

Appendix B-2: Alternative 8b

Pre-Agreement

HEC-ResSim Initial Alternative Assessment

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1. Alternative Description & Objective

The Pre-Agreement alternative represents Souris River Basin conditions prior to the 1989 International Souris River Flood Control Agreement (Reference 1). The purpose of this alternative is to model basin conditions prior to the construction of Grant Devine and Rafferty Reservoirs. Prior to the implementation of the 1989 Agreement, Boundary and Lake Darling Reservoirs were operated primarily for water supply in accordance to the 1959 Interim Operating Measures agreement between the Governments of Canada and the United States. Results derived to reflect the suggested alternative were compared to baseline model results. Baseline model results reflect present day operations (Annex A & Annex B).

1.1 Alternative Development

The U.S Fish and Wildlife Service (USFWS), the U.S Army Corps of Engineers (USACE) and the Saskatchewan Water Security Agency (SWSA) were consulted to establish reservoir modeling assumptions for the pre-1989 Agreement condition. Rafferty Reservoir, the Rafferty-Boundary Diversion Channel and Grant Devine Reservoir were removed from the pre-agreement model. The SWSA recommended that Boundary Reservoir's specified water supply usages and physical capacity relationships (elevation-area-storage and elevation-outlet capacity) not be modified from how they are defined for present day baseline conditions. The USACE and USFWS recommended that the Lake Darling elevation-area-storage relationship not be modified from how it is defined for present day baseline conditions. Lake Darling's outlet works were updated post the 1989 agreement. Consequently, Lake Darling's elevation-outlet capacity relationships had to be modified to represent pre-1989 conditions.

Prior to the 1989 International Agreement, neither Boundary Reservoir nor Lake Darling Reservoir were drawn down to provide additional flood storage prior to spring snowmelt runoff. Consequently, both reservoirs were held (as much as possible) at their respective normal pool/full supply levels year-around. Prior to 1989, the reservoirs were not operated for flood control, so for the pre-agreement condition there were no maximum flow rules in the reservoir model. This assumption was verified with the USFWS, USACE and SWSA.

Water supply rules were applied to Boundary Reservoir in accordance to the 1959 Interim Measures Report (Reference 3). The 1959 agreement allows for the Province of Saskatchewan to divert, store and use waters which originate in Saskatchewan, as long as water usages do not diminish the annual flow of the river at Sherwood Crossing by more than fifty percent of that which would have occurred in the state of nature (minimum 50:50 apportionment). Additionally, the flow at Sherwood Crossing shall not be less than 4 cfs when that much flow would have occurred under conditions of water use development prevailing in the Saskatchewan portion of the Souris River basin prior to the construction of Boundary Dam. The 1959 agreement also specifies that the state of North Dakota provide water to Manitoba as far as practicable at a rate of 20 cfs.

Although some physical modifications were made to the J. Clark Salyer Refuge structures after the 1989 agreement, operation of the Des Lacs and J. Clark refuge structures have been relatively consistent since they were constructed. Because none of the Plan of Study Alternatives are targeted at making major modifications to the Des Lacs or J. Clark Refuge structures, it was assumed that the operation and physical constraints associated with the refuges are consistent between present day and pre-agreement conditions. Both the pre-agreement and present day versions of the J. Clark model include a minimum

release rate of 20 cfs for Manitoba. Dedicating resources to determining changes in operation and the physical capacities of the refuge structure throughout the period of record was beyond the scope of this assessment.

1.2 HEC-ResSim Nomenclature

Within the HEC-ResSim model, a new network, alternative and simulation run was generated to reflect each proposed alternative. More detail related to the HEC-ResSim model is included in the HH6 ResSim Report. To generate the alternative network, a copy of the base network was made and modified to reflect the proposed alternative. A table indicating the nomenclature associated with the ResSim networks, alternatives and simulations used to model both baseline and alternative operations for the various index events are listed in Table 1.

Table 1. Model nomenclature

| Scenario | Time Window | ResSim Model Name | Network Name | Alternative Name | Simulation Name |
|---------------|-------------|-------------------|--------------|------------------|-----------------|
| Baseline | 1930-2017 | SourisRiverPOS | Base | BL_Norm | 1930-2017_BL-1 |
| Pre-Agreement | 1930-2017 | SourisRiverPOS | 8b_PreAgr_BL | 8b_Pre_BL | 8b_PreAgr_BL |

2. Changes to Flood Control Zones & Physical Capacity Relationships in ResSim

In the baseline model, both Boundary and Lake Darling's conservation pool/guide curve elevations are defined based on a state variable script which requires drawdown prior to spring runoff. In the Pre-Agreement model, the conservation pool/guide curve elevation is constant and equivalent to a normal pool elevation of 1840 feet for Boundary Reservoir and 1597 feet for Lake Darling Reservoir. Because Boundary and Lake Darling were held to 1840 feet and 1597, respectively year-round prior to the 1989 Agreement, the initial conditions used for the Pre-Agreement model runs had to be modified slightly from the baseline, initial conditions (Table 2).

Table 2. Initial pool elevations 1930-2017 model run

| Initial Pool (1 Jan 1930 24:00) | Baseline Model: Post- 1989 Agreement | Pre-Agreement Alternative |
|---------------------------------|--------------------------------------|----------------------------|
| Lake Darling | 1595.74 feet/ 486.38 m | 1597.0 feet/486.77 meters |
| Boundary Dam | 1836.80 feet/ 590.34 meters | 1840.0 feet/ 560.83 meters |

Lake Darling's top of flood control elevation was different prior to the 1989 agreement. A comparison of the critical pool elevations adopted within the baseline model versus the Pre-Agreement model is displayed in Table 3. Although, the maximum top of dam elevation was increased to 1606.5 feet in the nineties, as-builts and LiDAR data indicate the minimum dam crest elevation is likely still around 1606.0 feet. The original dam was an earth-filled structure about 30-feet high, with the crest at elevation 1606.0 feet. It included a flat crested, 320-foot long uncontrolled principle spillway on the left abutment, a 250-foot long, grass lined emergency spillway on the right abutment and a two barrel gated low-level outlet works. The reservoir was regulated through operation of the two gated 10- by 12-foot

concrete conduits (bottom elevation at 1577.0 ft) which passed through the dam and discharged into a stilling basin (References 10 and 11). A comparison of original and post-1989 outlet works is included in Table 4 and Table 5.

Table 3. Pre-Agreement vs Baseline critical pool elevations for Lake Darling Reservoir

| | Baseline Model: Post- 1989 | Pre-Agreement Alternative |
|----------------------|---|----------------------------------|
| Top of Dam | 1606.0 feet (low point)/489.66 meter | 1606.0 feet/489.51 meter |
| Top of Flood Control | 1601.0 feet (spring)/1598.0 feet (summer/fall/winter) 487.98 meter/487.07 meter | 1598.0 feet/487.07 meter |
| Normal Summer Pool | 1597.0 feet/486.77 meters | 1597.0 feet/486.77 meters |

Table 4. Lake Darling present day/baseline model outlet works

| Component | Metric Units | English Units |
|--|--|--|
| <i>Principal Spillway- Gravity Ogee- Controlled</i> | | |
| Length | 76.5 meters | 251 feet |
| Number of Gated Spillway Bays | 5 | |
| Width of Spillway Bay | 13.11 meters | 43 feet |
| Size of Tainter Gates | 13.11 m wide, 5.85 m high | 43 ft wide, 19.2 ft high |
| Invert Elevation | 480.2 meters | 1575.5 feet |
| Spillway Crest Elevation | 482.8 meters | 1584 feet |
| <i>Low Flow Outlet: Three Sluice-gate controlled conduits</i> | | |
| Size | 0.91 meters wide, 1.22 meters high, 24.38 meters long | 3-feet wide, 4 feet high, 80 feet long |
| Invert Elevation | 480.67 meters | 1577 feet |

Table 5. Lake Darling Original/Pre-Agreement model outlet works

| Component | Metric Units | English Units |
|--|--------------------------|----------------------------|
| <i>Emergency Spillway- Uncontrolled</i> | | |
| Length | 76.20 meter | 250 feet |
| Spillway Crest Elevation | 488.29 meter | 1602 feet |
| <i>Principal Spillway- Uncontrolled</i> | | |
| Length | 97.54 meter | 320 feet |
| Spillway Crest Elevation | 487.07 meter | 1598 feet |
| <i>Low Flow Outlet: Two Slide-gate Controlled Concrete Box Culverts</i> | | |
| Size of Slide Gates/Barrel Opening | 3.05 m high, 3.66 m wide | 10-feet high, 12 feet wide |
| Number of Barrel Openings | 2 | |
| Invert Elevation | 480.67 meters | 1577 feet |
| Top Elevation | 483.72 meters | 1587 feet |

The emergency and principal spillways were modeled in HEC-ResSim using the weir equations as computed within the ResSim user interface. A weir coefficient of 2.6 was selected for the emergency spillway and a weir coefficient of 3.033 was adopted to model the principal spillway. There is no information available to define the weir coefficient for the emergency spillway. According to the HEC-ResSim User Manual, weir coefficients typically range between 2.6 and 4.0 depending on the shape of the spillway. A coefficient of 2.6 (minimum conveyance) was selected to be conservative and because the spillway is earthen/grass lined (decreased efficiency compared to a concrete spillway). According to the Lake Darling Design Memorandums (References 10 and 11), at an elevation of 1601 feet the capacity of the service spillway is 5,000 cfs. A weir coefficient of 3.033 results in a capacity of 5,043 cfs for the principal spillway at 1601 feet. The elevation-outlet capacity curve for the low level outlet was computed by assuming orifice flow. Equation 1 was used to generate the elevation-outflow relationship:

Equation 1 Orifice flow formula

$$Q = CA\sqrt{64.4H},$$

C = Flow Coef., A = flow Area, H = Head

According to the Lake Darling Design Memorandums (References 9 & 10), at an elevation of 1601 feet the capacity of the low level outlet is 5,000 cfs. At elevation 1596 feet the capacity of the low level outlet is 4,650 cfs. A coefficient of 0.554 results in a capacity of 5,226 cfs for the low level outlet at 1601 feet and 4,650 cfs at 1596 feet. The adopted Elevation-Capacity Curve is displayed in Table 6.

Table 6. Elevation-outlet capacity curve Pre-Agreement low level outlet – Lake Darling

| Low Level Outlet Capacity | | | | |
|---------------------------|-------------------------|---------|------------|------------|
| Pool Elevation (feet) | Pool Elevation (meters) | H(feet) | Flow (cfs) | Flow (cms) |
| 1577.00 | 480.67 | 0 | 0.00 | 0.00 |
| 1578.00 | 480.97 | 1 | 1,066.83 | 30.21 |
| 1579.00 | 481.28 | 2 | 1,508.72 | 42.72 |
| 1580.00 | 481.58 | 3 | 1,847.80 | 52.32 |
| 1581.00 | 481.89 | 4 | 2,133.65 | 60.42 |
| 1582.00 | 482.19 | 5 | 2,385.49 | 67.55 |
| 1583.00 | 482.50 | 6 | 2,613.18 | 74.00 |
| 1584.00 | 482.80 | 7 | 2,822.55 | 79.93 |
| 1585.00 | 483.11 | 8 | 3,017.44 | 85.44 |
| 1586.00 | 483.41 | 9 | 3,200.48 | 90.63 |
| 1587.00 | 483.72 | 10 | 3,373.60 | 95.53 |
| 1588.00 | 484.02 | 11 | 3,538.26 | 100.19 |
| 1589.00 | 484.33 | 12 | 3,695.59 | 104.65 |
| 1590.00 | 484.63 | 13 | 3,846.49 | 108.92 |
| 1591.00 | 484.94 | 14 | 3,991.70 | 113.03 |
| 1592.00 | 485.24 | 15 | 4,131.80 | 117.00 |
| 1593.00 | 485.55 | 16 | 4,267.30 | 120.84 |
| 1594.00 | 485.85 | 17 | 4,398.63 | 124.56 |
| 1595.00 | 486.16 | 18 | 4,526.16 | 128.17 |
| 1596.00 | 486.46 | 19 | 4,650.18 | 131.68 |
| 1597.00 | 486.77 | 20 | 4,770.99 | 135.10 |
| 1598.00 | 487.07 | 21 | 4,888.81 | 138.44 |
| 1599.00 | 487.38 | 22 | 5,003.86 | 141.69 |
| 1600.00 | 487.68 | 23 | 5,116.32 | 144.88 |
| 1601.00 | 487.98 | 24 | 5,226.36 | 147.99 |
| 1602.00 | 488.29 | 25 | 5,334.13 | 151.05 |
| 1603.00 | 488.59 | 26 | 5,439.76 | 154.04 |
| 1604.00 | 488.90 | 27 | 5,543.39 | 156.97 |
| 1605.00 | 489.20 | 28 | 5,645.11 | 159.85 |
| 1606.00 | 489.51 | 29 | 5,745.03 | 162.68 |

3. Operational Rules

Table 7 presents the operational rules that were included in the base HEC-ResSim model alternative to specifically reflect the changes required in support of the Pre-Agreement alternative.

Table 7. Operation rules added specific to alternative

| Name of Dam | Name of Rule, Outlet or IF Statement or State Variable Element | Rule Description |
|--------------------|---|--|
| Boundary Reservoir | 4cfsMin- downstream constraint for Sherwood (<i>computed by state variable app_Master_Min_release_BNDRY</i>) | Maintains a minimum flow of 4 cfs at Sherwood Crossing between 01 March and 15 November if 4 cfs would have occurred naturally |
| | ApportionmentMin (<i>computed by state variable app_Master_Min_release_BNDRY</i>) | Requires a minimum release from Boundary Reservoir to maintain a 50:50 apportionment split at Sherwood Crossing |
| | Sherwood Force-Force Compute Lake Darling Force Compute | These rules are included in the inactive zone. These rules force ResSim to compute flows all the way downstream to Lake Darling before making final reservoir release decisions. |

Rafferty and Grant Devine Reservoirs were removed from the model. All the baseline model rules were removed from Boundary Reservoir. The only two rules in the Boundary Reservoir model are described in Table 7. The 4 cfs minimum rule was inputted as a downstream control rule for Sherwood Crossing and ensures that the flow at Sherwood Crossing is not to be less than 4 cfs when that much flow would have occurred under natural flow conditions. The apportionment minimum release rule is targeted at maintaining fifty percent of the flow that would have occurred naturally at Sherwood. The only remaining rule in Lake Darling reservoir is a water supply rule targeted at maintaining water supply releases for the Eaton Irrigation Project and the downstream J. Clark Refuge Structures. Based on discussions with the USFWS and the USACE, all maximum flood control rules were removed from Lake Darling. Releases from Lake Darling are only restricted by its outlet works.

Rules were added to Boundary's inactive pool to force ResSim to preliminarily compute flows all the way to Lake Darling prior to making final, reservoir release decisions. This was accomplished by including dummy downstream control rules targeted at Sherwood and just upstream of Lake Darling, respectively, that in themselves don't effect reservoir operation, but define the computation order in ResSim. These "dummy rules" ensure that data is available to carry out the apportionment computations.

The physical outlet capacity of Lake Darling Dam was modified as described in Section 2. Figure 1 and Figure 2 display how the ResSim model user interface was modified for each reservoir. The relevant model feature is indicated by the red box.

Reservoir
Boundary Reservoir
Description

Physical
Operations
Observed Data

Operation Set
CurrentOps
Description
copy of "Large Flood Ops" with variable drawdown and sherwood max targets

Zone-Rules
Rel. Alloc.
Outages
Stor. Credit
Dec. Sched.
Projected Elev.

TopOfDam
4cfsMin
ApportionmentMin
Conservation
4cfsMin
ApportionmentMin
Inactive
Dummy
Sherwood-Force Compute
Lake Darling Force Compute

Storage Zone
Conservation
Description

Function of
Date

| Date | Top Elevation (ft) |
|-------|--------------------|
| 01Jan | 1840.0 |
| | |
| | |
| | |
| | |

Figure 1. Modifications to Boundary Reservoir model inputs for Pre-Agreement condition

The guide curve and maximum allowable downstream constraint state variable script “a_fld_MASTER_gc_gd” and its associated slave state variables were removed from the Pre-Agreement model. Because Rafferty Reservoir and Grant Devine Reservoir are no longer part of the Pre-Agreement network, the apportionment and minimum allowable downstream constraint state variable script “app_MASTER_min_release_GD” had to be removed and re-written to be specific to Boundary Reservoir. Because the apportionment relationship was not dependent on the June 1st Lake Darling pool elevation prior to 1989, the original script had to be revised to reflect a constant apportionment ratio of 0.5 (50%). To compute the natural flow record at Sherwood, the junction representative of flow upstream of the present day location of Rafferty Reservoir had to be specified to be reflective of input to the headwaters of the Souris River. Additionally, the state variable script had to be revised such that all apportionment and minimum releases are being made from Boundary Dam instead of Grant Devine and Rafferty Reservoir. Figure 3 provides screenshots of where the state variable script was modified to model the alternative. Relevant lines of the state variable script are indicated by the red boxes.

```

7
8 # The following represents an undefined value in a time series
9 # Constants.UNDEFINED
10
11 # add your code here...
12 #####helper function to be used in main code
13 import calendar
14
15 app_target=apportTarget = 0.50
16
17 ##toggle this from True to False to do an approximation of the apportionment or to complete the apportionment during every iteration
18 fullCompute = True
19
20
21
22
23
24
25
26
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33
34
35
36
37
38
39
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77
78
79
80
81
82
83
84
85
86
87
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90
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92
93
94
95
96 # yellow grass and tatagwa non-contrib estimation
97 # Linear relationship from rafferty inflow from 1996 through 2017 y = 0.365x R2 = 0.9348
98 volRafIn = network.findJunction("SourisHW").getLocalFlowTimeSeries("Inflow to Rafferty")
99 #print doy, volRafIn.getCurrentValue(currentRuntimeStep)
100 volAccRafIn = volRafIn.sum(currentStep, (-daysToAccumulate+1))
101 #print doy, volAccRafIn
102 nonContribConvMultiplier = 0.365
103 volAccNonContribVol = volAccRafIn*convertCfsToAcreFeet*nonContribConvMultiplier
104 #print doy, volAccNonContribVol
105 # natural flow at sherwood = unreg vol- non-contrib vol
106 volAccNat = volAccUnreg-volAccNonContribVol
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122 if flowSherwoodNat10DayAverage>4:
123     app_4CfsMinFlow = 1
124 else:
125     app_4CfsMinFlow = 0
126 #print doy, flowUnregSherTS.getCurrentValue(currentRuntimeStep)
127 #print doy, app_4CfsMinFlow
128
129 # assume no minimum release at the beginning of each time step
130 appMinRelBNDRY = 0
131 app_4cfs_MinBNDRY = 0
132
133 appMinRelBNDRY = appMinReleaseRate
134 app_4cfs_MinBNDRY = app_4CfsMinFlow
135 #print doy, app_4cfs_MinBNDRY
136
137 currentVariable.setValue(currentRuntimeStep, appMinRelBNDRY)
138 network.getStateVariable("app_4cfs_MinBNDRY").setValue(currentRuntimeStep, app_4cfs_MinBNDRY)
139

```

Figure 3. Key modifications to the apportionment state variable script for Boundary Reservoir

4. Alternative vs Baseline Scenario Results

Plates 1-22 show hydrographs detailing the results of Alternative 8b relative to the baseline scenario at Boundary 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 8b, all index years within the simulation time window are plotted.

Plate 23 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.

5. Summary of Results

5.1 High Flow Events

For the 1969, 1975 and 1976 high flow events, the addition of Rafferty and Grant Devine Reservoirs and the application of Annex A flood control operating guidelines results in lower pool elevations and lower releases during the duration of the flood events at Lake Darling. There are not significant differences in the releases made from Boundary Reservoir for pre-1989 versus baseline operating conditions.

During the 1976 and 2011 events Boundary Reservoir is drawn down, while under pre-agreement conditions the reservoir would have been maintained at its full supply level of 1840 feet. During the 2011 event, Lake Darling Reservoir is maintained at a lower pool elevation for baseline conditions relative to pre-agreement conditions. The first spring flood peak at Lake Darling is reduced significantly in the baseline simulation relative to pre-agreement conditions for the 2011 event. The second, June 2011 peak is also smaller at Lake Darling when modeled using baseline operations. However, the duration at which the Lake Darling pool and releases remain high is extended for baseline conditions versus the pre-agreement condition.

Peak flows and volumes occurring at critical Souris River mainstem flow locations during the modeled 1969, 1975 and 1976 events are significantly less for the baseline condition relative to the pre-agreement condition. During the June 2011 event there is a moderate reduction at Minot and a slight reduction in the peak at Sherwood for the baseline condition relative to the pre-agreement condition. The flows are not reduced significantly because the storage capacity of the reservoirs was fully utilized during the June 2011 event. The peak associated with the spring 2011 event is significantly reduced for baseline conditions relative to the pre-agreement condition. The duration and magnitude of high flows is increased for the baseline condition relative to the pre-agreement condition as the reservoirs release stored water over a longer period.

5.2 Normal Flow Conditions

During normal flow conditions (1946, 1952, and 1987) less flow reaches Sherwood and Minot during runoff events during baseline conditions, relative to when the pre-agreement conditions are modeled. This is because a significant volume of flow is being stored in the upstream reservoirs. Lake Darling's pool remains lower during baseline conditions and releases from Lake Darling are less substantial. There is not a significant difference in flow at Westhope, ND.

5.3 Drought Sequences

During 1988, 1991, and 1992, and throughout the 1930s, having Grant Devine, Rafferty and Lake Darling available to provide for water supply results in greater volumes of flow being available at Minot for baseline conditions. At Sherwood and upstream it appears that more flow would have reached Sherwood during pre-agreement conditions versus post-agreement conditions. Under pre-agreement conditions, Boundary's pool remains lower relative to baseline conditions, because Boundary Reservoir is not benefiting from pumped flows from Rafferty Reservoir. Lake Darling's pool is lower during

baseline conditions, because more water is being stored in the upstream reservoirs, thus less water is available to Lake Darling.

5.4 Performance Indicators

5.4.1 Reservoirs

In the Pre-Agreement scenario, Boundary Reservoir's ability to provide water supply to the Boundary Dam Power Station is negatively impacted, particularly during drought. At Lake Darling, the reservoir's higher pool during most years means historic sites, boat ramps and Mouse River Park are inundated more often. Higher pool elevations also improve water supply and fish and wildlife habitat.

5.4.2 Riverine Reaches

The Pre-Agreement flow regime is very similar to the Unregulated flow regime upstream of Lake Darling, since Boundary Reservoir's ability to store and attenuate floods is very small. This leads to more flood damages to structures, agriculture, and historic sites, as well as increased erosion upstream of Lake Darling. Below Lake Darling, there are increases to the number of very low flow days as well as the number of very high flow days, as shown in Figure 4. This change in the flow regime results in negative impacts to nearly all flood control performance indicators, more damages to agriculture, historic sites and recreational sites, and more erosion.

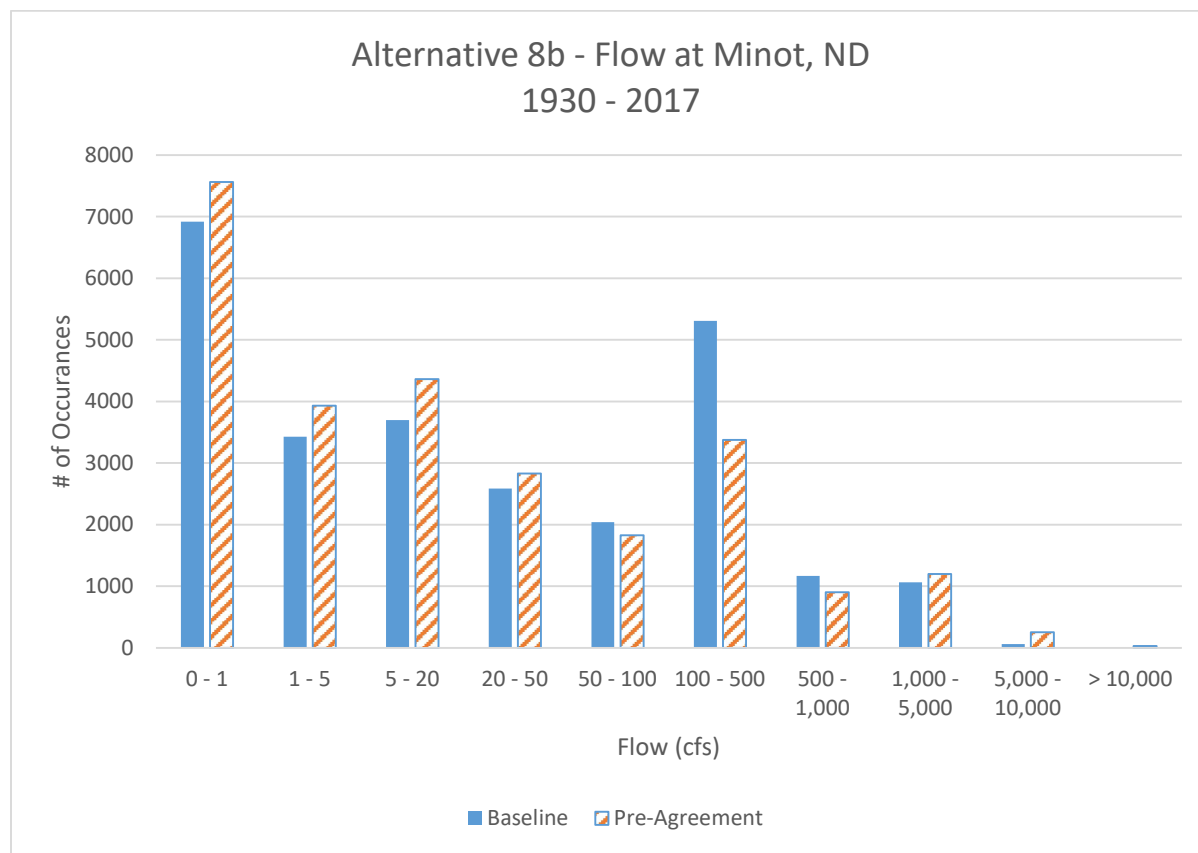


Figure 4. Flow distribution at Minot, ND

6. Recommendation

The Pre-Agreement alternative will be assessed as part of Phase 3 of the Plan of Study to determine whether the 1989 International Souris River Flood Control Agreement (Reference 1) effectively improves water management in the Souris River Basin. This alternative will enable the Plan of Study team to evaluate whether or not the objectives of the operating agreement are fulfilled by the operating guidelines outlined in Annex A.

7. Model Limitations

Although HEC-ResSim is able to route negative inflows through a reservoir component, the model assumes that negative flows are equivalent to zero when routing flows through non-null routing reaches. The inflows to Rafferty and Grant Devine Reservoir were computed using reverse routing and consequently include a considerable number of negative values. The local flow hydrographs were computed using the holdout (difference) method and also include a considerable number of negative values. By assuming negative routed flows to be equivalent to zero, the model no longer maintains the mass balance principals used to derive reservoir inflows and local flows. Consequently, this results in a slight overestimation of volume. More detail related to the impact of how negative inflows are accounted for is included in the HH6 ResSim model report. Additionally, the precipitation on the present day reservoir pools for Rafferty and Grant Devine is not fully captured within the model inputs.

The effects of any differences between Pre-Agreement and baseline conditions for the Des Lacs Wildlife Refuge Structures and the J. Clark Salyer Refuge Structures have not been taken into consideration. Accounting for differences in operation that occurred between their construction and present day is outside the scope of this assessment. Additionally, analysis to evaluate what impact not accounting for these differences has on Pre-Agreement results is beyond the scope of this analysis. The USFWS and the USACE were consulted, and both parties agree that changes to the refuge structures would not have an operationally significant impact on the results for this application.

Natural flow used to define apportionment and 4 cfs minimum flow releases was approximated by subtracting an estimation of the flows contributing to the Souris River from the Yellow Grass Ditch and the Tatagwea Lake Drain from the computed, unregulated flow record at Sherwood. If these drains were not in place, the flows captured by the Yellow Grass Ditch and Tatagwea Lake Drain gages would not contribute to the Souris River. Without the man-made drains, the drainage areas captured by these two gage site would only start contributing to the Souris River during extreme events like 2011 and not during typical flow conditions. Thus, these flows were excluded from the natural flow record used to compute the apportionment. These ditches were constructed starting in the early 1900s and have been expanded upon and renovated throughout the 1960s and 70s (Reference 9). The current model computations assume that the same degree of drainage has occurred since the 1930s. A variable approach to defining natural flows depending on changes/improvements to the drainage network throughout the first half of the 20th century is not being applied.

The elevation-outlet capacity curves developed to be representative of pre-agreement conditions at Lake Darling have only been coarsely approximated. They are based on simplifying assumptions and only facilitate a comparative, hypothetical assessment.

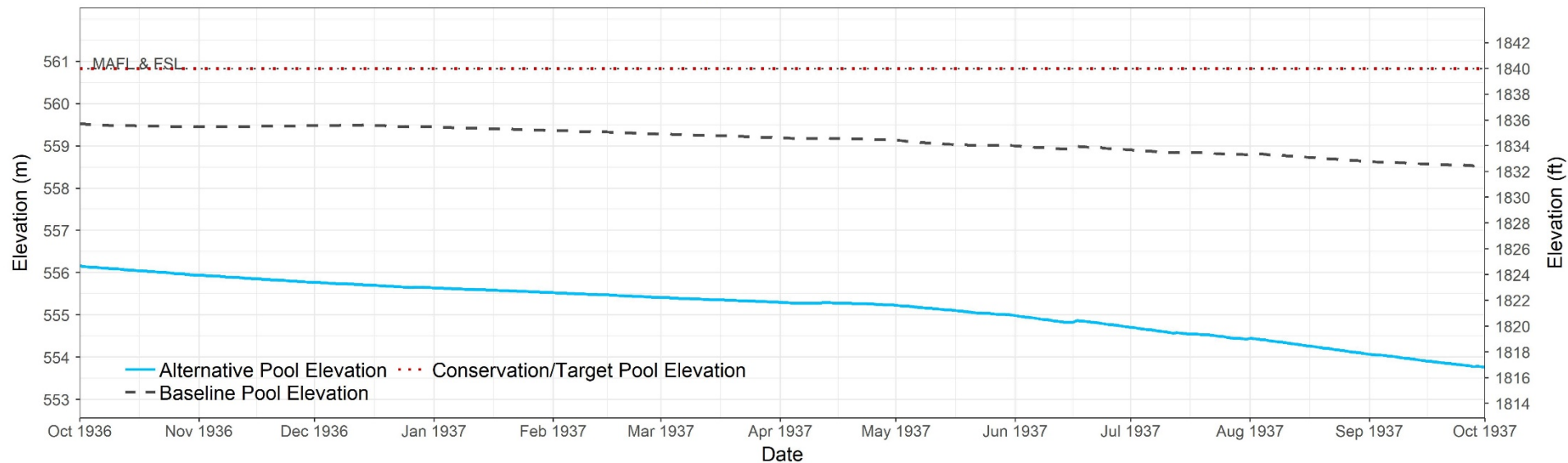
The method used to compute inflow records to some of the reservoirs changed in the mid-1990s (see HH1 Regional & Reconstructed Hydrology Report for more detail). The inflow records and corresponding

pool elevations for Lake Darling appear to show this effect, with a marked decrease in variability in the pool elevation after approximately 1992.

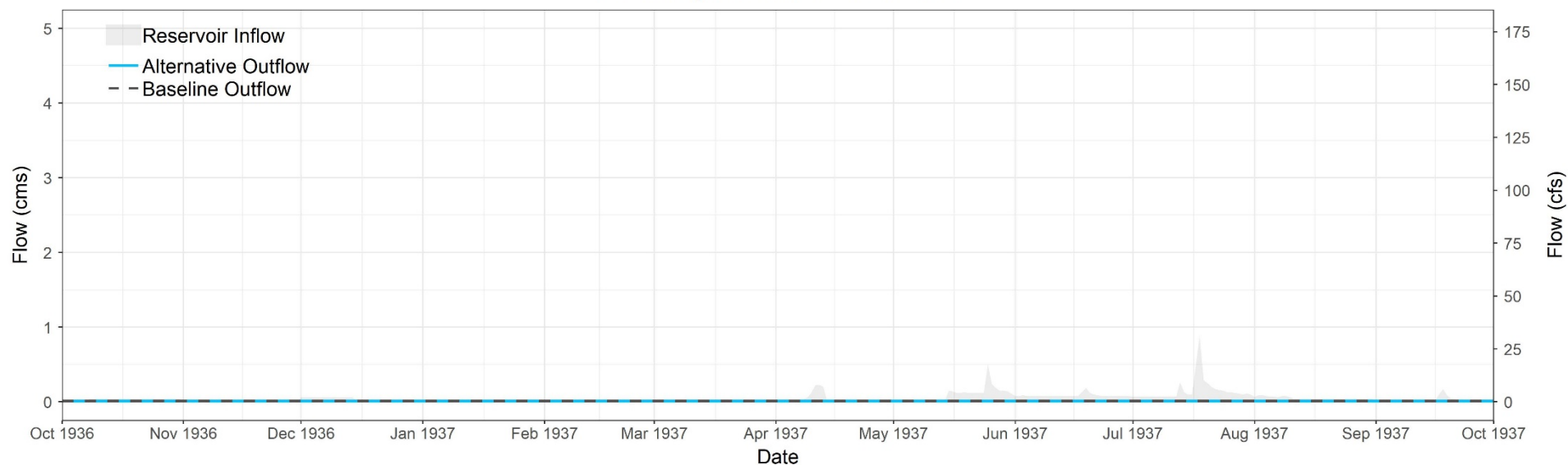
8. References

1. 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.
2. Canada and USA, 2000. Interim Measures As Modified For Apportionment of the Souris River.
3. Canada and USA, 1959. 1959 Interim Measures. *IJC Docket#41 IJC Report to Governments on the Souris River*, March 19, 1959.
4. Caruso, Brian. 2019. Personal conversation. USFWS Employee.
5. Durbian, Frank. 2019. Personal conversation. USFWS Employee.
6. “HEC-DSSVue,” U.S Army Corps of Engineers, Hydraulic Engineering Center, February 2010. “HEC-ResSim, Reservoir System Simulation, Version 3.3”, U.S Army Corps of Engineers, Hydraulic Engineering Center, December 2018.
7. Hallborg, C. 2019. Personal conversation. Saskatchewan Water Security employee.
8. Nelsen, L. 2019. Personal conversation. USACE Employee.
9. Souris River Basin Study Board. 1978. *Souris River Basin Study Report*. Chapter 4 Existing Water Problems and Concerns, June 1978.
10. U.S Army Corps of Engineers, 1983. Design Memorandum No. 3 General –Project Design: Lake Darling Flood Control Project Souris River, North Dakota, June 1953.
11. U.S Army Corps of Engineers, 1992. Design Memorandum No. 15 and Environmental Assessment Lake Darling Dam, May 1953.
12. USACE, 2012. Lake Darling Water Control Manual. Lake Darling Dam and Reservoir Souris River Basin Flood Control. Prepared by USACE St. Paul District. November 2012.

Boundary Reservoir - Elevation

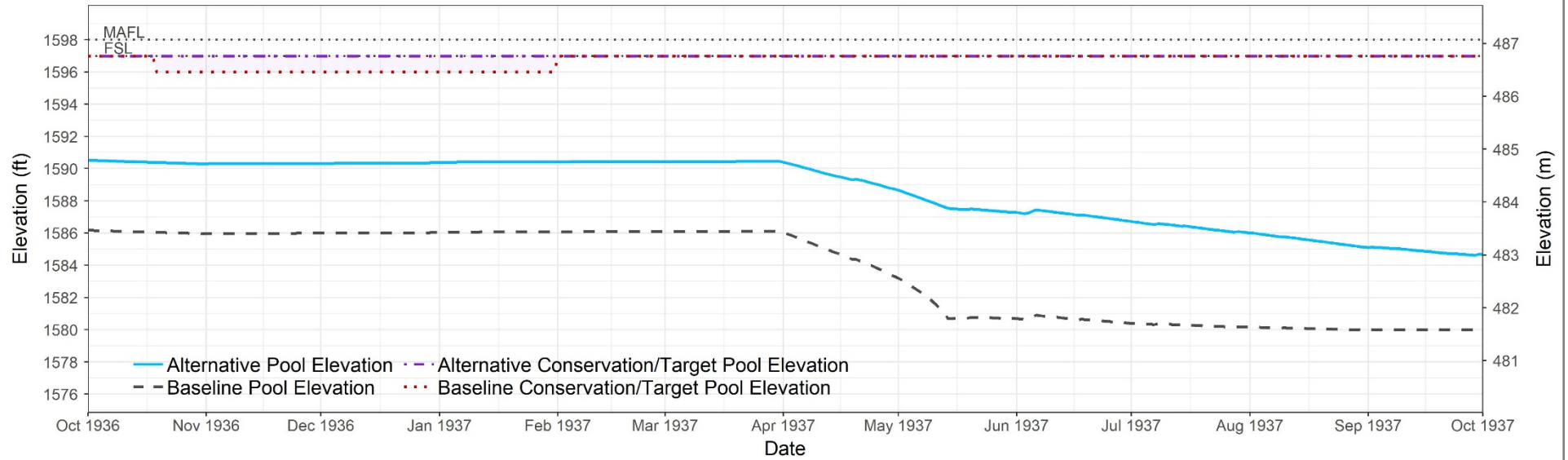


Boundary Reservoir - Releases

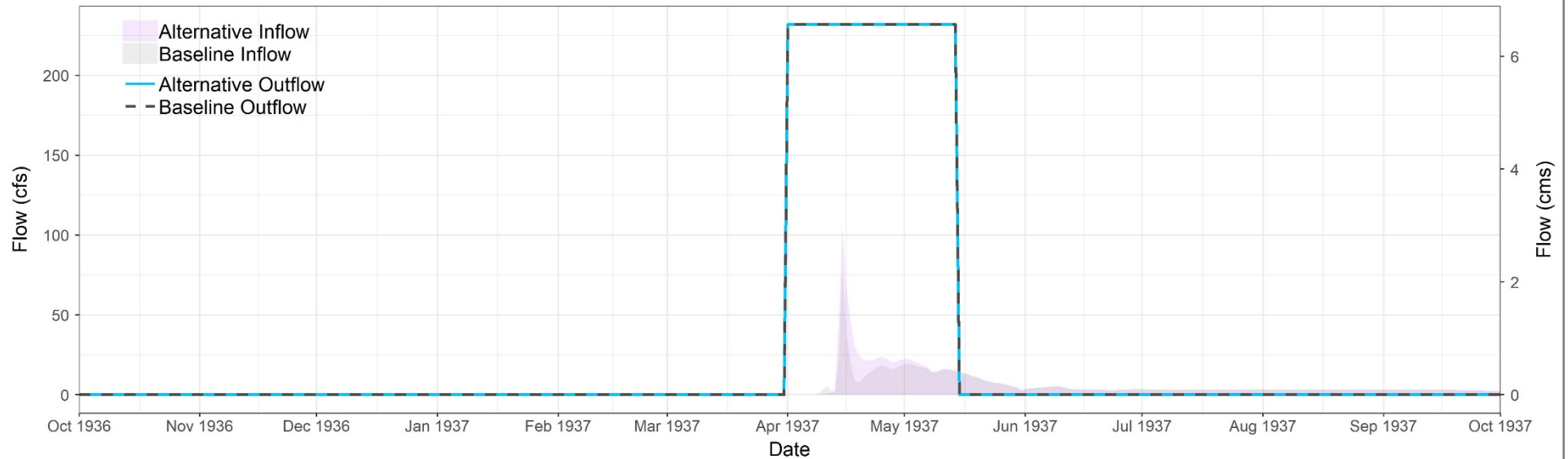


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



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

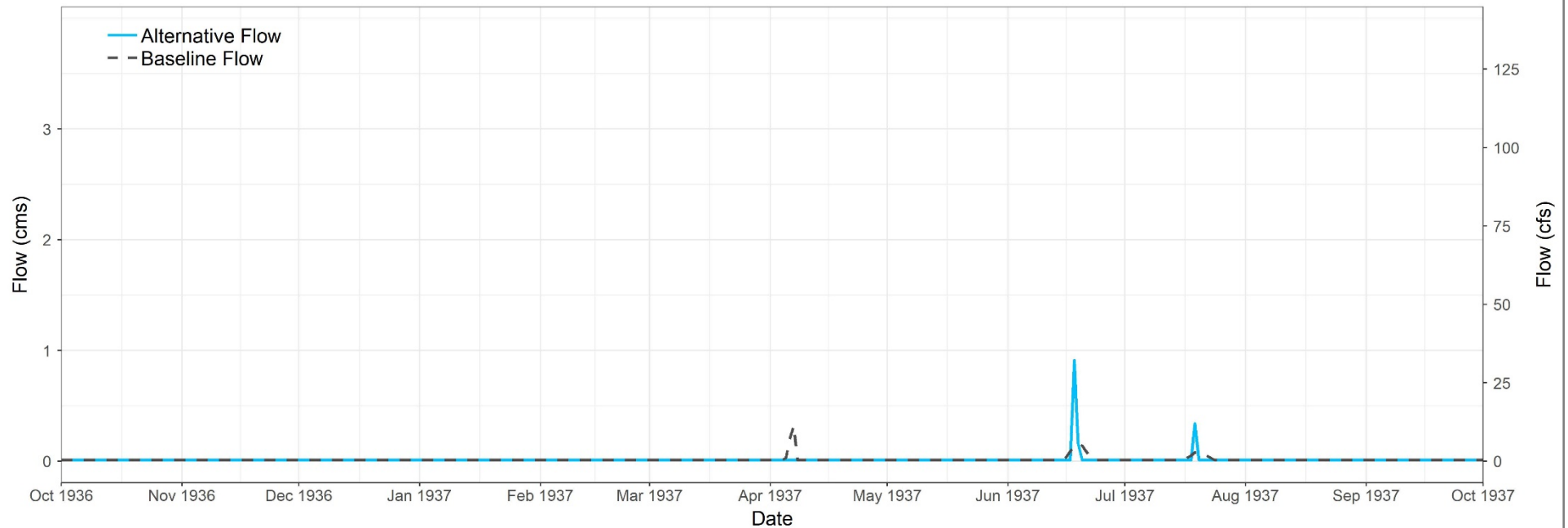
Plate 02

Critical Flow Locations – 1937

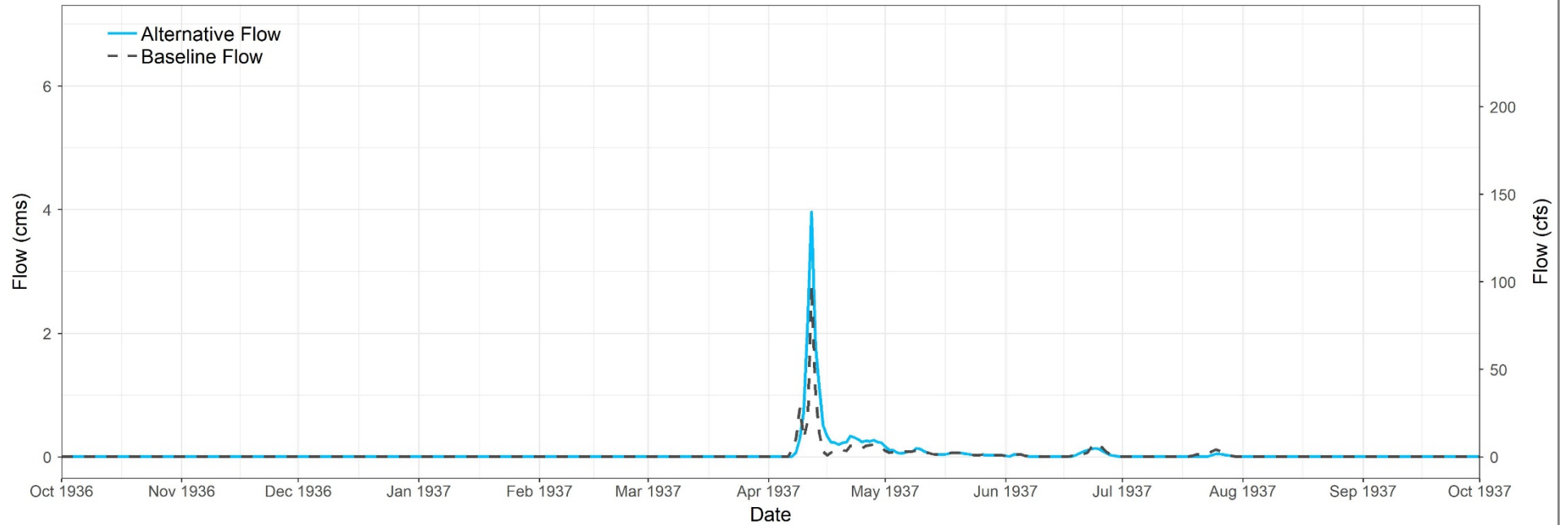
Alternative 8b (Phase 2)

