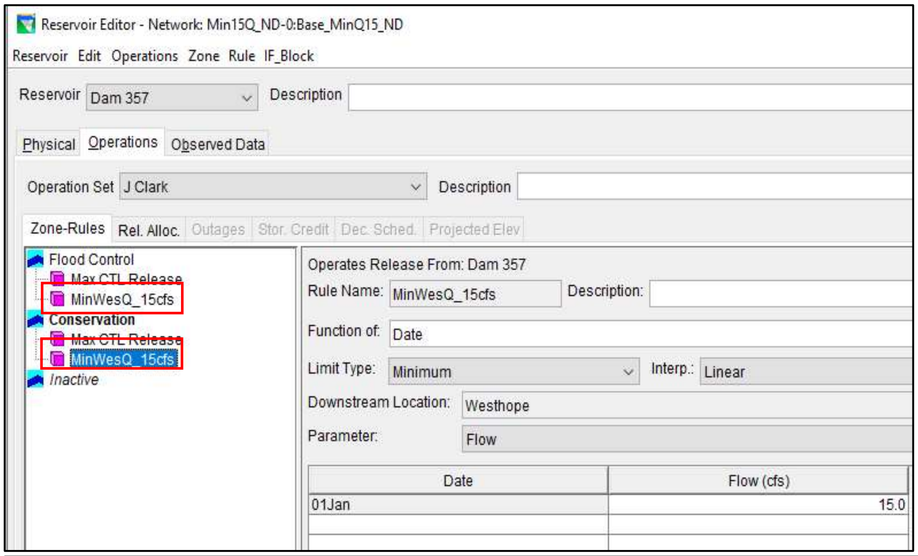


Figure 3. Modifications made to Lake Darling operations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Reservoir Dam 357
Description
Physical Operations Observed Data
Operation Set J Clark
Description
Zone-Rules Rel. Alloc. Outages Stor. Credit Dec. Sched. Projected Elev
Flood Control
Max CTL Release
MinWesQ_15cfs
Conservation
Max CTL Release
MinWesQ_15cfs
Inactive
Operates Release From: Dam 357
Rule Name: MinWesQ_15cfs
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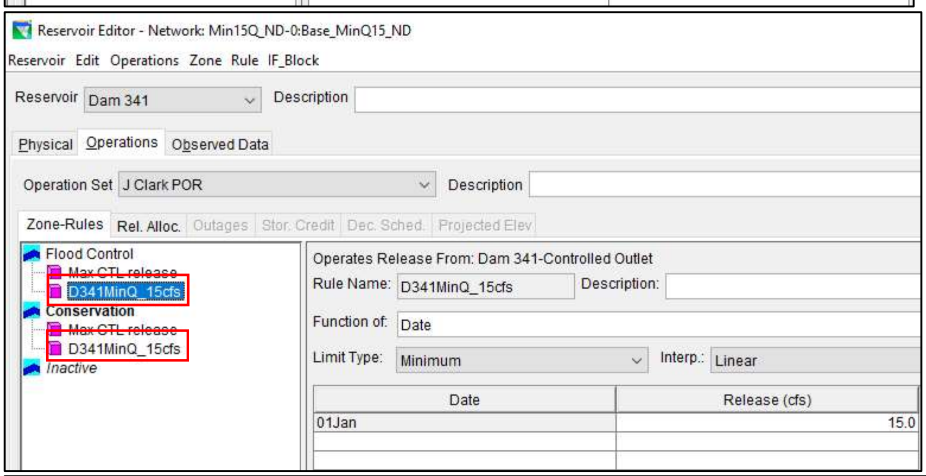
Interp.: Linear
Downstream Location: Westhope
Parameter: Flow
Date
Flow (cfs)
01Jan
15.0

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Physical Operations Observed Data
Operation Set J Clark POR
Description
Zone-Rules Rel. Alloc. Outages Stor. Credit Dec. Sched. Projected Elev
Flood Control
Max CTL release
D341MinQ_15cfs
Conservation
Max CTL release
D341MinQ_15cfs
Inactive
Operates Release From: Dam 341-Controlled Outlet
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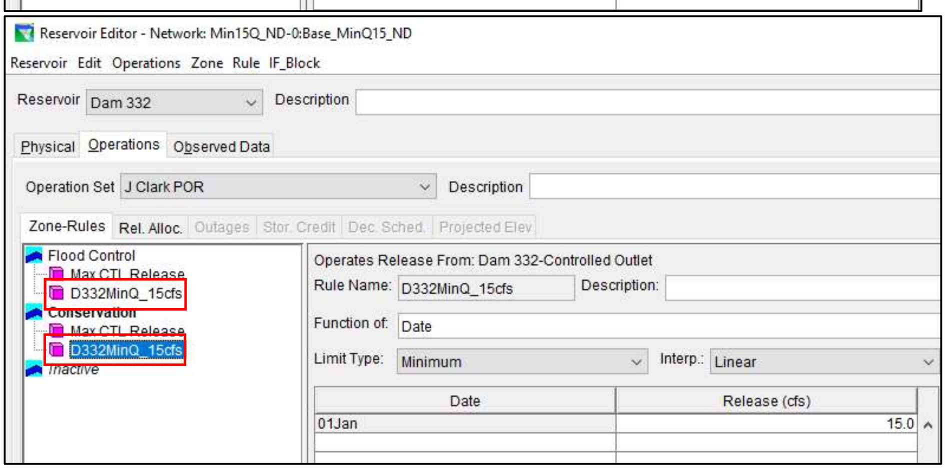
Limit Type: Minimum
Interp.: Linear
Date
Release (cfs)
01Jan
15.0

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Operation Set J Clark POR
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Max CTL Release
D332MinQ_15cfs
Conservation
Max CTL Release
D332MinQ_15cfs
Inactive
Operates Release From: Dam 332-Controlled Outlet
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Function of: Date
Limit Type: Minimum
Interp.: Linear
Date
Release (cfs)
01Jan
15.0

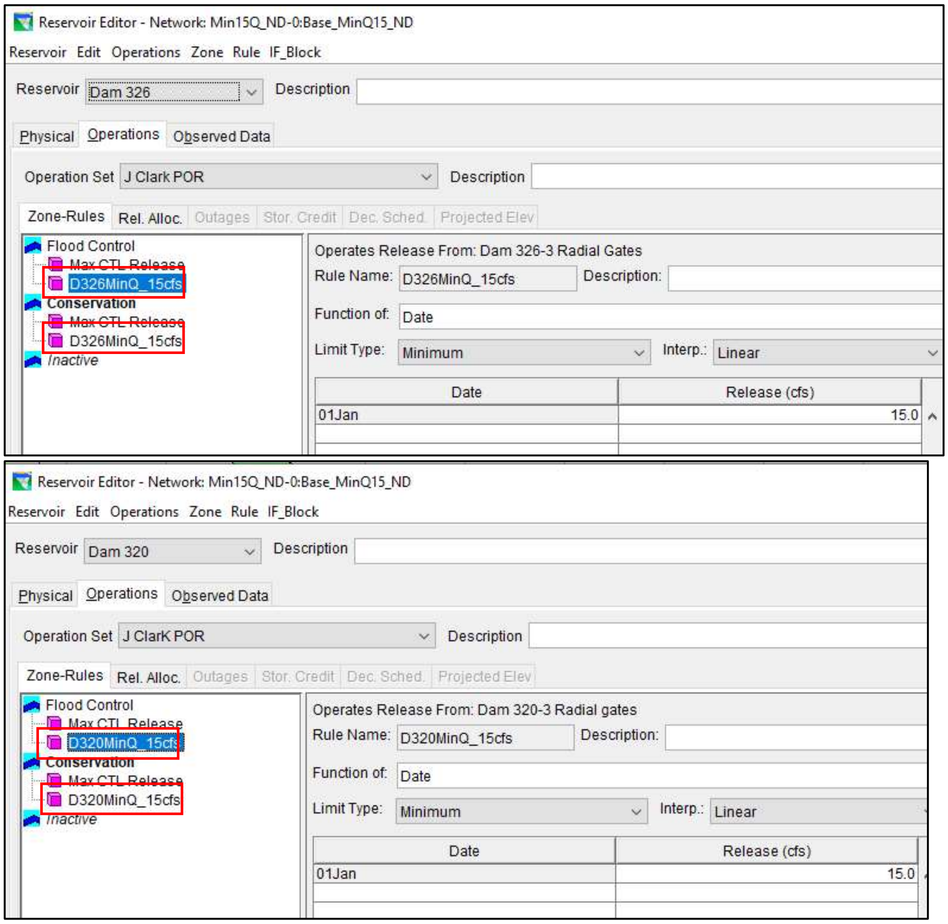


Figure 4. Modifications made to the J. Clark Salyer structures operations

3. Alternative vs Baseline Scenario Results

Plates 01-06 show hydrographs detailing the results of Alternative 310 relative to the baseline scenario at Rafferty, Boundary, Grant Devine, and Lake Darling reservoirs, as well as seven critical mainstem flow locations, for the most severe drought sequences in the observed record (1935-1943, 1961-1969, 1988-1996). These years were chosen to show the maximum amount of change from the baseline simulation. Even though three simulations were run with minimum flows of 4, 10, and 15 cfs, respectively, only the 4 and 15 cfs simulation results for the normal pool initial conditions are plotted. Results from the additional simulations are described below and can be obtained by contacting the study team.

Plate 07 displays performance indicator results for all study reaches over the entire simulation (1930-2017). More information regarding performance indicator (PI) results and PI development can be found in the Data Collection for the Analysis of Alternatives Report (DW4) and Appendix A-5.

Since minimum flow rules at Rafferty and Grant Devine were modeled separately from Lake Darling, simulation results for all reaches upstream of Lake Darling reflect the simulations in which minimum flow rules were only applied to Rafferty and Grant Devine (alternative name: MinXQ_SK). Results for all reaches downstream of Lake Darling reflect the simulations in which minimum flow rules were only applied to Lake Darling and J. Clark Salyer (alternative name: MinXQ_ND). For each drought sequence, hydrographs are shown at Lake Darling for both simulations (with and without upstream minimum flow rules).

4. Summary of Results

Scenario 310 was evaluated utilizing two different sets of initial conditions – normal and low pool elevations. During the first 25 years of the simulation (1930-1955), the normal and low pool simulations differed, making analysis of the 1930s drought difficult. The two simulations tended to converge in the early 1950s, when the reservoirs reached FSL for the first time, and are very similar for the remainder of the simulation period. As expected, this alternative only showed changes from the baseline simulation in normal and dry years. Results for those years for normal and low pool elevations are summarized below.

4.1 Normal Starting Pool

4.1.1 Saskatchewan

This alternative impacted reservoir pool elevations significantly during historical drought periods. 4 to 15 cfs minimum flows caused the minimum pool elevation reached at Rafferty Reservoir during the 1930s drought to drop by 1.3 to 2.1 ft relative to the baseline simulation. In the 1960s drought, Rafferty's minimum elevation reached was 3.1 to 3.5 ft lower than the baseline, and in the late 1980s drought, minimum pool elevations were 0.3 to 2.3 ft lower. During all three major drought sequences, Rafferty's elevation dropped below 1790 ft, and the minimum flow rule was turned off. During wetter periods, the reservoir was able to maintain its minimum flow requirement.

Grant Devine's elevation was impacted more significantly by this scenario due to the additional apportionment releases that take place primarily from Grant Devine Lake. Also, with Grant Devine being a smaller reservoir than Rafferty, impacts to its elevation are greater. As was the case with Rafferty, this scenario had the most impact during extended droughts. For the 1930s drought, the lowest elevation reached in the baseline was 1,812 ft in 1942, but for this scenario, the lowest point was 1,804, 1,793 and 1,782 ft, for the minimum flow of 4, 10, and 15 cfs, respectively. In the 1960s, elevations were 6.7, 10.1 and 20.8 ft below the baseline minimum elevation of 1,820.6 ft. In the late 1980s drought, the lowest elevation reached decreased by 5, 15.8, and 28 ft for the three different minimum flows when compared to the baseline. In all major drought periods, Grant Devine dropped low enough to turn off its minimum flow rule, although it could typically maintain minimum flow releases longer than Rafferty.

4.1.2 North Dakota

Minimum flow rules were applied to Lake Darling and the J. Clark Salyer pools separately from the Saskatchewan reservoirs. This was done to determine if Lake Darling could maintain minimum releases without receiving additional water from Saskatchewan. As was the case at Rafferty and Grant Devine, the main impact to Lake Darling's pool took place during the 1930s, 1960s, and late 1980s drought periods. In the 1930s and late 1980s drought periods, Lake Darling was drawn virtually dry (below its lowest outlet) for all three minimum flows modeled in this scenario. In the baseline simulation, Lake Darling was drawn dry in the 1930s, but only for about two months. In the 4 cfs minimum flow simulation, Lake Darling stayed dry for approximately four years during this period.

4.2 Low Starting Pool

4.2.1 Saskatchewan

In general, when using low pool initial conditions, results differed from the normal pool simulations during the first 25 years (1930-1955). Rafferty's pool elevations did not change significantly from the baseline during this time, because the reservoir started below 1790 ft, and its minimum flow rule did not come into effect. Larger variation from baseline was observed at Grant Devine, as its minimum flow rule was active at the beginning of the simulation. During the 1940s, Grant Devine's elevation dropped approximately 12 to 40 ft lower than the baseline depending on the simulation. After 1948, the low pool and normal pool simulations converged.

4.2.2 North Dakota

Minimum flow requirements resulted in Lake Darling drawing dry in 1932 for each minimum flow simulated, which is about 11 ft lower than baseline during this period. In 1935, the low and normal pool simulations converged, so low and normal pool results are equivalent for 1936-2017. The initial starting conditions had no impact on the J. Clark Salyer pools.

4.3 Overall

While adding thresholds at which minimum releases are no longer required at Rafferty and Grant Devine allowed the reservoirs to retain more water during periods of low flow, this change was not enough to substantially reduce risk to water supply during sustained droughts. At Lake Darling, the lack of a minimum release threshold caused the reservoir to run dry multiple times over the period of record, significantly impacting the reservoir's ability to maintain its function as a national wildlife refuge.

4.4 Performance Indicators

4.4.1 Reservoirs

Performance Indicator (PI) results indicate water supply, fish habitat, and recreation at Rafferty and Grant Devine is negatively affected by both the 4 cfs (0.1 cms) and 15 cfs (0.4 cms) minimum flow rules, with the 15 cfs (0.4 cms) resulting in more negative impacts. Rafferty is generally kept lower for longer during droughts, and there is a greater number of years in which the reservoir does not return to FSL. At Grant Devine, although the 15 cfs rule does not substantially inhibit the reservoir from returning to FSL, the reservoir is maintained at a critically low elevation for longer during droughts, as shown by the Permitted Water Use PI. The Reservoir Supply Potential PI indicates both Rafferty and Grant Devine are consistently lower than their pool elevations in the baseline simulation.

At Lake Darling, all minimum flow rules can inhibit the reservoir from returning to FSL after a drawdown, and the Reservoir Supply Potential PI indicates the reservoir's pool elevation is consistently lower than the baseline simulation. This leads to fish and wildlife habitat being negatively impacted more often. The Boating and Fishing Access PI shows improvement from the baseline, indicating boating access sites are flooded less often. However, in reality, boating access could be hindered at some access points if the pool is too low. This case was not taken into account in the development of this PI.

4.4.2 Riverine Reaches

In Saskatchewan, riverine water supply and fish habitat is improved when additional minimum flow rules are implemented. Although the plots show change to the Agricultural Damages PI, the magnitude of change to agricultural impacts is not significant in any given year.

From Lake Darling to Westhope, PI results are similar to those seen in Phase 2 Alternative 5. As expected, the Fish Mortality PI shows the greatest benefit, as flows are maintained above 0 cfs much more often. Fish and wildlife habitat, riverine water supply, boating safety, and water quality also show improvement from baseline. These improvements are all due to the drastic reduction in the occurrences of very low flow in the river.

Downstream of Westhope, low flows are largely governed by releases from the J. Clark Salyer National Wildlife Refuge. When Lake Darling's pool is very low, it does not pass as much water downstream to J. Clark Salyer. Consequently, the refuge pools do not pass as much excess water to Manitoba.

In general, the number of years each PI is significantly impacted in each riverine reach is similar in both the 4 cfs (0.1 cms) and 15 cfs (0.4 cms) scenarios. However, the magnitude of impacts is much greater in the 15 cfs (0.4 cms) scenarios. For example, in the Sherwood to Mouse River Park reach, flows are kept above the critical threshold for fish kill prevention (10 cfs, 0.3 cms) approximately twice as often when the 15 cfs (0.4 cms) minimum flow rule is applied relative to when the 4 cfs (0.1 cms) rule is applied.

It is important to note the baseline simulation does not include many operational rules for Lake Darling. Generally, when the reservoir is below 1597 ft, the baseline model does not release any water from the reservoir. This leads to more days of 5 cfs or less than have historically occurred under real reservoir operation. If the model outputs from Alternative 310 were compared to the observed record, the PIs would likely show less improvement.

5. Additional Analysis (Phase 3.5)

After modeling of Alternative 310 and presentation of results at the August face-to-face meeting in Bismarck, ND, the Plan Formulation Committee decided to do additional analysis of Lake Darling's capacity for minimum flows, particularly the level at which minimum releases should be turned off. This analysis, performed in Phase 3.5, was deemed necessary before a decision could be made regarding whether or not minimum flows would be pursued in Phases 4 and 5.

A simple analysis of the baseline ResSim model run indicated Lake Darling falls below 1594 ft, a critical elevation for the maintenance of fish and wildlife habitat, approximately 50% of years in the period of record. Approximately 25% of years the reservoir's minimum elevation was below 1591 ft. Several experimental ResSim simulations were run with minimum flows of 4, 10, and 20 cfs, along with cut-off elevations ranging from 1590 to 1596 ft. These simulations suggested Lake Darling has the volumetric capacity to maintain some sort of minimum flow, likely 20 cfs or less, for extended durations as long as the basin is not in severe drought. Minimum flows greater than 20 cfs were not simulated, because a volumetric analysis of the baseline simulation indicated Lake Darling would likely have to release more than 10,000 additional ac-ft of water each year to maintain higher minimum flows, reducing the reservoir's pool elevation by over 1 ft per year.

While Lake Darling may be large enough to maintain minimum flows of 20 cfs or less in most years, it is unclear exactly when that minimum flow should be lowered or ceased. Lake Darling is owned and operated by the U.S. Fish and Wildlife Service (USFWS) as a national wildlife refuge and provides water supply for the J. Clark Salyer National Wildlife Refuge downstream. According to the USFWS, environmental factors other than reservoir elevation, such as temperature, season, and tributary flows play a role in the magnitude of minimum flows that can be released from Lake Darling during non-flood years. In recent years, the USFWS has attempted to maintain a minimum release of 20 cfs from Lake Darling and will likely continue to do so in the future.

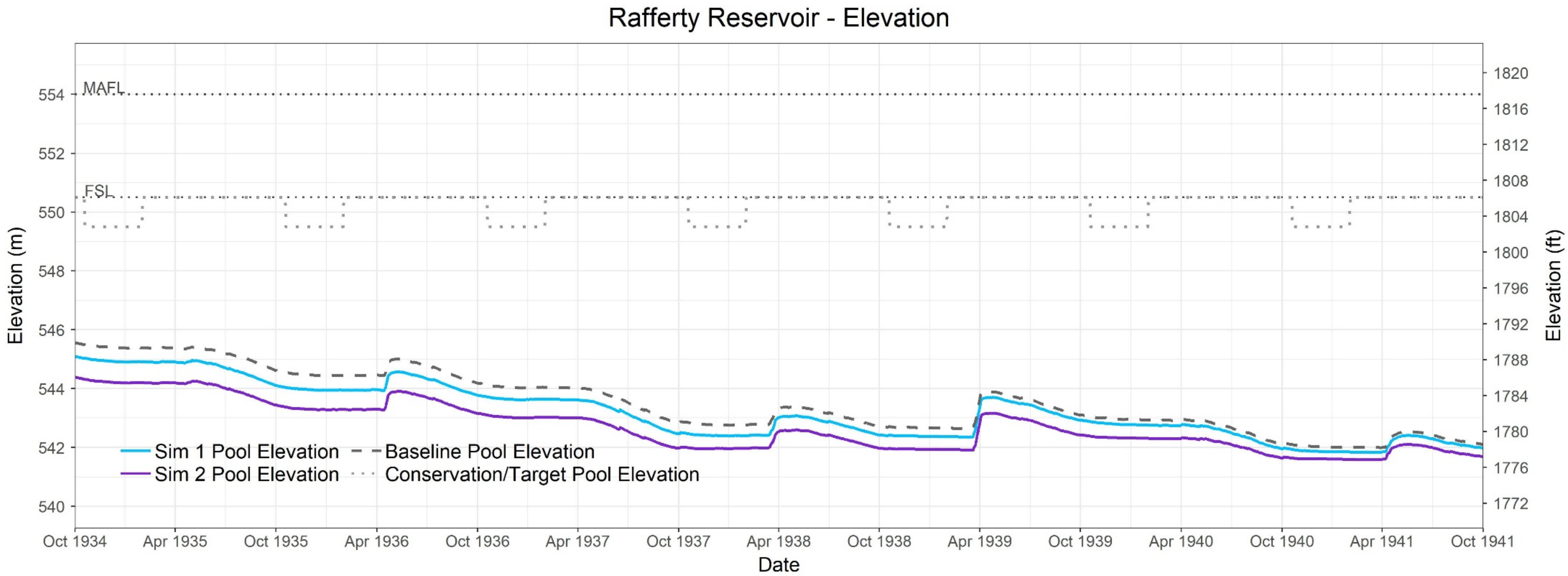
6. Path Forward

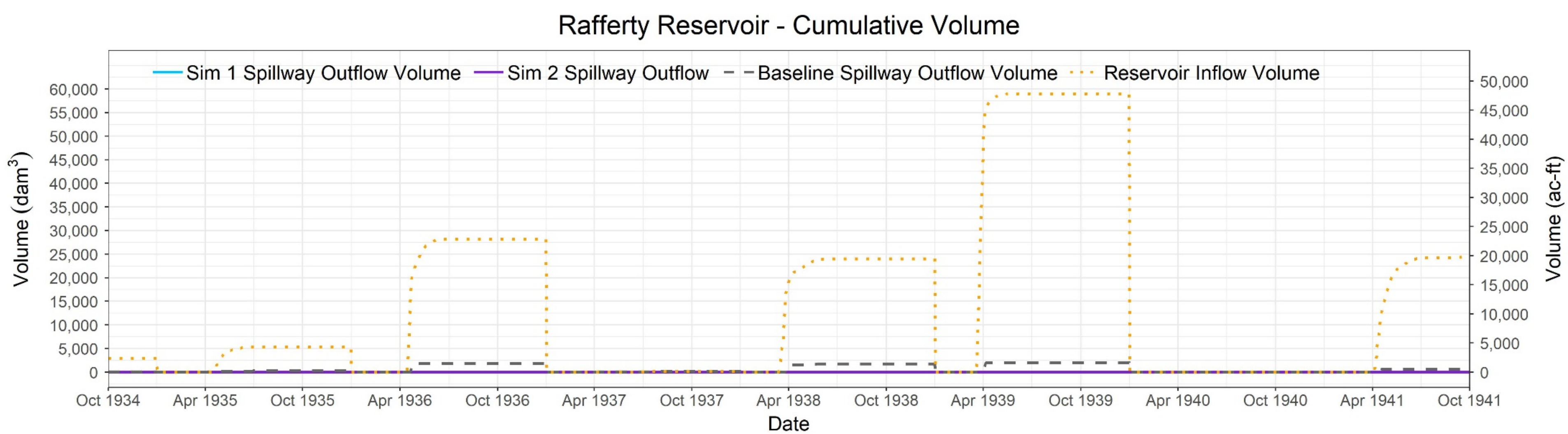
Due to the substantial risk to water supply, as well as regulations that could make reservoir operators in Saskatchewan susceptible to litigation if minimum flows were increased and then allowed to cease, this alternative is not recommended to be carried forward into Phase 4 for the Saskatchewan reservoirs. At Lake Darling, although investigative modeling showed maintaining some sort of minimum flow, likely 20 cfs or less, is attainable in most years, more research outside the scope of this study is required before pool elevation-based minimum flow rules could be included in an international agreement. If agencies in North Dakota complete this research prior to Phase 5, minimum flows from Lake Darling could be included in Phase 5 alternatives.

7. References

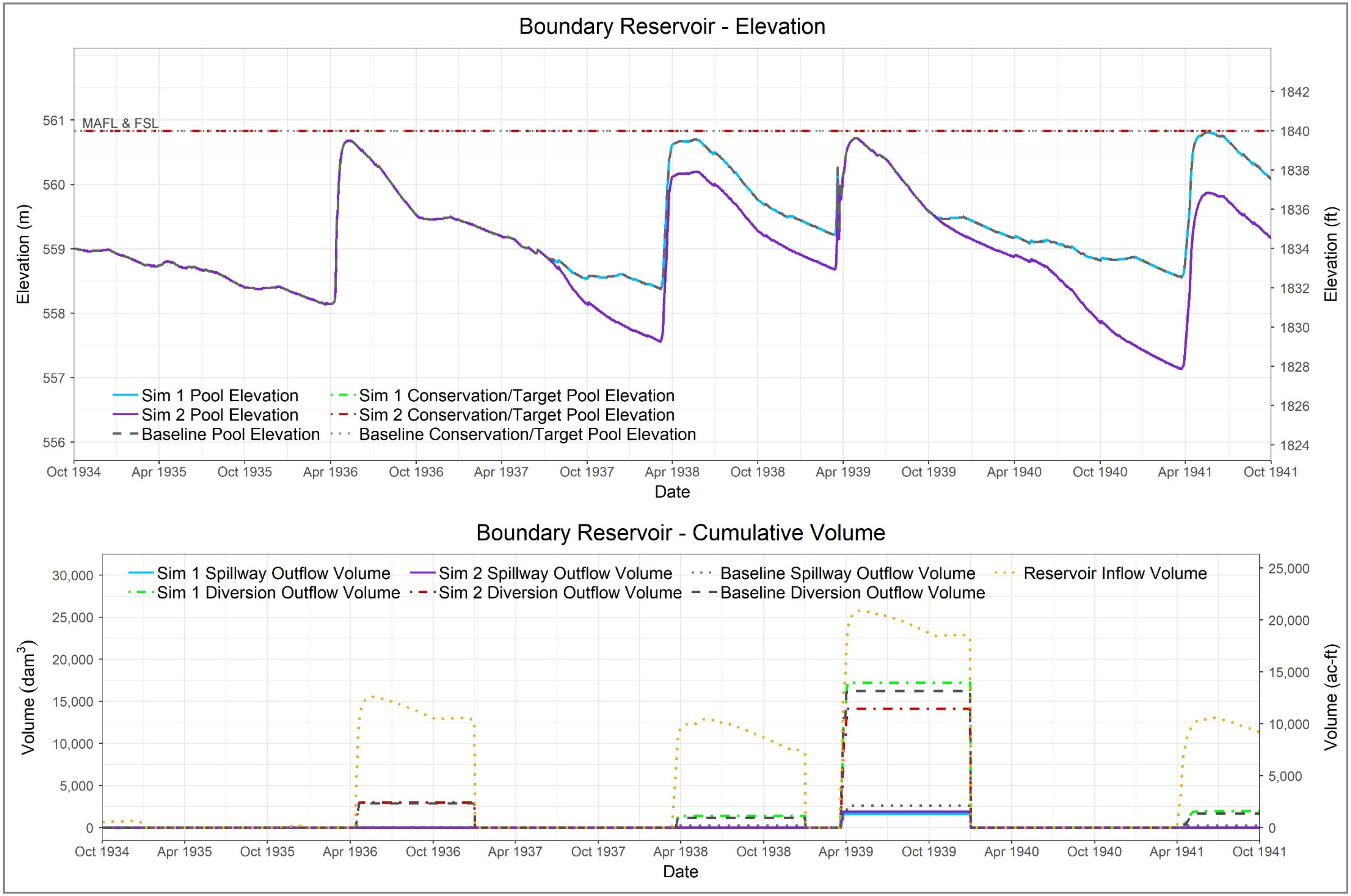
1. "HEC-DSSVue," U.S Army Corps of Engineers, Hydraulic Engineering Center, February 2010.
2. "HEC-ResSim, Reservoir System Simulation, Version 3.3", U.S Army Corps of Engineers, Hydraulic Engineering Center, December 2018.
3. Canada and USA, 1989. Agreement between the Government of Canada and the United States for Water Supply and Flood Control in the Souris River Basin.
4. Canada and USA, 2000. Interim Measures As Modified For Apportionment of the Souris River.

Plate 01	Reservoirs – 1935-1943 (drought)	Alternative 310 (Phase 3) Souris River Plan of Study





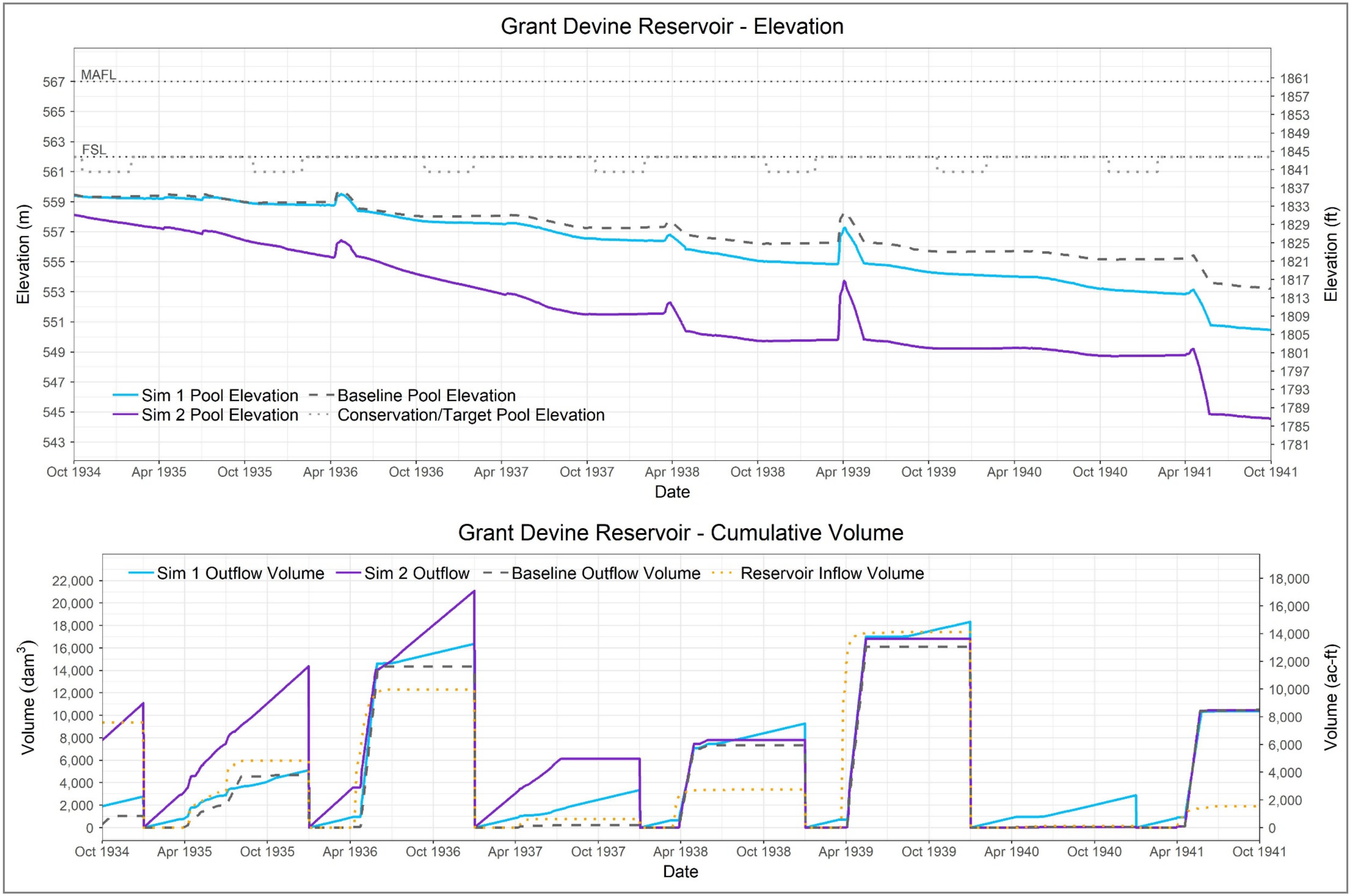
***Sim1** = 4 cfs minimum flow (SK only, Normal Pool), **Sim2** = 15 cfs minimum flow (SK only, Normal Pool)*



***Sim1** = 4 cfs minimum flow (SK only, Normal Pool)*

***Sim2** = 15 cfs minimum flow (SK only, Normal Pool)*

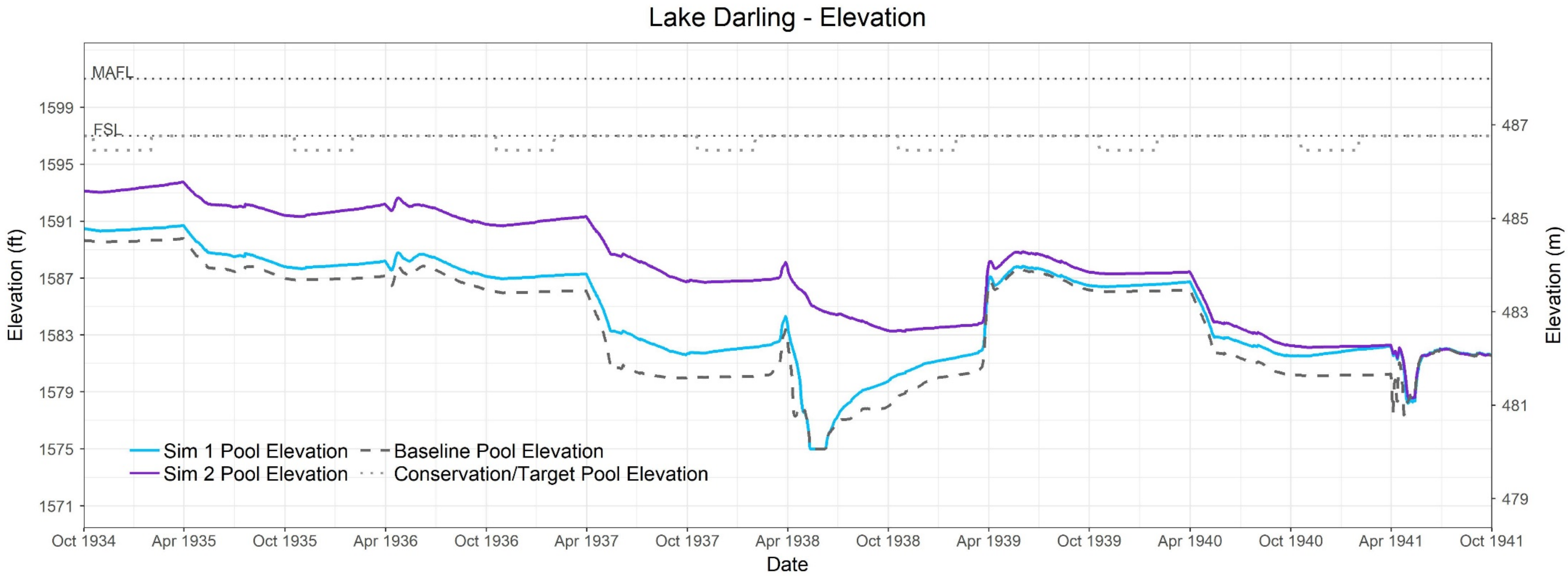
MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

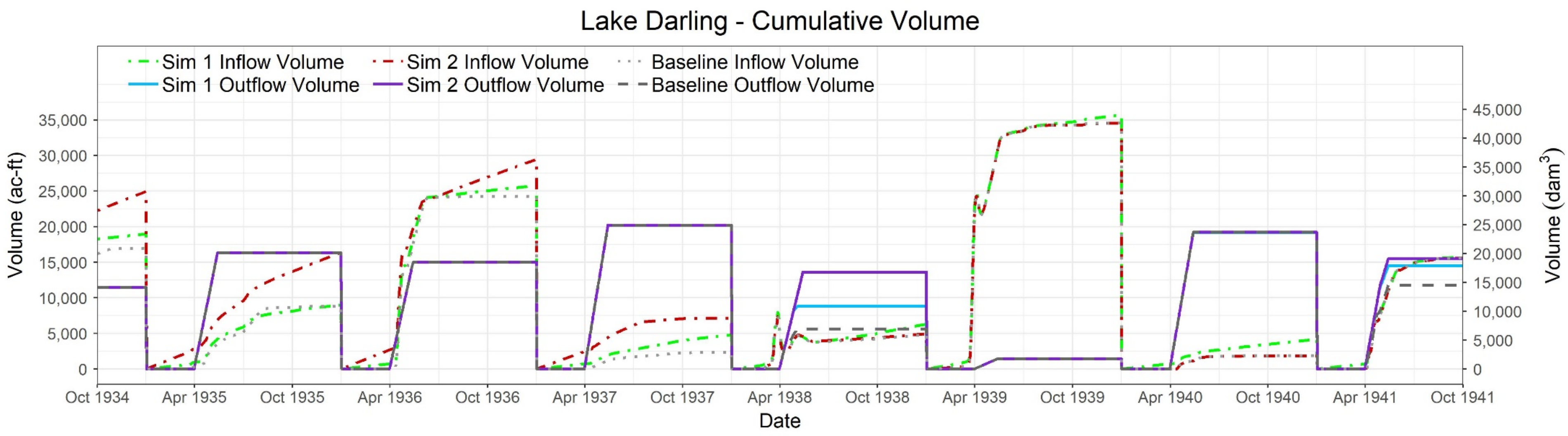


Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

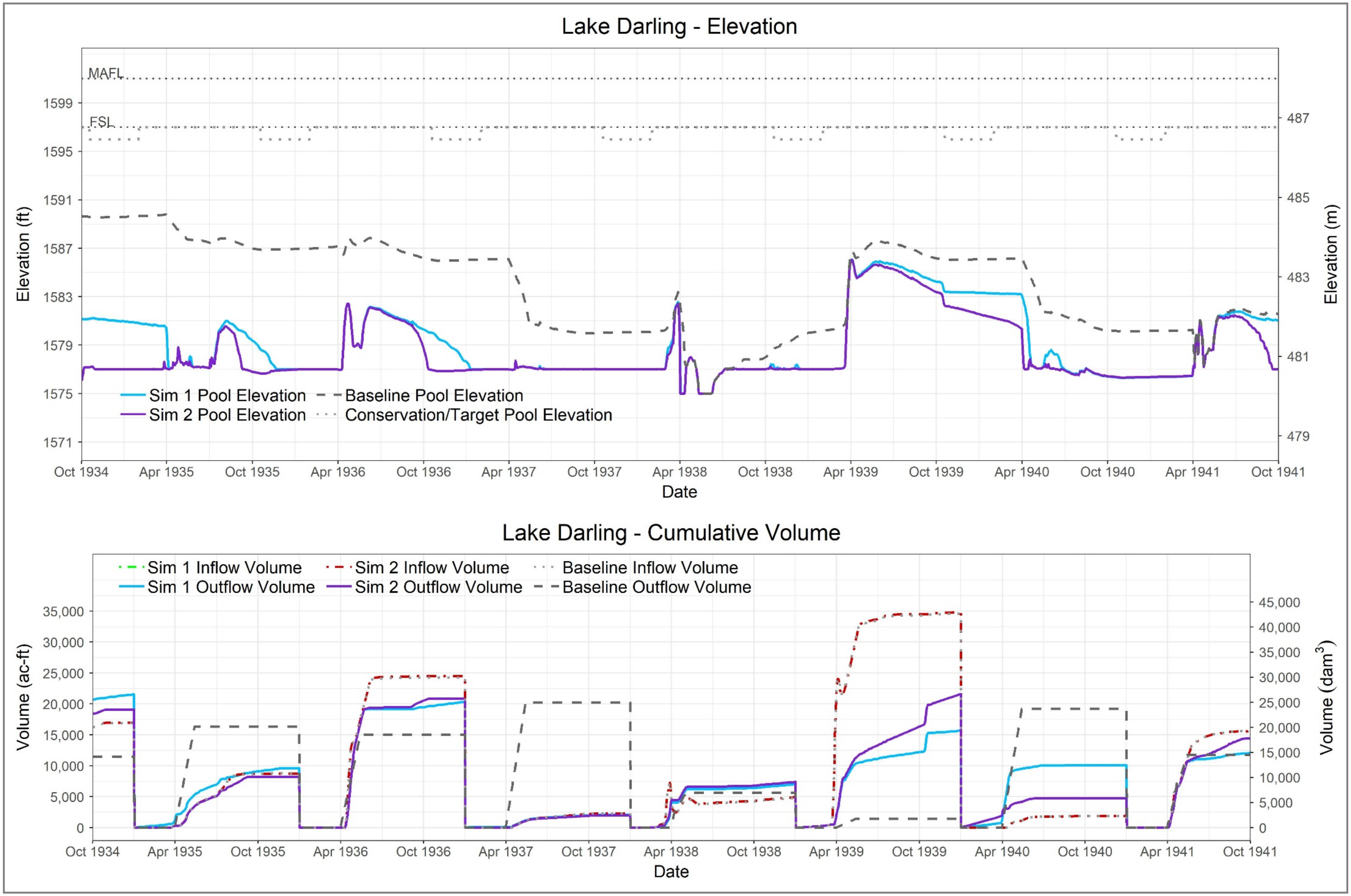




Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level



Sim1 *= 4 cfs minimum flow (ND only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (ND only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

