Appendix B-8: Alternative 9

WSA Dam Safety

HEC-ResSIM Initial Alternative Assessment

Table of Contents

Figures

Tables

Plates

Plate 03 – 1975: Baseline vs Alternative Reservoir Operations
Plate 04 – 1975: Baseline vs Alternative Flows at Critical Locations
Plate 05 – 1976: Baseline vs Alternative Reservoir Operations
Plate 06 – 1976: Baseline vs Alternative Flows at Critical Locations
Plate 07 – 2011: Baseline vs Alternative Reservoir Operations
Plate 08 – 2011: Baseline vs Alternative Flows at Critical Locations
Plate 09 – 1946-2017: Baseline vs Alternative Performance Indicators

1. Alternative Description & Objective

Alternative 9 models the operating plans defined by the newly developed Reservoir Management Manuals created for Rafferty Reservoir and Grant Devine Lake by the Saskatchewan Water Security Agency (WSA) (WSA, 2019). Both manuals define an Inflow Design Flood Storage Level (IDFSL) for the corresponding reservoir that must be reached by June 1st each year to ensure each reservoir can safely pass its newly developed summer Inflow Design Flood (IDF) event. The objective of this alternative is to analyze the effects of new IDFSL operations at Rafferty and Grant Devine reservoirs. This analysis was conducted using the full period of record available at the time of the simulation (1946-2017).

Under the current operating agreement, outflows at Rafferty and Grant Devine reservoirs are limited by a maximum flow constraint at Sherwood crossing. Rafferty's releases are also limited by the SaskPower coal haul roads and bankfull capacity at the Estevan, SK, and Grant Devine's releases are limited by a downstream railroad crossing. In the baseline scenario, outflows from Rafferty and Grant Devine are restricted by the aforementioned constraints until the pool reaches Maximum Allowable Flood Level (MAFL). Once that occurs, the reservoir will ignore downstream constraints, with the exception of the railroad constraint at Grant Devine, and release its inflows to prevent the pool from exceeding MAFL. If inflows exceed the maximum release capacity of the reservoir, the pool will climb above MAFL, creating a dam safety risk.

Under the new IDFSL operating plans, both Rafferty and Grant Devine will be drawn down to IDFSL from May 1st to June 1st, and each reservoir will be allowed to exceed its maximum downstream flow restrictions to keep the pool below IDFSL until September 1st. Figure 1 and Figure 2 show IDFSL for Rafferty and Grant Devine reservoirs, respectively. As can be seen, the IDFSL for Rafferty Reservoir is 1 m (3.28 ft) above Full Supply Level (FSL) at 1809.4 ft (551.5 m). This corresponds to a decrease in flood storage during the summer months of approximately 142,700 dam3 (115,690 ac-ft). The IDFSL for Grant Devine Reservoir is 562 m (1843.8 ft), which is equal to the current FSL. This corresponds to a decrease in flood storage during the summer months of approximately 84,100 dam^3 (68,180 ac-ft).

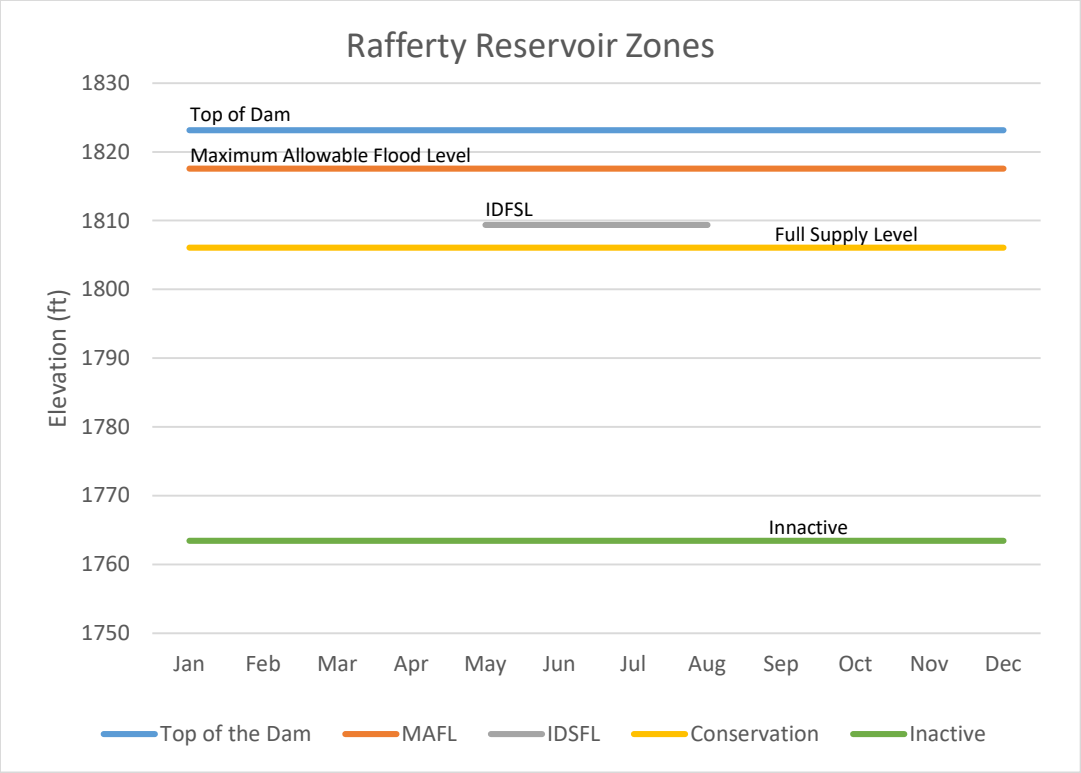


Figure 1. Rafferty Reservoir zones

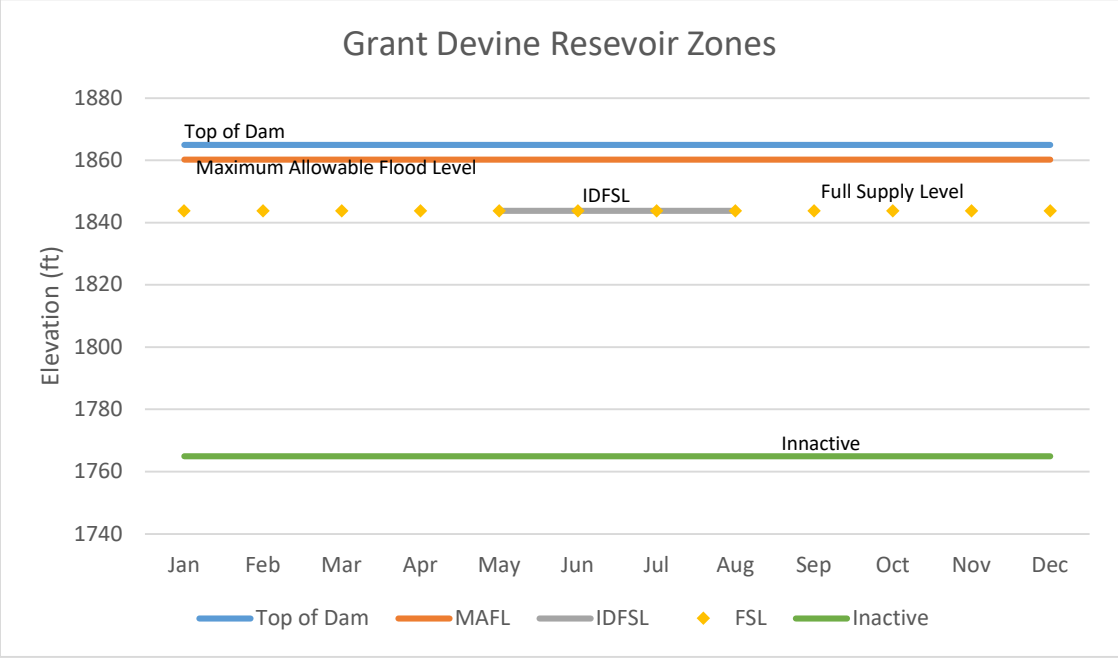


Figure 2. Grant Devine Reservoir zones

1.1 Alternative Development

This alternative was defined based on the Reservoir Management Manual for Rafferty and Grant Devine developed by WSA and the information provided to the Plan of Study team members in January 2019. The alternative was developed by incorporating the script within the state variable in the Dam Safety network created by USACE available within the preliminary model (SourisRiverPoS).

The alternative incorporates a new zone (IDSFSL) in Rafferty and Grant Devine reservoirs between FSL and MAFL, and the state variable defines an IDFSL guide curve for when the reservoir's pool exceeds IDFSL. The operation to reduce reservoir levels to IDFSL by June 1st starts on May 1st. This new guide curve calculates a release rate for the month of May based on how far the reservoir is above IDFSL. After June 1st, no downstream flow constraints are applied when the reservoir's pool exceeds IDFSL. In summary, the following rules were added to Rafferty and Grant Devine reservoirs:

May 1st: if the pool is above IDFSL, a linear drawdown is initiated to get back to IDFSL by June 1st.

June 1st: if the reservoir is below IDFSL, operations are equivalent to the baseline scenario. If the reservoir is above IDFSL, downstream constraints are removed.

1.2 HEC-ResSim Nomenclature

Within HEC-ResSim, a new network, alternative and simulation run was generated to reflect each proposed alternative. To generate the alternative, a copy of the base network was made and modified accordingly. The nomenclature associated with the ResSim networks, alternatives, and simulations used to model both baseline and alternative operations are listed in Table 1.

Table 1. Model nomenclature

Scenario	Time Window	ResSIM Model Name	Network Name	Alternative Name	Simulation Name
Baseline	1946-2017	SourisRiver PoS	Base	Cal2FSL	09_DS_WSA_SY_EY2
Dam Safety	1946-2017	SourisRiverPoS	09_DA_WSA_1	09_DS_WSA1	09_DS_WSA_SY_EY2

2. Operational Rules

Error! Reference source not found. presents the operational rules that were added to the base HEC-ResSim model to specifically reflect the changes required in support of the Dam Safety alternative.

Table 2. Operation rules added specific to alternative

Name of Dam	Name of Rule, Outlet or IF Statement or State Variable Element	Rule Description
Rafferty Reservoir	MAX ROD/ROI	
	DownstreamMaxMAFL	If block that applies the rules only before May 1st
	IDFSL guide curve was created within the State variable	The idfsl guide curve is used to decrease water levels when

Name of Dam	Name of Rule, Outlet or IF Statement or State Variable Element	Rule Description
		they are above IDFSL levels
Note that the new IDFSL zone was created		
Grant Devine Reservoir	MAX ROD/ROI	
	DownstreamMaxMAFL	If block that applies the rules only before May 1st
	IDFLS guide curve was also created within The state variable for Grant Devine	The idfsl guide curve is used to decrease water levels when they are above IDFSL levels

In order to properly run this alternative, the rules for Rafferty Reservoir and Grant Devine Lake needed to be changed. First, a new zone was created to simulate the operation between FSL and IDFLS, which resulted in the addition of a new guide curve (this was done in the a_fld_MASTER_gc_gd state variable script).

In the case that water levels are above the specified IDFSL as of May 1st, releases are initiated in order to get to the desire level by June 1st. To make sure this is done, an IF block that does not apply the downstream constraints during the month of May was added to the MAFL zone (DownstreamMaxMAFL). The inclusion of this IF block makes sure the reservoirs reach IDFSL by June 1st. The same rules as the baseline were applied to the model if water levels are below the IDFSL during the summer months.

The last change was the addition of the max rate of increase (ROI) and rate of decrease (ROD) to all zones. This was done to limit how much the reservoirs can increase and decrease by. Operations to reduce pools to IDFSL in spring and summer have precedence over target flows at Estevan and Sherwood; therefore, the maximum flow restrictions at these locations were not applied for this alternative.

In addition to adding rules, some existing rules needed to be changed. Table 3 presents the operational rules that were changed from the base HEC-ResSim model to specifically reflect the changes required in support of the Dam Safety alternative.

Table 3. Operation rules changed specific to alternative

Name of Dam	Name of Rule, Outlet or IF Statement or State Variable Element	Rule Description
Rafferty Reservoir	Ds_EstevanMax-1	Not removed but a conditional was applied
	Ds_sherwood_sv	Not removed but a conditional was applied
Grant Devine Reservoir	MaxReleasesGD	Not removed but a conditional was applied
	Ds_sherwood_sv	Not removed but a conditional was

Name of Dam	Name of Rule, Outlet or IF Statement or State Variable Element	Rule Description
		applied

Figure 3 and Figure 4 display where the rule/if statement/outlet was inserted into the ResSIM model user interface for each reservoir. The relevant model feature is indicated by the red box. **Error! Reference source not found.**Figure 5 to Figure 8 provide screenshots of where the state variable script was modified for this alternative. Relevant lines of the state variable script are highlighted in red.

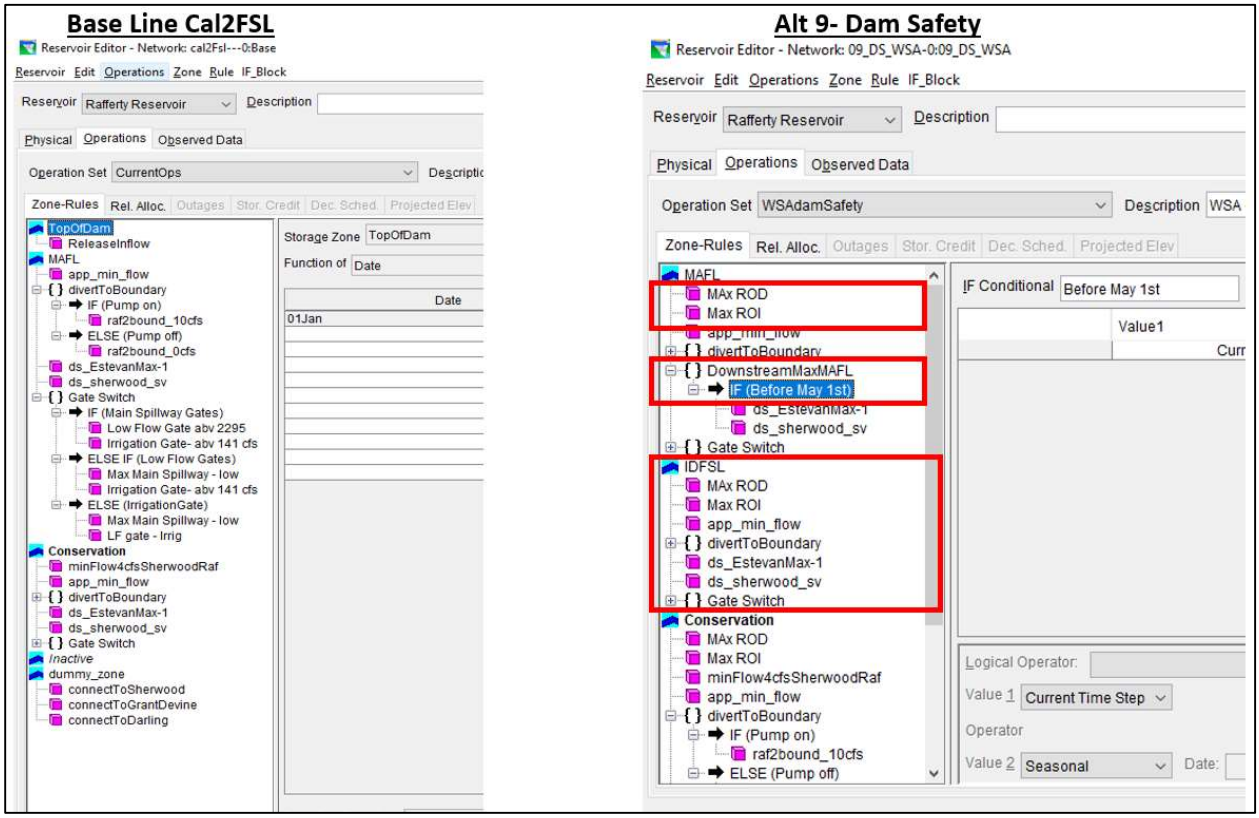


Figure 3. Changes made to Rafferty Reservoir

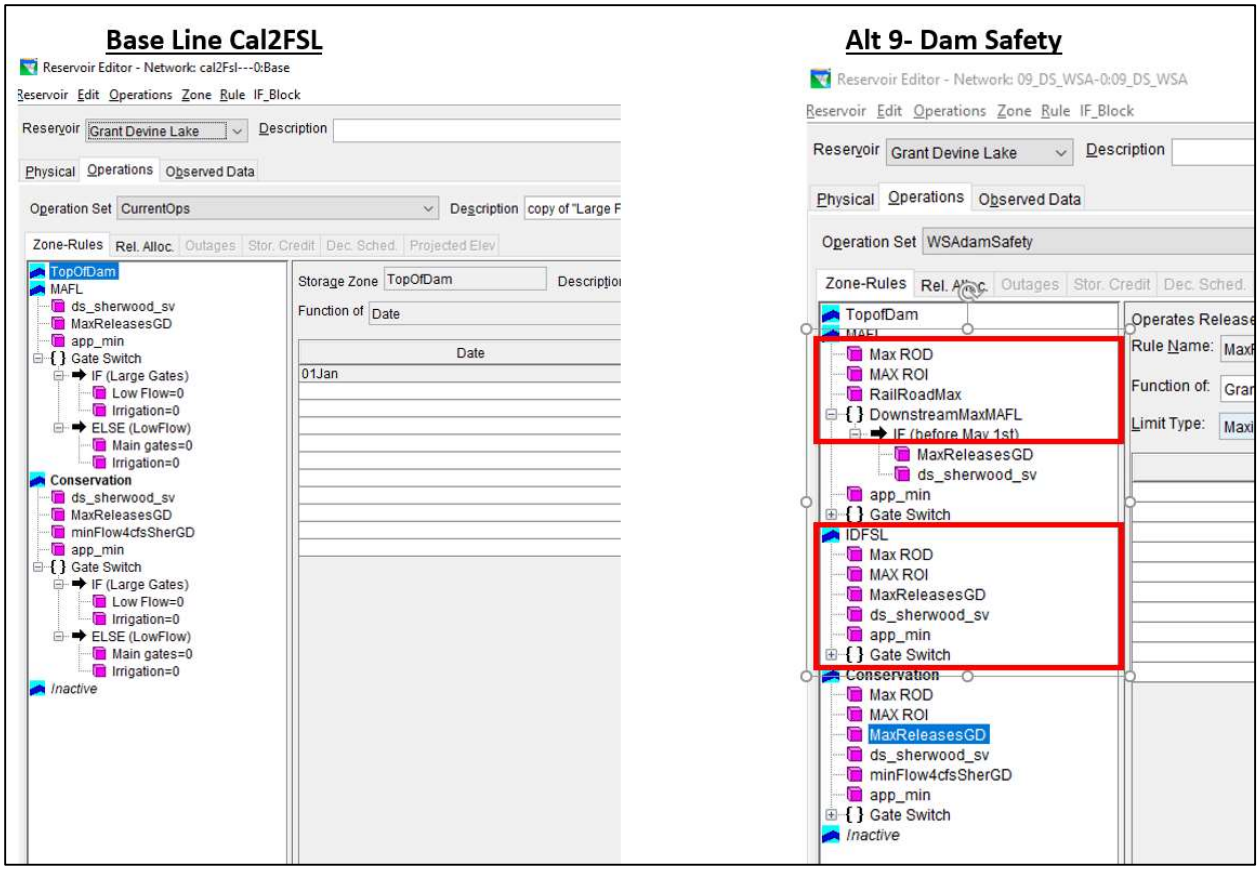


Figure 4. Changes made to Grant Devine Reservoir

```
                    # calculates the number of days standard drawdown will occur over
                    totalDrawdownDays = stndDrawdownEndDay-stndDrawdownStartDay
                    # calculates the daily drawdown rate
                    stndDrawdownRate = (elevStartDD-stndDrawdown)/(totalDrawdownDays)
                    GC = elevStartDD-stndDrawdownRate*(totalDrawdownDays-daysToStndDrawdownEnd) #function based on standard Feb 1 drawdown

        else: # other times of year when not flooding
            GC = fsl
        return GC

def guideCurveIDFSL(doy, idfsl, elevStartDD, drawdownStartDay, drawdownEndDay):

    """Generates drawdown for IDFSL for Rafferty and GD reservoirs"""
    # calculates the number of days until drawdown to IDFSL ends
    daysToStndDrawdownEnd = drawdownEndDay-doy
    # calculates the number of days standard drawdown will occur over
    totalDrawdownDays = drawdownEndDay-drawdownStartDay
    # calculates the daily drawdown rate
    drawdownRate = (elevStartDD-idfsl)/(totalDrawdownDays)
    GC = elevStartDD-drawdownRate*(totalDrawdownDays-daysToStndDrawdownEnd) #function based on drawdown from pool elevation Apr30
    return GC

# get current timestep
currentStep = currentRuntimestep.getStep()
# get current day of year
doy = currentRuntimestep.getHecTime().dayOfYear()
# get year for leap year check
year = currentRuntimestep.getHecTime().year()
if calendar.isleap(year):
    leapOffset = 1
else:
    leapOffset = 0

convertCfsToAcreFeet = currentRuntimestep.getTimeStepSeconds()/43560.

# save julian days for future reference
jan31 = 31
feb1 = 32
mar1 = 50+leapOffset
mar15 = 74+leapOffset
apr1 = 91+leapOffset
apr30 = 120+leapOffset
may15 = 135+leapOffset
may31 = 151+leapOffset
jun1 = 152+leapOffset
jul1 = 182+leapOffset
```

Figure 5. Definition of the IDFSL guide curve within the state variable

```
#============================================================================
# ####Annex A - Section 4.3.5 Operating plan steps
#============================================================================
rafFullSupply = 1806.10
rafNormDrawdown = 1802.82 #standard Feb 1st drawdown
rafElev = network.getTimeSeries("Reservoir","Rafferty Reservoir", "Pool", "Elev").getPreviousValue(currentRuntimestep)
rafFullSupplyVol = 356400
rafVolMaxFlood = 513000
rafMaxDD = 1796.26
rafIDFSL = 1809.38

gdFullSupply = 1843.83
gdNormDrawdown = 1840.55 #standard Feb 1st drawdown
gdElev = network.getTimeSeries("Reservoir","Grant Devine Lake", "Pool", "Elev").getPreviousValue(currentRuntimestep)
gdFullSupplyVol = 85530
gdVolMaxFlood = 153710
gdMaxDD = 1823.65
gdIDFSL = 562/.3048

boundFullSupply = 1840
boundElev = network.getTimeSeries("Reservoir","Boundary Reservoir", "Pool", "Elev").getPreviousValue(currentRuntimestep)
boundVolMaxFlood = 49845
boundMaxDD = 1830.0

darNormPool = 1597
darNormDrawdown = 1596
darMaxDD = 1591

darElev = network.getTimeSeries("Reservoir","Lake Darling", "Pool", "Elev").getPreviousValue(currentRuntimestep)

rafElevIDFSLstartDD_TS = currentVariable.localTimeSeriesGet("rafElevIDFSLstartDD")
gdElevIDFSLstartDD_TS = currentVariable.localTimeSeriesGet("gdElevIDFSLstartDD")
```

Figure 6. IDFSL elevations and time series (state variable)

```
443     if doy == stndDrawdownStartDay:
444         rafElevStartDD = rafElev
445         gdElevStartDD = gdElev
446 
447         darElevStartDD = darElev
448 elif doy == apr30:
449         rafElevIDFSLstartDD = rafElev
450         gdElevIDFSLstartDD = gdElev
451     else:
452         # write out start day elevations to TS
453         rafElevStartDD = rafElevStartDD_TS.getPreviousValue(currentRuntimestep)
454         gdElevStartDD = gdElevStartDD_TS.getPreviousValue(currentRuntimestep)
455         darElevStartDD = darElevStartDD_TS.getPreviousValue(currentRuntimestep)
456         rafElevIDFSLstartDD = rafElevIDFSLstartDD_TS.getPreviousValue(currentRuntimestep)
457         gdElevIDFSLstartDD = gdElevIDFSLstartDD_TS.getPreviousValue(currentRuntimestep)
458 
459     rafElevStartDD_TS.setCurrentValue(currentRuntimestep, rafElevStartDD)
460     gdElevStartDD_TS.setCurrentValue(currentRuntimestep, gdElevStartDD)
461     darElevStartDD_TS.setCurrentValue(currentRuntimestep, darElevStartDD)
462 
463 rafElevIDFSLstartDD_TS.setCurrentValue(currentRuntimestep, rafElevIDFSLstartDD)
464 gdElevIDFSLstartDD_TS.setCurrentValue(currentRuntimestep, gdElevIDFSLstartDD)
465 
466 
467     ## calculate guide curve
468 # if IDFSL drawdown is needed
469 if apr30<doy<jun1:
470         """
471         # calculate elevation that is reasonably above IDSFL to prevent resetting the GC if elev is only a little bit over IDSFL
472         # get sherwood max
473         sherMaxPrevStep = network.getStateVariable("a_fld_sherwoodMax").getPreviousValue(currentRuntimestep)
474         # calculate volume of max limit release between start and stop window...assume 50/50 split between GD and Raf
475         volAbvIDFSL = sherMaxPrevStep*(may31-apr30)*convertCfsToAcreFeet/2
476         # calc storage trigger above idsfsl
477         rafStorAbvIDSFL = network.findReservoir("Rafferty Reservoir").getStorageFunction().elevationToStorage(rafIDFSL)+volAbvIDFSL
478         # calc elevation trigger above idsfsl
479         rafElevAbvIDSFL = network.findReservoir("Rafferty Reservoir").getStorageFunction().storageToElevation(rafStorAbvIDSFL)
480 
481         # calc storage trigger above idsfsl
482         gdStorAbvIDSFL = network.findReservoir("Grant Devine Lake").getStorageFunction().elevationToStorage(gdIDFSL)+volAbvIDFSL
483         # calc elevation trigger above idsfsl
484         gdElevAbvIDSFL = network.findReservoir("Grant Devine Lake").getStorageFunction().storageToElevation(gdStorAbvIDSFL)
485 
486         print sherMaxPrevStep, volAbvIDFSL, rafStorAbvIDSFL, rafElevAbvIDSFL, gdStorAbvIDSFL, gdElevAbvIDSFL
487         """
```

Figure 7. Drawdown calculation

```
481         # calc storage trigger above idsfsl
482         gdStorAbvIDSFL = network.findReservoir("Grant Devine Lake").getStorageFunction().elevationToStorage(gdIDFSL)+volAbvIDFSL
483         # calc elevation trigger above idsfsl
484         gdElevAbvIDSFL = network.findReservoir("Grant Devine Lake").getStorageFunction().storageToElevation(gdStorAbvIDSFL)
485 
486         print sherMaxPrevStep, volAbvIDFSL, rafStorAbvIDSFL, rafElevAbvIDSFL, gdStorAbvIDSFL, gdElevAbvIDSFL
487         """
488 
489         if rafElevIDFSLstartDD>rafIDFSL:
490             rafGC = guideCurveIDFSL(doy, rafIDFSL, rafElevIDFSLstartDD, apr30, may31)
491             # set IDFSL to GC so zones don't overlap
492             rafIDFSL =rafGC
493         else:
494             rafGC = guideCurve(doy, rafElev, rafFullSupply, rafNormDrawdown, floodDrawdownEndDay, rafFinalDD, rafElevStartDD, stndDrawdownStartDay, feb1, feb1, fld_status)
495         if gdElevIDFSLstartDD>gdIDFSL:
496             gdGC = guideCurveIDFSL(doy, gdIDFSL, gdElevIDFSLstartDD, apr30, may31)
497             # set IDFSL to GC so zones don't overlap
498             gdIDFSL = gdGC
499         else:
500             gdGC = guideCurve(doy, gdElev, gdFullSupply, gdNormDrawdown, floodDrawdownEndDay, gdFinalDD, gdElevStartDD, stndDrawdownStartDay, feb1, feb1, fld_status)
501 else:
```

Figure 8. Definition of the guide curve for the alternative within the state variable

```
# write out IDFSL
network.getStateVariable("a_fld_idfsl_raf").setValue(currentRuntimestep,rafIDFSL)
network.getStateVariable("a_fld_idfsl_gd").setValue(currentRuntimestep,gdIDFSL)
#=========================================================================
# ## calc estevan target
#=========================================================================
estevanFloodMax = 55*35.31 # coal haul road bridge limit
# if during flood, estevan has a higher limit
if fld_status == 1:
    # get TS to track max occured flow during flood
    flowPeakEstevanMaxOccuredTS = currentVariable.localTimeSeriesGet("flowPeakEstevanMaxOccured")
```

Figure 9. Writing out the IDFSL curves

```
67    currentVariable.localTimeSeriesNew("volExcessRaf", 0.0)
68    currentVariable.localTimeSeriesNew("volExcessGD", 0.0)
69    currentVariable.localTimeSeriesNew("volBoundDD_appliedToRaf", 0.0)
70    currentVariable.localTimeSeriesNew("exceedFSL_callDarling", 0.0)
71    currentVariable.localTimeSeriesNew("vol30SherwoodUncontrolled", 0.0)
72
73    currentVariable.localTimeSeriesNew("flowPeakSherwoodMaxOccured", 0.0)
74    currentVariable.localTimeSeriesNew("flowPeakMinotMaxOccured", 0.0)
75    currentVariable.localTimeSeriesNew("flowPeakEstevanMaxOccured", 0.0)
76
77    currentVariable.localTimeSeriesNew("rafElevStartDD", 1806.10)
78    currentVariable.localTimeSeriesNew("gdElevStartDD", 1843.83)
79    currentVariable.localTimeSeriesNew("darElevStartDD", 1597.)
80
81    currentVariable.localTimeSeriesNew("rafElevIDFSLstartDD", 1809.38)
82    currentVariable.localTimeSeriesNew("gdElevIDFSLstartDD", 1843.4)
83    currentVariable.localTimeSeriesNew("rafFinalDD", 1802.82)
84    currentVariable.localTimeSeriesNew("gdFinalDD", 1840.55)
85    currentVariable.localTimeSeriesNew("boundFinalDD", 1840.)
86    currentVariable.localTimeSeriesNew("darFinalDD",1596.)
87    currentVariable.localTimeSeriesNew("sherwoodMaxPeak", 1000.)
88    currentVariable.localTimeSeriesNew("minotMaxPeak", 1000.)
89
90
91    return Constants.TRUE
```

Figure 10. Changes to the initialization script

3. Alternative vs Baseline Scenario Results

Plates 01-08 show hydrographs detailing the results of Alternative 9 relative to the baseline scenario at Rafferty, Boundary, Grant Devine, and Lake Darling reservoirs, as well as seven critical mainstem flow locations, for select “index” years. Index years were selected to be representative of high, medium, and low flow years in the basin. High flow years include 2011, 1976, 1975, and 1969, medium flow years include 1987, 1952, and 1946, and low flow years include 1937, 1988, and two extended drought sequences: 1931-1937 and 1988-1991. For Alternative 9, only the high flow index years are plotted, as this alternative only deviates from the baseline scenario during large flood events.

Plate 09 displays performance indicator results for all study reaches over the entire simulation (1946-2017). 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.

4. Summary of Results

Results from this alternative show IDFSL operations at Rafferty and Grant Devine reservoirs reduce the amount of time spent at or near MAFL at both reservoirs during the 2011 event, which is the only event in the simulation those reservoirs approach MAFL. IDFSL operations also increase flows throughout the basin during the month of May during large flood events. The consequences of increased flows in May depend on the timing of the flood and shape of the hydrograph in a given year. For example, in 1975,

the spring flood peak occurs in May, and releases from Rafferty and Grant Devine increase the flood peak by approximately 1,500 cfs (42.5 cms) at Sherwood. In 1976, the spring flood peak occurs in April, and IDFSL releases from Rafferty and Grant Devine have a much smaller downstream impact. In 2011, IDFSL operations cause Lake Darling to reach MAFL sooner, and significant flooding at Minot and other downstream locations occurs approximately 20 days earlier than the baseline scenario. The Minot peak in June 2011 is decreased from approximately 28,750 cfs (814 cms) in the baseline scenario to 23,750 cfs (673 cms) in the alternative due to lower peak releases from Rafferty Reservoir. These lower peak releases are the result of the rate of increase and rate of decrease rules added to the ResSim model.