Souris River Plan of Study

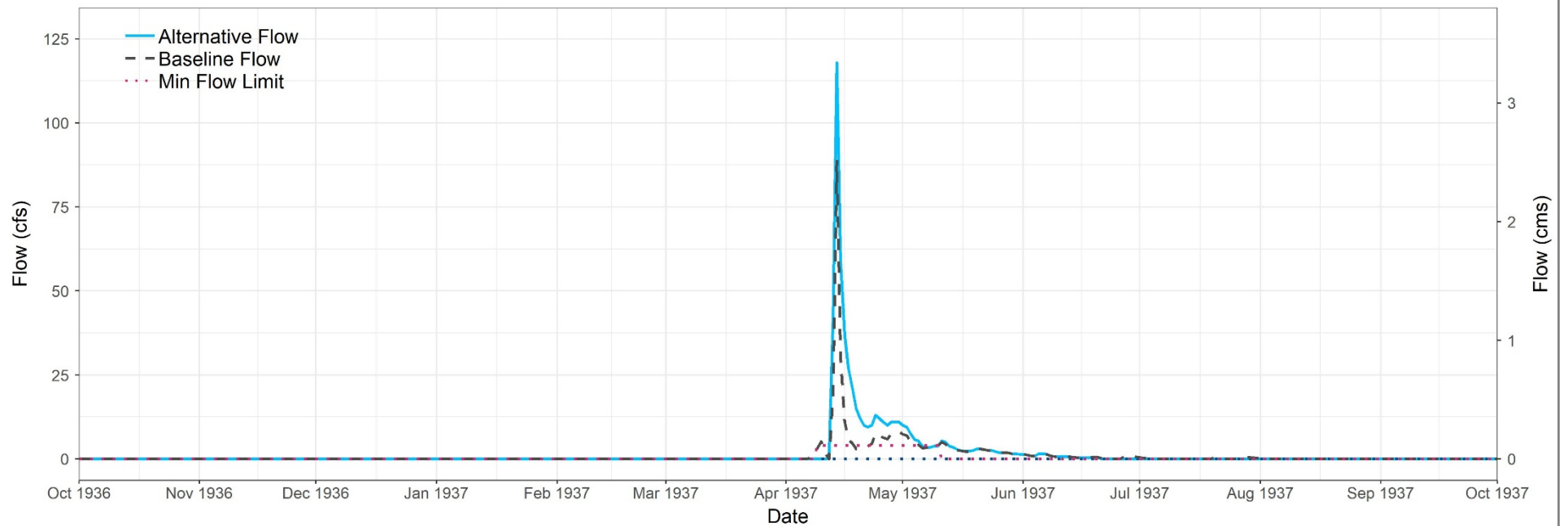
Souris River at Estevan, SK



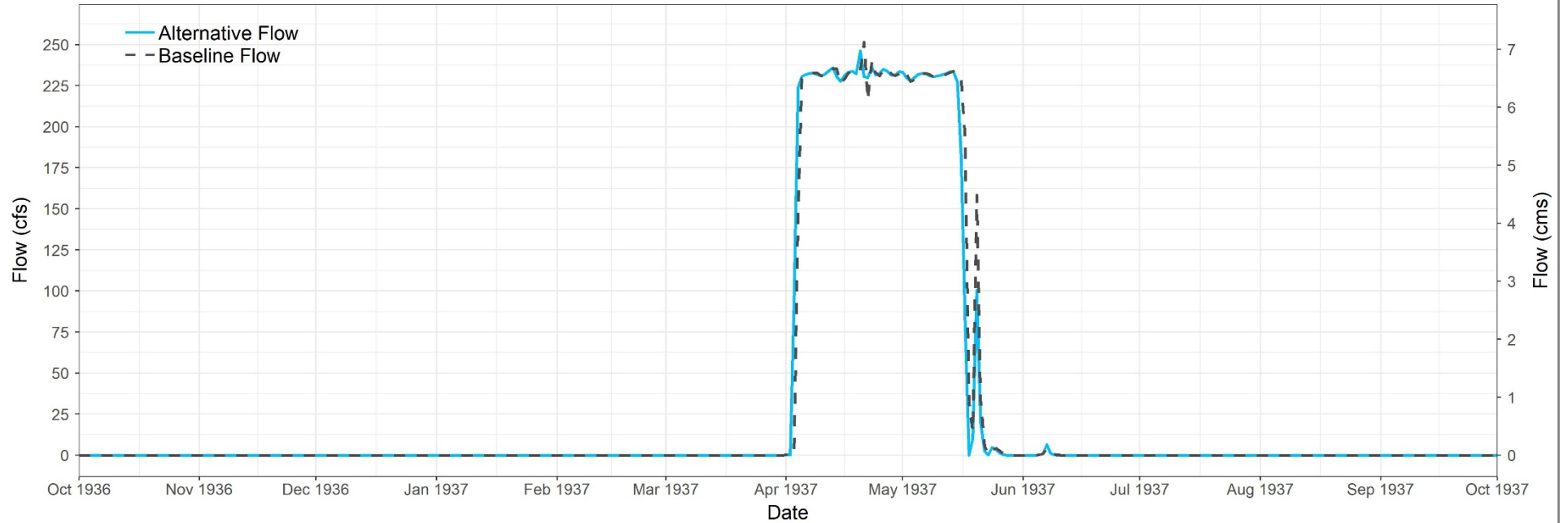
Souris River at Oxbow, SK



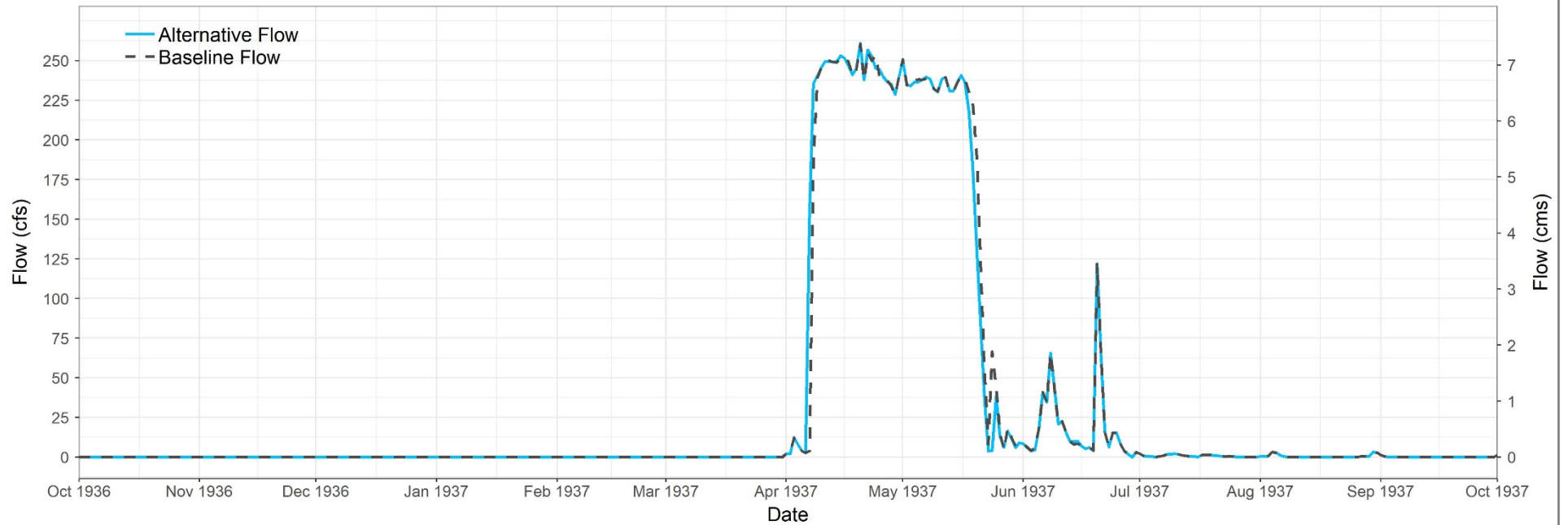
Souris River at Sherwood, ND



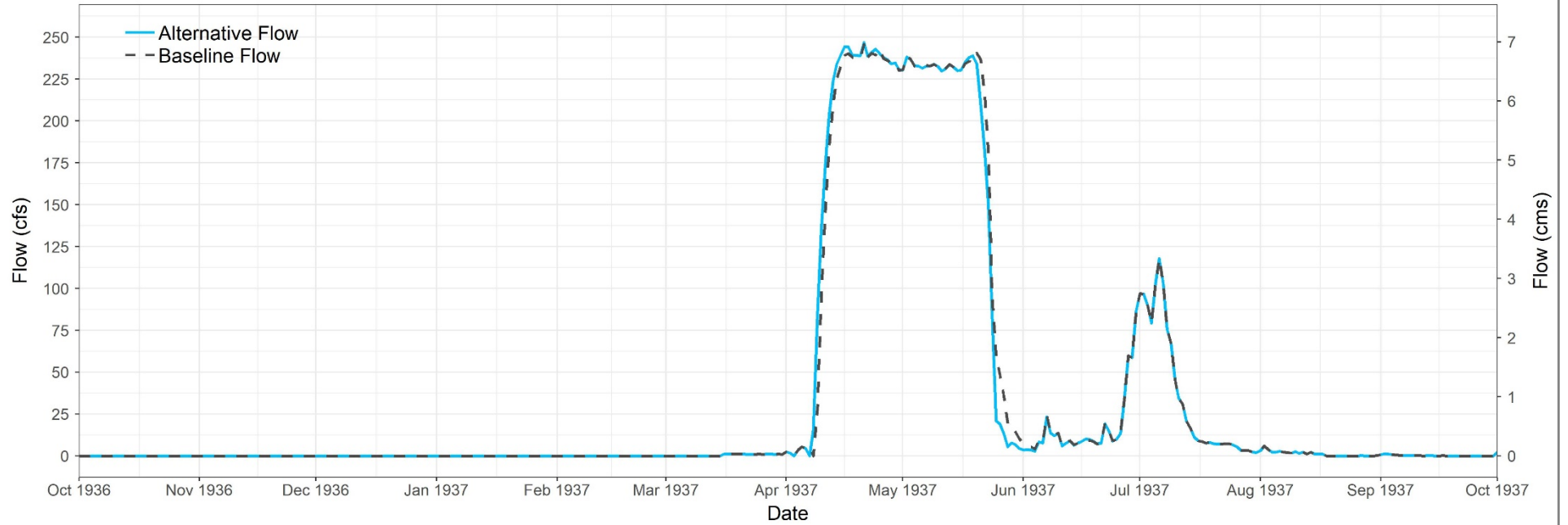
Souris River at Minot, ND - Flow



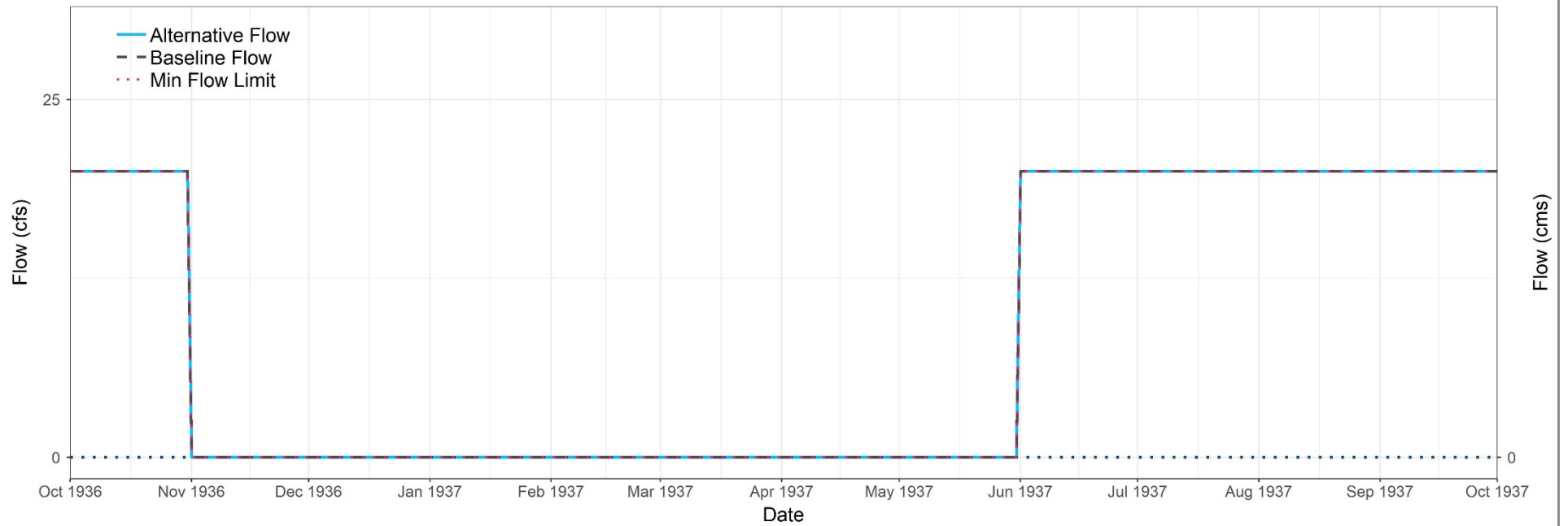
Souris River at Verendrye, ND



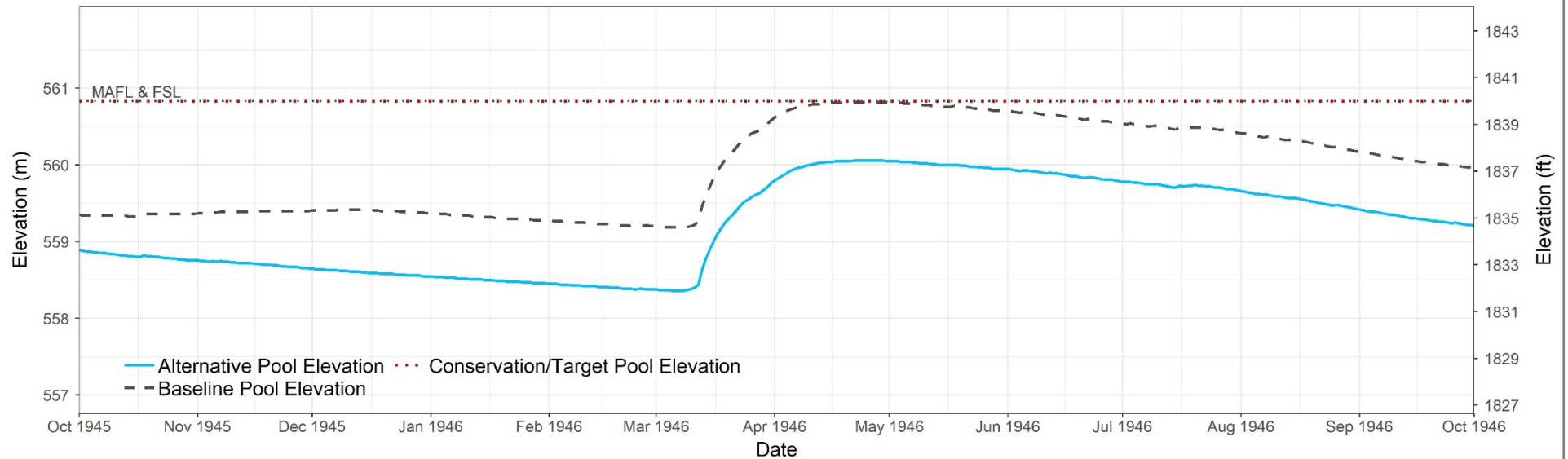
Souris River at Bantry, ND



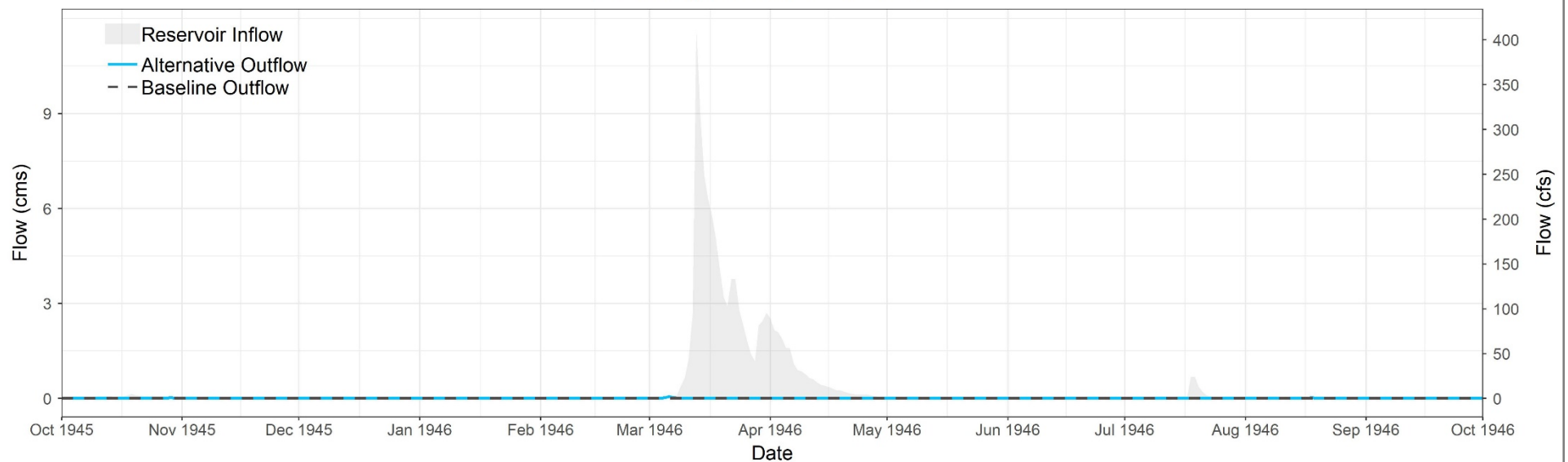
Souris River at Westhope, ND



Boundary Reservoir - Elevation

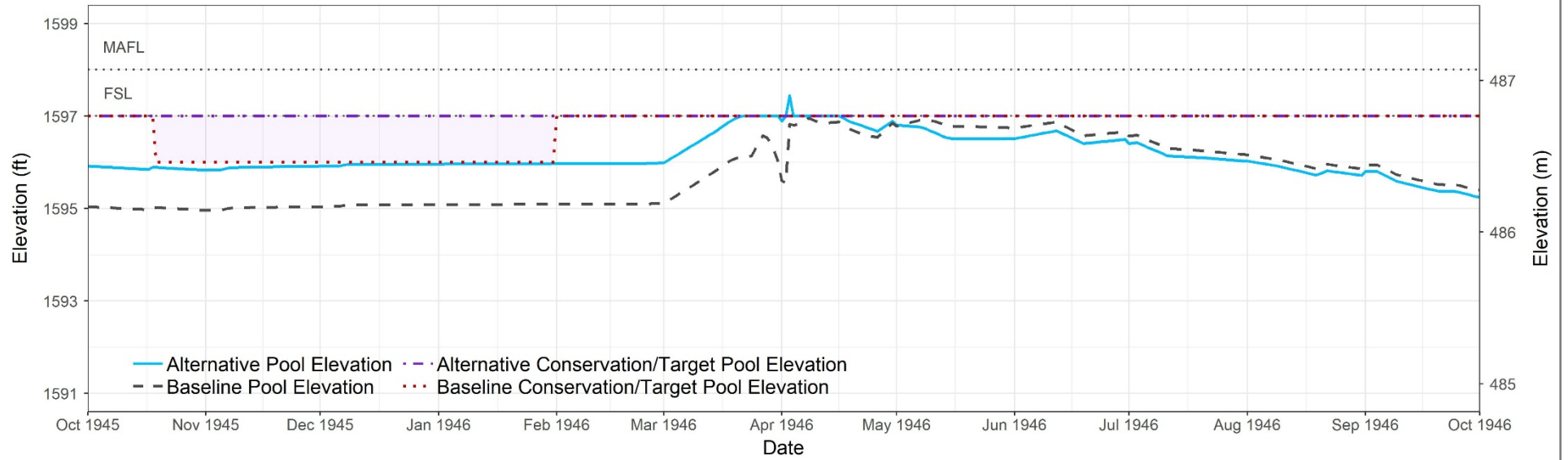


Boundary Reservoir - Releases

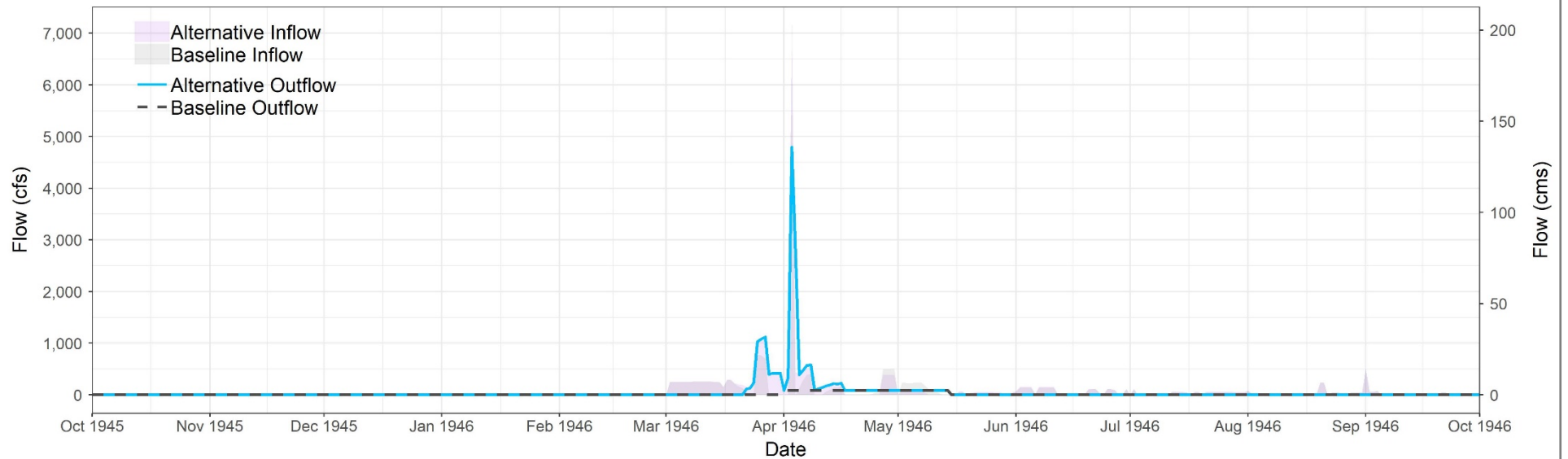


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



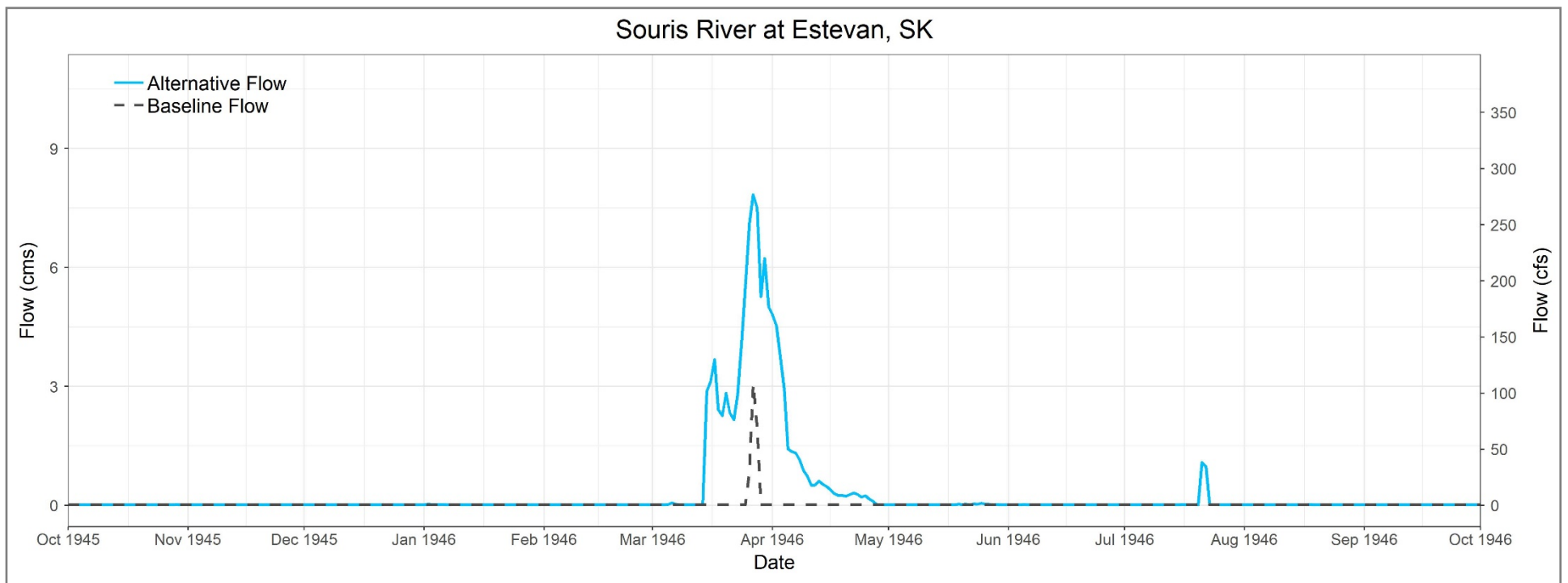
*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Plate 04

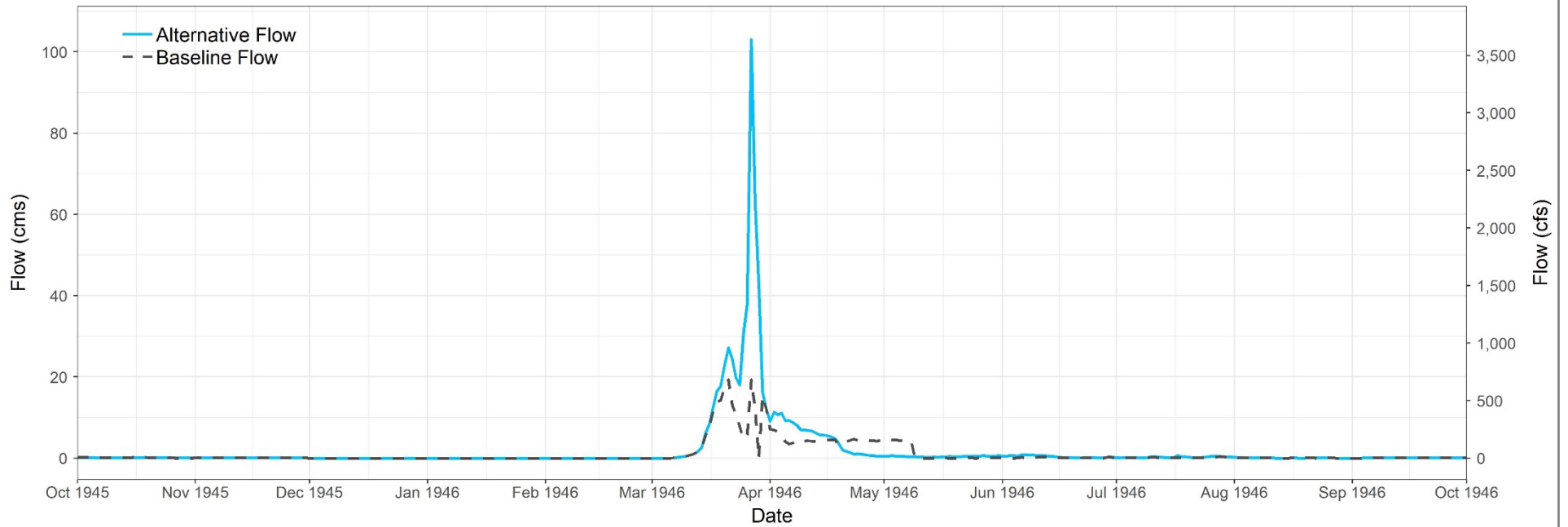
Critical Flow Locations – 1946

Alternative 8b (Phase 2)