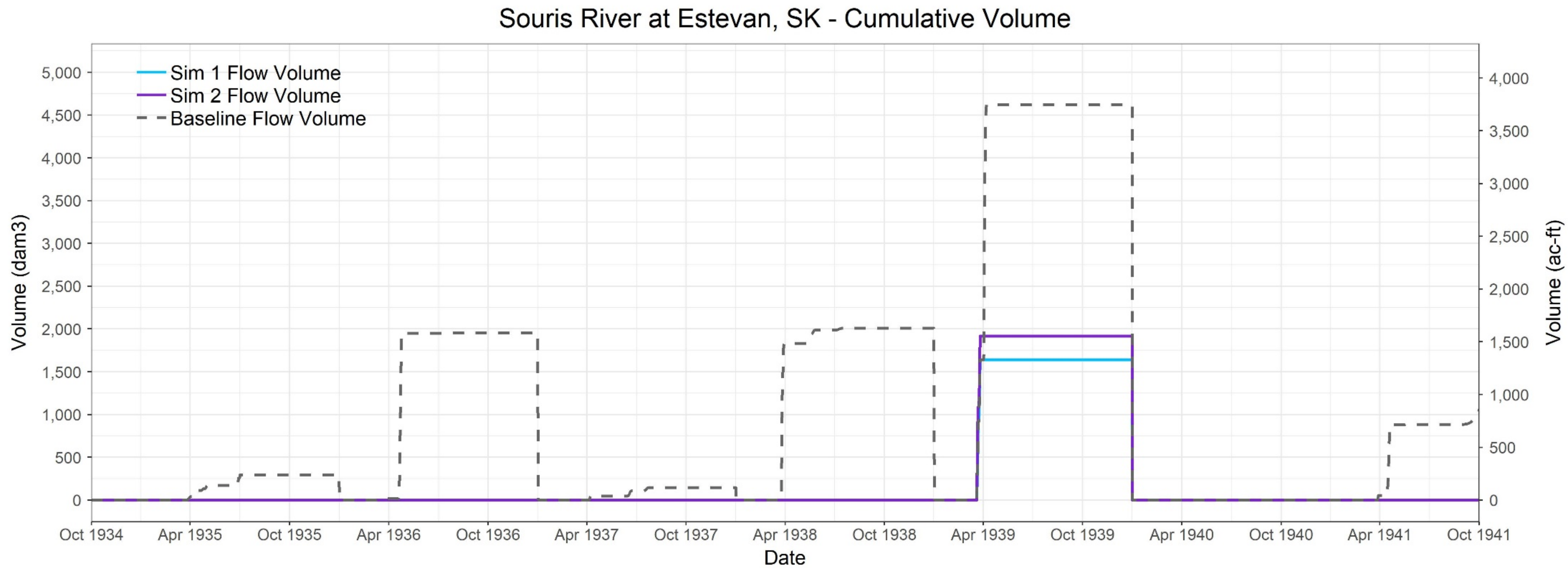
Plate 02

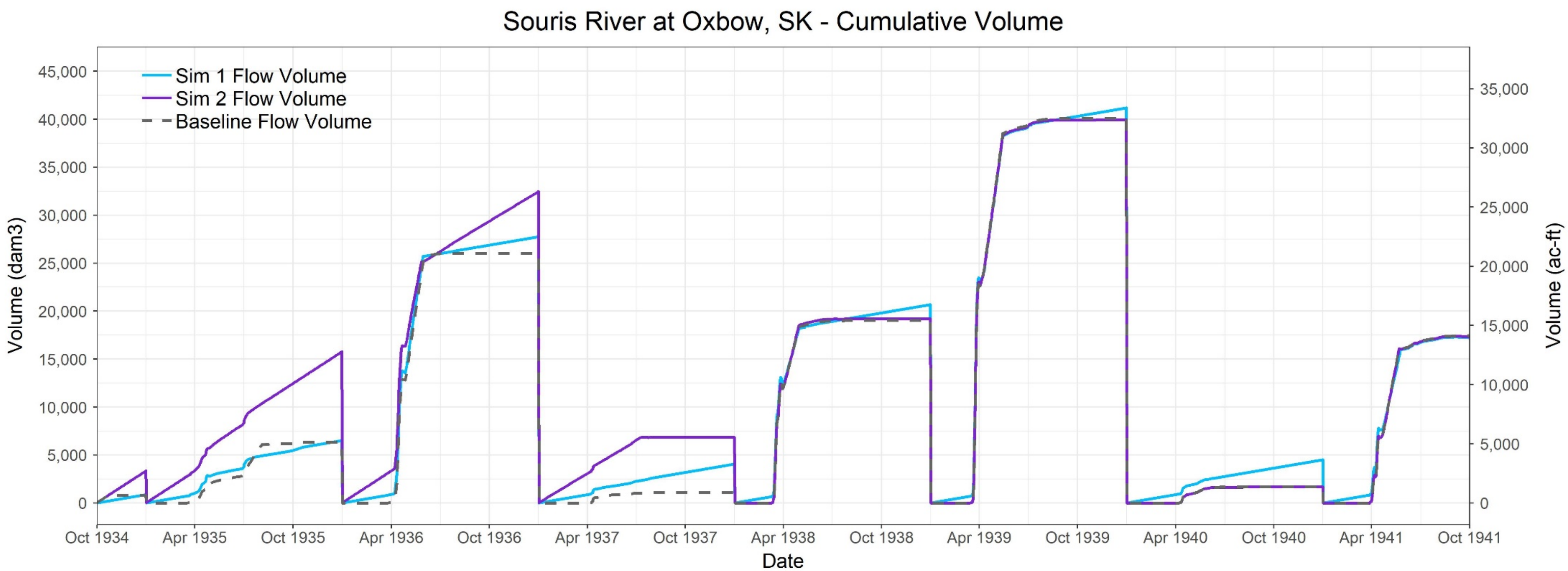
Critical Flow Locations – 1935-1943 (drought)

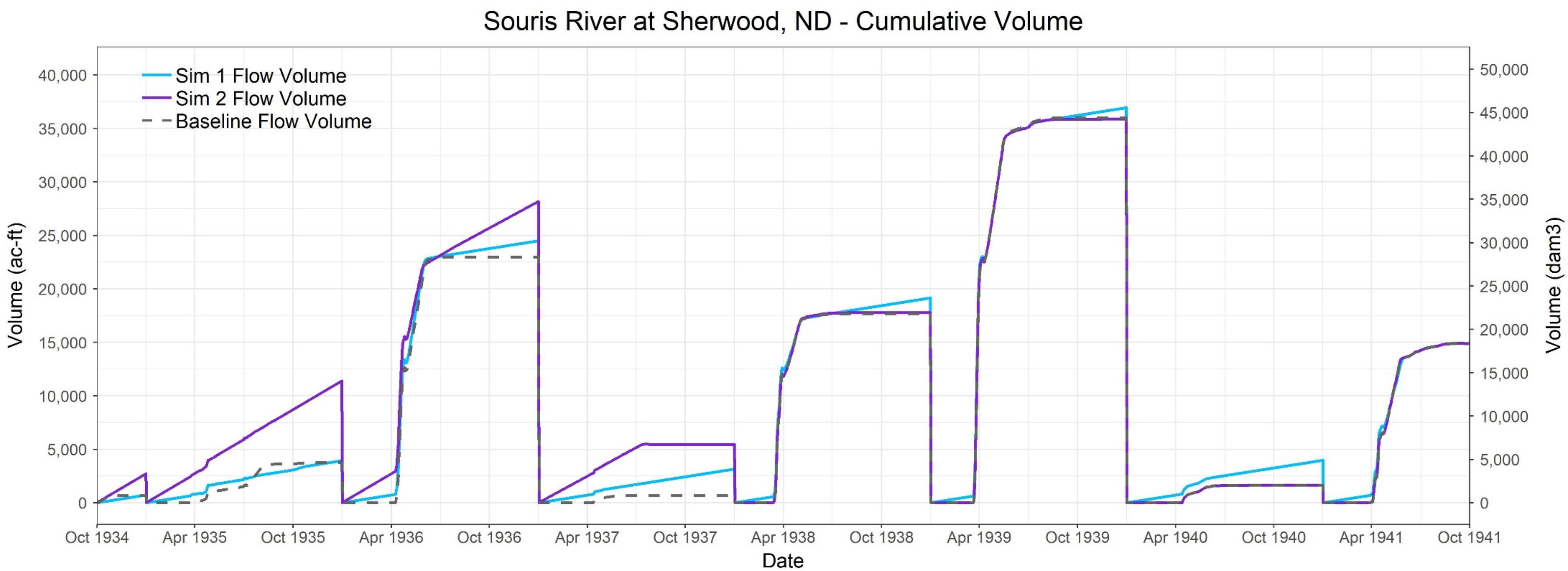
Alternative 310 (Phase 3)

Souris River Plan of Study

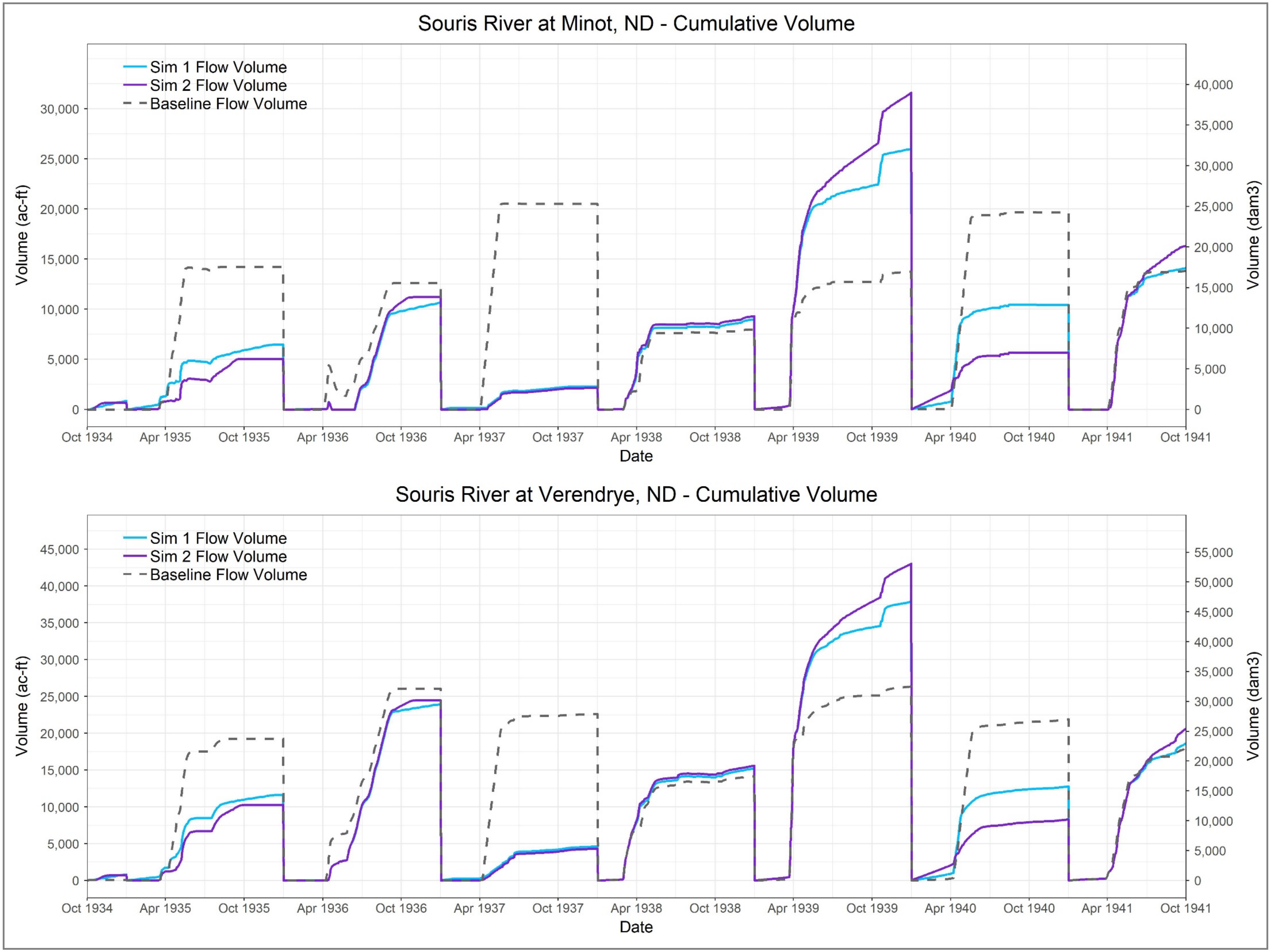
Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*
Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*



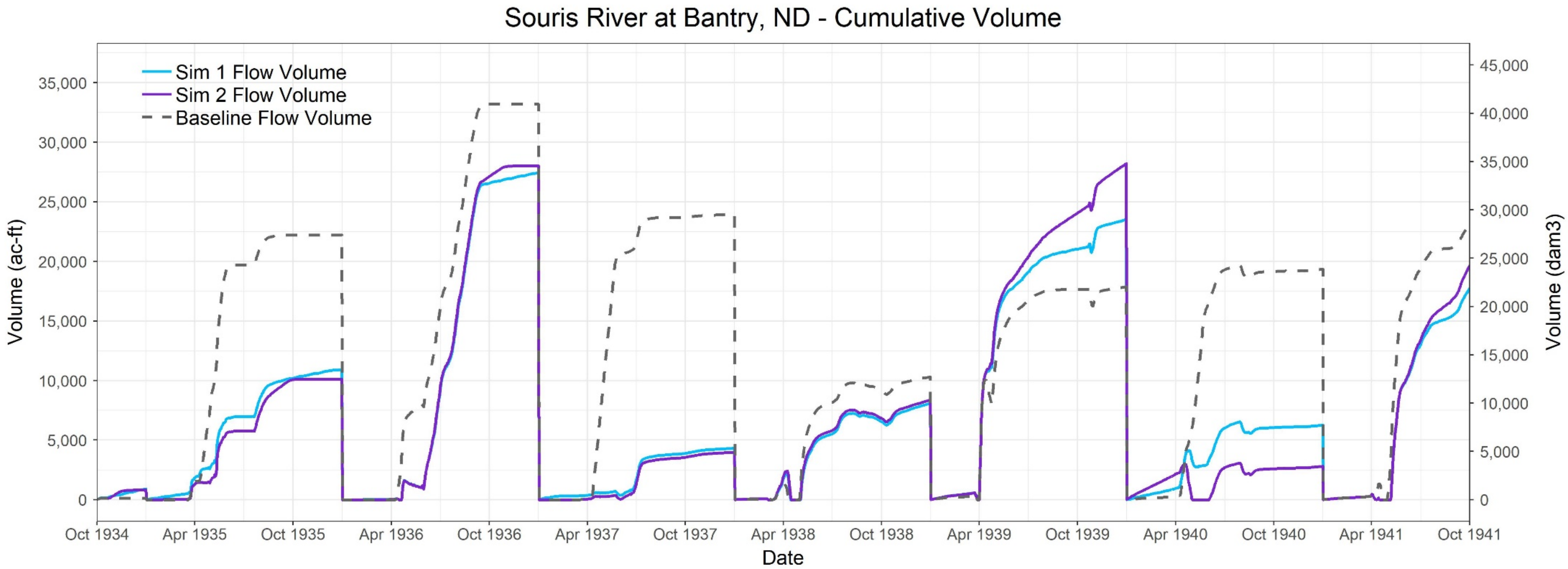


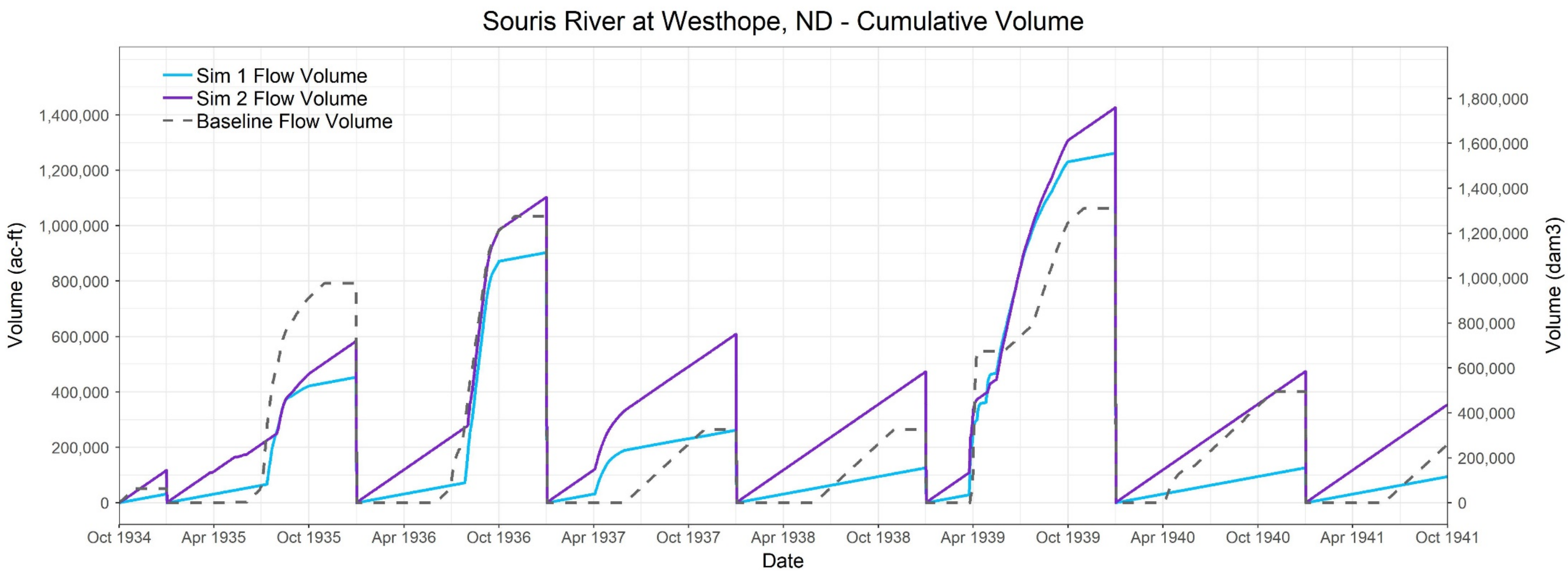


***Sim1** = 4 cfs minimum flow (SK only, Normal Pool), **Sim2** = 15 cfs minimum flow (SK only, Normal Pool)*



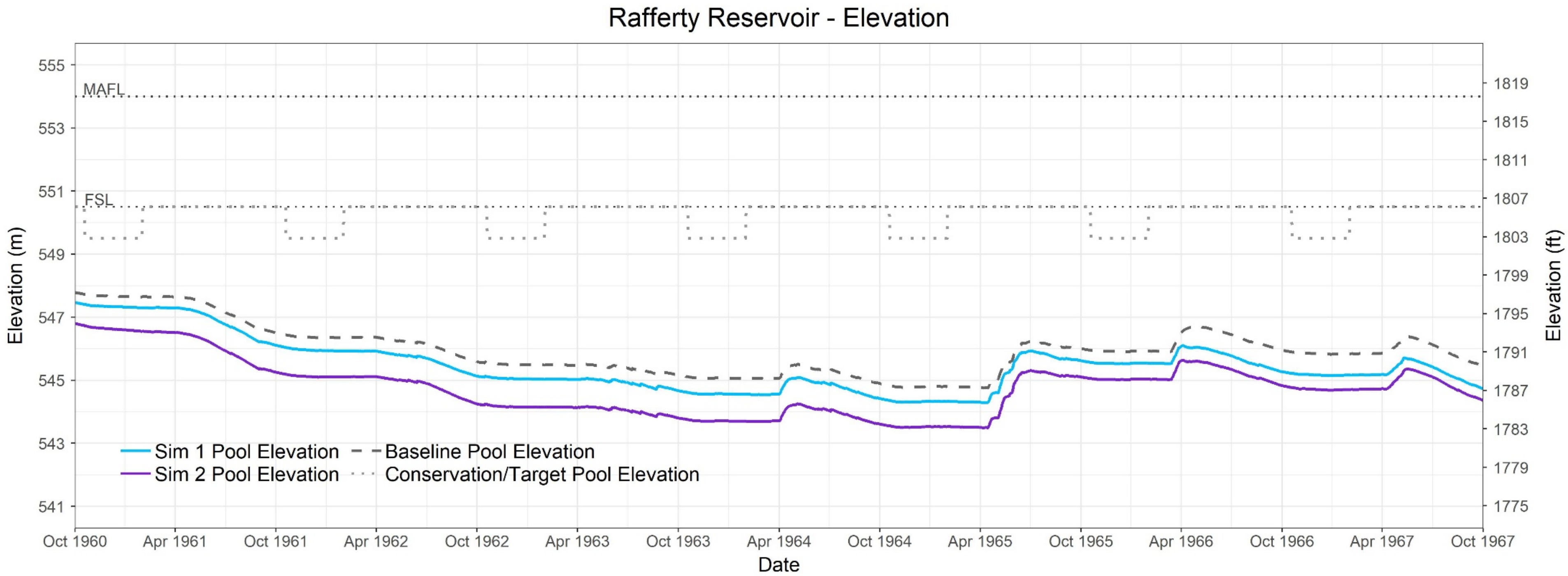
***Sim1** = 4 cfs minimum flow (ND only, Normal Pool), **Sim2** = 15 cfs minimum flow (ND only, Normal Pool)*

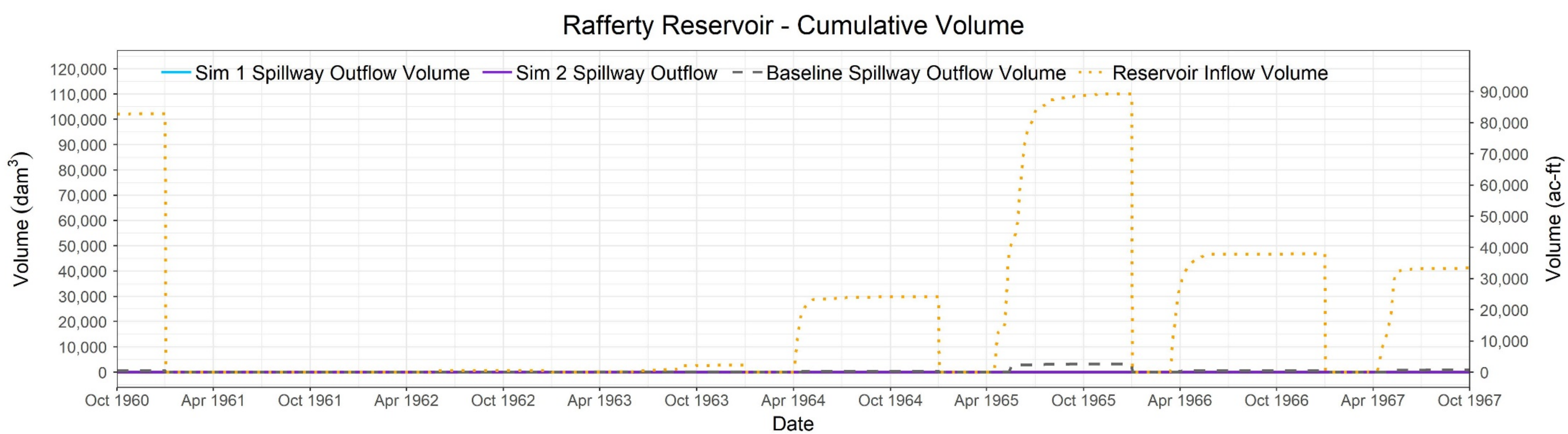




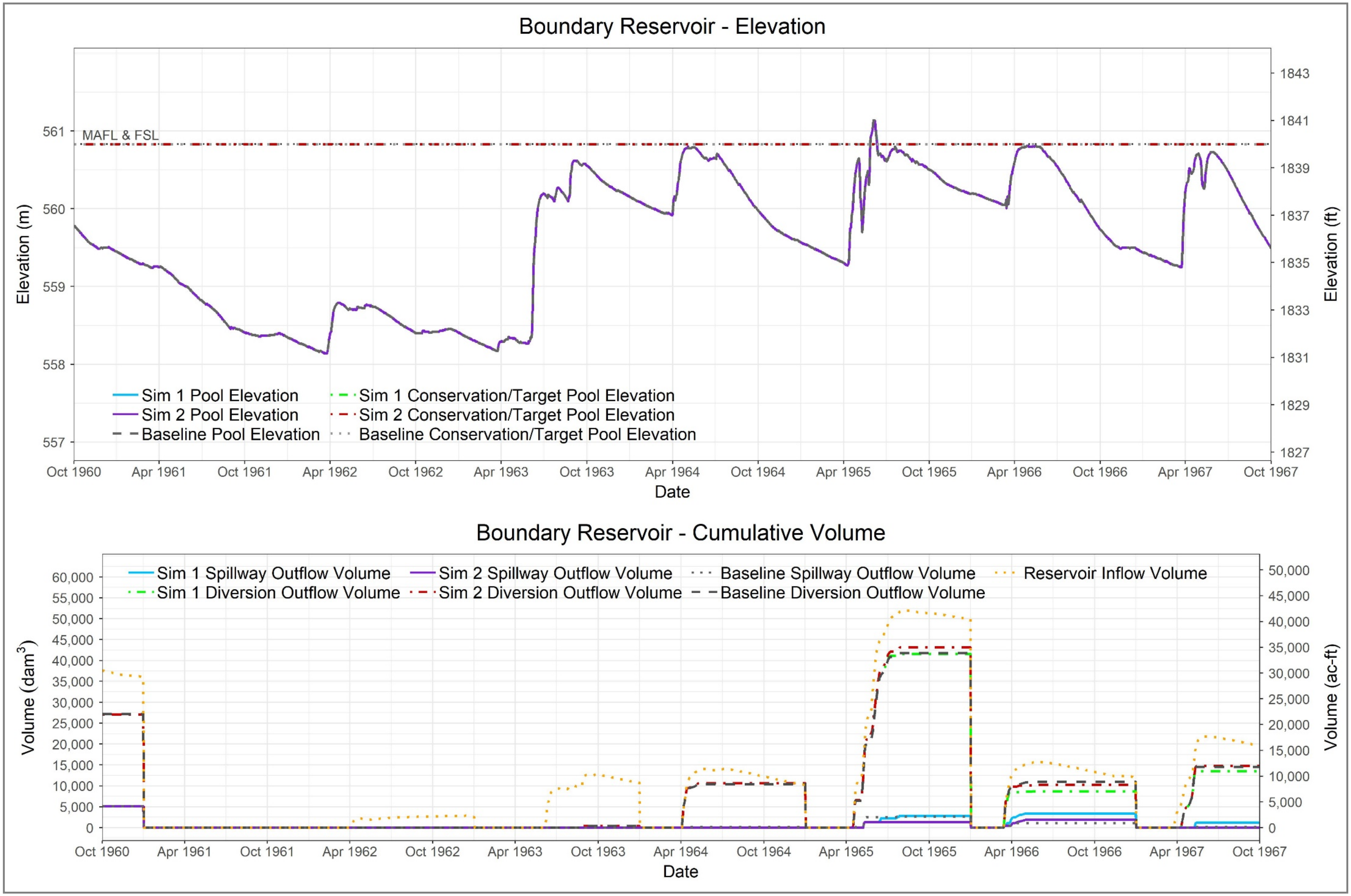
Sim1 *= 4 cfs minimum flow (ND only, Normal Pool),* ***Sim2*** *= 15 cfs minimum flow (ND only, Normal Pool)*

Plate 03	Reservoirs – 1961-1969 (drought)	Alternative 310 (Phase 3) Souris River Plan of Study





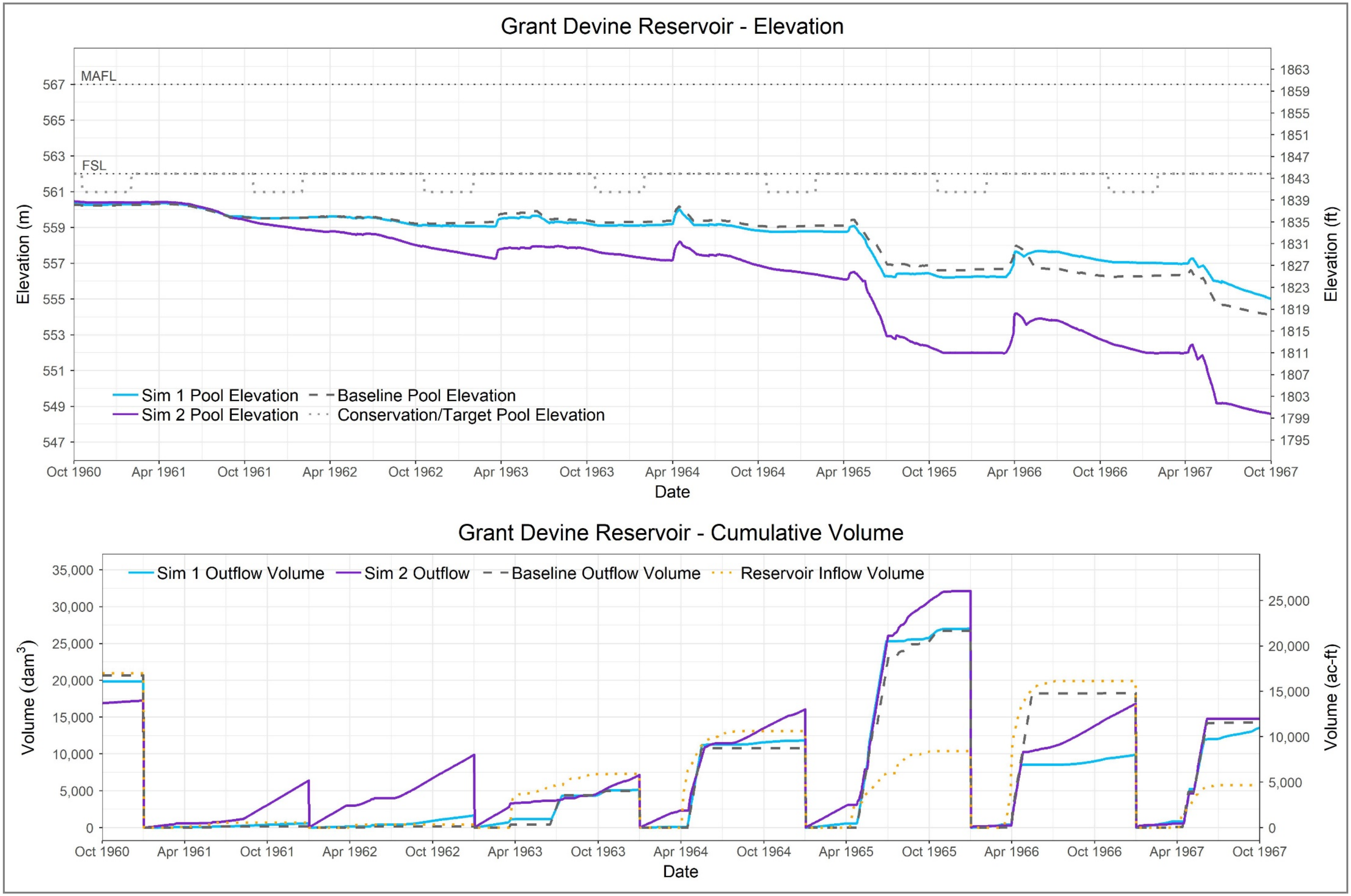
***Sim1** = 4 cfs minimum flow (SK only, Normal Pool), **Sim2** = 15 cfs minimum flow (SK only, Normal Pool)*



Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

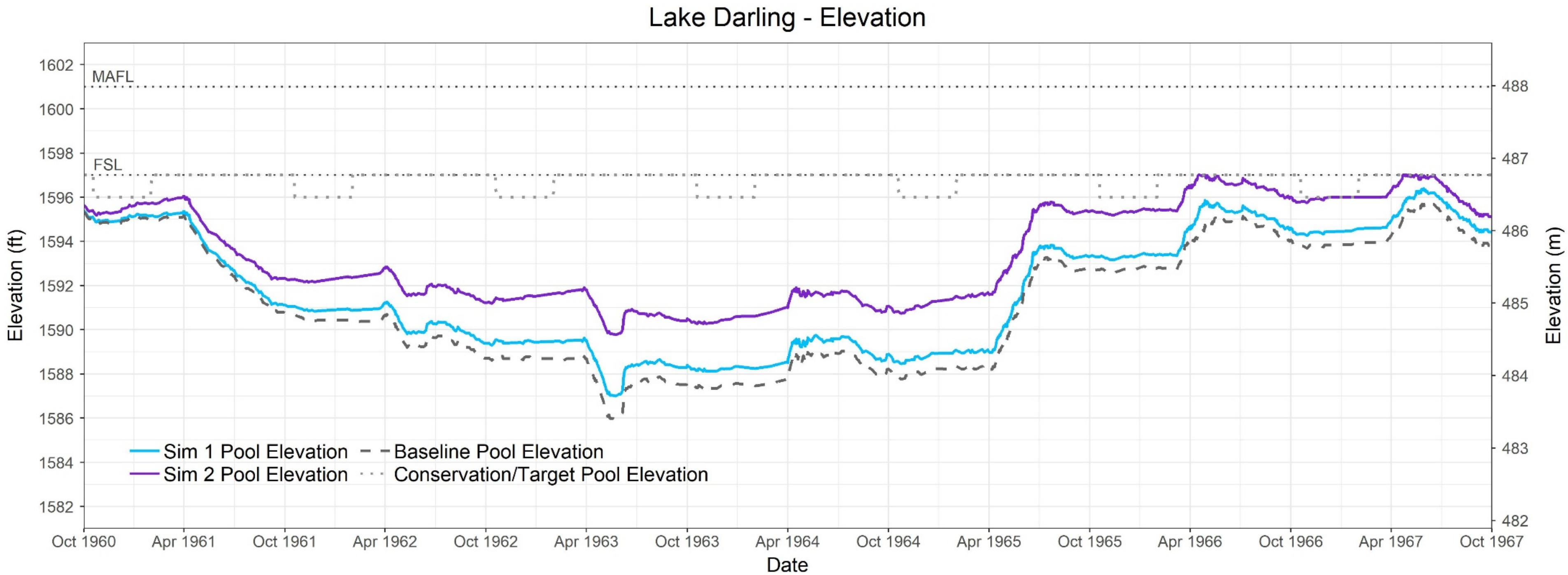
MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

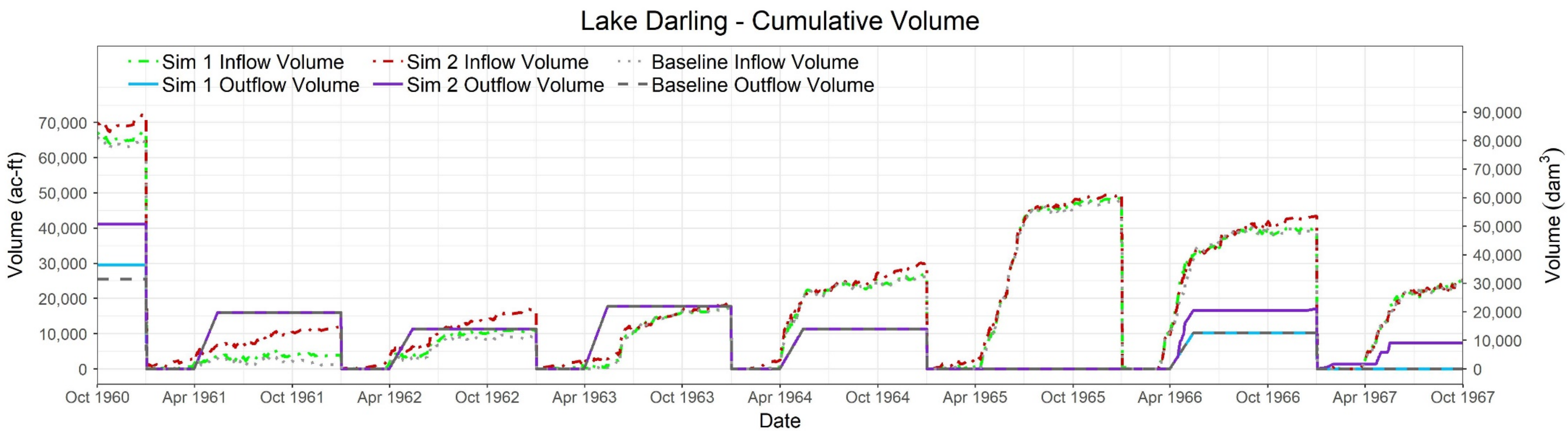


Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

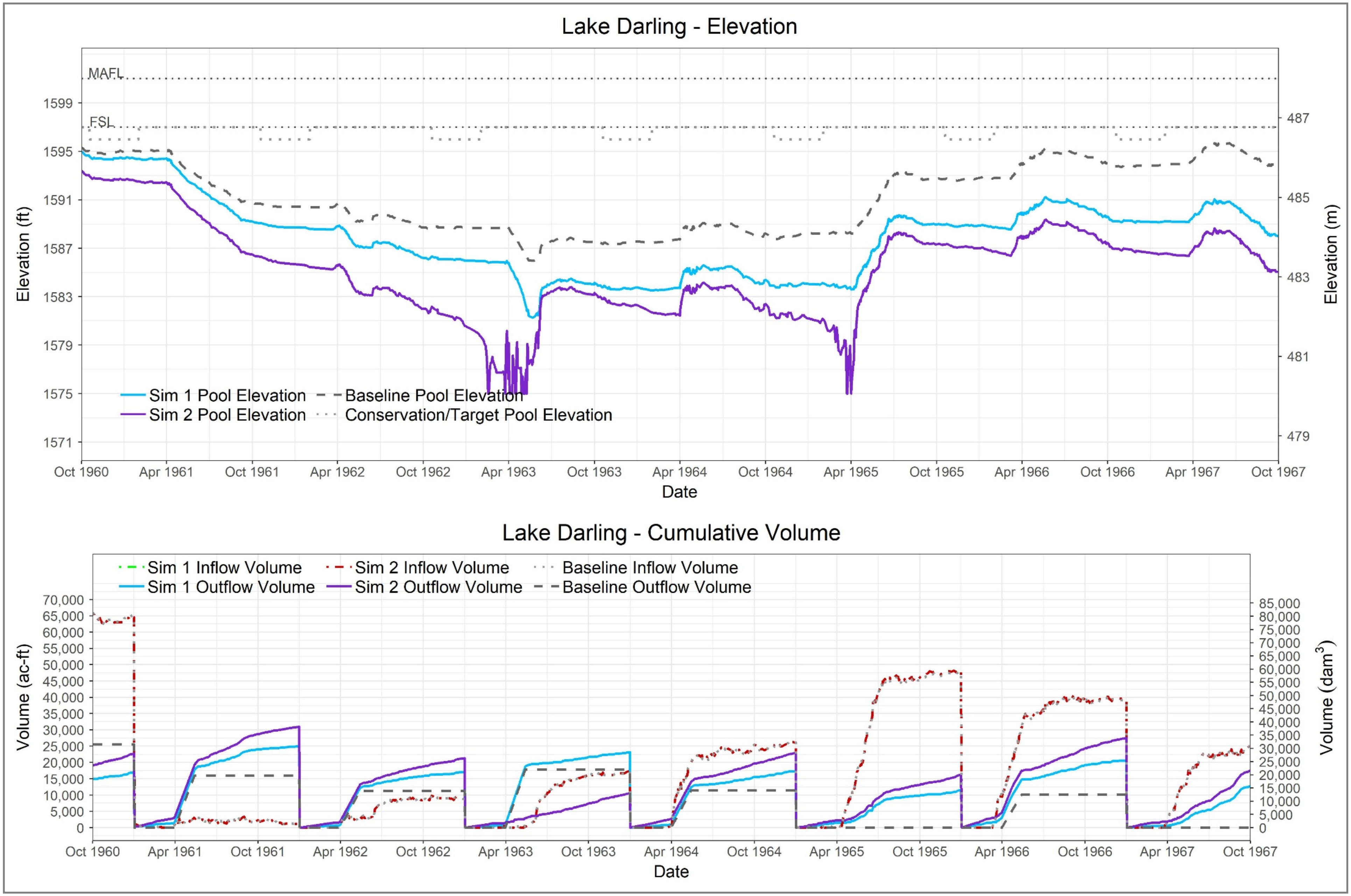




Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level



Sim1 *= 4 cfs minimum flow (ND only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (ND only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