4.1 Performance Indicators

4.1.1 Reservoirs

During some years, higher pool elevations at Rafferty improve boat access at the marina. Performance indicators (PIs) are not significantly impacted at Grant Devine or Boundary reservoirs. Increased outflows from the Saskatchewan reservoirs during flood events in May cause higher pool elevations at Lake Darling, resulting in increased flooding at Mouse River Park.

4.1.2 Riverine Reaches

For this model run, the largest change from the baseline scenario occurs during the 2011 event. May releases from the Canadian reservoirs result in higher flow through the river during May and lower peak flows during the June rain event. Lower peak flows correspond to slightly less structural damages in all reaches, but flooding of bridges, railroads, and the City of Minot occurs earlier and for a longer period. Outside of 2011, changes measured by the performance indicators are minor.

5. Suggested Further Alternative Fine Tuning

Since the period of record does not have many events that fully test this alternative, it may be beneficial to further test this alternative using stochastic hydrology traces. Currently, this alternative assumes steady releases during May which can be modified in order to change the duration of events (i.e. larger peak and shorter duration, smaller peak and larger duration, optimal release duration based on storage and time of the year). Also, the rate of increase and rate of decrease rules may require further definition, and additional reservoir release constraints based on downstream conditions may be required at Rafferty and Grant Devine.

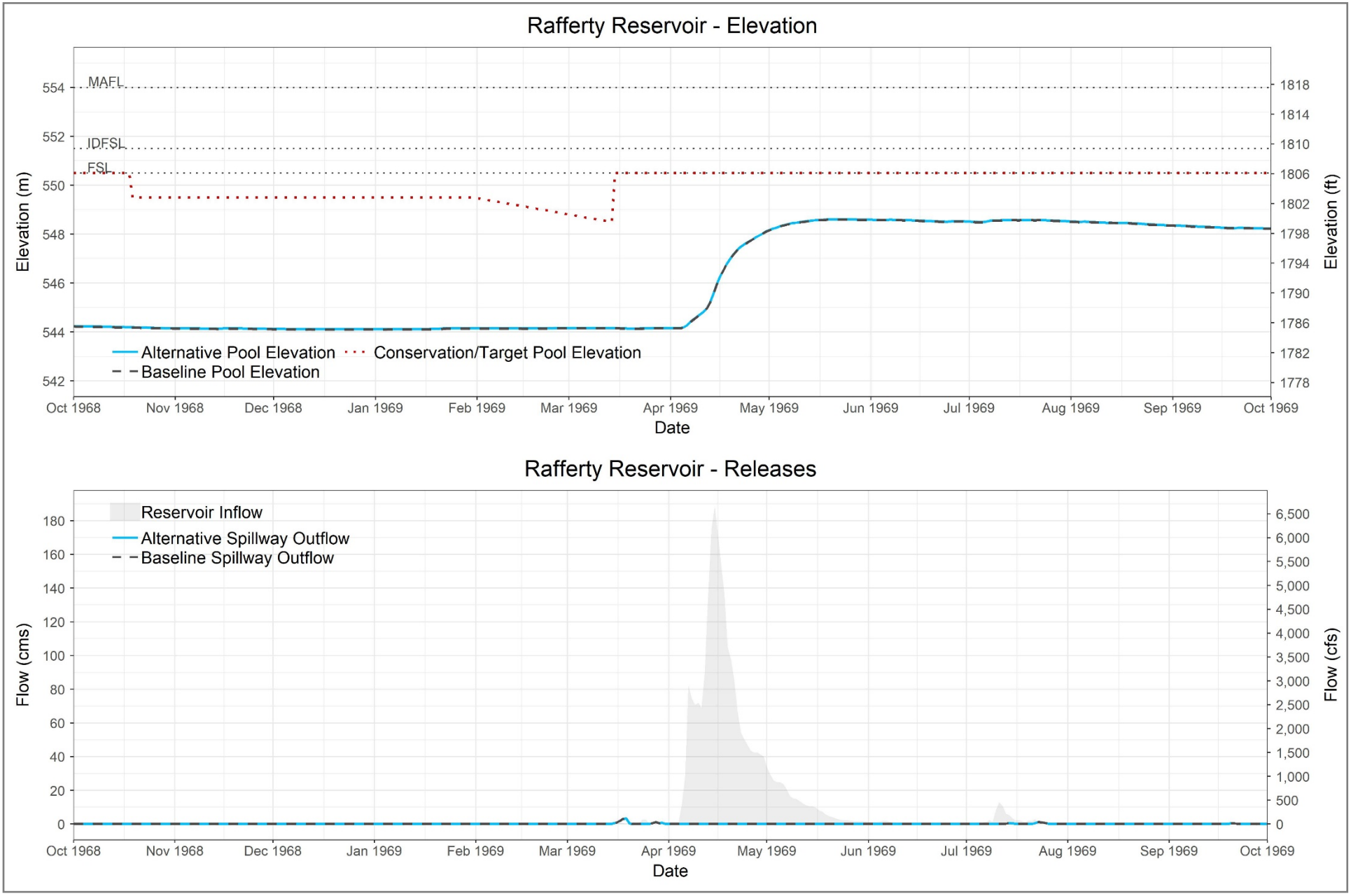
6. Path Forward

Since this alternative (Alternative 9) is very similar to Alternative 11 – Summer Rainfall Operations, both alternatives will be combined in Phase 3, Alternative 305 of the Plan of Study to further analyze how damages from summer floods can be reduced while maintaining dam safety. Simulations from Alternative 305 will be completed using the full period of record (1930-2017) and the finalized ResSim model. At this time, no further analysis of Alternative 9 is required, and the preliminary results using the 1946-2017 dataset is sufficient.

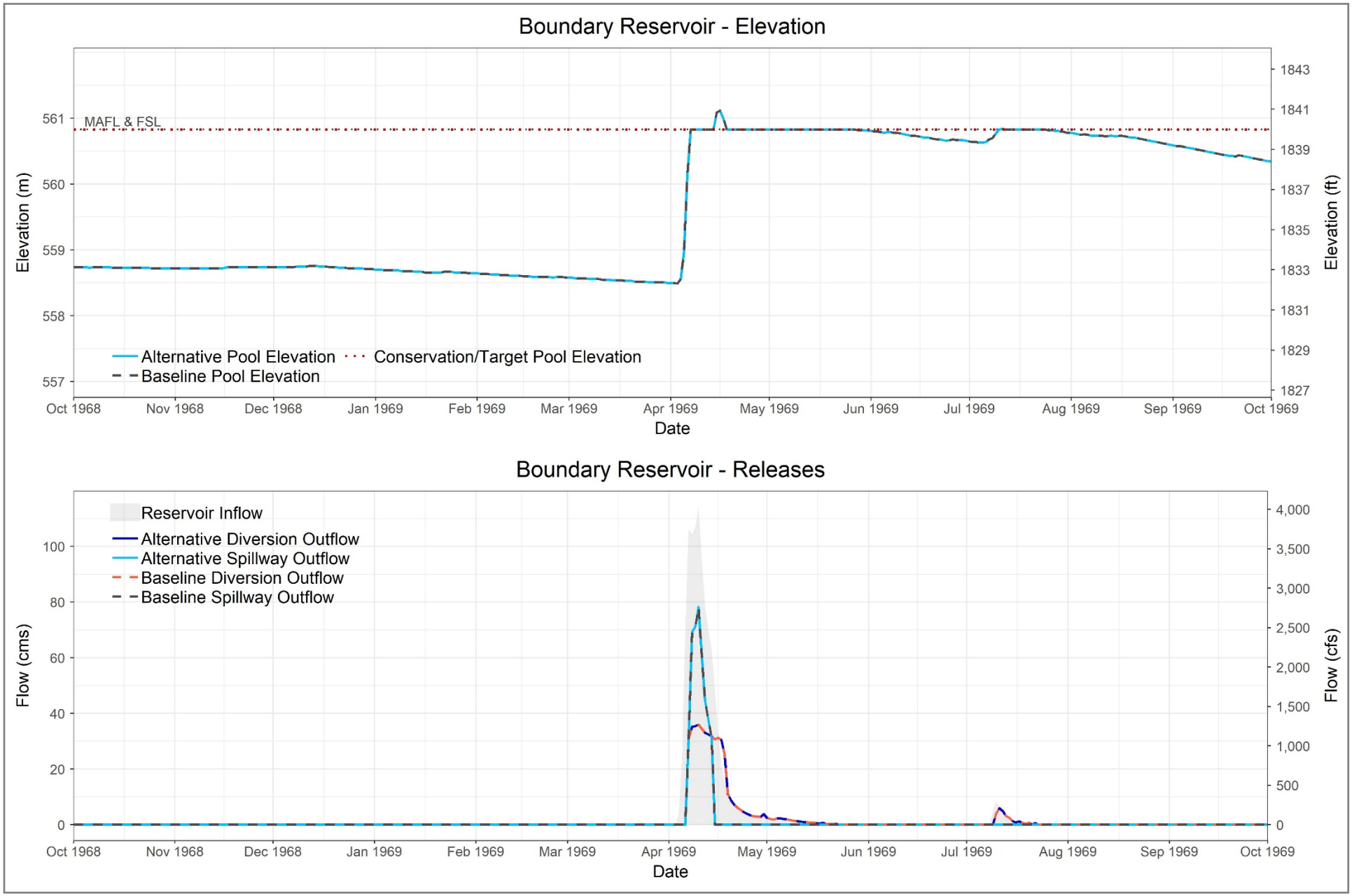
7. References

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.
5. Water Security Agency, 2019. Reservoir Operating Plan. Rafferty Reservoir and Grant Devine Lake. Interim reports.

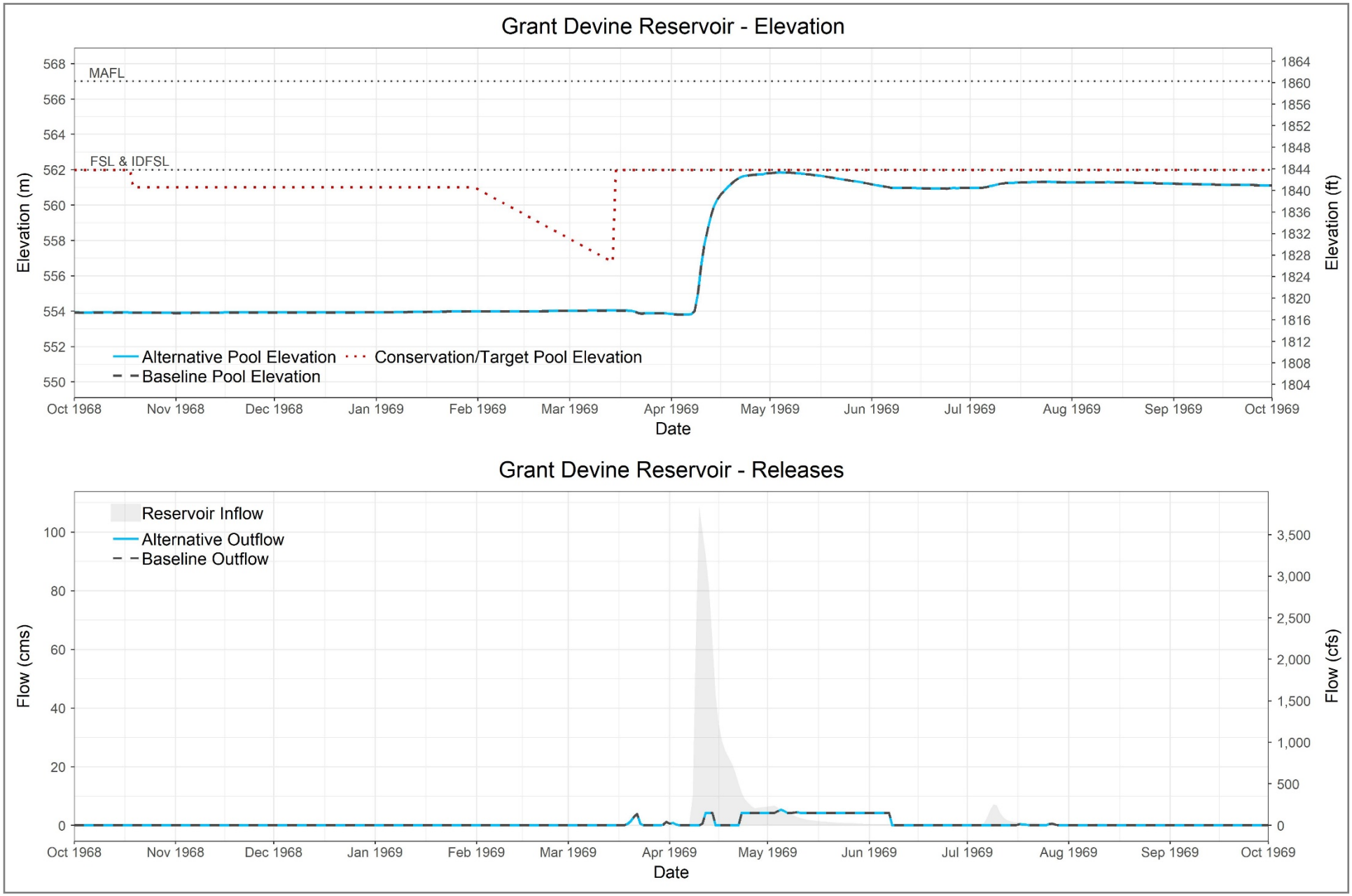
Plate 01	Reservoirs – 1969	Alternative 9 (Phase 2) Souris River Plan of Study



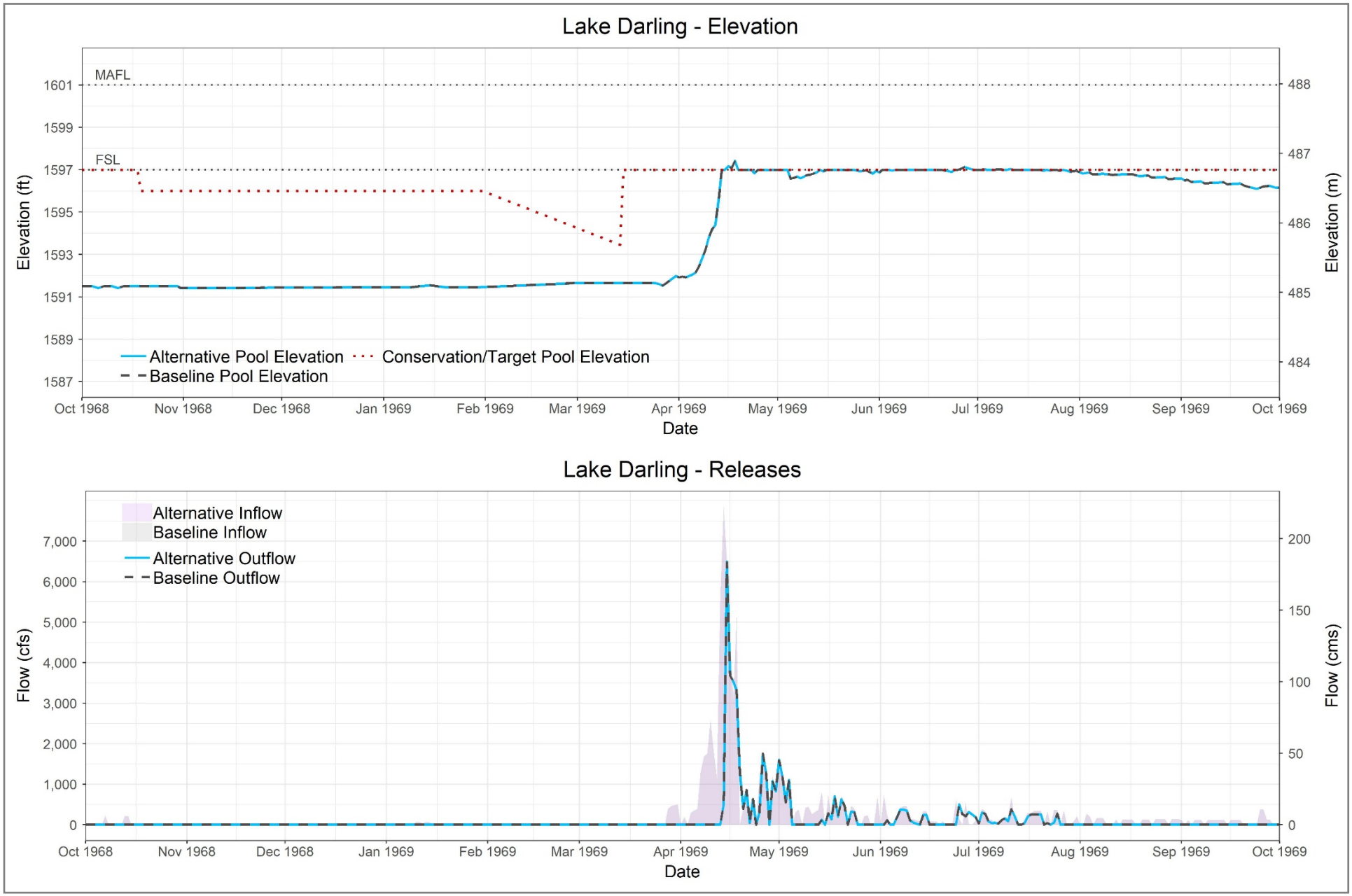
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



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



**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



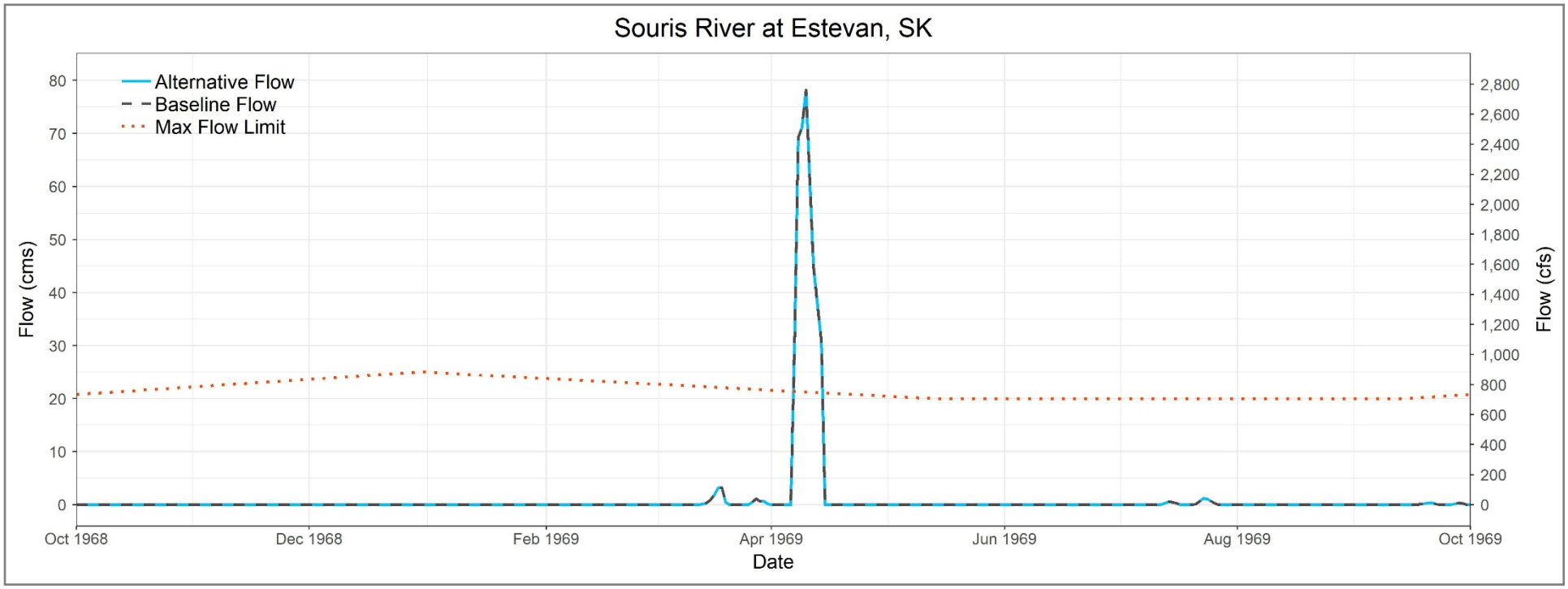
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*

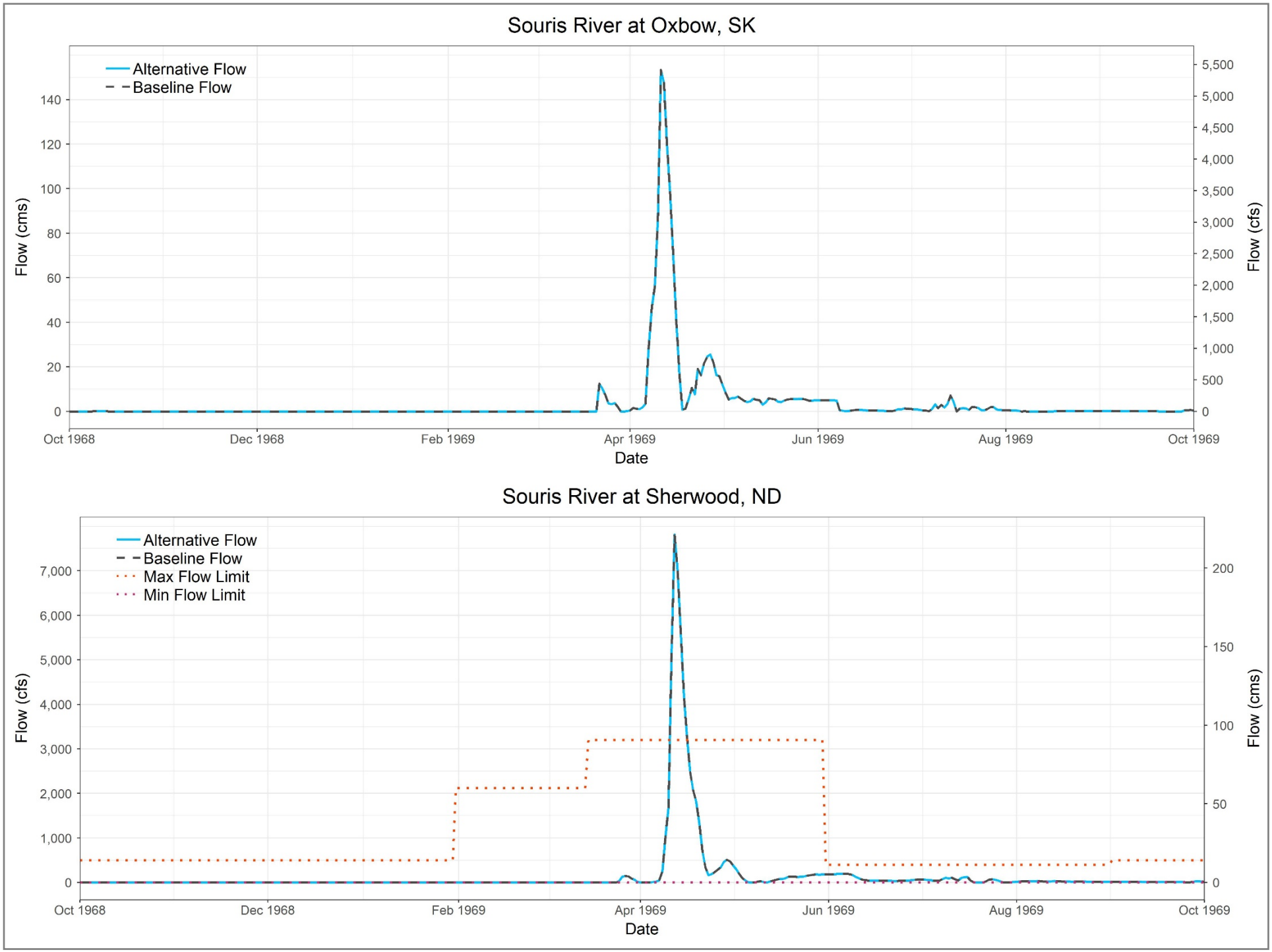
Plate 02

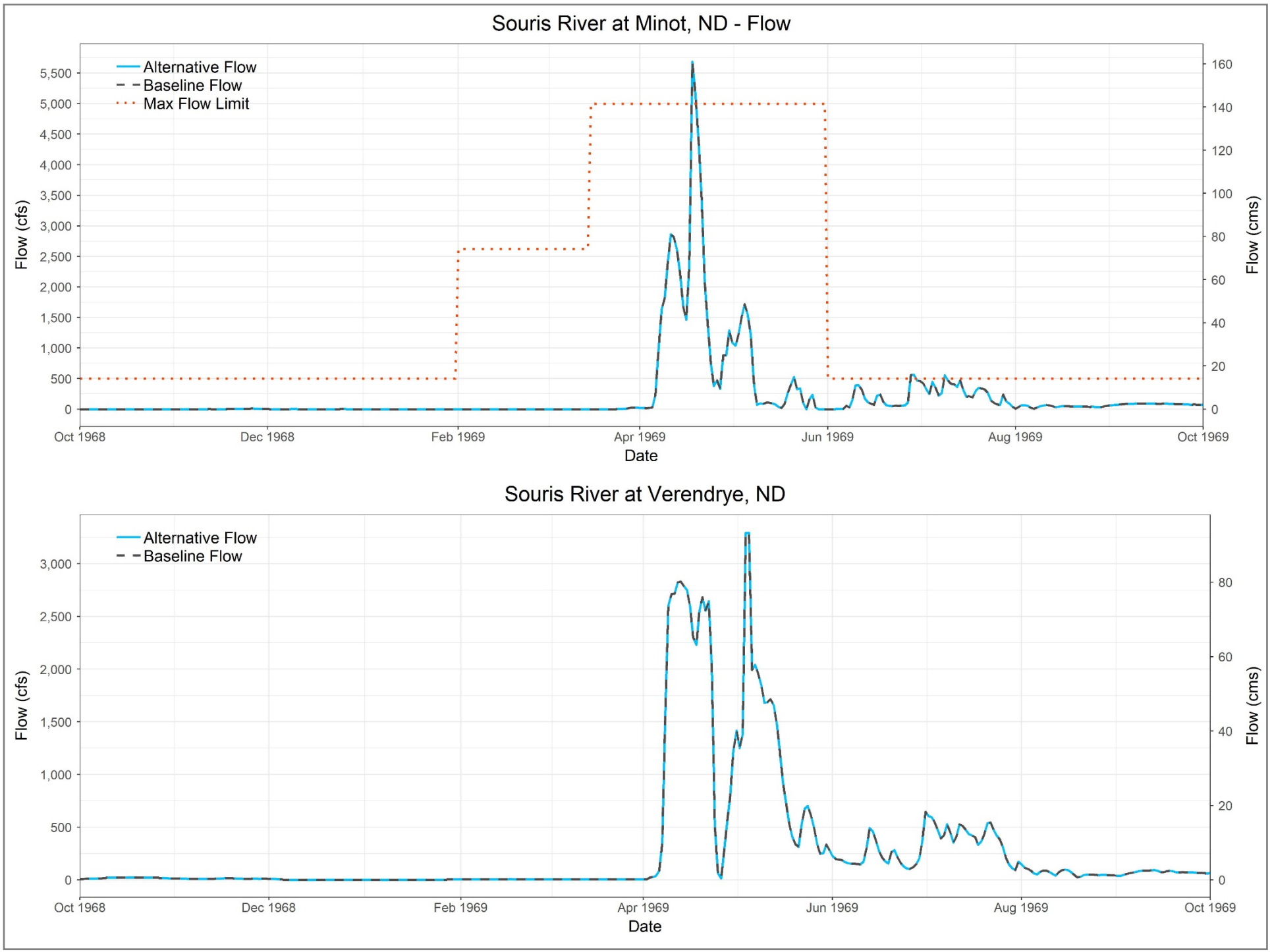
Critical Flow Locations – 1969

Alternative 9 (Phase 2)

Souris River Plan of Study




Souris River at Oxbow, SK
Alternative Flow
Baseline Flow
Flow (cms)
Flow (cfs)
Date
Oct 1968
Dec 1968
Feb 1969
Apr 1969
Jun 1969
Aug 1969
Oct 1969
Souris River at Sherwood, ND
Alternative Flow
Baseline Flow
Max Flow Limit
Min Flow Limit
Flow (cfs)
Flow (cms)
Date
Oct 1968
Dec 1968
Feb 1969
Apr 1969
Jun 1969
Aug 1969
Oct 1969


Souris River at Minot, ND - Flow
Alternative Flow
Baseline Flow
Max Flow Limit
Flow (cfs)
Flow (cms)
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
160
140
120
100
80
60
40
20
0
Oct 1968
Dec 1968
Feb 1969
Apr 1969
Jun 1969
Aug 1969
Oct 1969
Date
Souris River at Verendrye, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
3,000
2,500
2,000
1,500
1,000
500
0
80
60
40
20
0
Oct 1968
Dec 1968
Feb 1969
Apr 1969
Jun 1969
Aug 1969
Oct 1969
Date