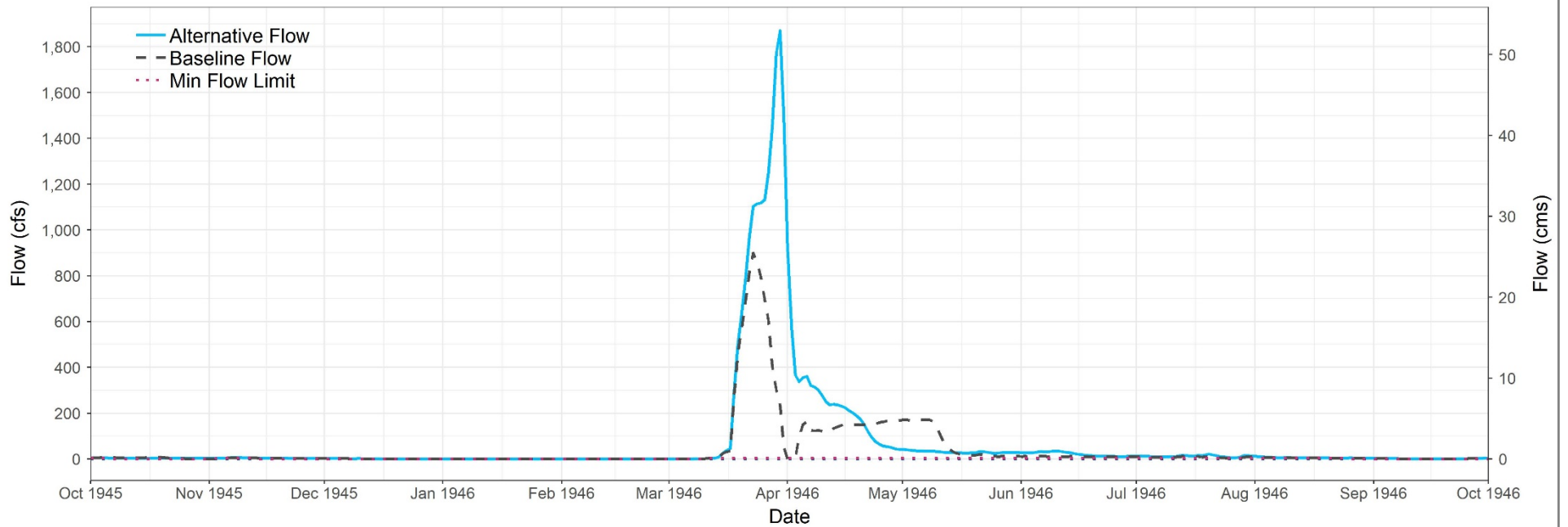
Souris River Plan of Study



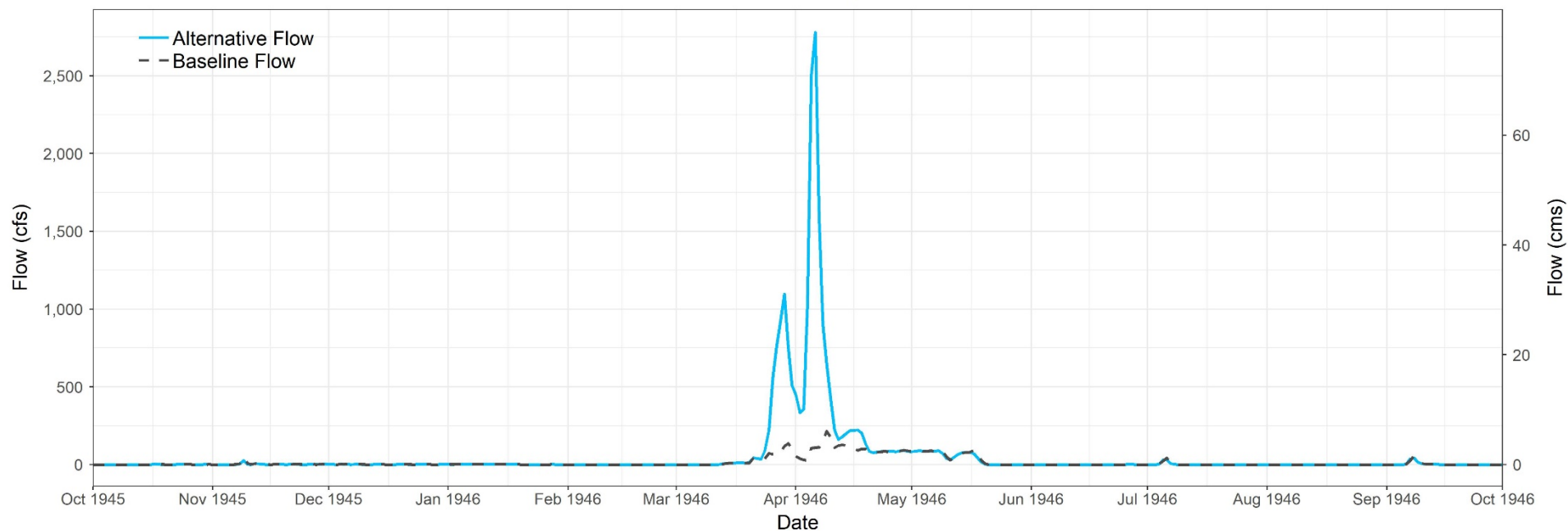
Souris River at Oxbow, SK



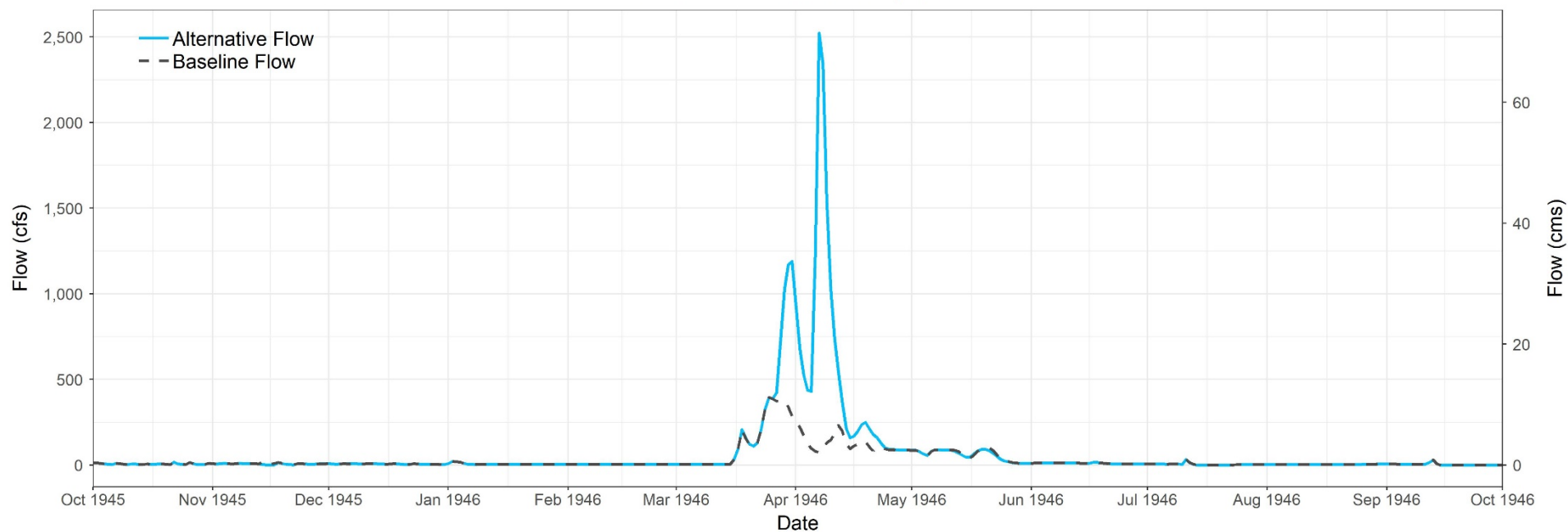
Souris River at Sherwood, ND



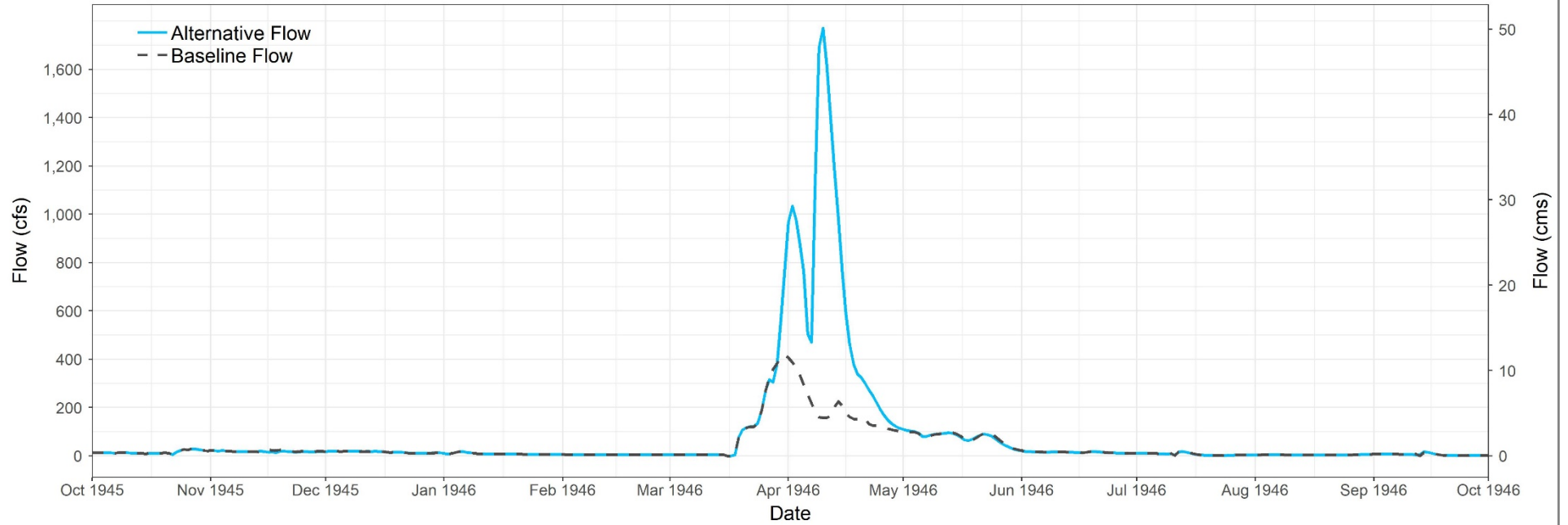
Souris River at Minot, ND - Flow



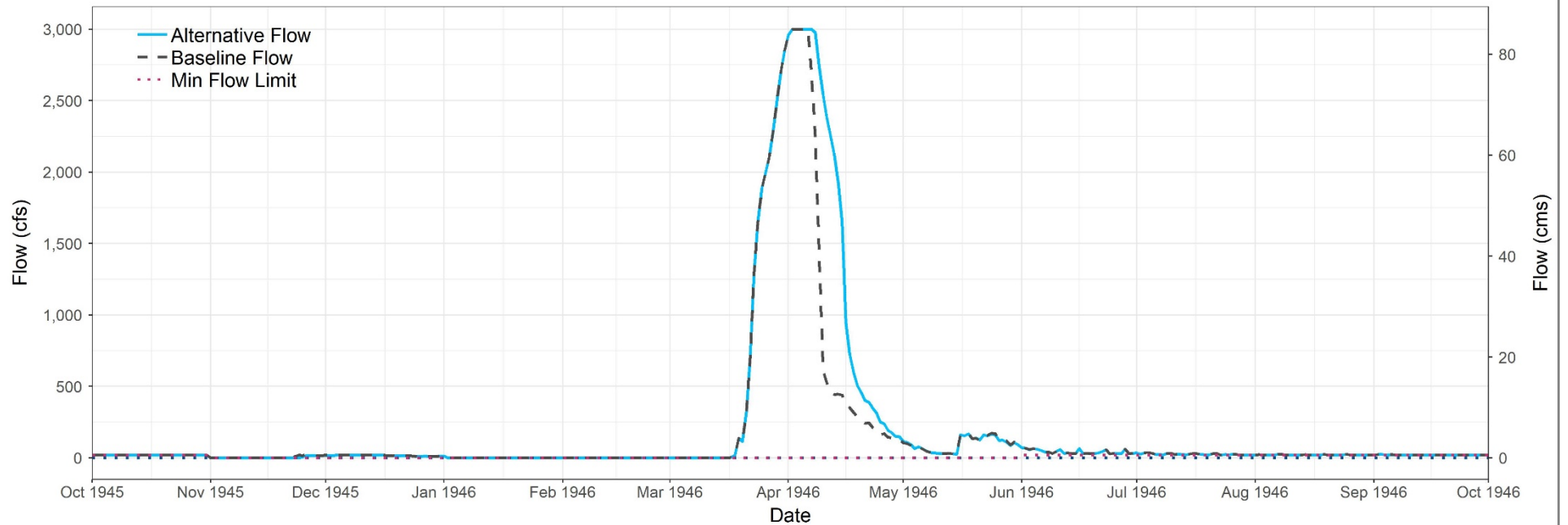
Souris River at Verendrye, ND



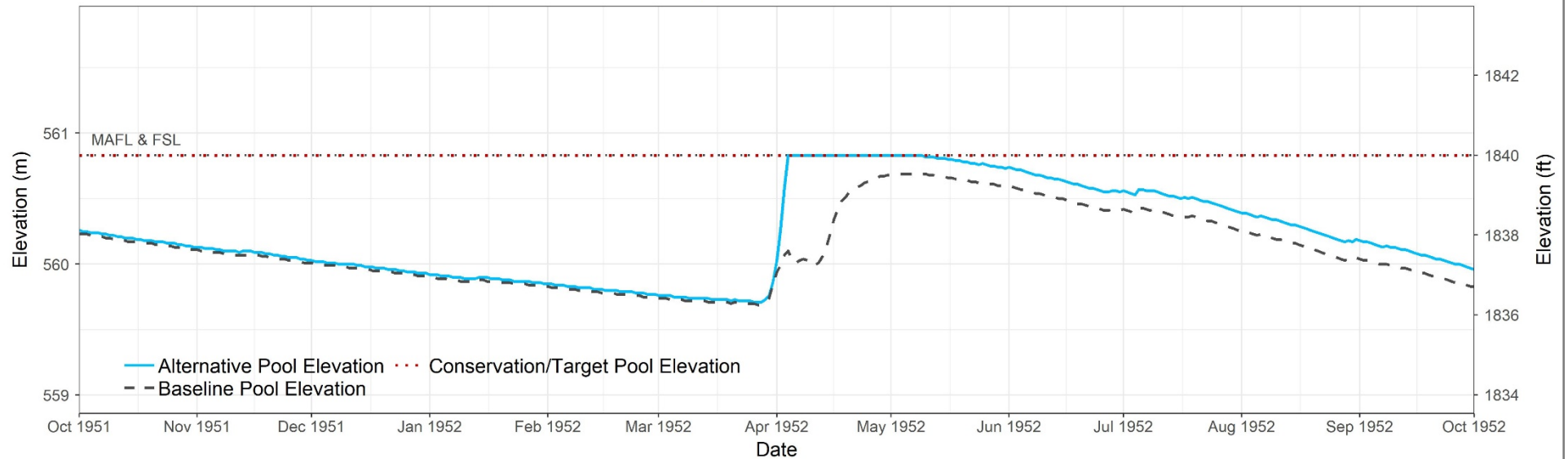
Souris River at Bantry, ND



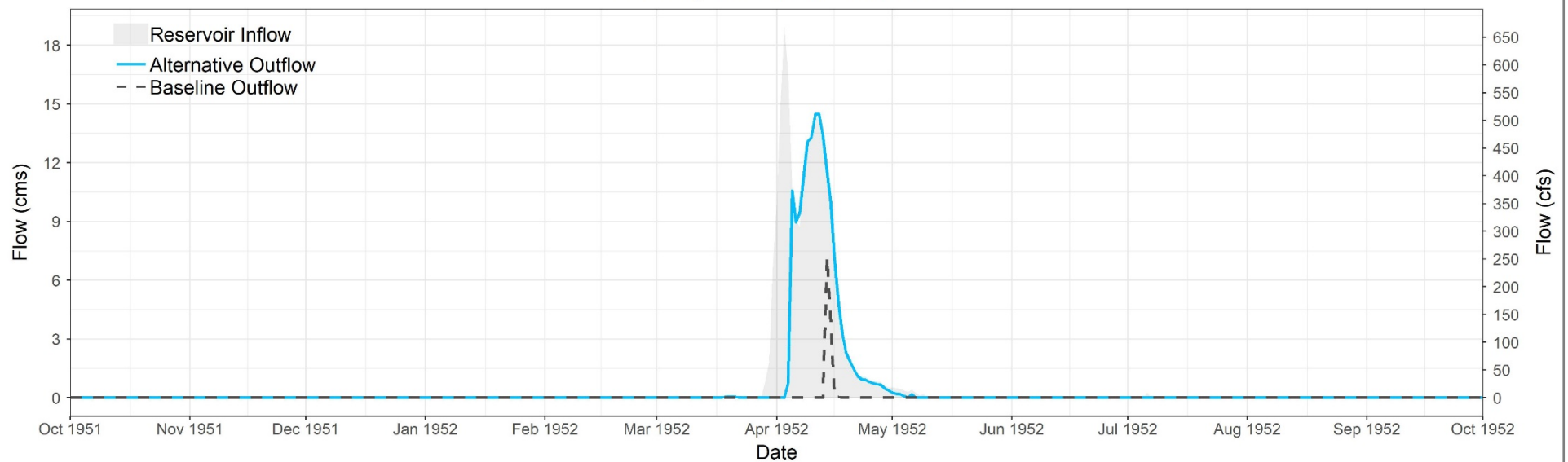
Souris River at Westhope, ND



Boundary Reservoir - Elevation

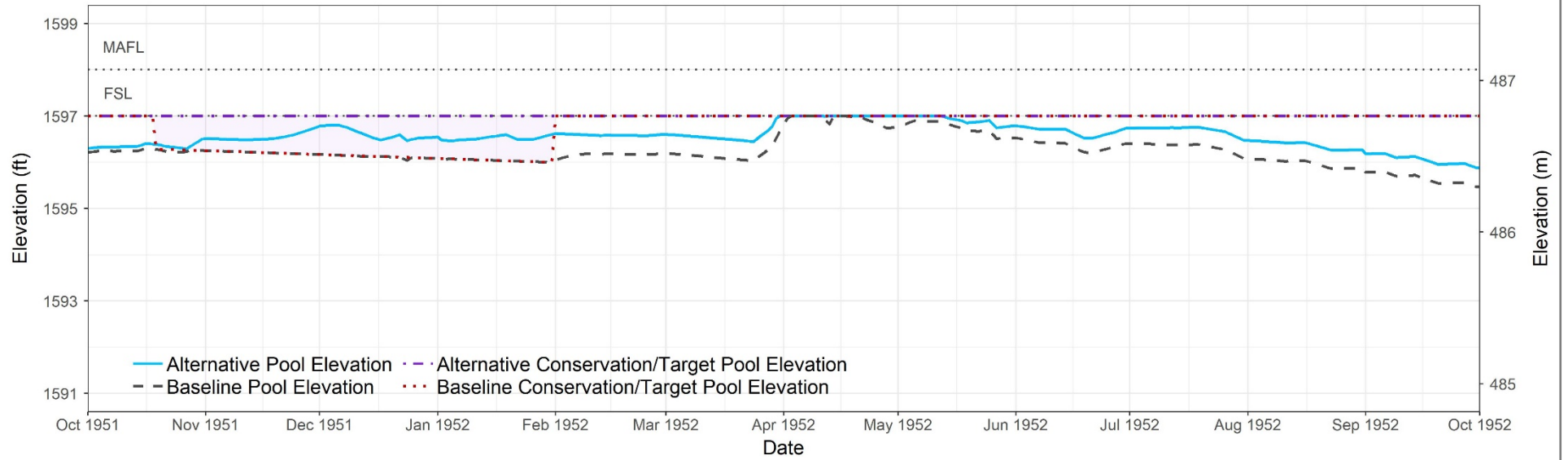


Boundary Reservoir - Releases

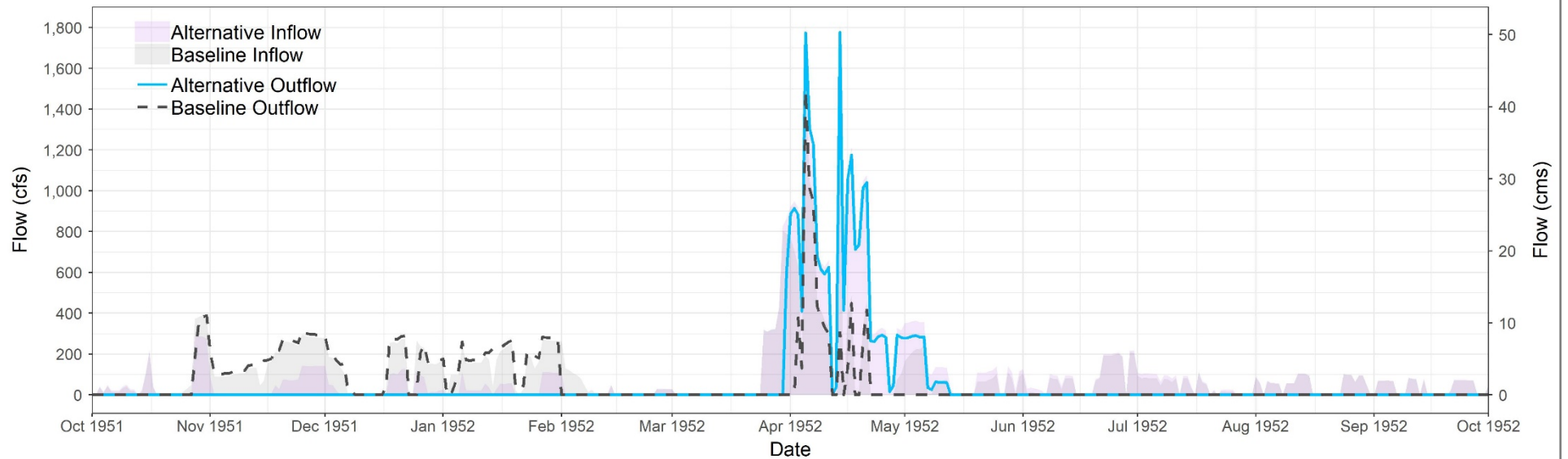


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



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

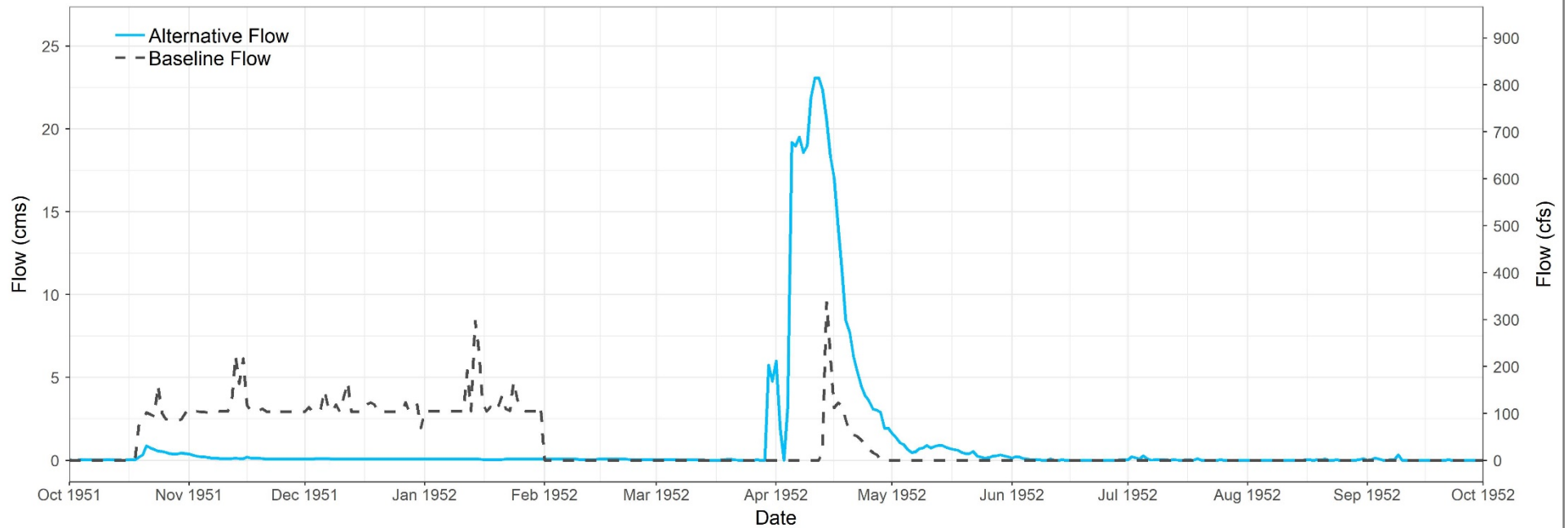
Plate 06

Critical Flow Locations – 1952

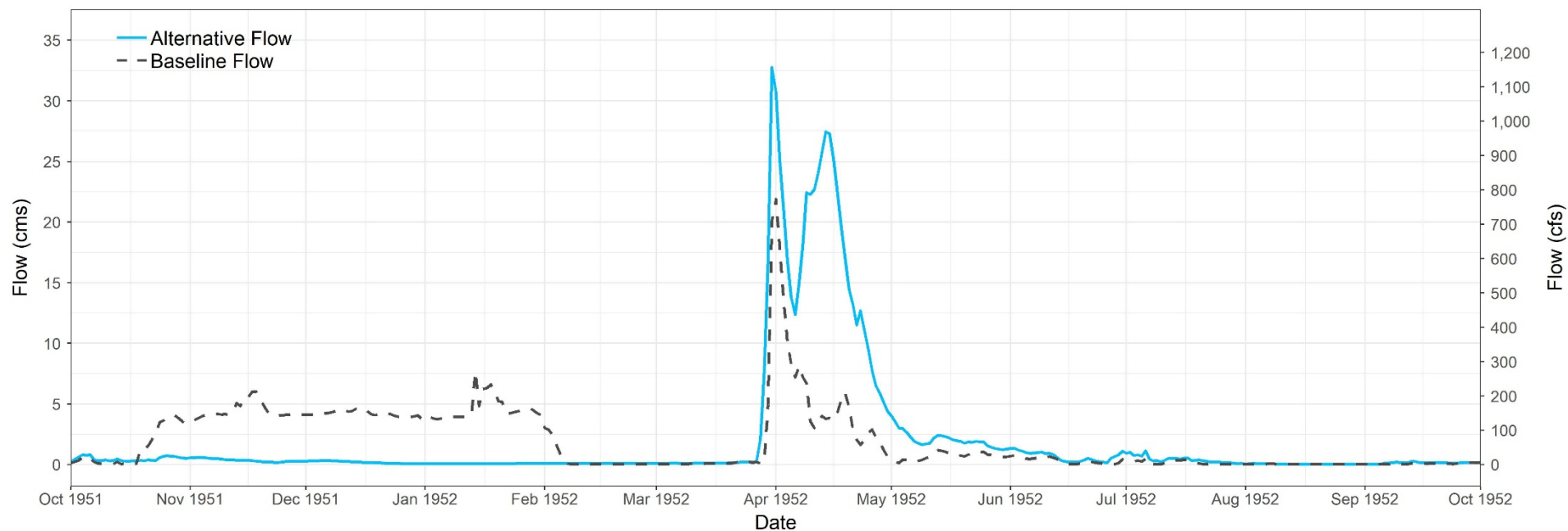
Alternative 8b (Phase 2)

Souris River Plan of Study

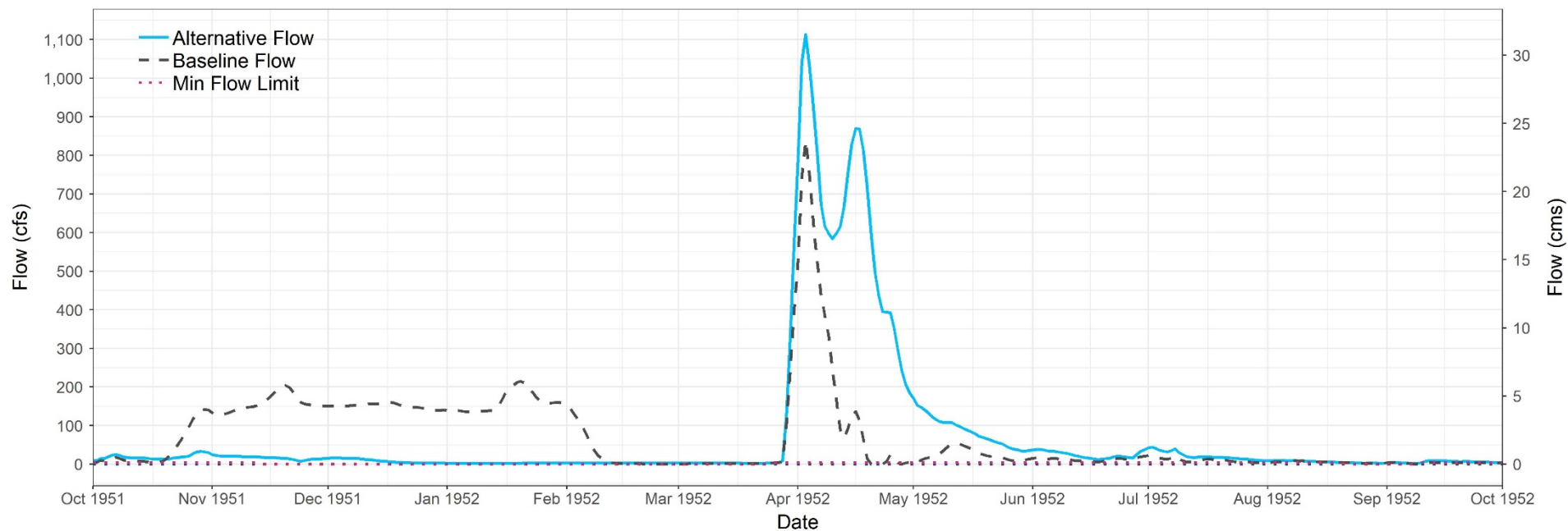
Souris River at Estevan, SK



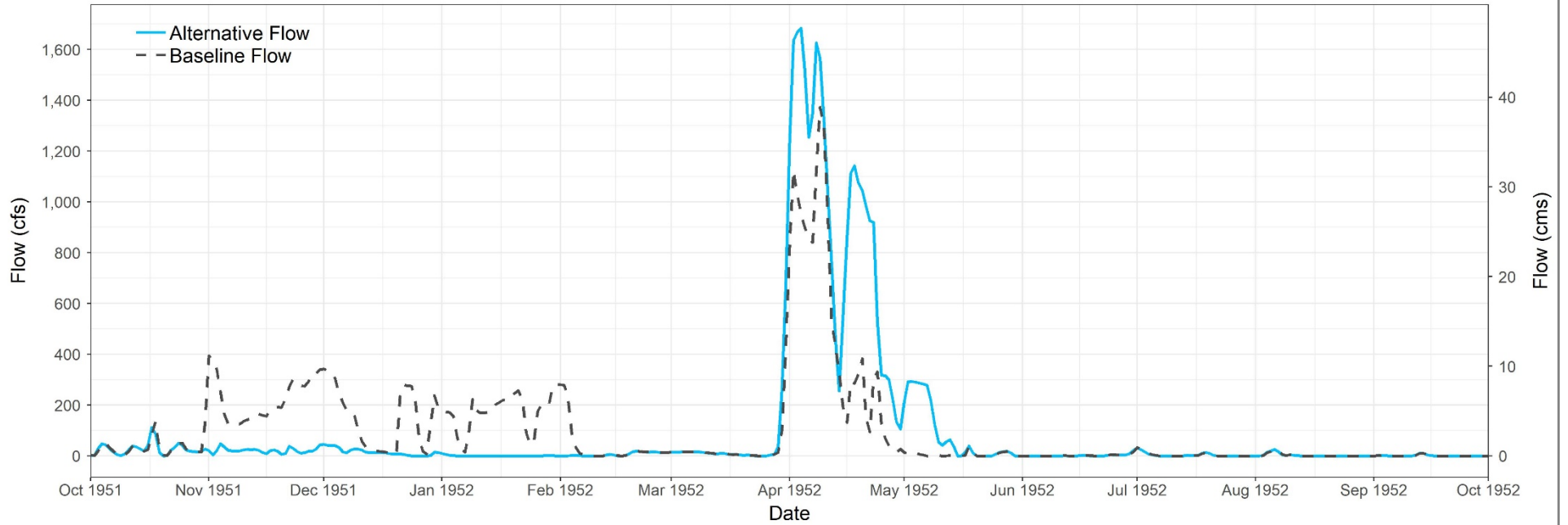
Souris River at Oxbow, SK



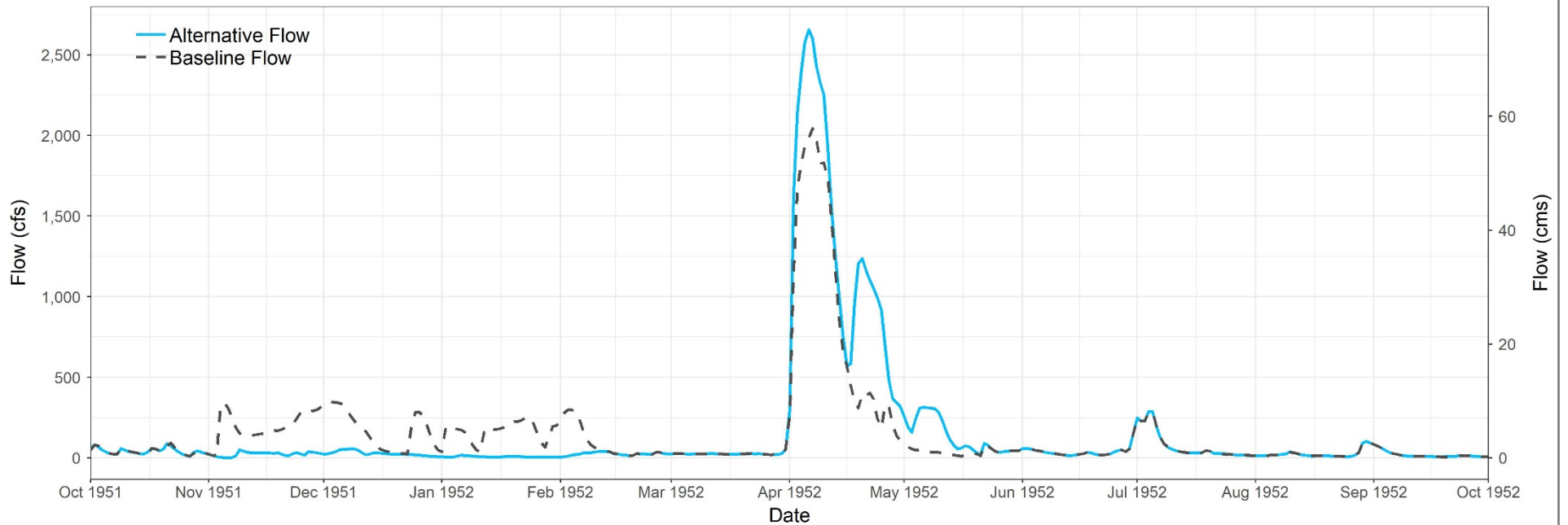
Souris River at Sherwood, ND



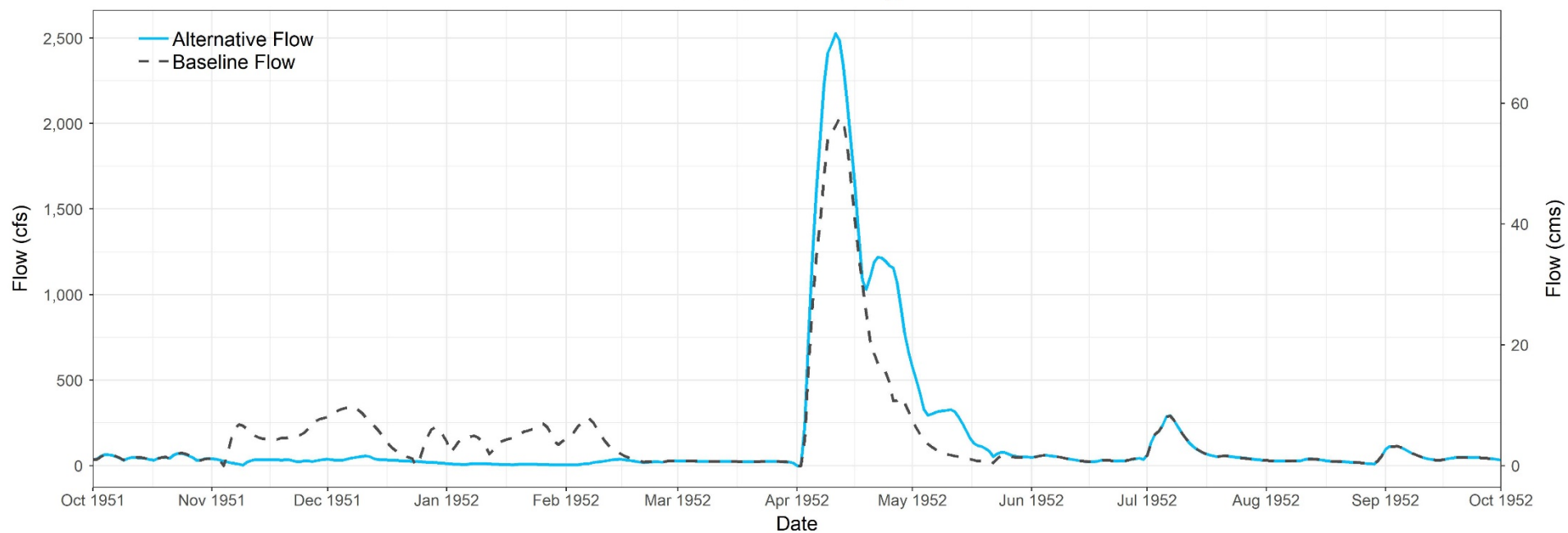
Souris River at Minot, ND - Flow



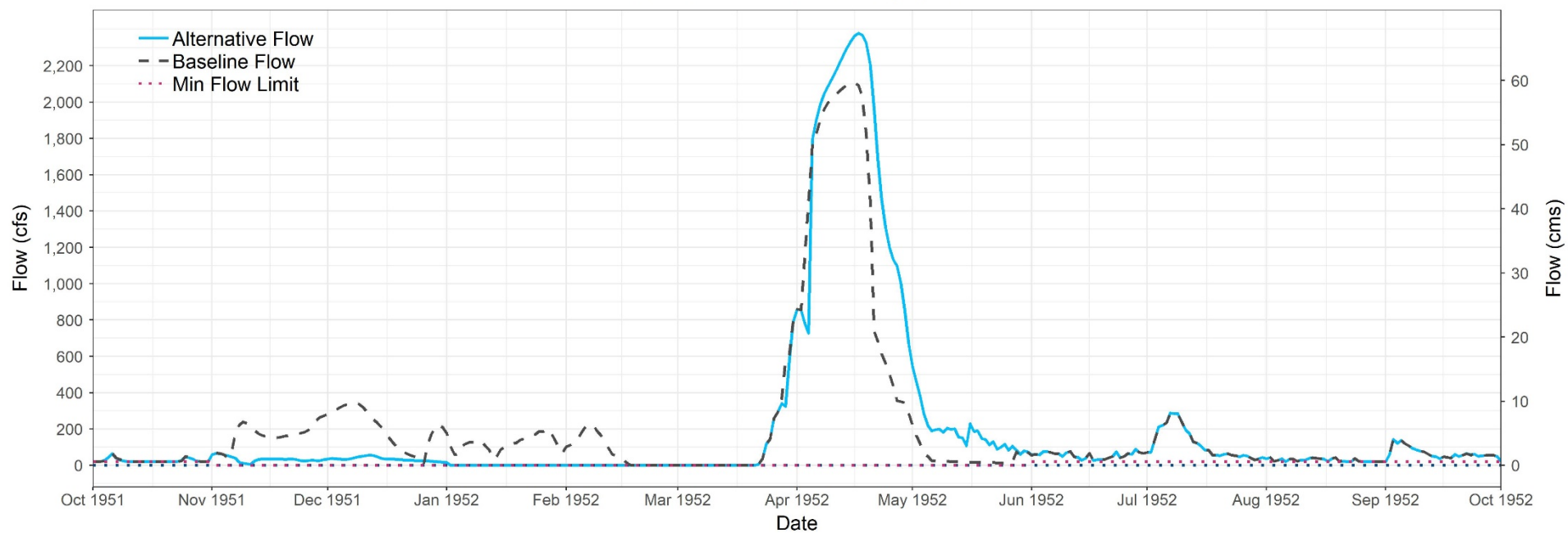
Souris River at Verendrye, ND



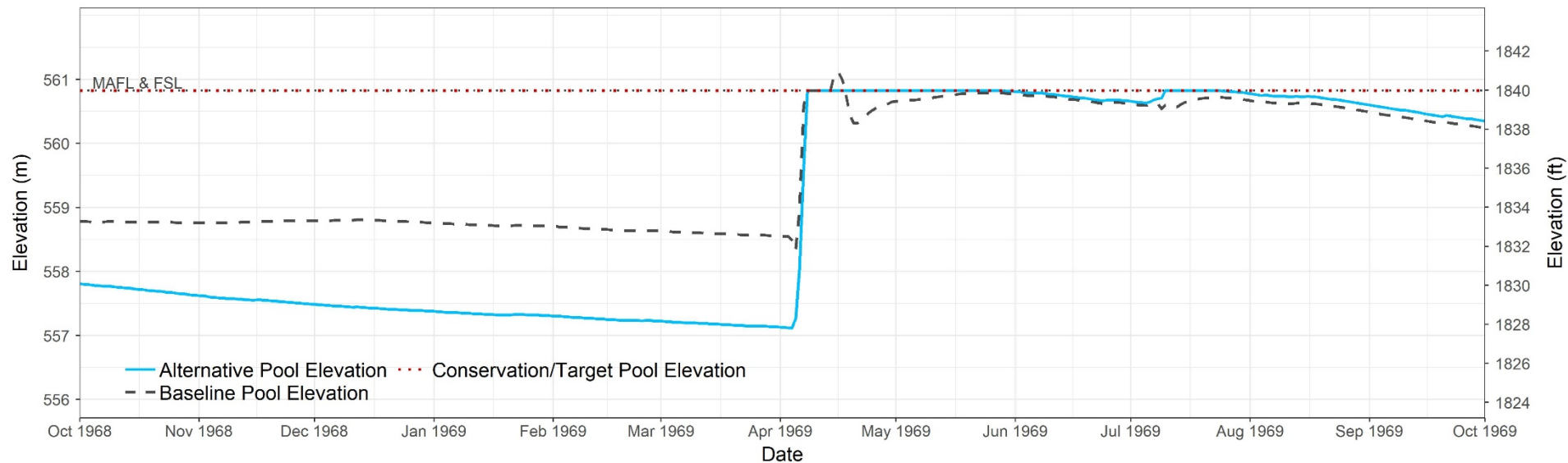
Souris River at Bantry, ND



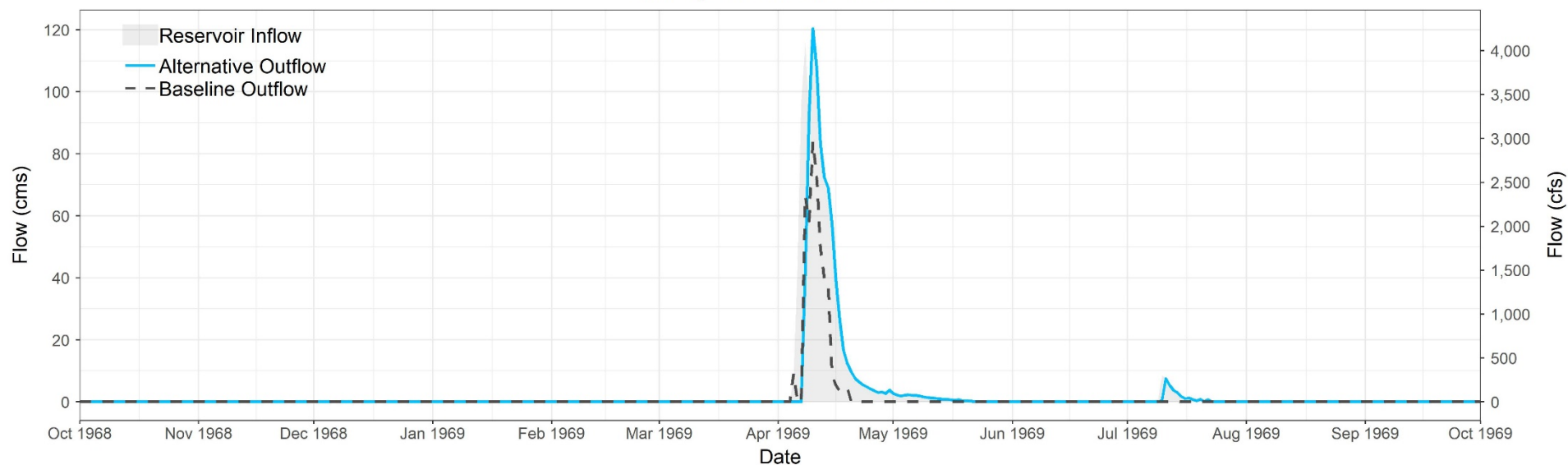
Souris River at Westhope, ND



Boundary Reservoir - Elevation

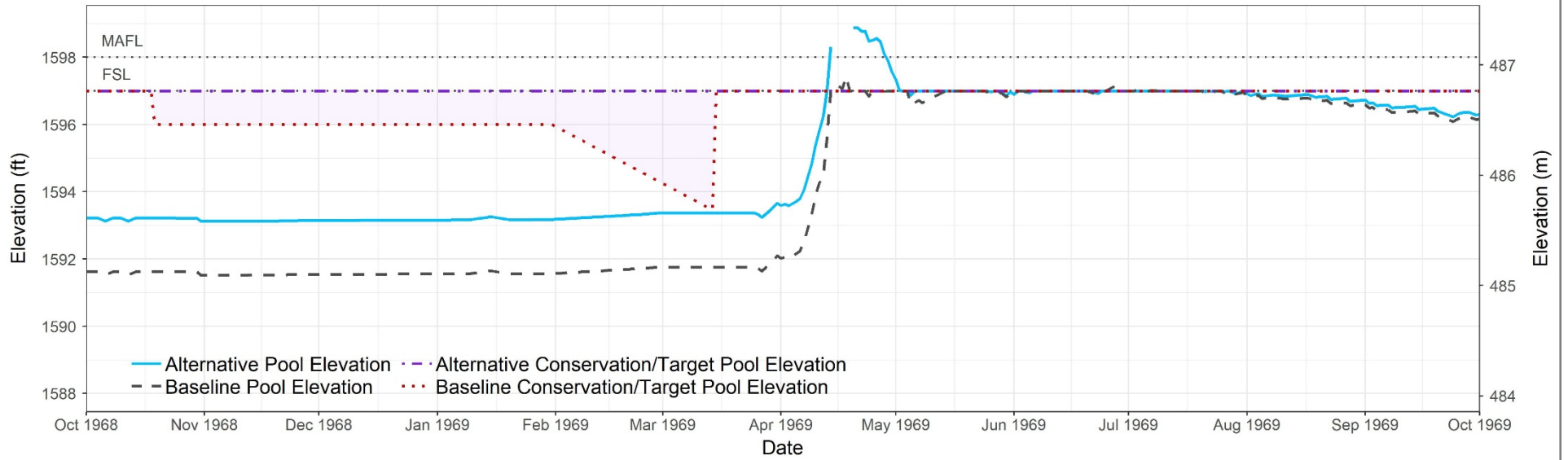


Boundary Reservoir - Releases

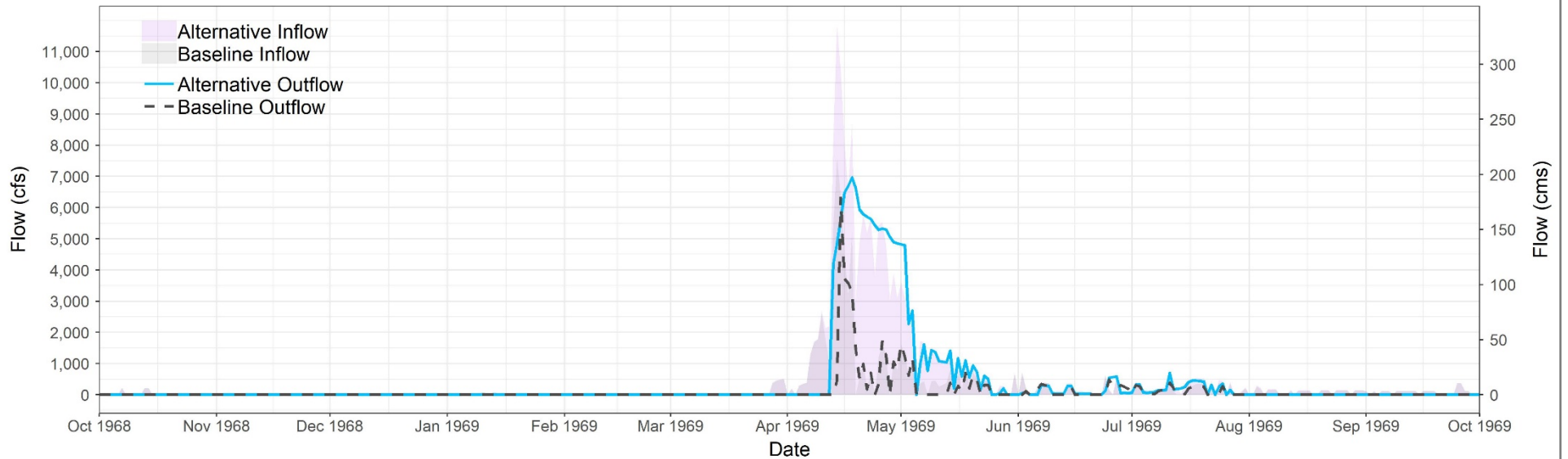


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



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

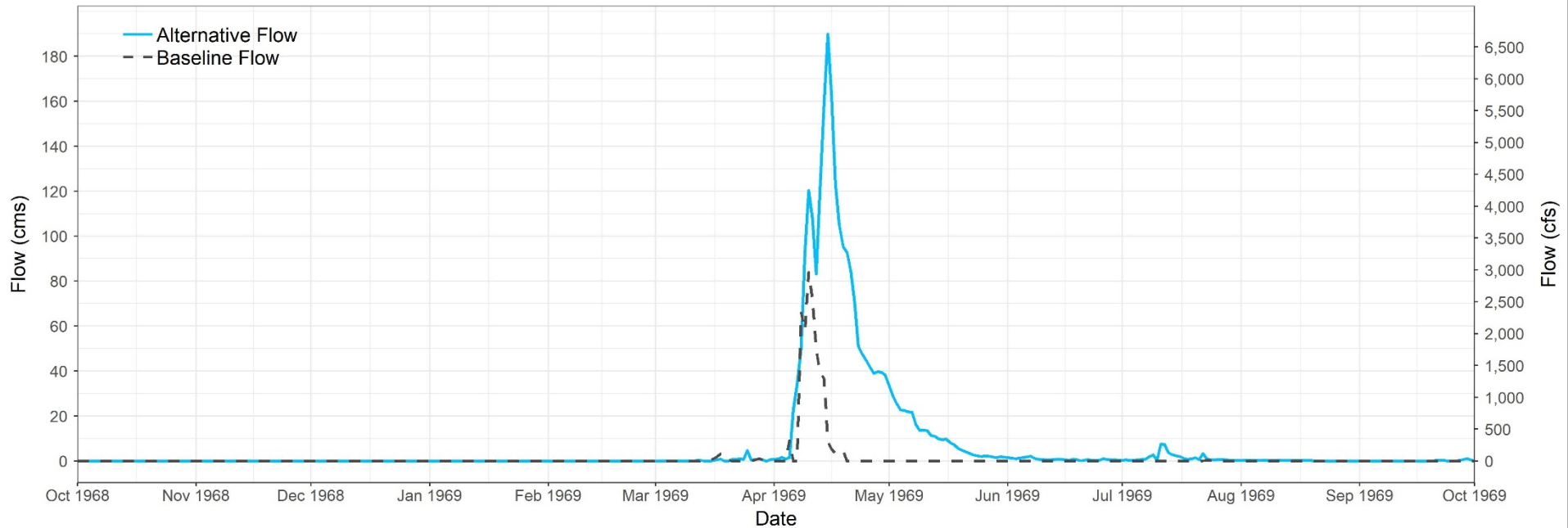
Plate 08

Critical Flow Locations – 1969

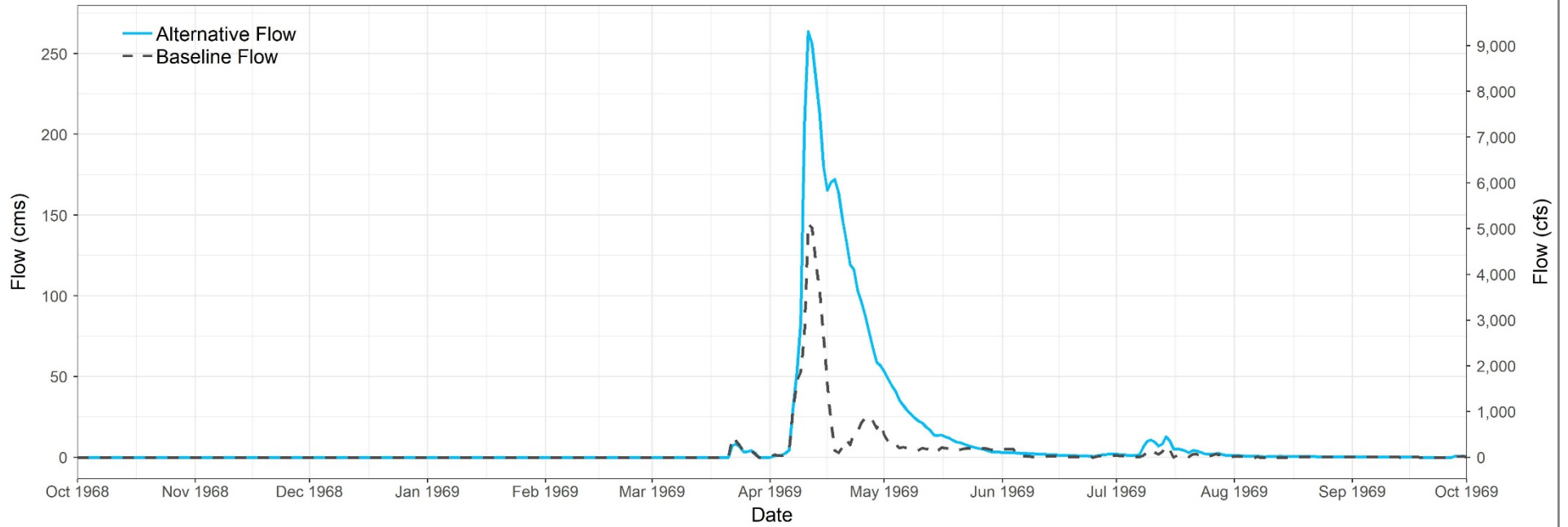
Alternative 8b (Phase 2)