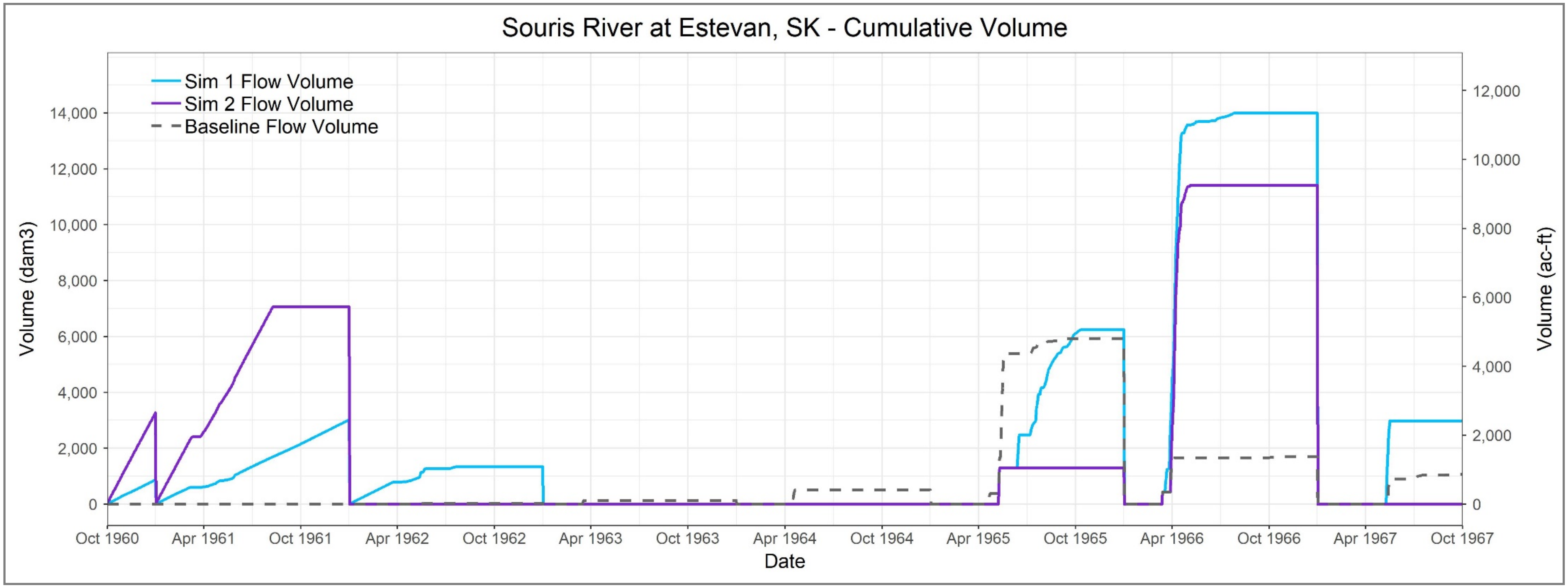
Plate 04

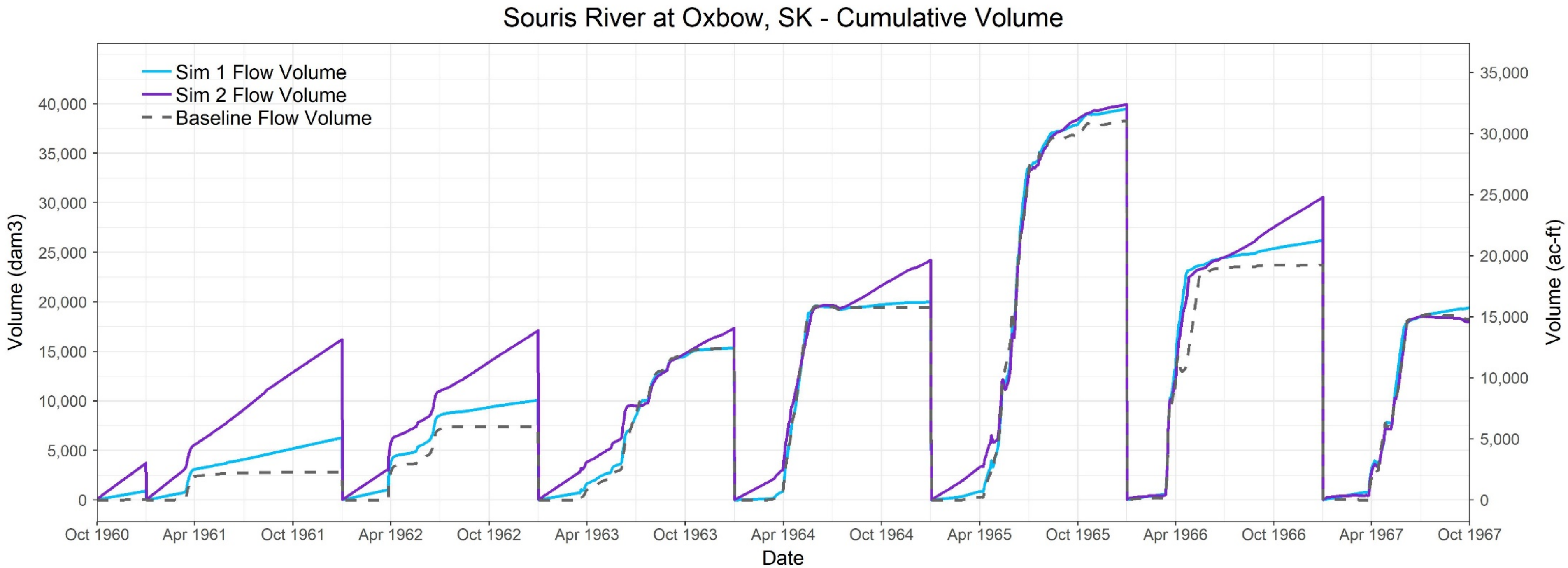
Critical Flow Locations – 1961-1969 (drought)

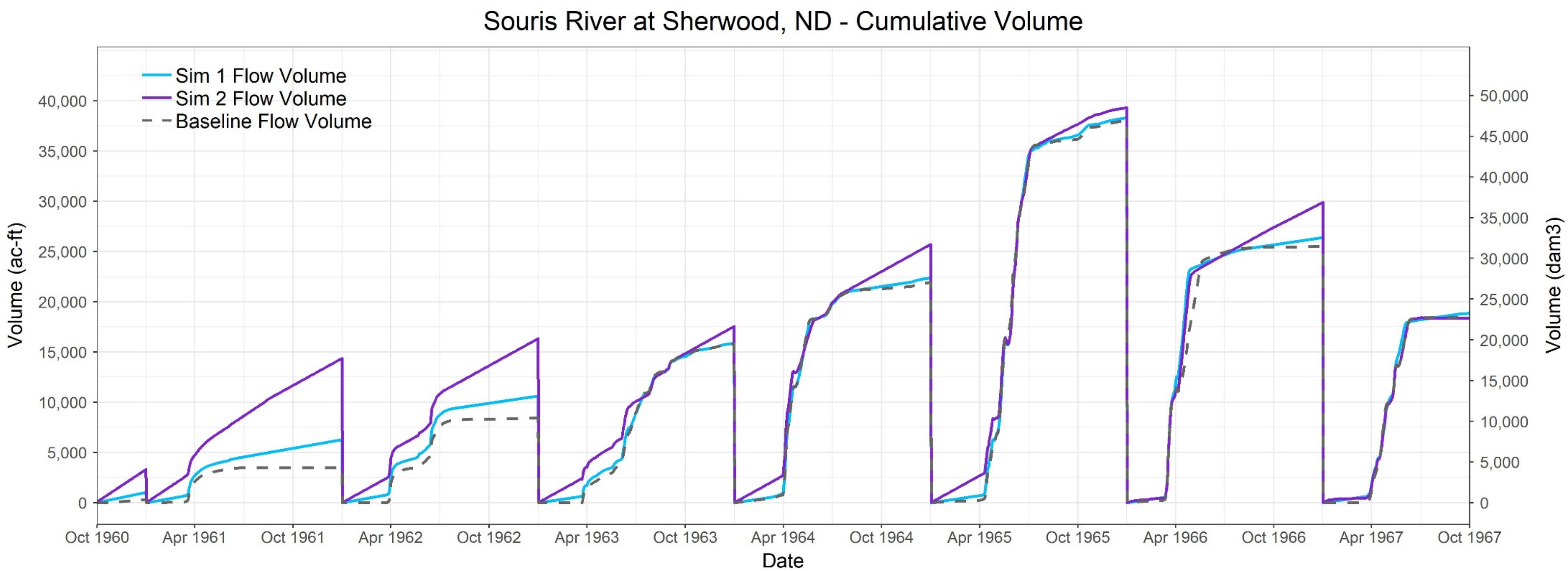
Alternative 310 (Phase 3)

Souris River Plan of Study

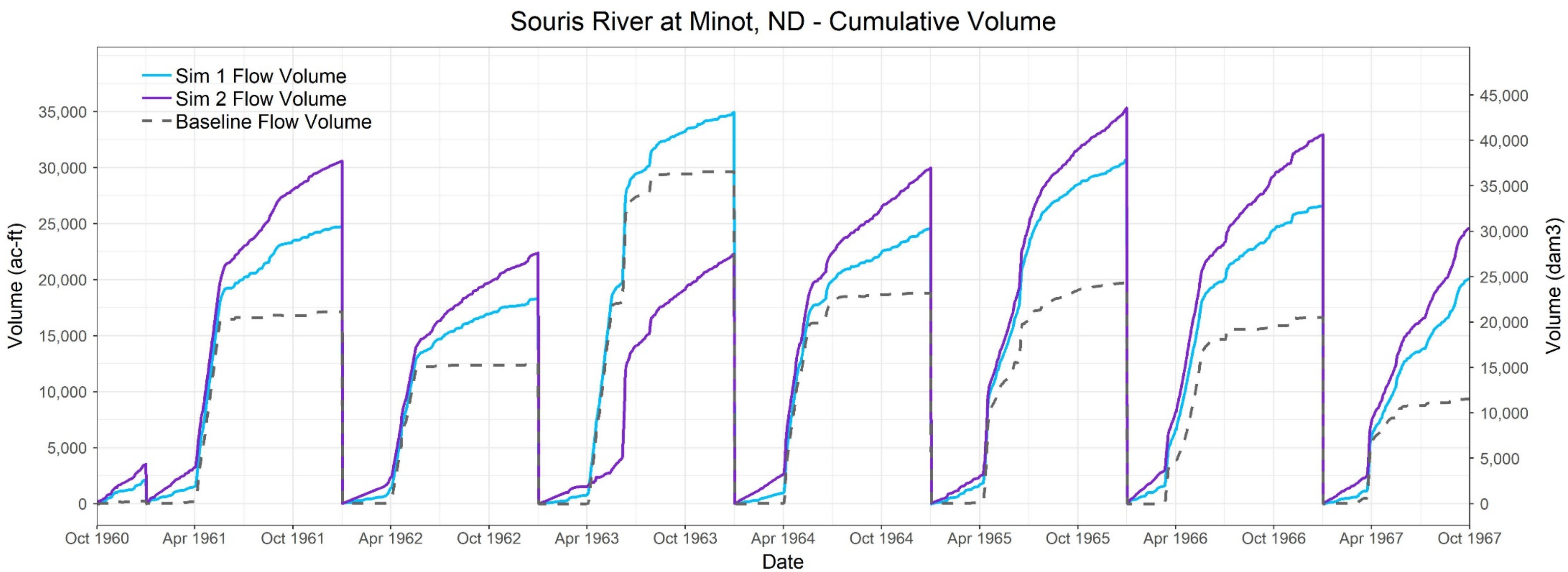
Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*
Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

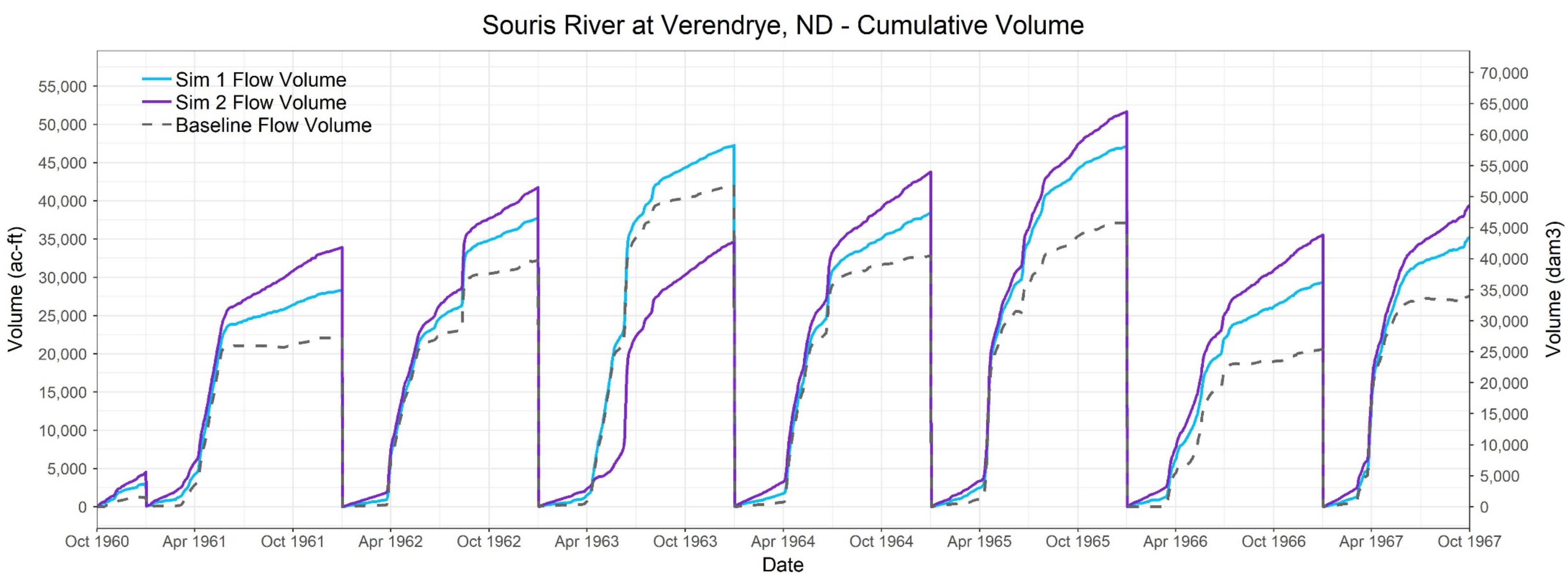




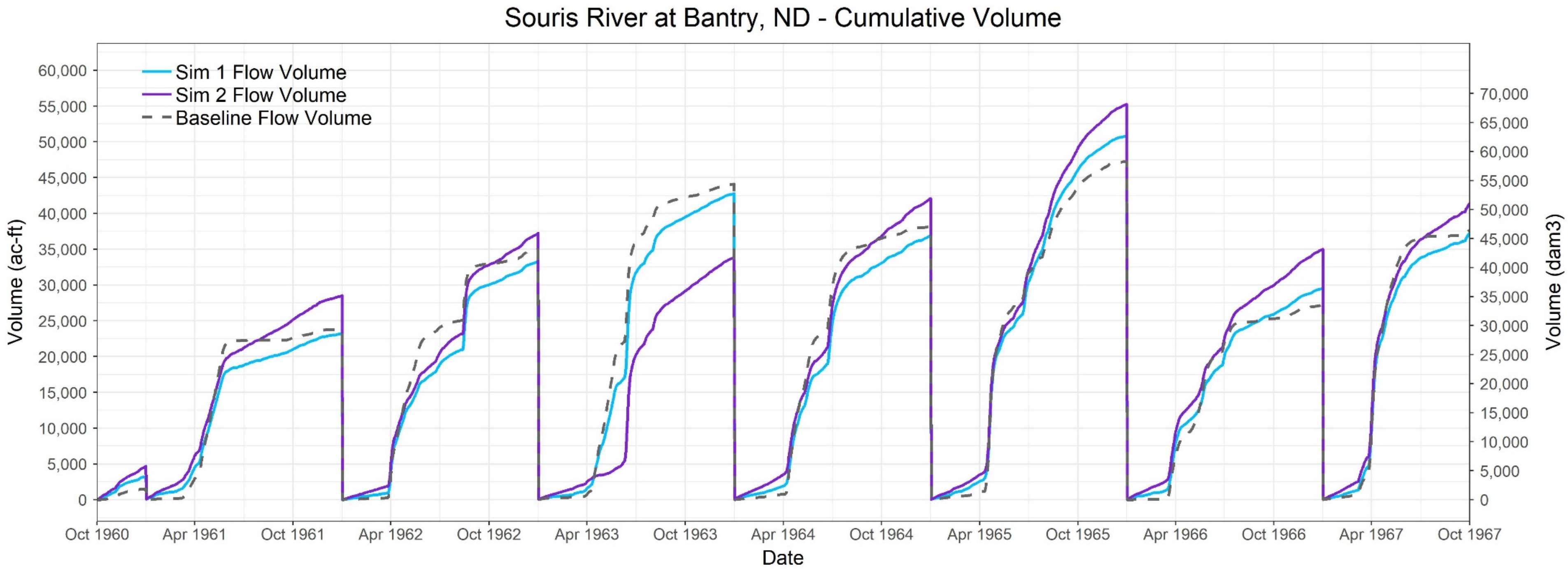


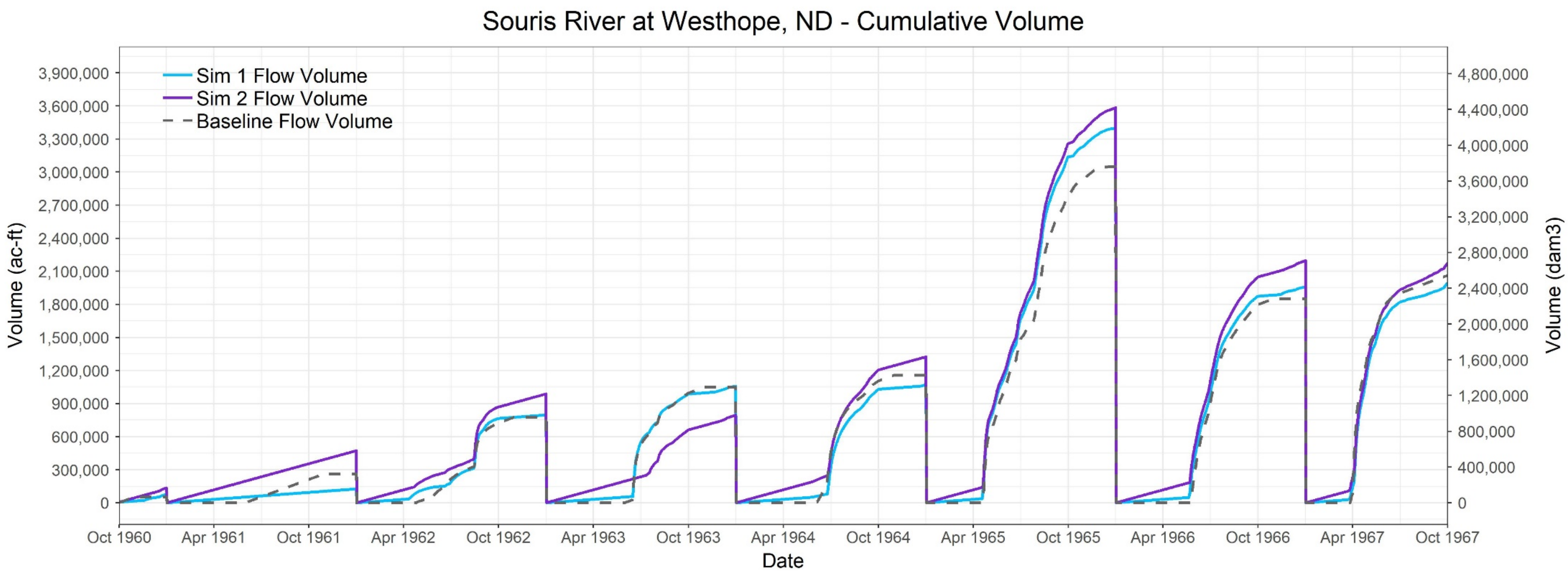
Sim1 *= 4 cfs minimum flow (SK only, Normal Pool),* ***Sim2*** *= 15 cfs minimum flow (SK only, Normal Pool)*





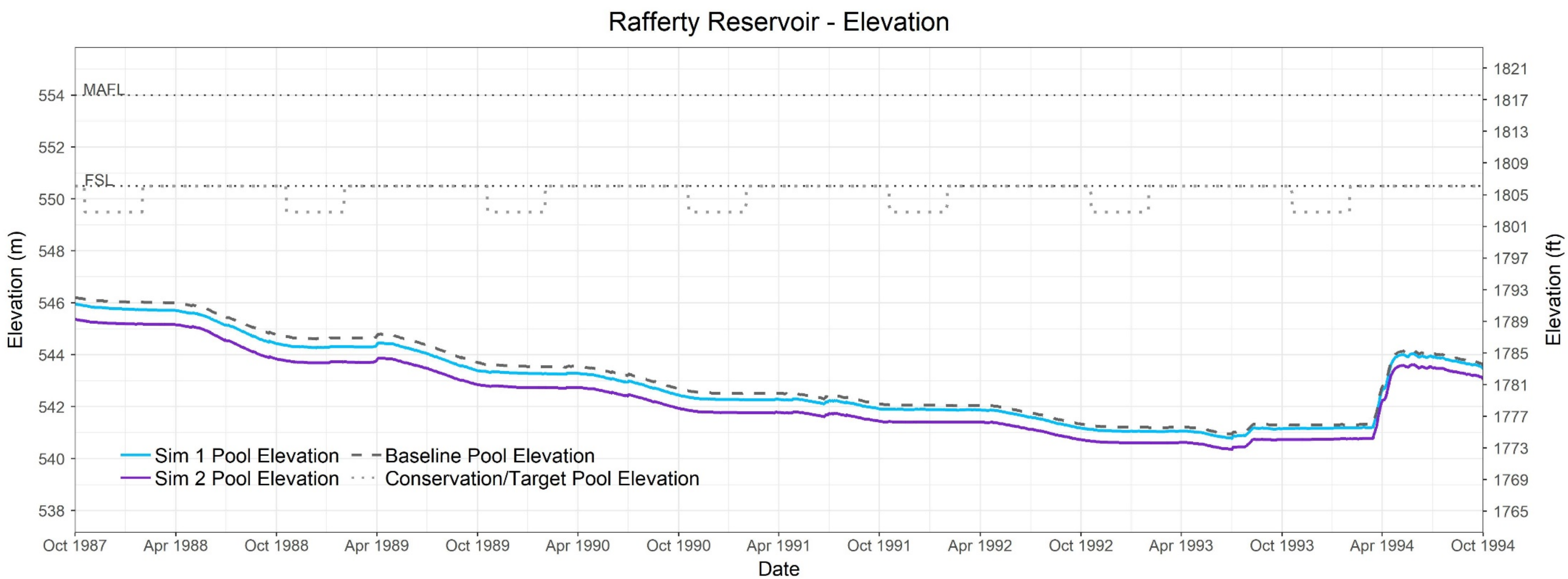
***Sim1** = 4 cfs minimum flow (ND only, Normal Pool), **Sim2** = 15 cfs minimum flow (ND only, Normal Pool)*

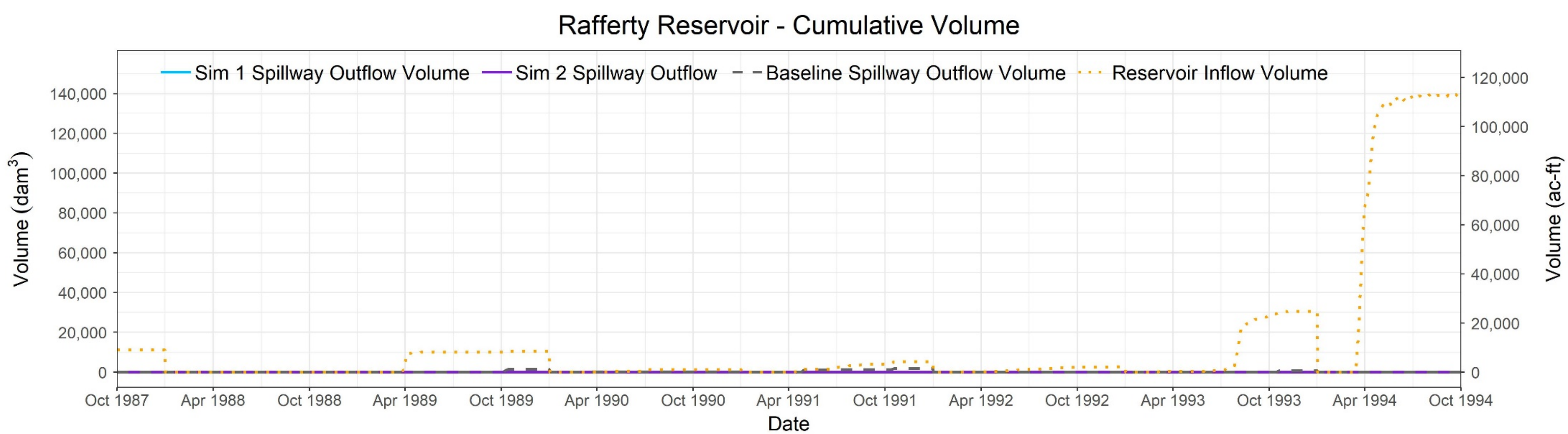




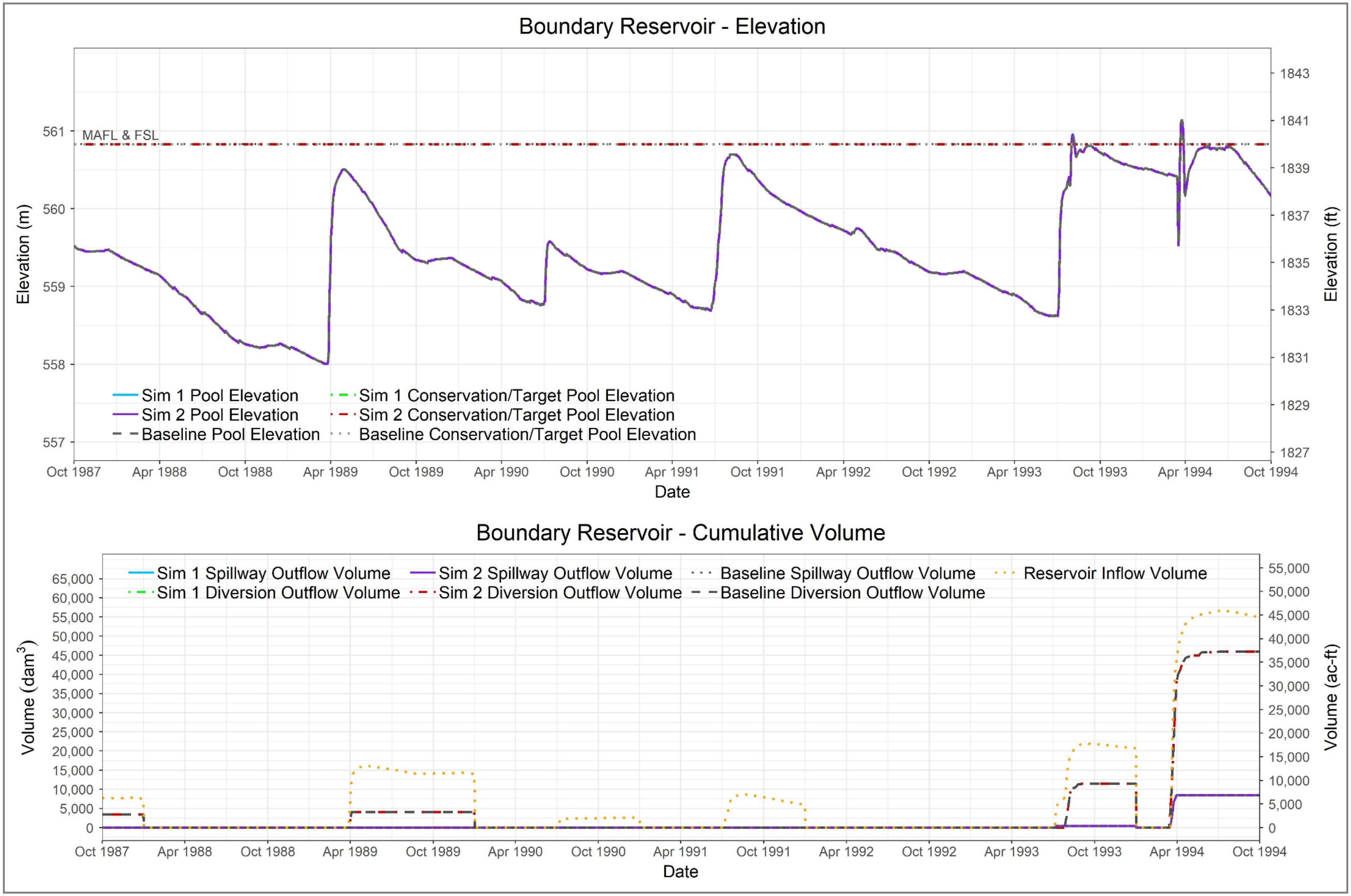
Sim1 *= 4 cfs minimum flow (ND only, Normal Pool),* ***Sim2*** *= 15 cfs minimum flow (ND only, Normal Pool)*

Plate 05	Reservoirs – 1988-1996 (drought)	Alternative 310 (Phase 3) Souris River Plan of Study





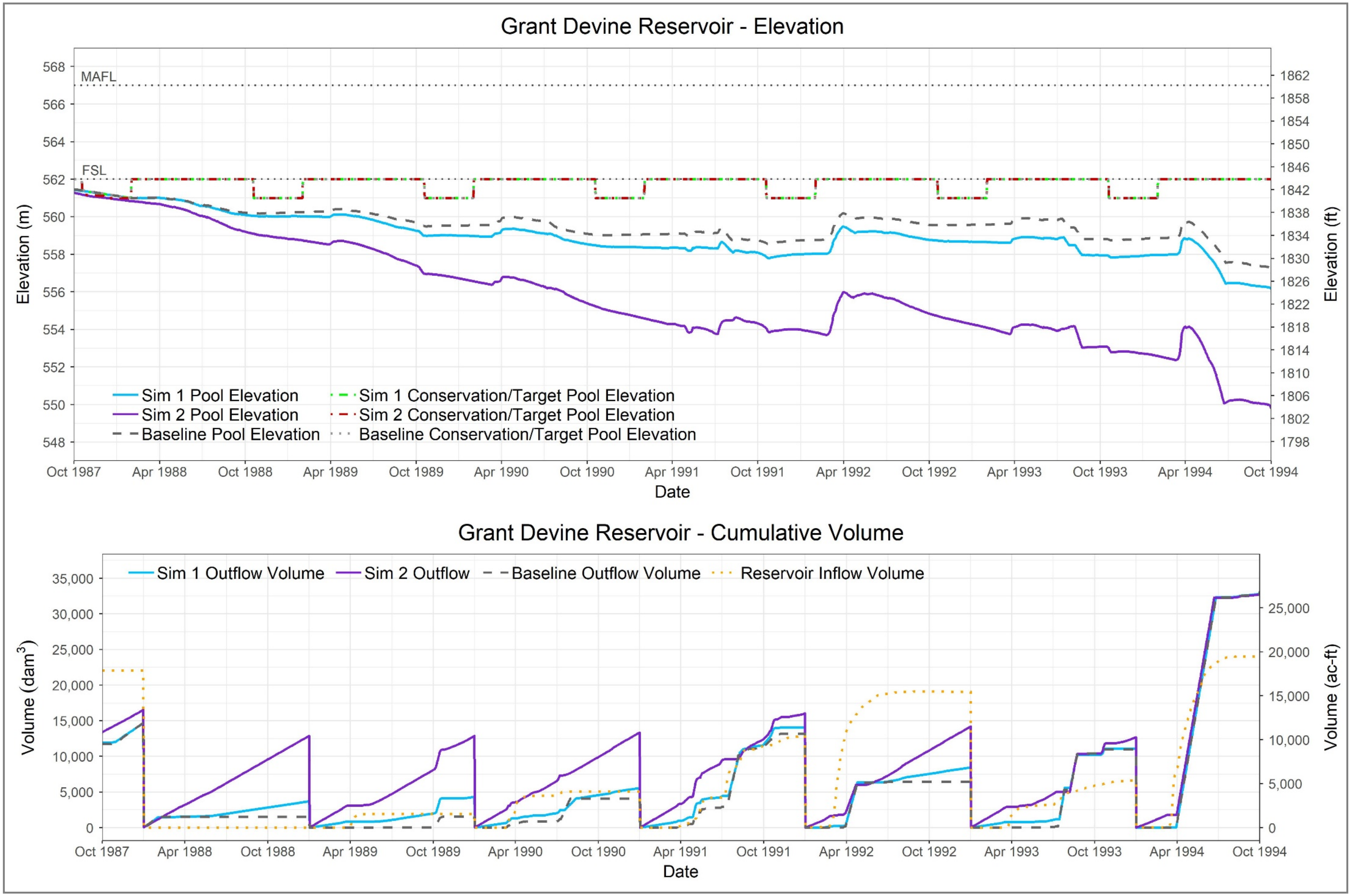
***Sim1** = 4 cfs minimum flow (SK only, Normal Pool), **Sim2** = 15 cfs minimum flow (SK only, Normal Pool)*



Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

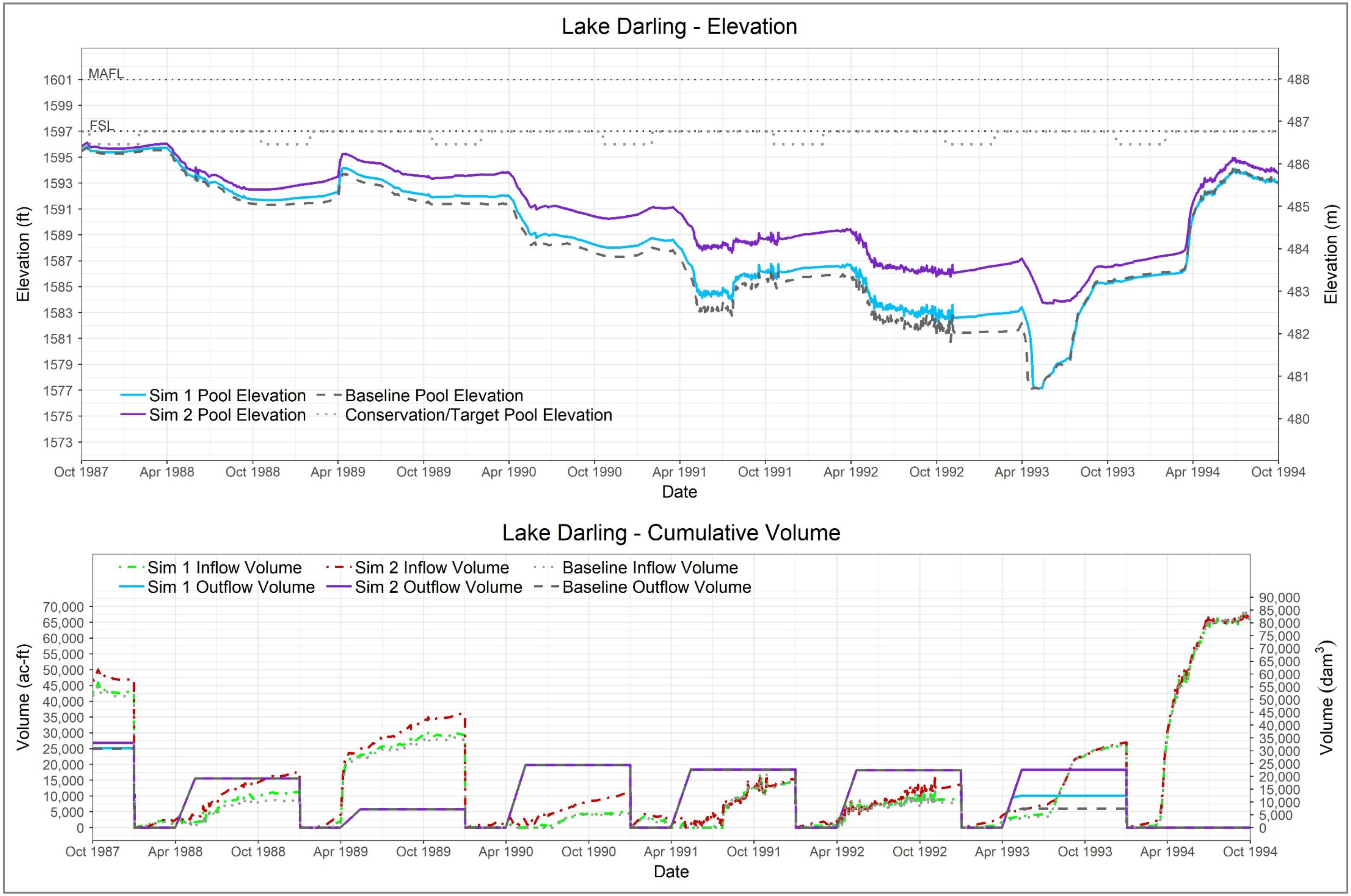
MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level



Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

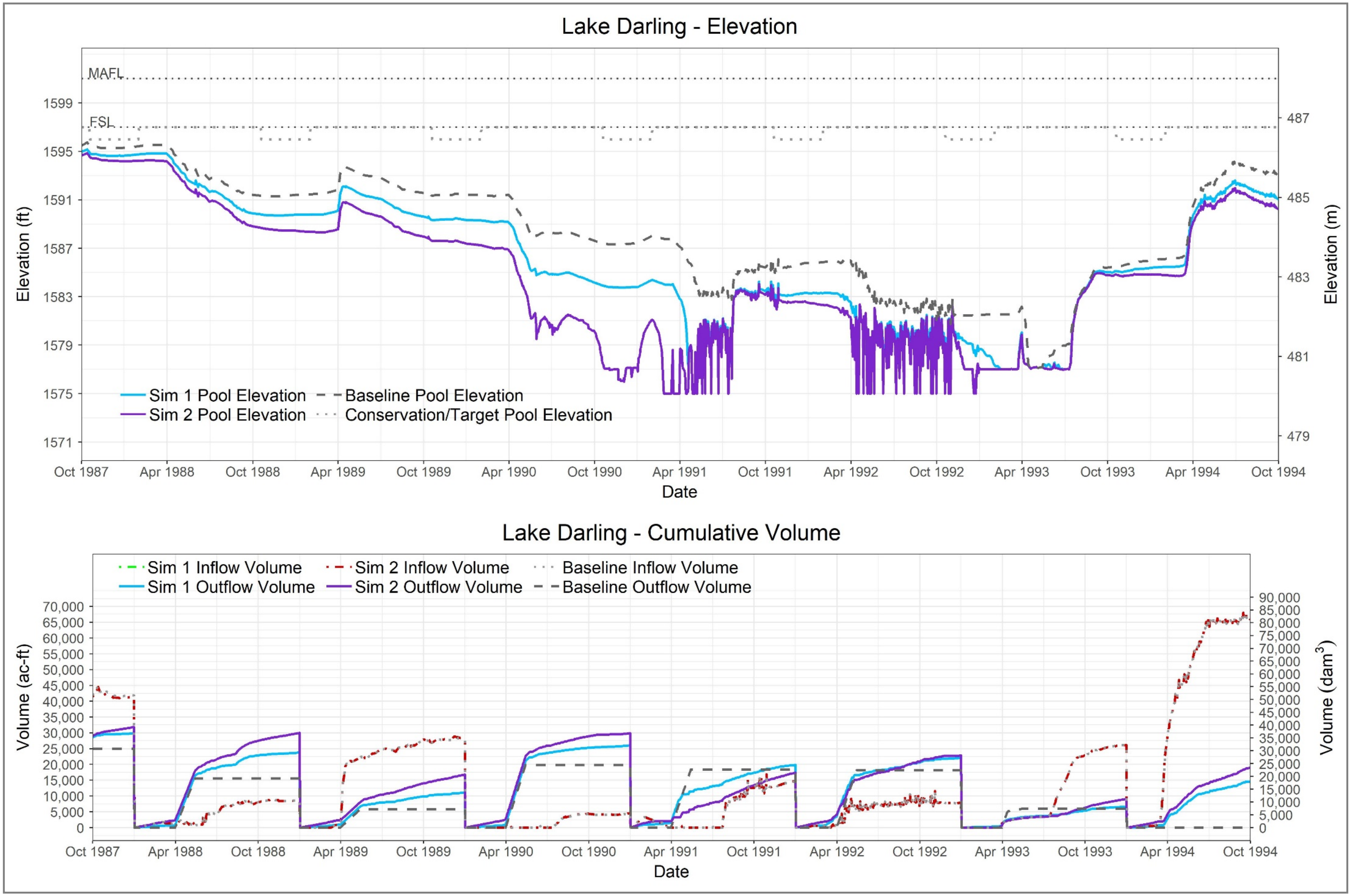
MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level



Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level



Sim1 *= 4 cfs minimum flow (ND only, Normal Pool)*

Sim2 *= 15 cfs minimum flow (ND only, Normal Pool)*

MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

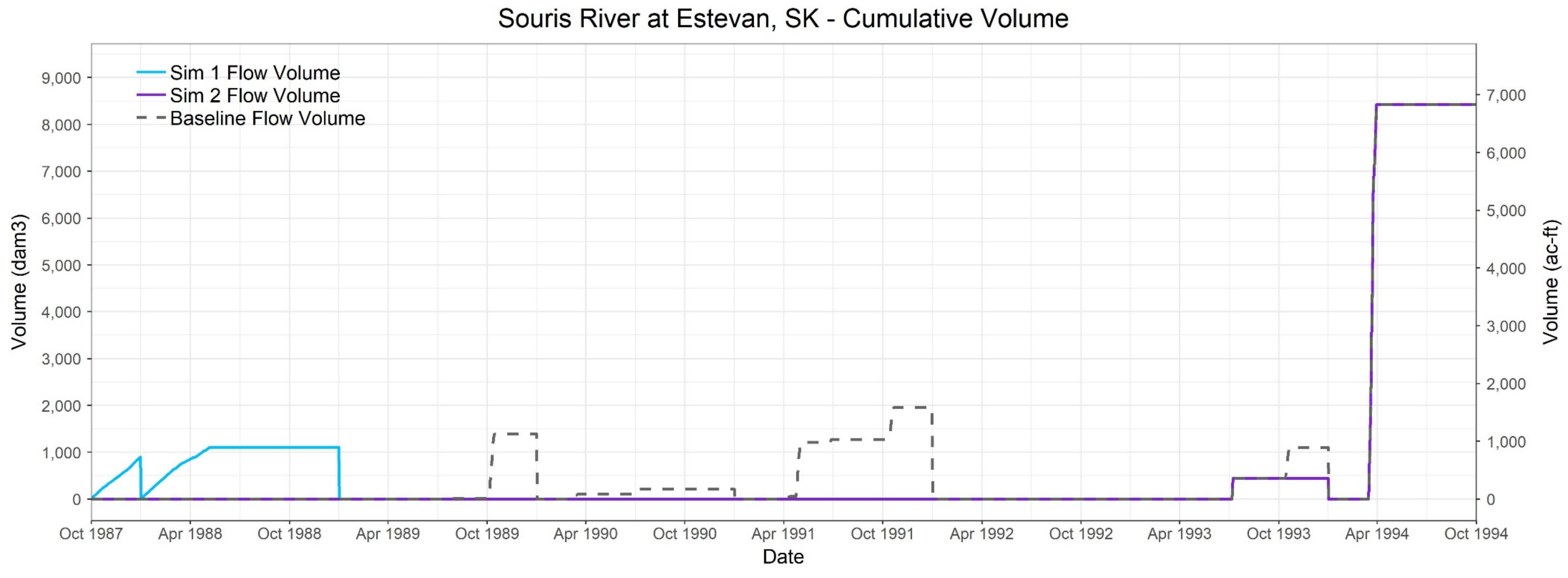
Plate 06

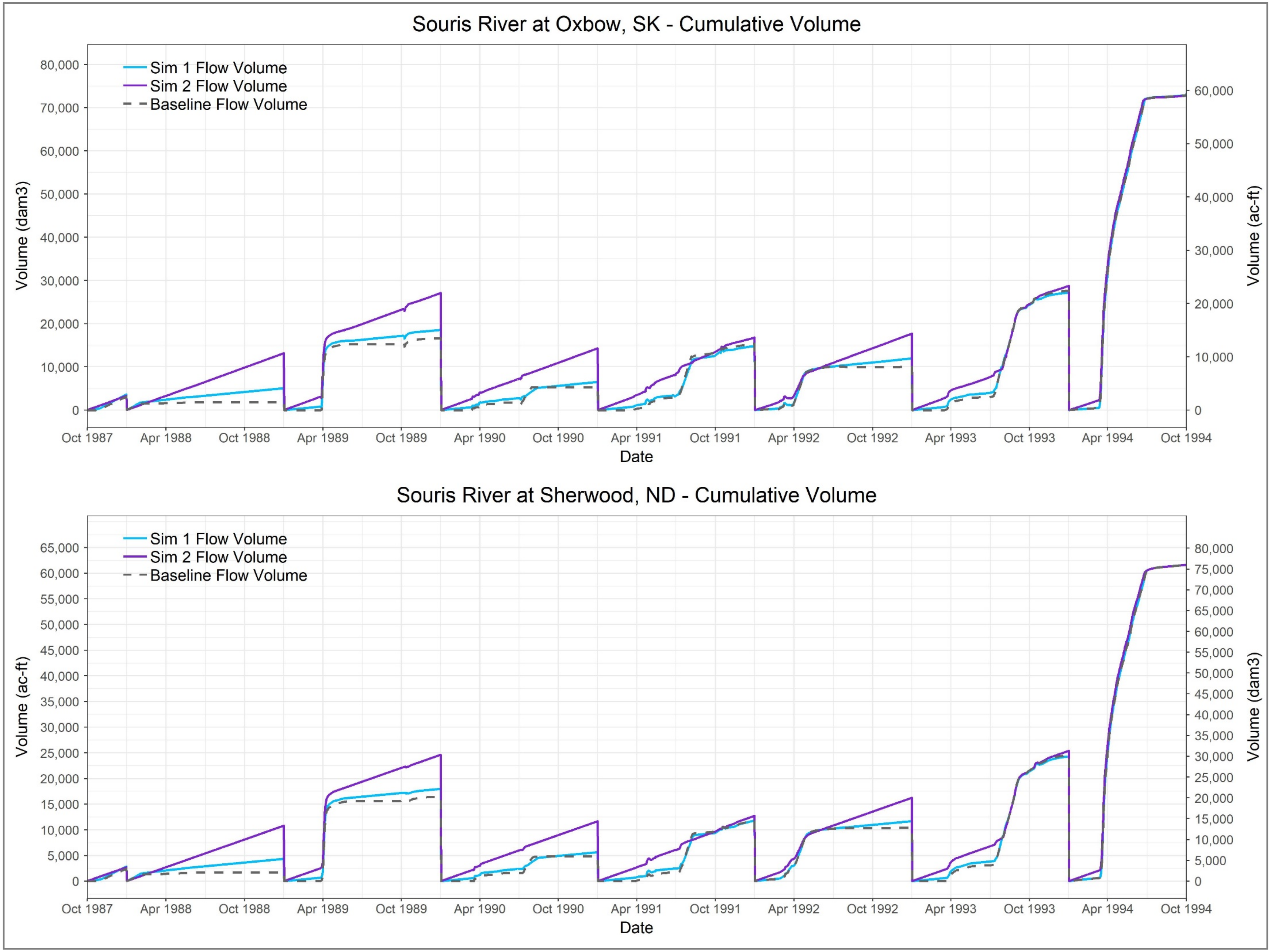
Critical Flow Locations – 1988-1996 (drought)

Alternative 310 (Phase 3)

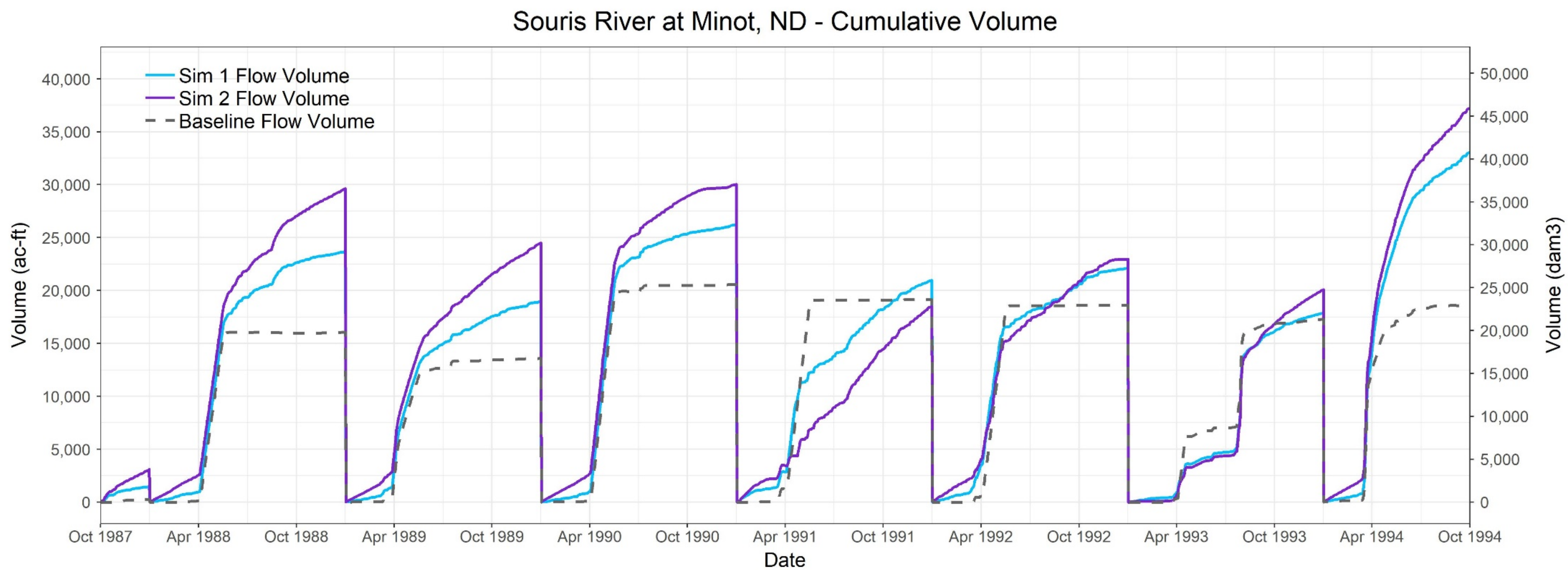
Souris River Plan of Study

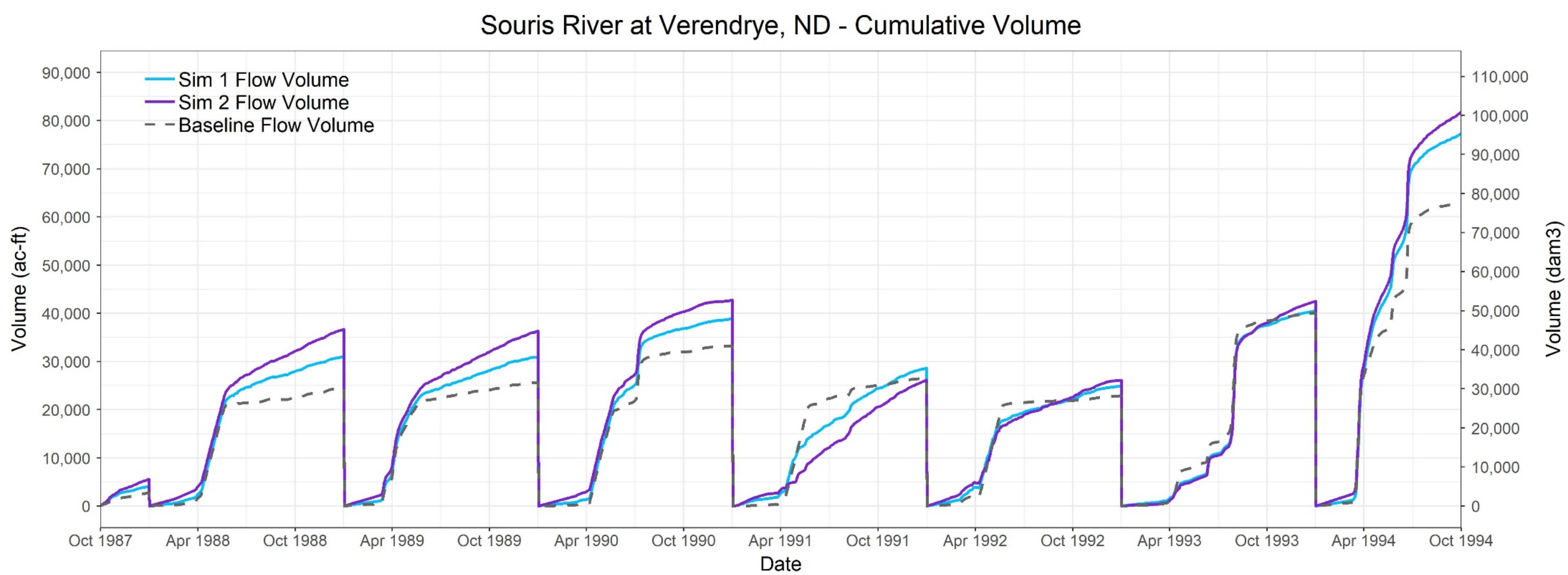
Sim1 *= 4 cfs minimum flow (SK only, Normal Pool)*
Sim2 *= 15 cfs minimum flow (SK only, Normal Pool)*



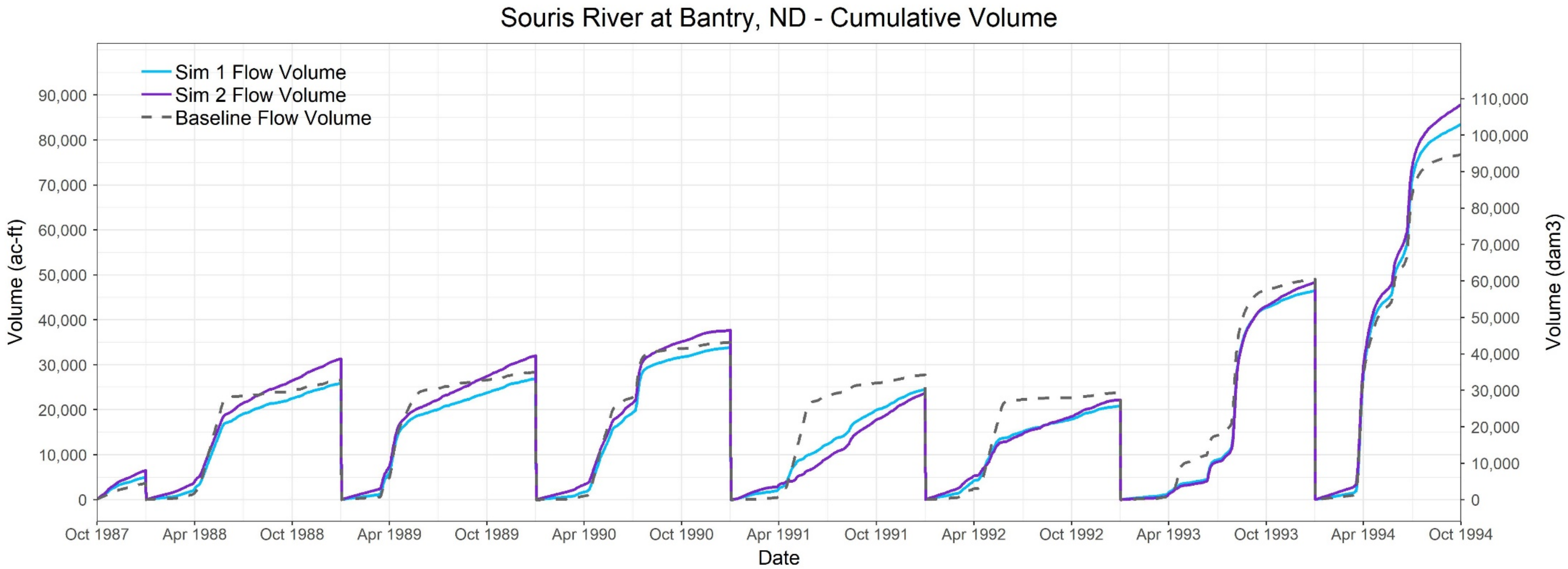


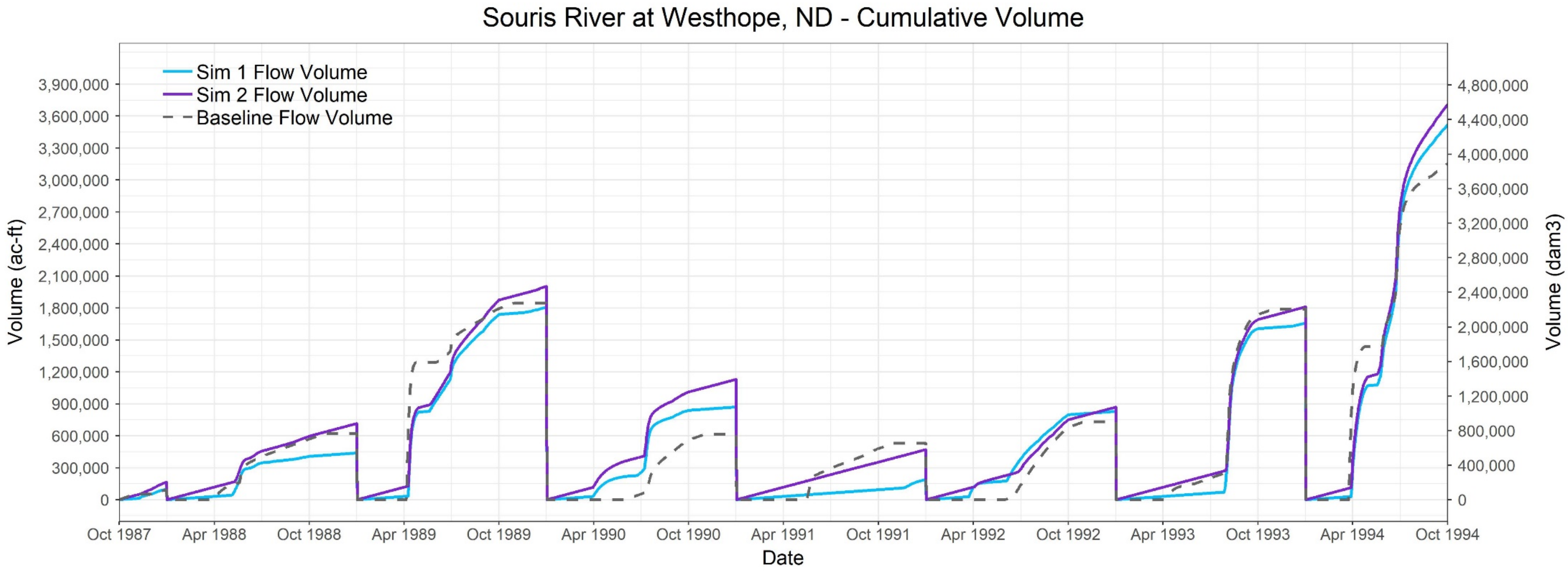
***Sim1** = 4 cfs minimum flow (SK only, Normal Pool), **Sim2** = 15 cfs minimum flow (SK only, Normal Pool)*





Sim1 *= 4 cfs minimum flow (ND only, Normal Pool),* ***Sim2*** *= 15 cfs minimum flow (ND only, Normal Pool)*



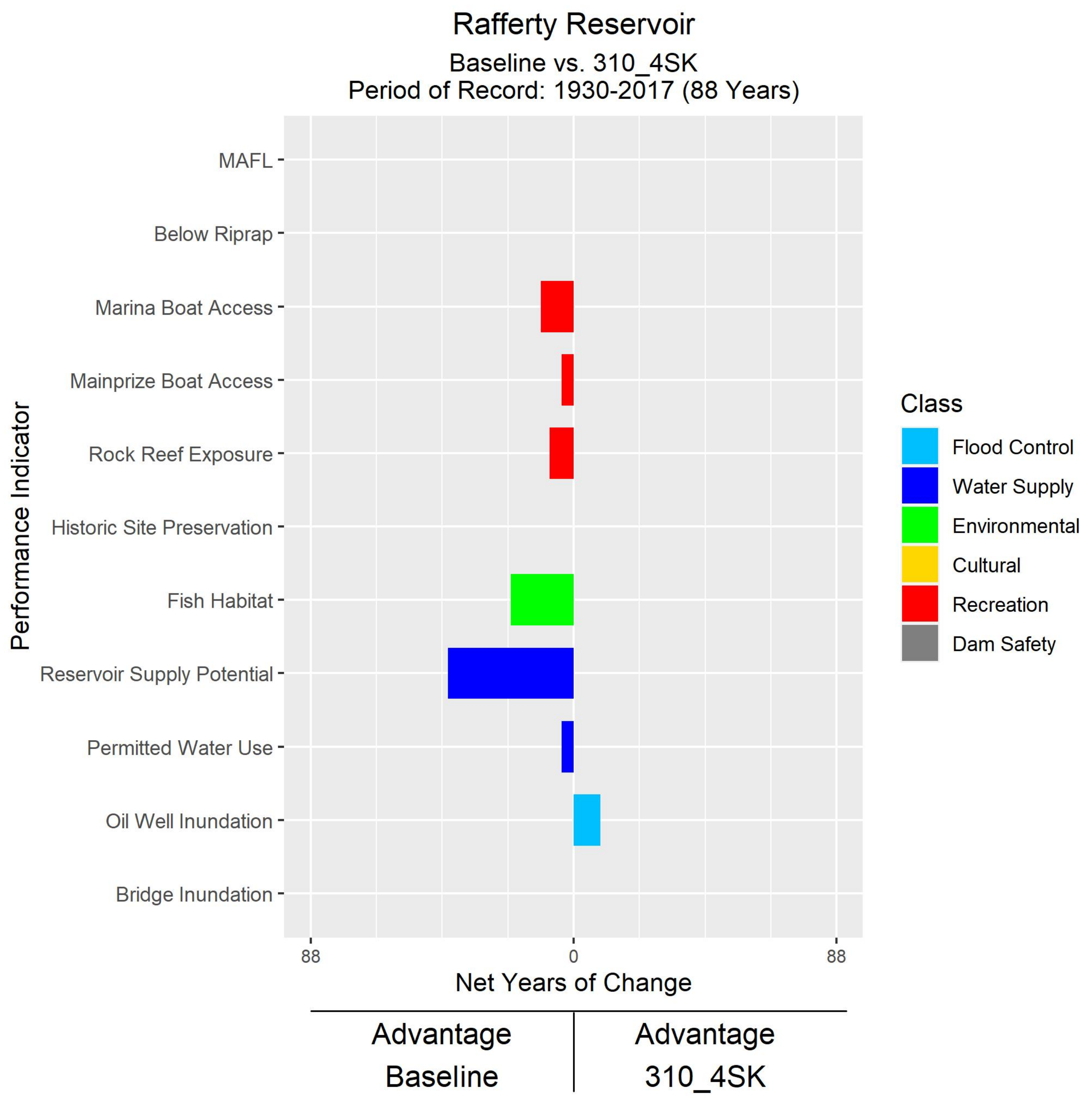


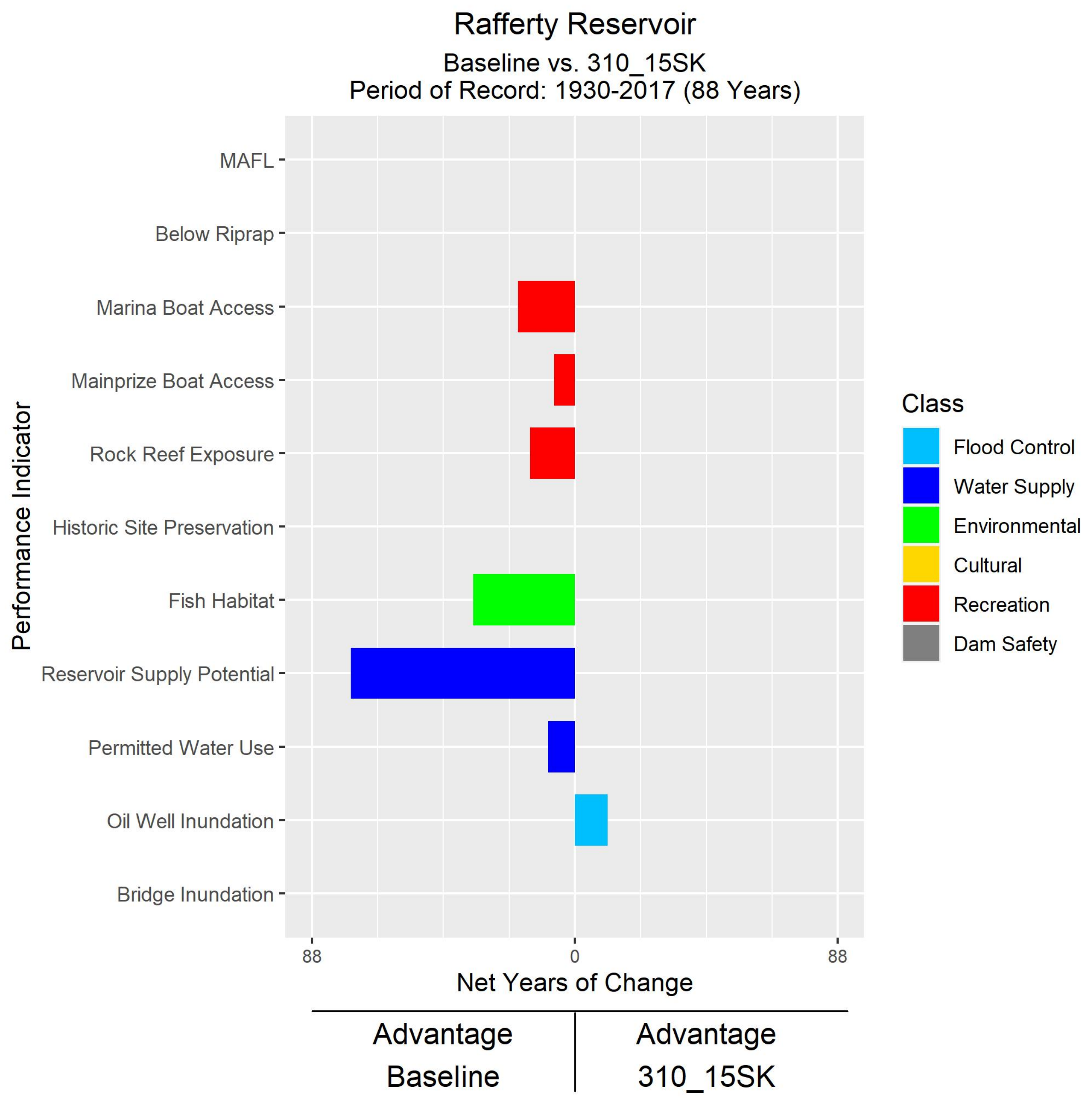
Sim1 *= 4 cfs minimum flow (ND only, Normal Pool),* ***Sim2*** *= 15 cfs minimum flow (ND only, Normal Pool)*

Plate 07

Performance Indicators – 1930-2017

Alternative 310 (Phase 3)



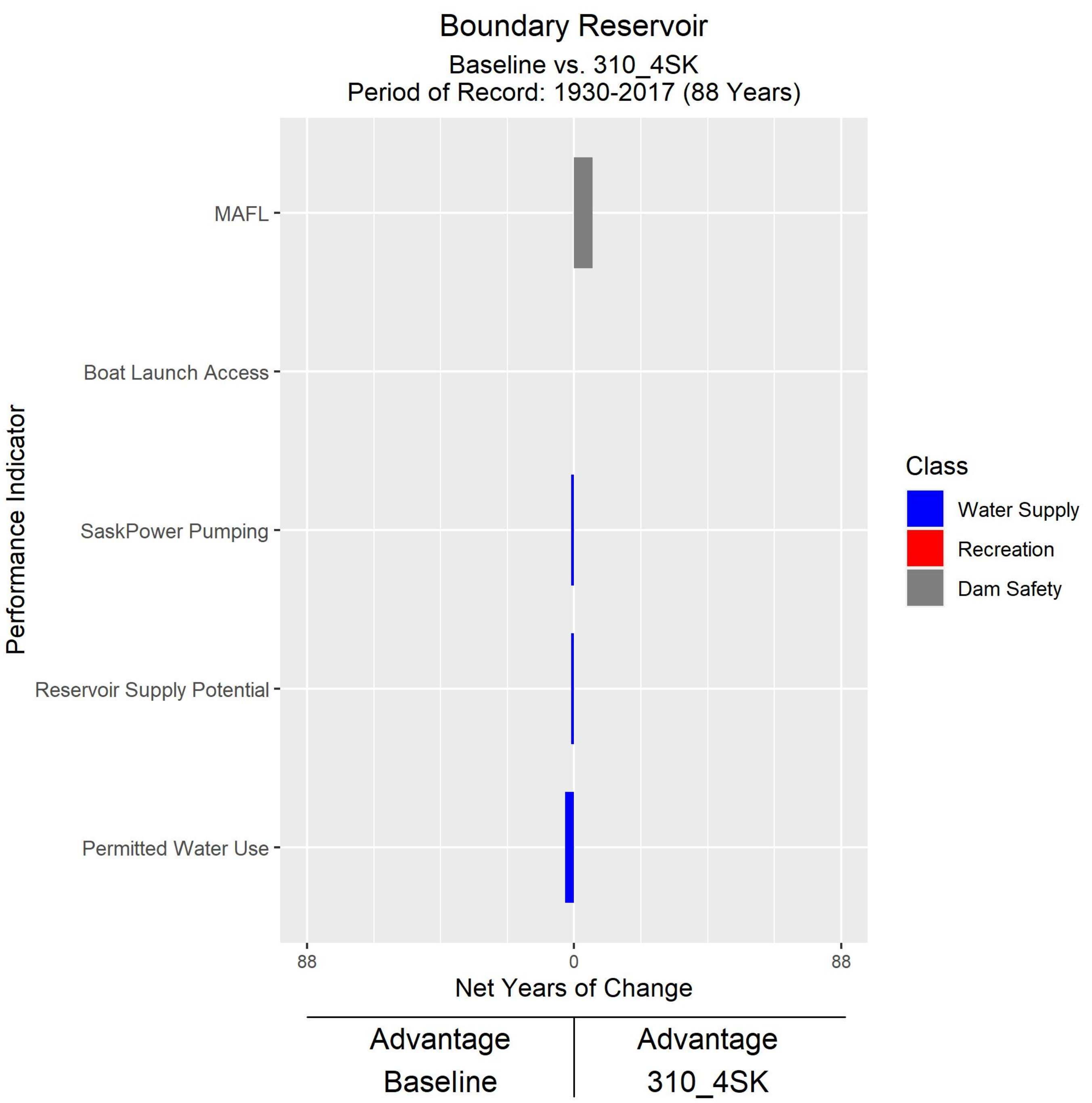


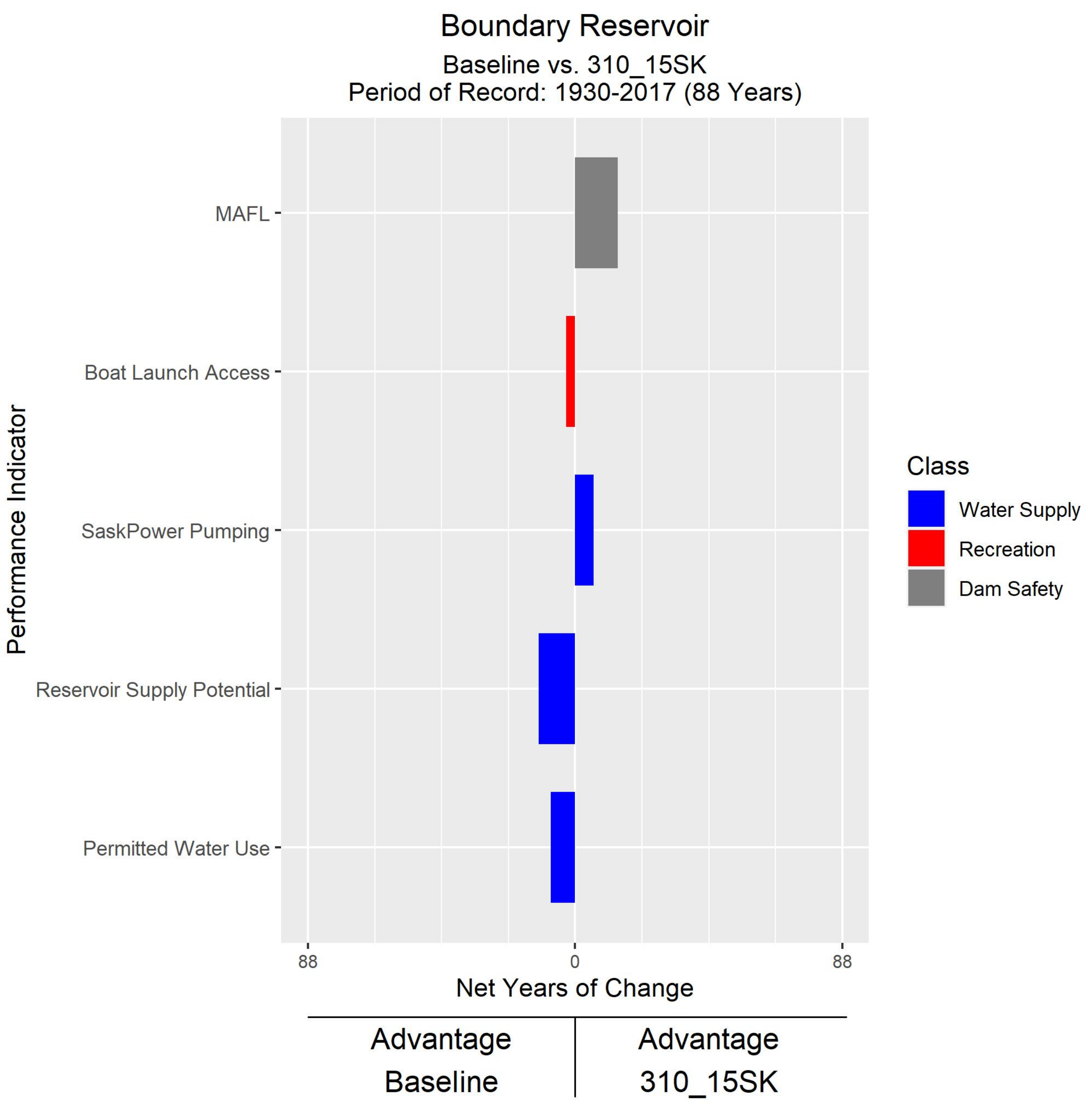
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