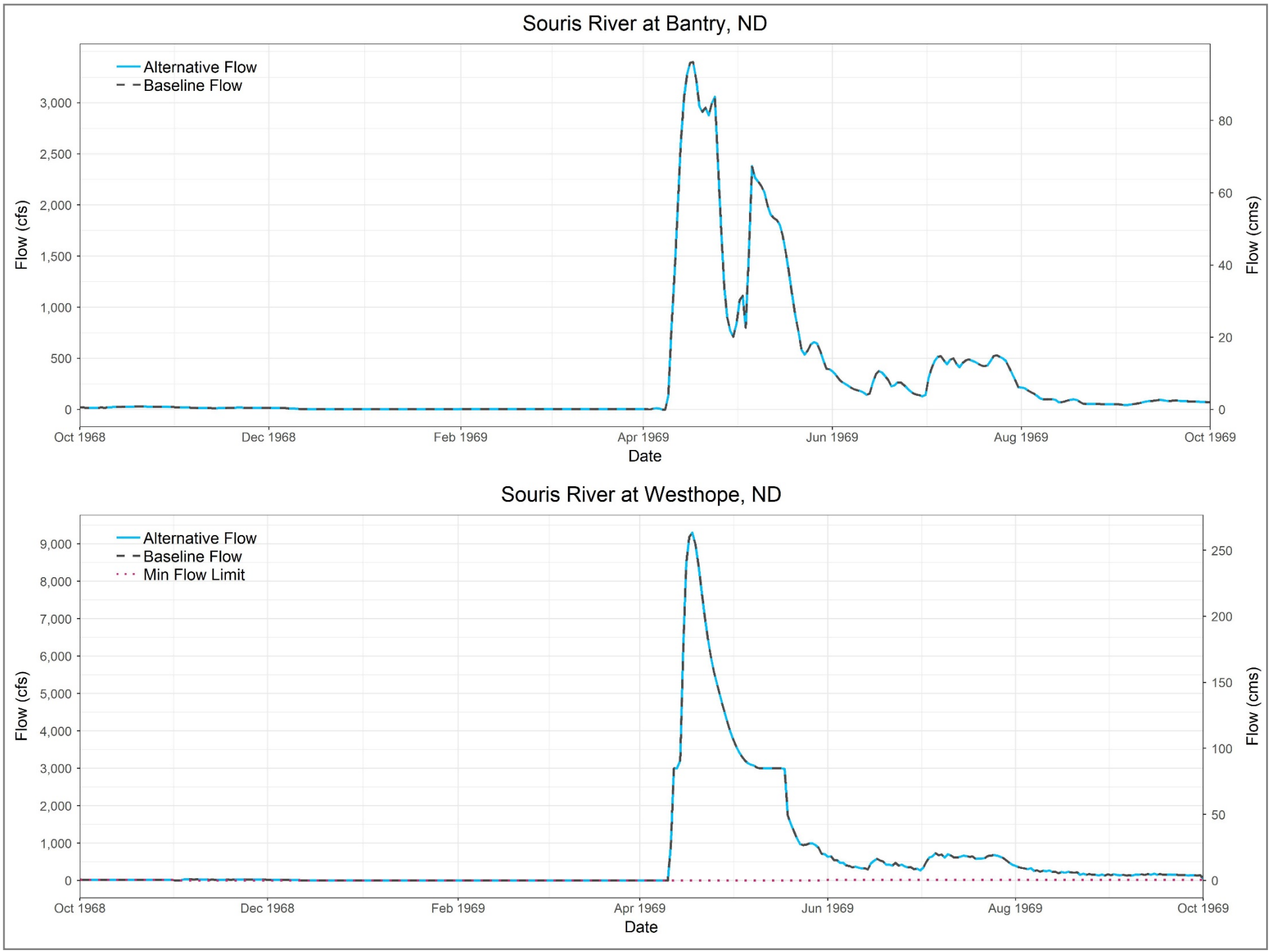
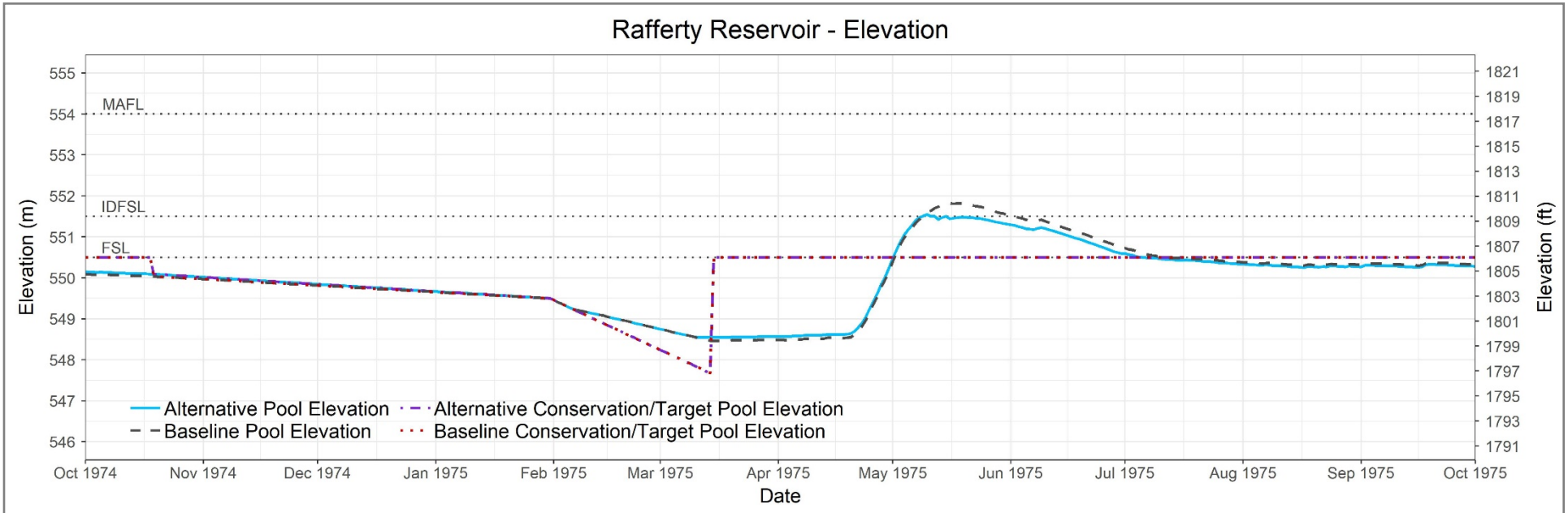
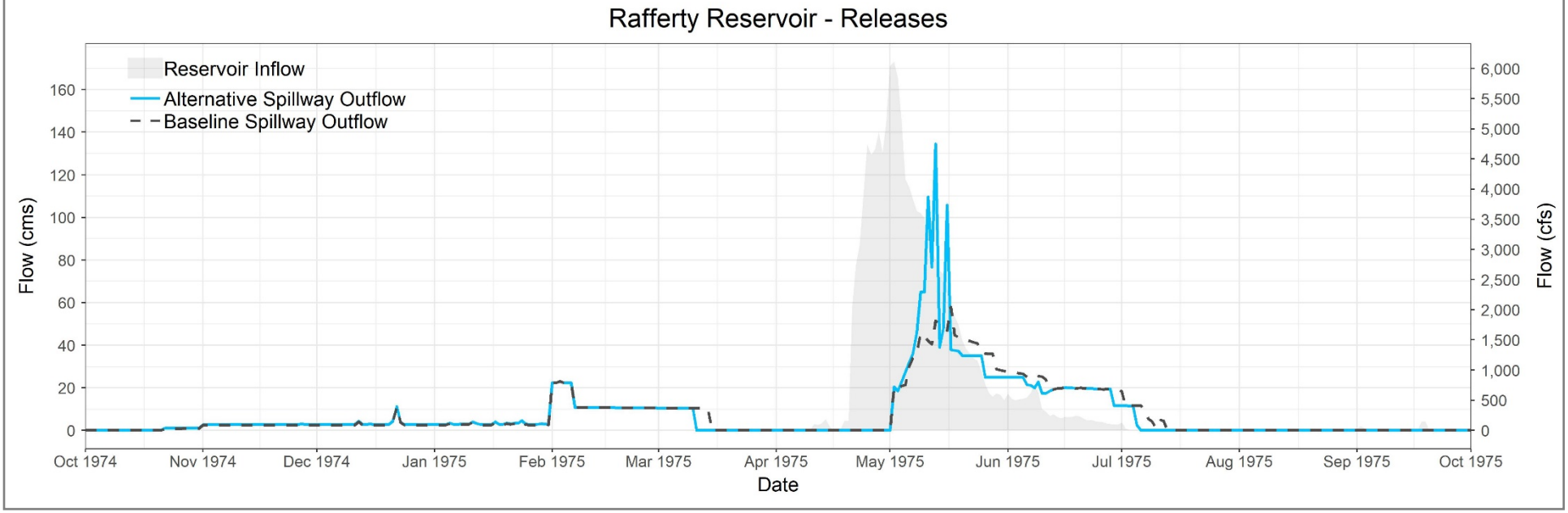
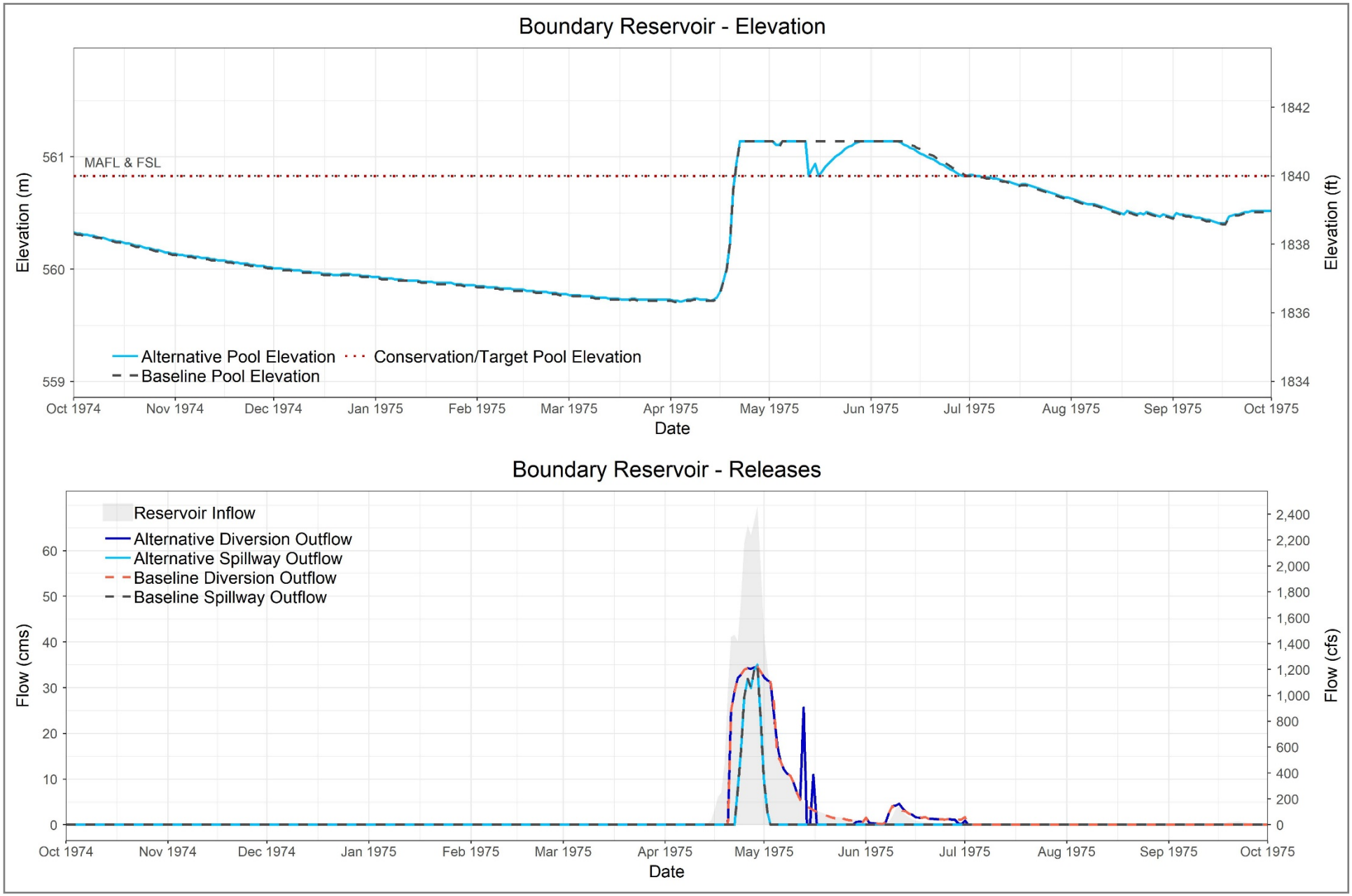

Souris River at Bantry, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
3,000
2,500
2,000
1,500
1,000
500
0
80
60
40
20
0
Oct 1968
Dec 1968
Feb 1969
Apr 1969
Jun 1969
Aug 1969
Oct 1969
Date
Souris River at Westhope, ND
Alternative Flow
Baseline Flow
Min Flow Limit
Flow (cfs)
Flow (cms)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
250
200
150
100
50
0
Oct 1968
Dec 1968
Feb 1969
Apr 1969
Jun 1969
Aug 1969
Oct 1969
Date

Plate 03	Reservoirs – 1975	Alternative 9 (Phase 2) Souris River Plan of Study

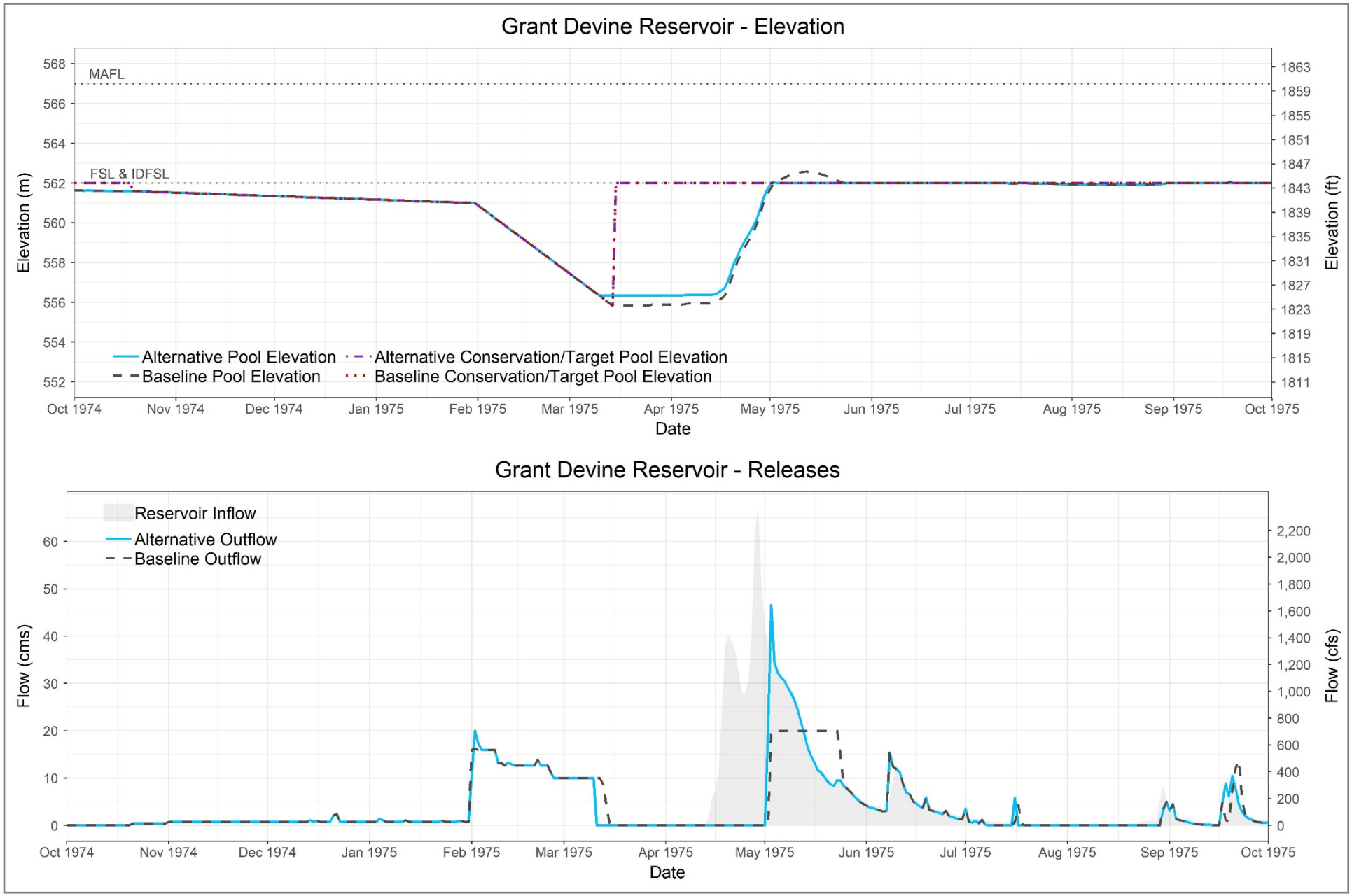




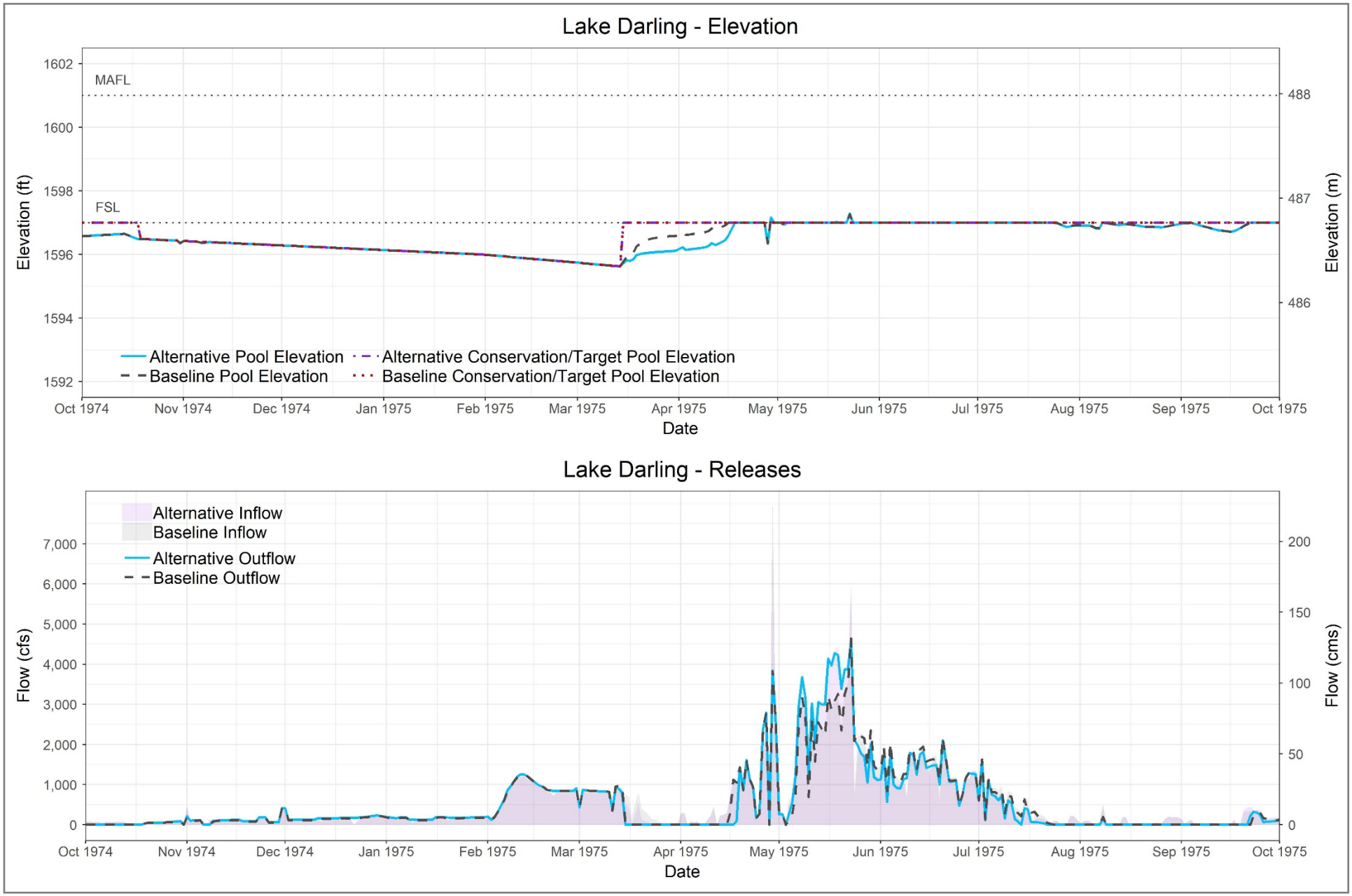
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



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



**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



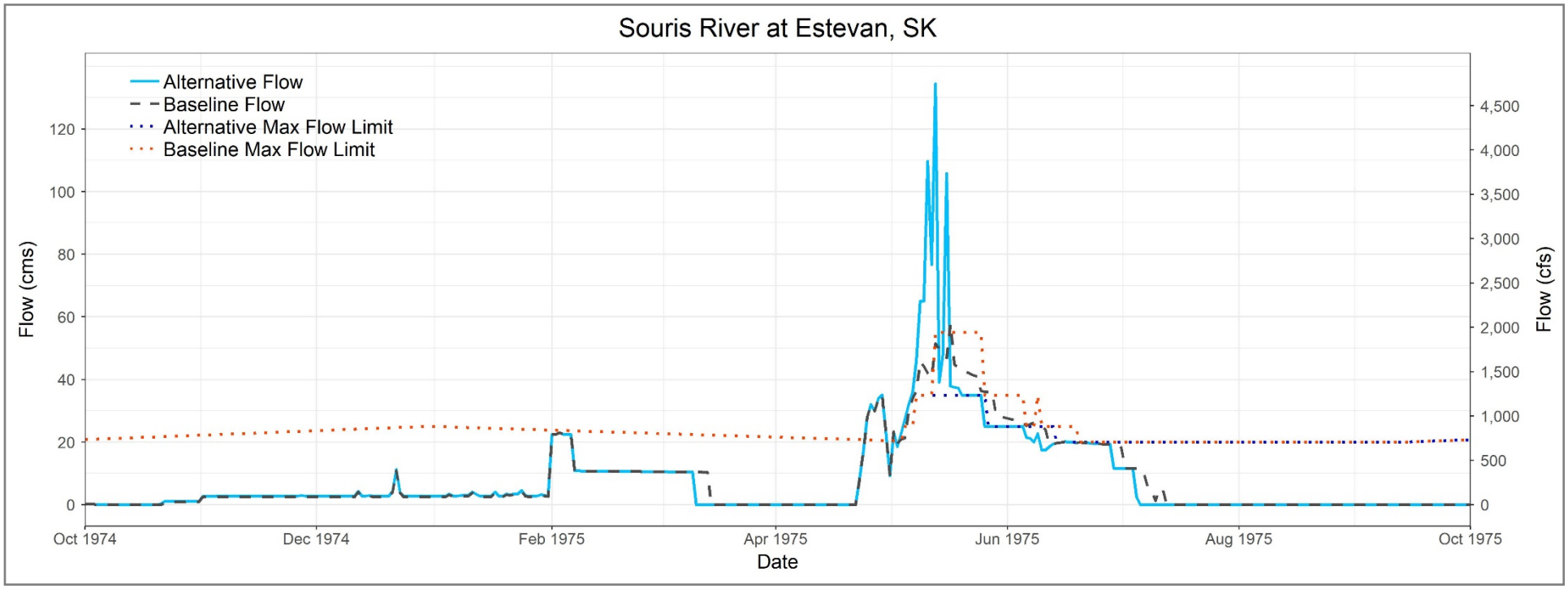
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*

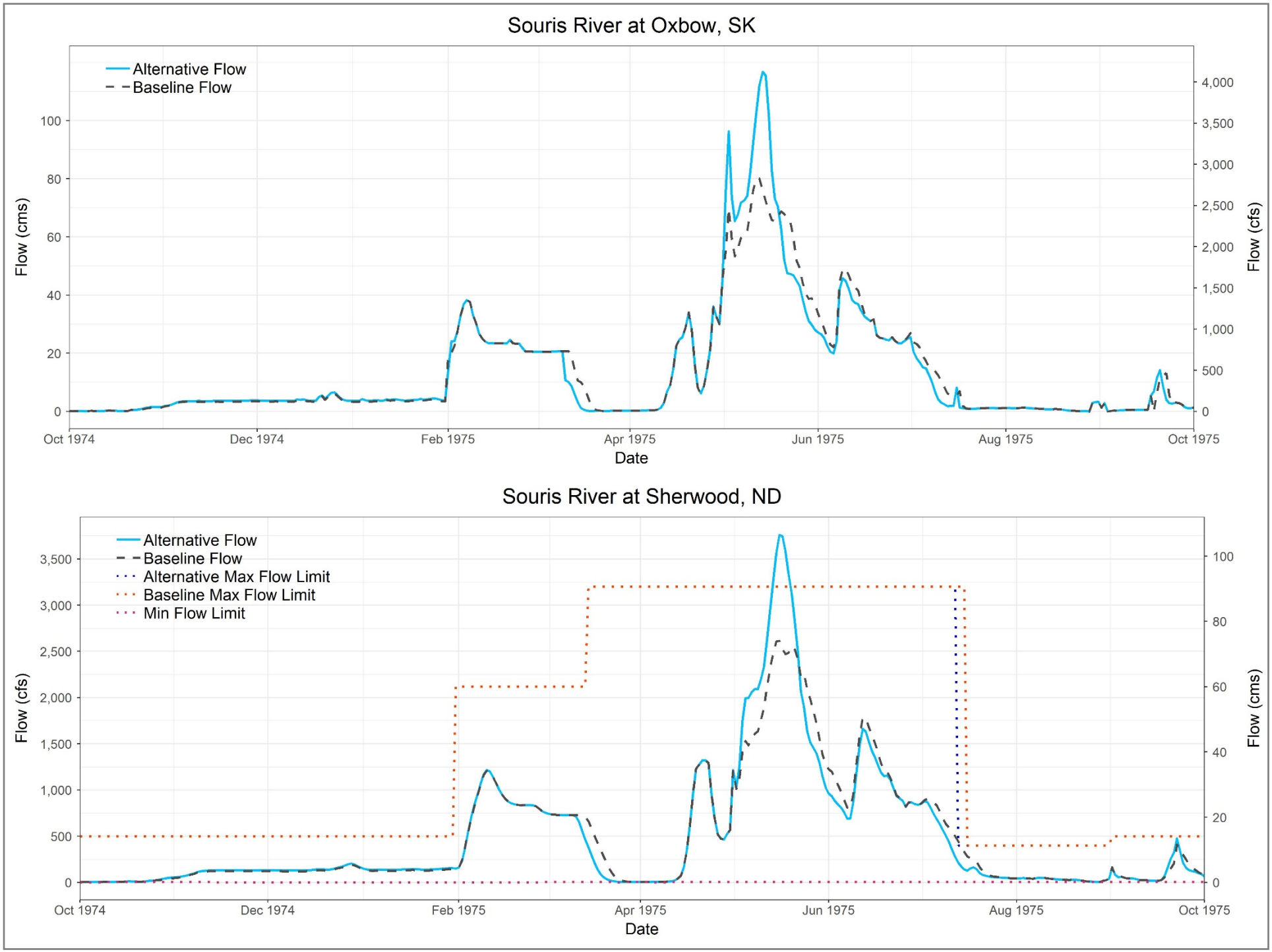
Plate 04

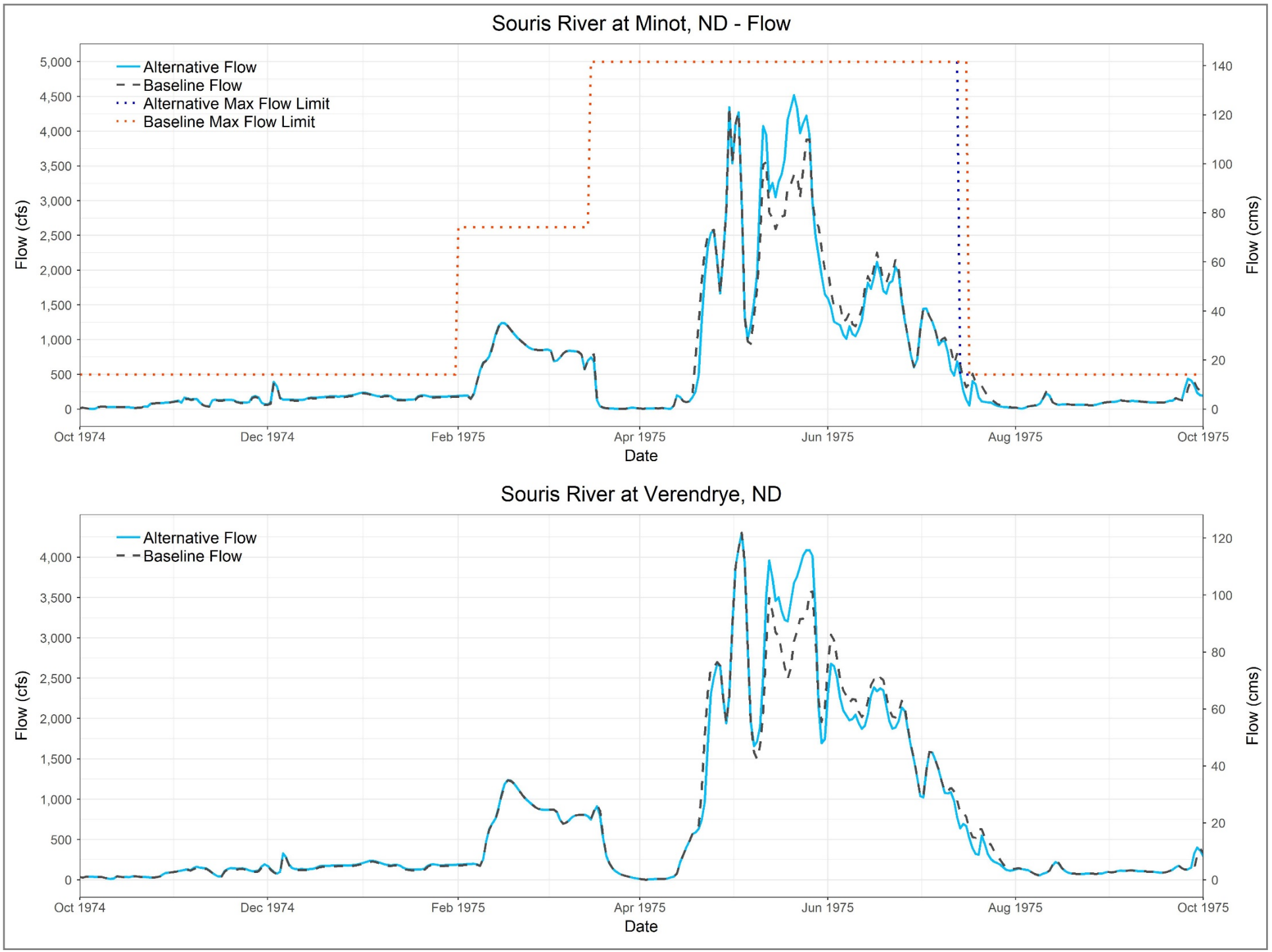
Critical Flow Locations – 1975

Alternative 9 (Phase 2)

Souris River Plan of Study




Souris River at Oxbow, SK
Alternative Flow
Baseline Flow
Flow (cms)
Flow (cfs)
Date
Oct 1974
Dec 1974
Feb 1975
Apr 1975
Jun 1975
Aug 1975
Oct 1975
Souris River at Sherwood, ND
Alternative Flow
Baseline Flow
Alternative Max Flow Limit
Baseline Max Flow Limit
Min Flow Limit
Flow (cfs)
Flow (cms)
Date


Souris River at Minot, ND - Flow
Alternative Flow
Baseline Flow
Alternative Max Flow Limit
Baseline Max Flow Limit
Flow (cfs)
Flow (cms)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
140
120
100
80
60
40
20
0
Oct 1974
Dec 1974
Feb 1975
Apr 1975
Jun 1975
Aug 1975
Oct 1975
Date
Souris River at Verendrye, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
120
100
80
60
40
20
0
Oct 1974
Dec 1974
Feb 1975
Apr 1975
Jun 1975
Aug 1975
Oct 1975
Date