Souris River Plan of Study

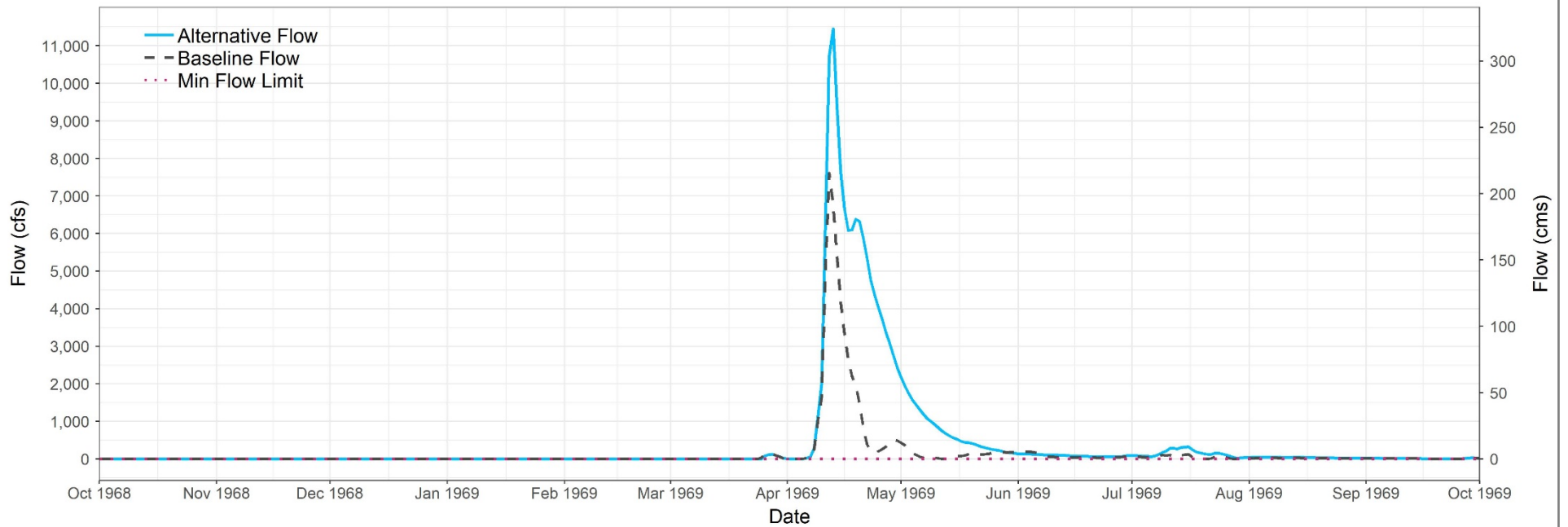
Souris River at Estevan, SK



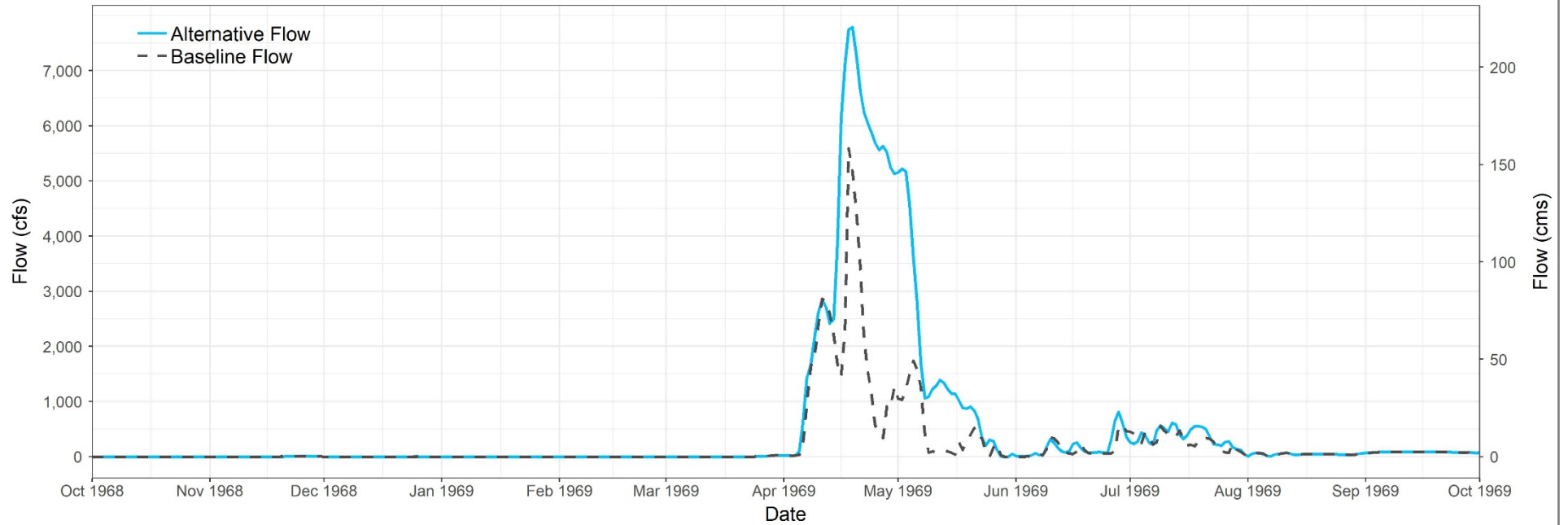
Souris River at Oxbow, SK



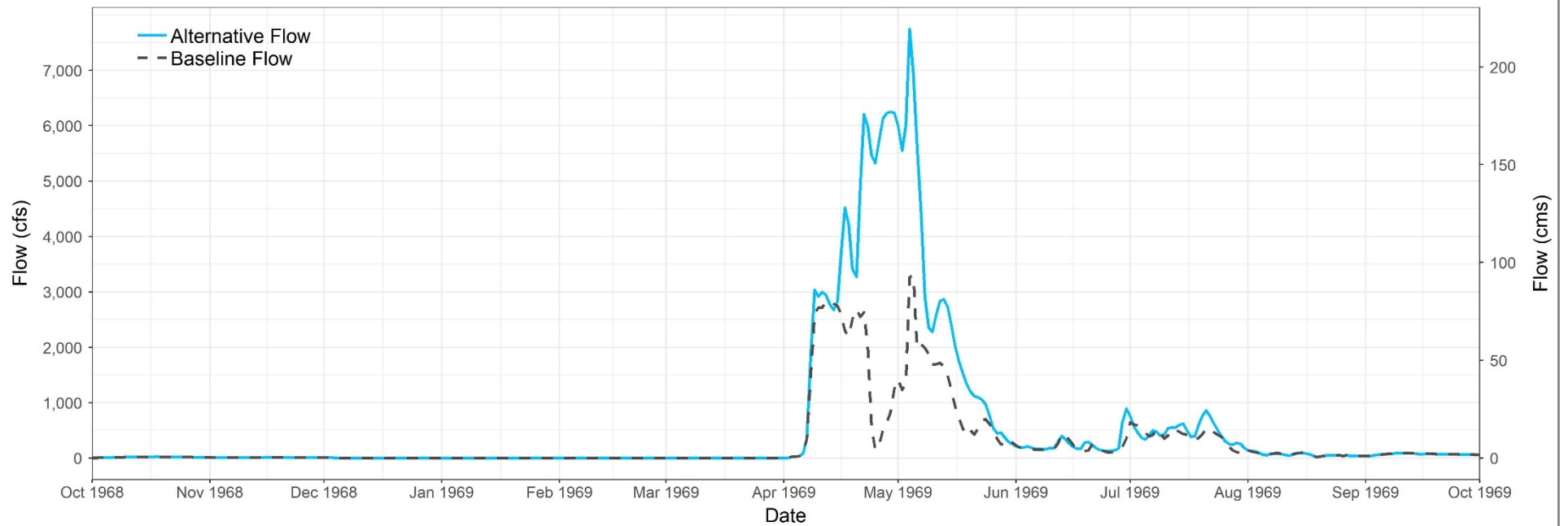
Souris River at Sherwood, ND



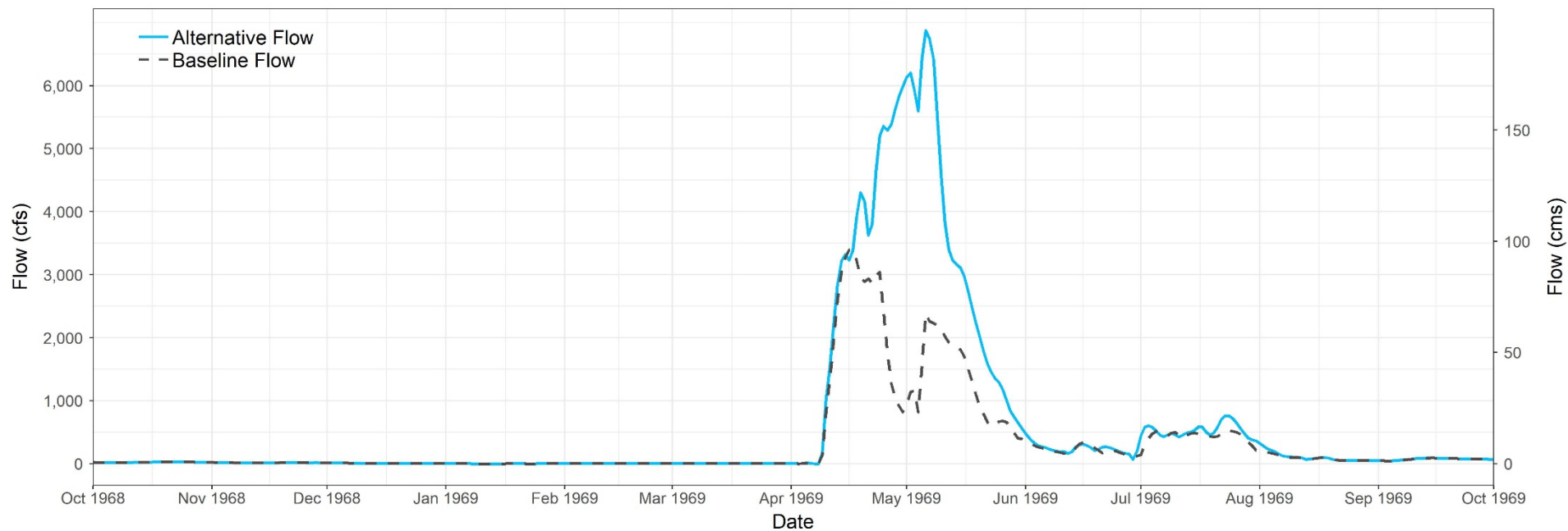
Souris River at Minot, ND - Flow



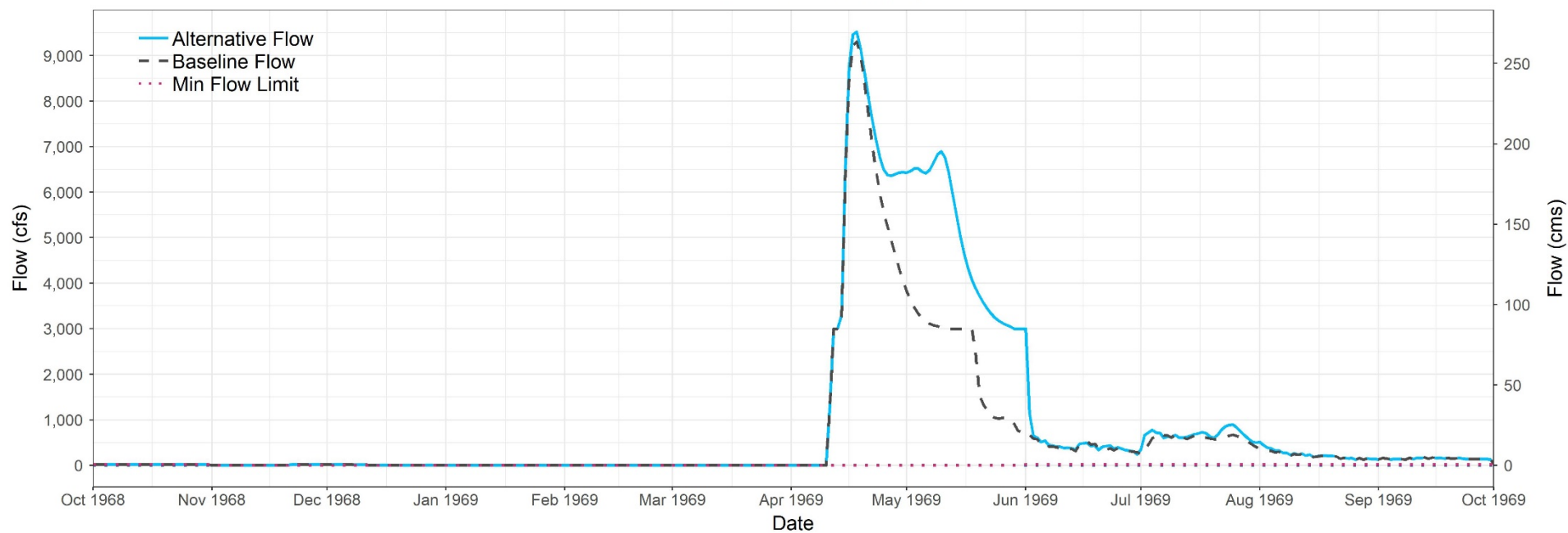
Souris River at Verendrye, ND



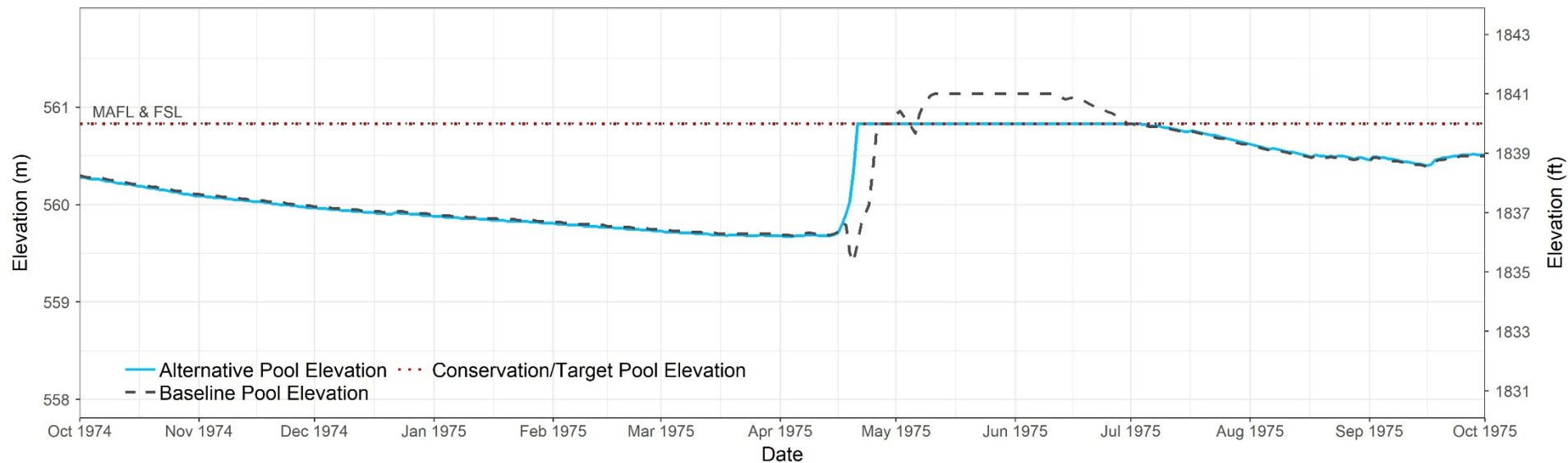
Souris River at Bantry, ND



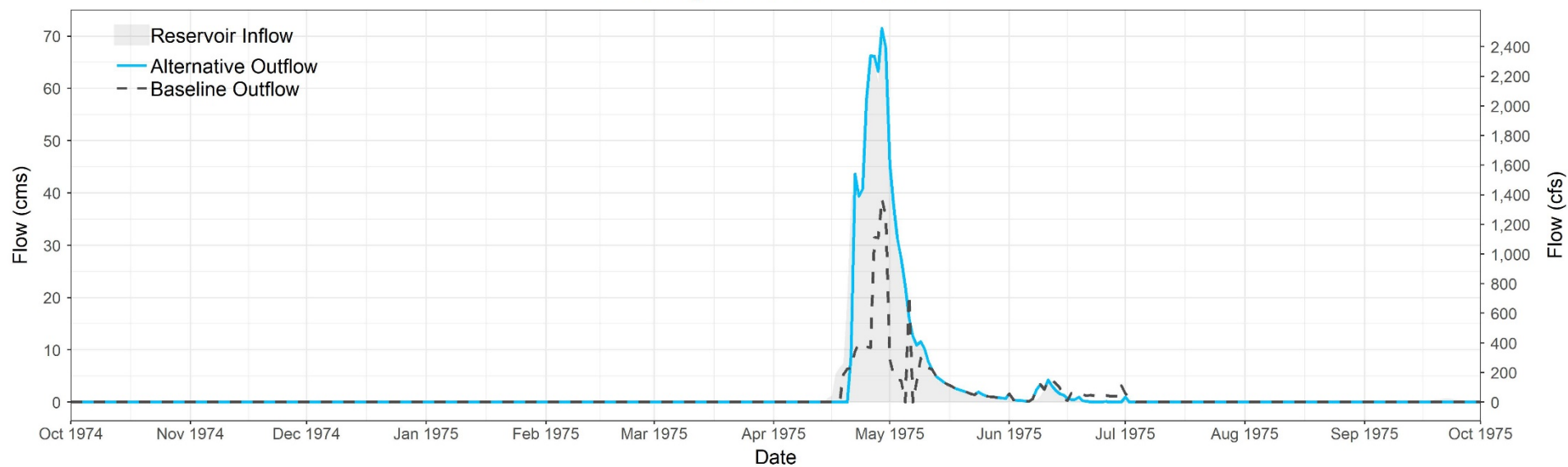
Souris River at Westhope, ND



Boundary Reservoir - Elevation

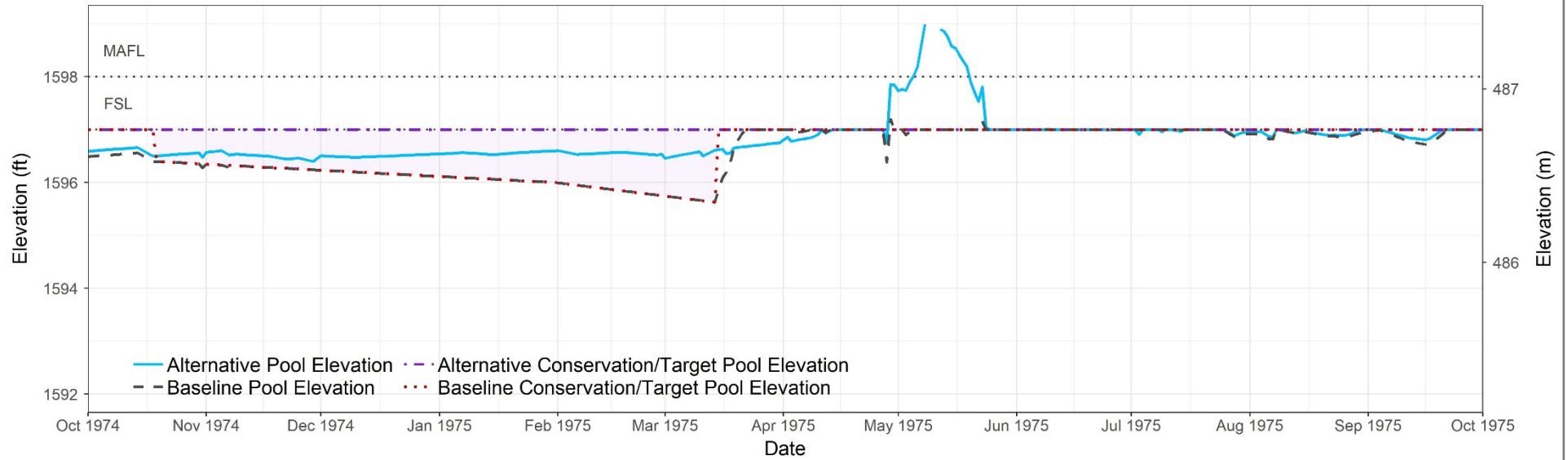


Boundary Reservoir - Releases

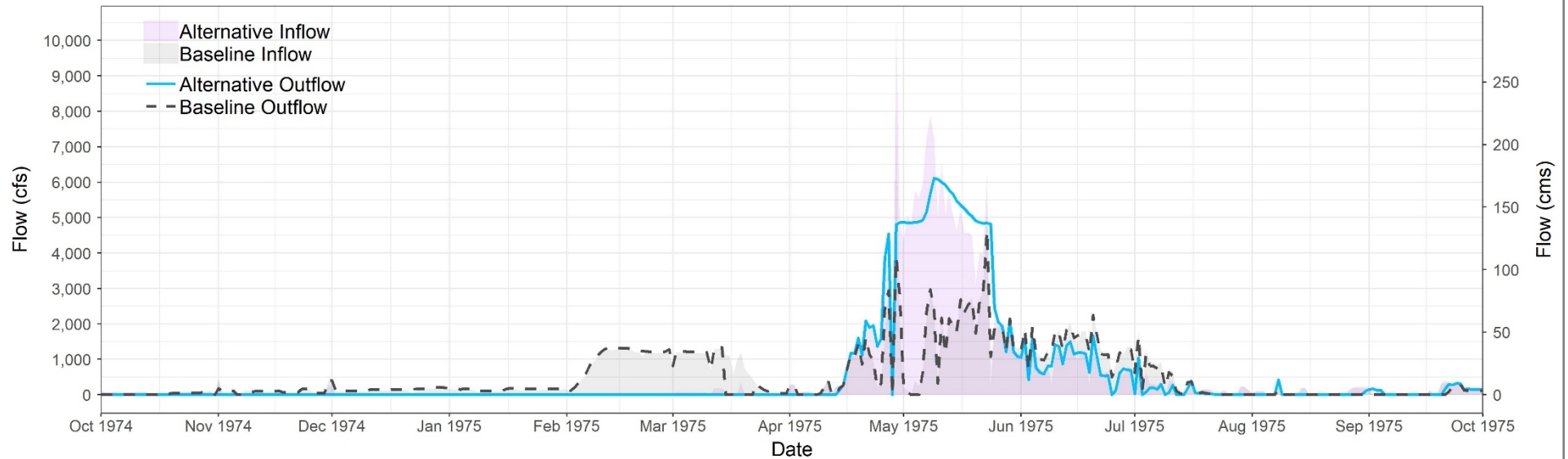


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



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

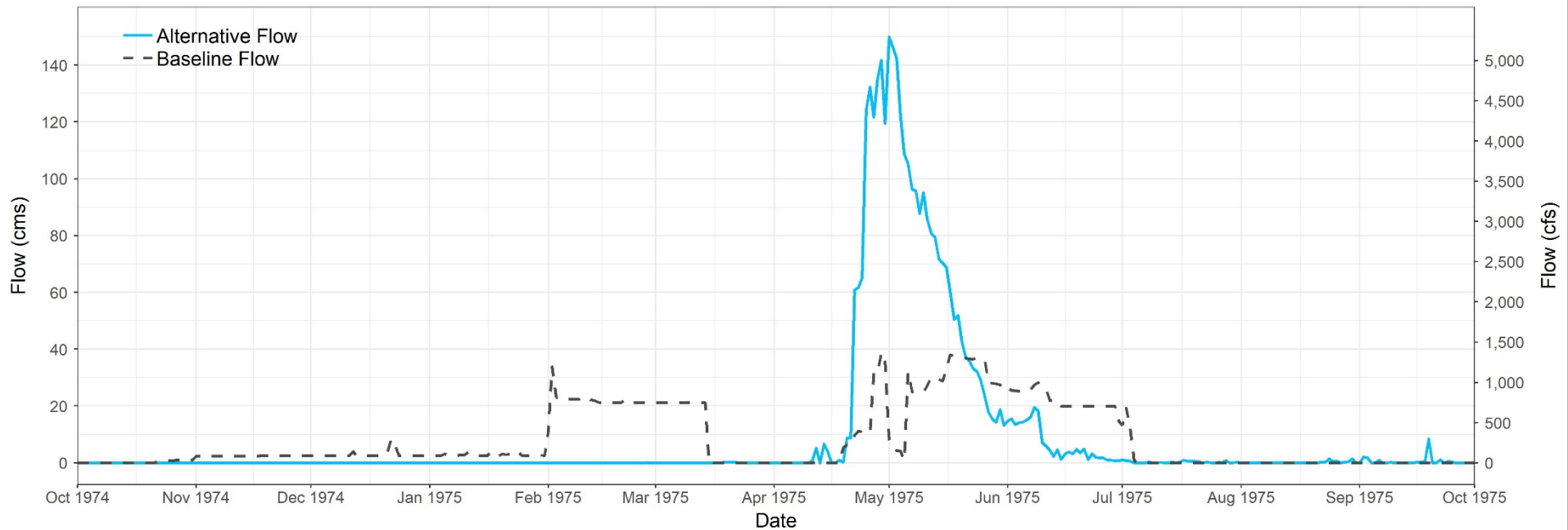
Plate 10

Critical Flow Locations – 1975

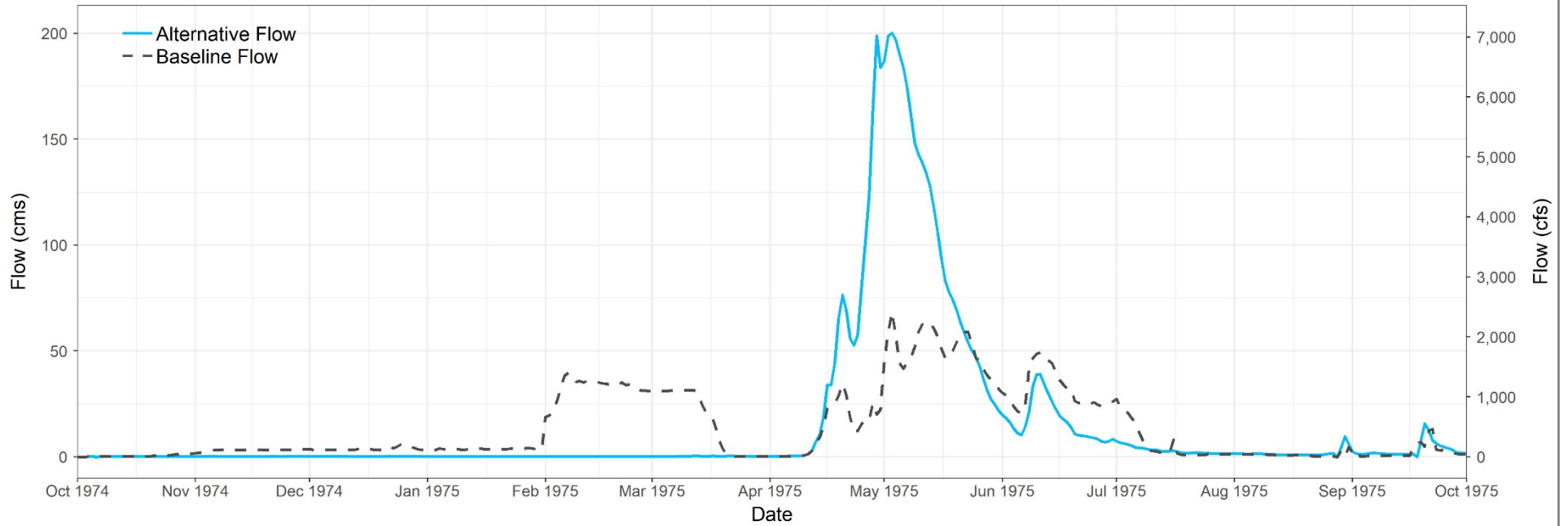
Alternative 8b (Phase 2)