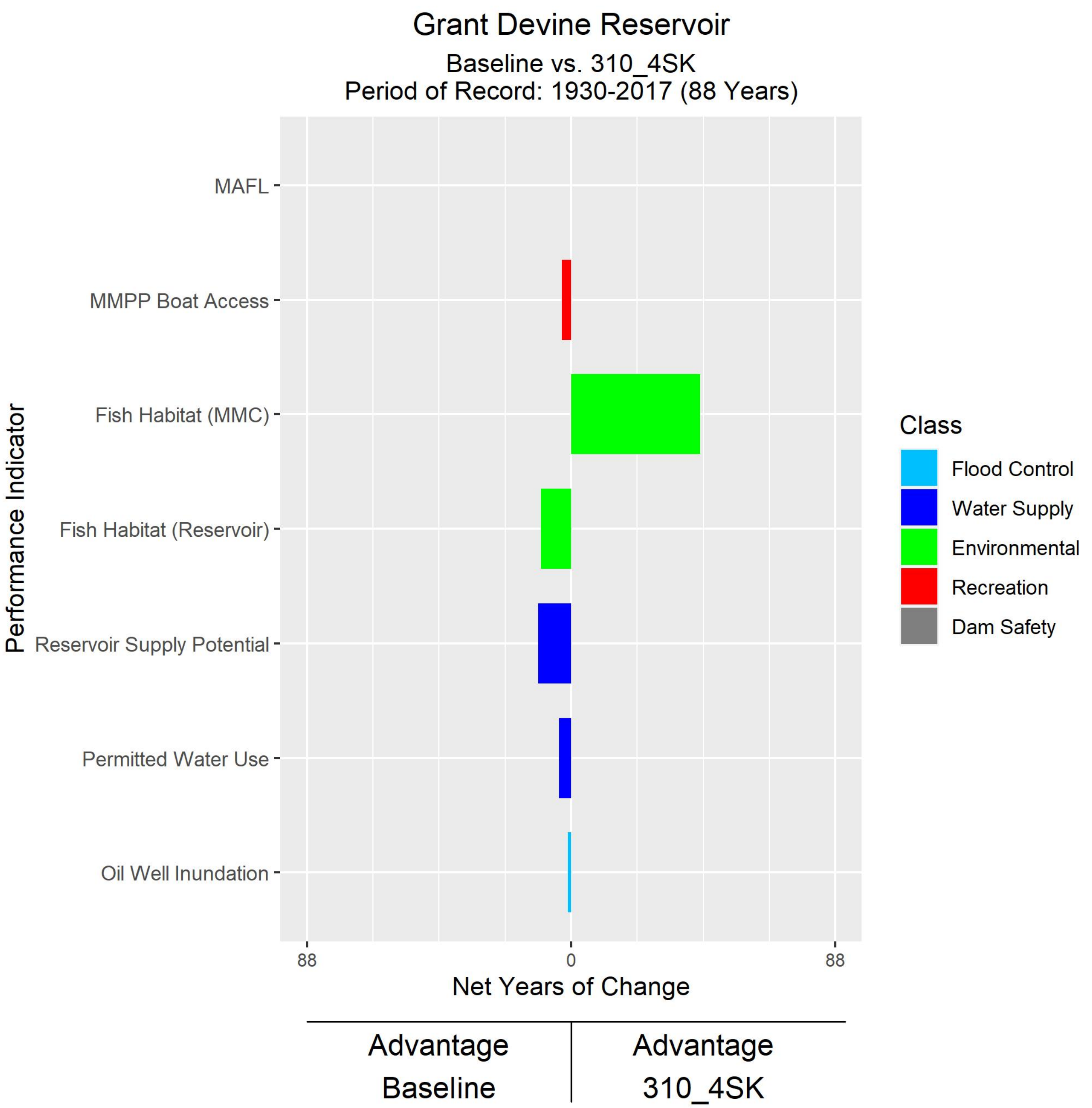


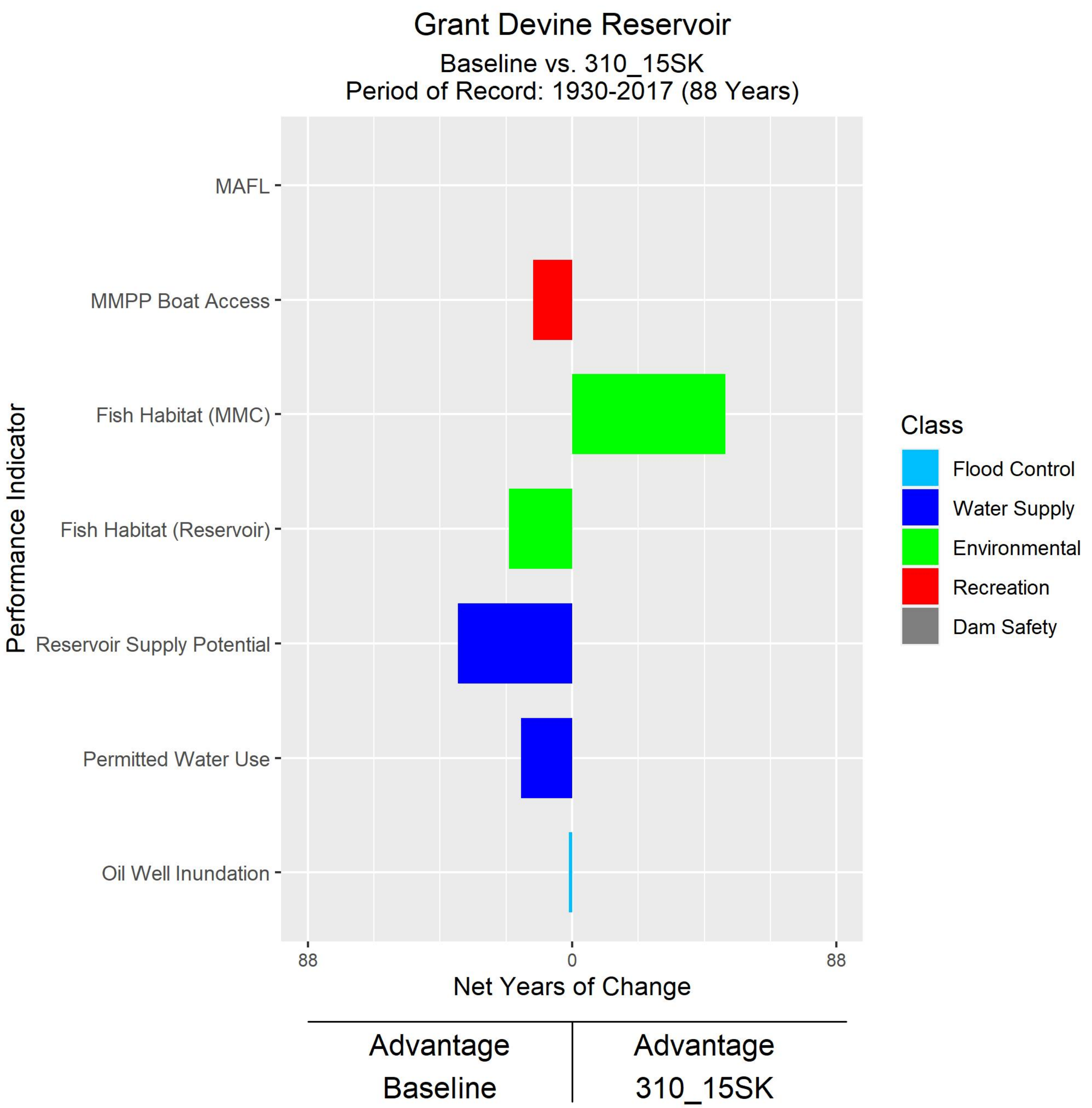
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



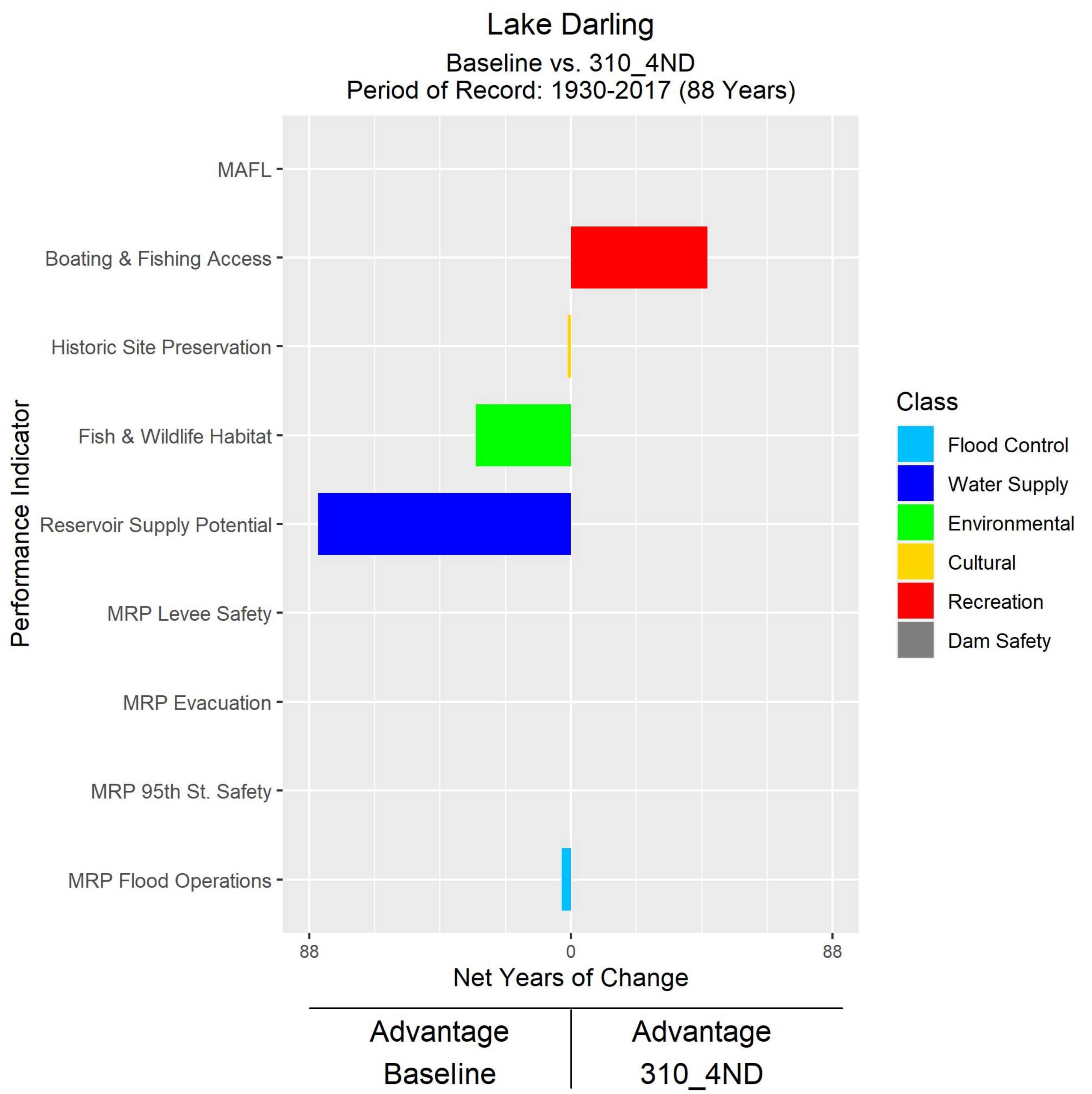


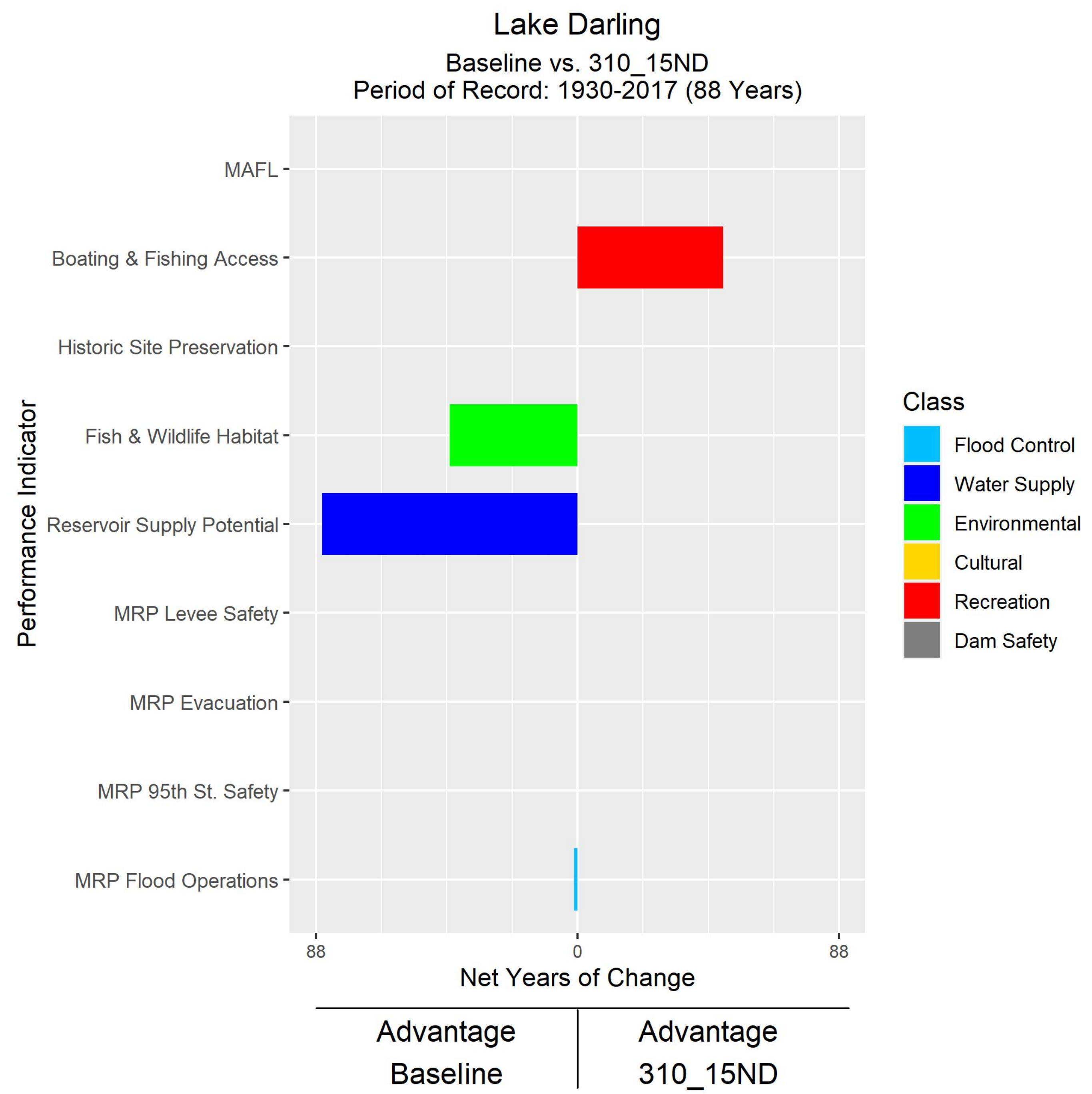
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



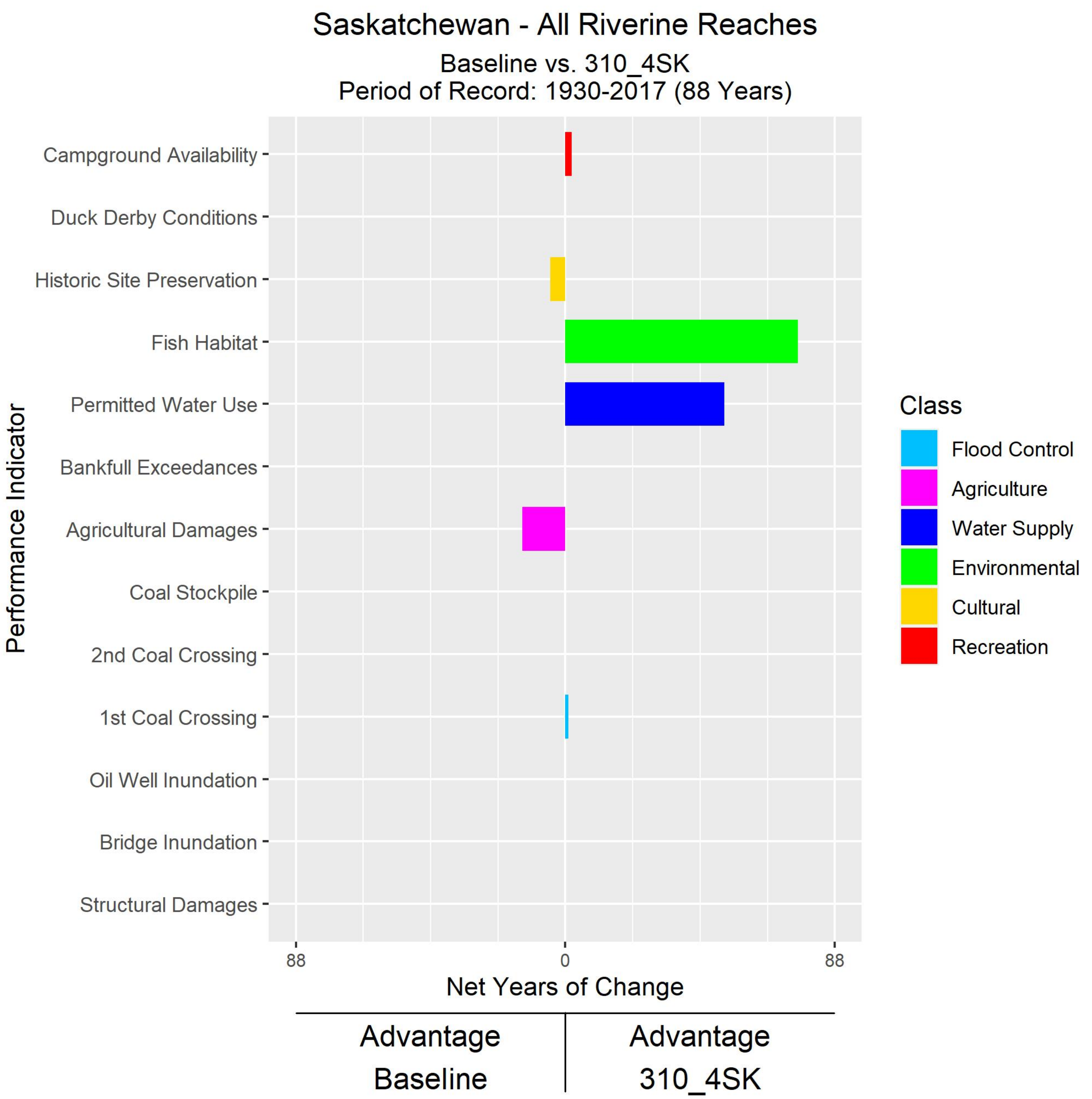


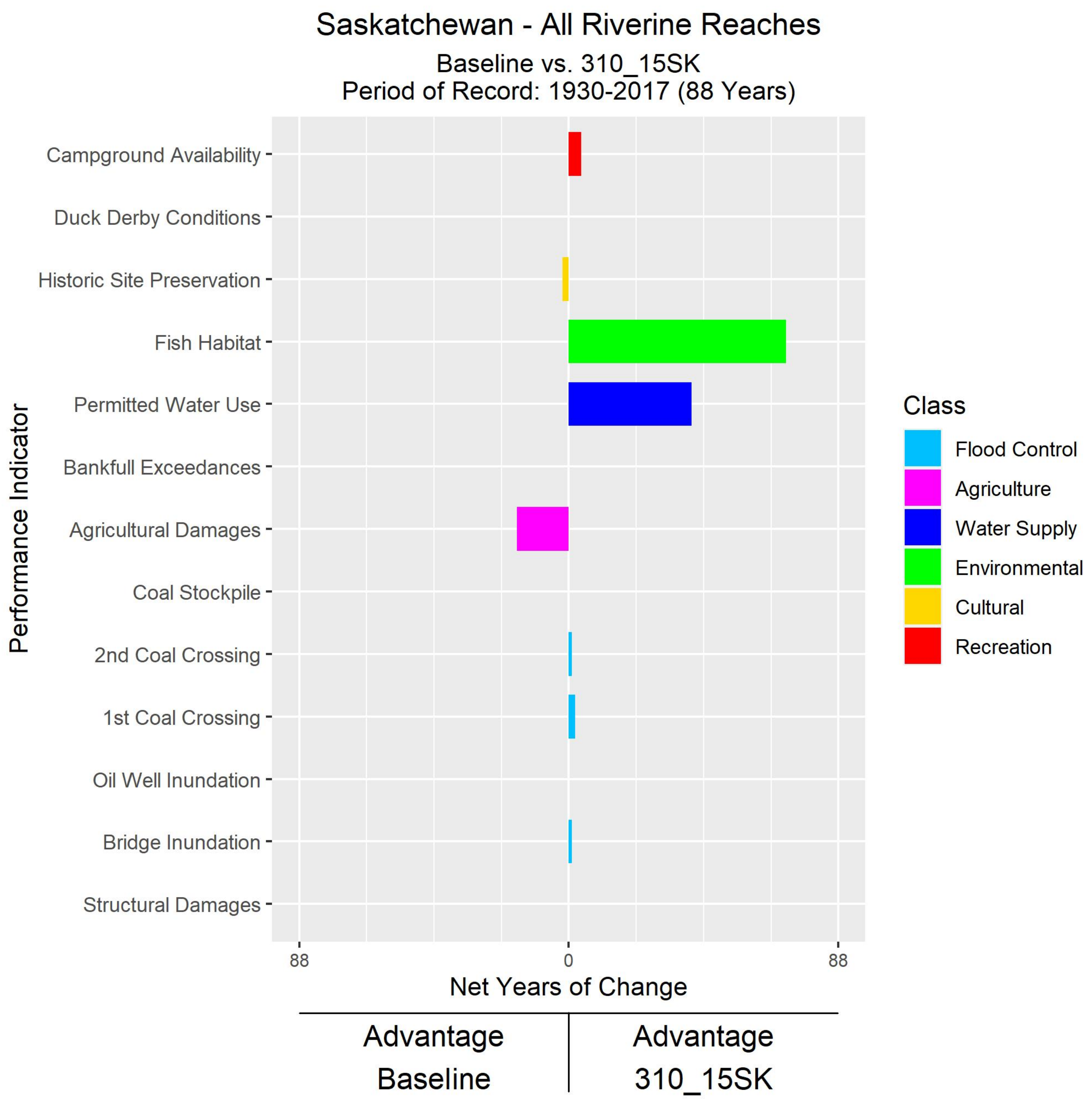
Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



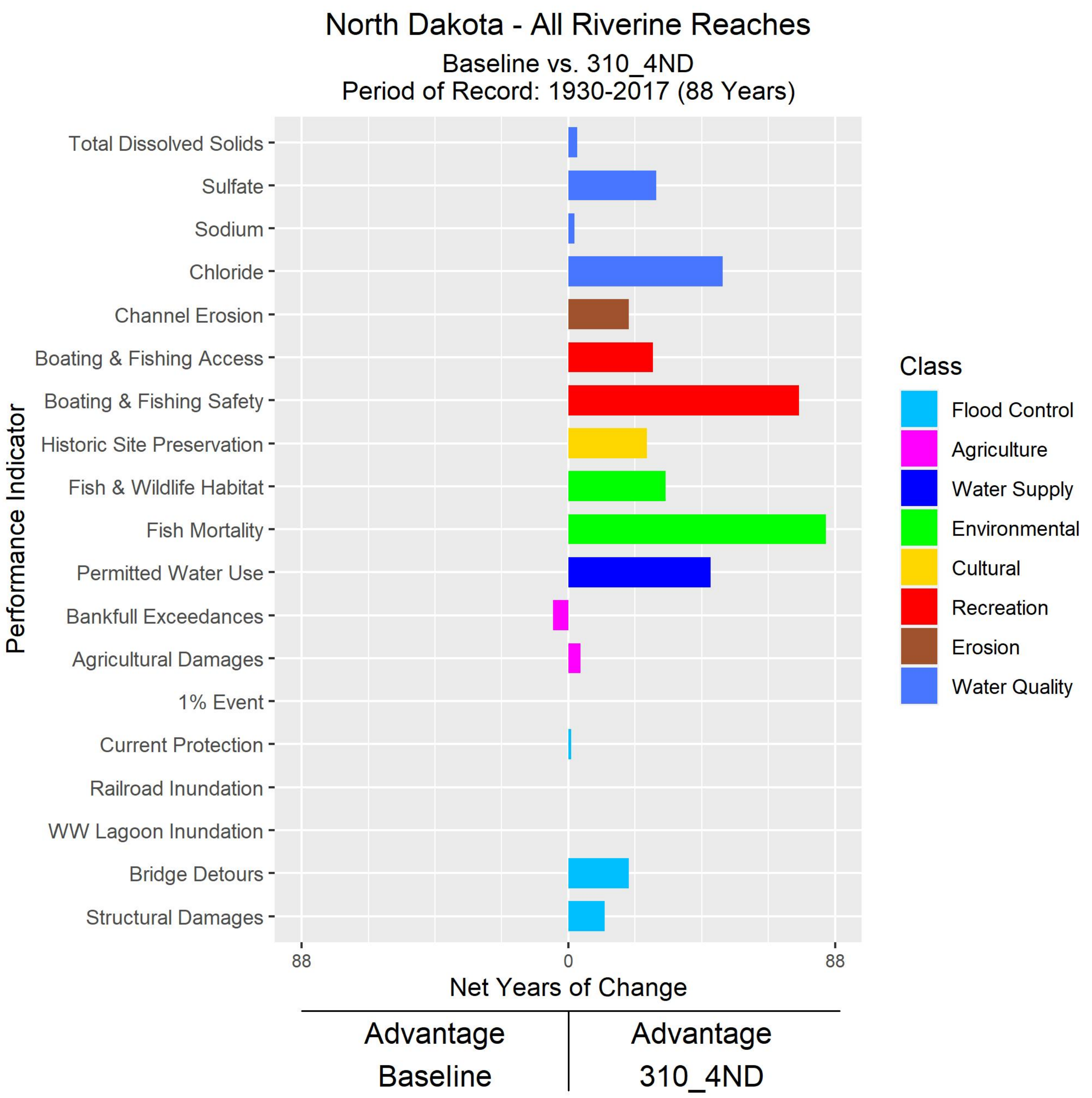


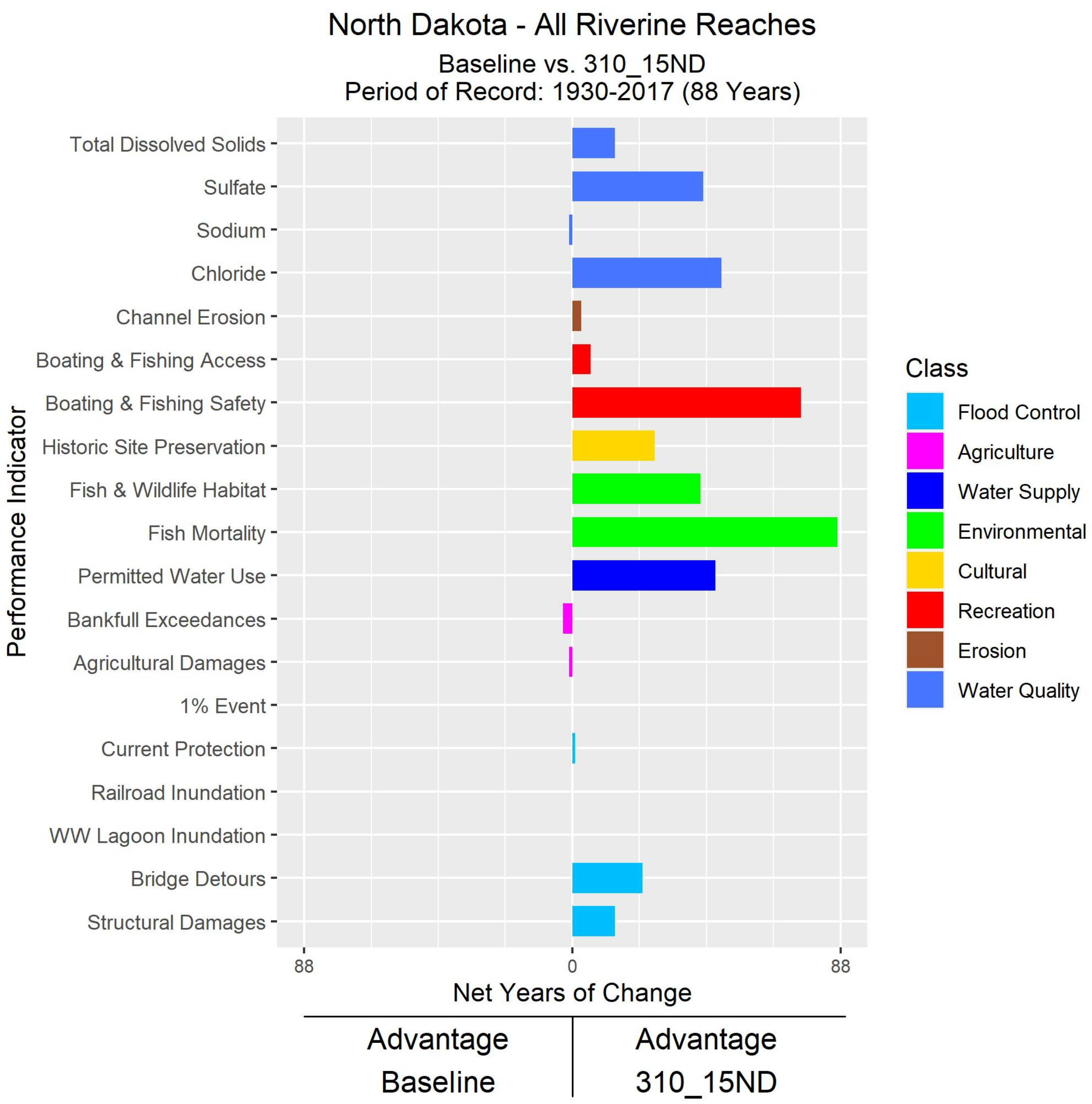
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



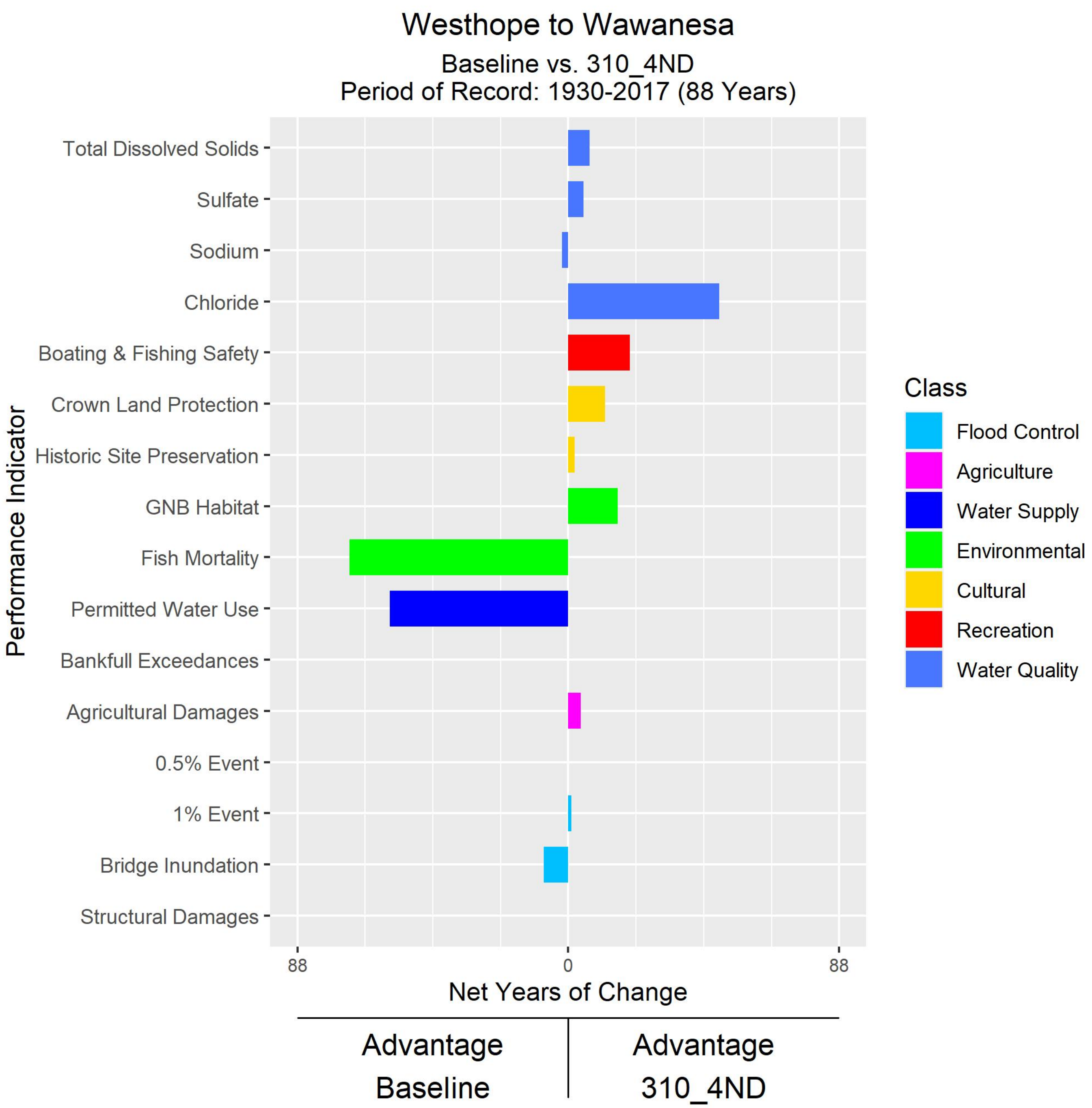


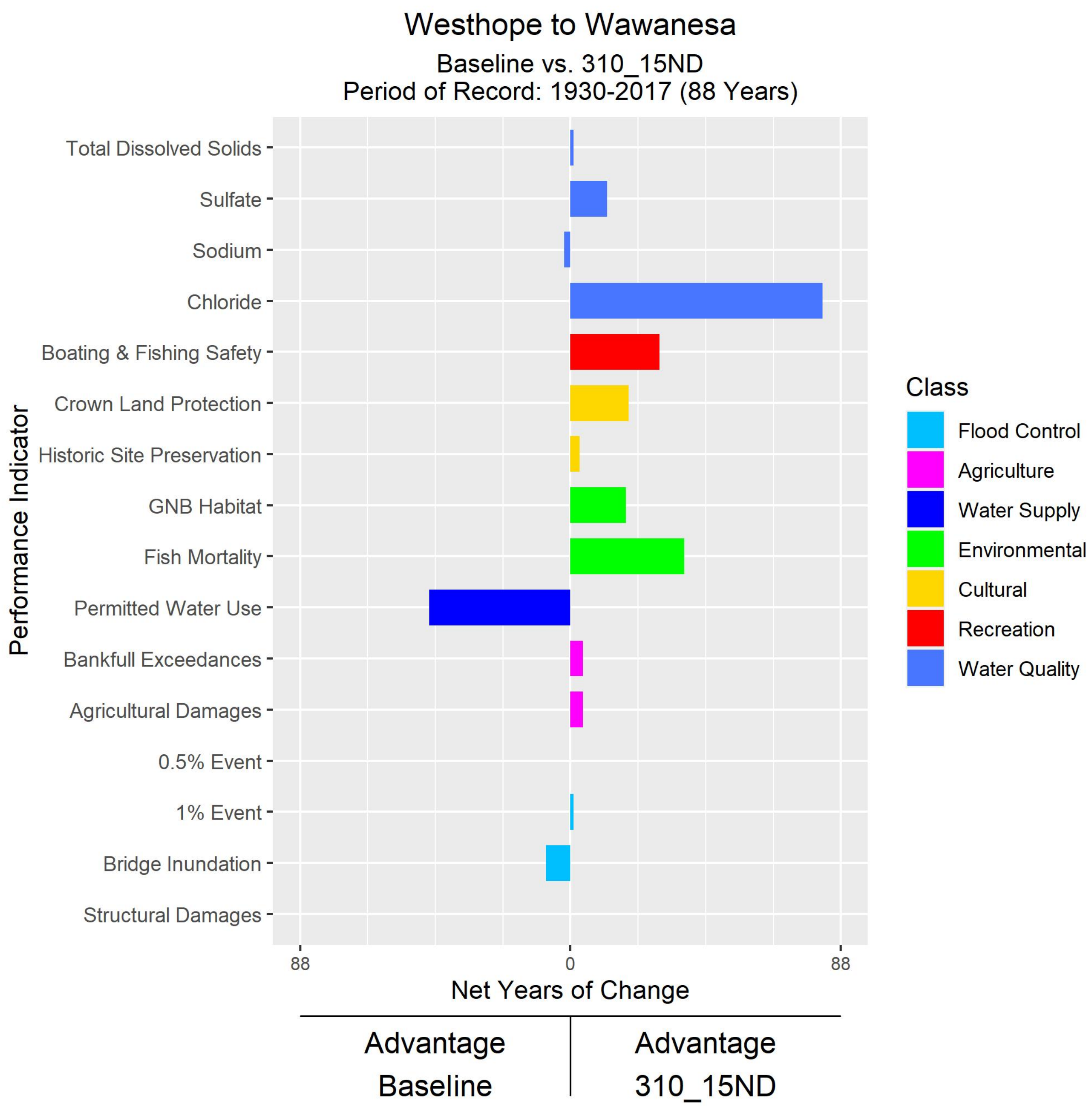
Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