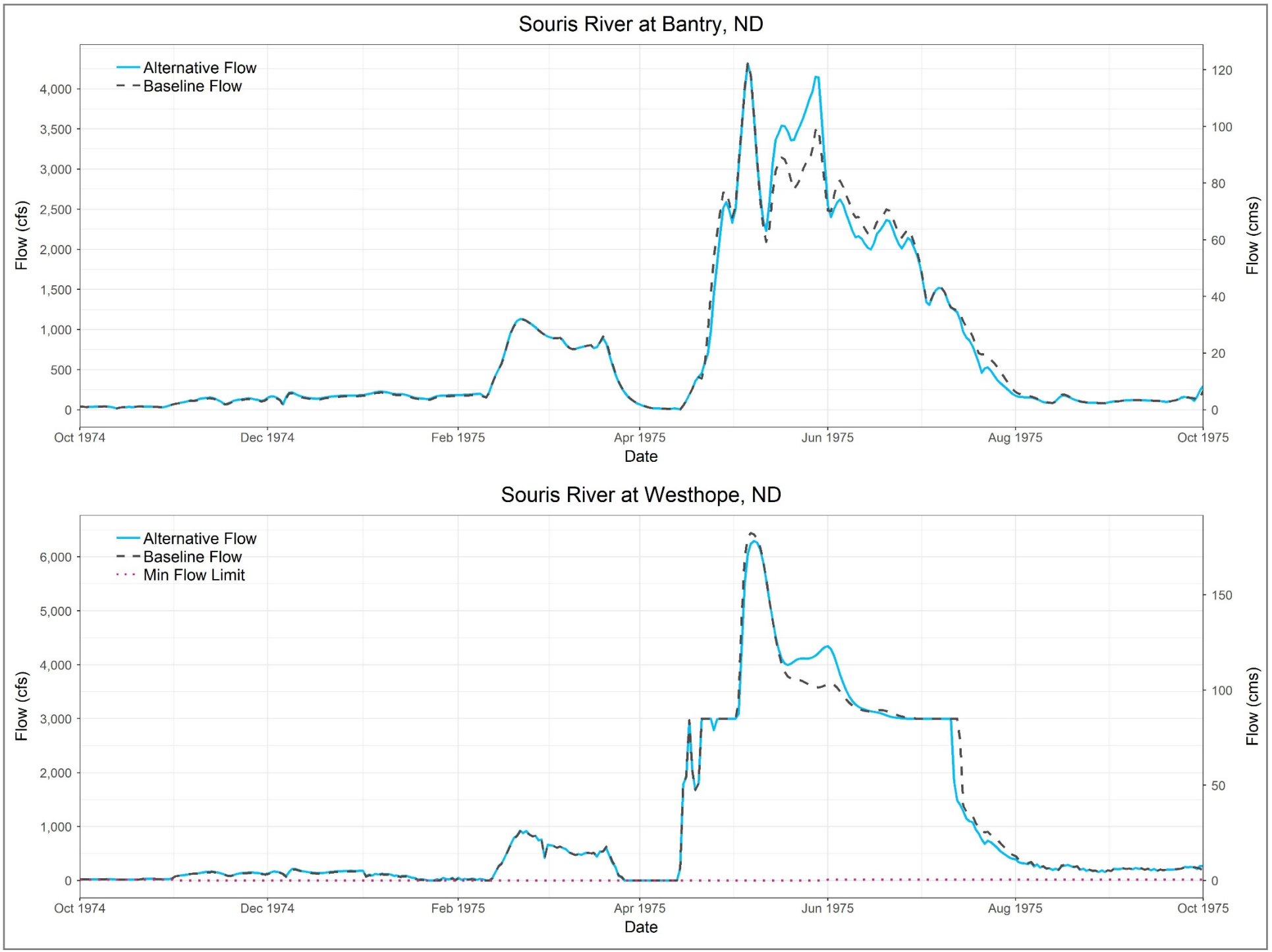
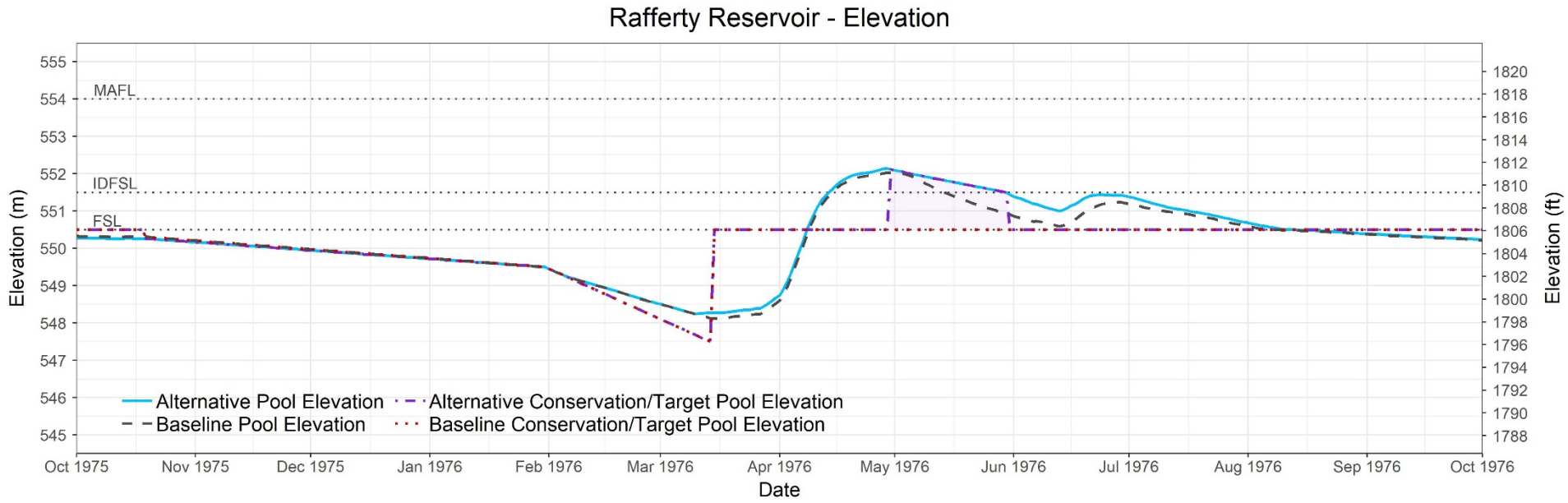
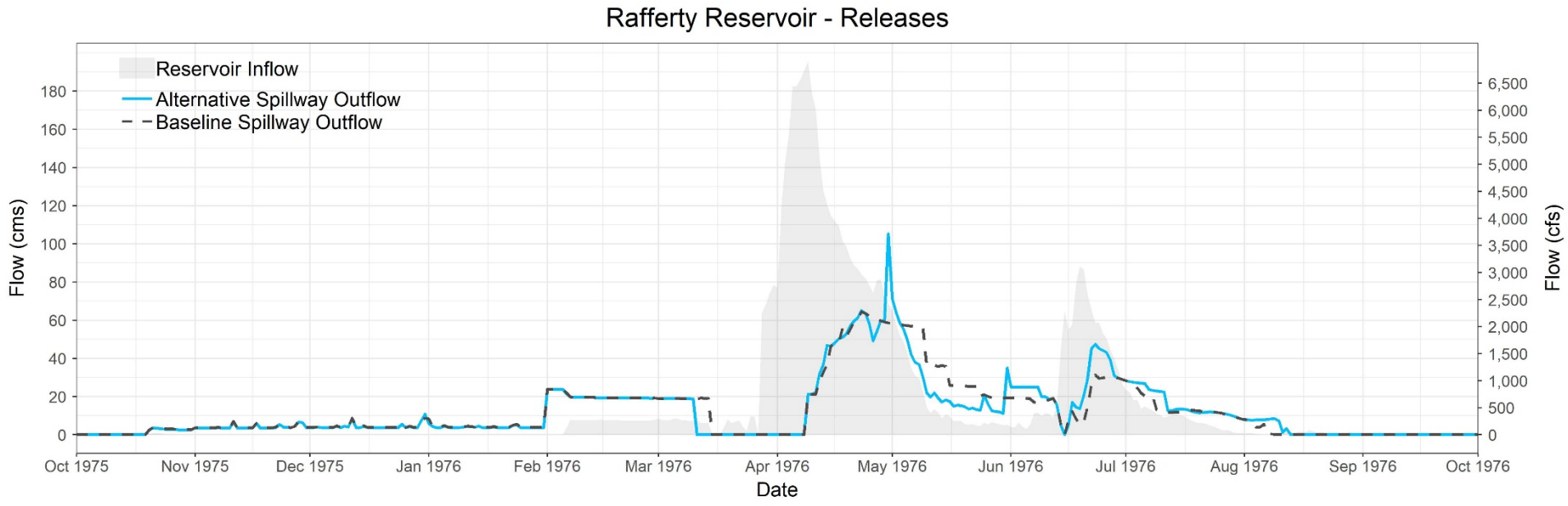
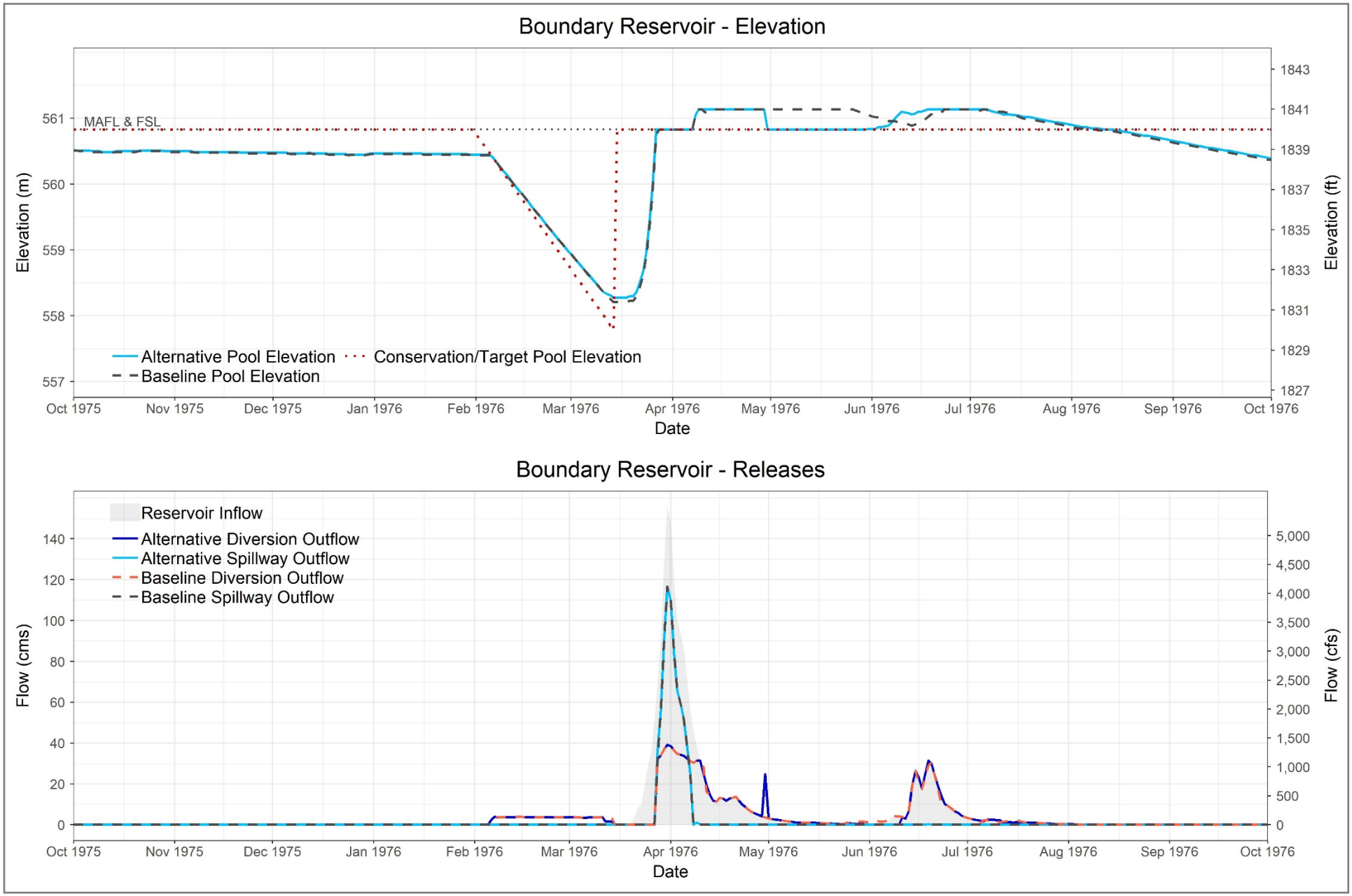

Souris River at Bantry, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
Date
Oct 1974
Dec 1974
Feb 1975
Apr 1975
Jun 1975
Aug 1975
Oct 1975
Souris River at Westhope, ND
Alternative Flow
Baseline Flow
Min Flow Limit
Flow (cfs)
Flow (cms)
Date

Plate 05	Reservoirs – 1976	Alternative 9 (Phase 2) Souris River Plan of Study

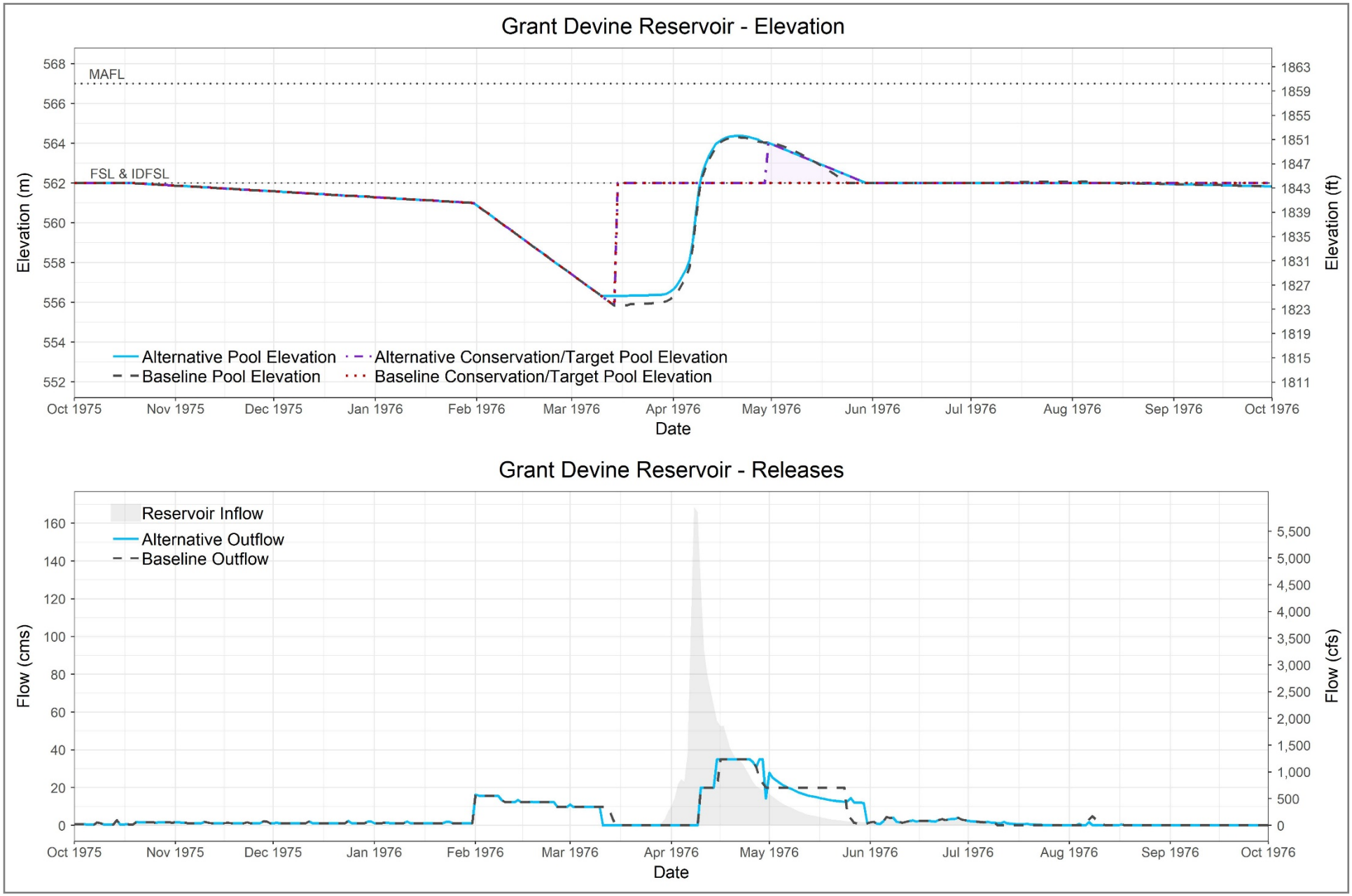




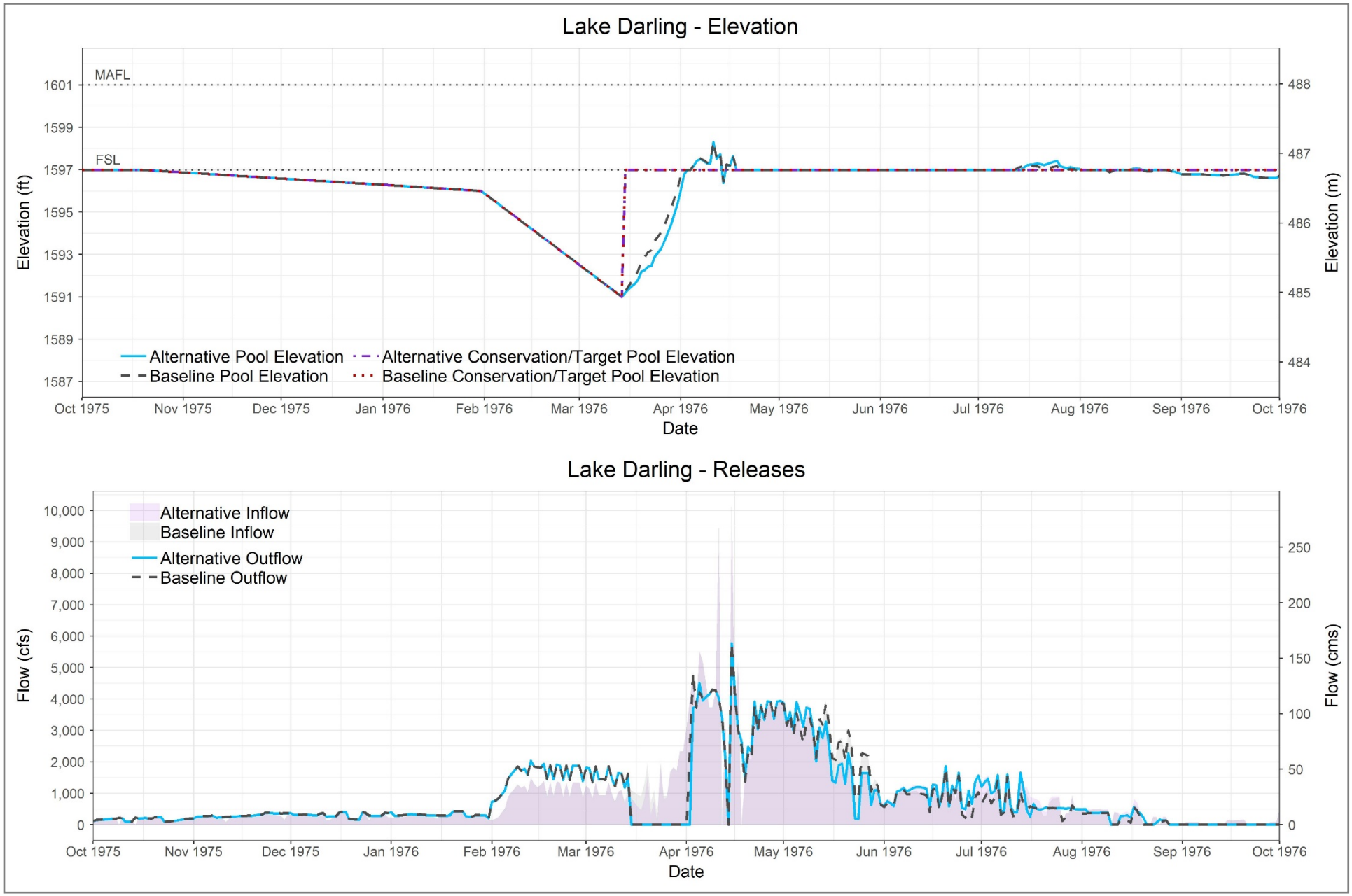
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



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



**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



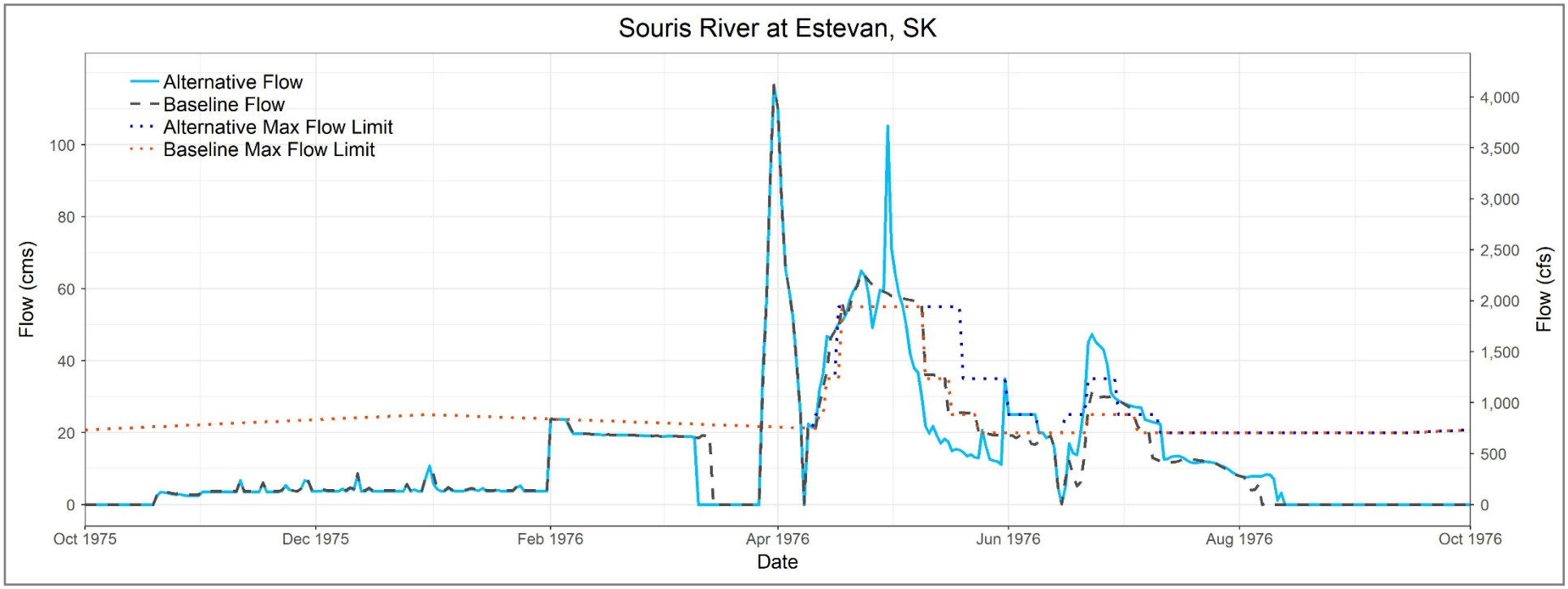
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*

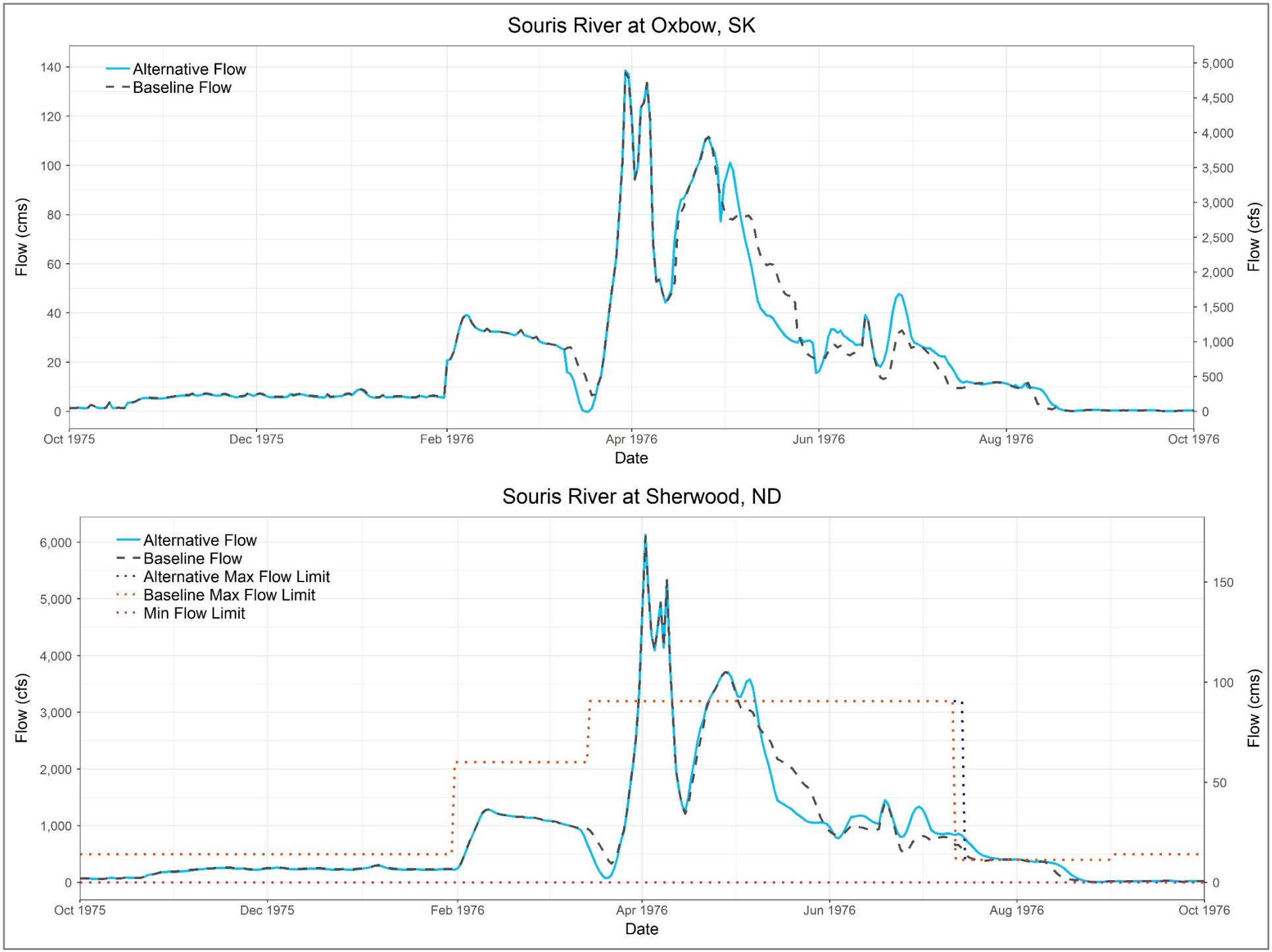
Plate 06

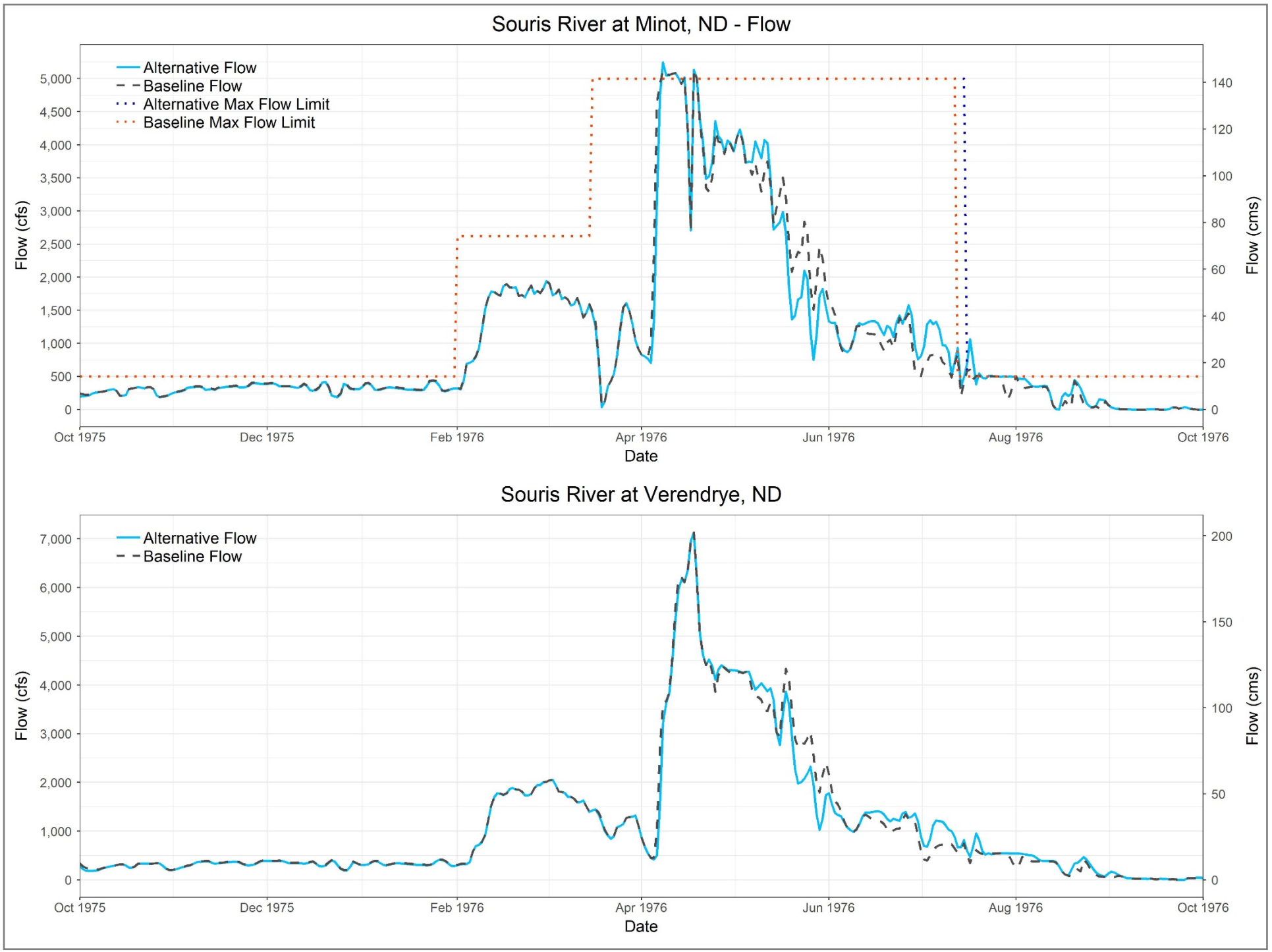
Critical Flow Locations – 1976

Alternative 9 (Phase 2)

Souris River Plan of Study




Souris River at Oxbow, SK
Alternative Flow
Baseline Flow
Flow (cms)
Flow (cfs)
Date
Oct 1975
Dec 1975
Feb 1976
Apr 1976
Jun 1976
Aug 1976
Oct 1976
Souris River at Sherwood, ND
Alternative Flow
Baseline Flow
Alternative Max Flow Limit
Baseline Max Flow Limit
Min Flow Limit
Flow (cfs)
Flow (cms)
Date


Souris River at Minot, ND - Flow
Alternative Flow
Baseline Flow
Alternative Max Flow Limit
Baseline Max Flow Limit
Flow (cfs)
Flow (cms)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
140
120
100
80
60
40
20
0
Oct 1975
Dec 1975
Feb 1976
Apr 1976
Jun 1976
Aug 1976
Oct 1976
Date
Souris River at Verendrye, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
200
150
100
50
0
Oct 1975
Dec 1975
Feb 1976
Apr 1976
Jun 1976
Aug 1976
Oct 1976
Date