Souris River Plan of Study

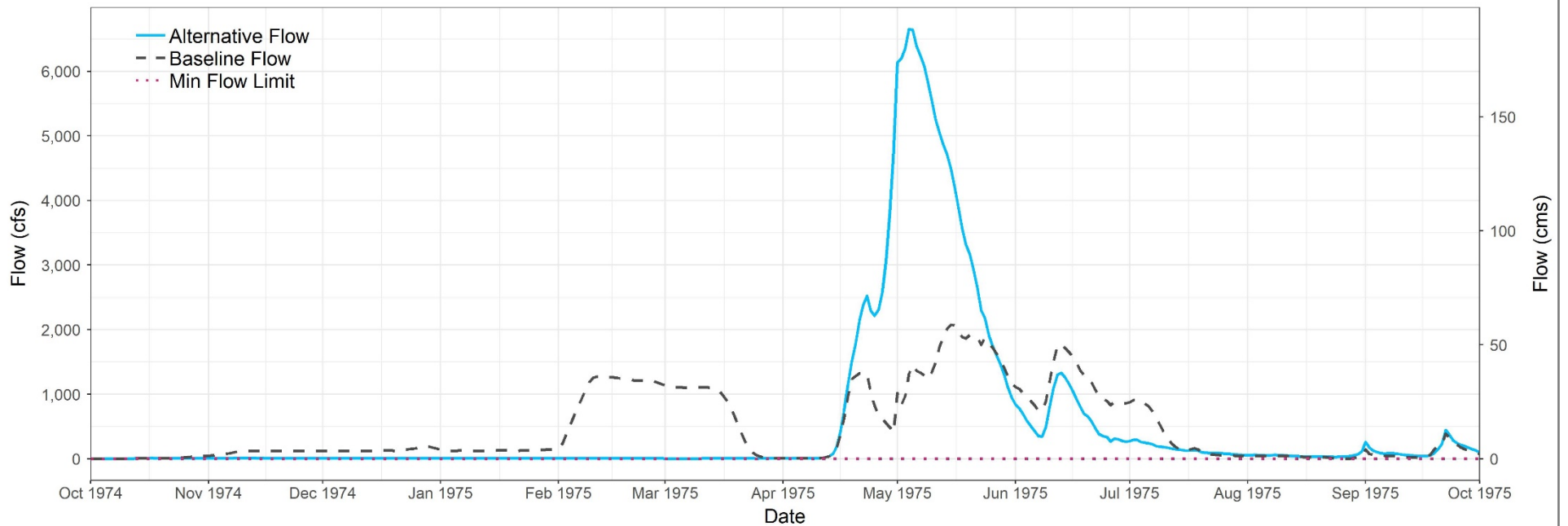
Souris River at Estevan, SK



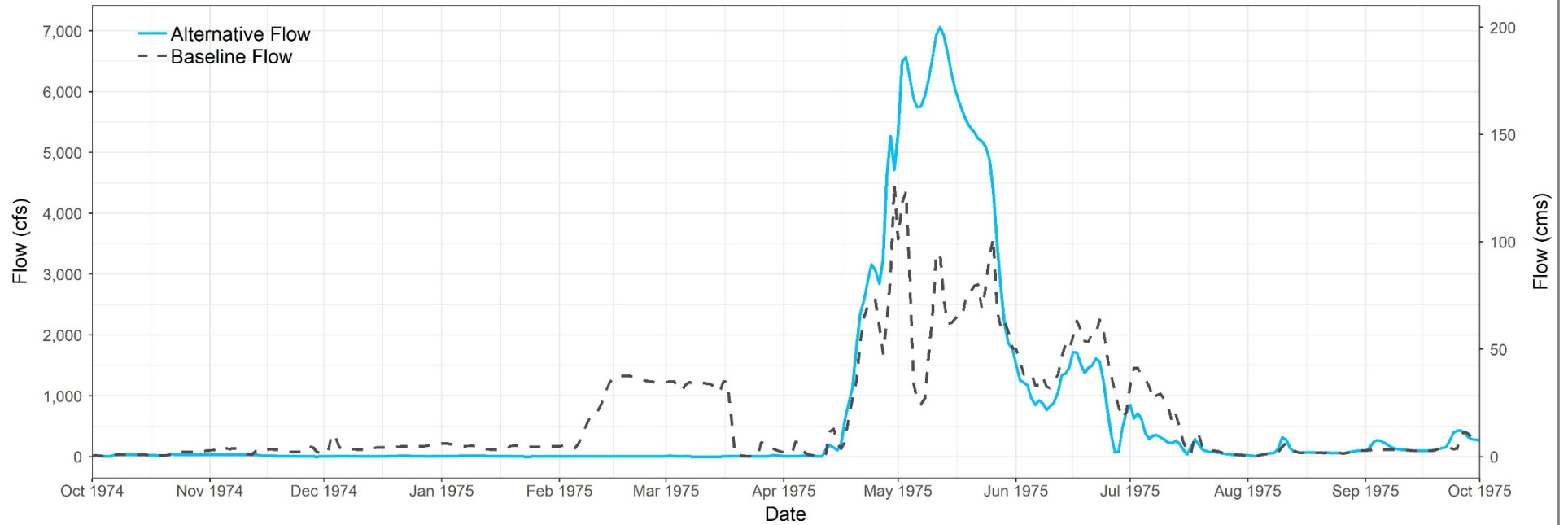
Souris River at Oxbow, SK



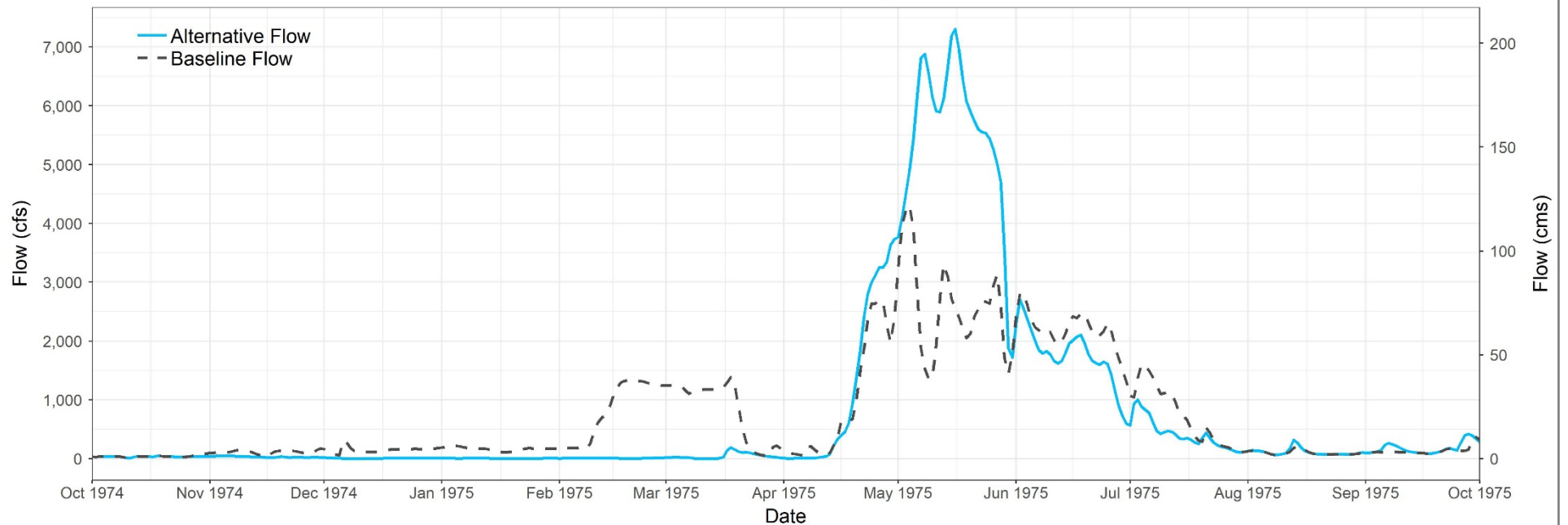
Souris River at Sherwood, ND



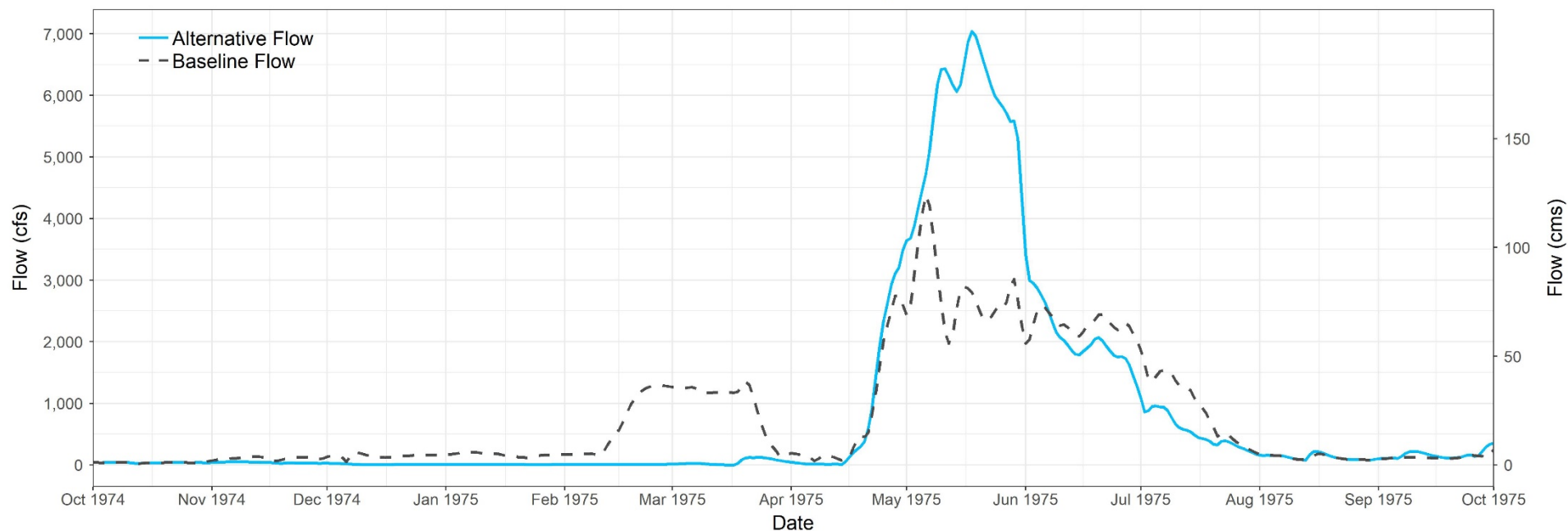
Souris River at Minot, ND - Flow



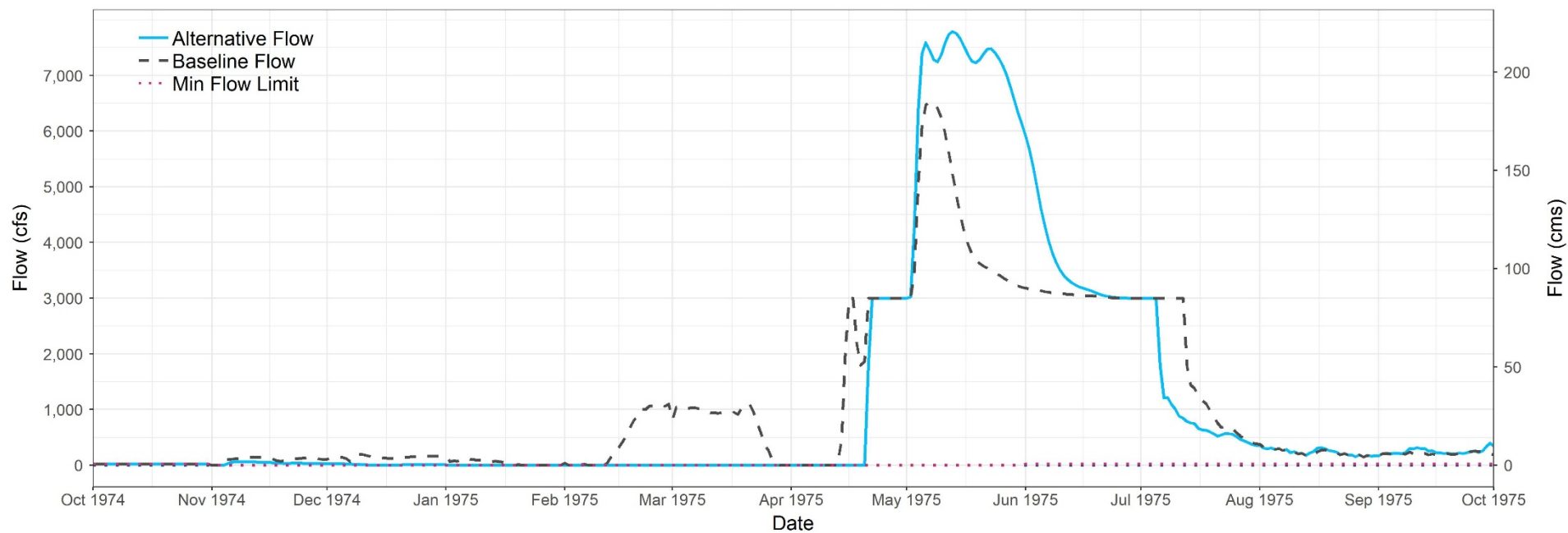
Souris River at Verendrye, ND



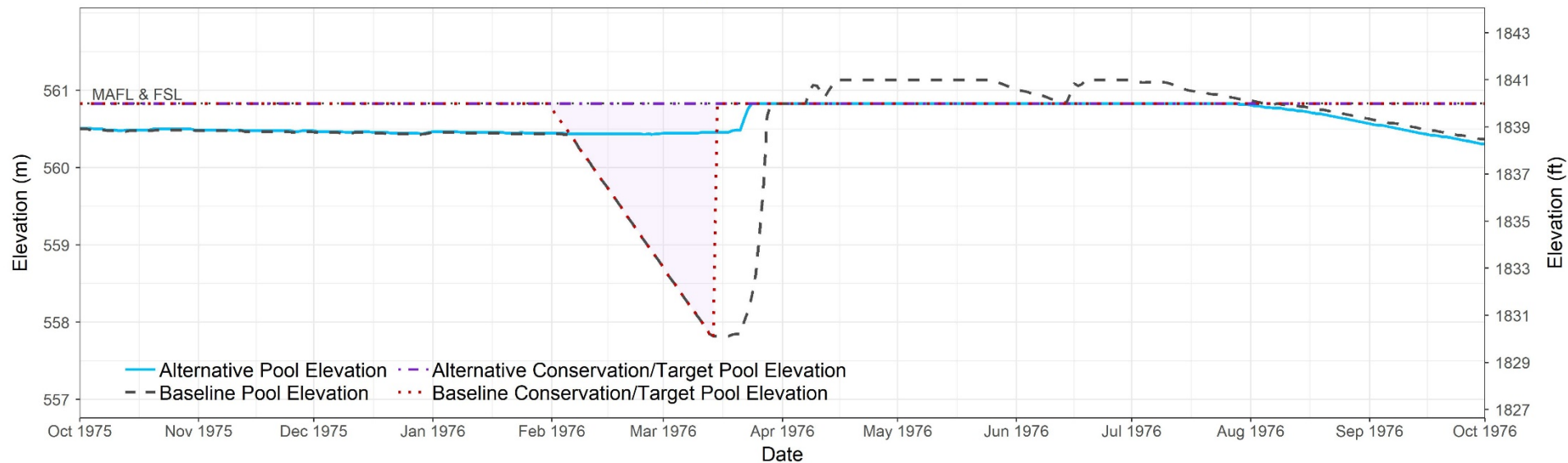
Souris River at Bantry, ND



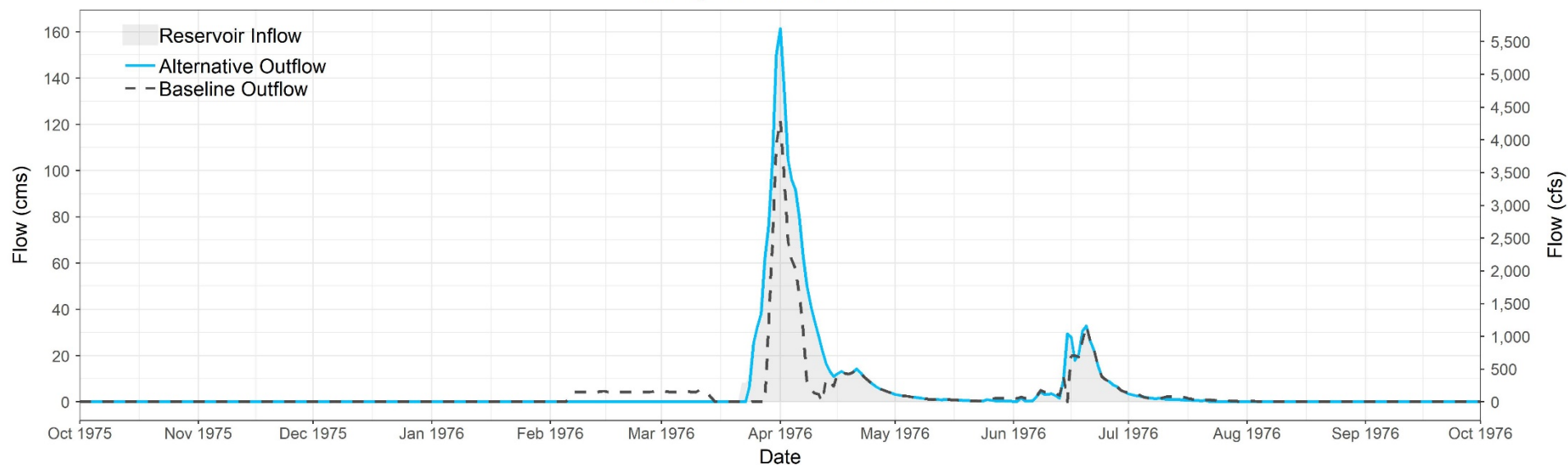
Souris River at Westhope, ND



Boundary Reservoir - Elevation

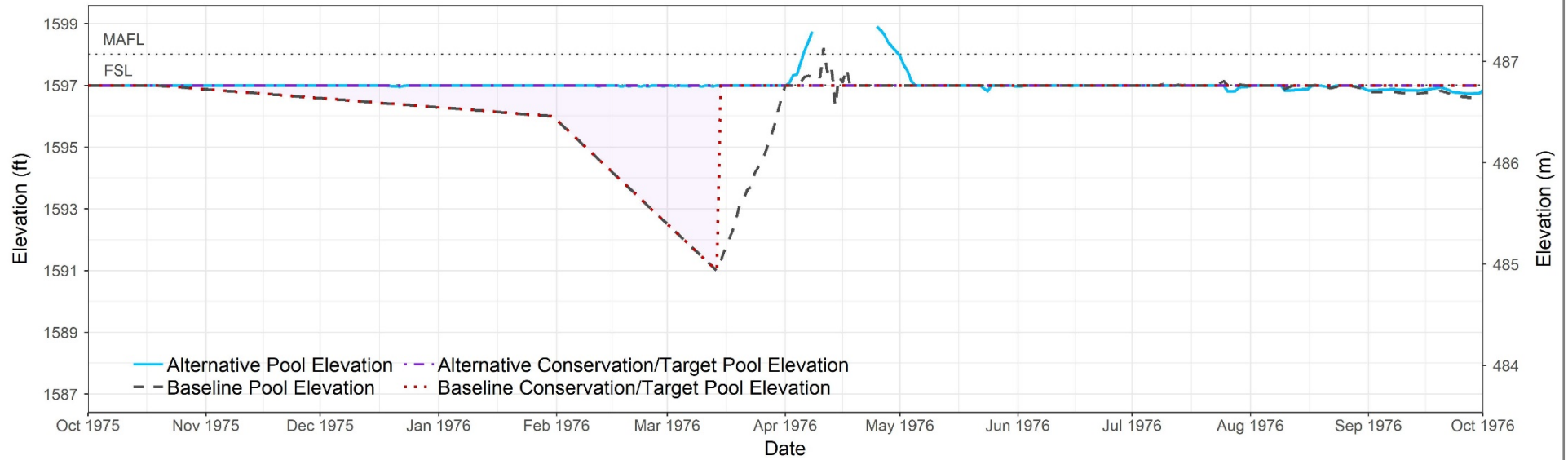


Boundary Reservoir - Releases

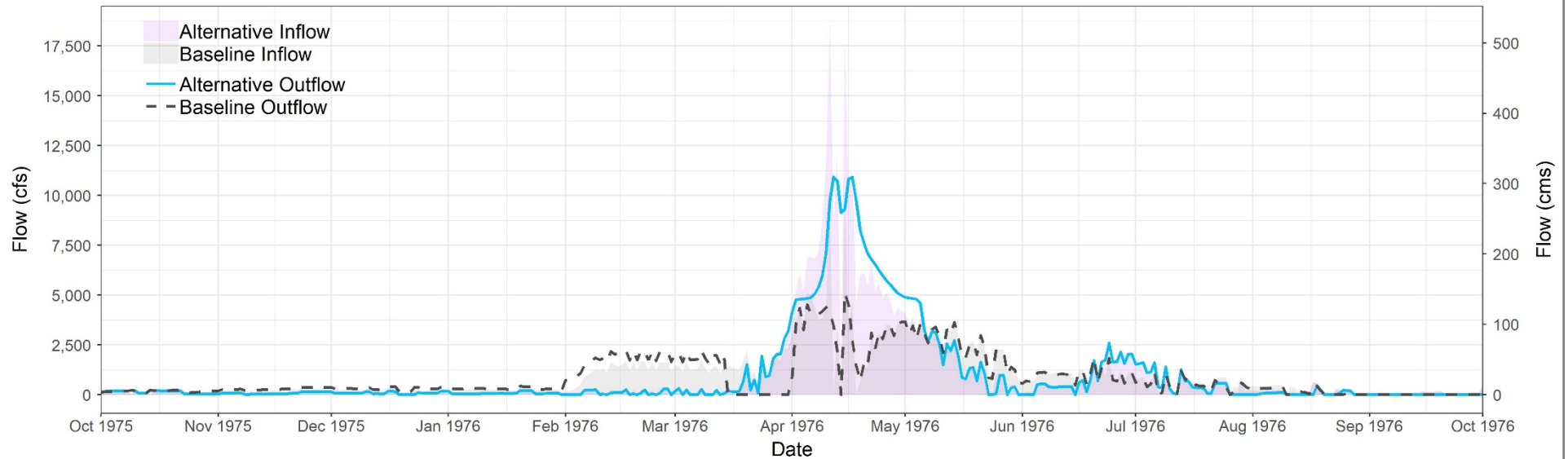


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



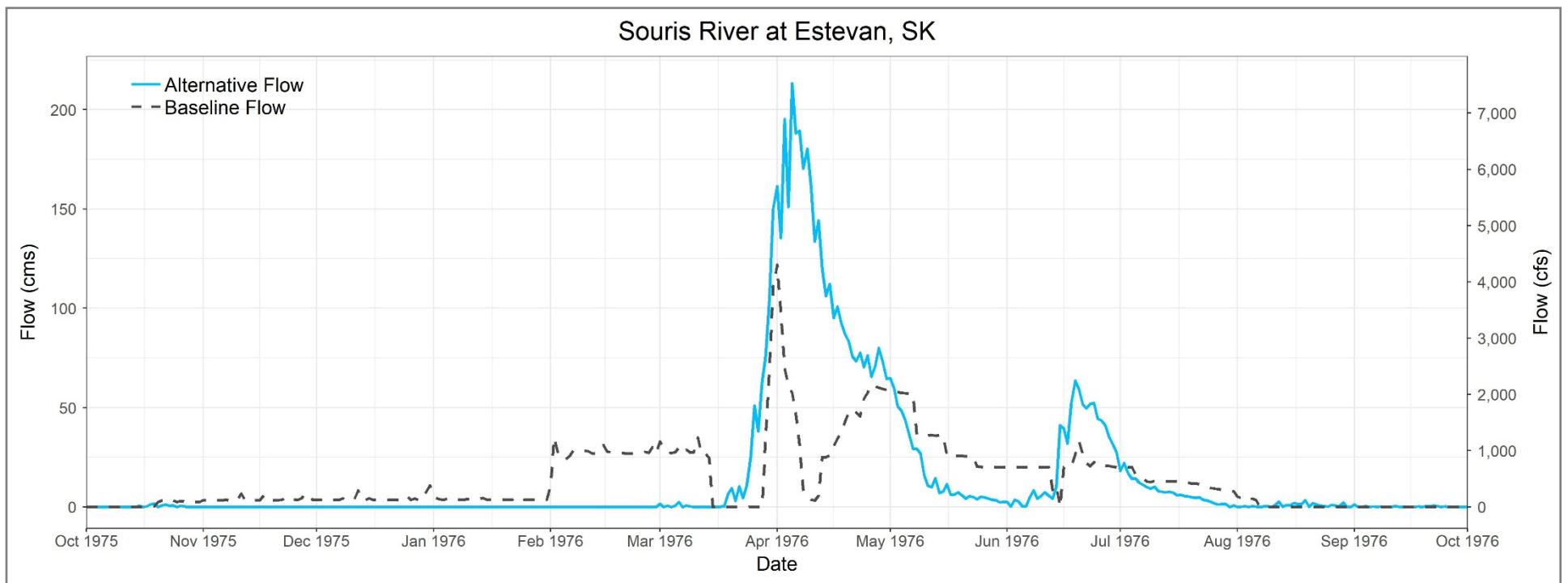
*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Plate 12

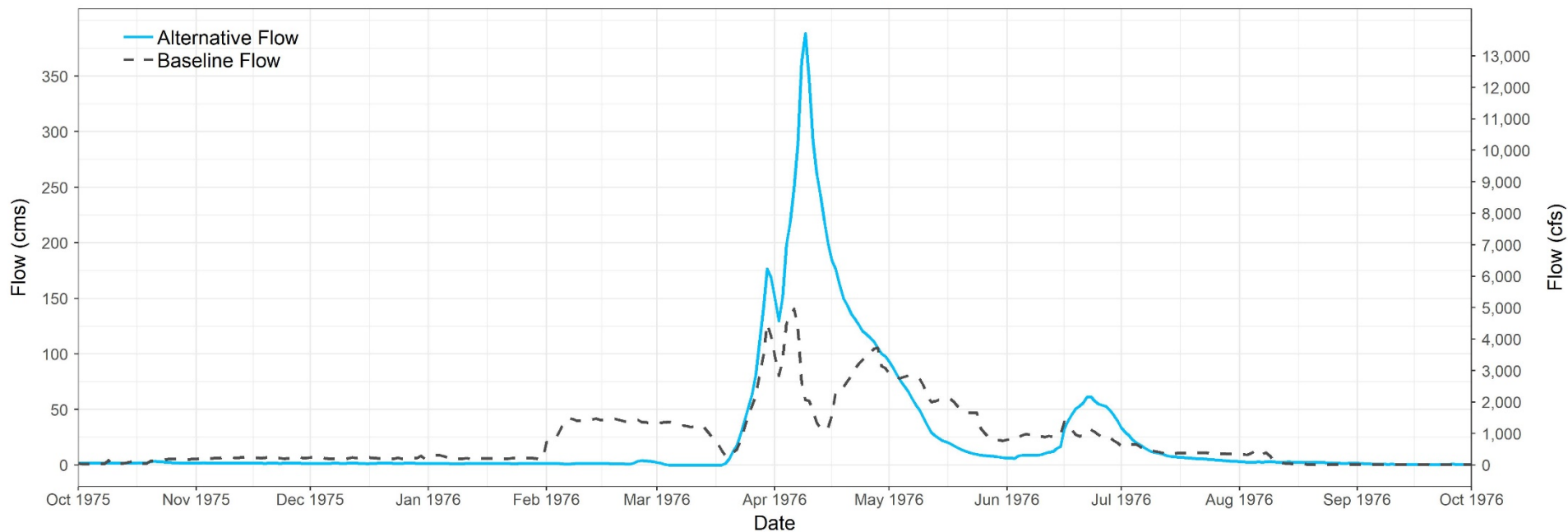
Critical Flow Locations – 1976

Alternative 8b (Phase 2)

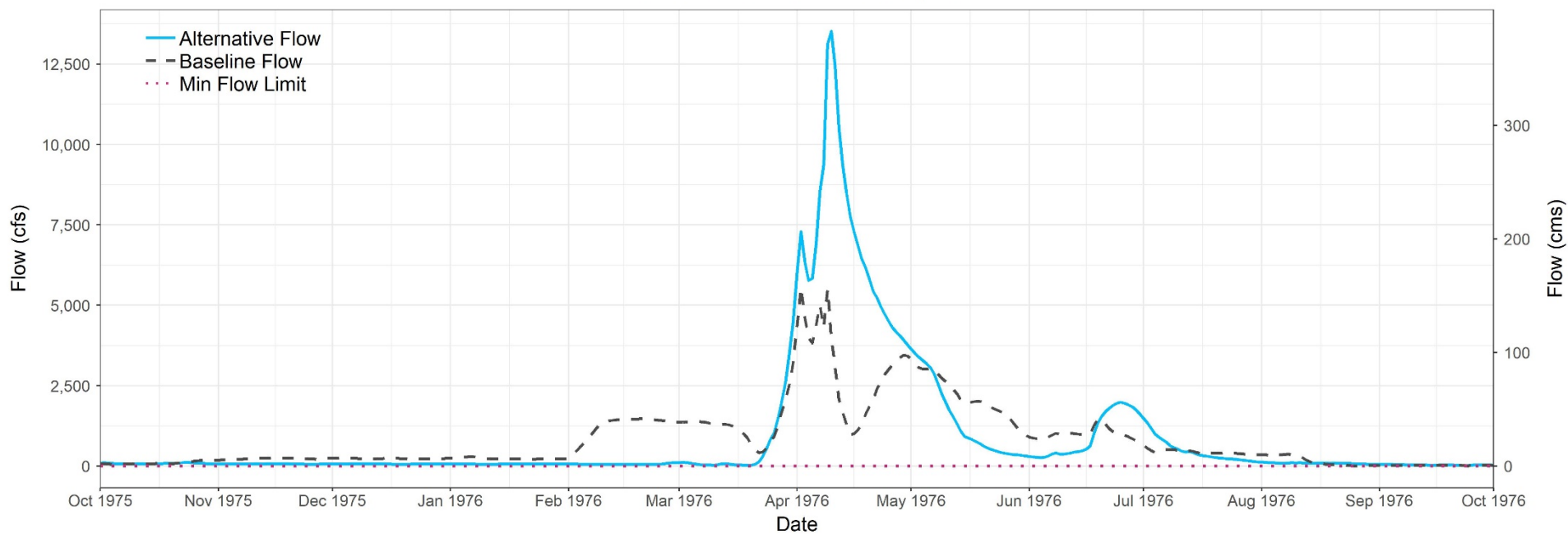
Souris River Plan of Study



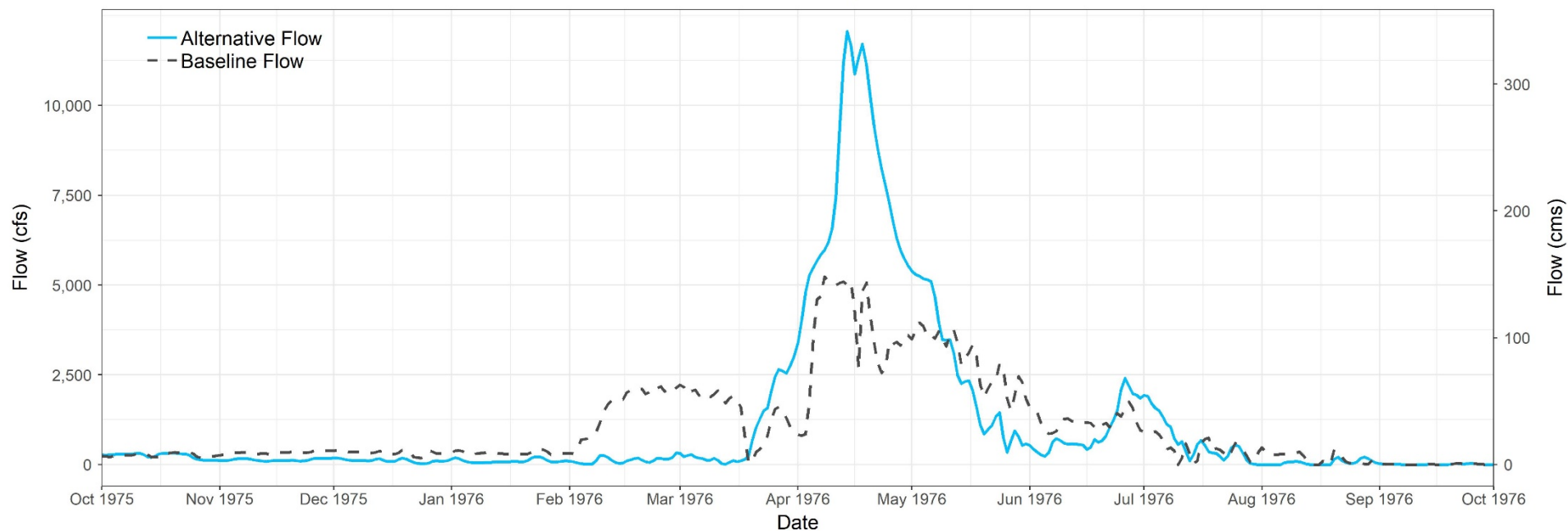
Souris River at Oxbow, SK



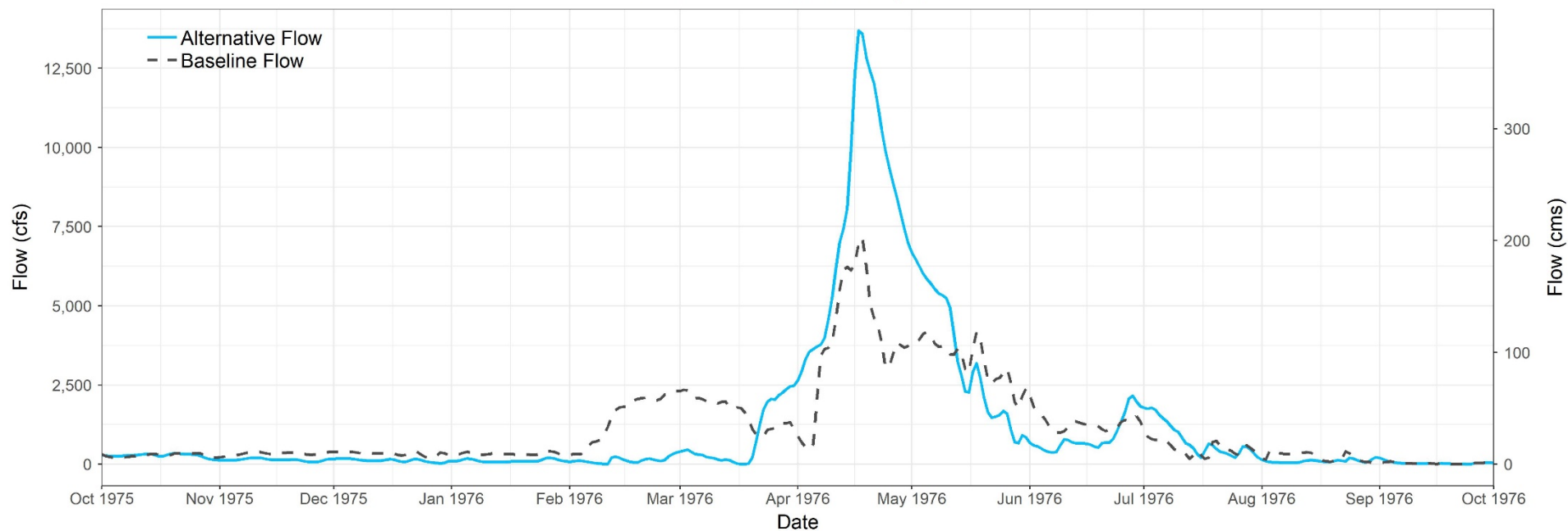
Souris River at Sherwood, ND



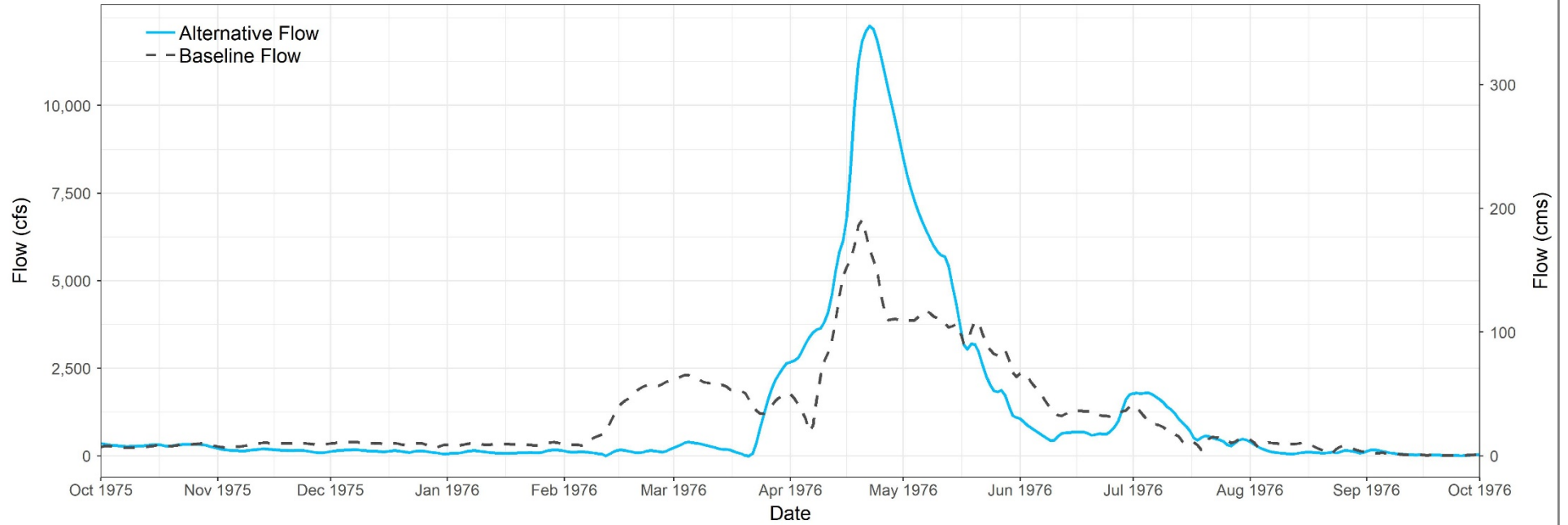
Souris River at Minot, ND - Flow



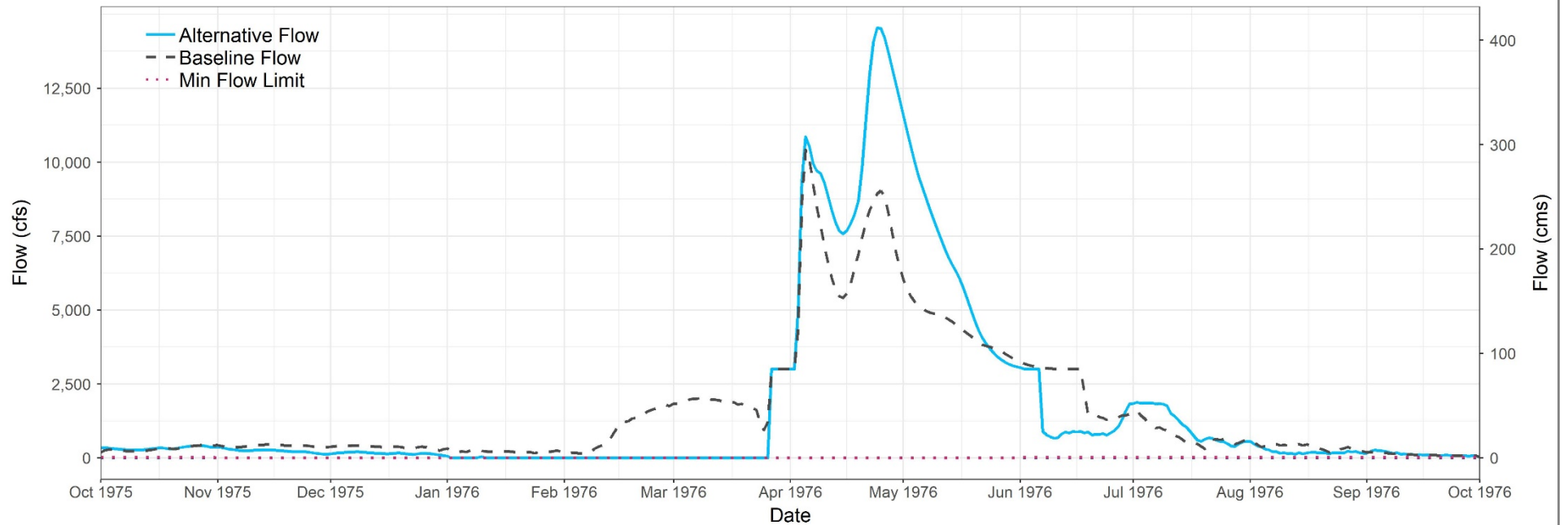
Souris River at Verendrye, ND



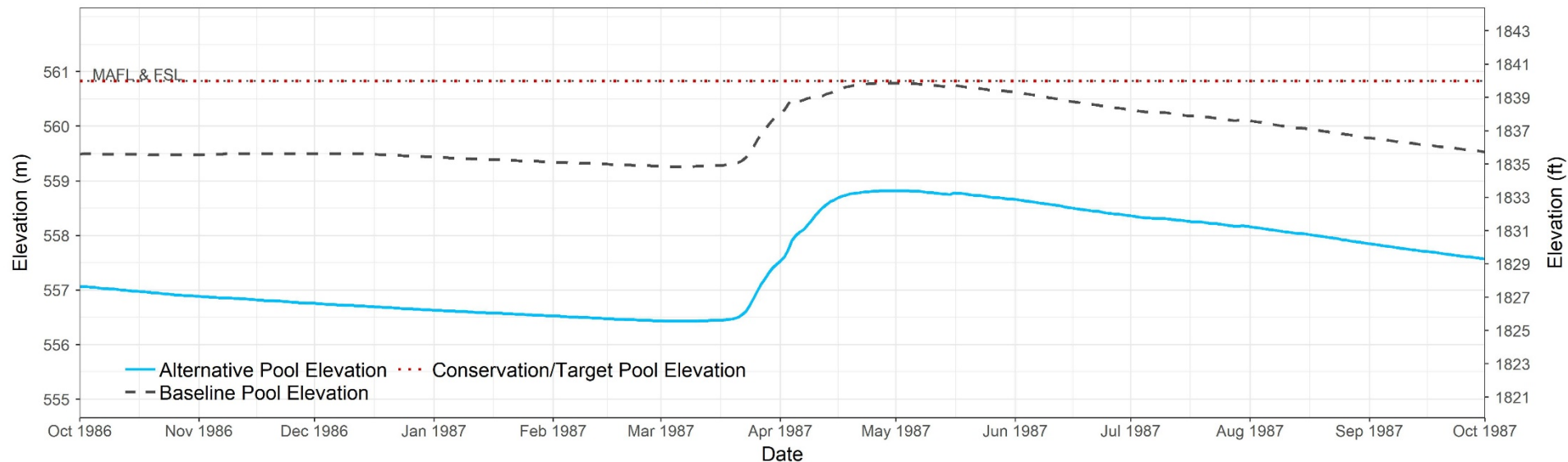
Souris River at Bantry, ND



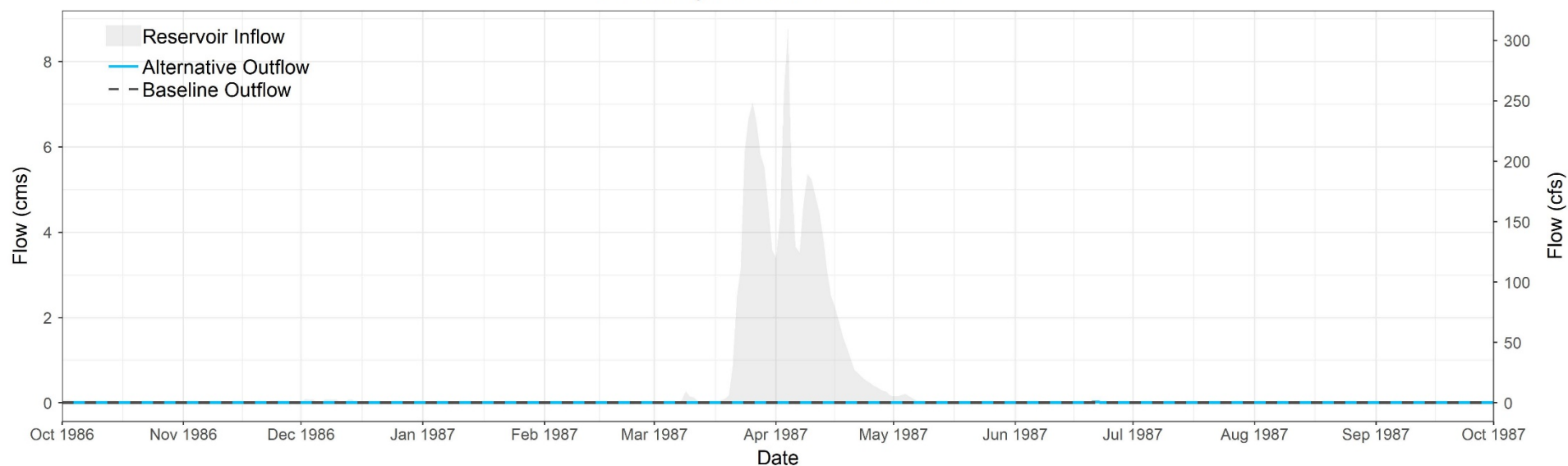
Souris River at Westhope, ND



Boundary Reservoir - Elevation

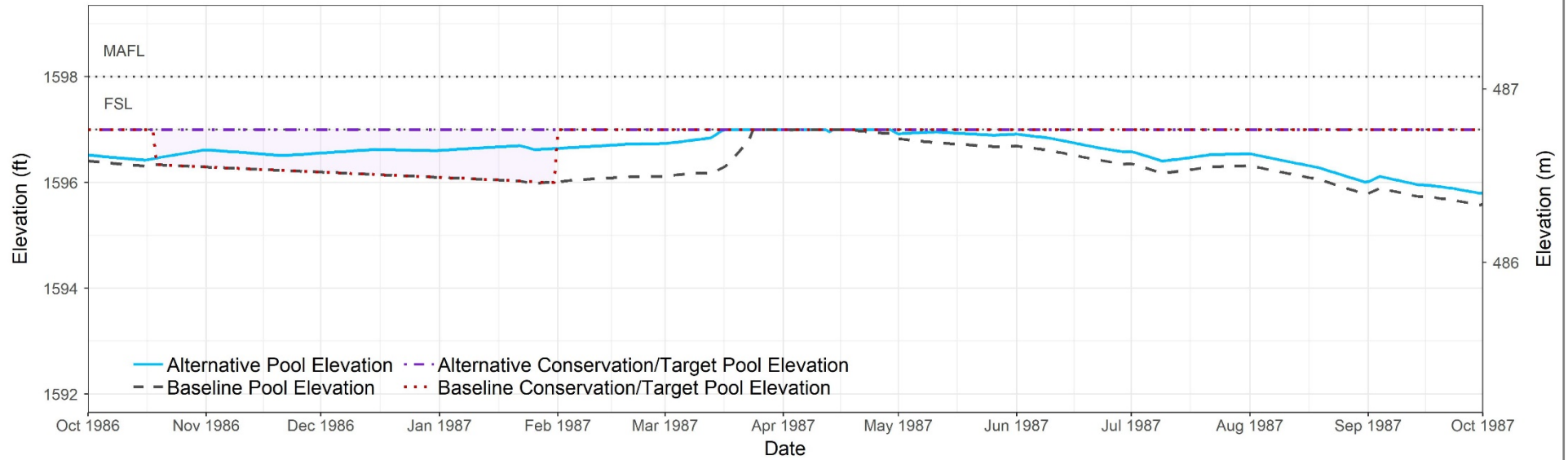


Boundary Reservoir - Releases

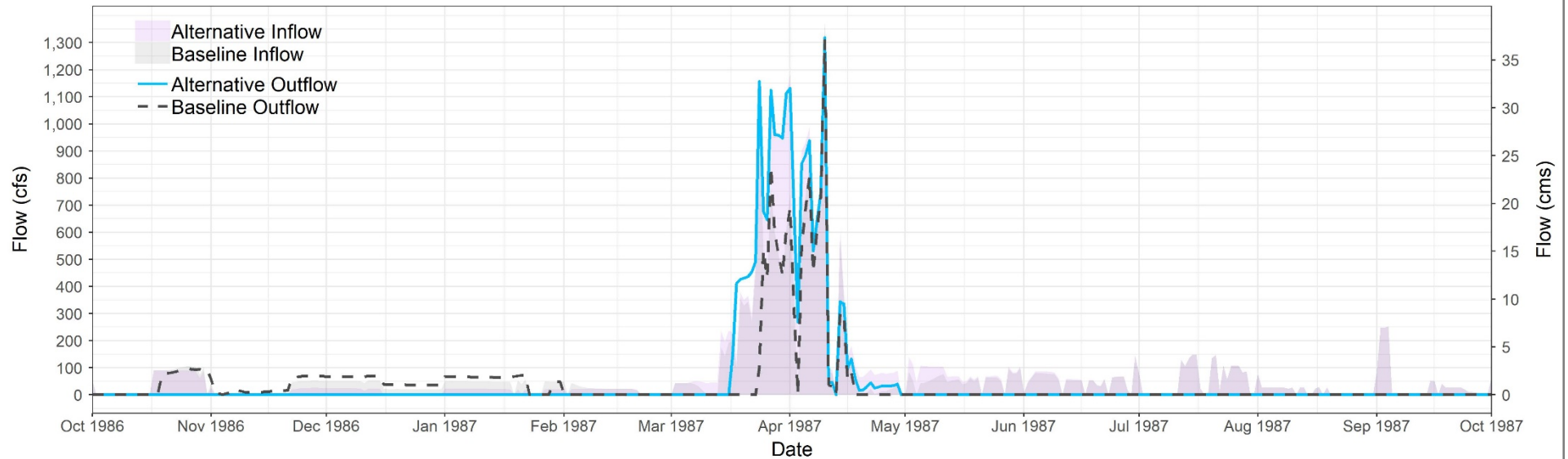


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



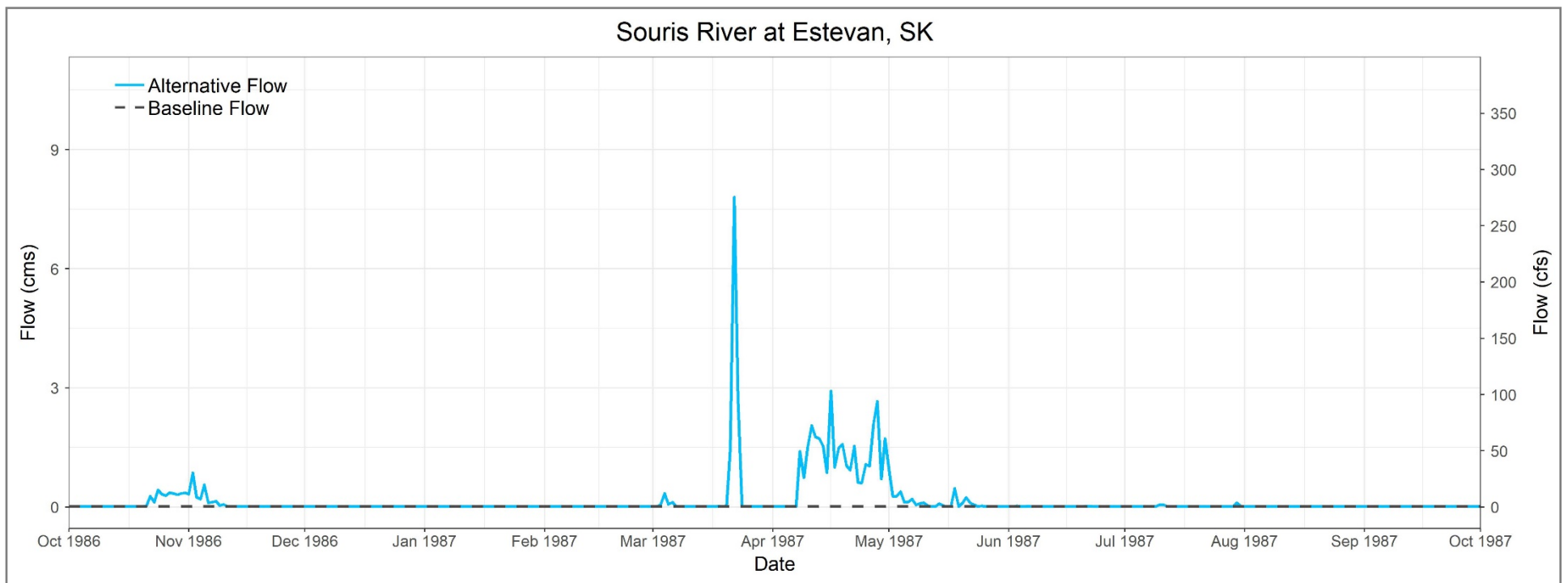
*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Plate 14