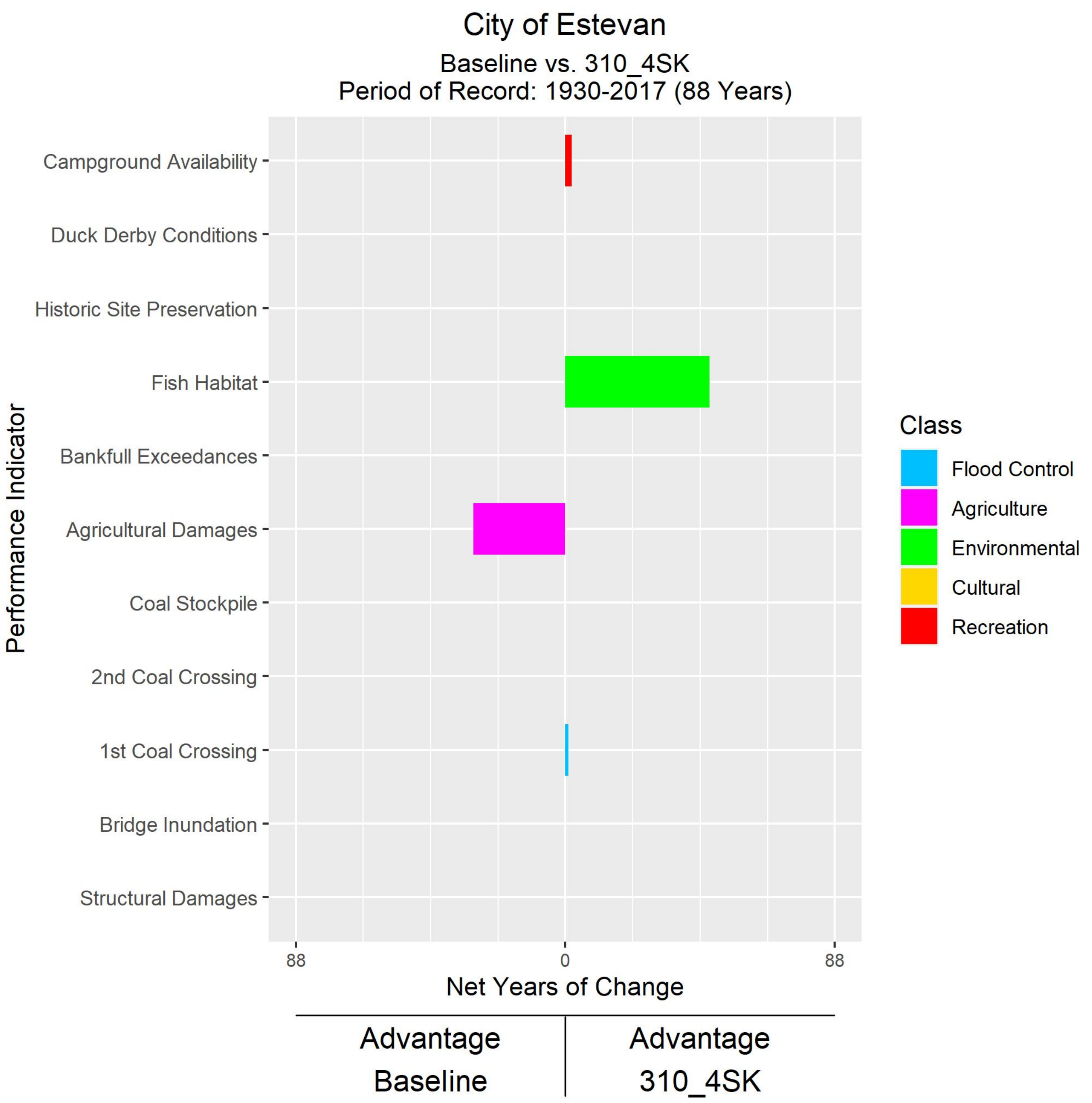


Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling

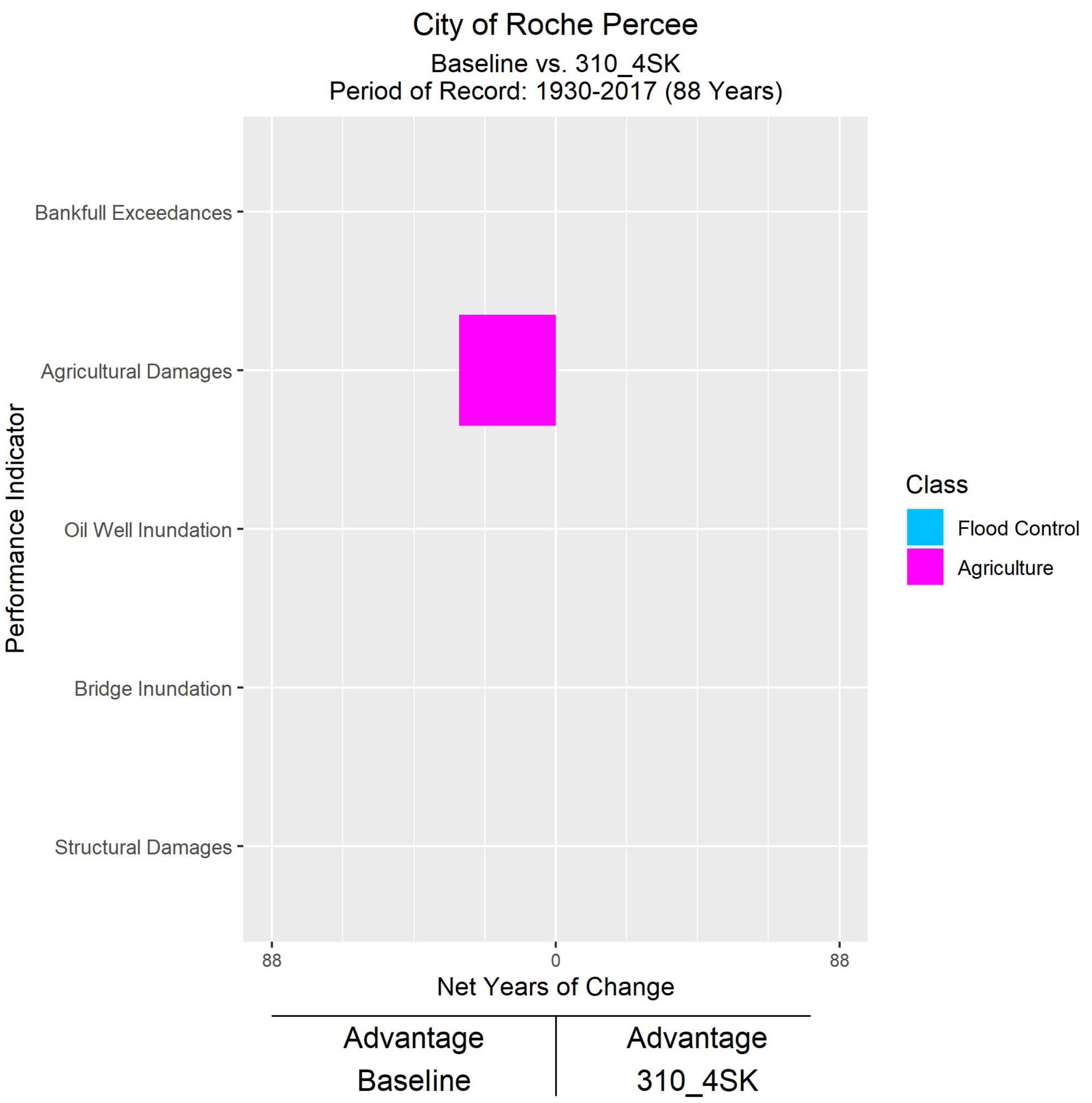


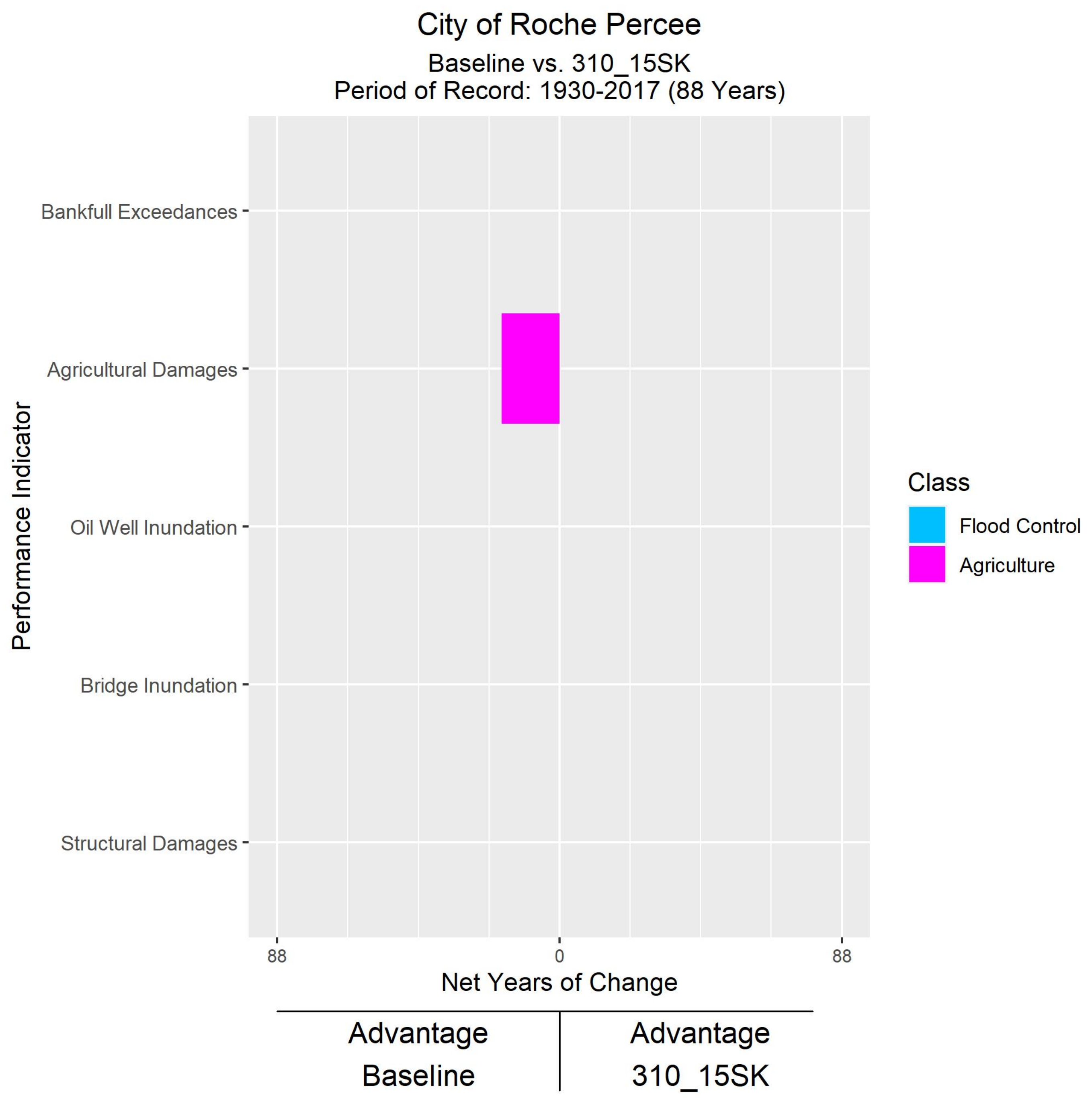
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



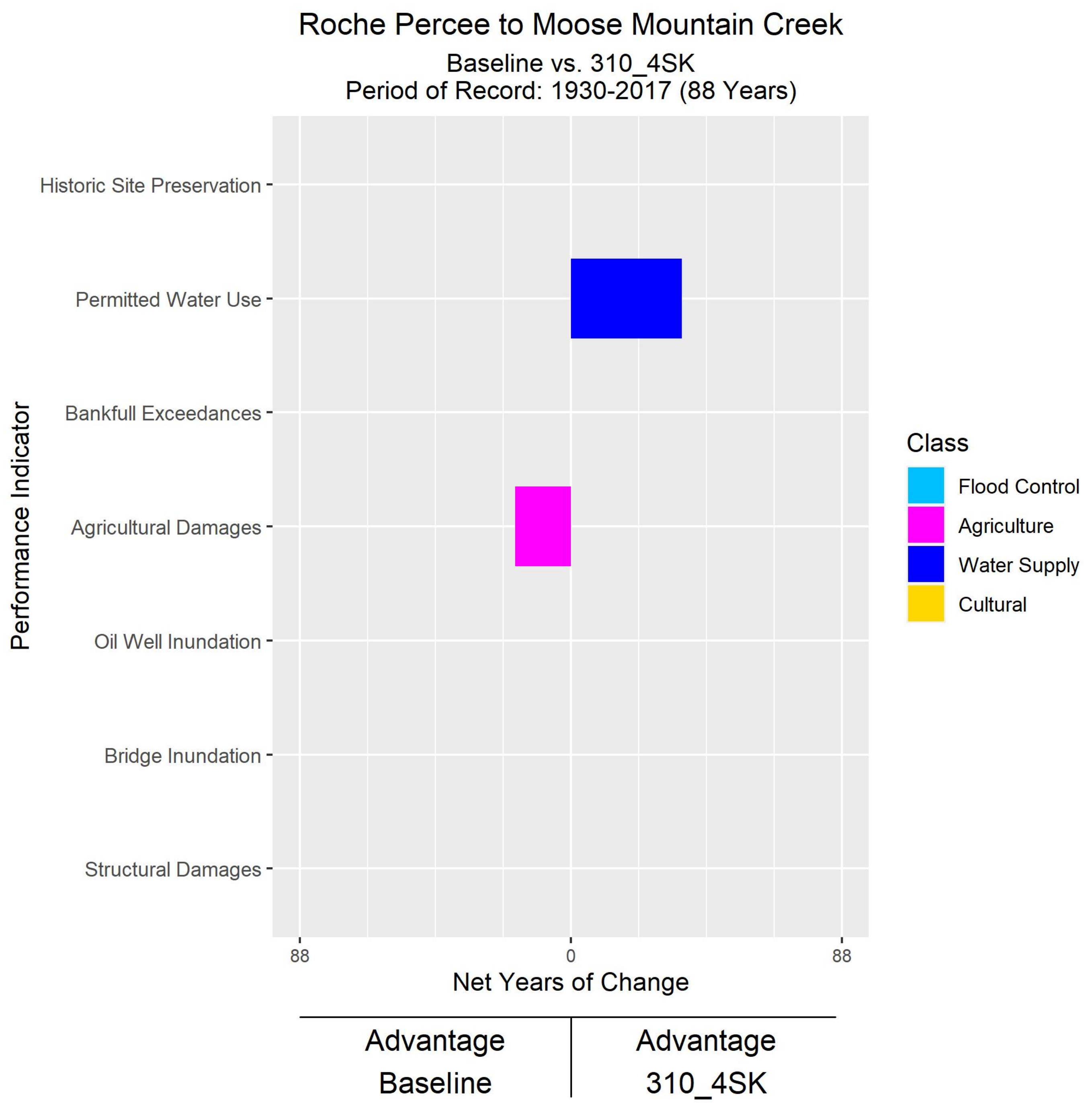


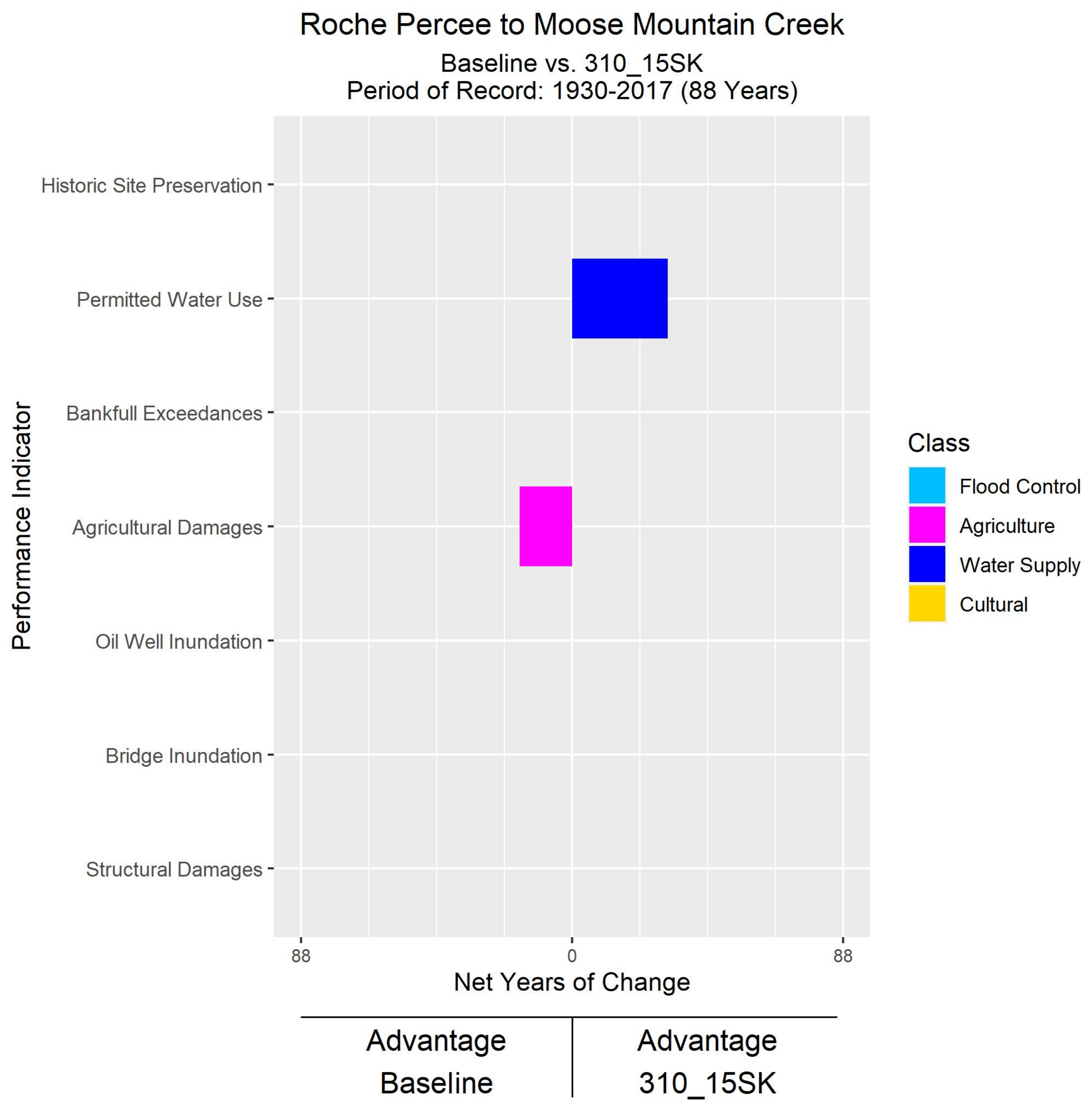
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



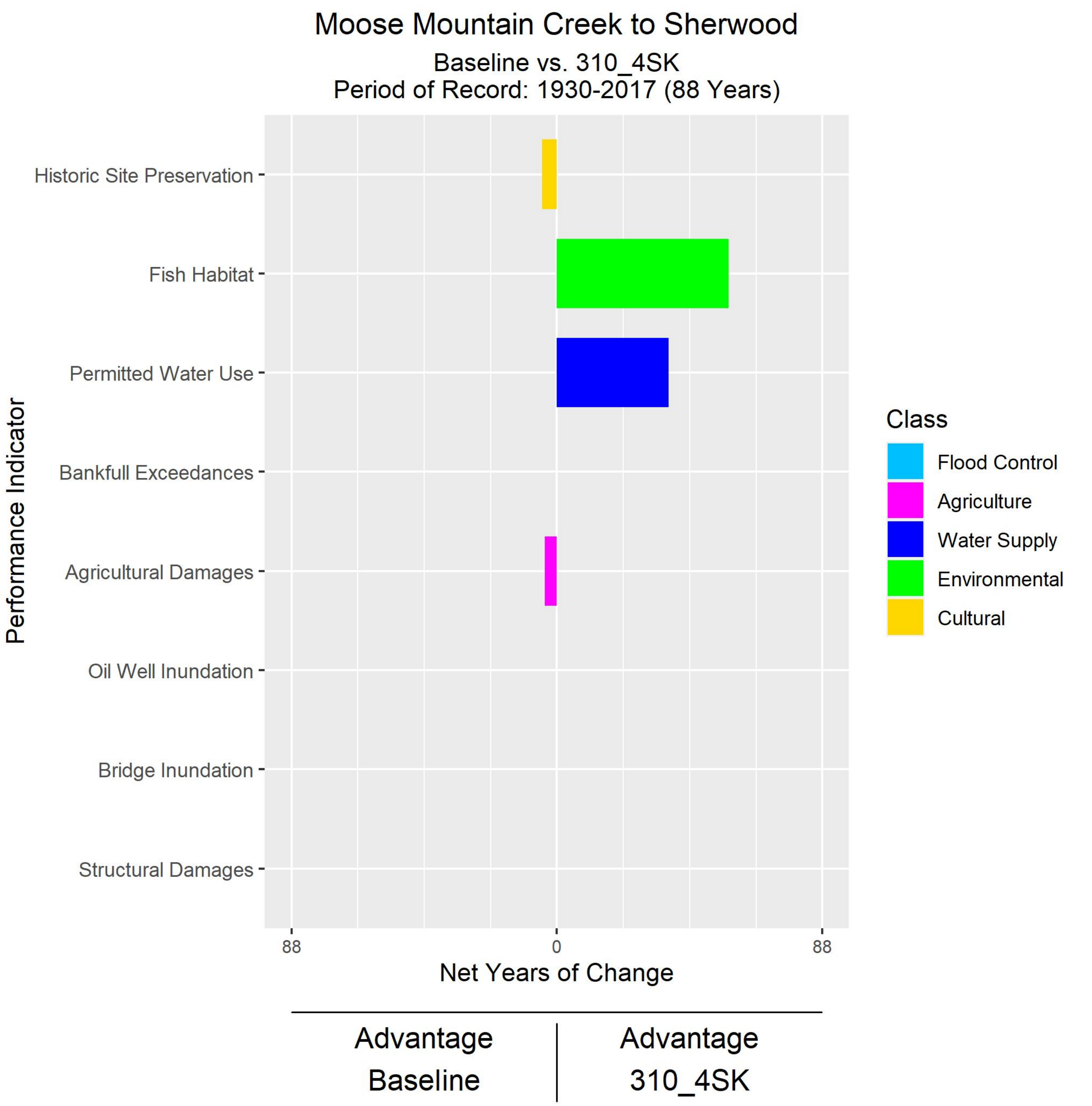


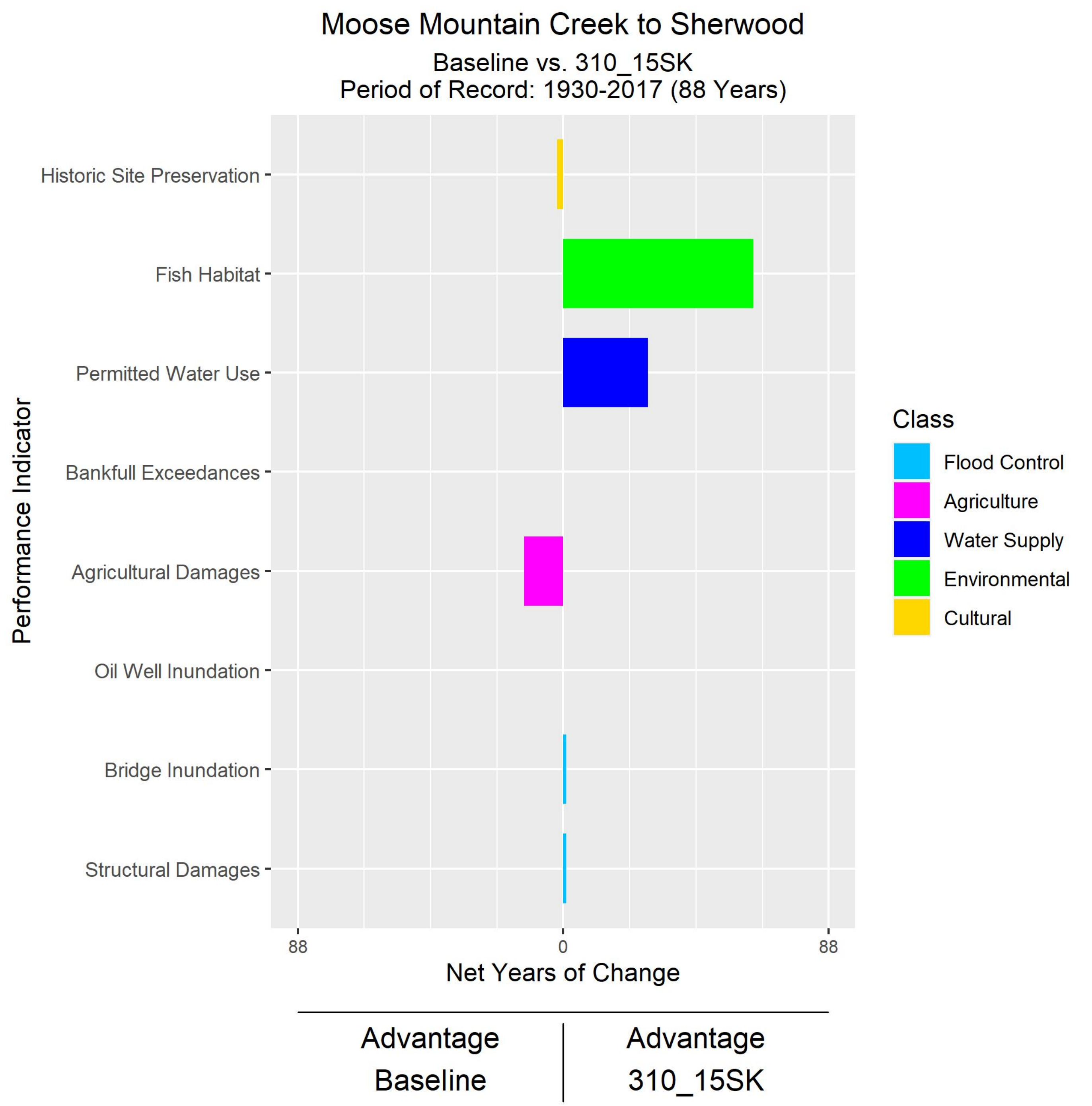
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



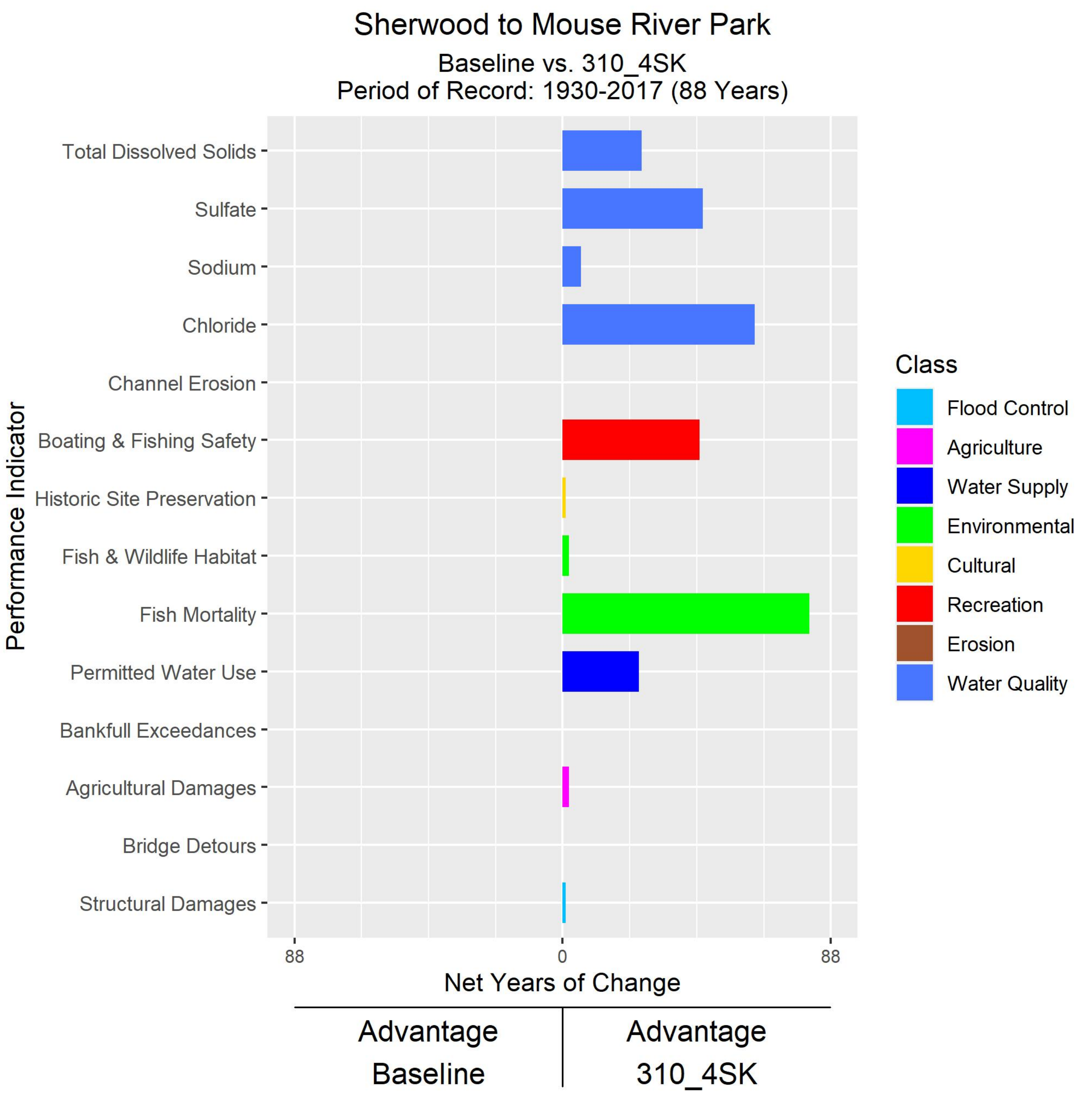


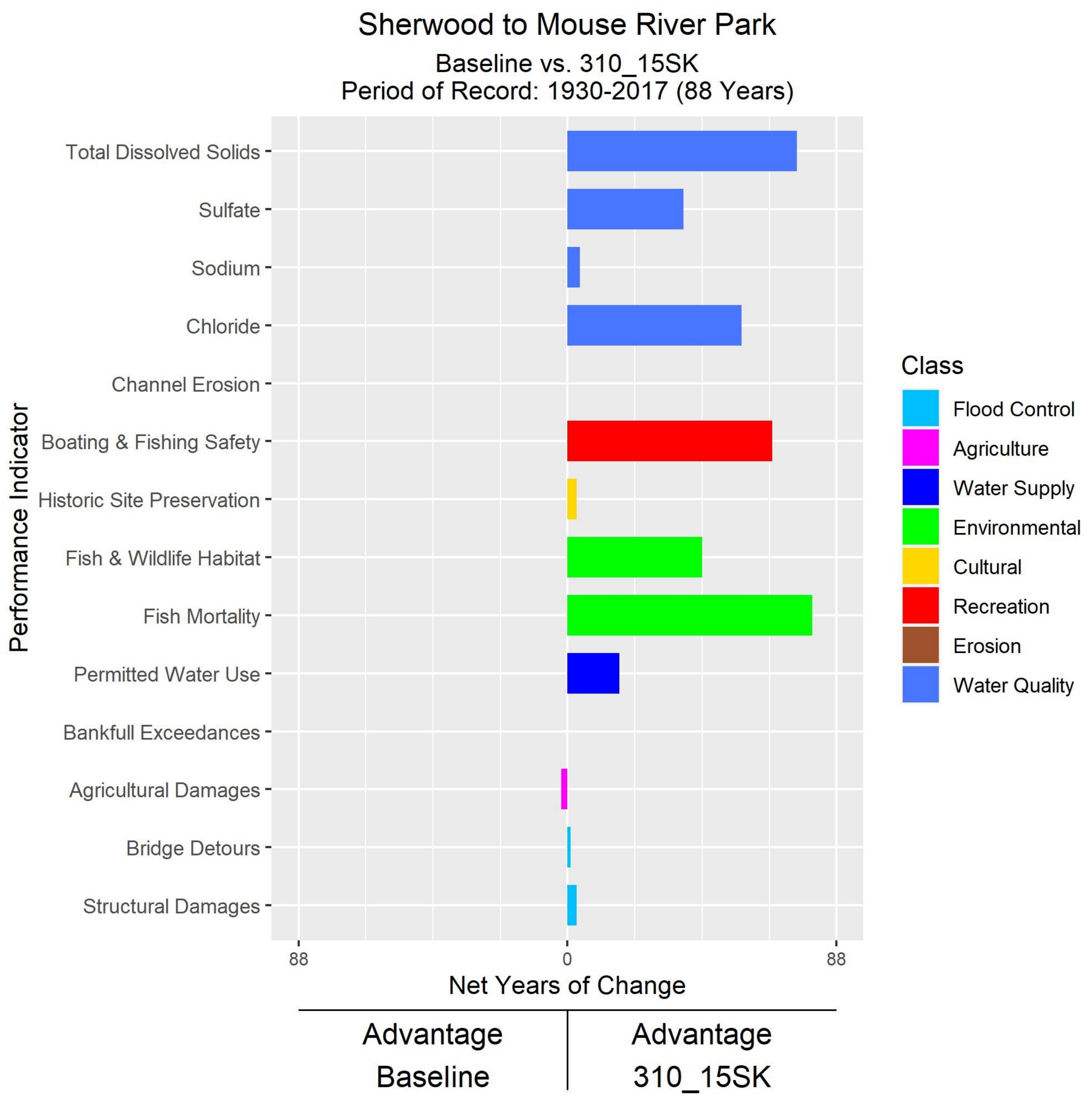
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



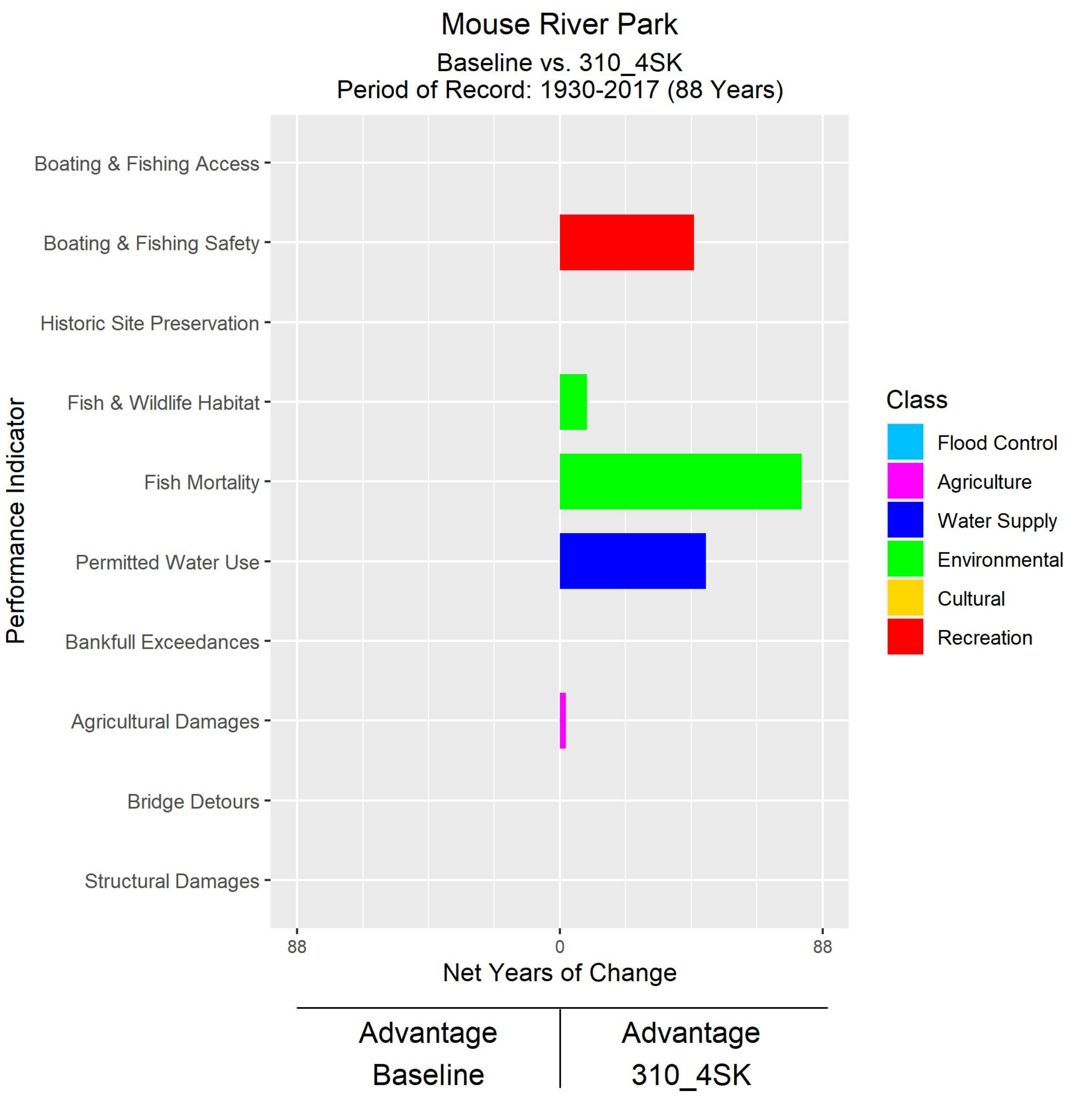


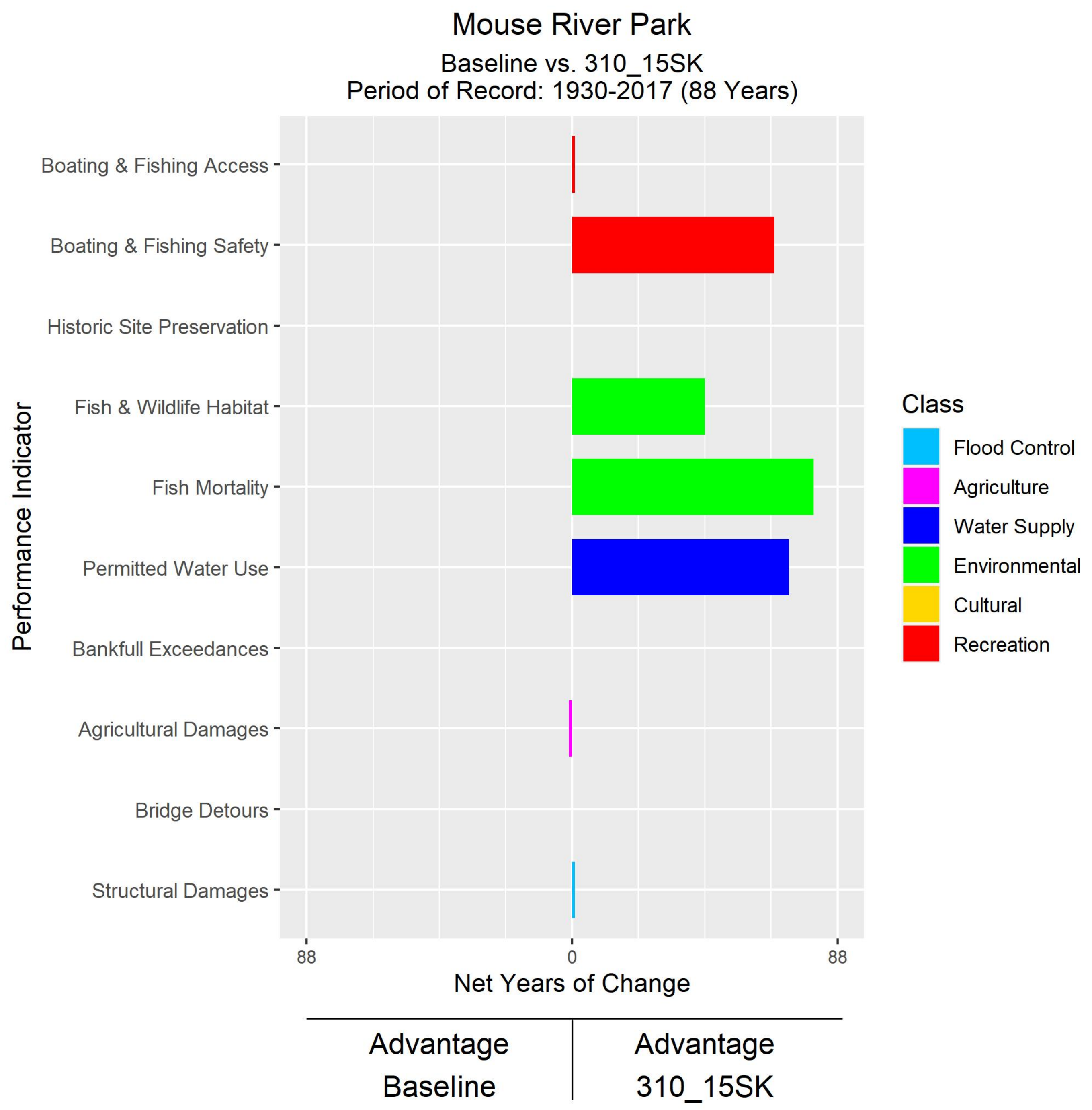
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