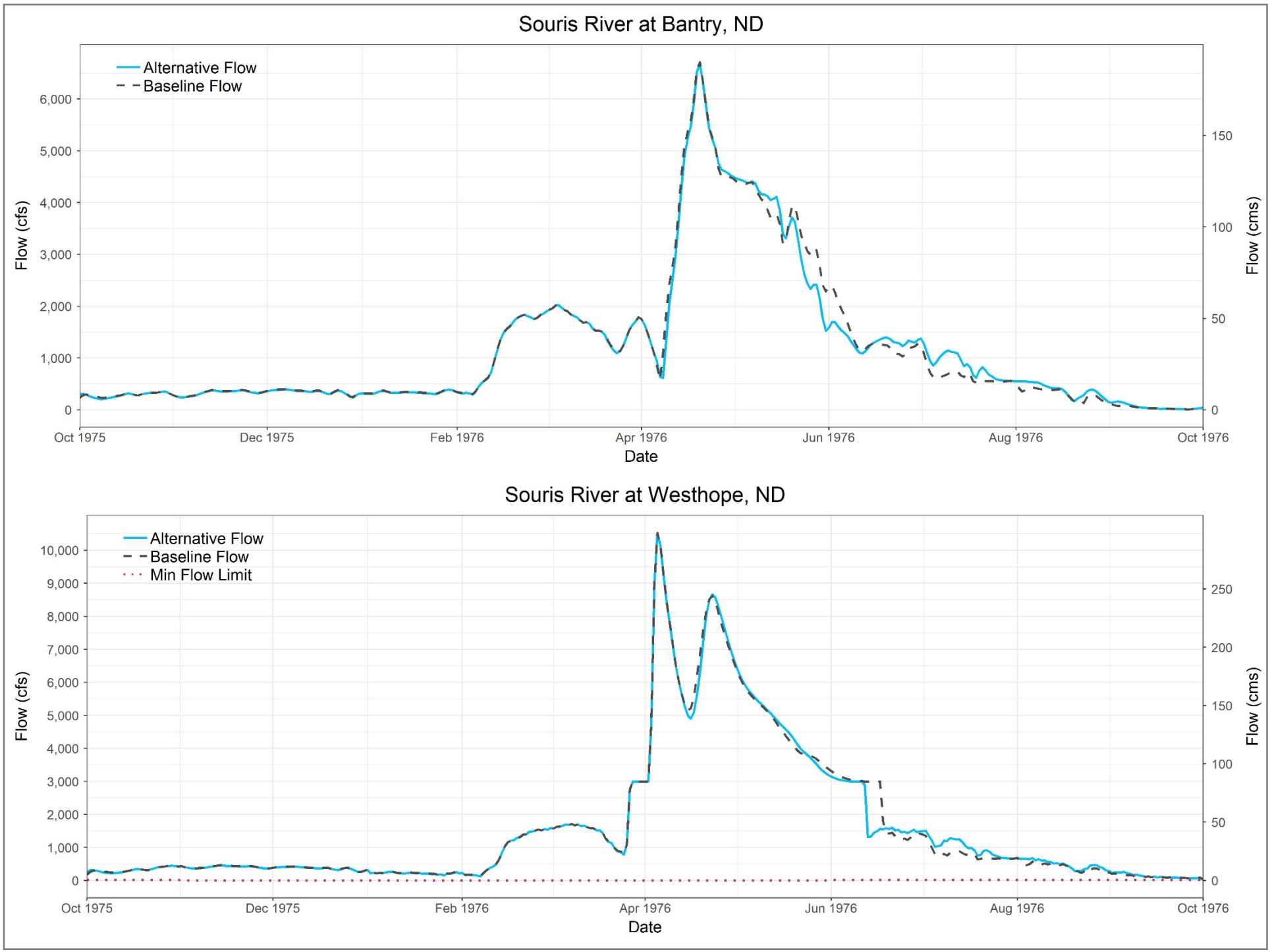
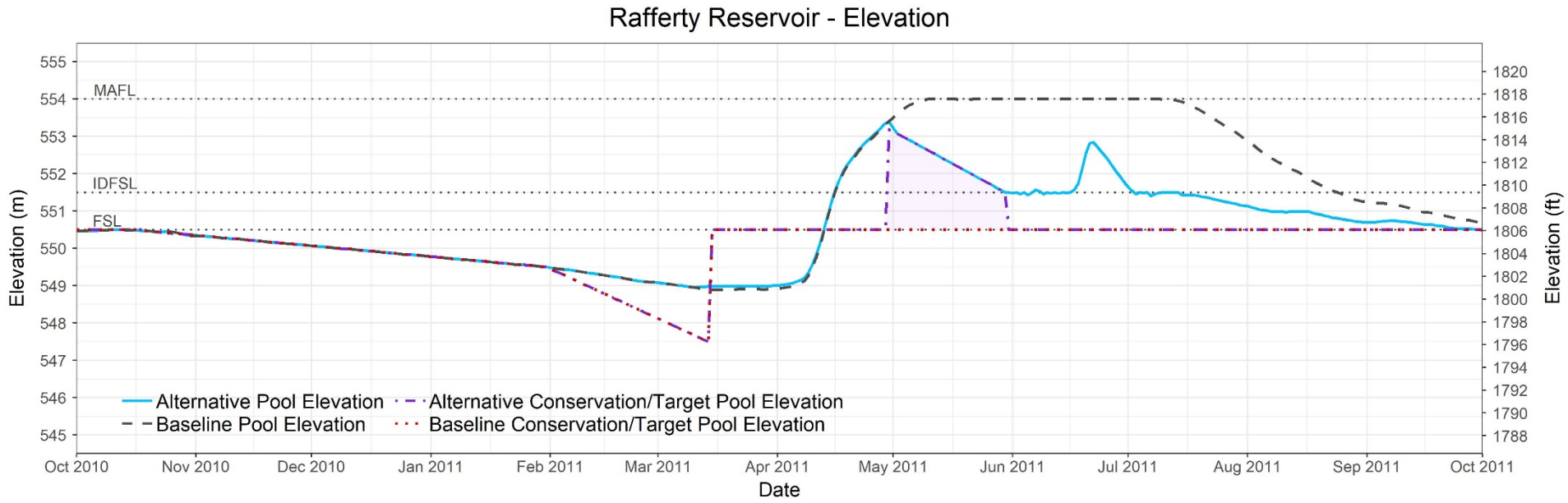
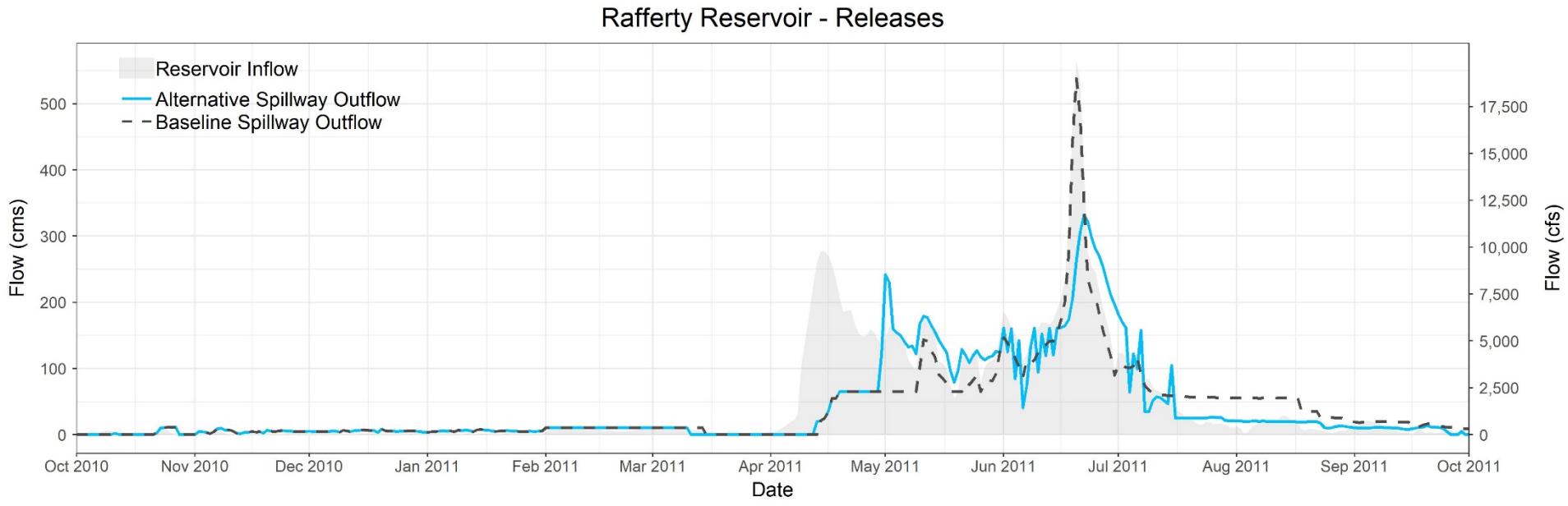
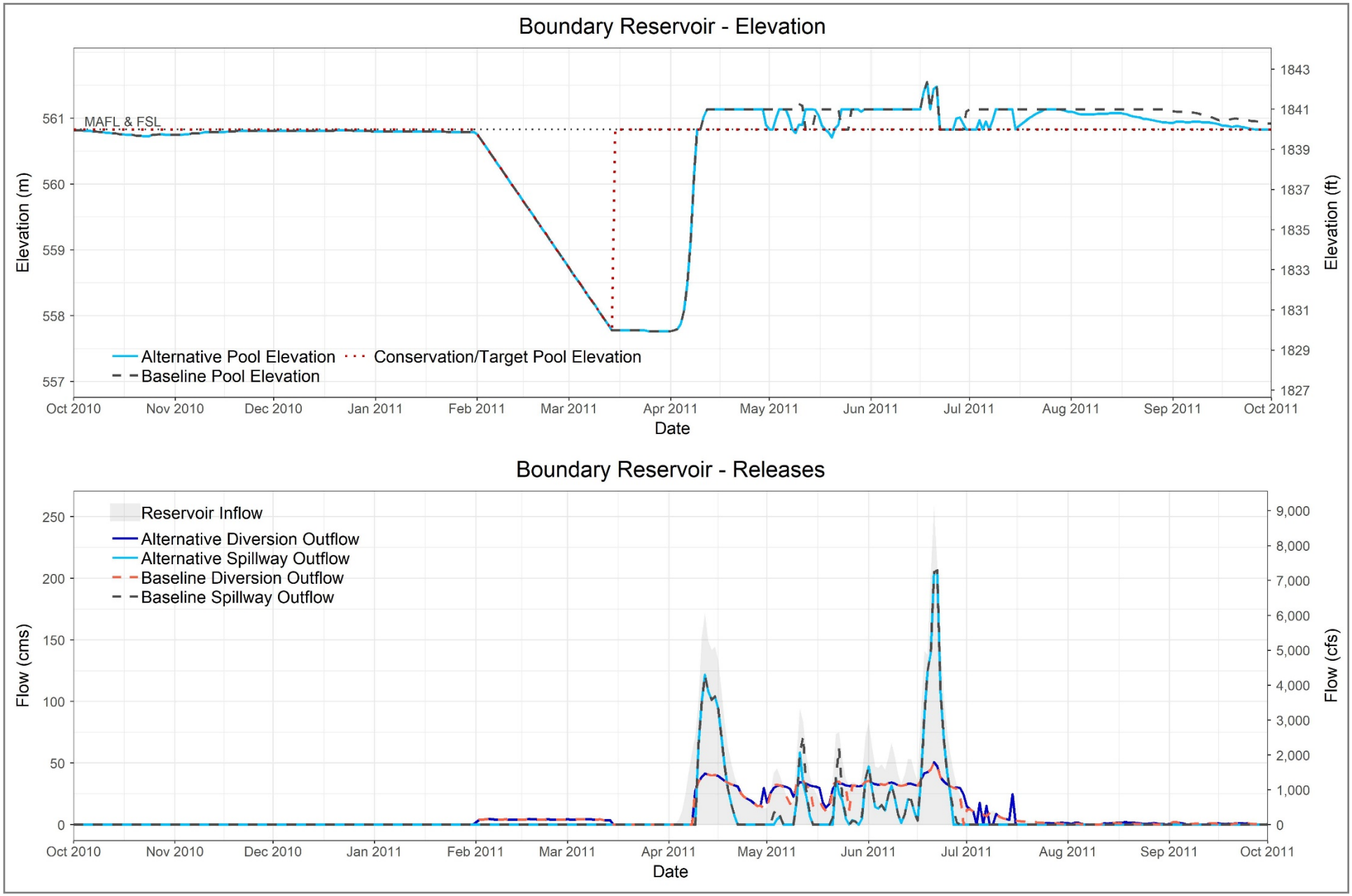

Souris River at Bantry, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
6,000
5,000
4,000
3,000
2,000
1,000
0
150
100
50
0
Oct 1975
Dec 1975
Feb 1976
Apr 1976
Jun 1976
Aug 1976
Oct 1976
Date
Souris River at Westhope, ND
Alternative Flow
Baseline Flow
Min Flow Limit
Flow (cfs)
Flow (cms)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
250
200
150
100
50
0
Oct 1975
Dec 1975
Feb 1976
Apr 1976
Jun 1976
Aug 1976
Oct 1976
Date

Plate 07	Reservoirs – 2011	Alternative 9 (Phase 2) Souris River Plan of Study

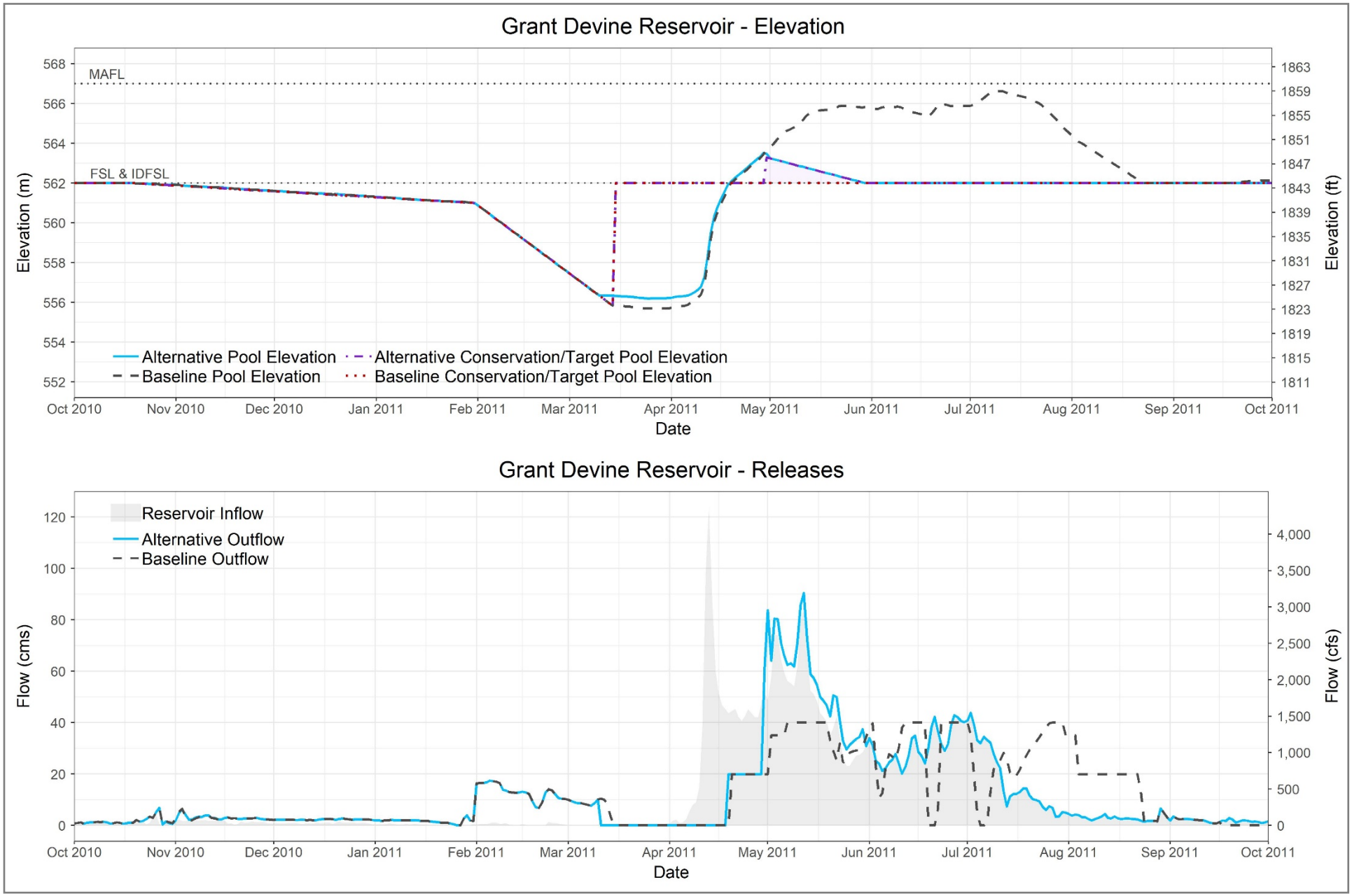




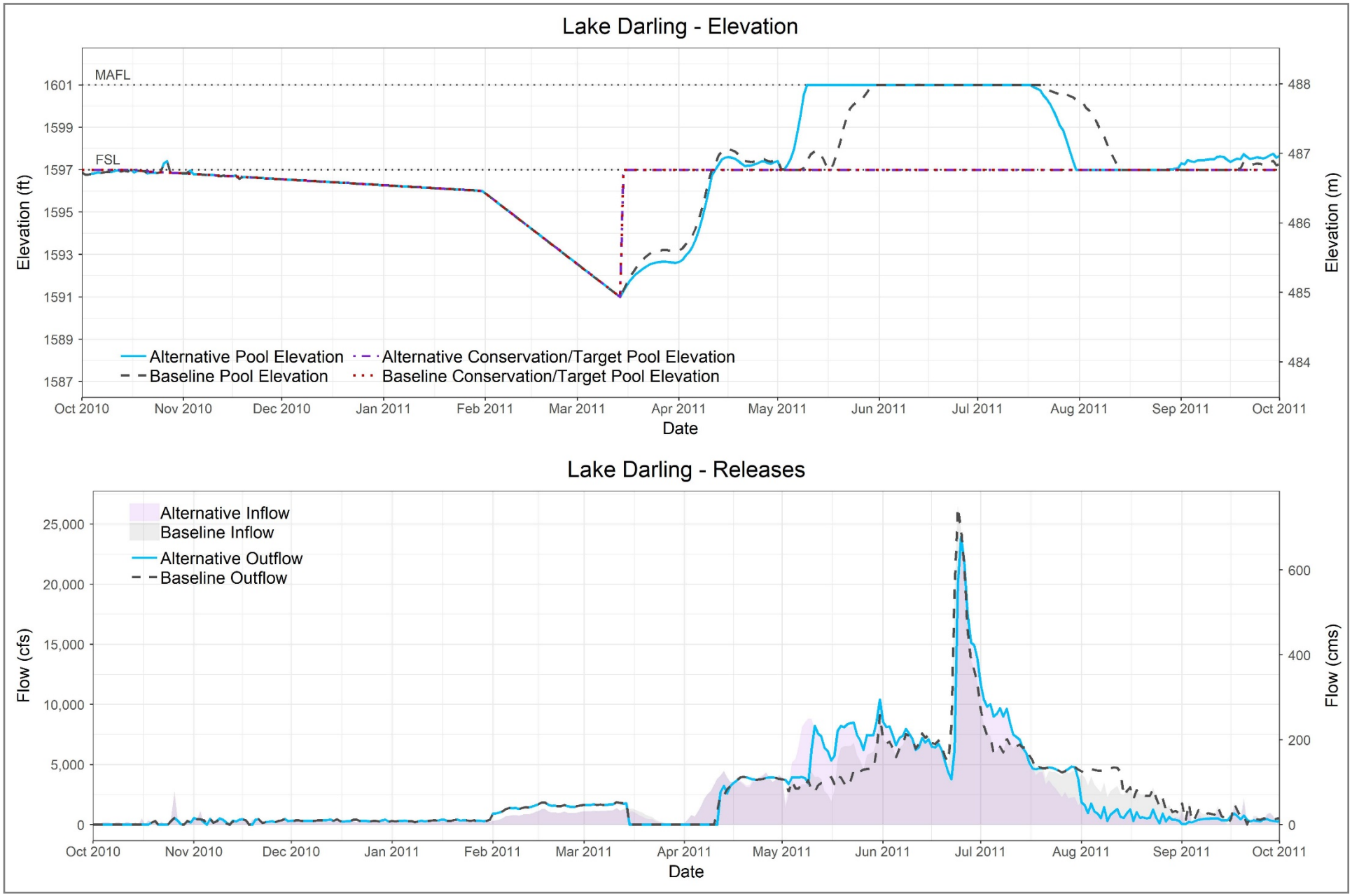
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



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



**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*



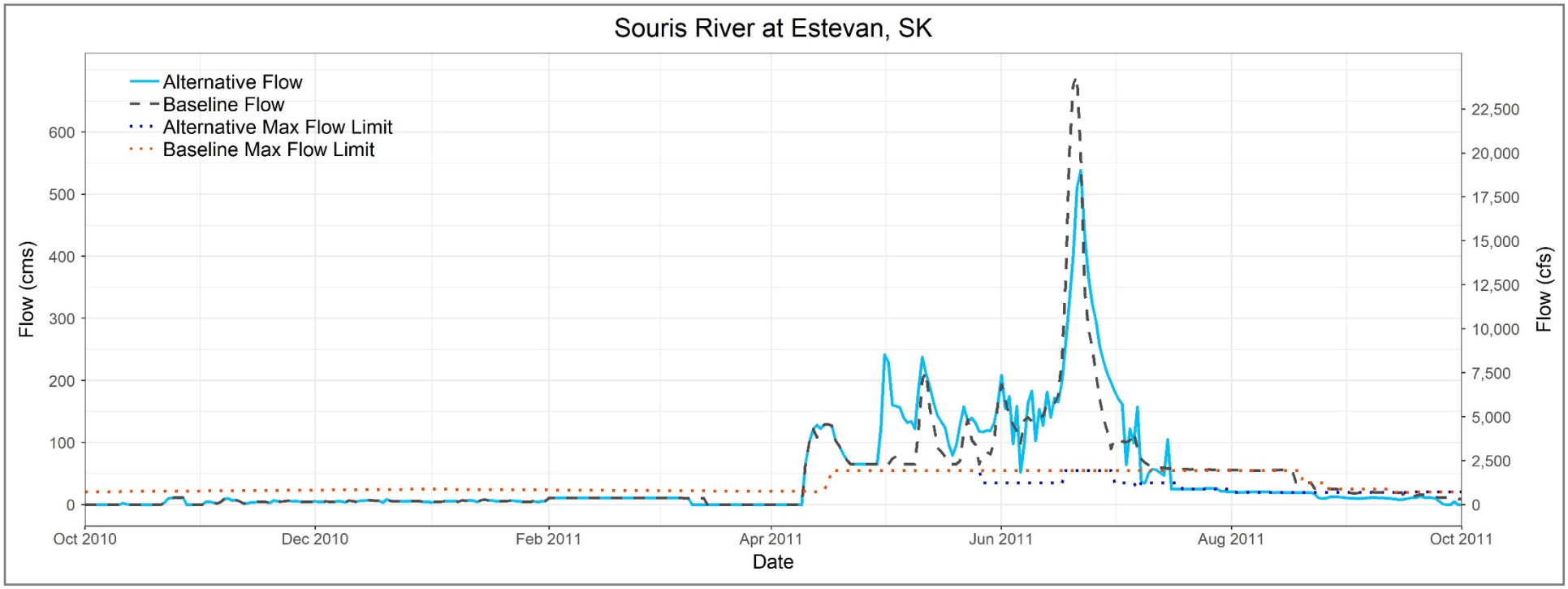
**MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level, IDFSL = Inflow Design Flood Supply Level*

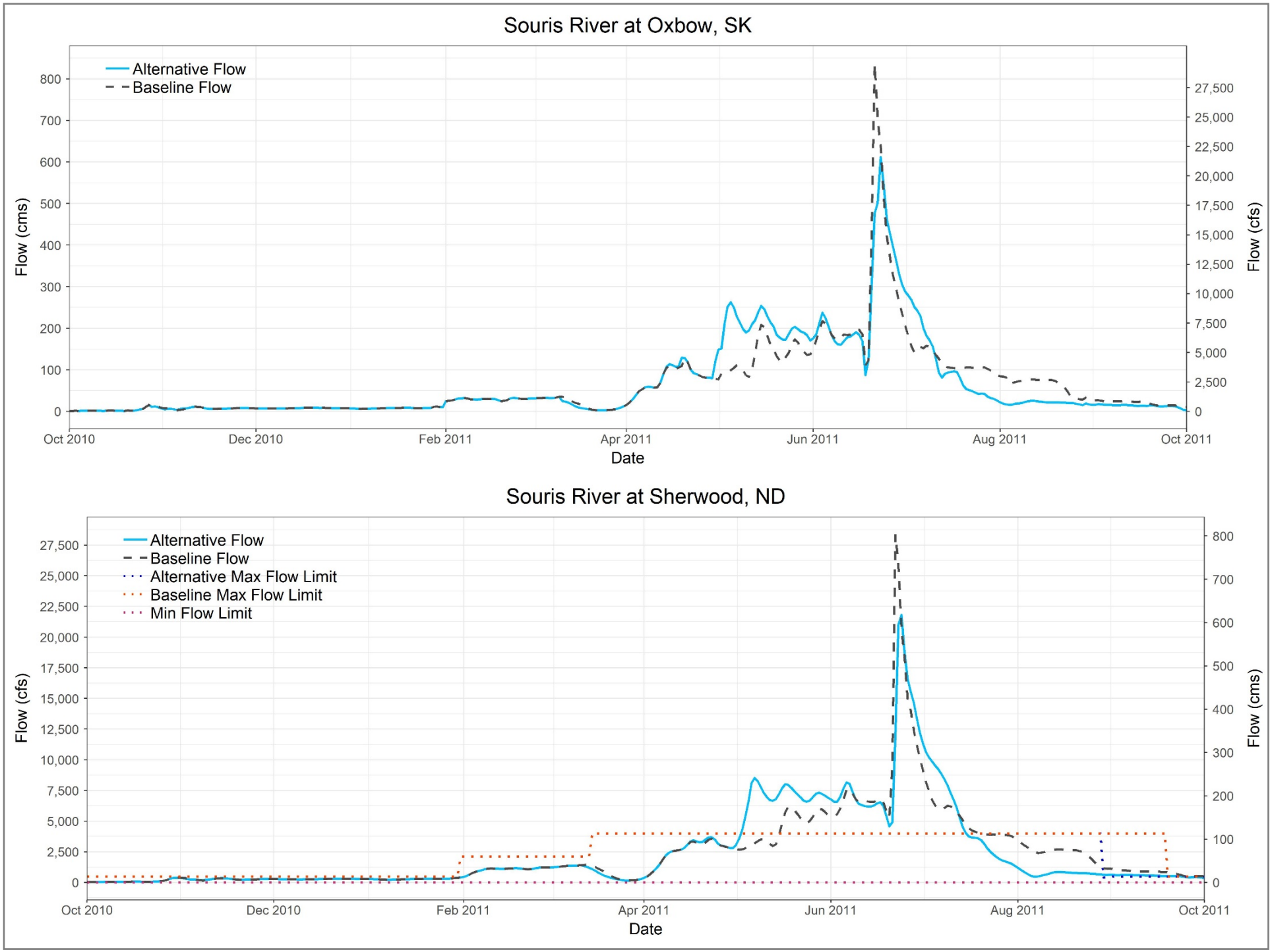
Plate 08

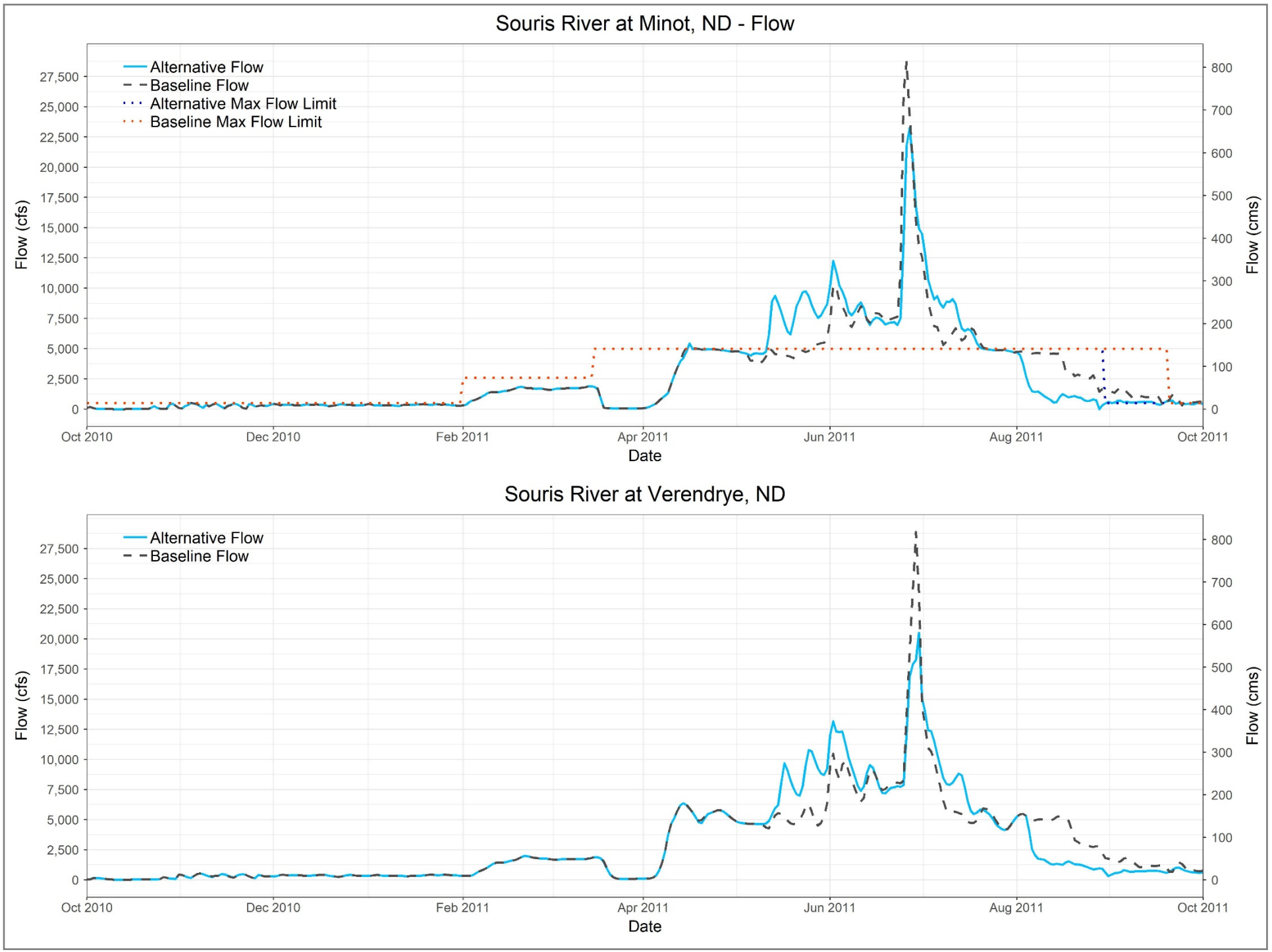
Critical Flow Locations – 2011

Alternative 9 (Phase 2)

Souris River Plan of Study




Souris River at Oxbow, SK
Alternative Flow
Baseline Flow
Flow (cms)
Flow (cfs)
Date
Oct 2010
Dec 2010
Feb 2011
Apr 2011
Jun 2011
Aug 2011
Oct 2011
Souris River at Sherwood, ND
Alternative Flow
Baseline Flow
Alternative Max Flow Limit
Baseline Max Flow Limit
Min Flow Limit
Flow (cfs)
Flow (cms)
Date


Souris River at Minot, ND - Flow
Alternative Flow
Baseline Flow
Alternative Max Flow Limit
Baseline Max Flow Limit
Flow (cfs)
Flow (cms)
Date
Oct 2010
Dec 2010
Feb 2011
Apr 2011
Jun 2011
Aug 2011
Oct 2011
Souris River at Verendrye, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
Date