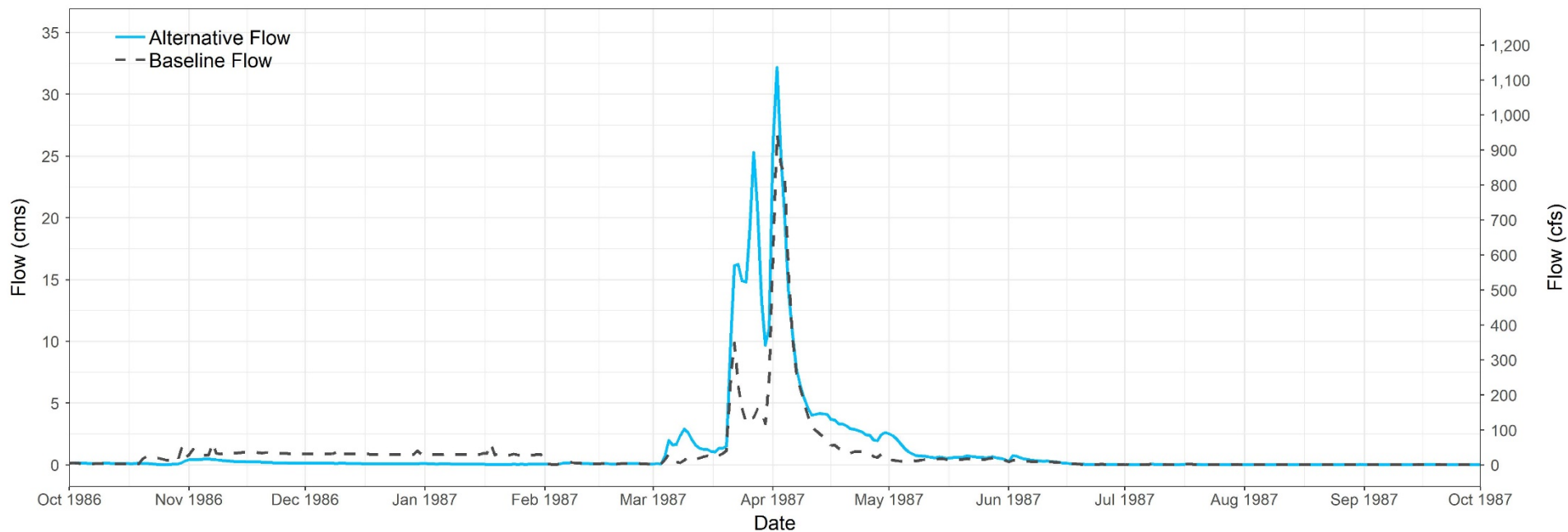
Critical Flow Locations – 1987

Alternative 8b (Phase 2)

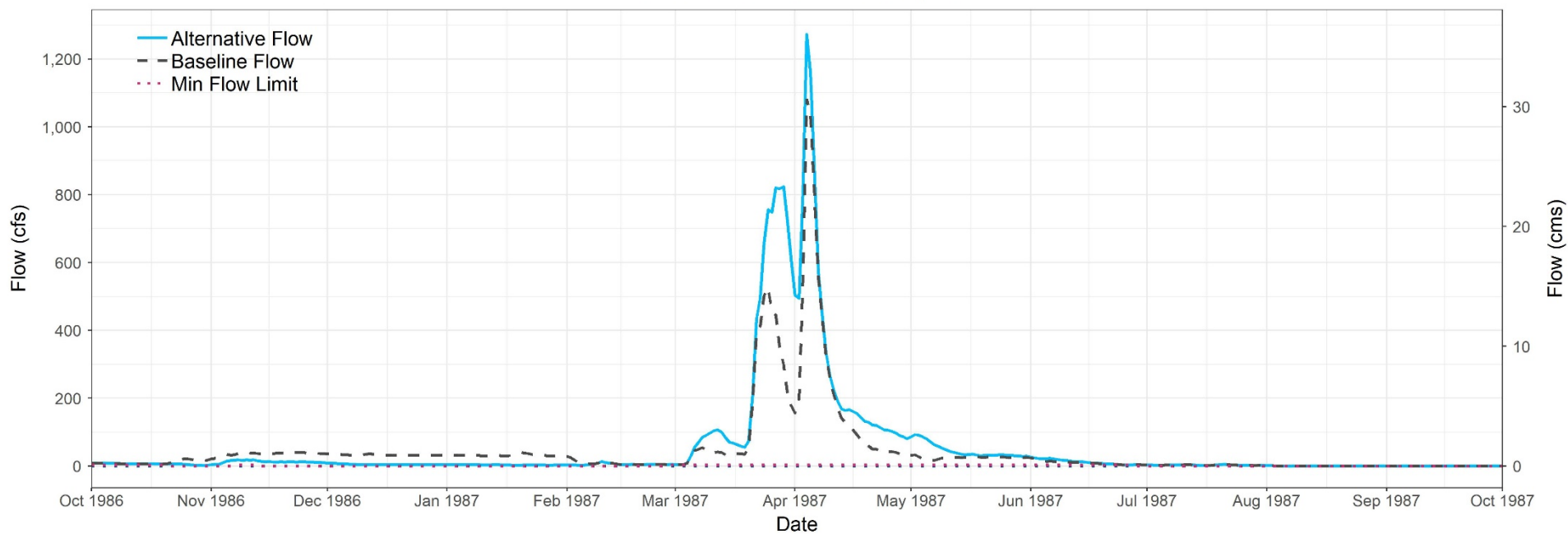
Souris River Plan of Study



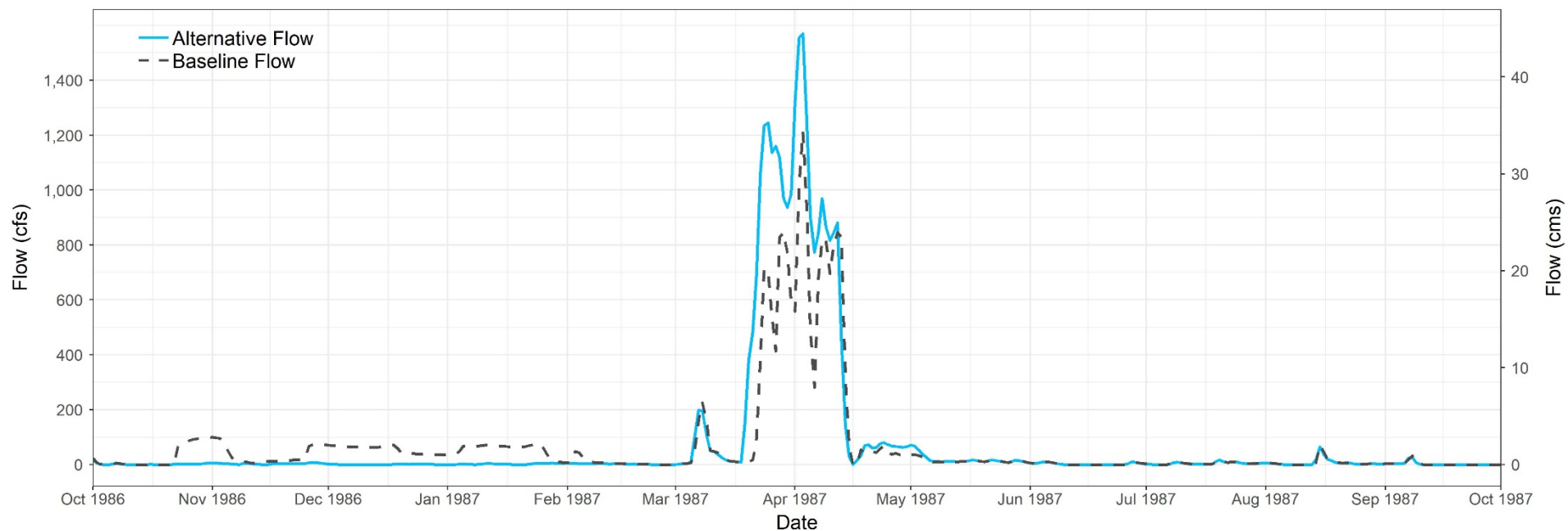
Souris River at Oxbow, SK



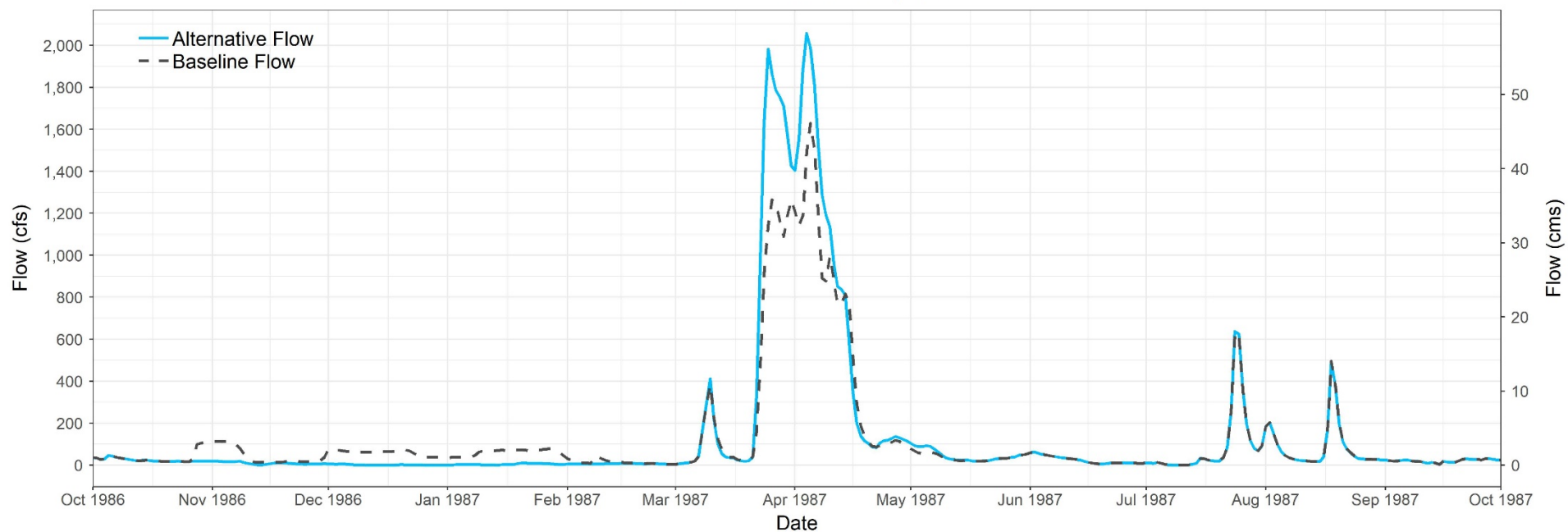
Souris River at Sherwood, ND



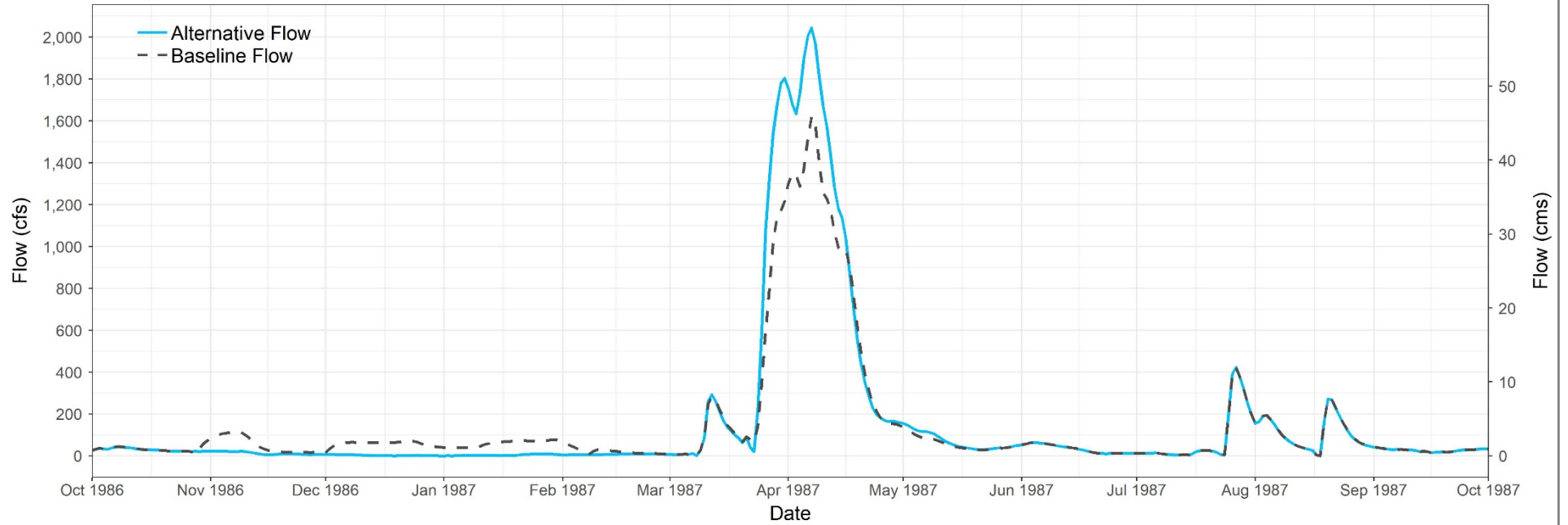
Souris River at Minot, ND - Flow



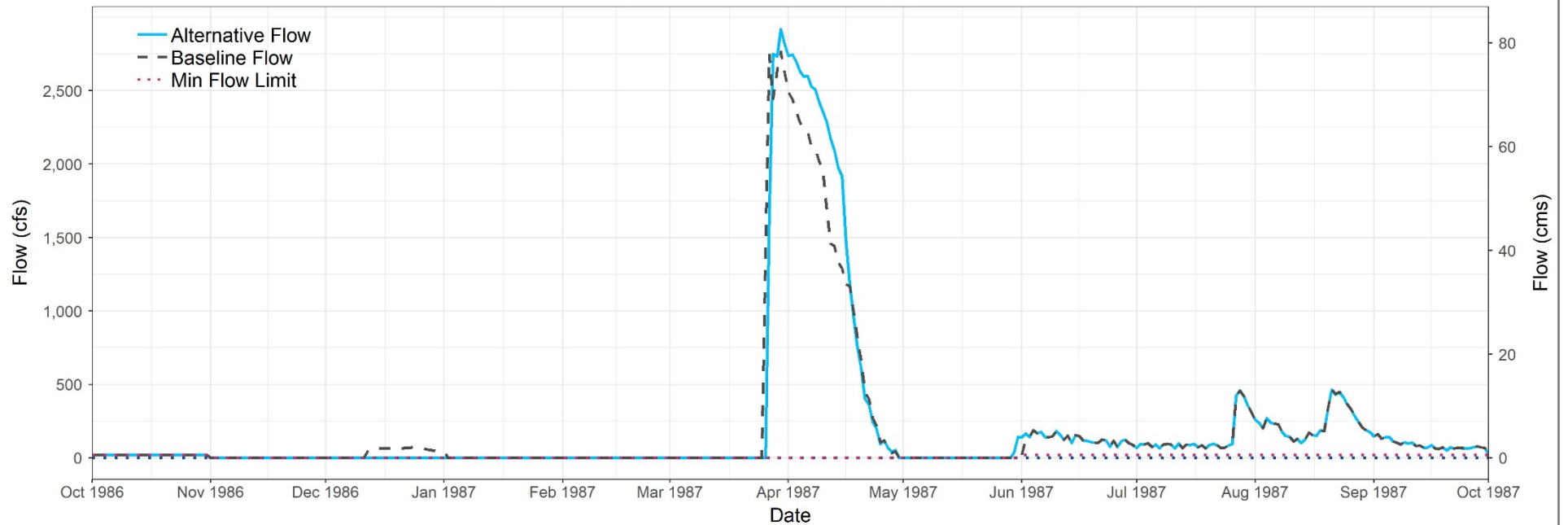
Souris River at Verendrye, ND



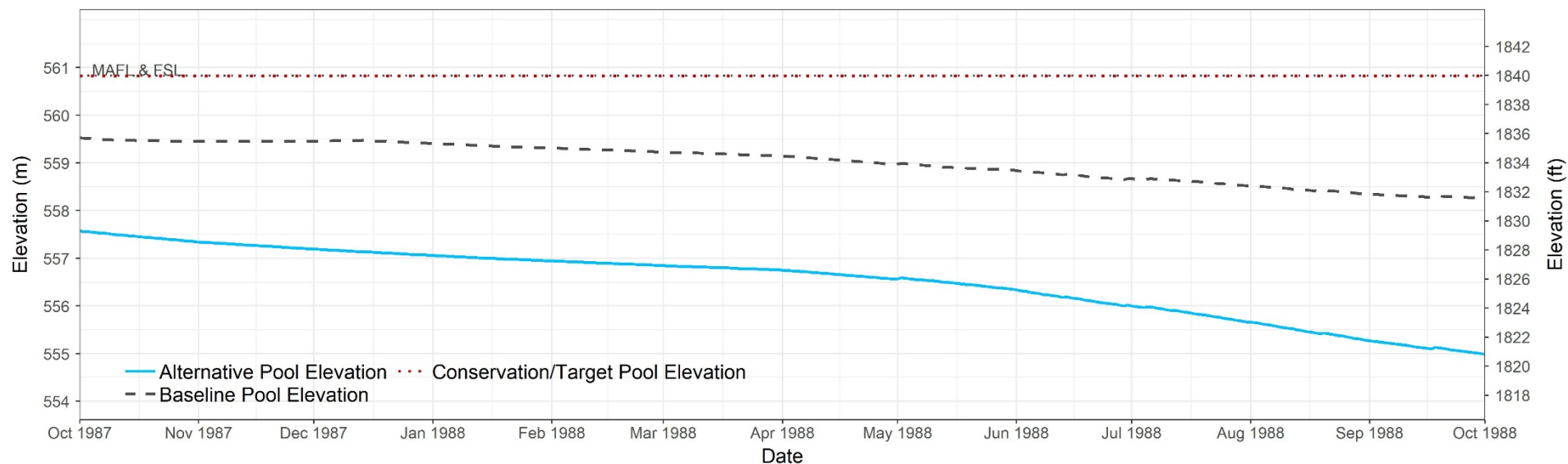
Souris River at Bantry, ND



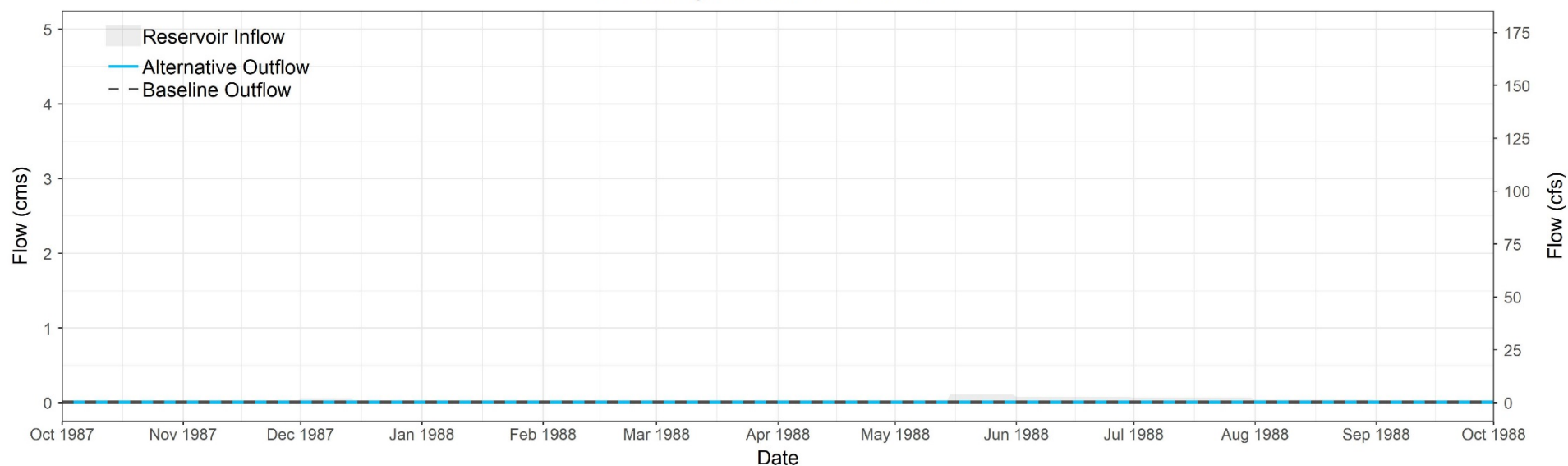
Souris River at Westhope, ND



Boundary Reservoir - Elevation

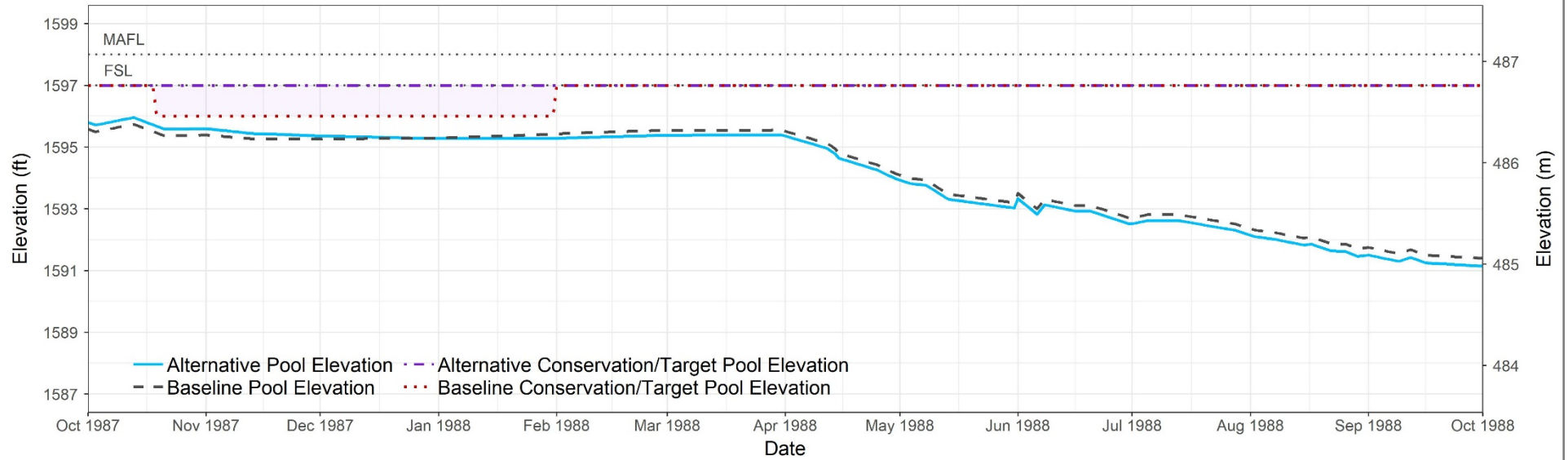


Boundary Reservoir - Releases

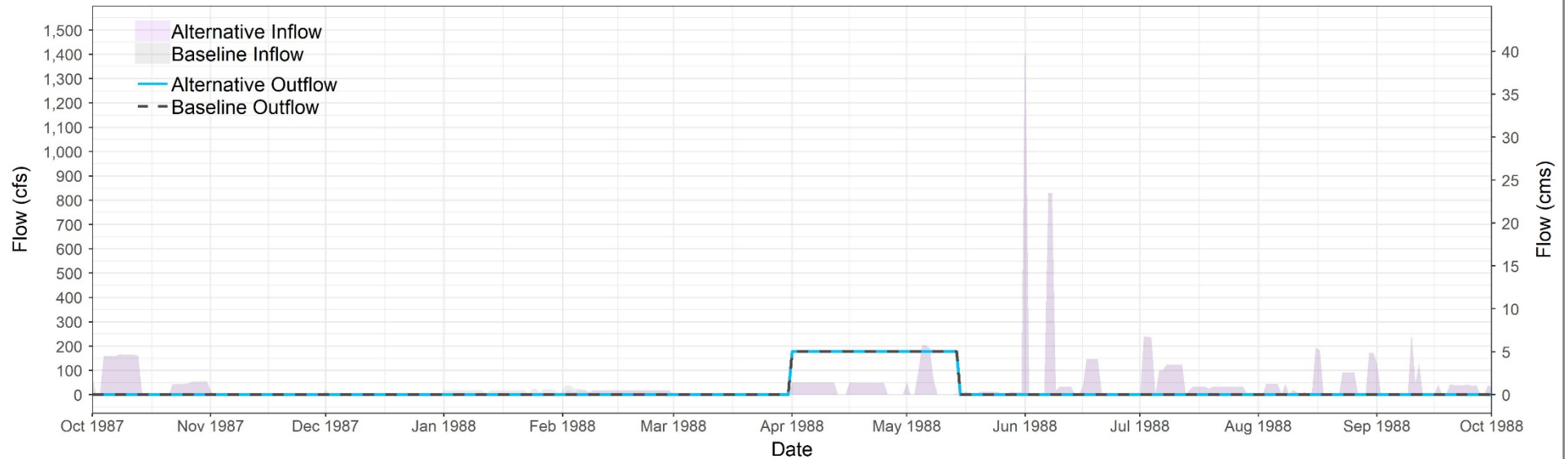


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



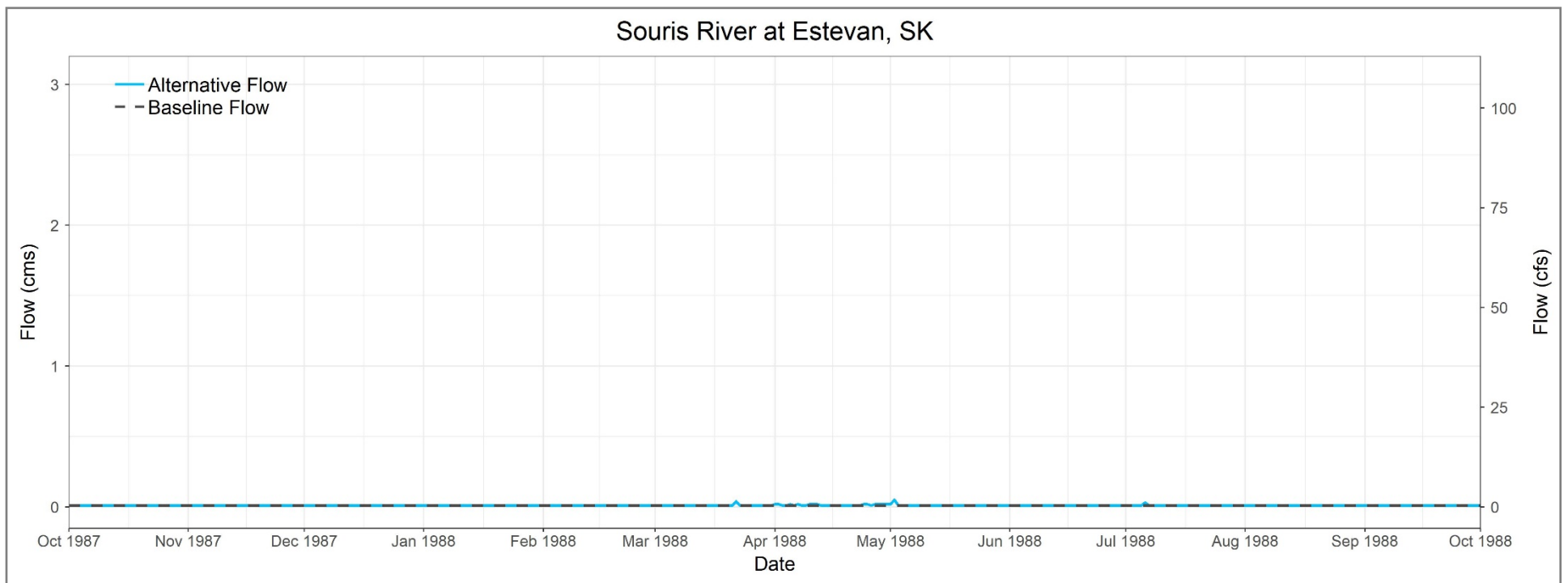
*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Plate 16

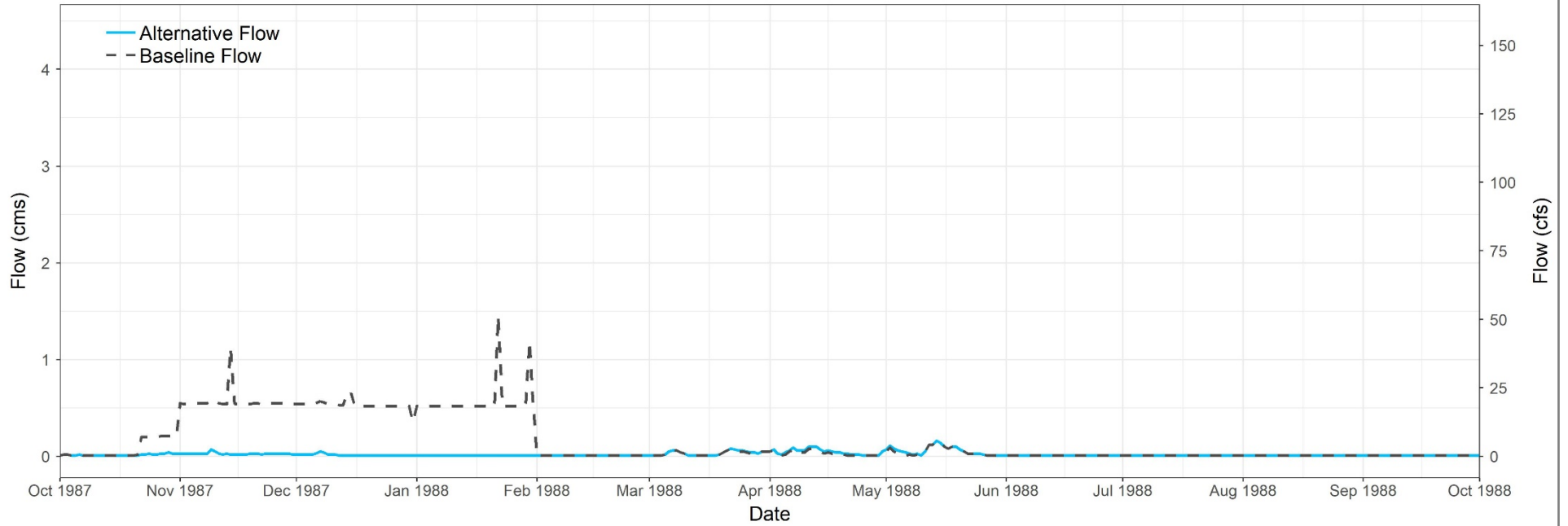
Critical Flow Locations – 1988

Alternative 8a (Phase 2)