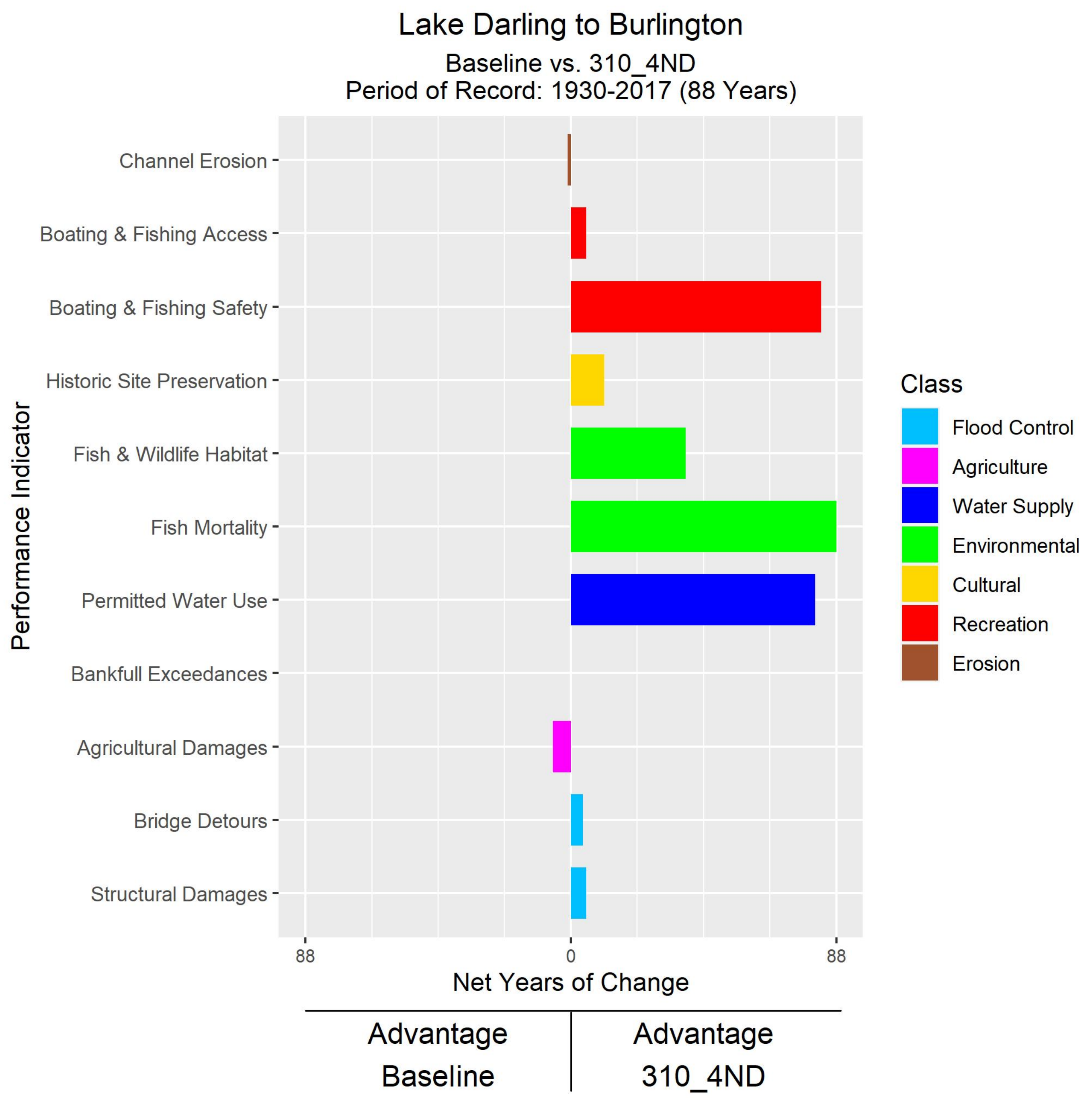


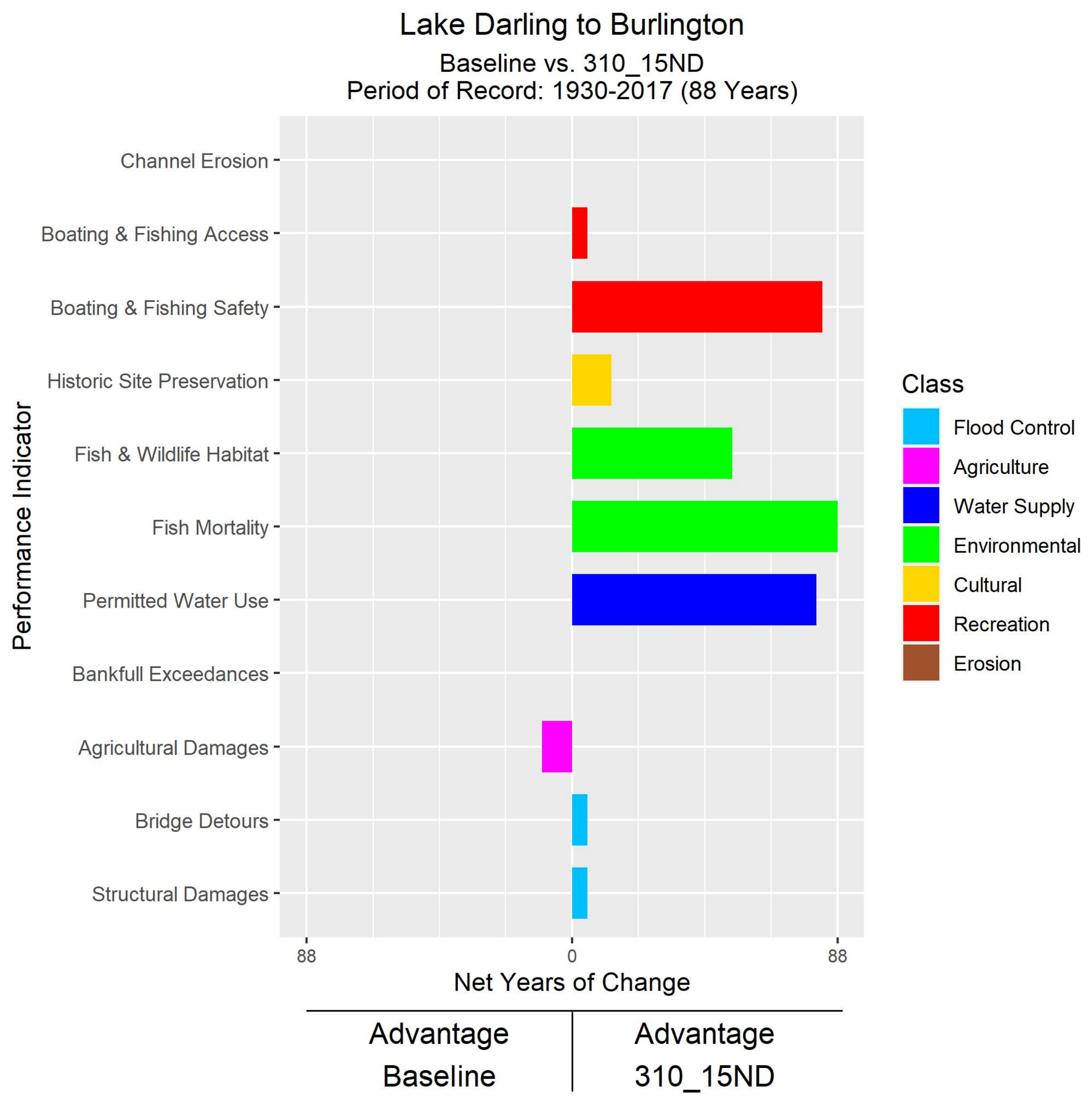
Alternative 310_4SK

- 4 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation

Alternative 310_15SK

- 15 cfs (0.1 cms) constant, year-round minimum flow rule just downstream of Moose Mountain Creek and at Sherwood, ND
- Rafferty and Grant Devine may ignore this rule if the reservoir is below its minimum allowable pool elevation



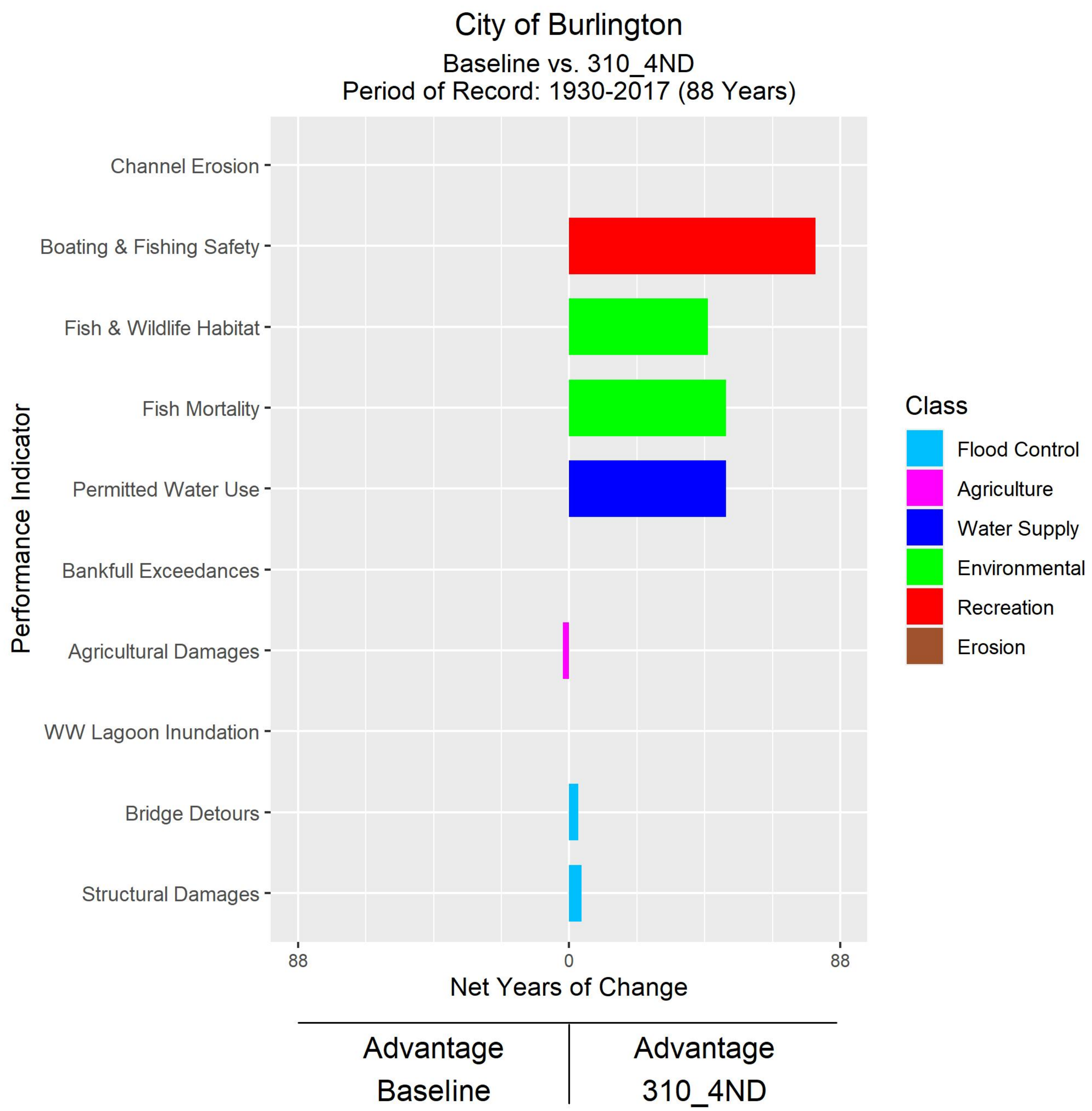


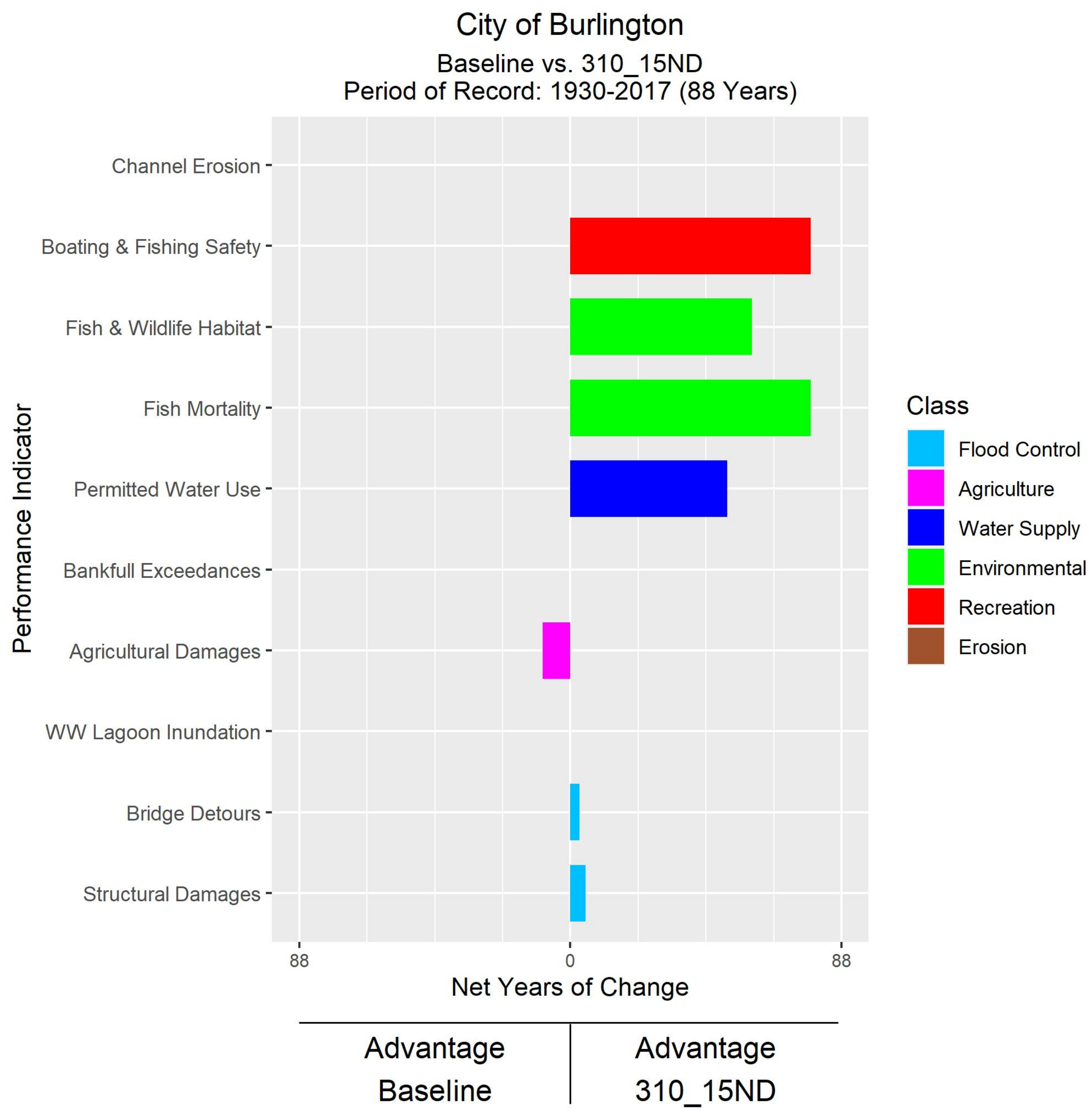
Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



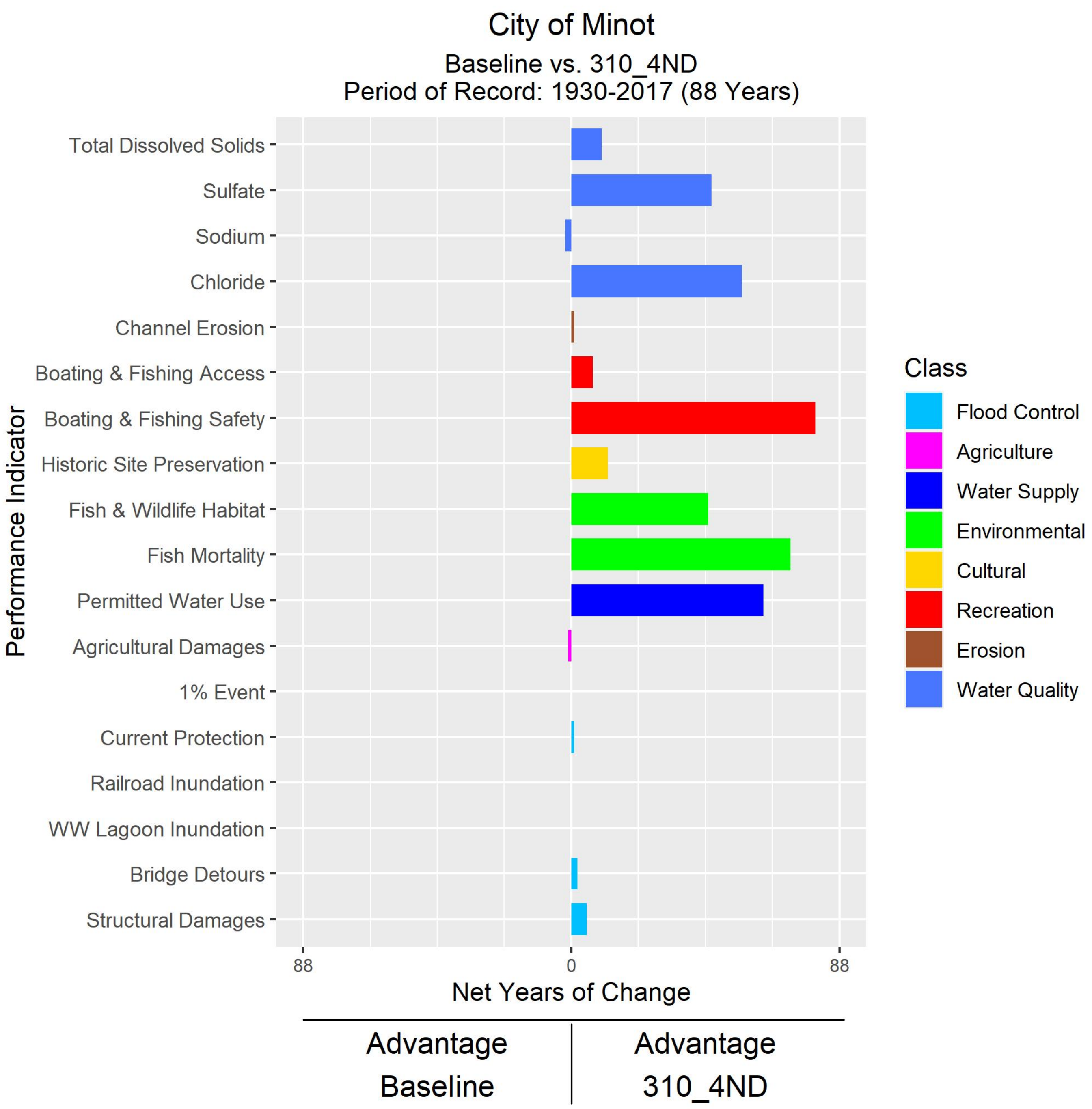


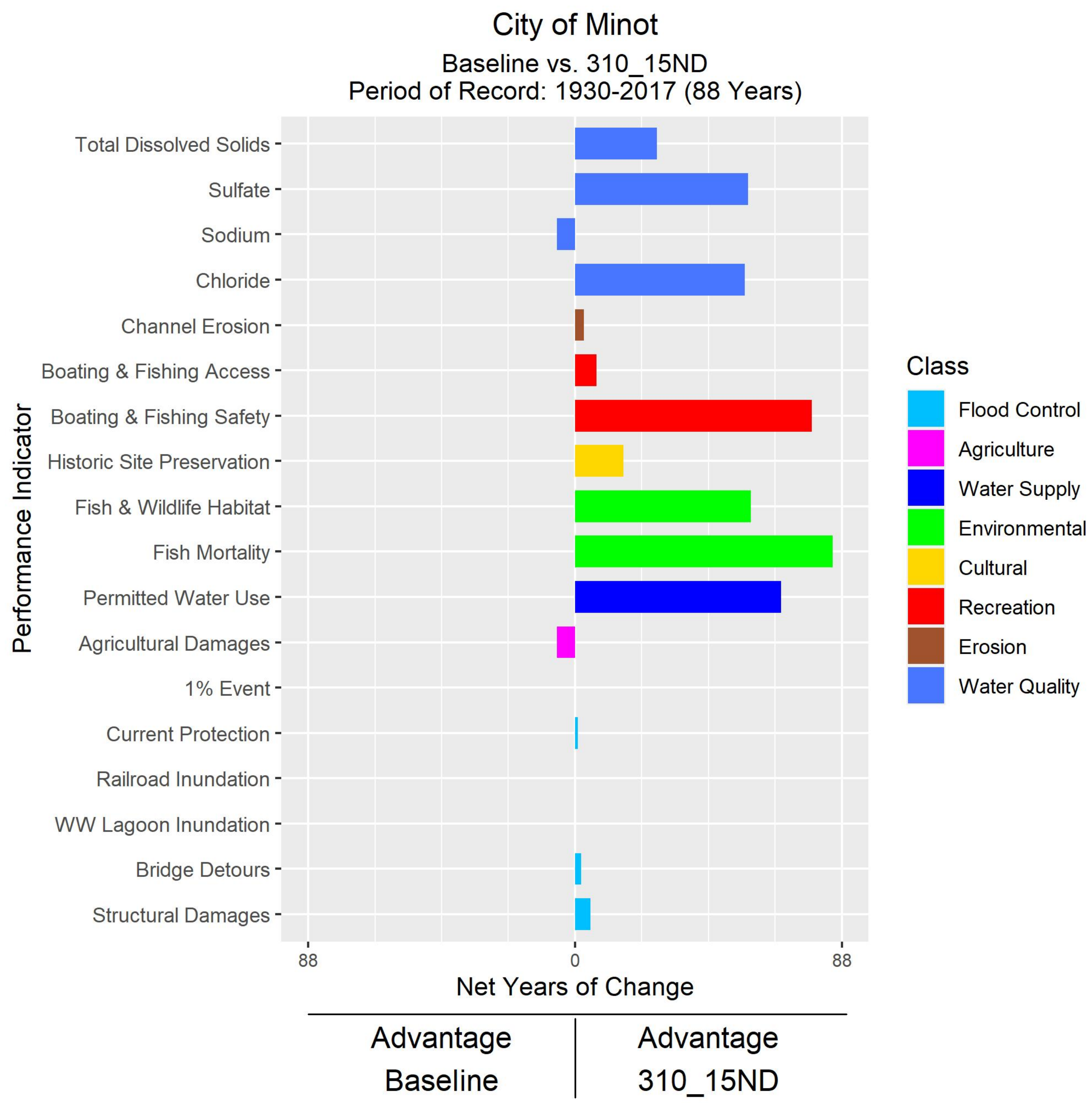
Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



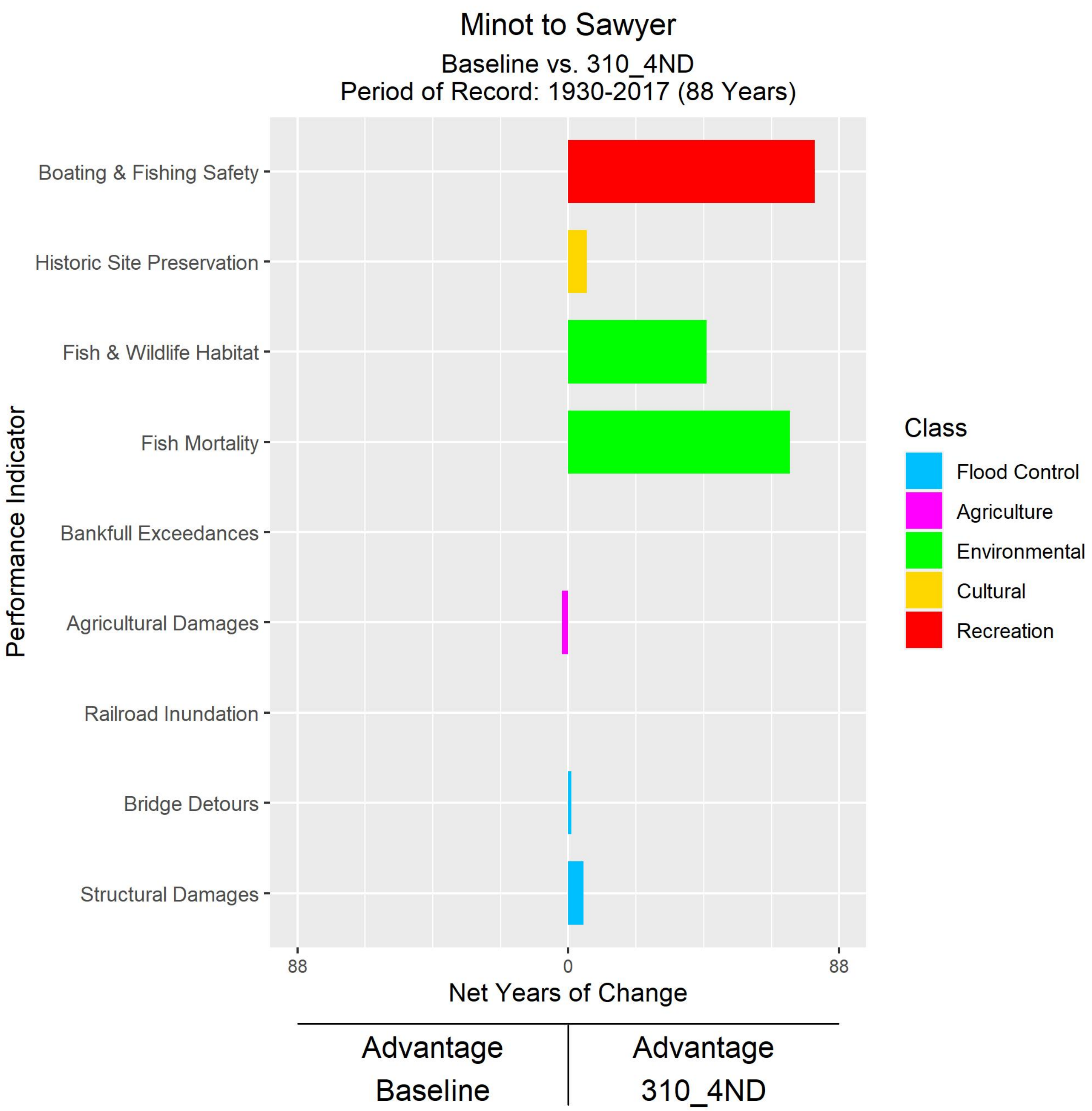


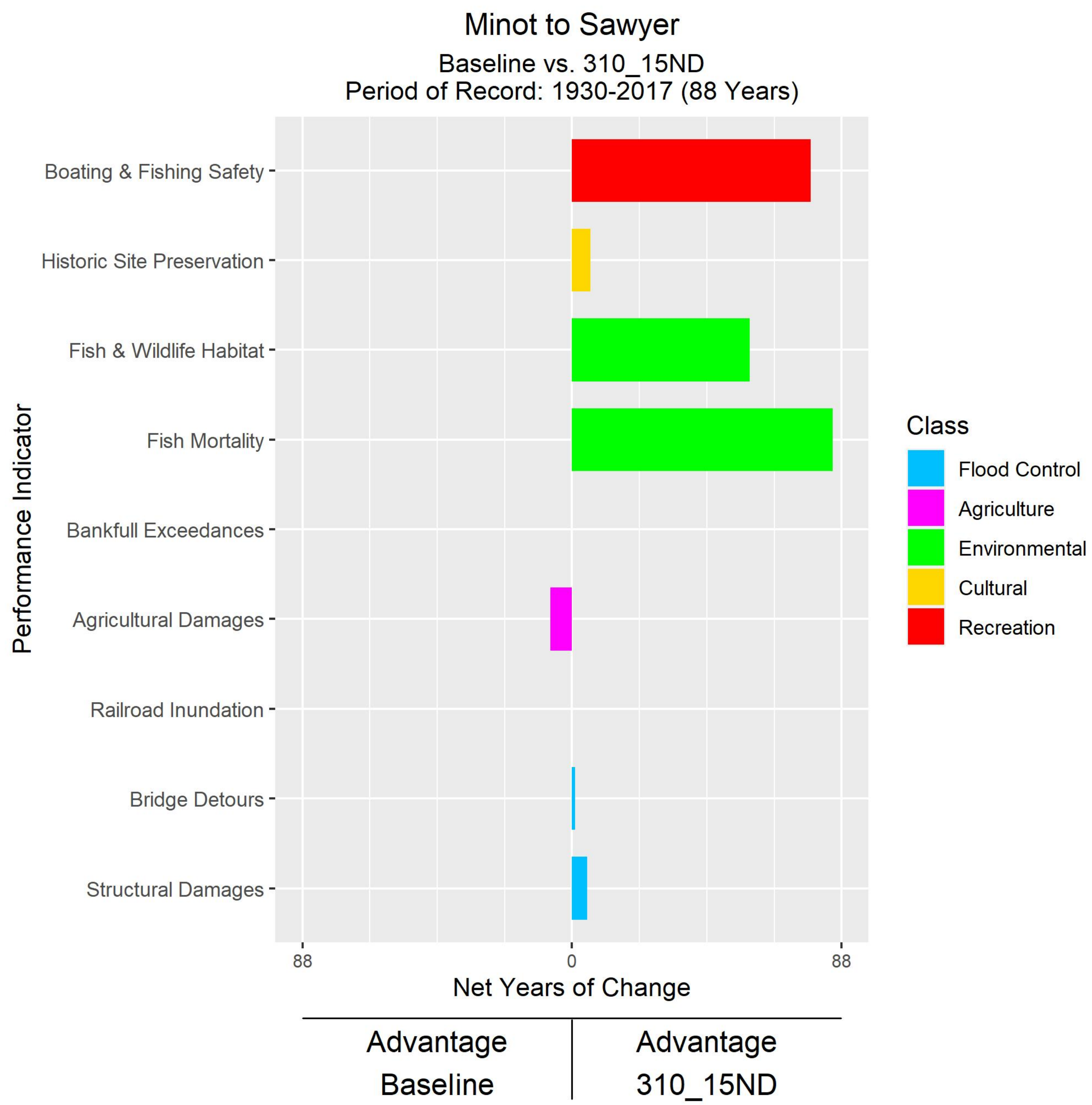
Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



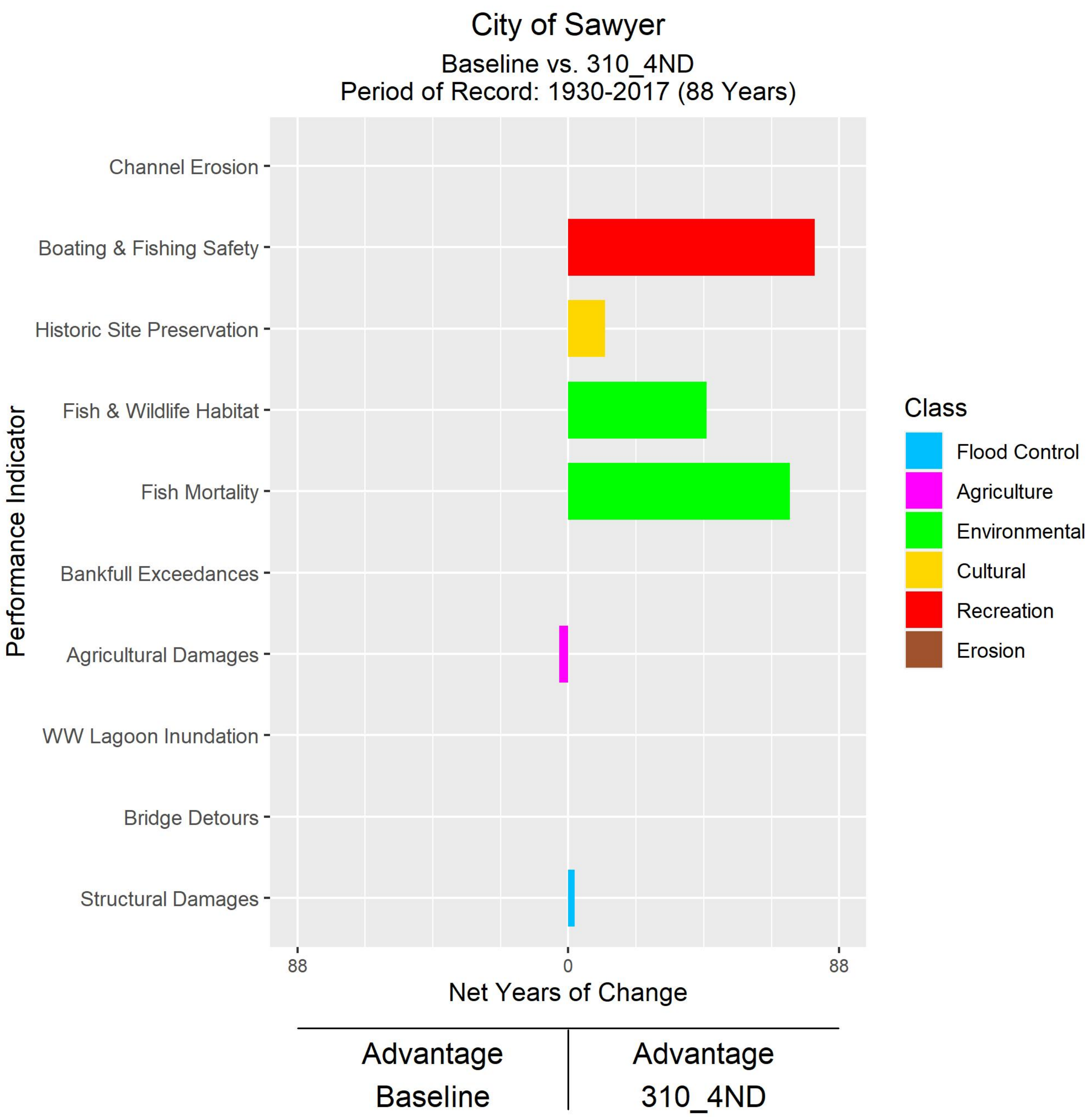


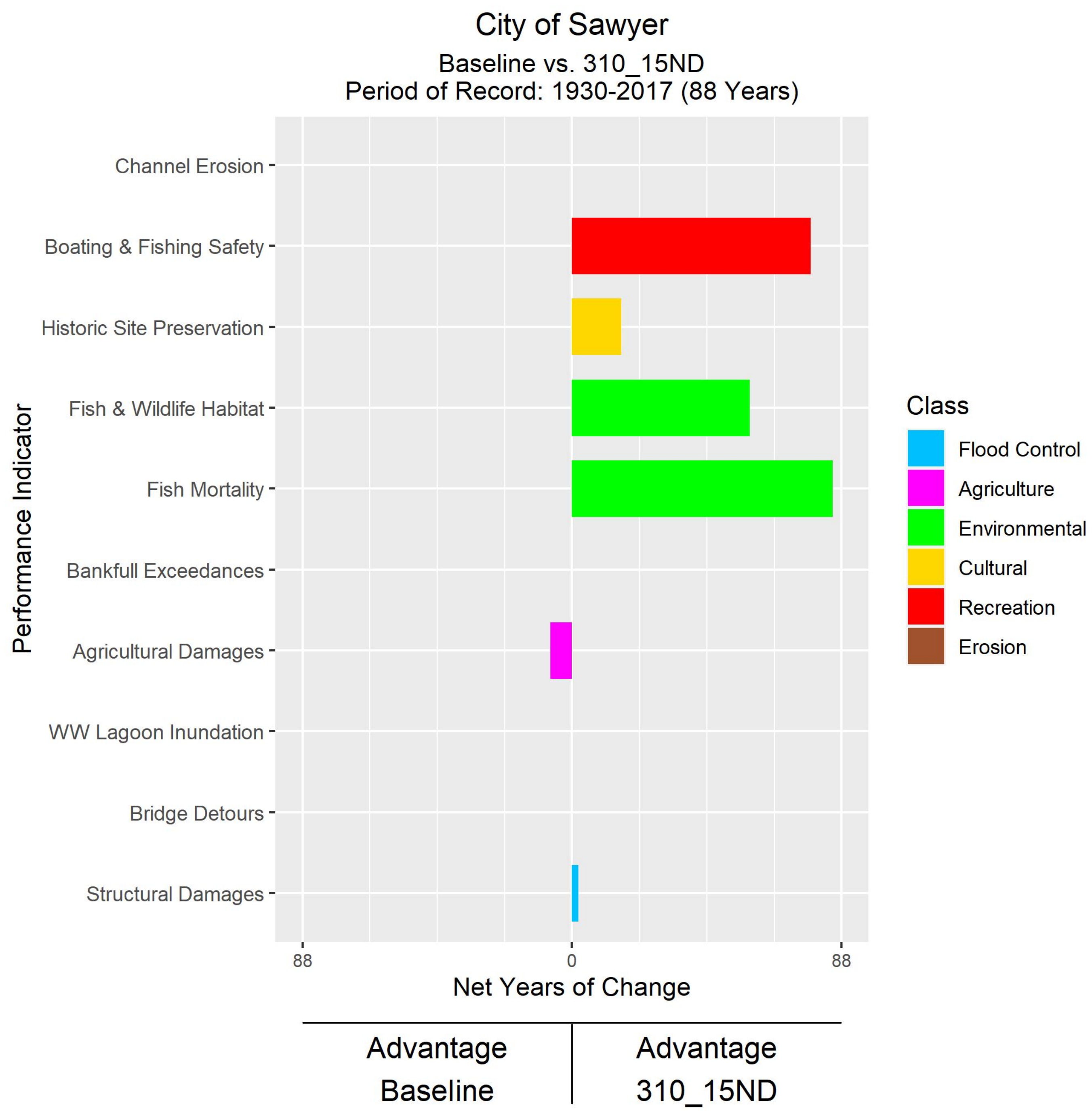
Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling