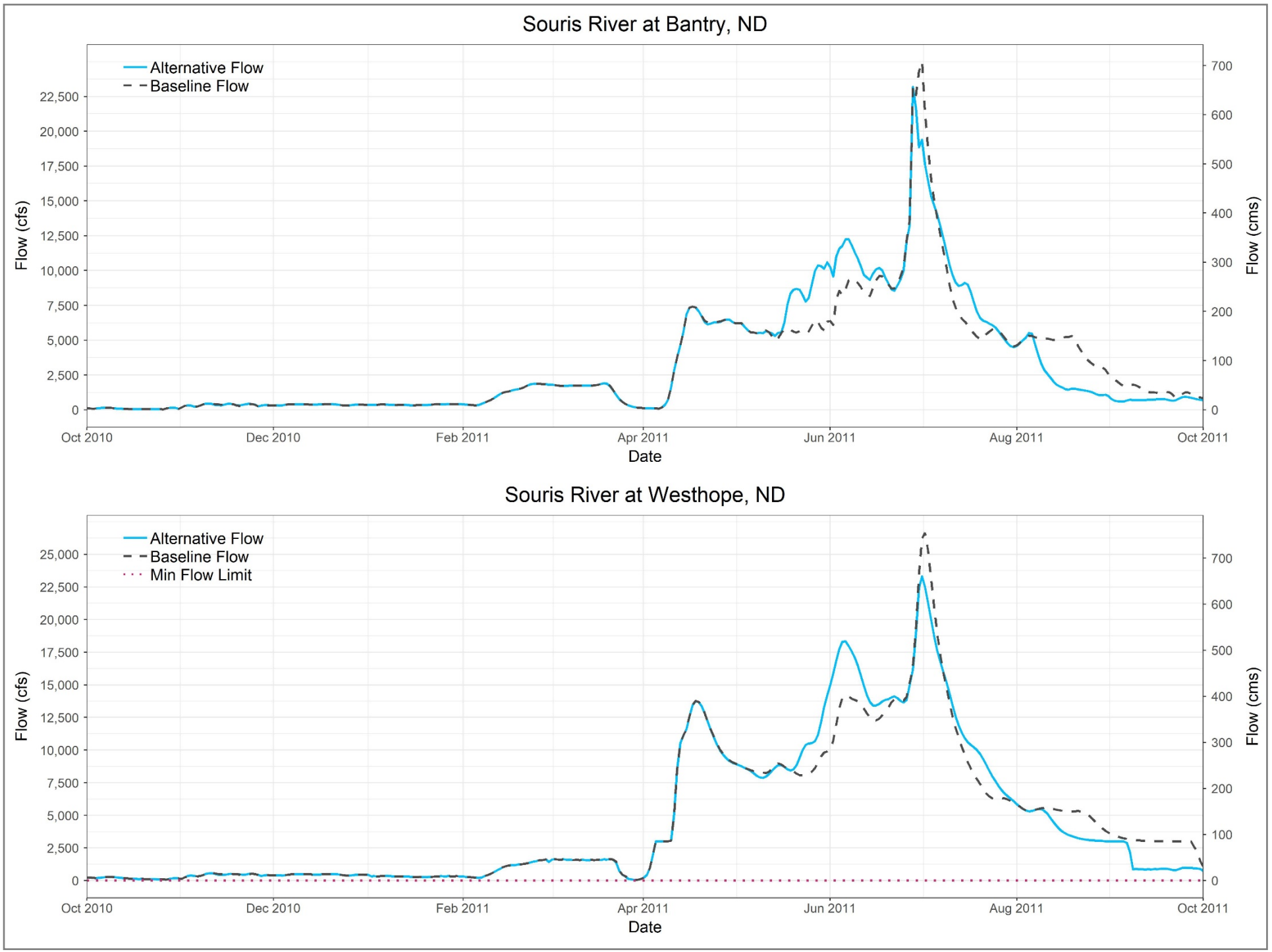
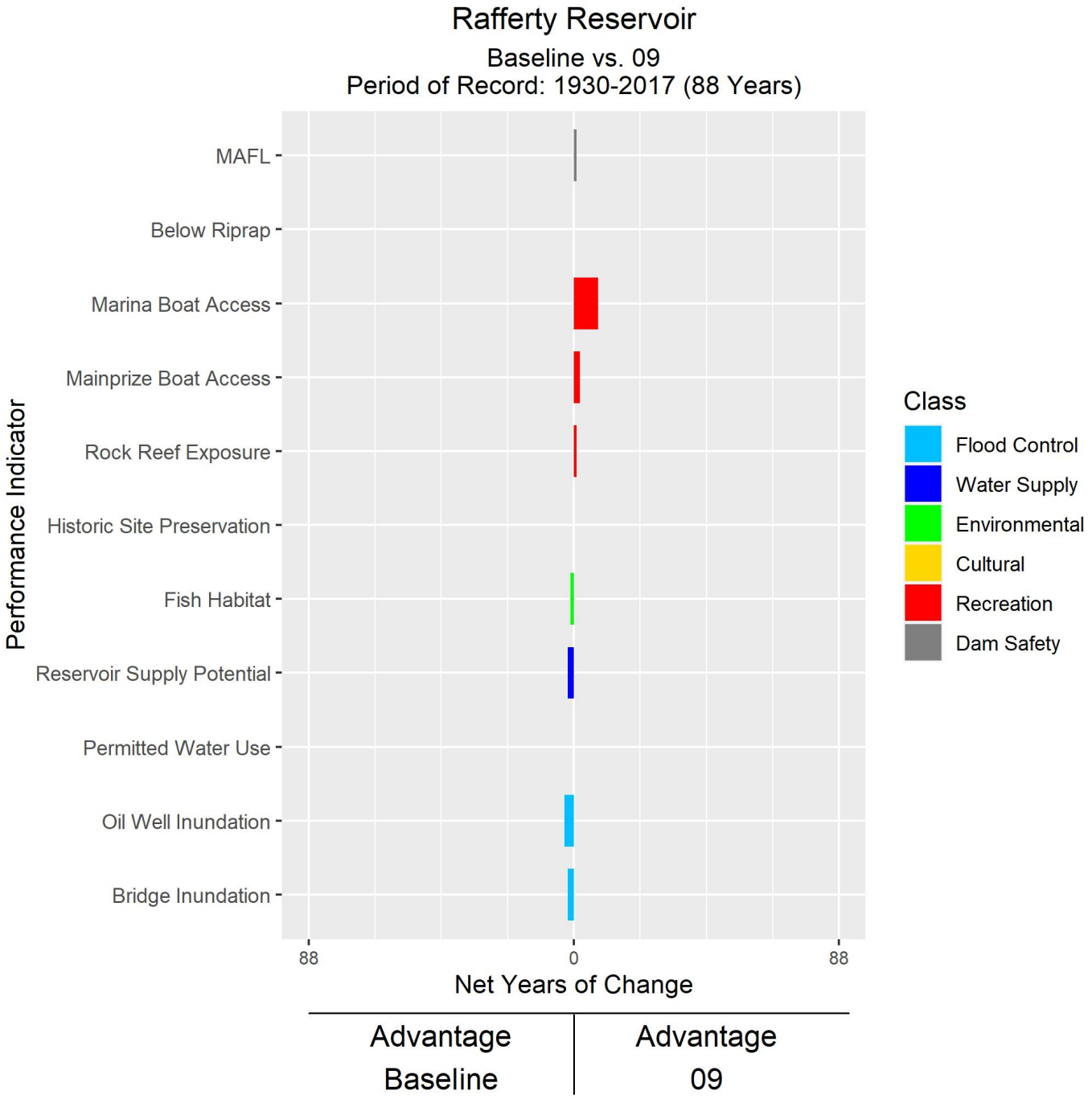
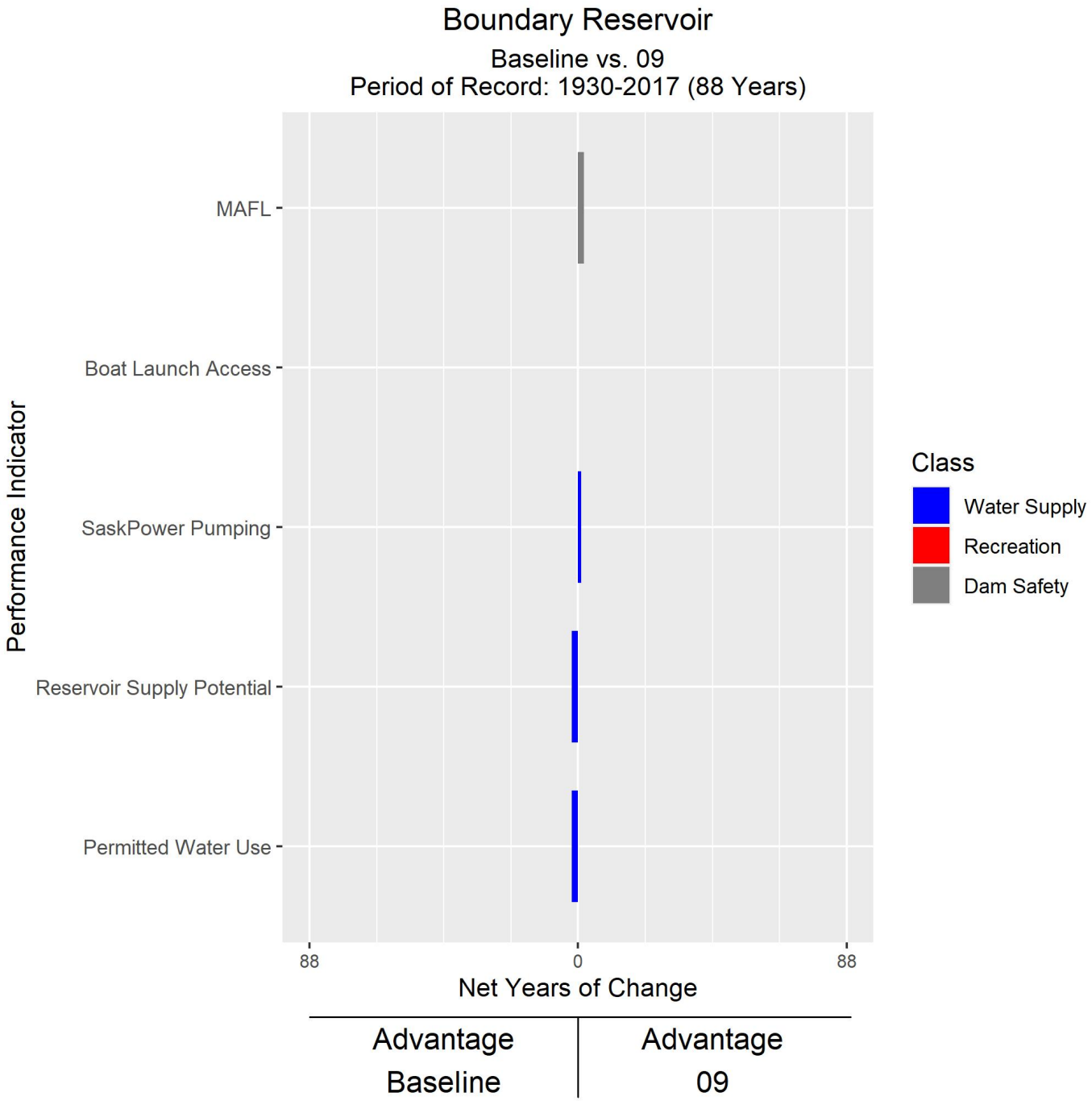
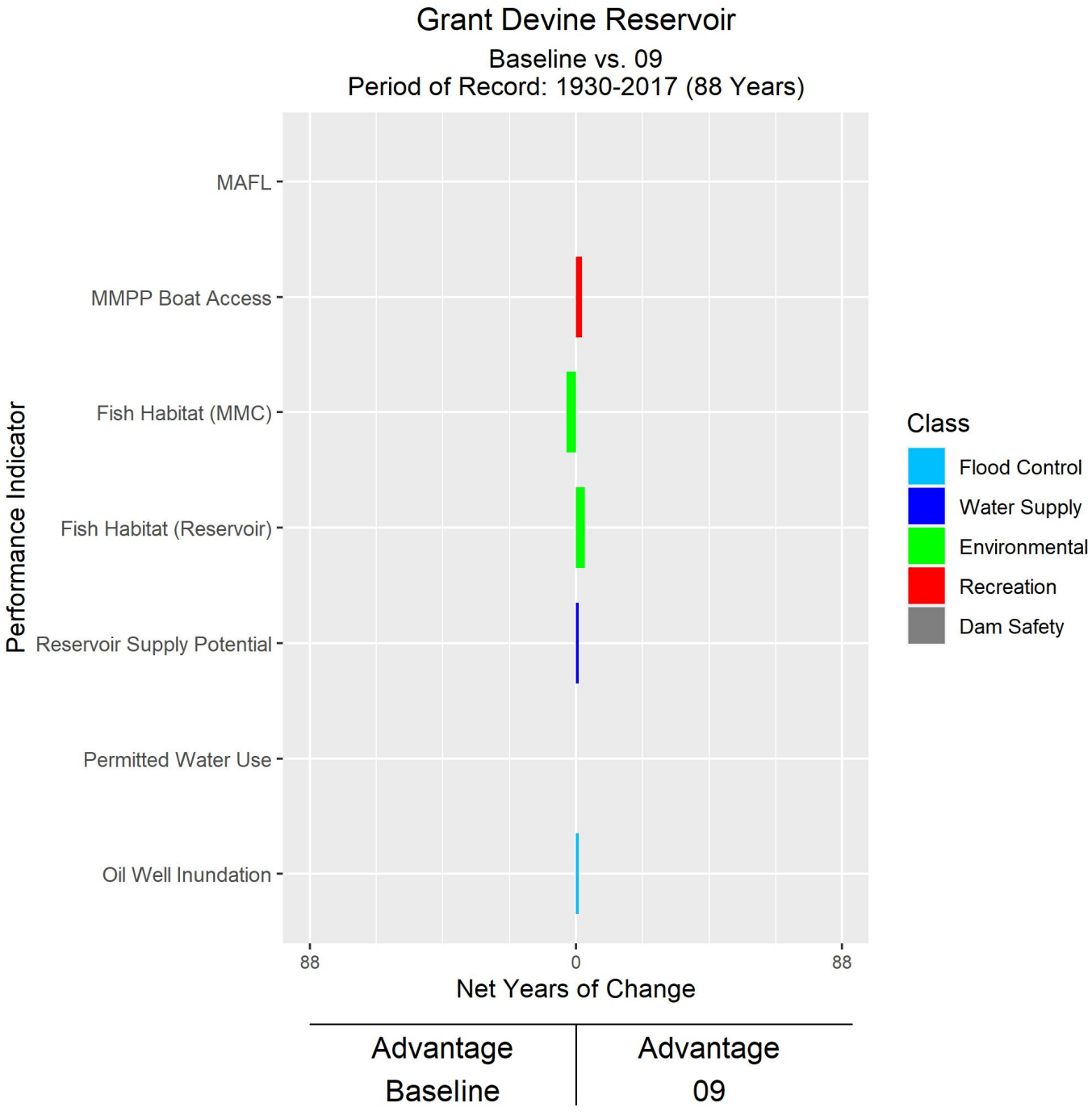
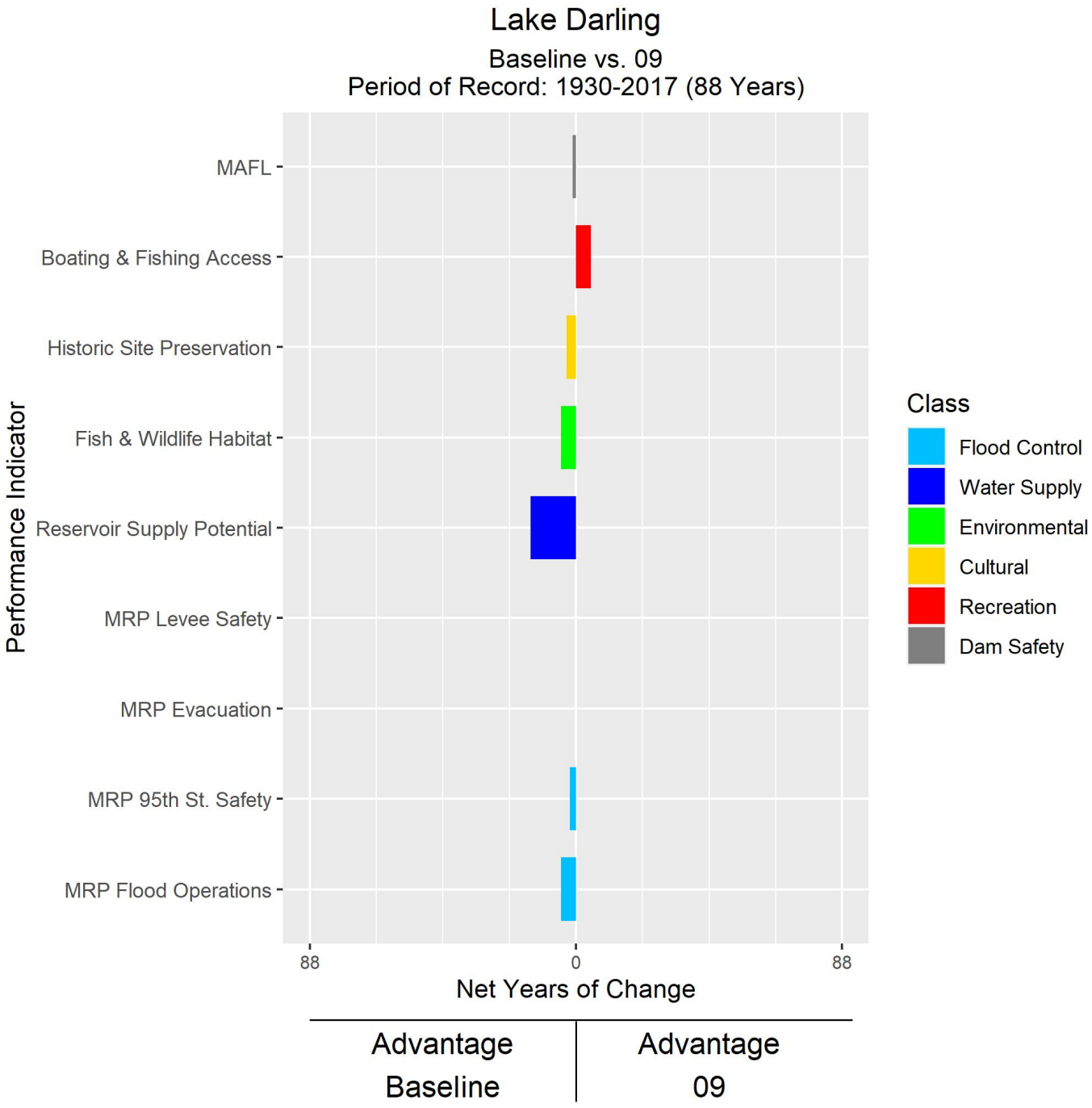

Souris River at Bantry, ND
Alternative Flow
Baseline Flow
Flow (cfs)
Flow (cms)
Date
Oct 2010
Dec 2010
Feb 2011
Apr 2011
Jun 2011
Aug 2011
Oct 2011
Souris River at Westhope, ND
Alternative Flow
Baseline Flow
Min Flow Limit
Flow (cfs)
Flow (cms)
Date
Oct 2010
Dec 2010
Feb 2011
Apr 2011
Jun 2011
Aug 2011
Oct 2011

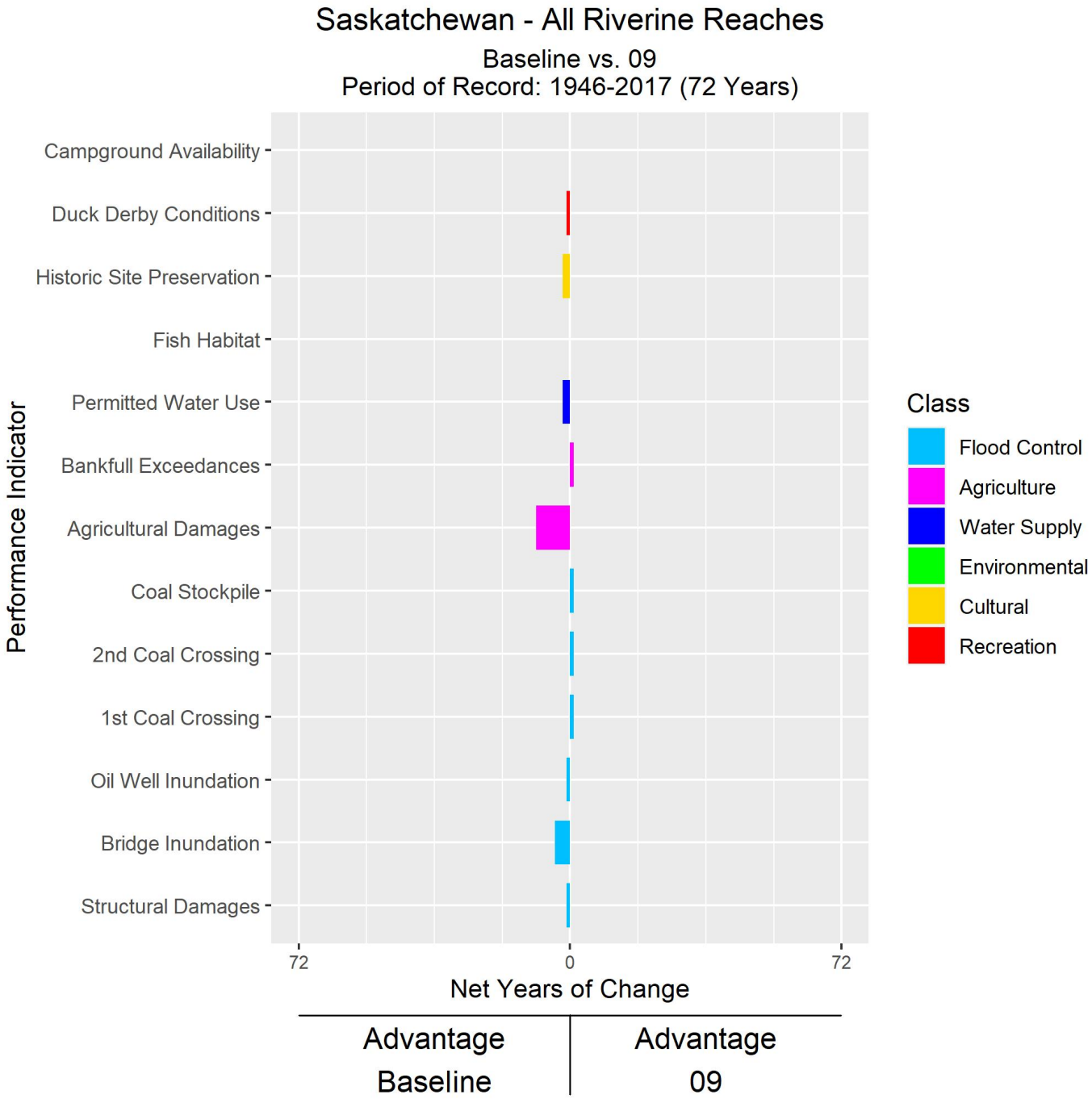
Plate 09	Performance Indicators 1946-2017 (72 years)	Alternative 09 vs. Baseline (Phase 2)

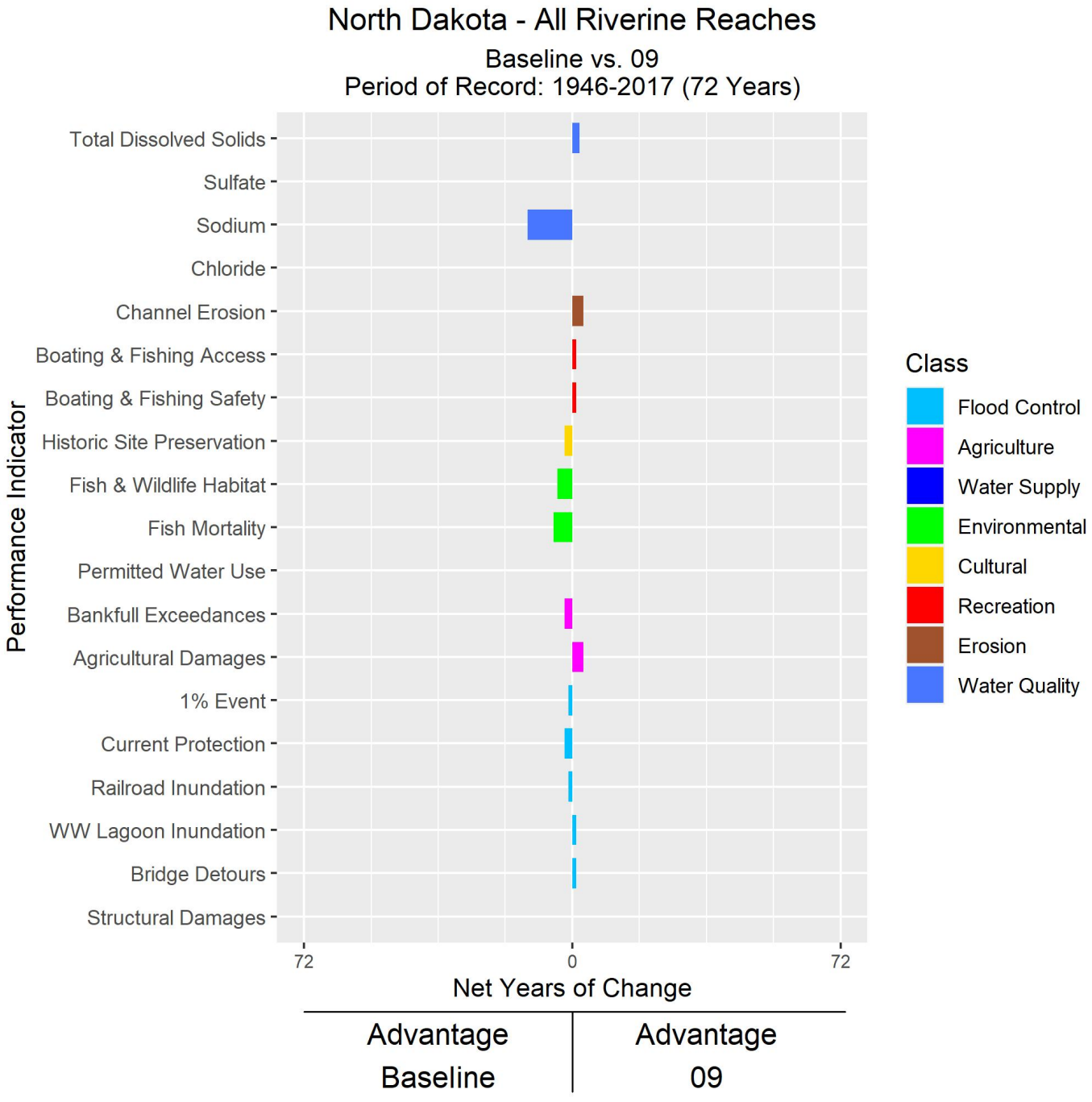


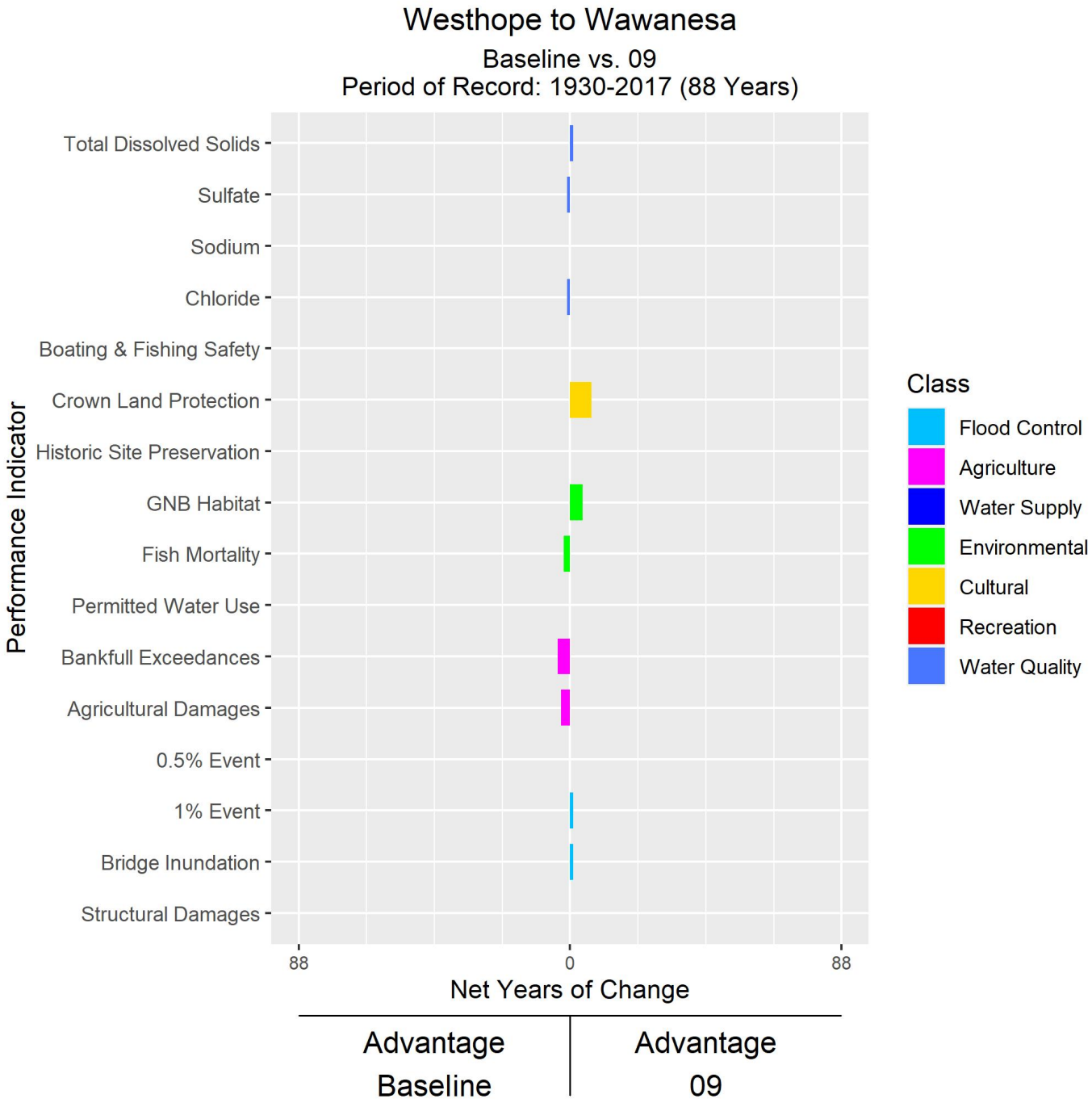

Boundary Reservoir
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
MAFL
Boat Launch Access
SaskPower Pumping
Reservoir Supply Potential
Permitted Water Use
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Water Supply
Recreation
Dam Safety

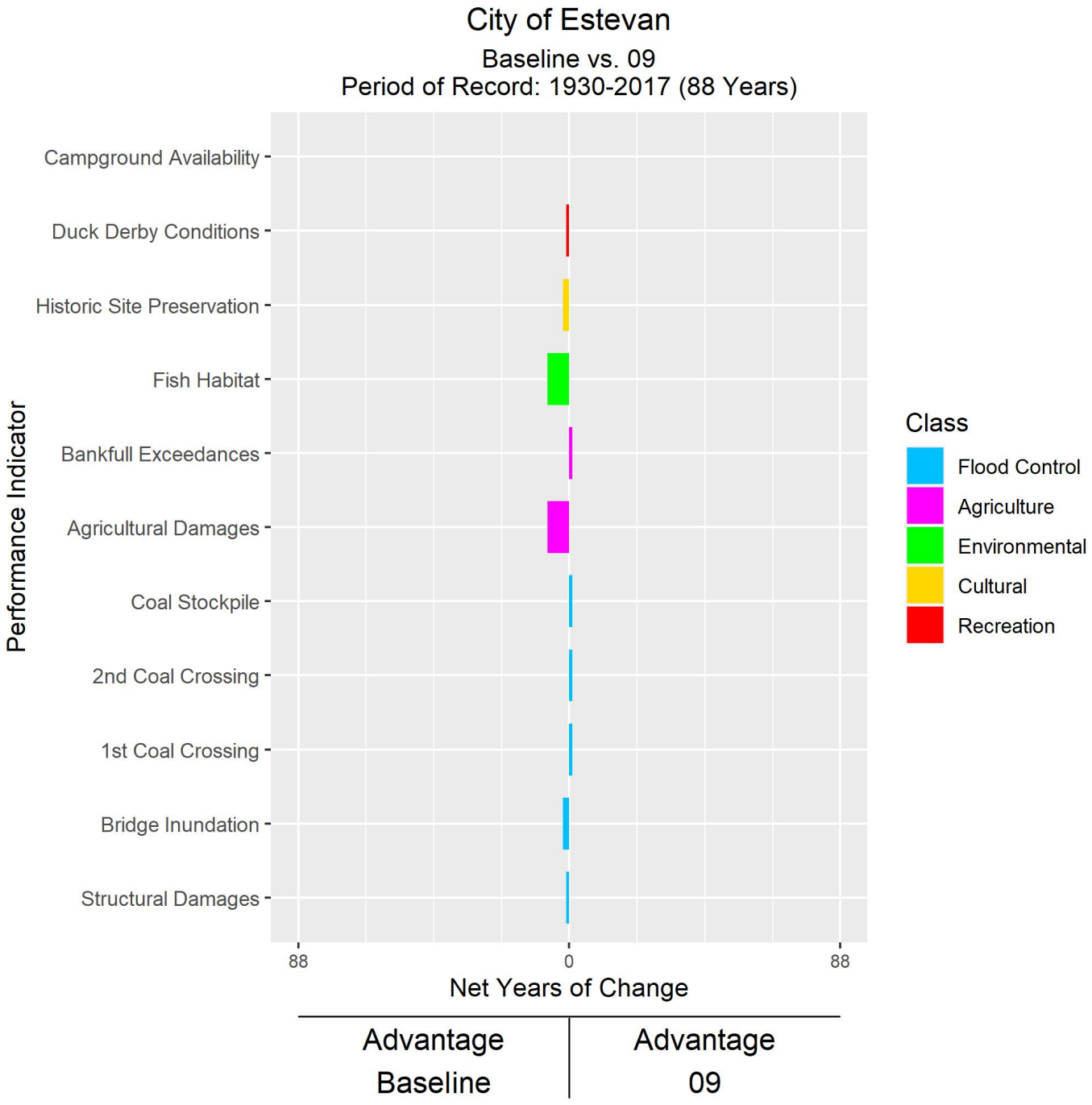

Grant Devine Reservoir
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
MAFL
MMPP Boat Access
Fish Habitat (MMC)
Fish Habitat (Reservoir)
Reservoir Supply Potential
Permitted Water Use
Oil Well Inundation
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Water Supply
Environmental
Recreation
Dam Safety