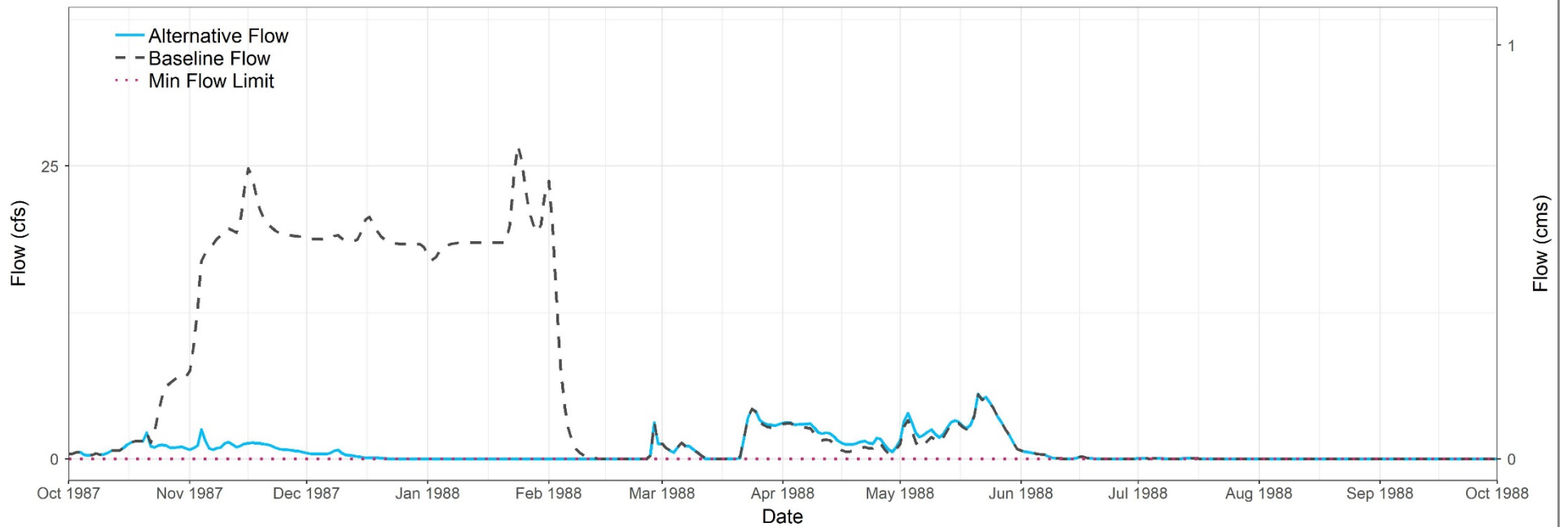
Souris River Plan of Study



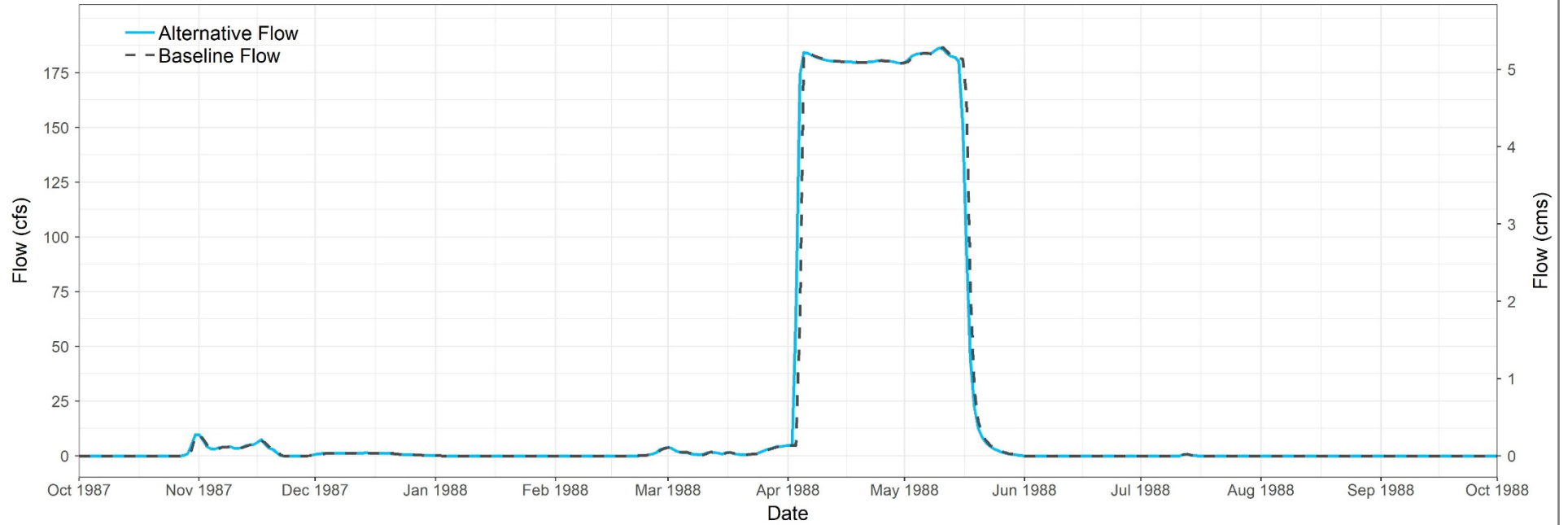
Souris River at Oxbow, SK



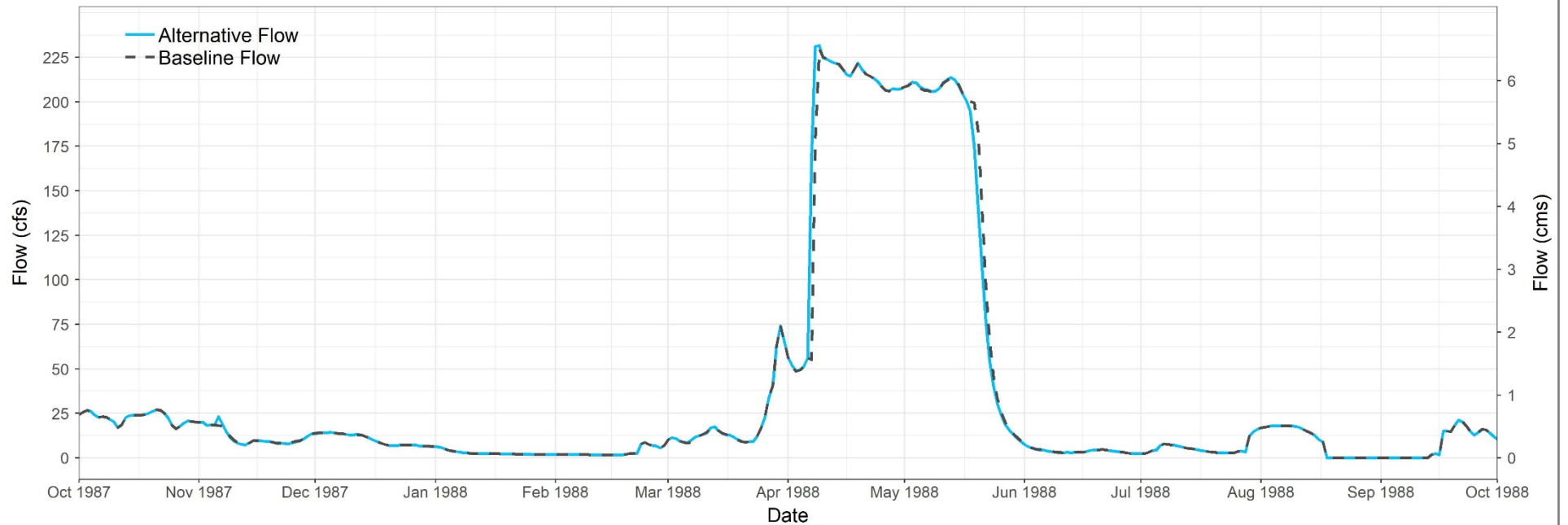
Souris River at Sherwood, ND



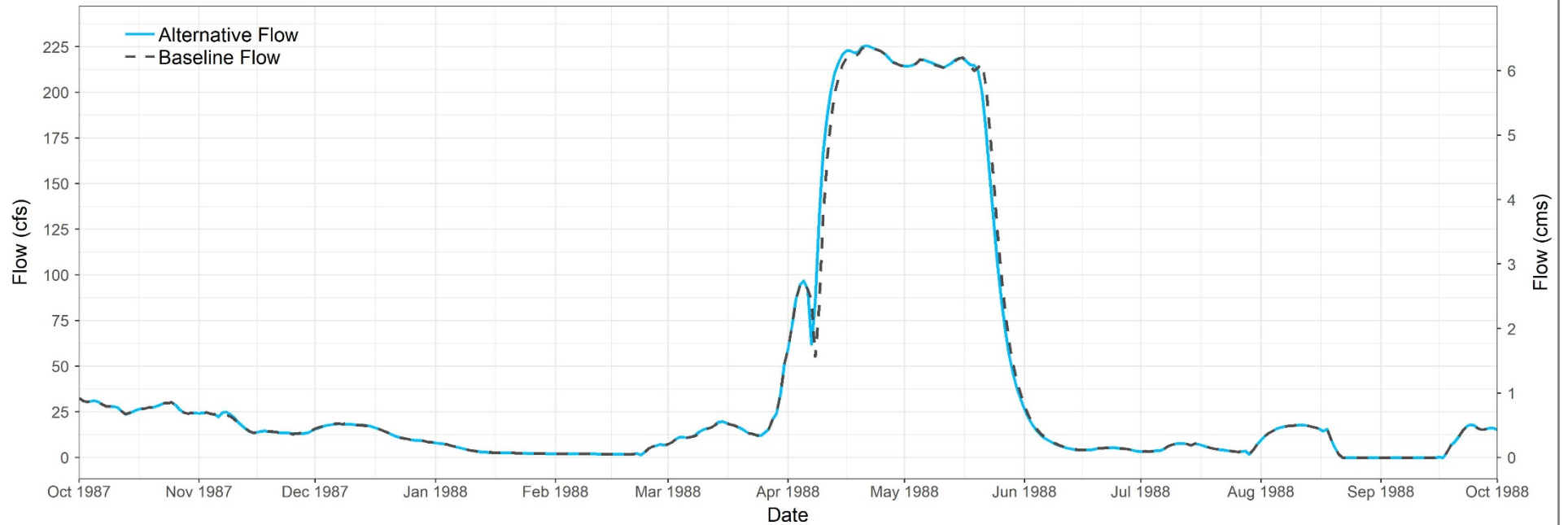
Souris River at Minot, ND - Flow



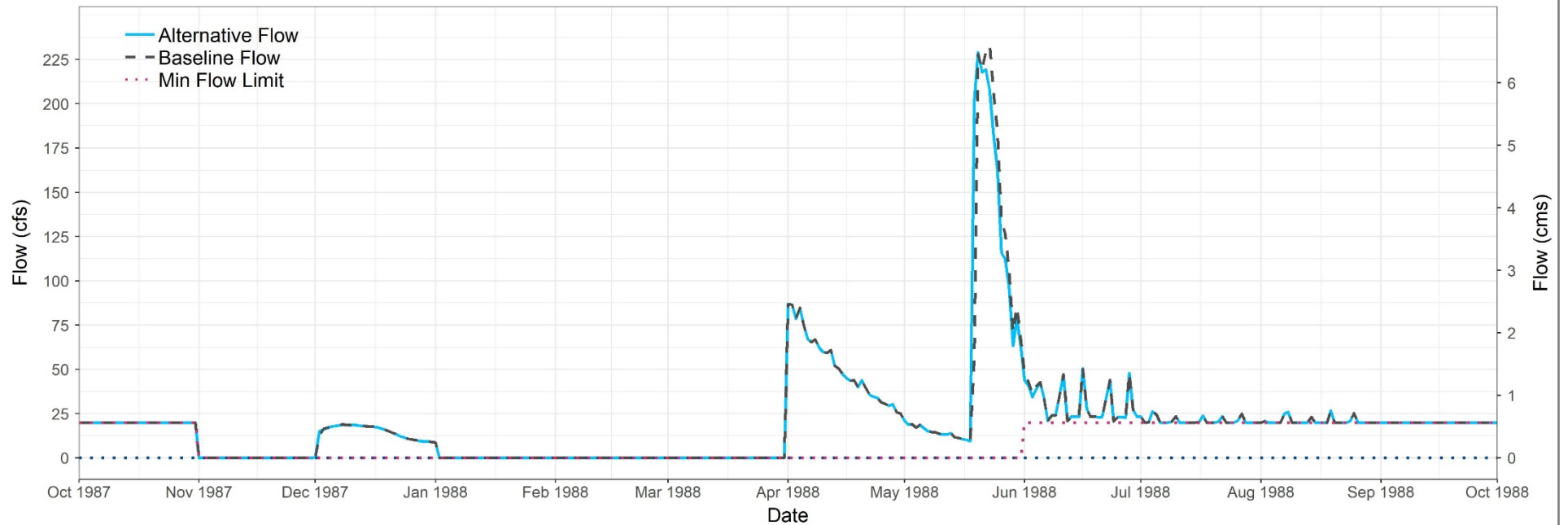
Souris River at Verendrye, ND



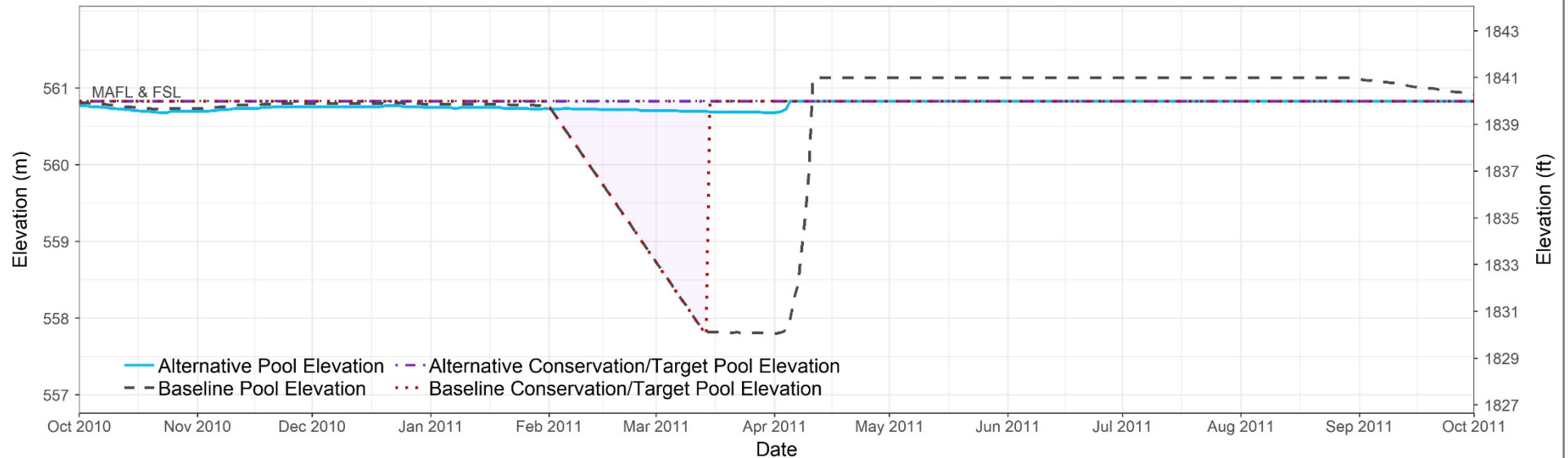
Souris River at Bantry, ND



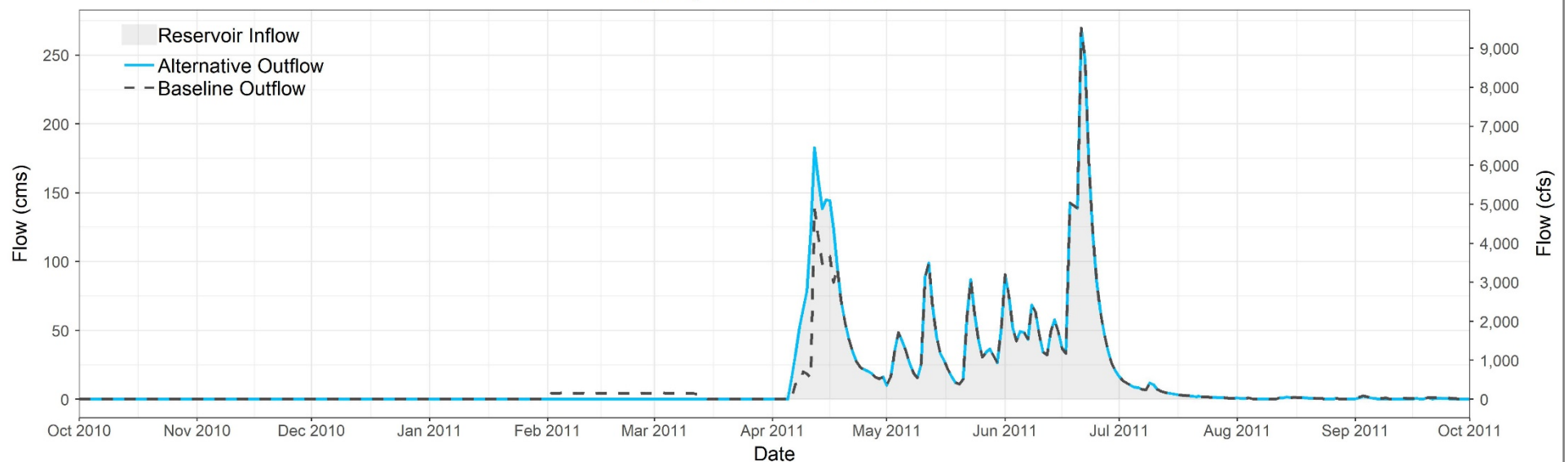
Souris River at Westhope, ND



Boundary Reservoir - Elevation

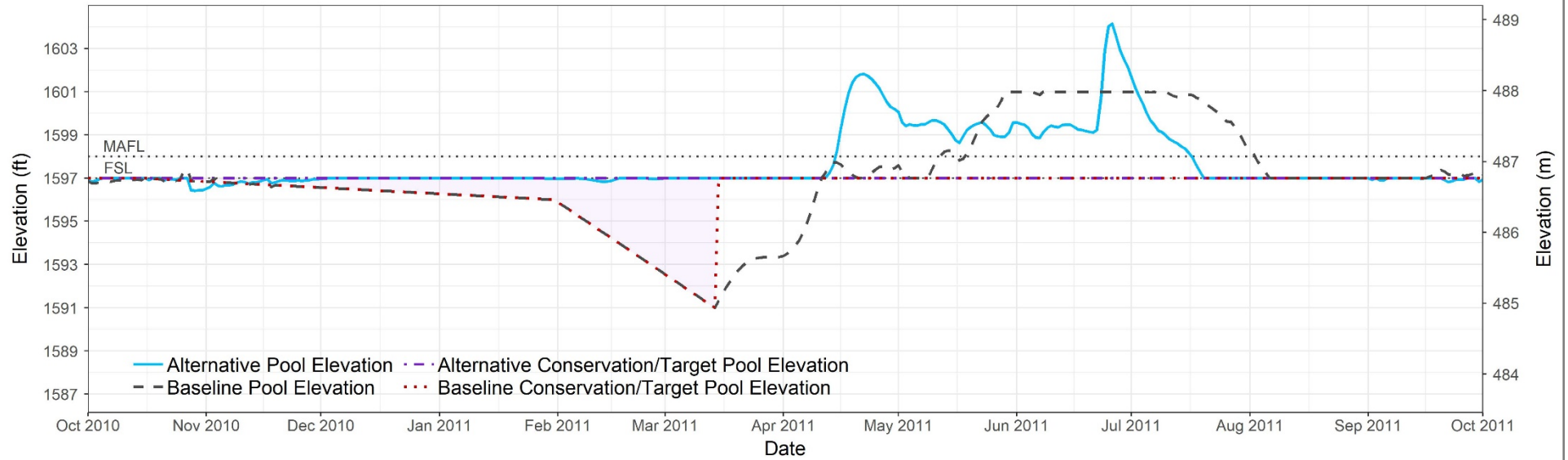


Boundary Reservoir - Releases

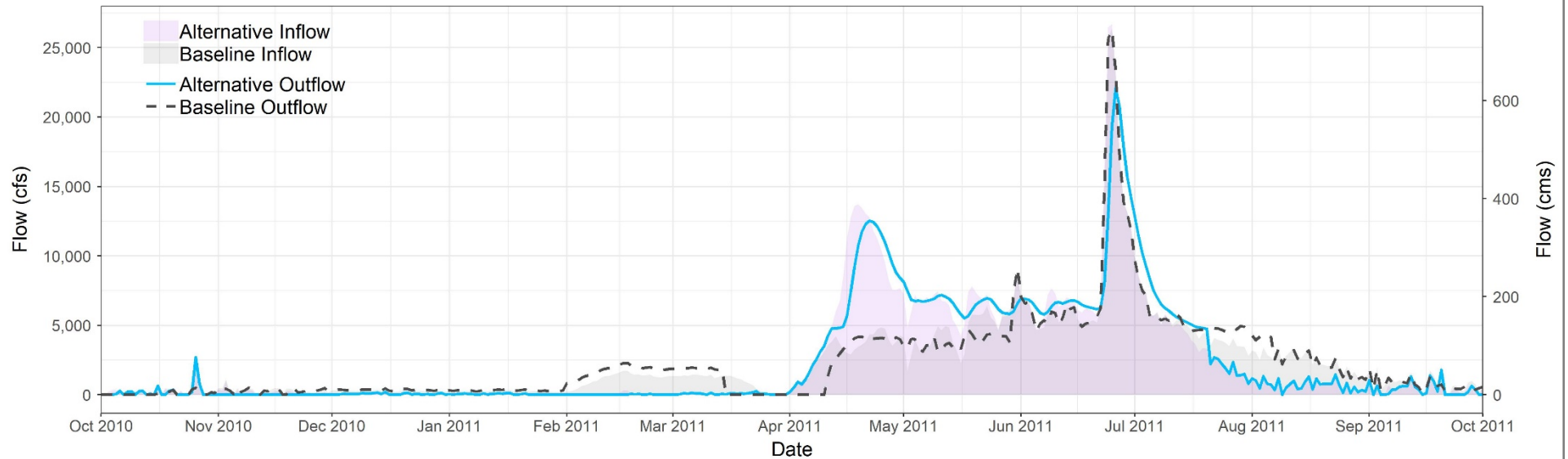


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Releases



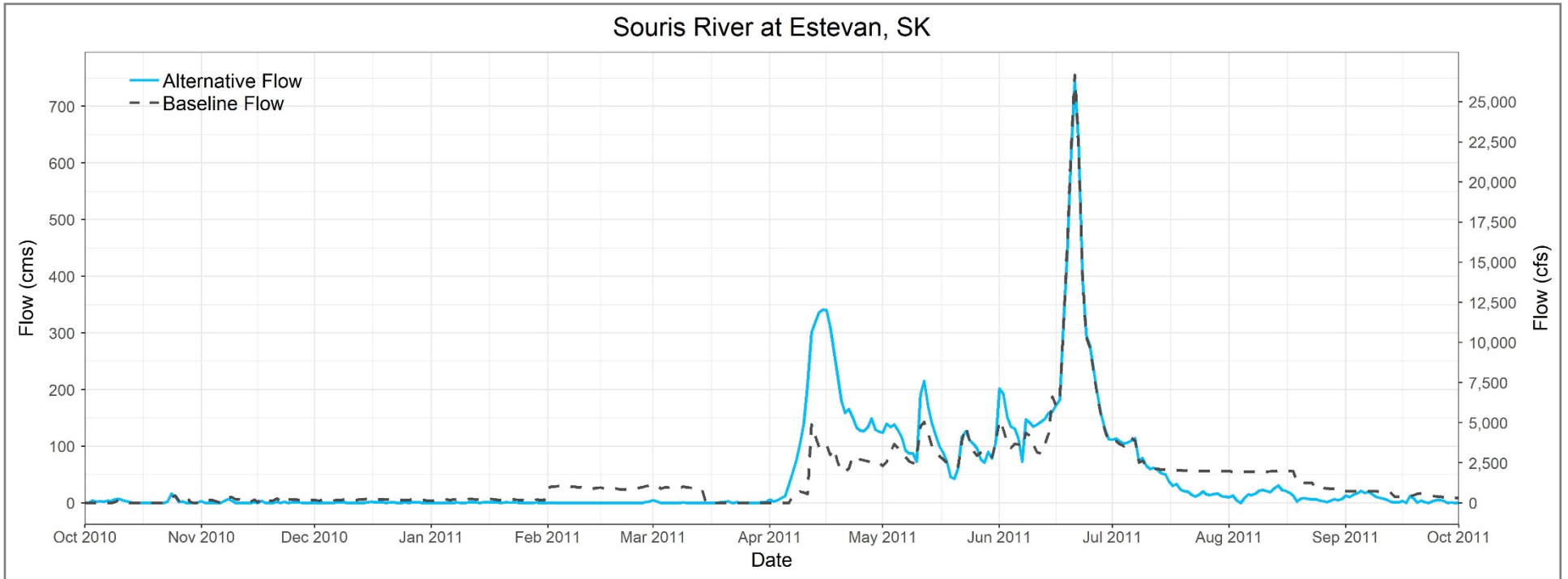
*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Plate 18

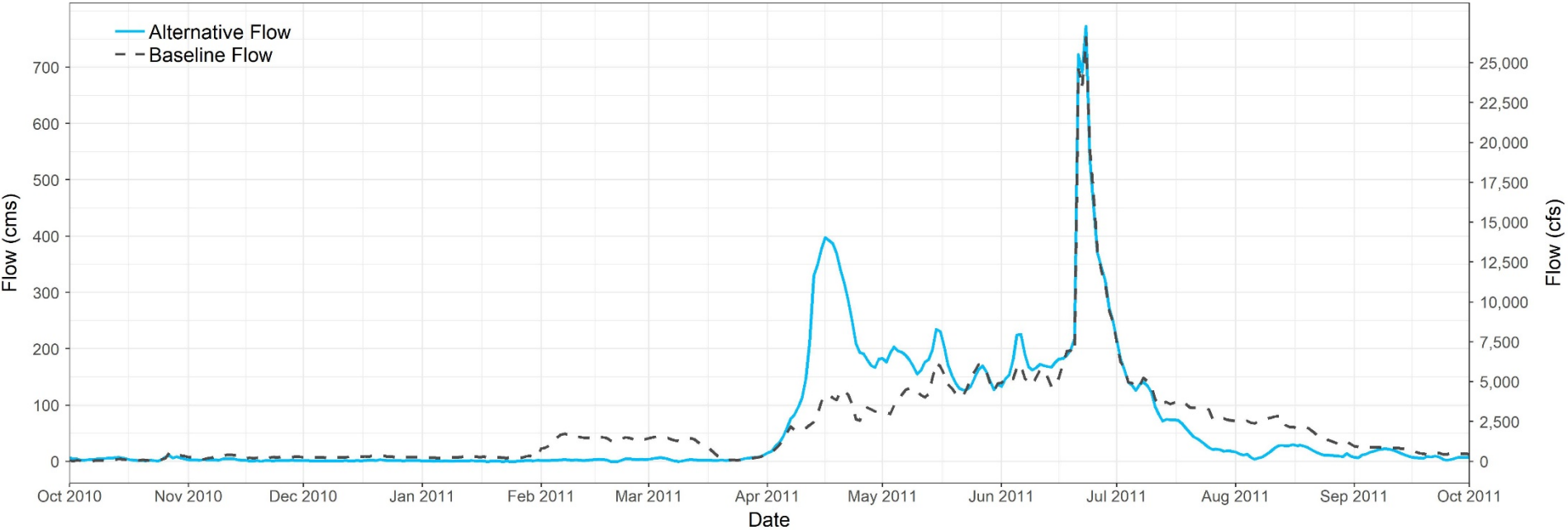
Critical Flow Locations – 2011

Alternative 8b (Phase 2)

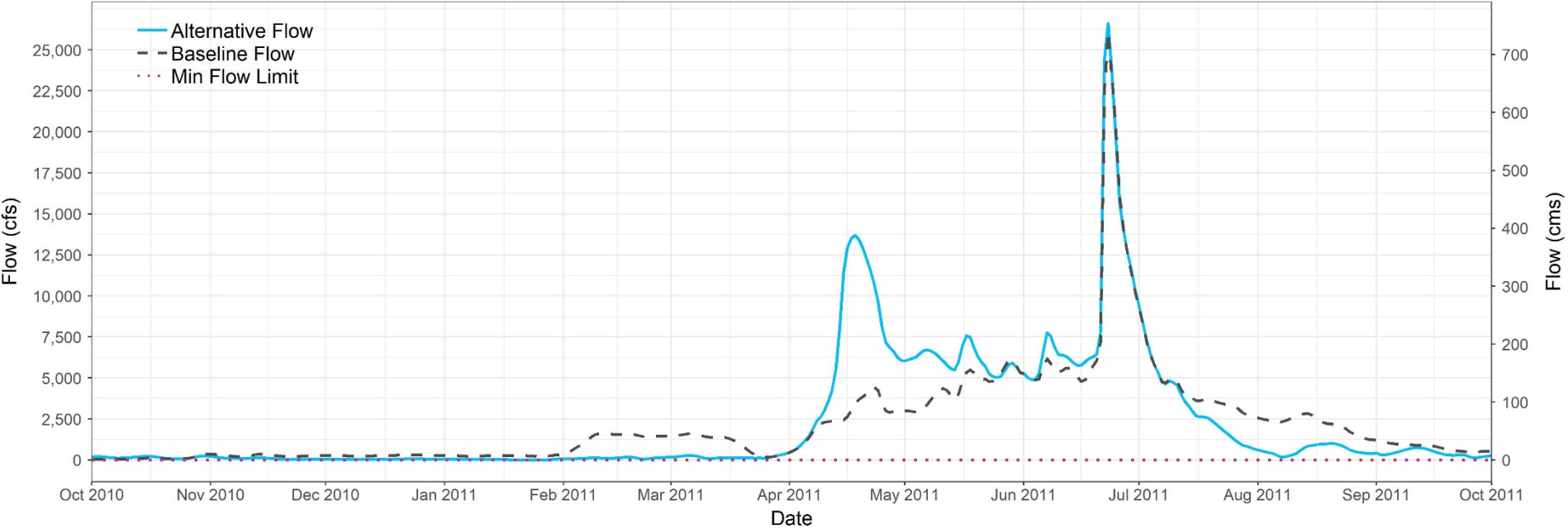
Souris River Plan of Study



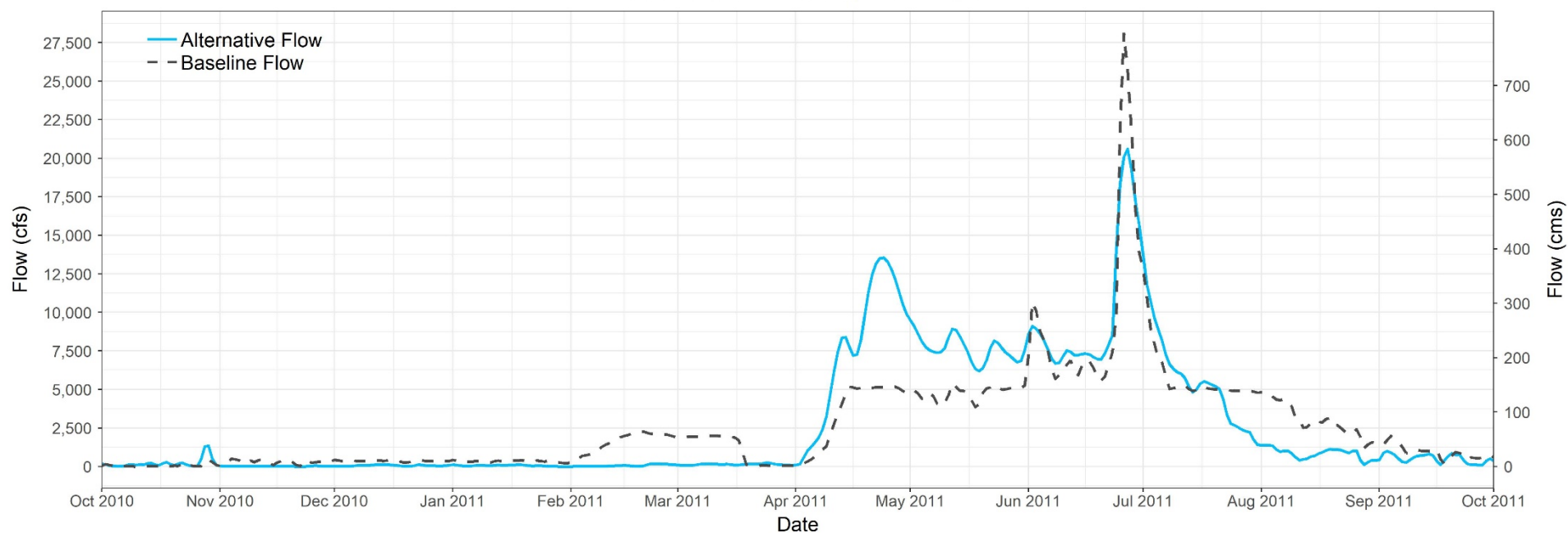
Souris River at Oxbow, SK



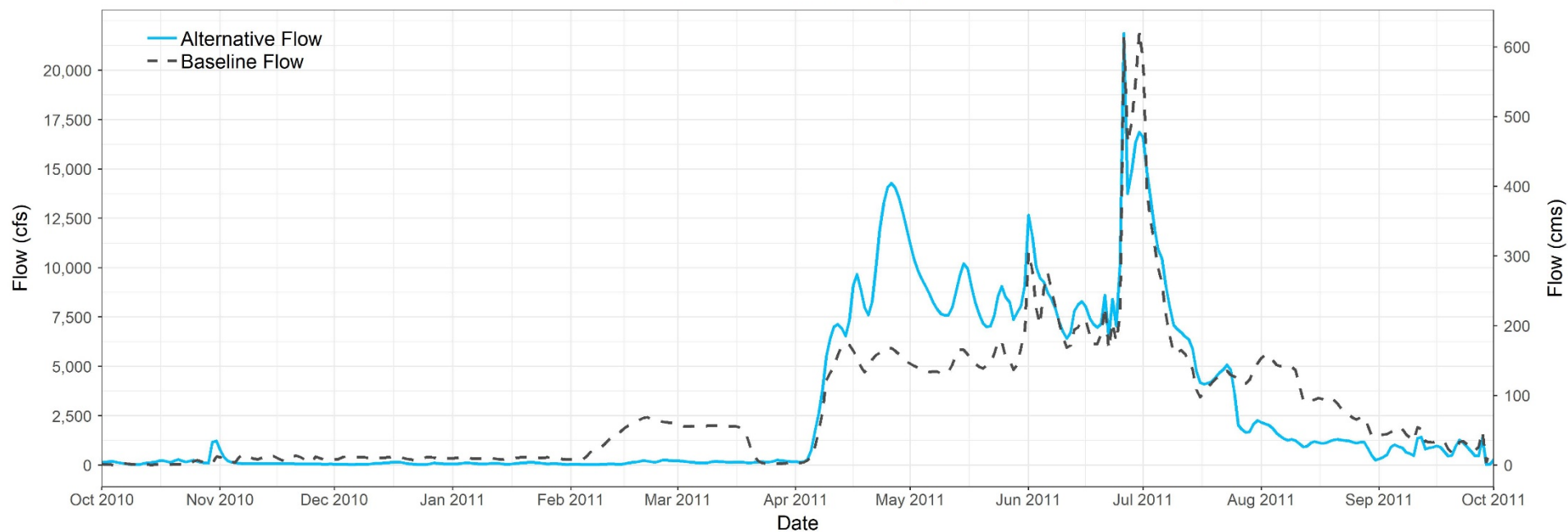
Souris River at Sherwood, ND



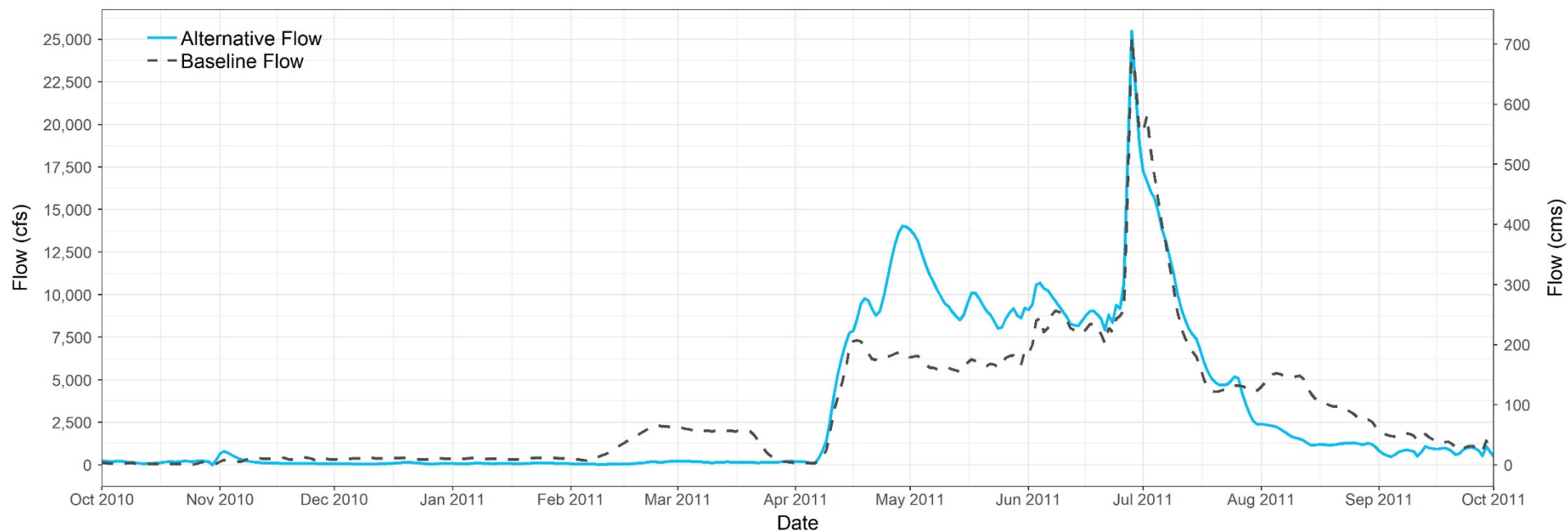
Souris River at Minot, ND - Flow



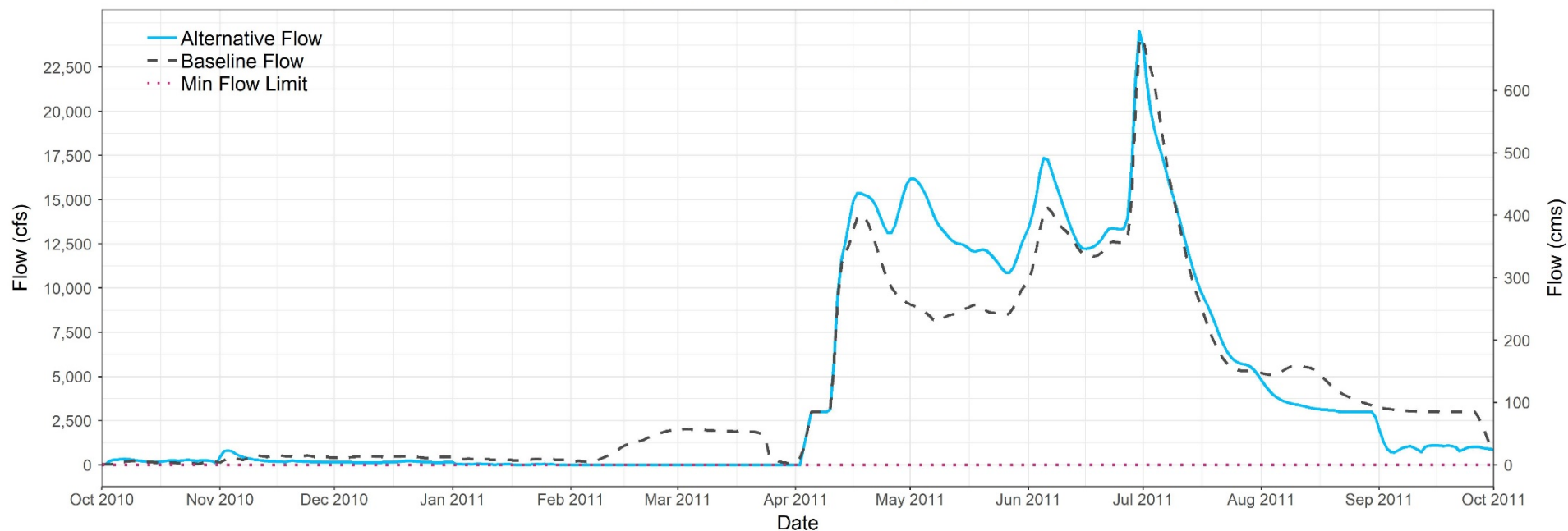
Souris River at Verendrye, ND



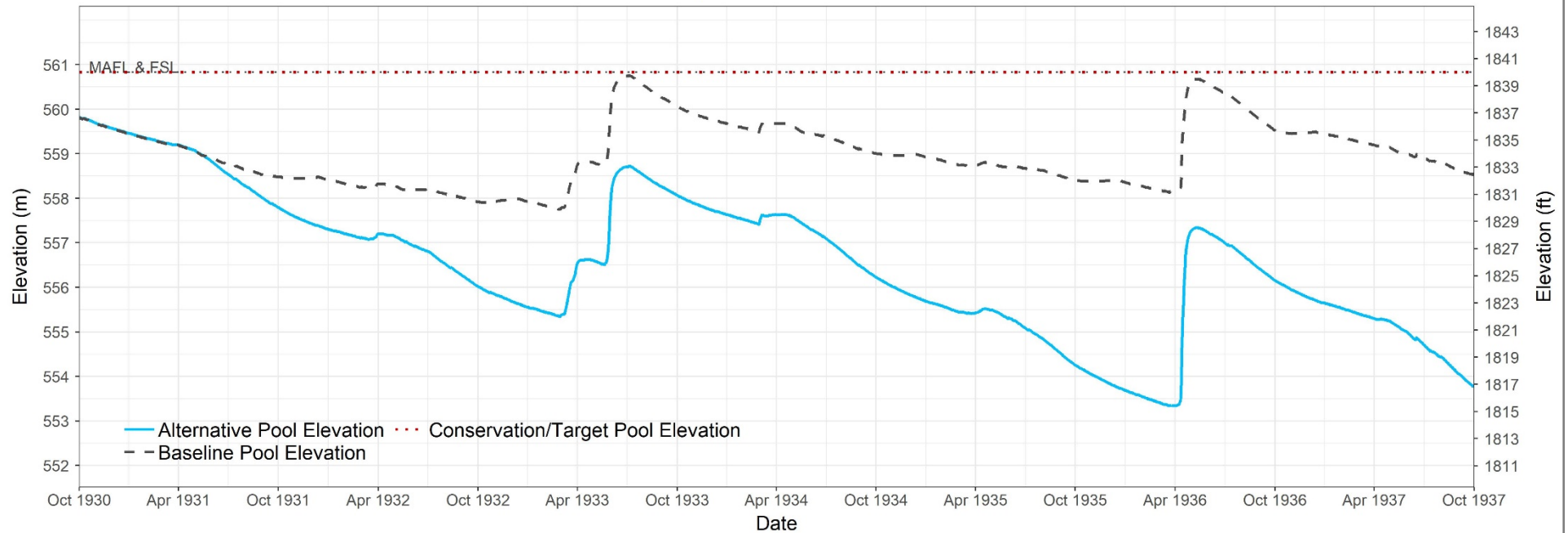
Souris River at Bantry, ND



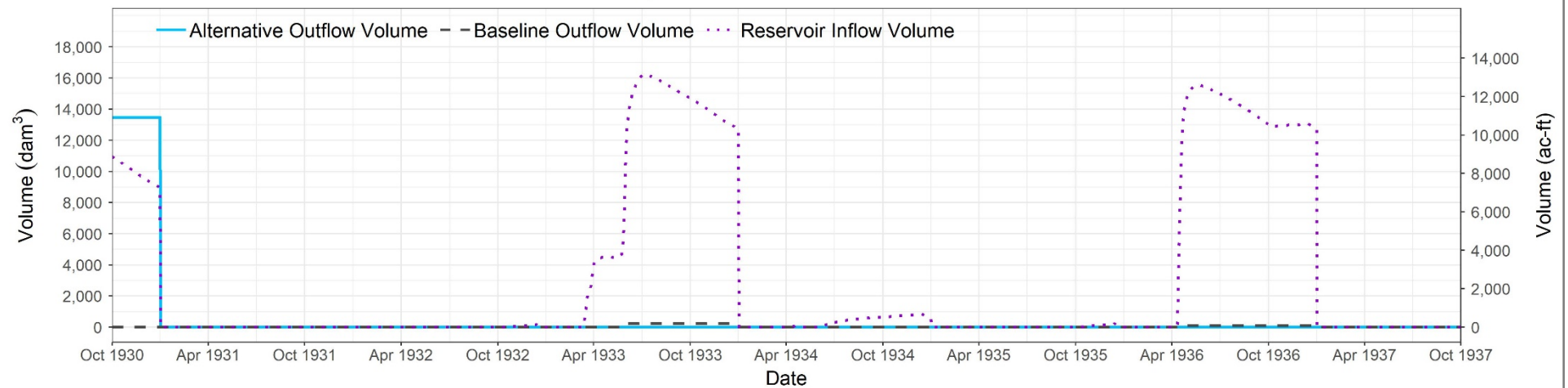
Souris River at Westhope, ND



Boundary Reservoir - Elevation

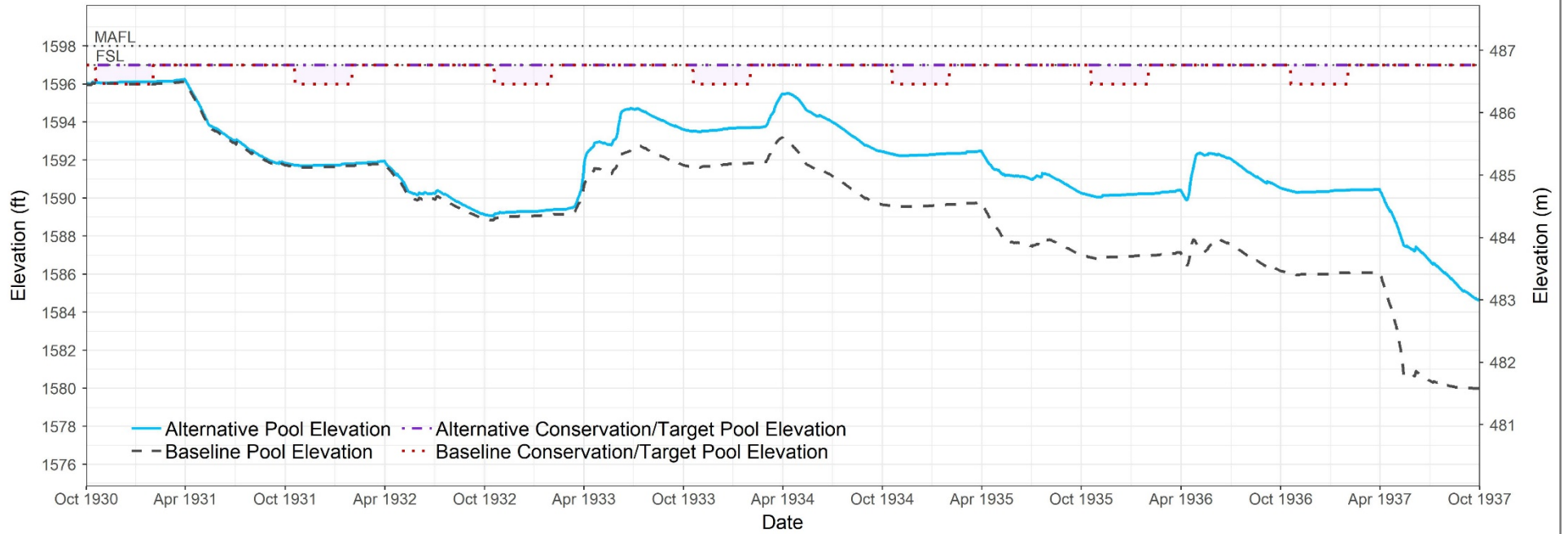


Boundary Reservoir - Cumulative Volume

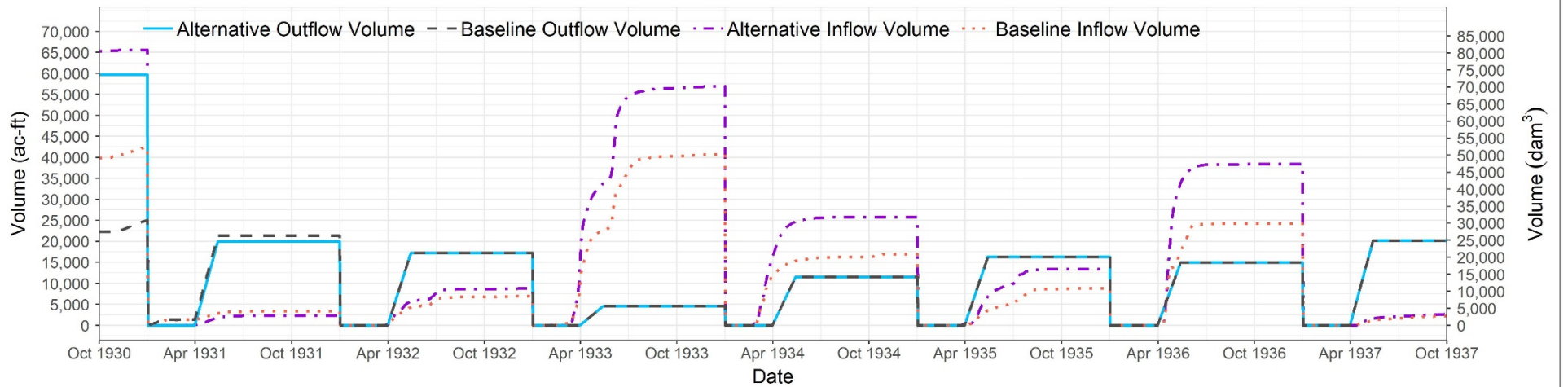


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Cumulative Volume



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

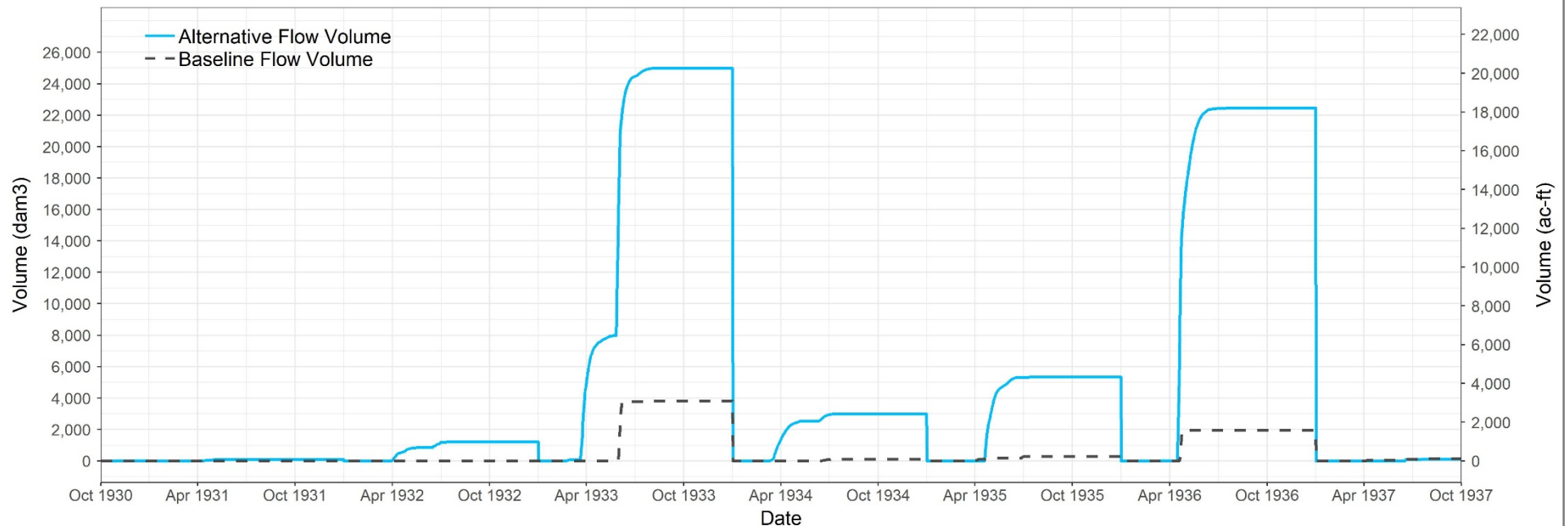
Plate 20

Critical Flow Locations – 1931-1937

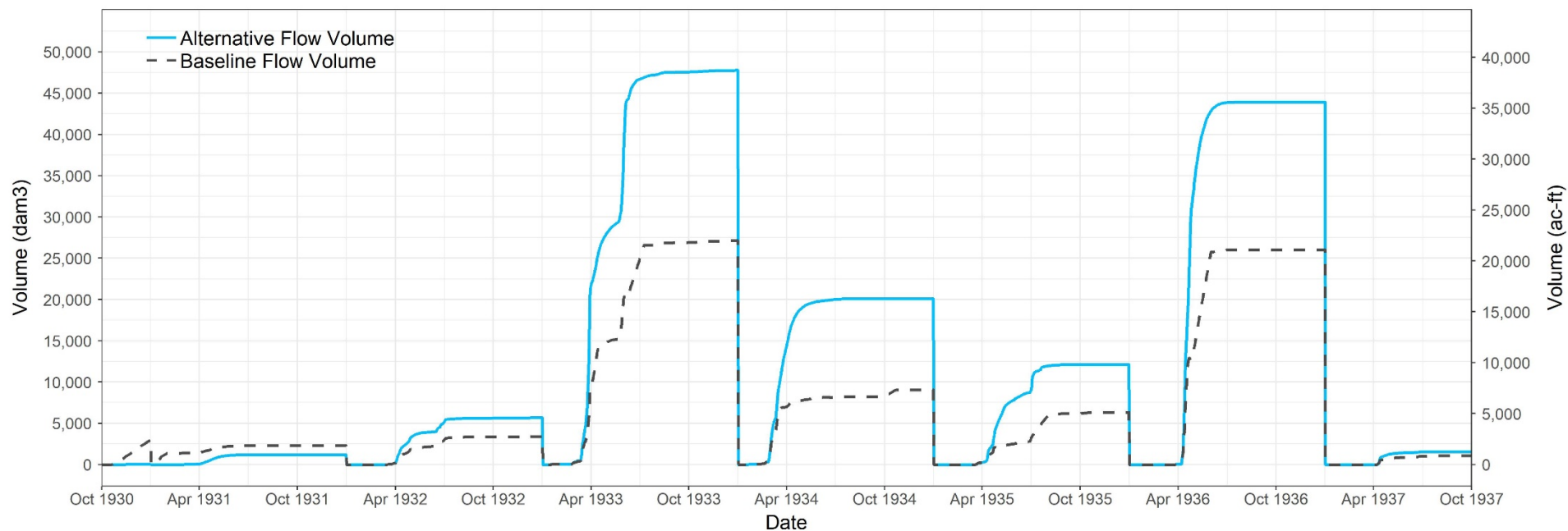
Alternative 8b (Phase 2)