Alternative 310_4ND

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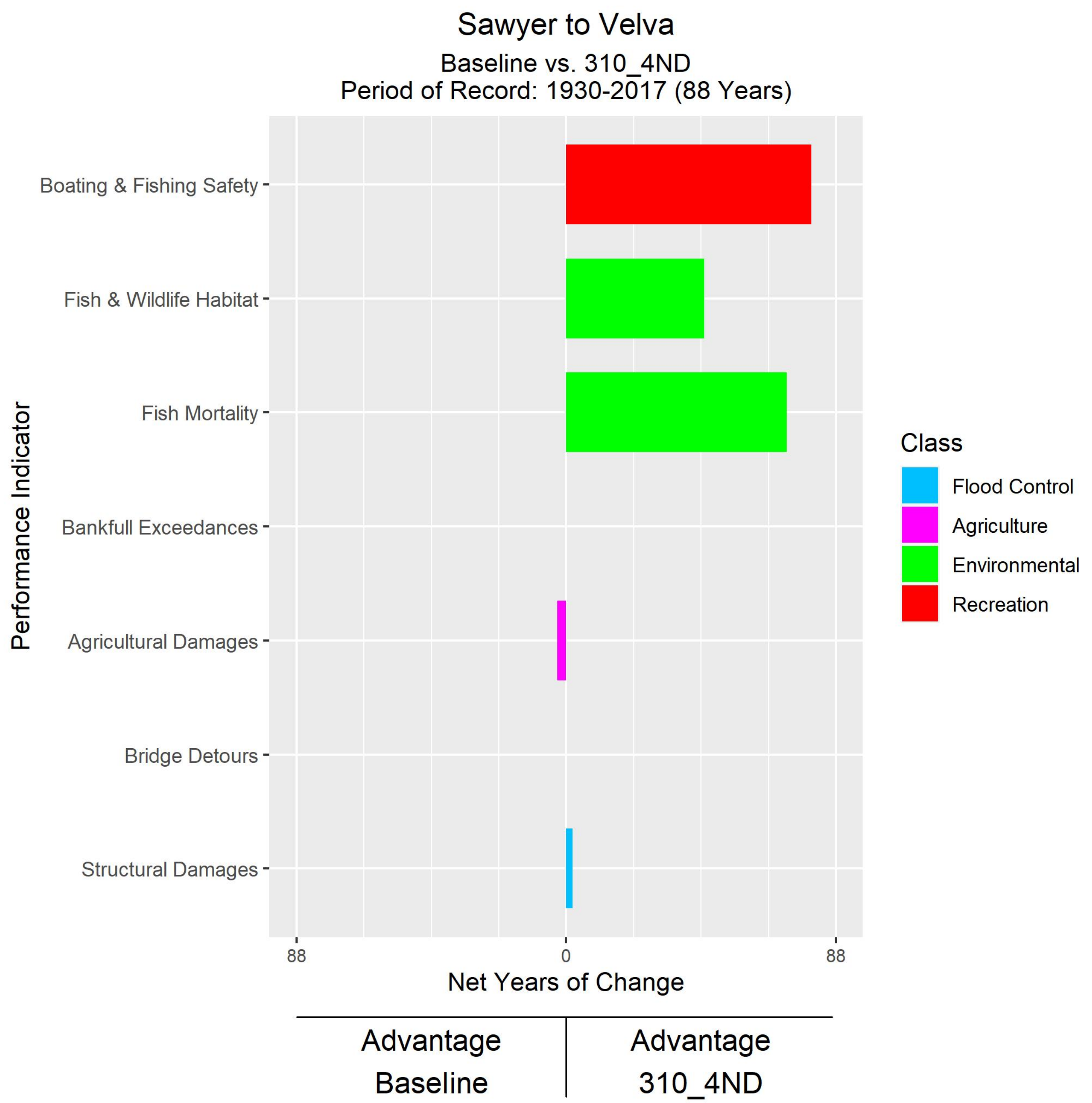
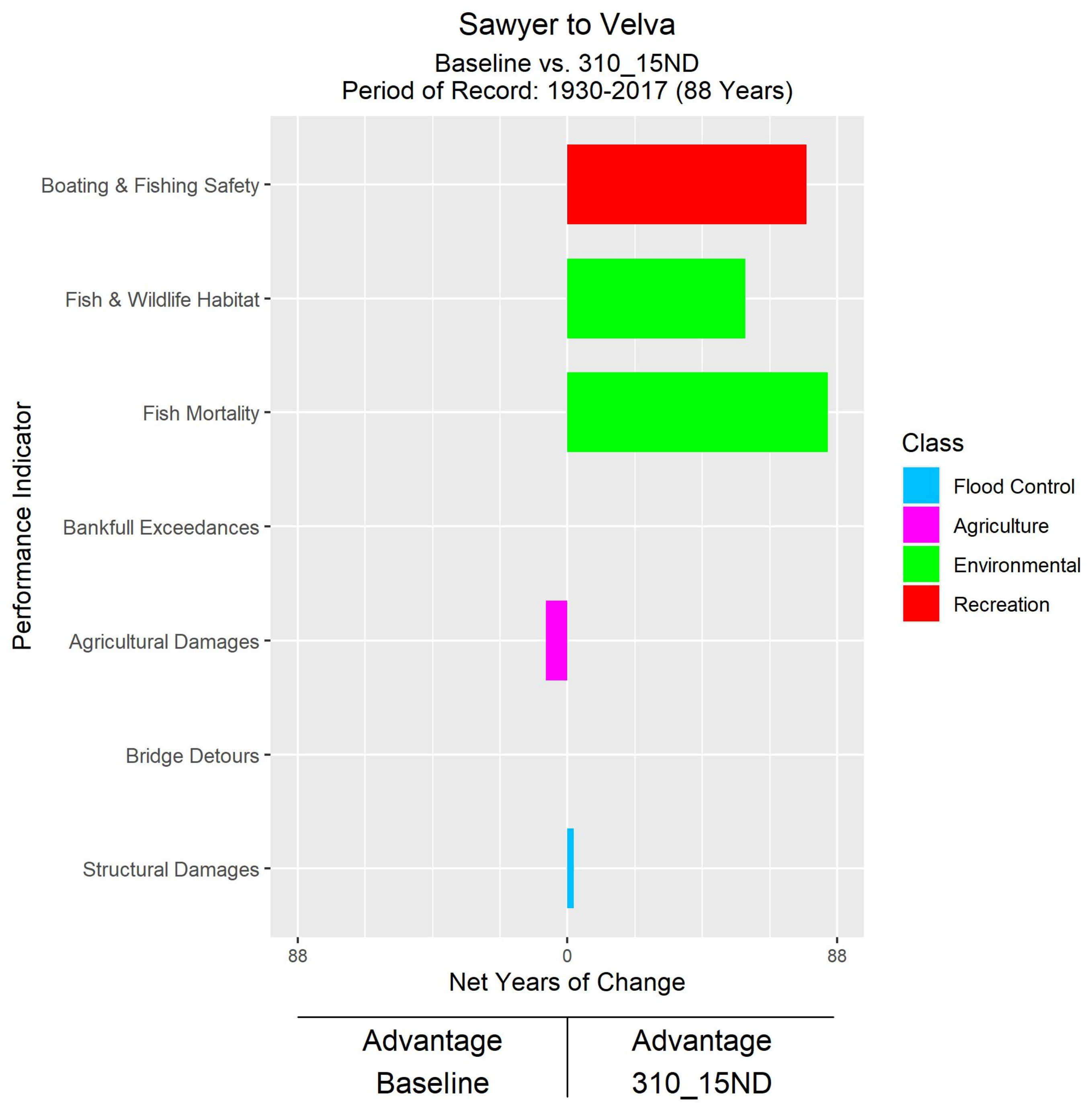
Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



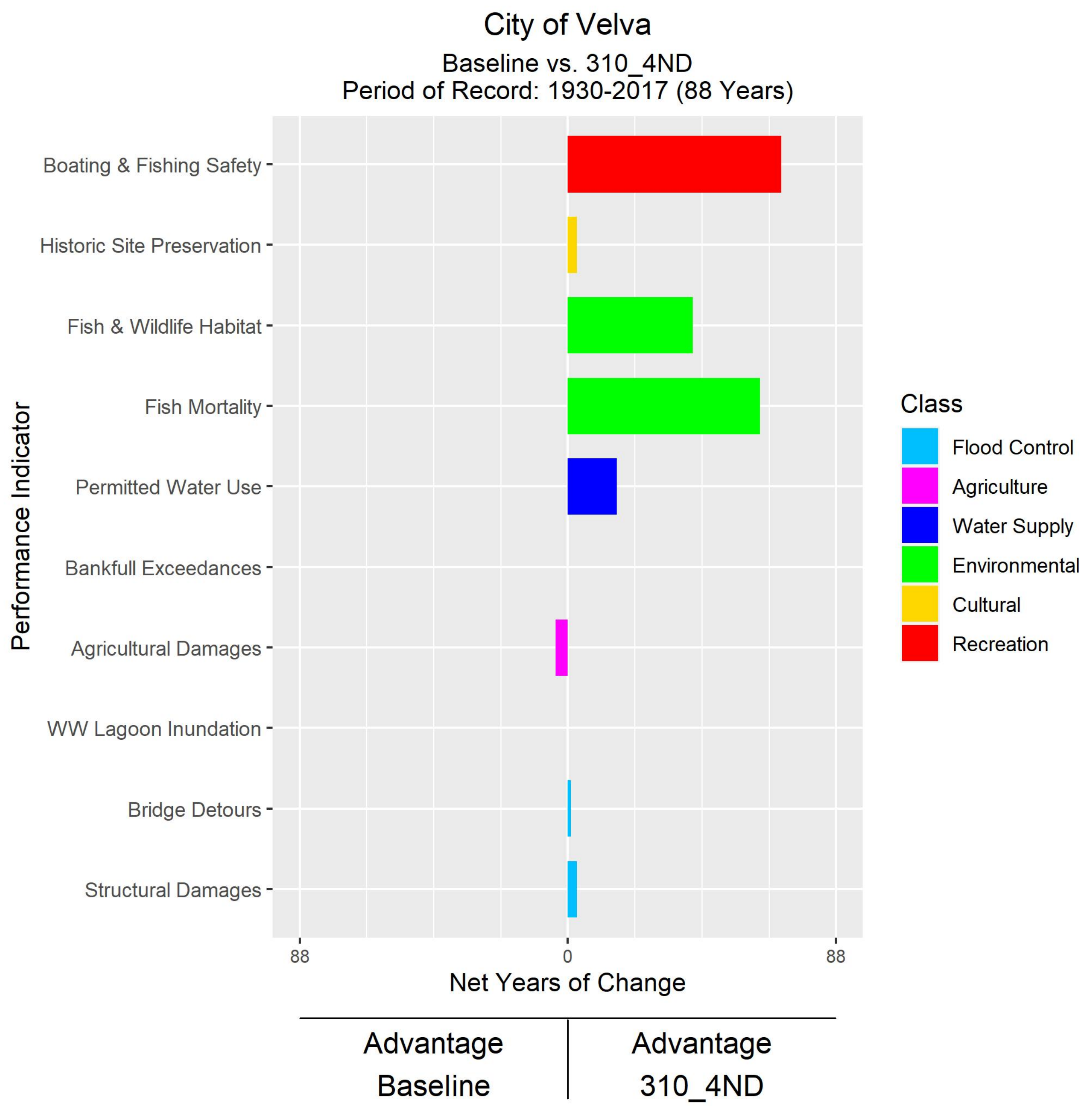


Alternative 310_4ND

- 4 cfs (0.1 cms) constant, year-round release from Lake Darling

Alternative 310_15ND

- 15 cfs (0.1 cms) constant, year-round release from Lake Darling



Alternative 310_4ND

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Alternative 310_15ND

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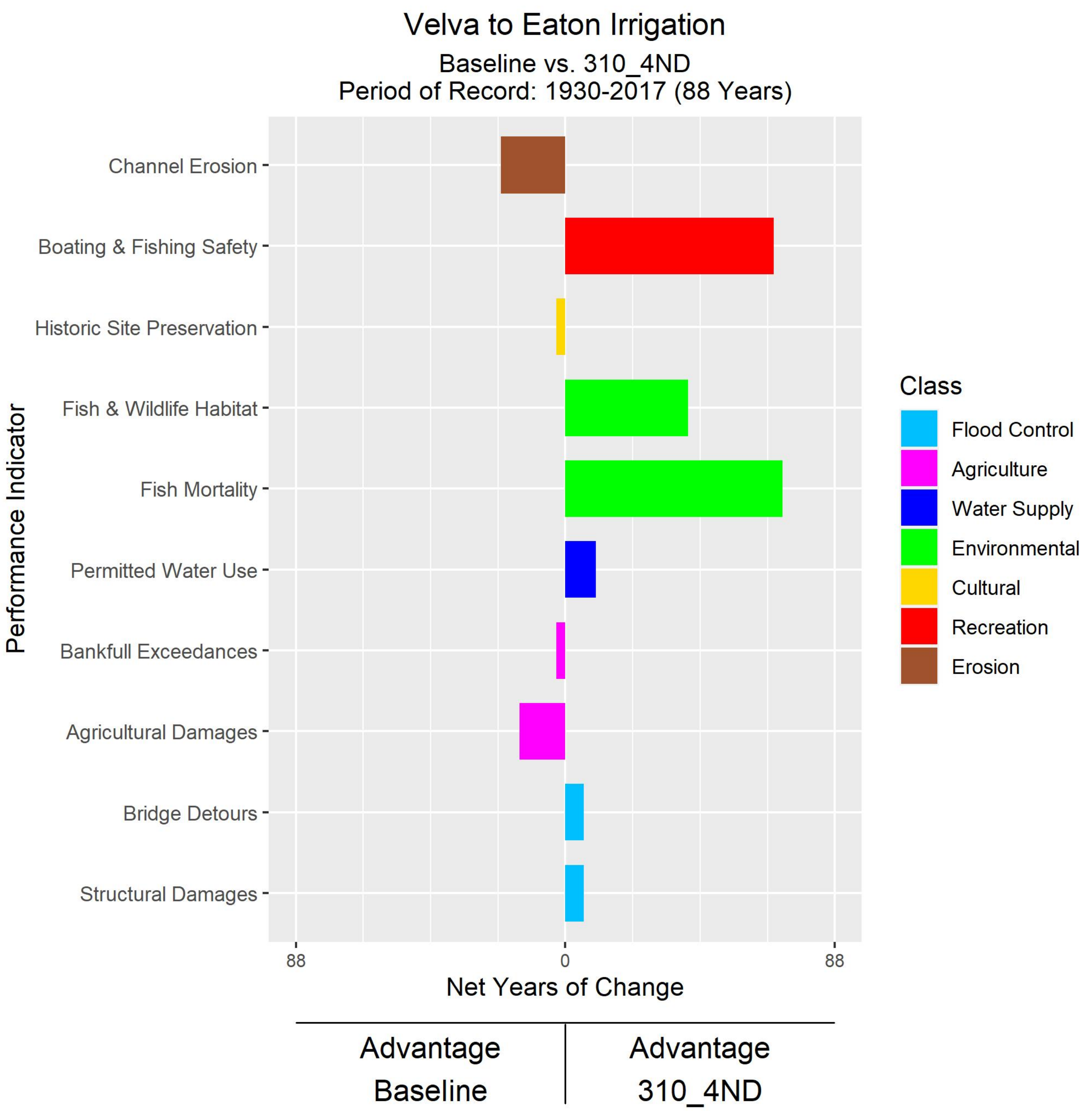

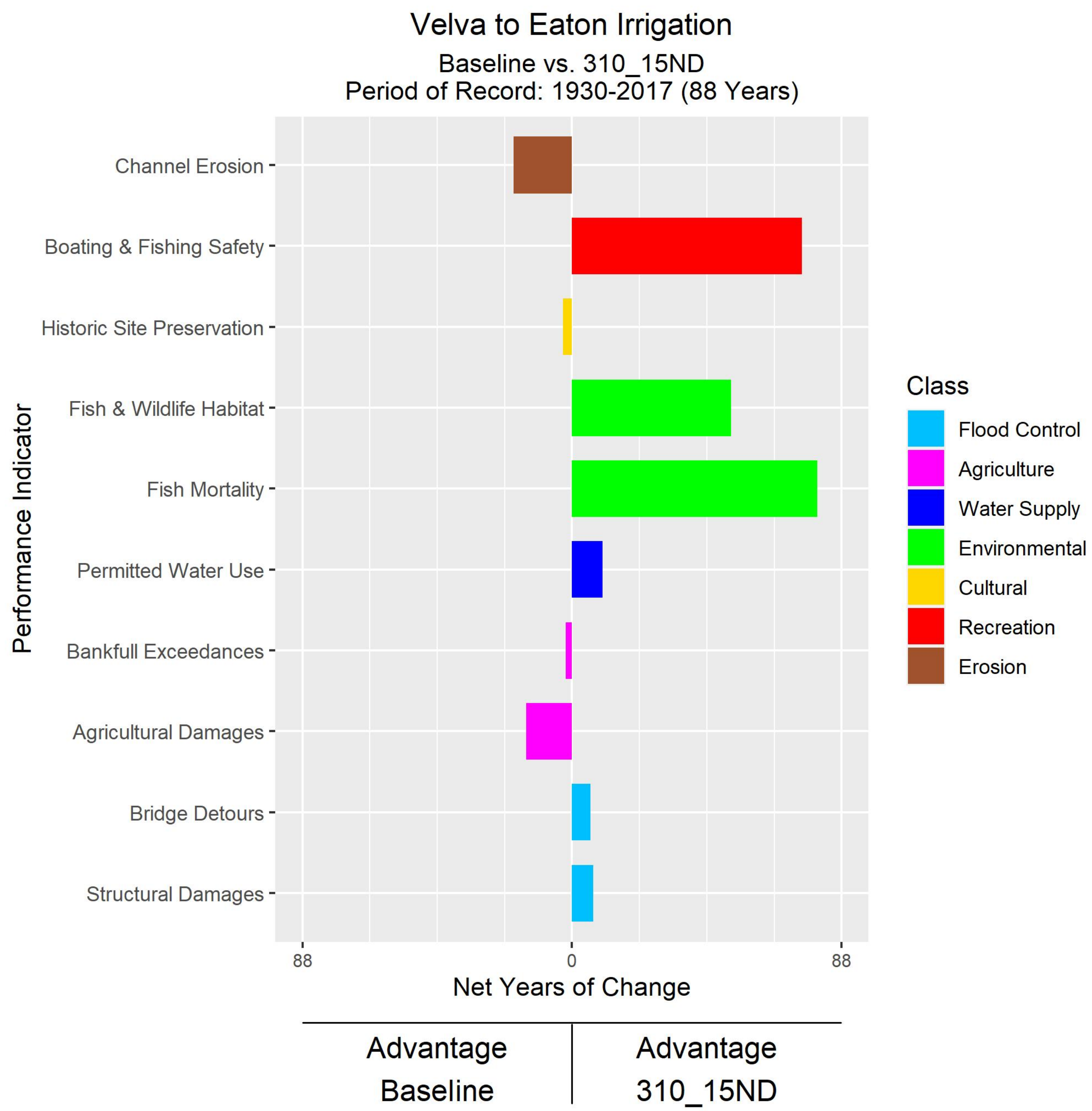

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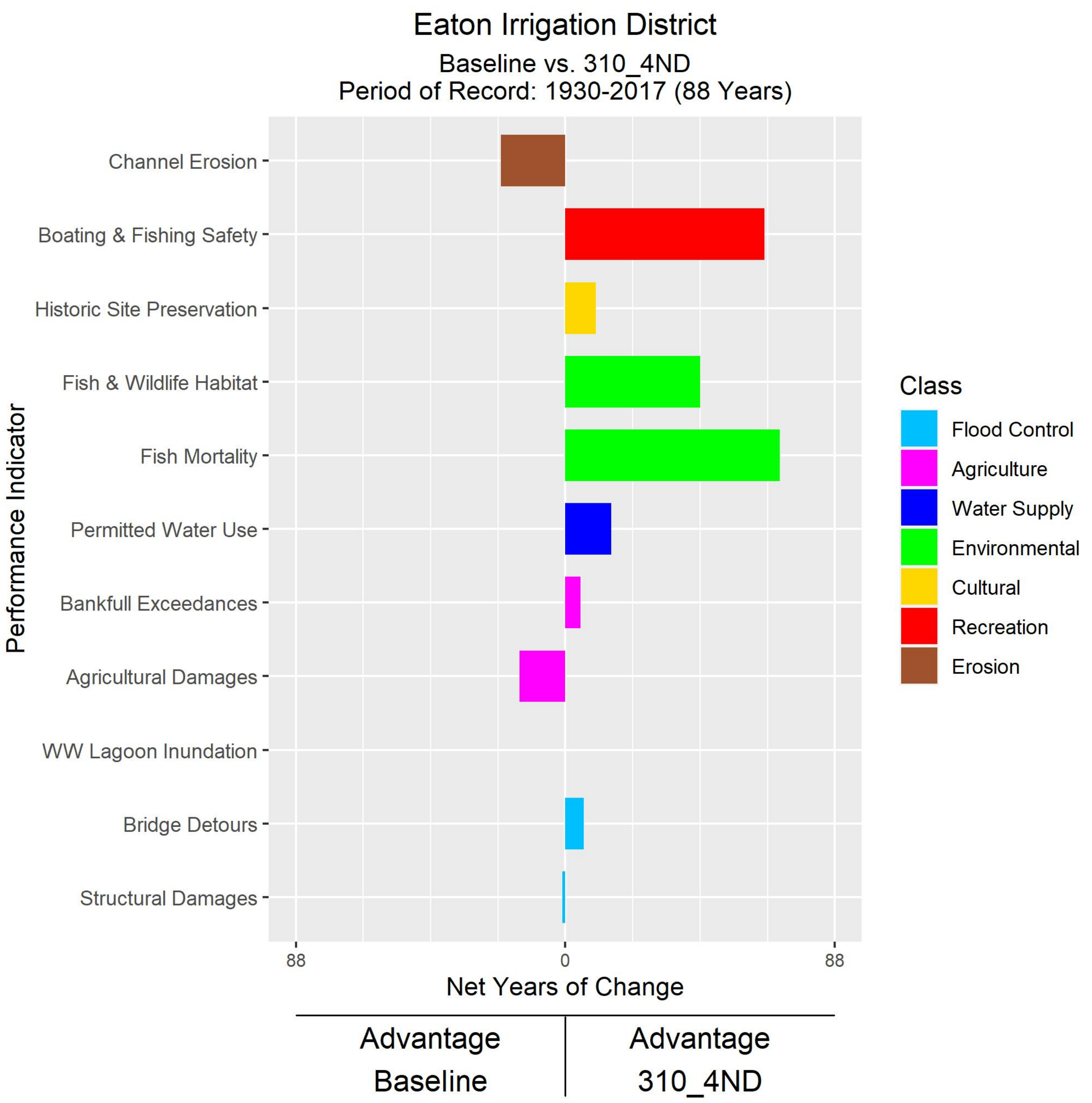

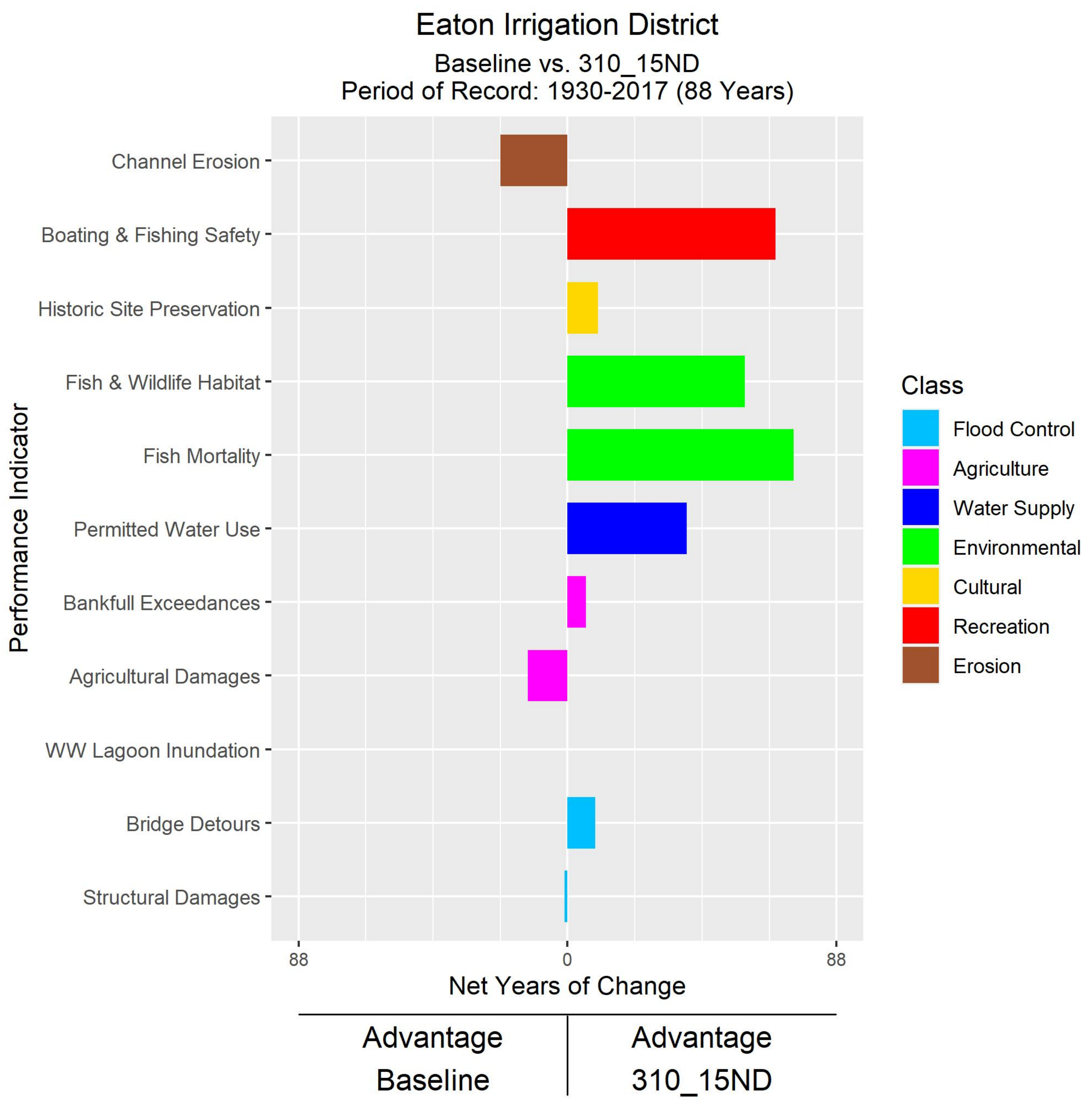

Alternative 310_4ND

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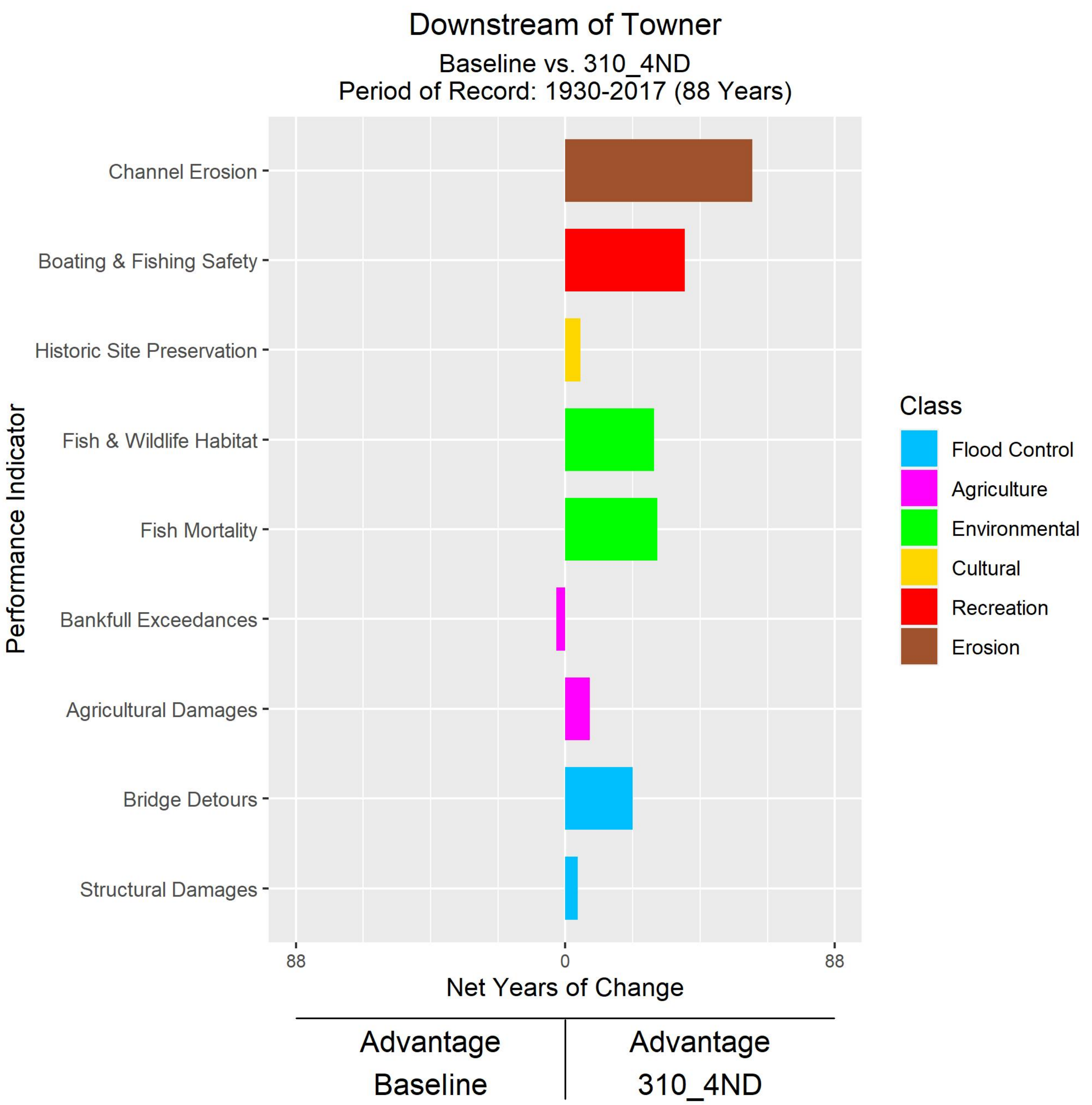

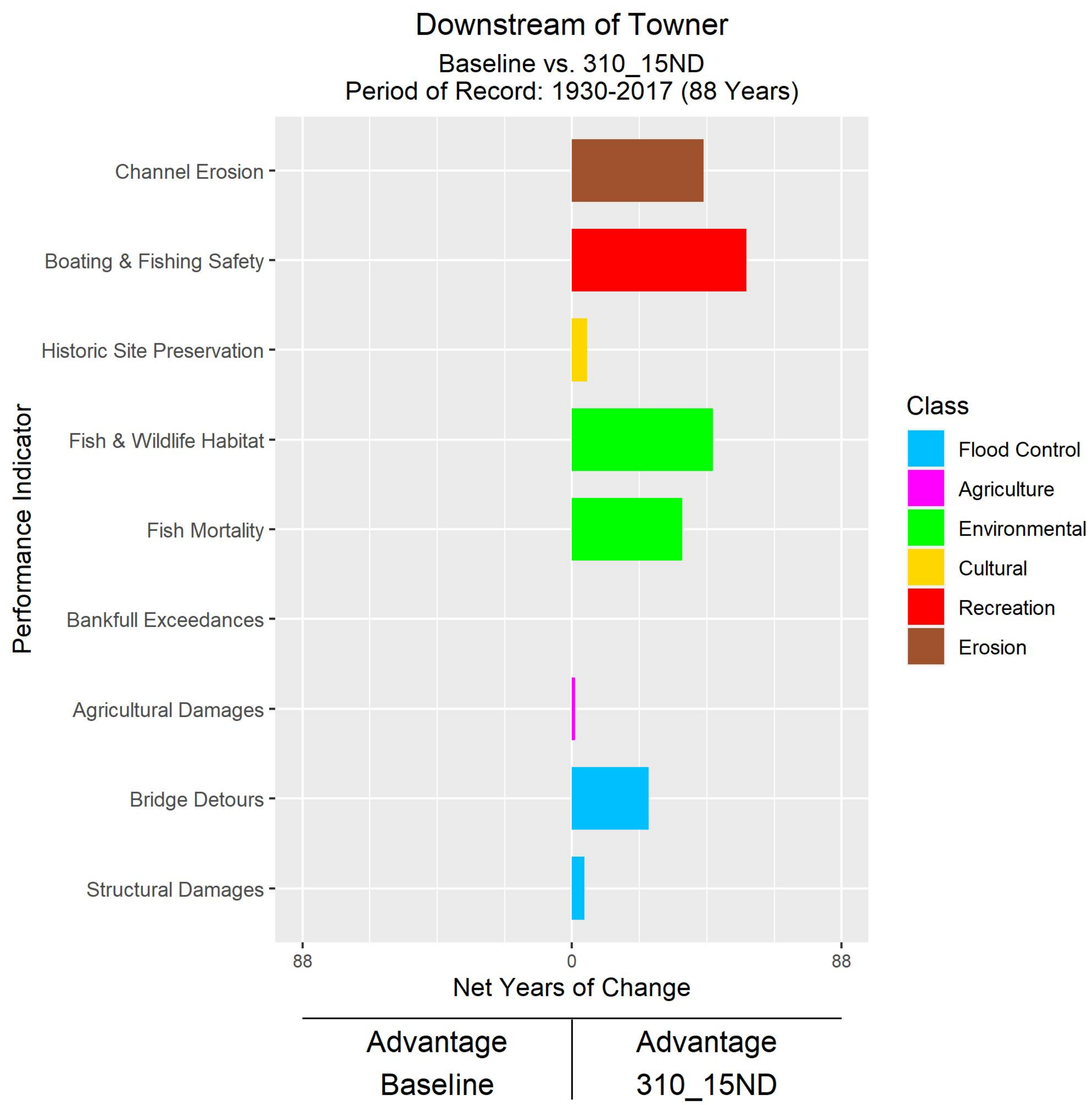

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Alternative 310_15ND

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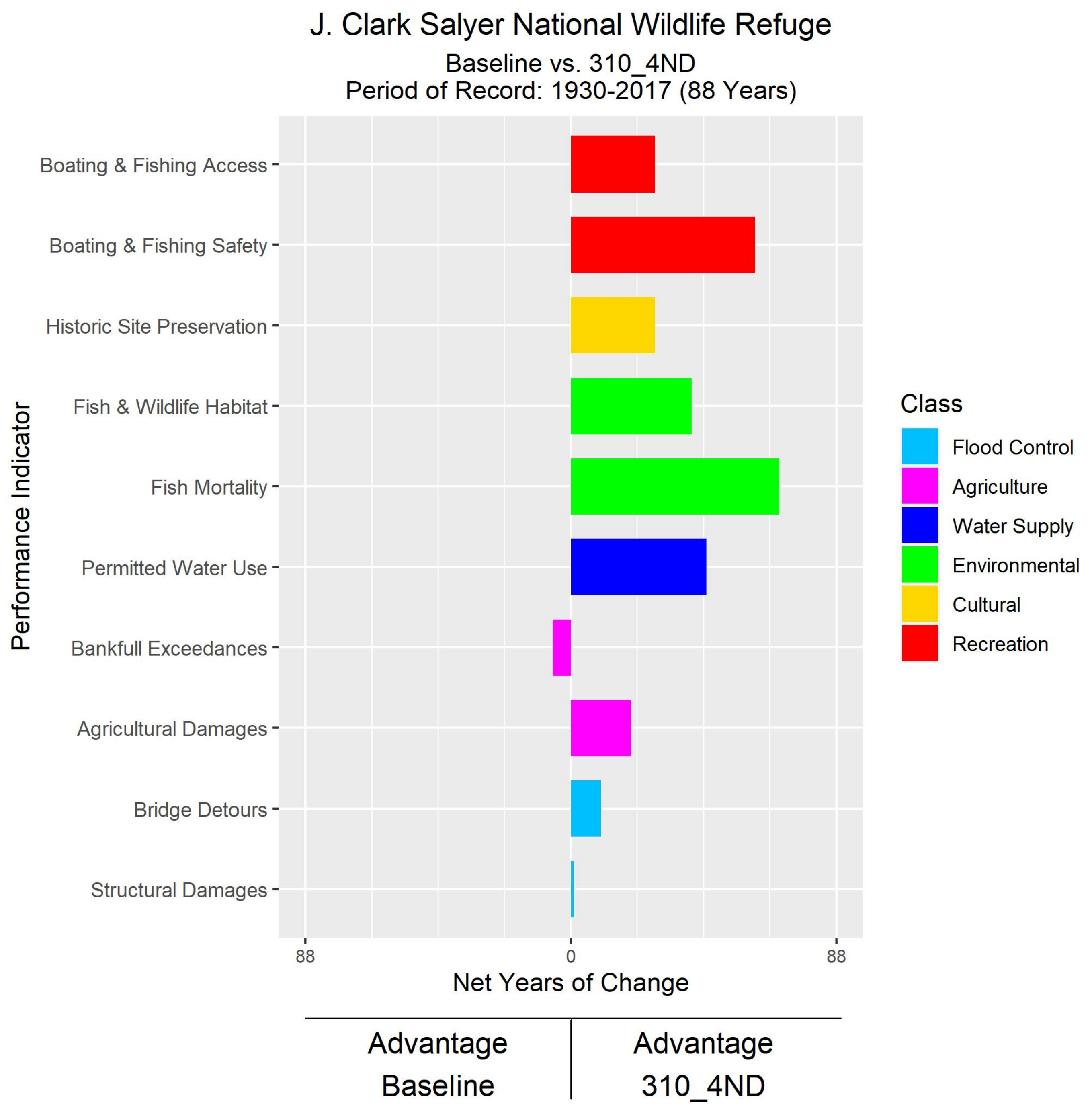

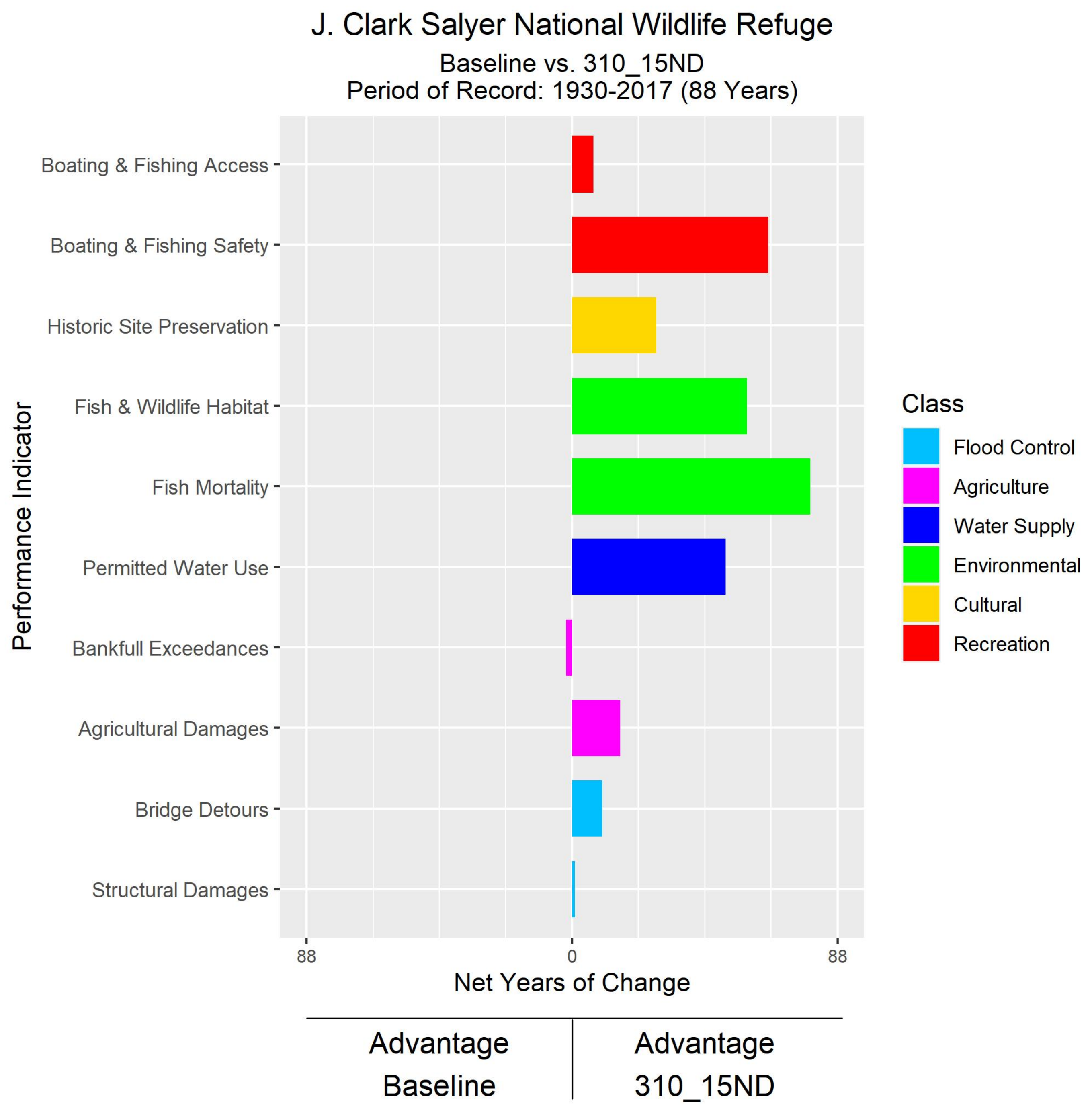

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