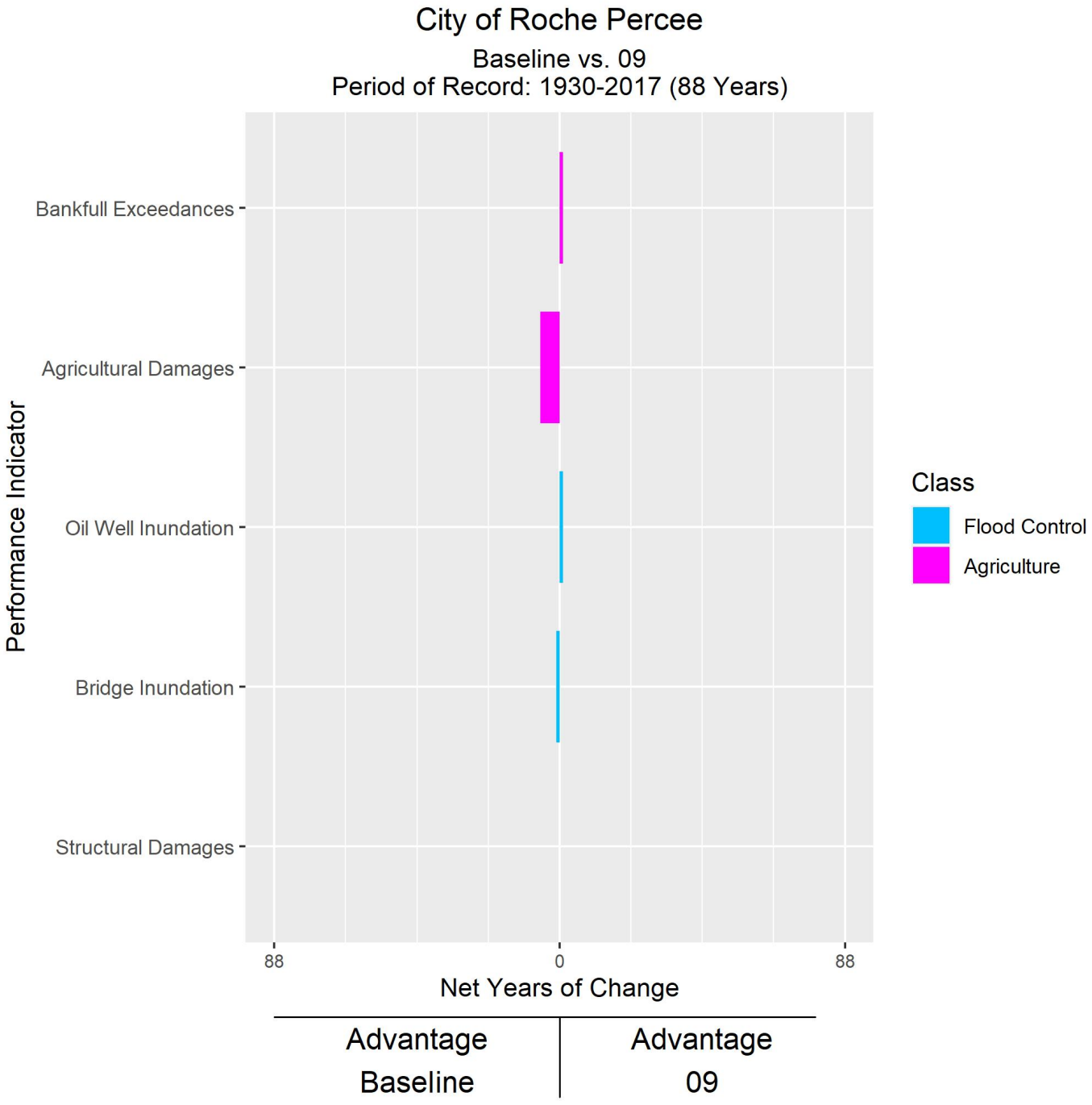

Lake Darling
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
MAFL
Boating & Fishing Access
Historic Site Preservation
Fish & Wildlife Habitat
Reservoir Supply Potential
MRP Levee Safety
MRP Evacuation
MRP 95th St. Safety
MRP Flood Operations
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Water Supply
Environmental
Cultural
Recreation
Dam Safety

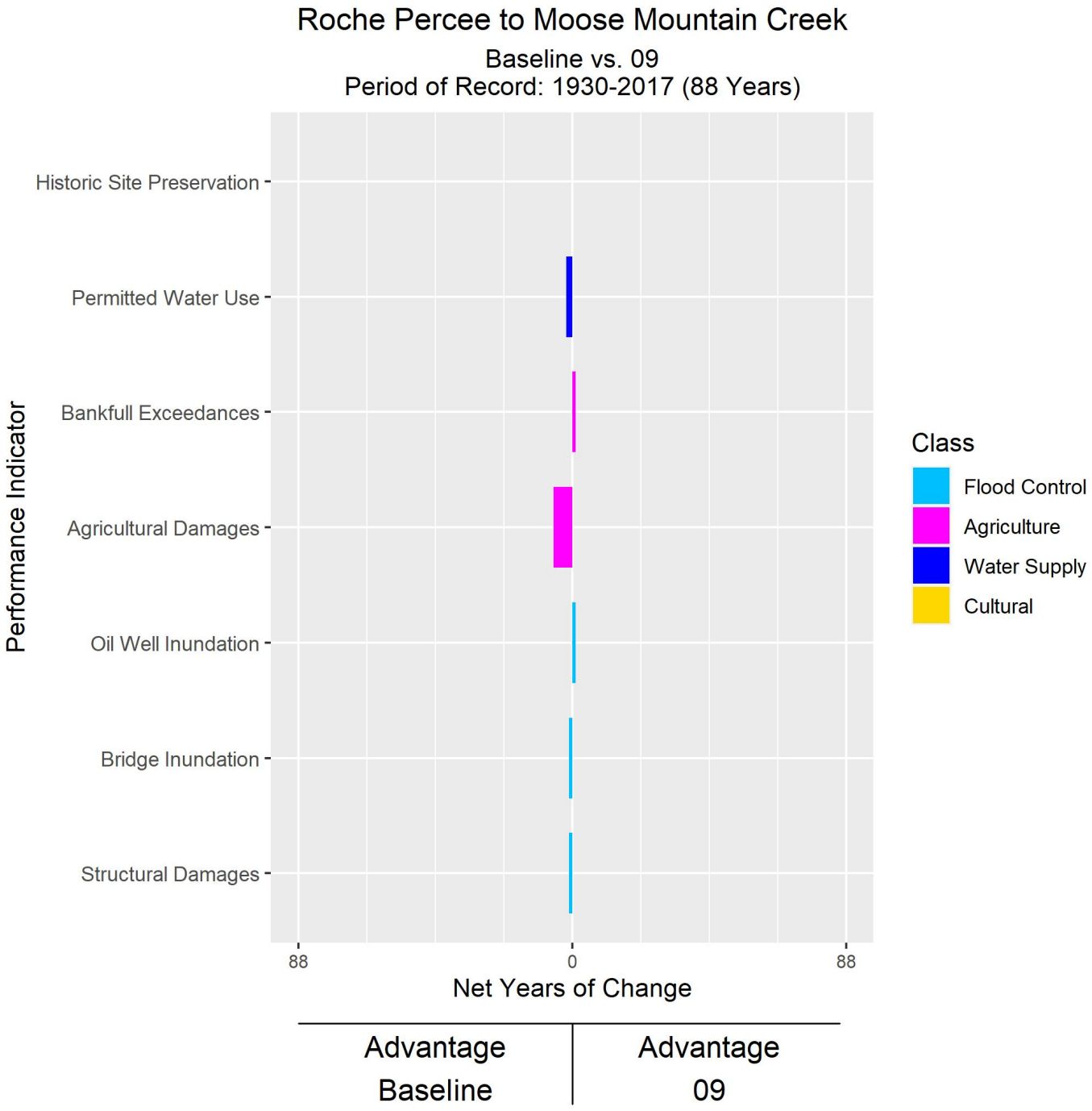

Saskatchewan - All Riverine Reaches
Baseline vs. 09
Period of Record: 1946-2017 (72 Years)
Performance Indicator
Campground Availability
Duck Derby Conditions
Historic Site Preservation
Fish Habitat
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Coal Stockpile
2nd Coal Crossing
1st Coal Crossing
Oil Well Inundation
Bridge Inundation
Structural Damages
72
0
72
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation

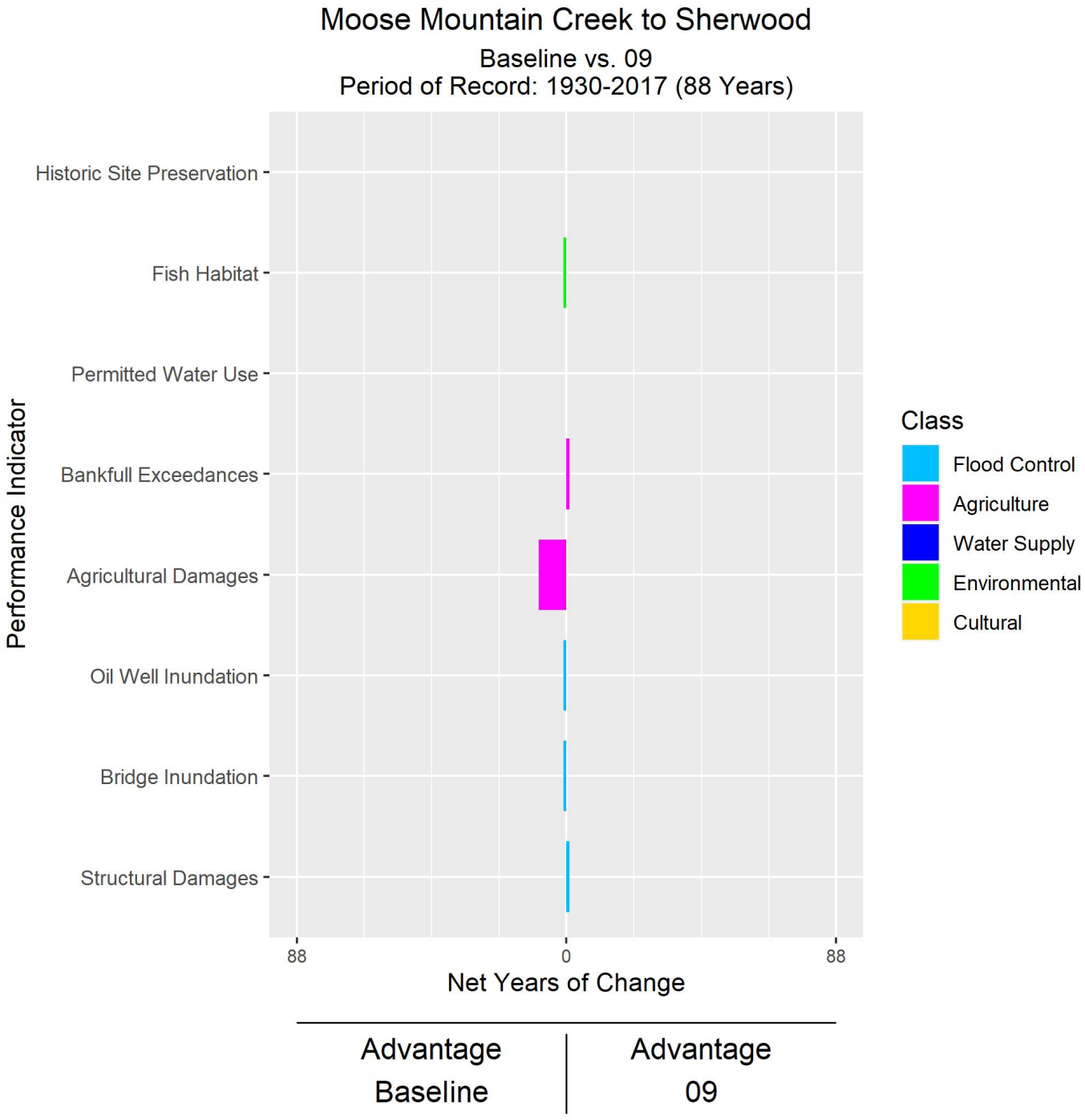

North Dakota - All Riverine Reaches
Baseline vs. 09
Period of Record: 1946-2017 (72 Years)
Performance Indicator
Total Dissolved Solids
Sulfate
Sodium
Chloride
Channel Erosion
Boating & Fishing Access
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
1% Event
Current Protection
Railroad Inundation
WW Lagoon Inundation
Bridge Detours
Structural Damages
72
0
72
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Erosion
Water Quality

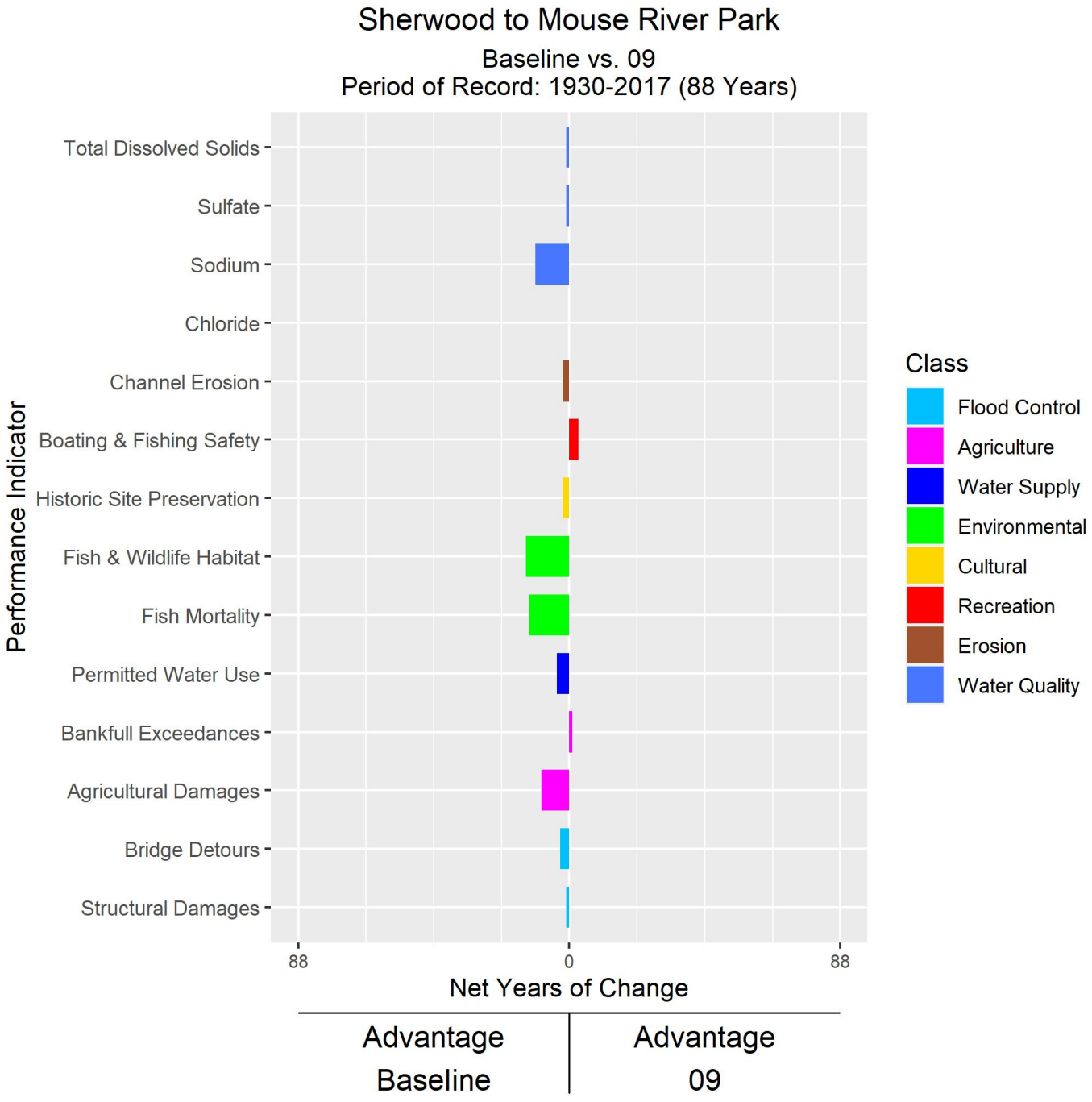

Westhope to Wawanesa
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Total Dissolved Solids
Sulfate
Sodium
Chloride
Boating & Fishing Safety
Crown Land Protection
Historic Site Preservation
GNB Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
0.5% Event
1% Event
Bridge Inundation
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Water Quality

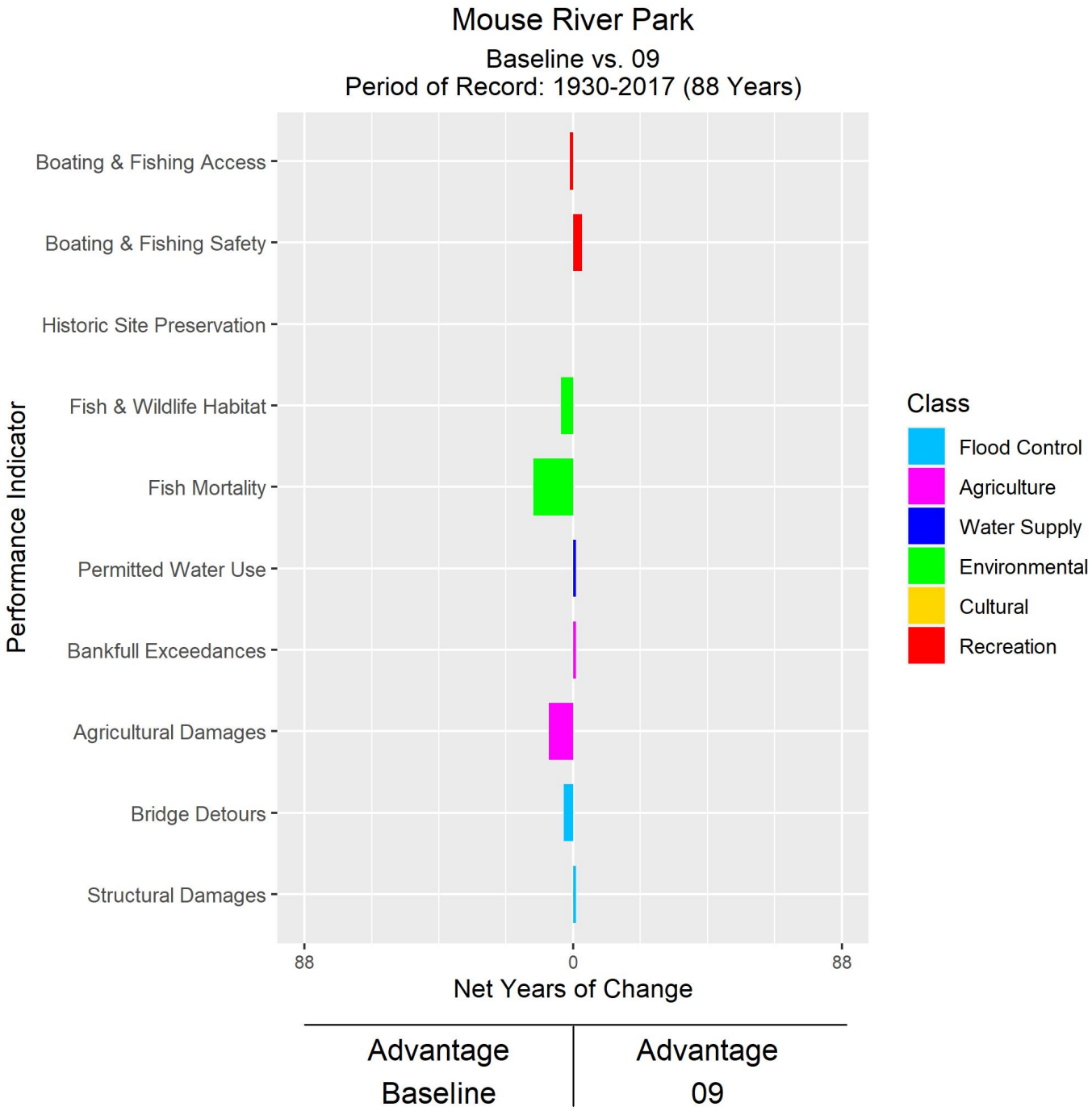

City of Estevan
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Campground Availability
Duck Derby Conditions
Historic Site Preservation
Fish Habitat
Bankfull Exceedances
Agricultural Damages
Coal Stockpile
2nd Coal Crossing
1st Coal Crossing
Bridge Inundation
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Environmental
Cultural
Recreation

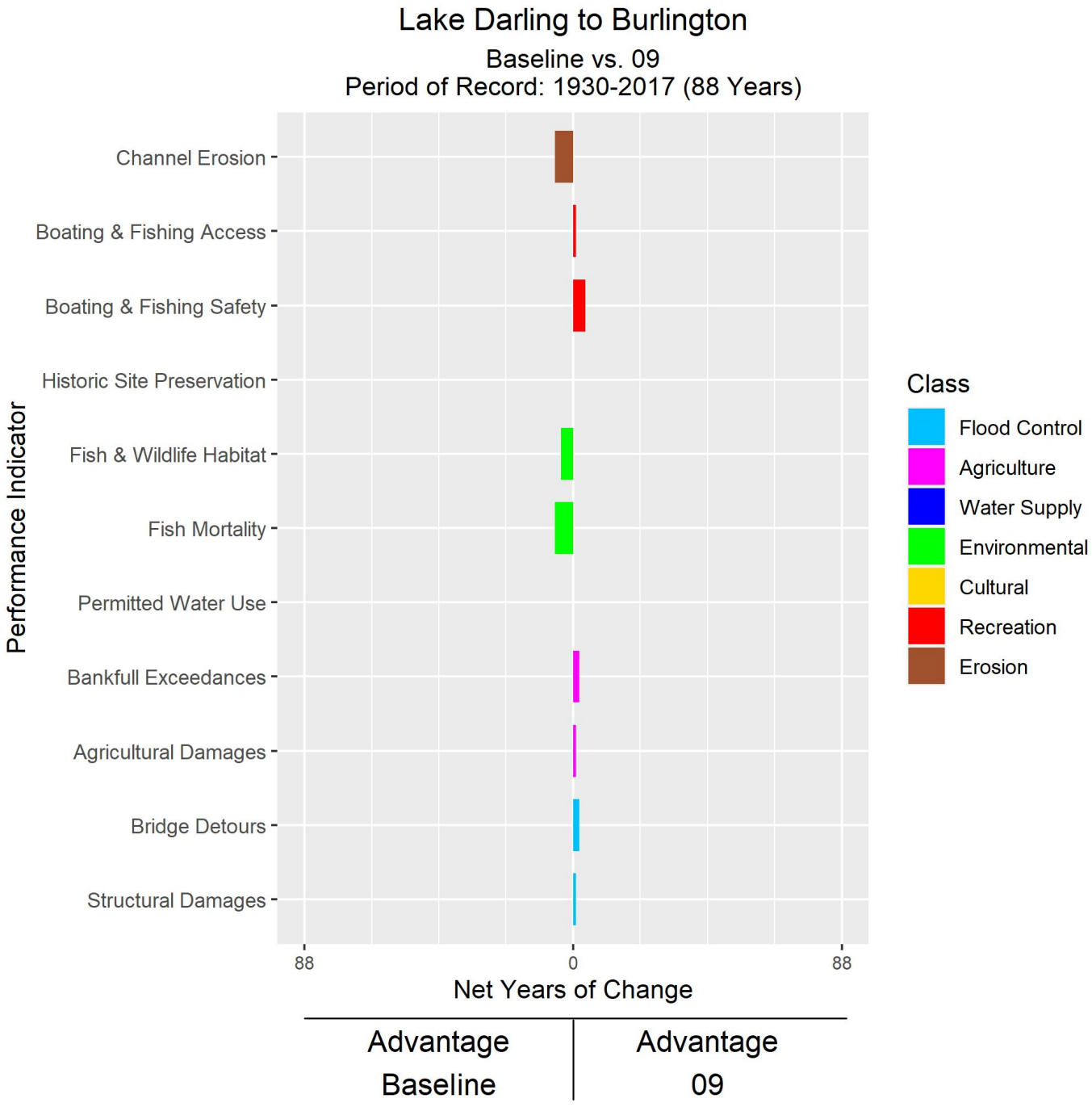

City of Roche Percee
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Bankfull Exceedances
Agricultural Damages
Oil Well Inundation
Bridge Inundation
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture

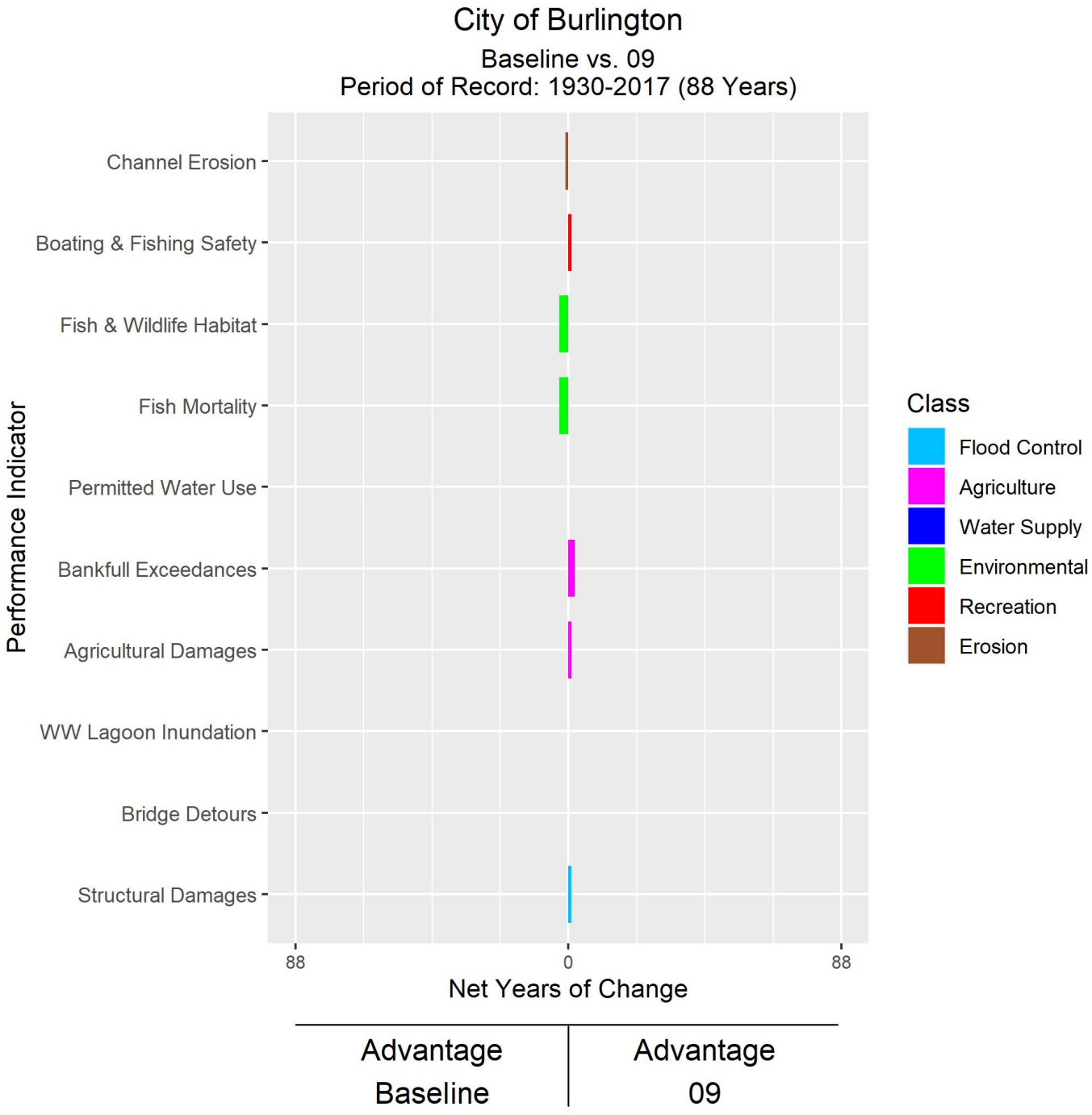

Roche Percee to Moose Mountain Creek
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Historic Site Preservation
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Oil Well Inundation
Bridge Inundation
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Cultural

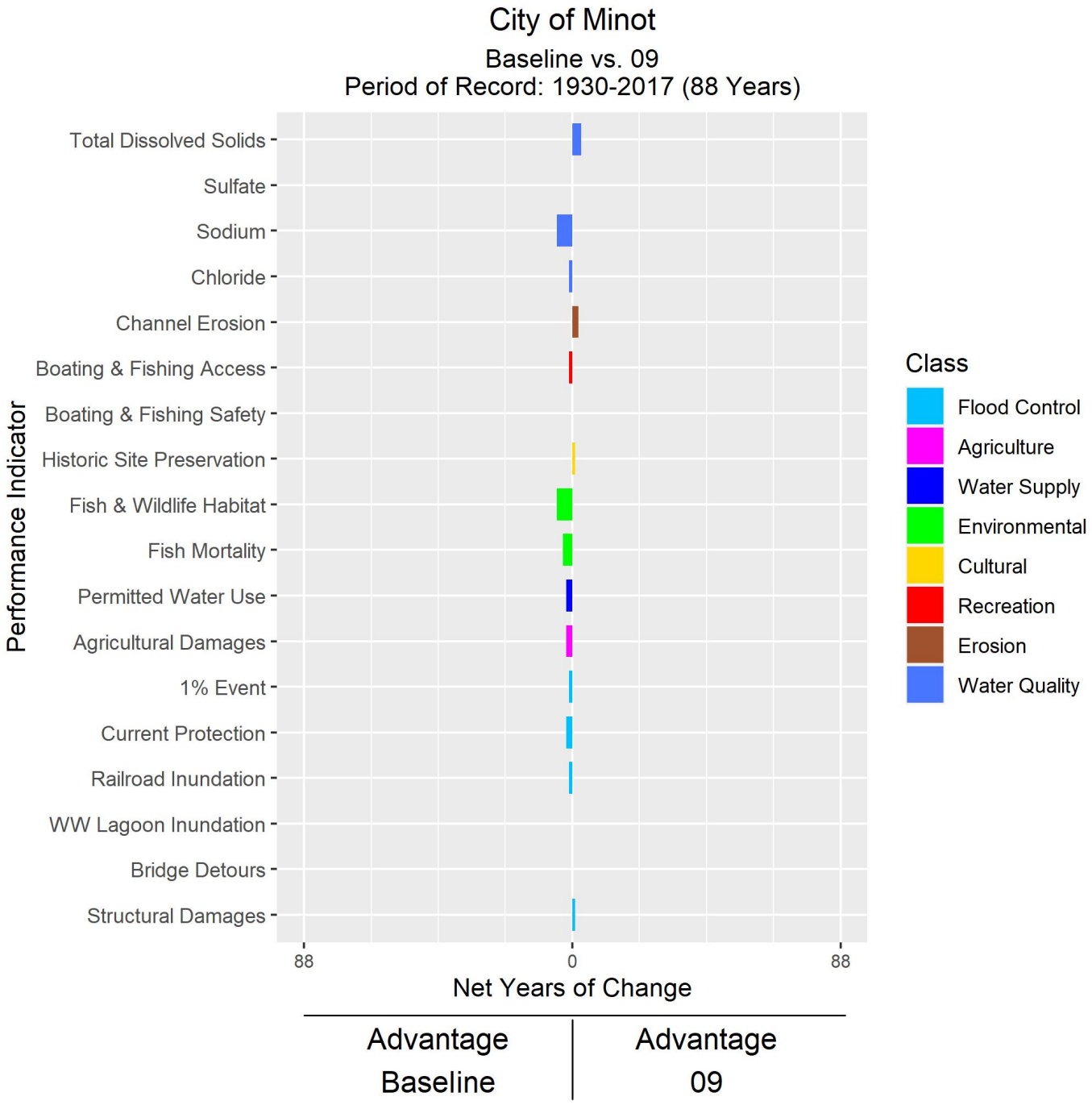

Moose Mountain Creek to Sherwood
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Historic Site Preservation
Fish Habitat
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Oil Well Inundation
Bridge Inundation
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural

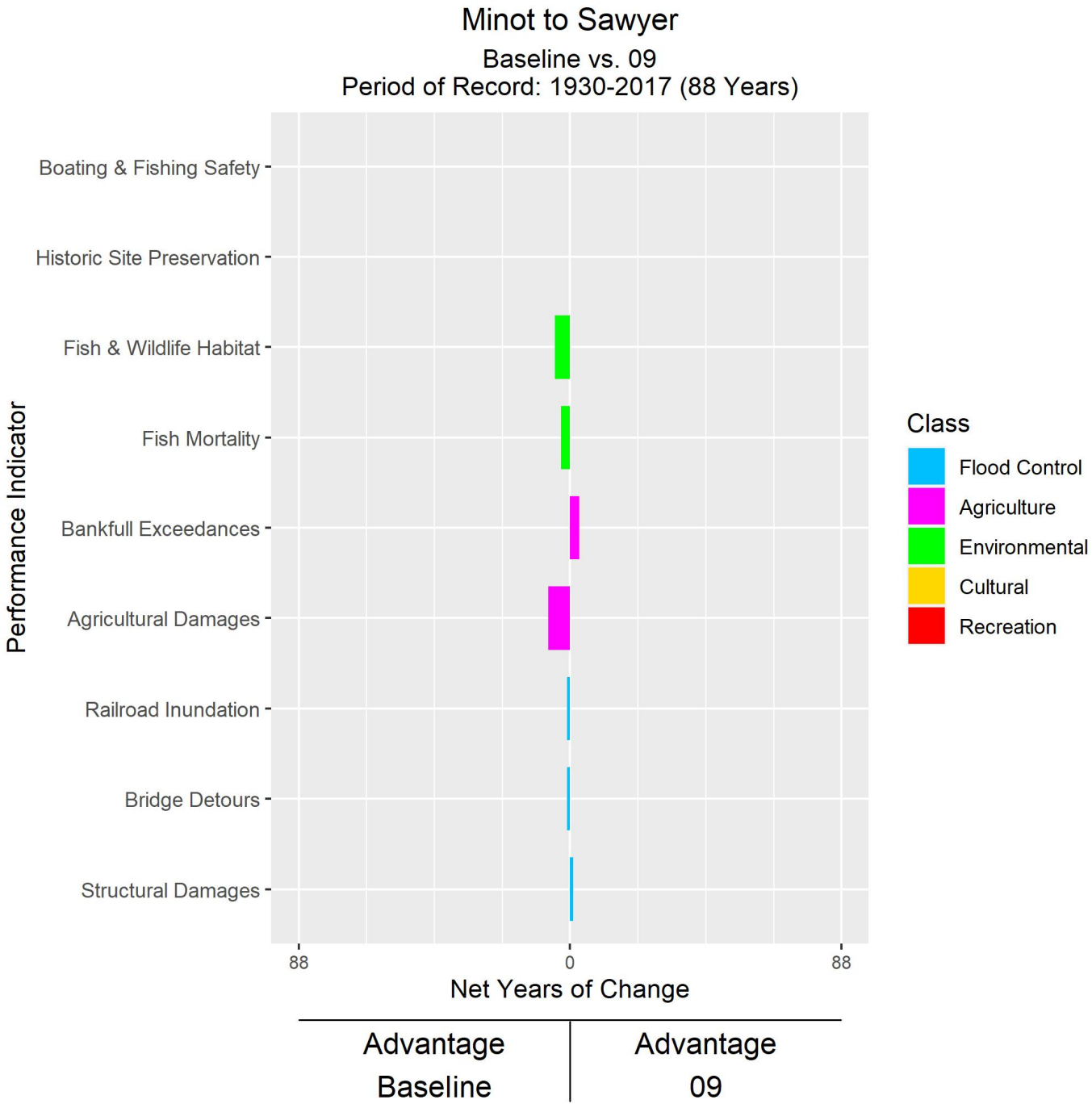

Sherwood to Mouse River Park
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Total Dissolved Solids
Sulfate
Sodium
Chloride
Channel Erosion
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Erosion
Water Quality

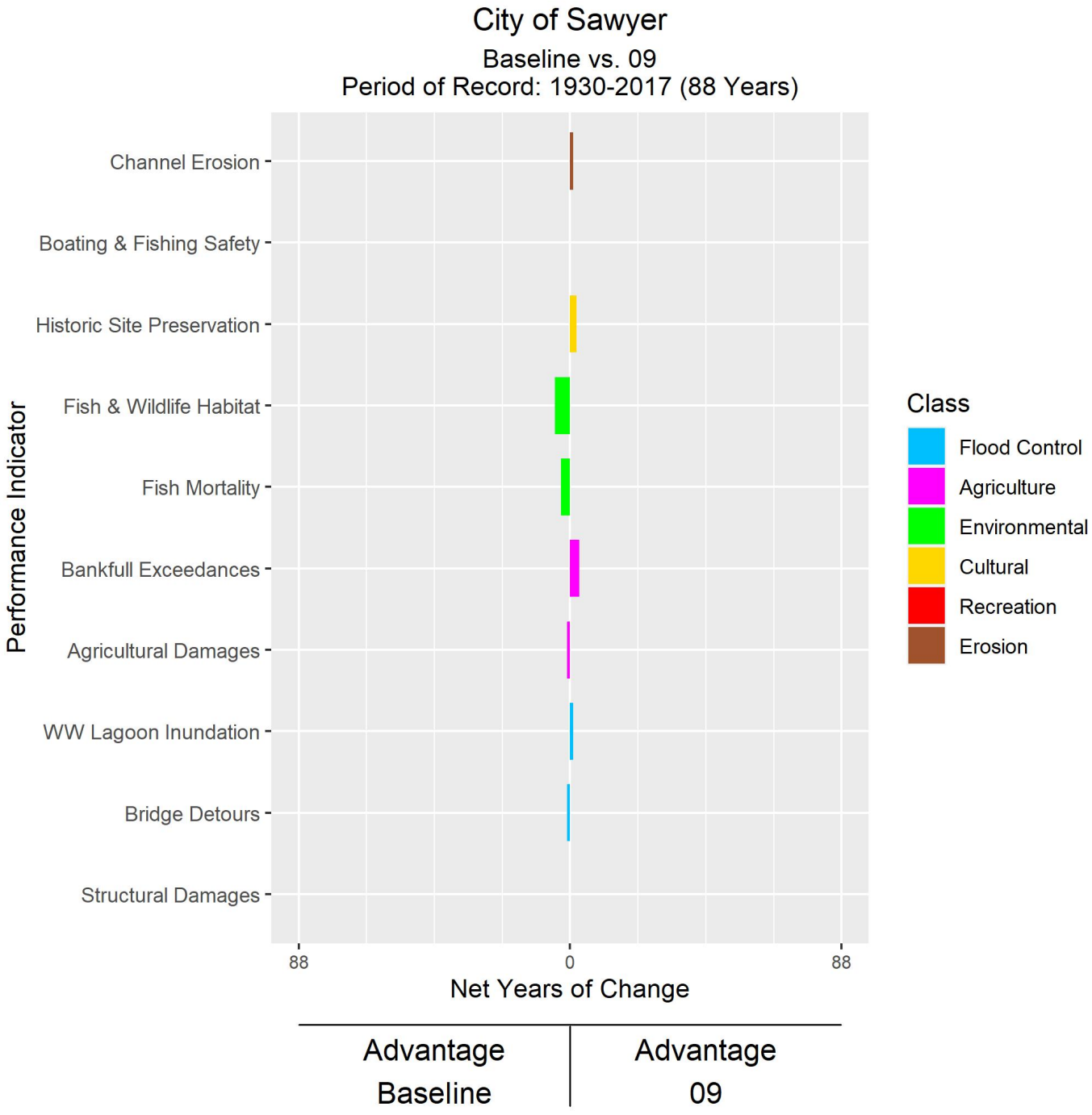

Mouse River Park
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Boating & Fishing Access
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation

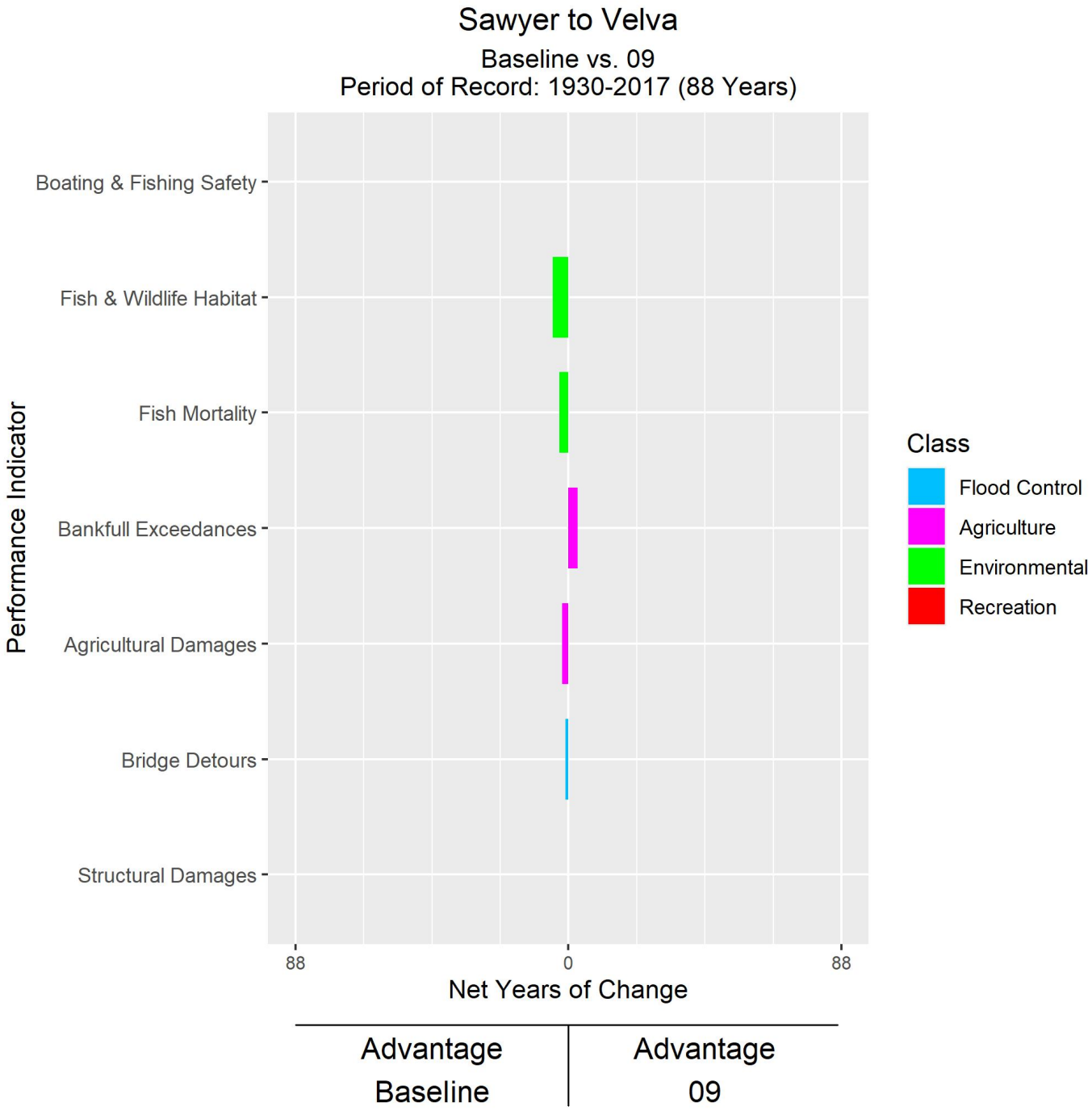

Lake Darling to Burlington
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Channel Erosion
Boating & Fishing Access
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Erosion

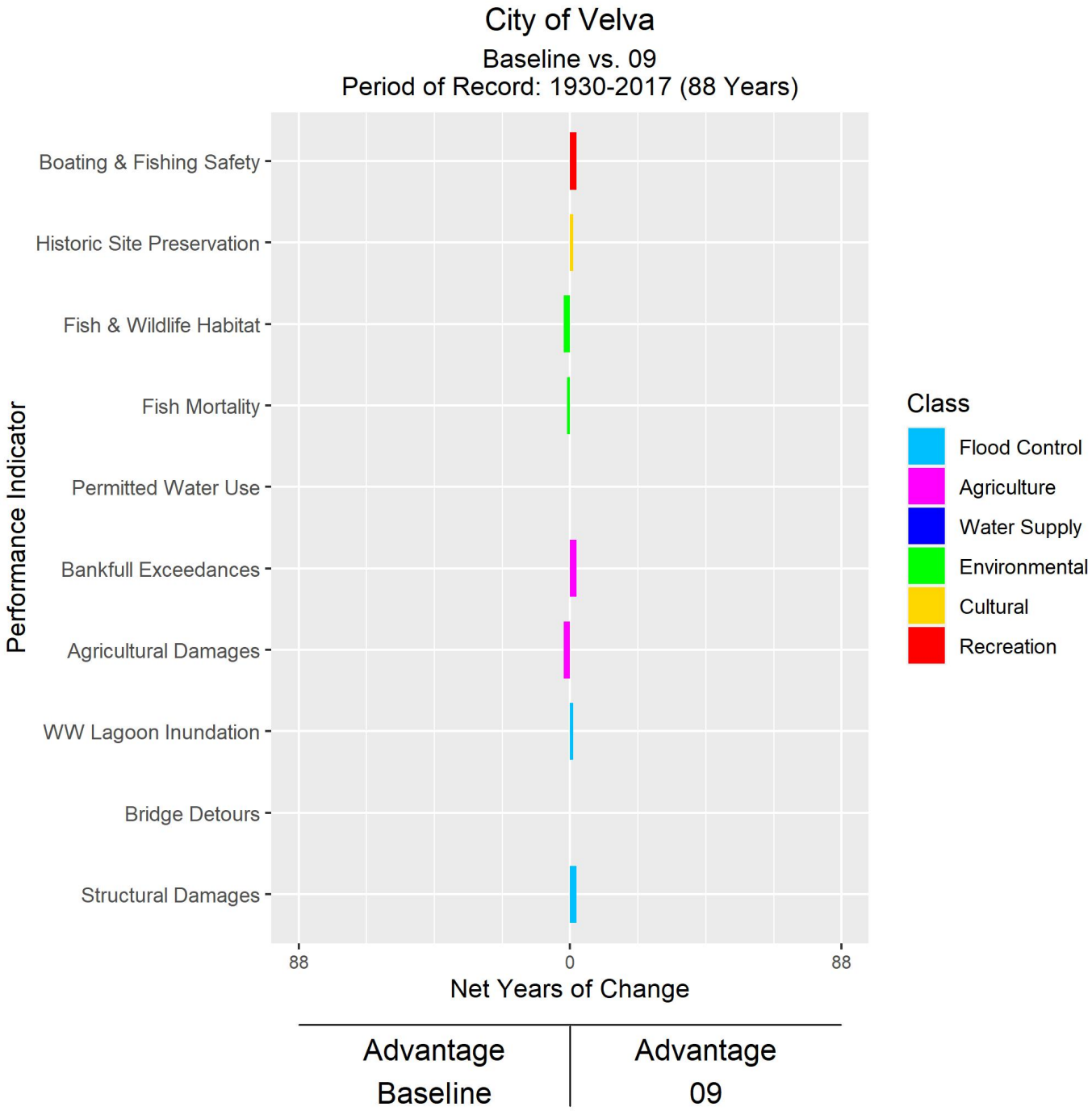

City of Burlington
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Channel Erosion
Boating & Fishing Safety
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
WW Lagoon Inundation
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Recreation
Erosion

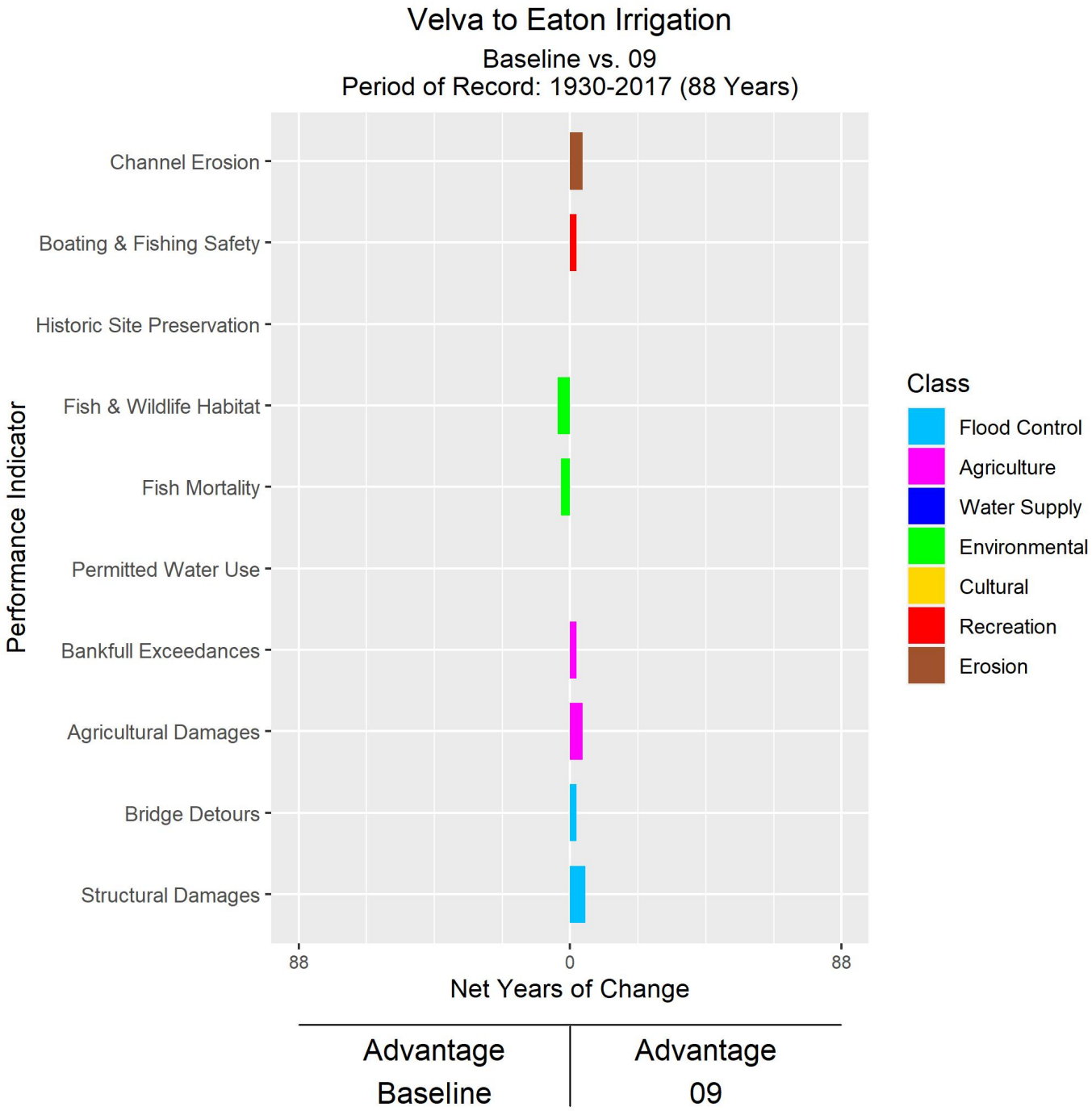

City of Minot
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Total Dissolved Solids
Sulfate
Sodium
Chloride
Channel Erosion
Boating & Fishing Access
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Agricultural Damages
1% Event
Current Protection
Railroad Inundation
WW Lagoon Inundation
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Erosion
Water Quality

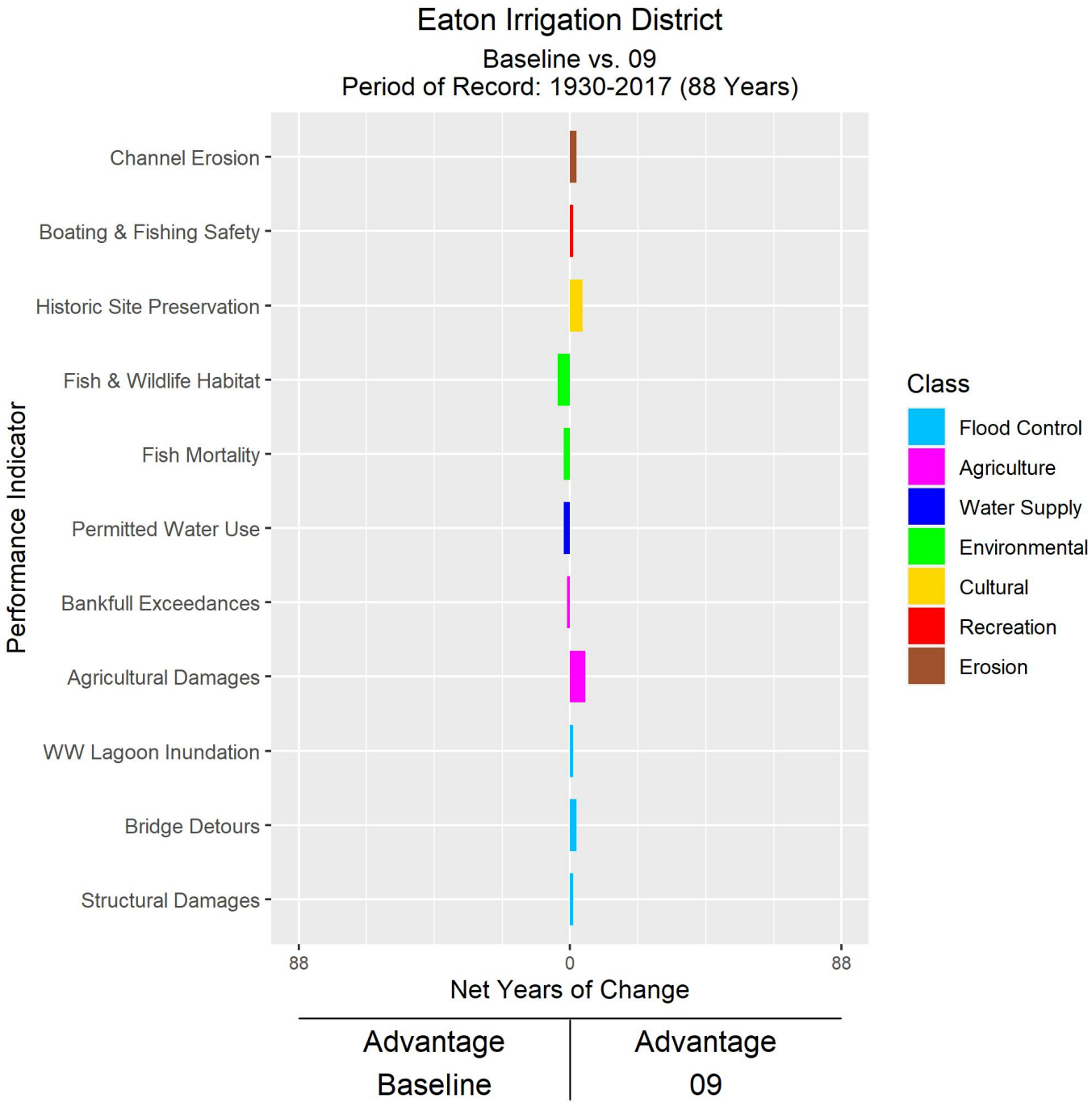

Minot to Sawyer
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Bankfull Exceedances
Agricultural Damages
Railroad Inundation
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Environmental
Cultural
Recreation

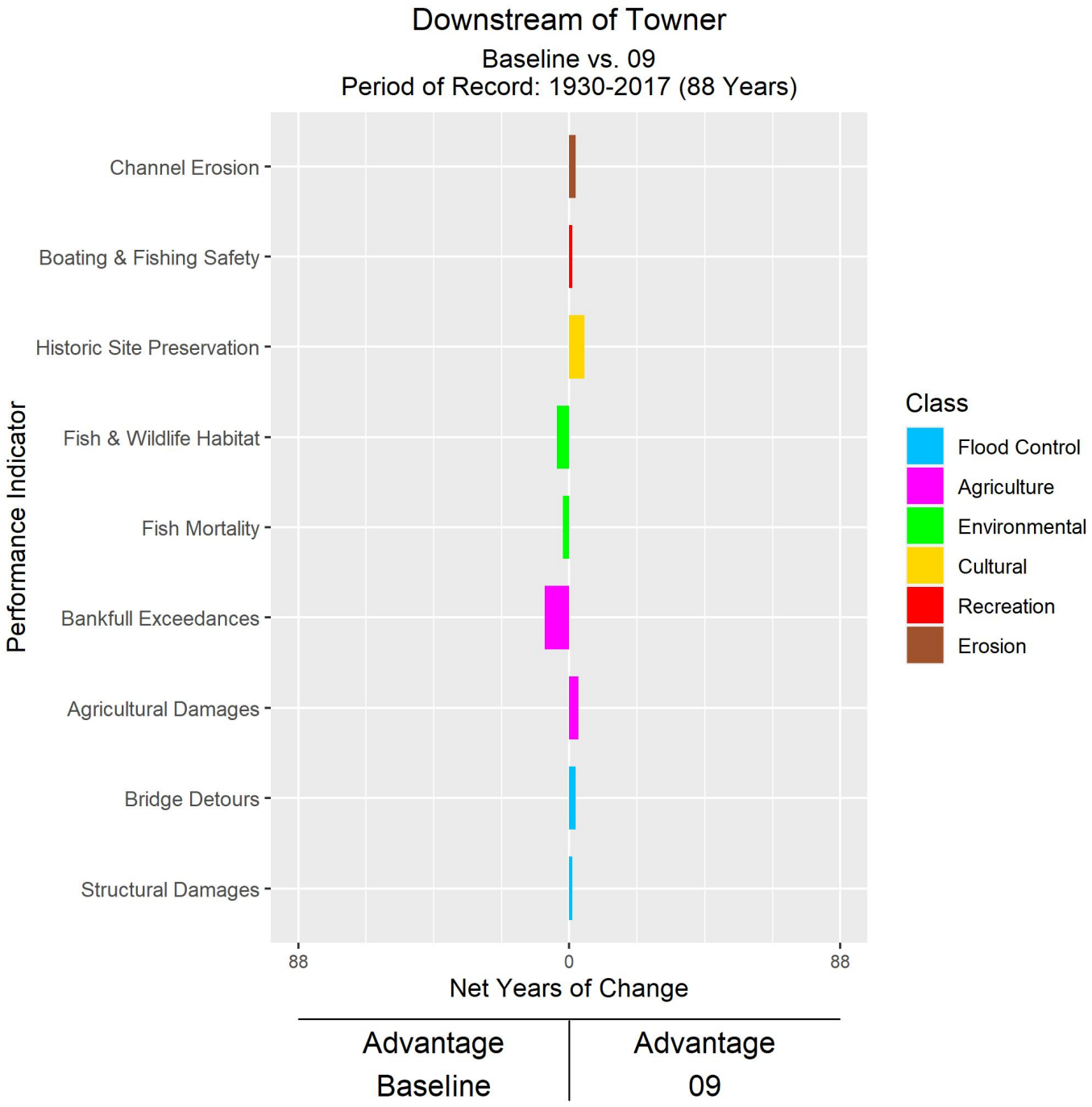

City of Sawyer
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Channel Erosion
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Bankfull Exceedances
Agricultural Damages
WW Lagoon Inundation
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Environmental
Cultural
Recreation
Erosion

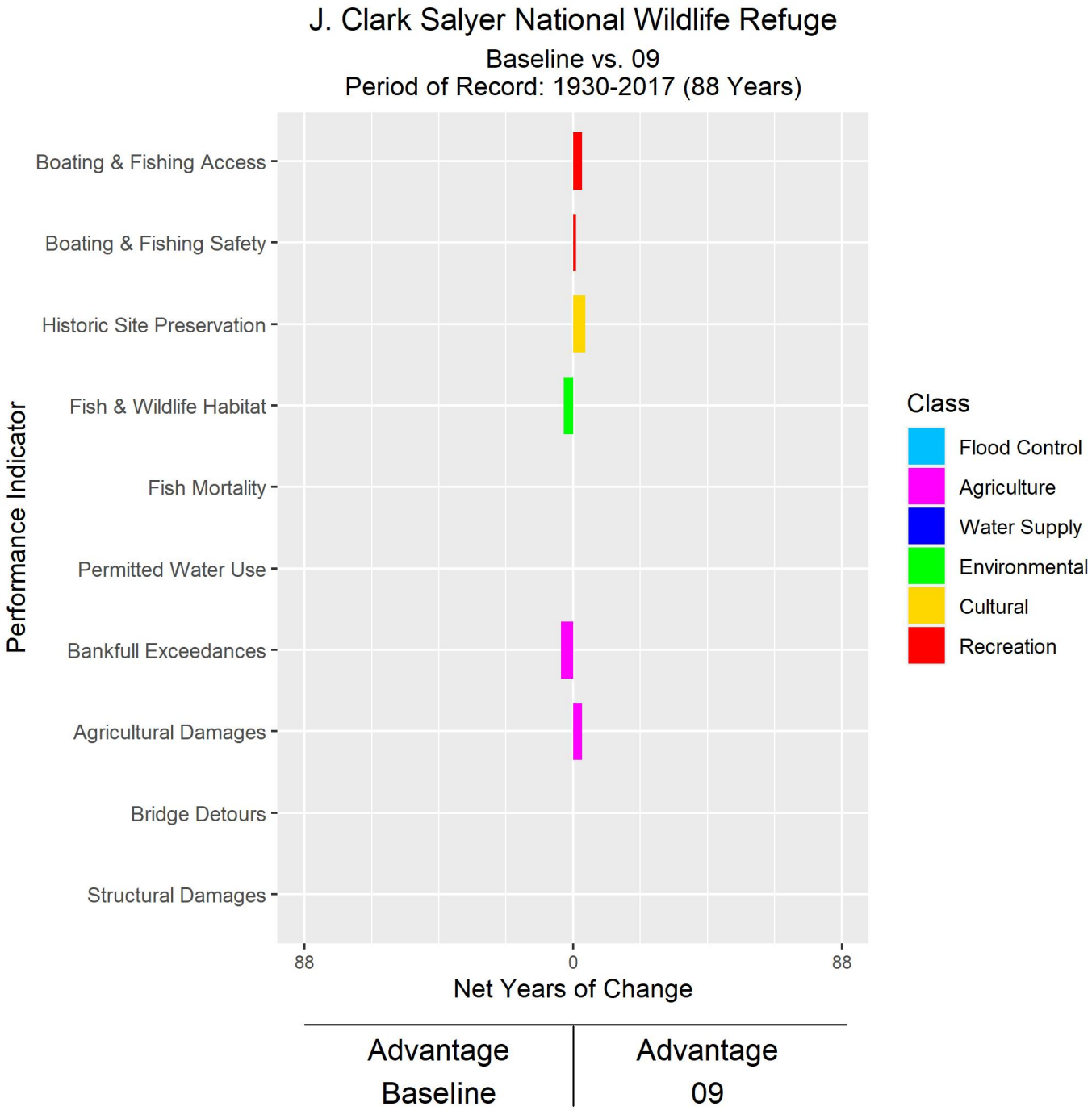

Sawyer to Velva
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Boating & Fishing Safety
Fish & Wildlife Habitat
Fish Mortality
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Environmental
Recreation


City of Velva
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
WW Lagoon Inundation
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage
Baseline
Advantage
09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation


Velva to Eaton Irrigation
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Channel Erosion
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Erosion


Eaton Irrigation District
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Channel Erosion
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
WW Lagoon Inundation
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation
Erosion


Downstream of Towner
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Channel Erosion
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Environmental
Cultural
Recreation
Erosion


J. Clark Salyer National Wildlife Refuge
Baseline vs. 09
Period of Record: 1930-2017 (88 Years)
Performance Indicator
Boating & Fishing Access
Boating & Fishing Safety
Historic Site Preservation
Fish & Wildlife Habitat
Fish Mortality
Permitted Water Use
Bankfull Exceedances
Agricultural Damages
Bridge Detours
Structural Damages
88
0
88
Net Years of Change
Advantage Baseline
Advantage 09
Class
Flood Control
Agriculture
Water Supply
Environmental
Cultural
Recreation