Souris River Plan of Study

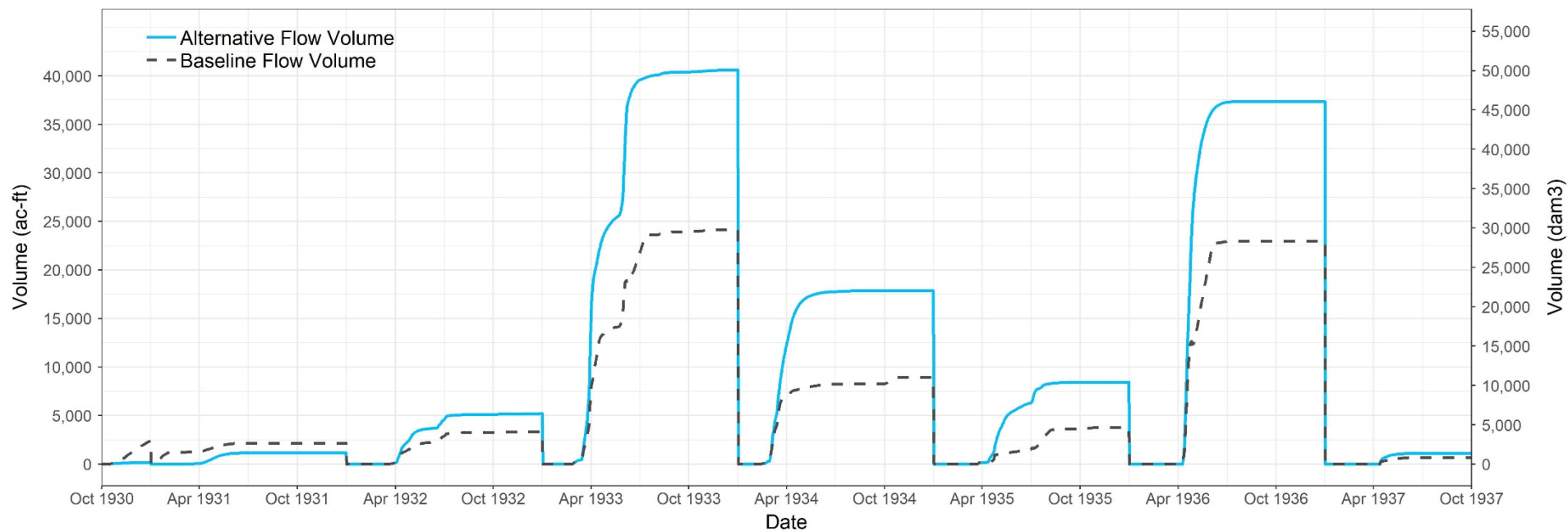
Souris River at Estevan, SK - Cumulative Volume



Souris River at Oxbow, SK - Cumulative Volume



Souris River at Sherwood, ND - Cumulative Volume



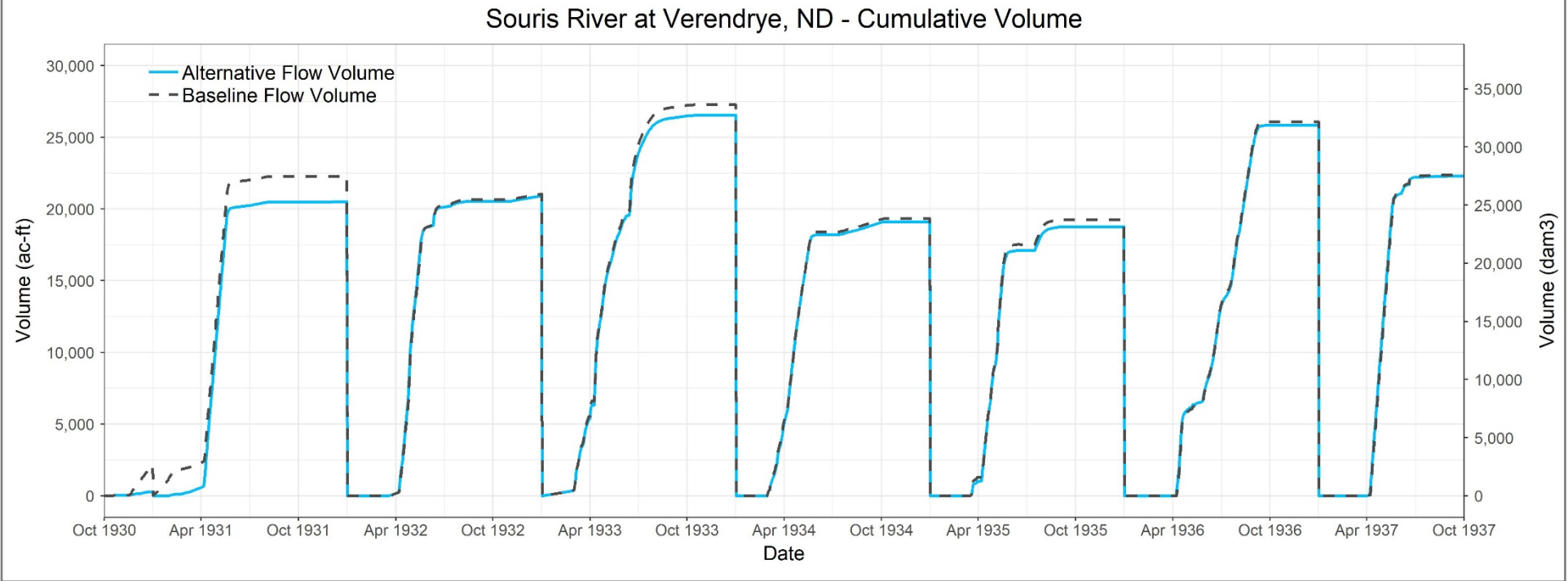
The figure consists of two line graphs, one for the Souris River at Minot, ND, and one for the Souris River at Verendrye, ND. Both graphs compare the Alternative Flow Volume (solid blue line) and the Baseline Flow Volume (dashed black line) from October 1930 to October 1937. The left y-axis represents Volume in acre-feet (ac-ft), and the right y-axis represents Volume in dam-cubic meters (dam3). The x-axis represents the Date.

Souris River at Minot, ND - Cumulative Volume

The graph for Minot shows the Alternative Flow Volume (solid blue line) and the Baseline Flow Volume (dashed black line). The Alternative Flow Volume is generally lower than the Baseline Flow Volume, especially during the initial rise in 1931 and the subsequent peaks in 1932, 1933, 1935, and 1936. The Baseline Flow Volume shows a more pronounced step-like pattern, with sharp increases and decreases. The Alternative Flow Volume follows a similar but smoother pattern, with lower peak values.

Souris River at Verendrye, ND - Cumulative Volume

The graph for Verendrye shows the Alternative Flow Volume (solid blue line) and the Baseline Flow Volume (dashed black line). The Alternative Flow Volume is generally lower than the Baseline Flow Volume, particularly during the initial rise in 1931 and the subsequent peaks in 1932, 1933, 1935, and 1936. The Baseline Flow Volume shows a more pronounced step-like pattern, with sharp increases and decreases. The Alternative Flow Volume follows a similar but smoother pattern, with lower peak values.



Souris River at Bantry, ND - Cumulative Volume

Volume (ac-ft) (Left Y-axis): 0 to 45,000
 Volume (dam3) (Right Y-axis): 0 to 55,000

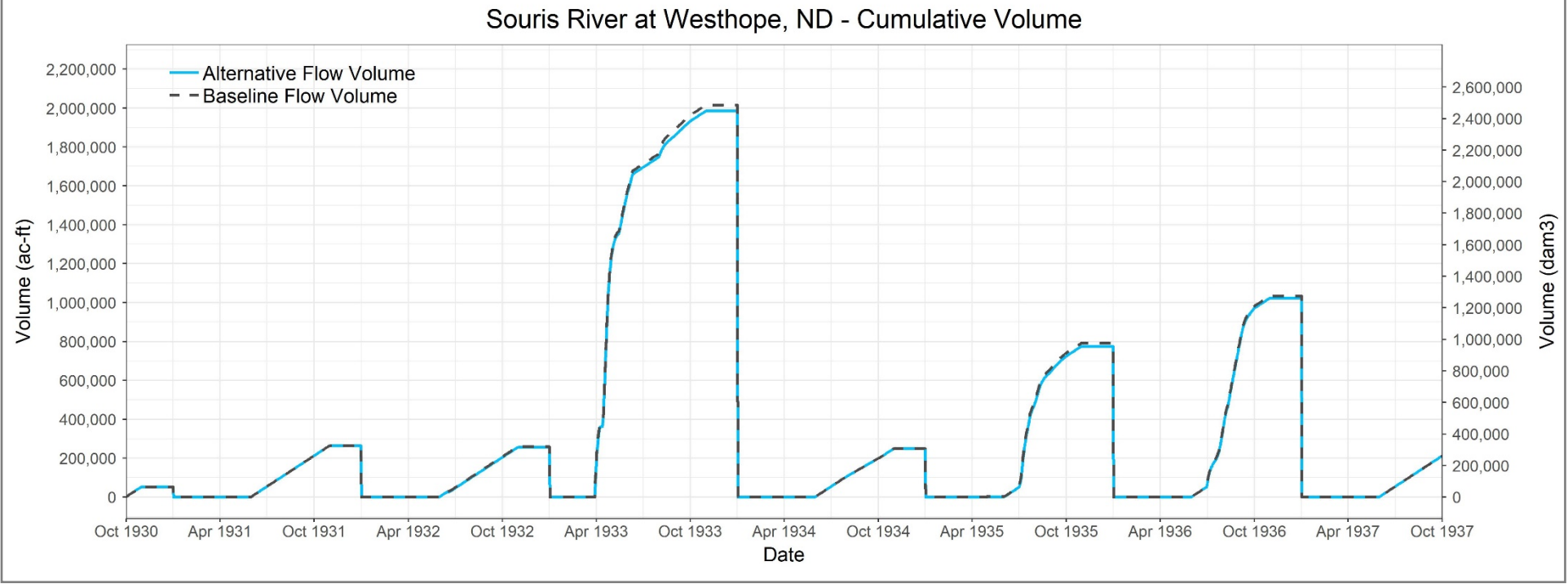
Legend: Alternative Flow Volume (Solid Blue Line), Baseline Flow Volume (Dashed Black Line)

Souris River at Westhope, ND - Cumulative Volume

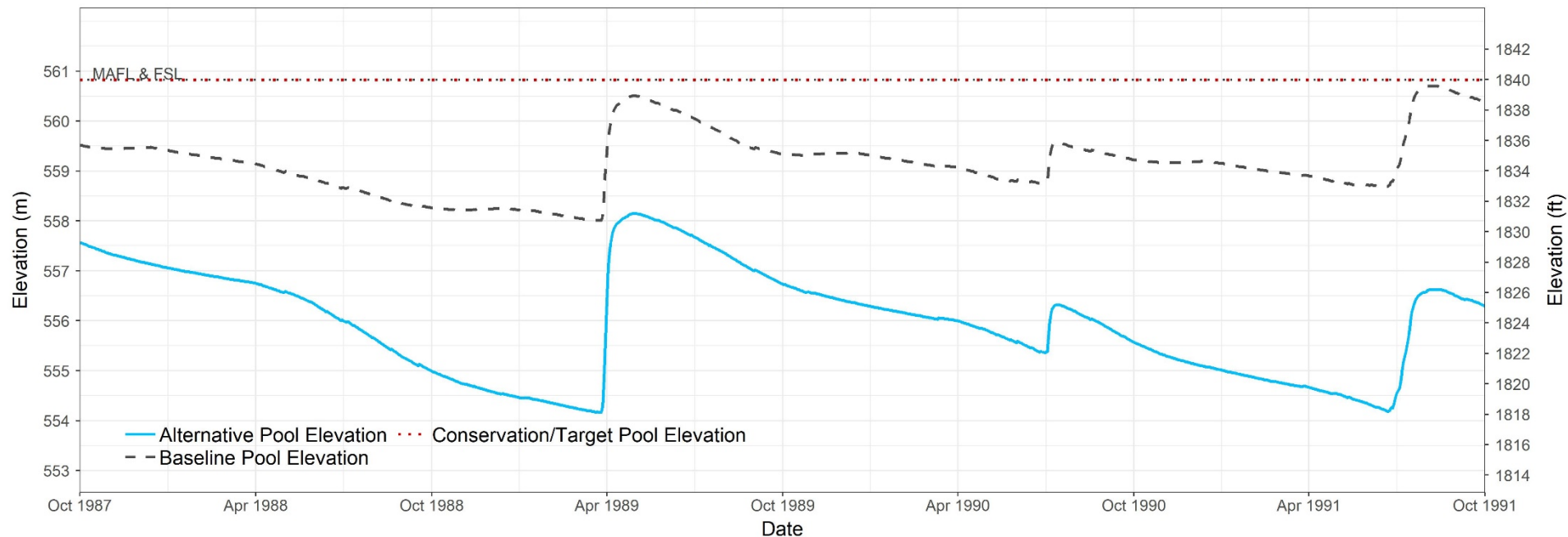
Volume (ac-ft) (Left Y-axis): 0 to 2,200,000
 Volume (dam3) (Right Y-axis): 0 to 2,600,000

Legend: Alternative Flow Volume (Solid Blue Line), Baseline Flow Volume (Dashed Black Line)

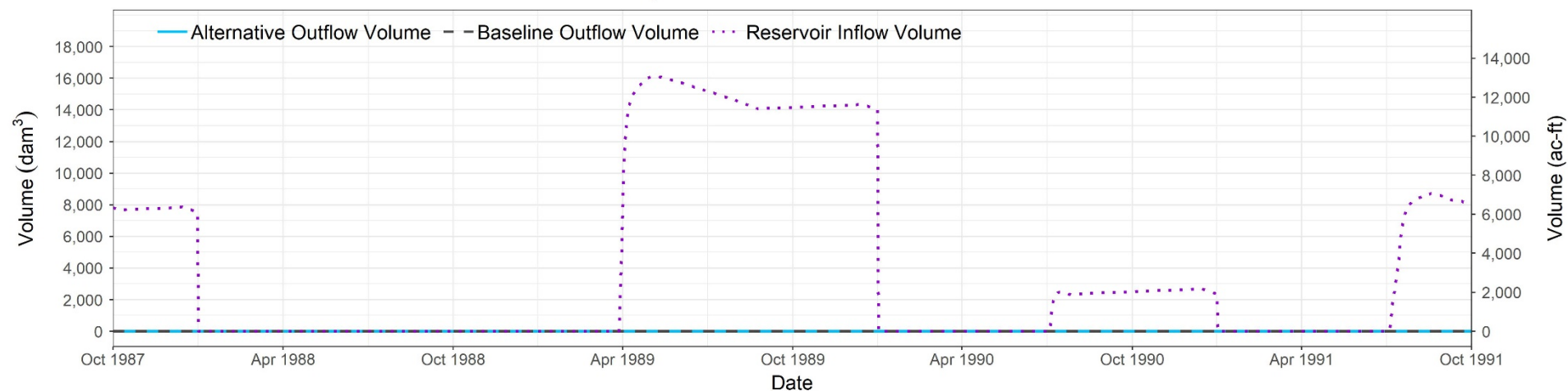
Both graphs show a significant increase in volume starting around 1933, peaking around 1934, and then declining. The Alternative Flow Volume is generally slightly lower than the Baseline Flow Volume during the peak periods.



Boundary Reservoir - Elevation

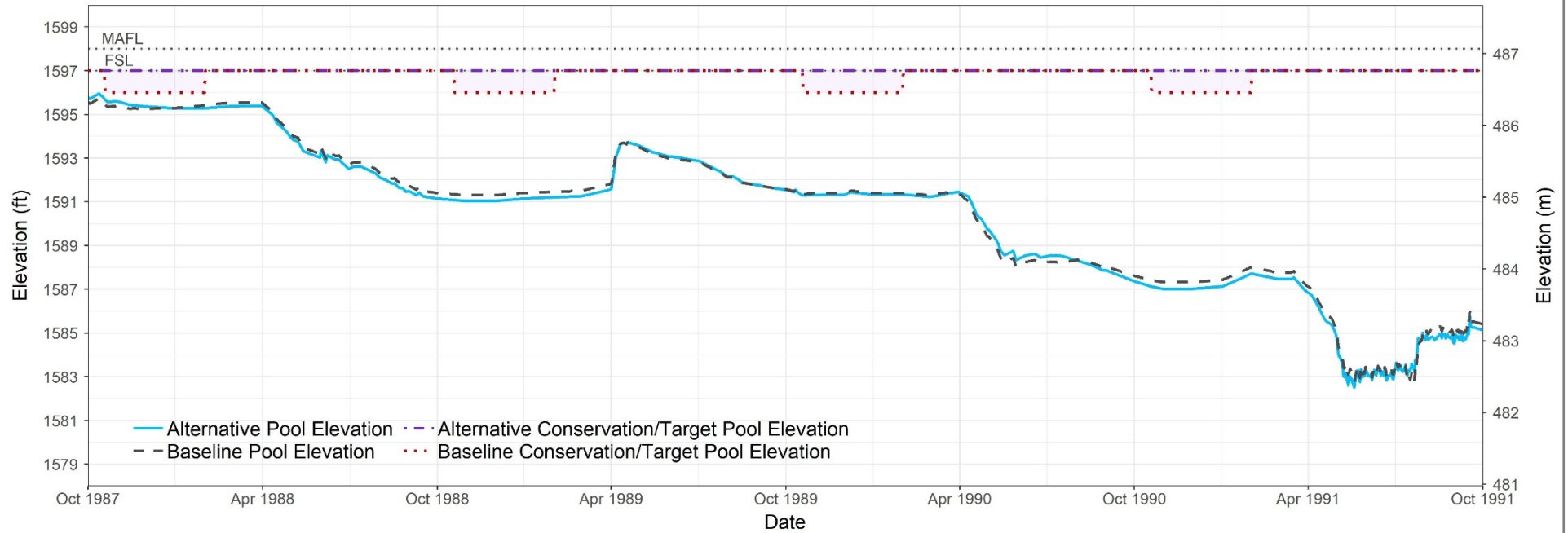


Boundary Reservoir - Cumulative Volume

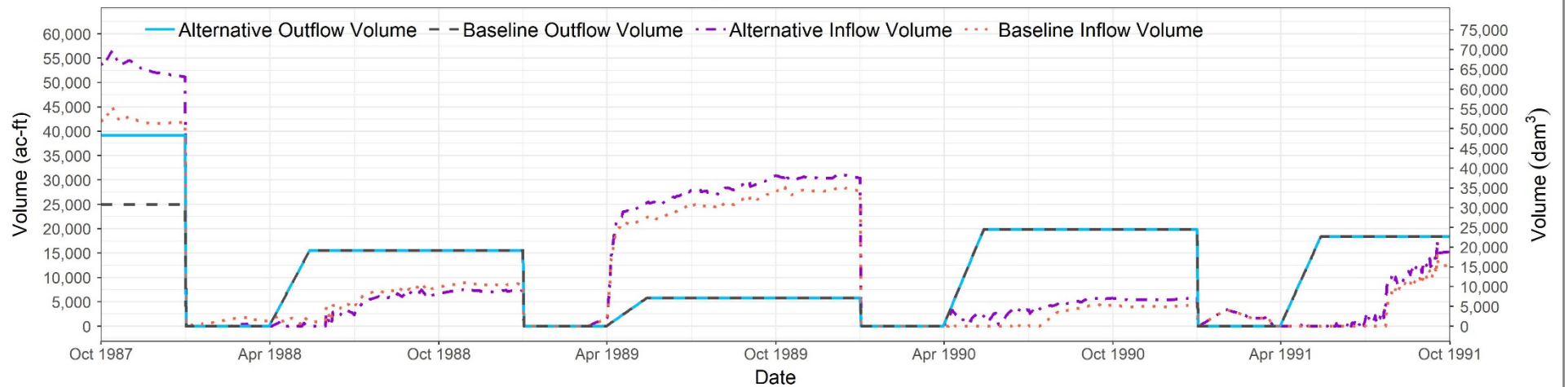


*MAFL = Maximum Allowable Flood Level, FSL = Full Supply Level

Lake Darling - Elevation



Lake Darling - Cumulative Volume



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

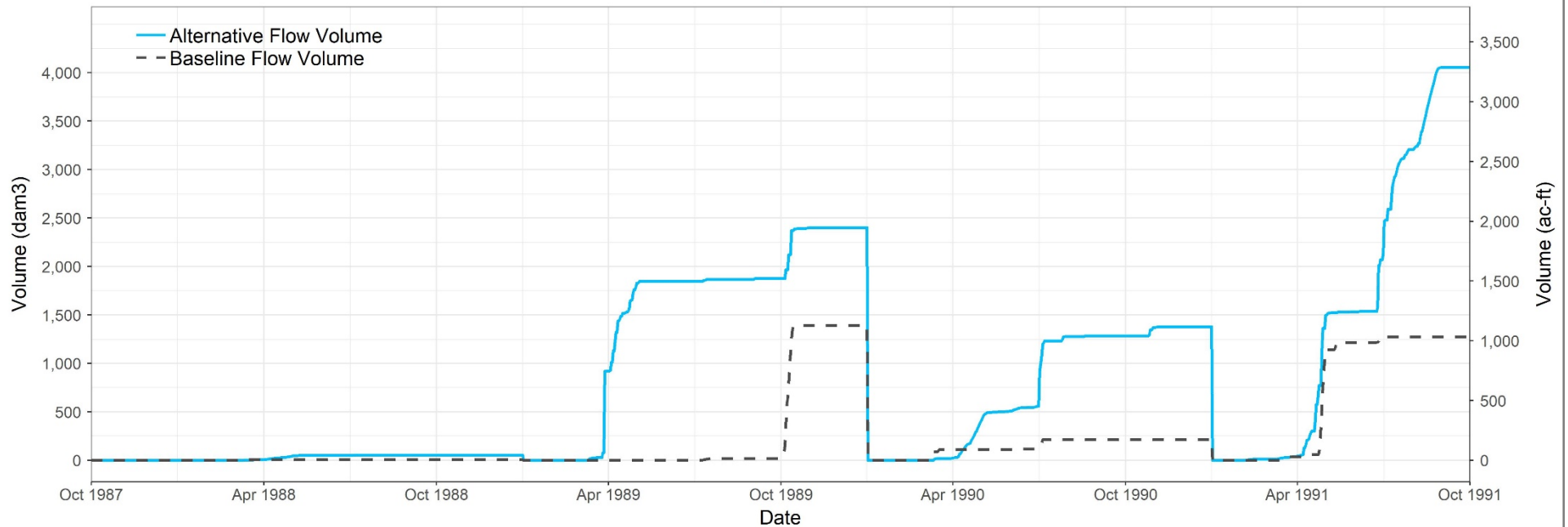
Plate 22

Critical Flow Locations – 1988-1991

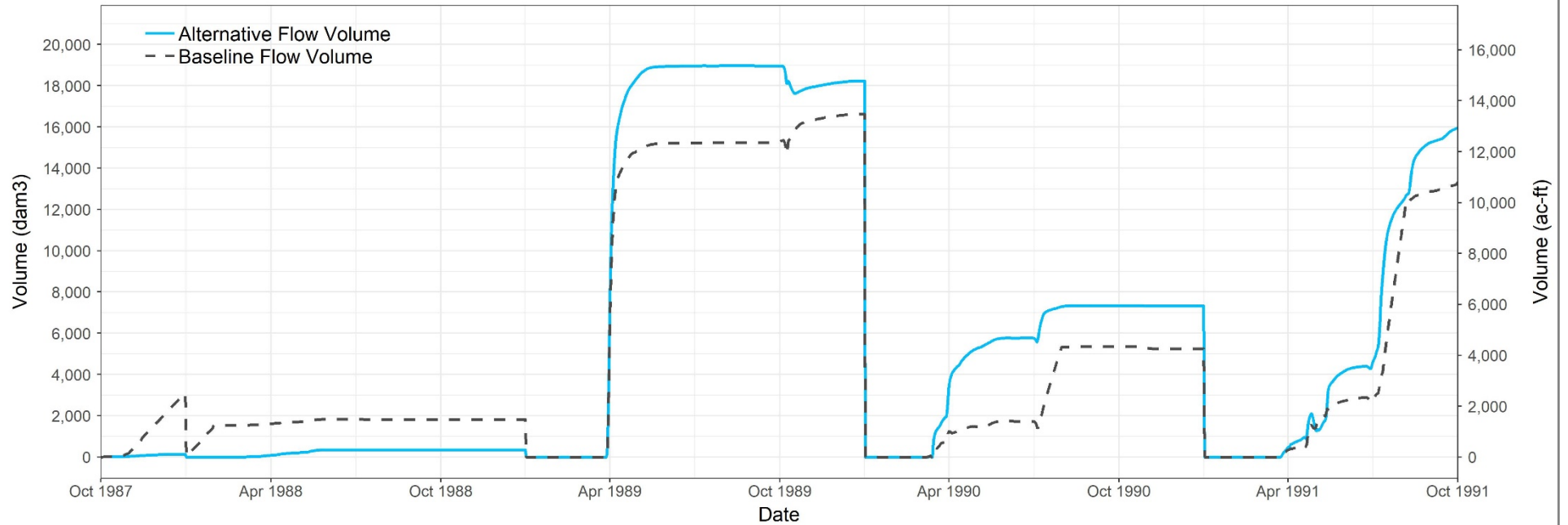
Alternative 8b (Phase 2)

Souris River Plan of Study

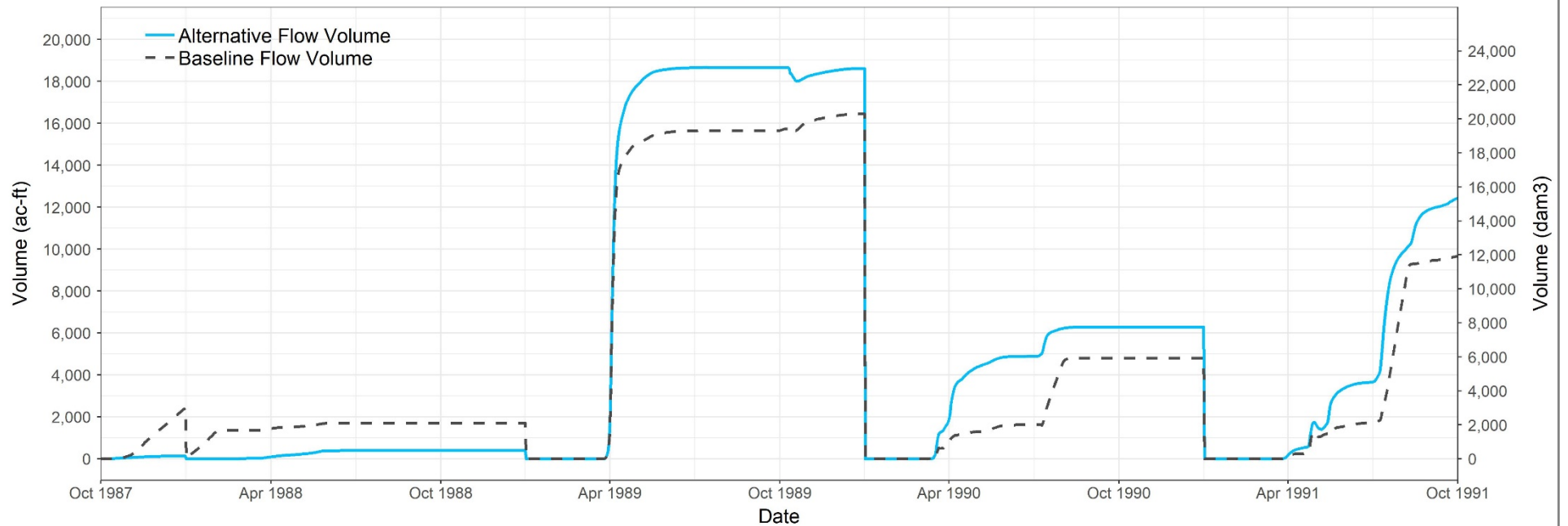
Souris River at Estevan, SK - Cumulative Volume



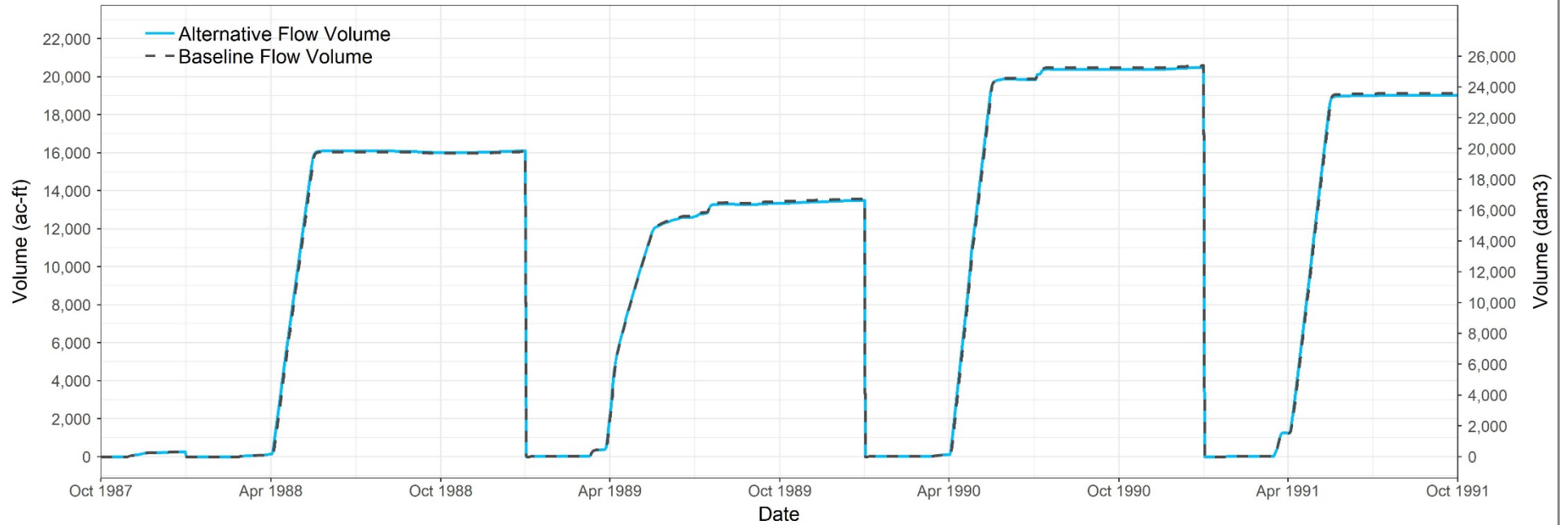
Souris River at Oxbow, SK - Cumulative Volume



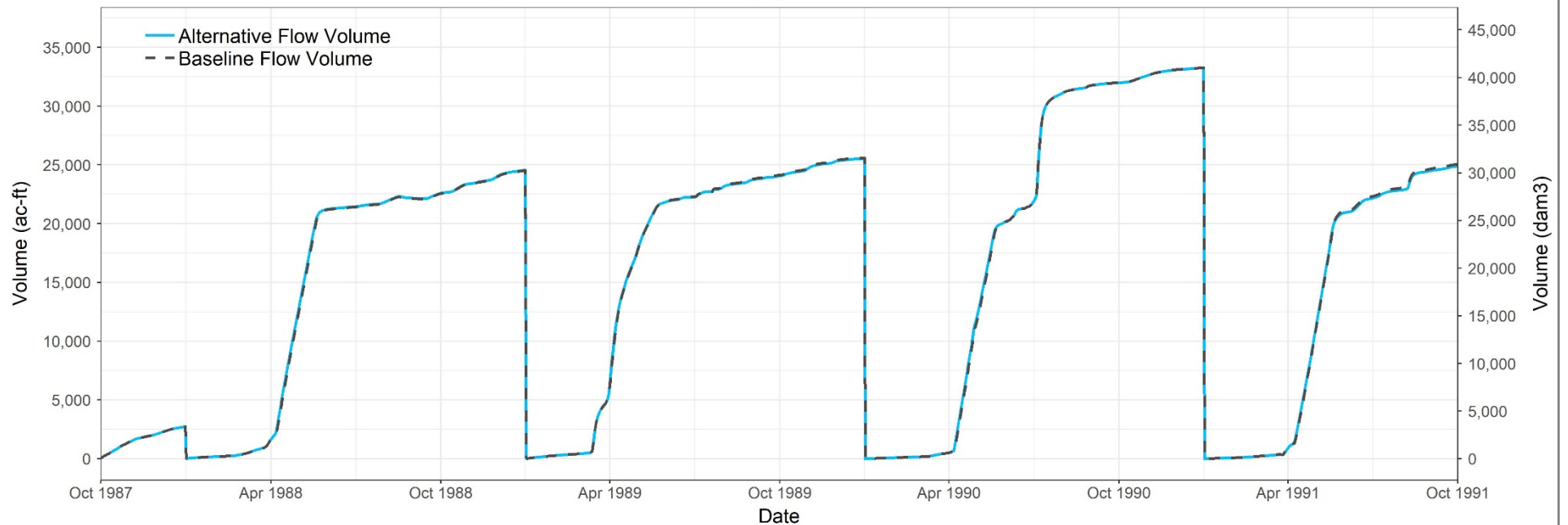
Souris River at Sherwood, ND - Cumulative Volume



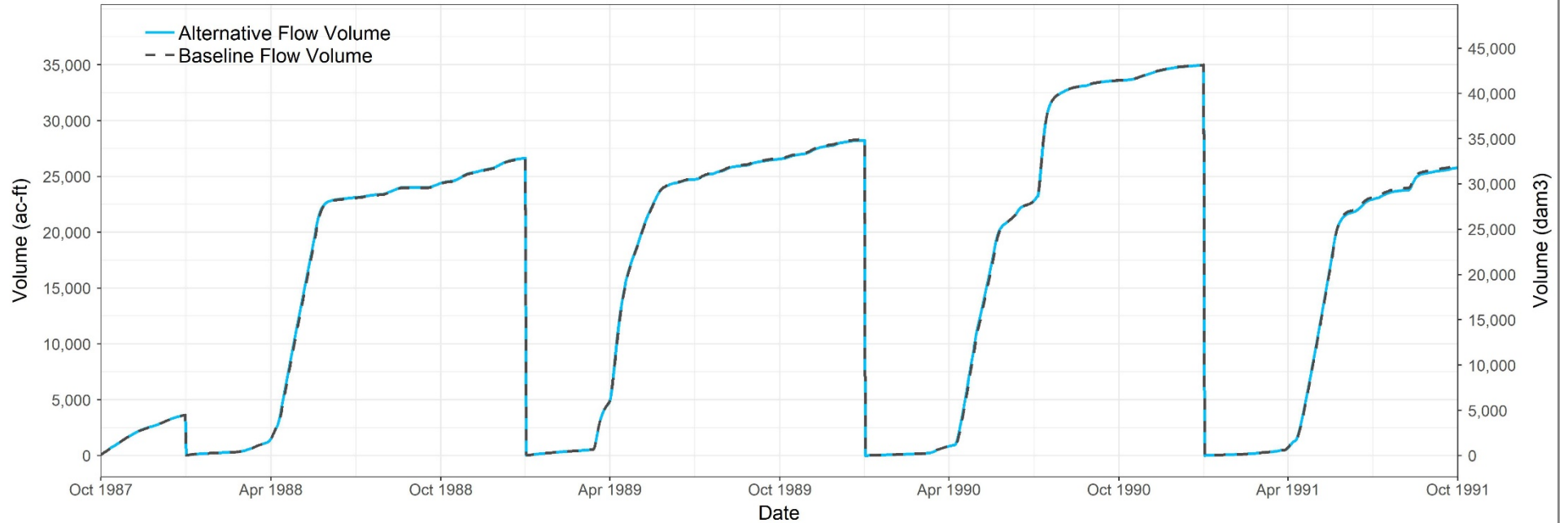
Souris River at Minot, ND - Cumulative Volume



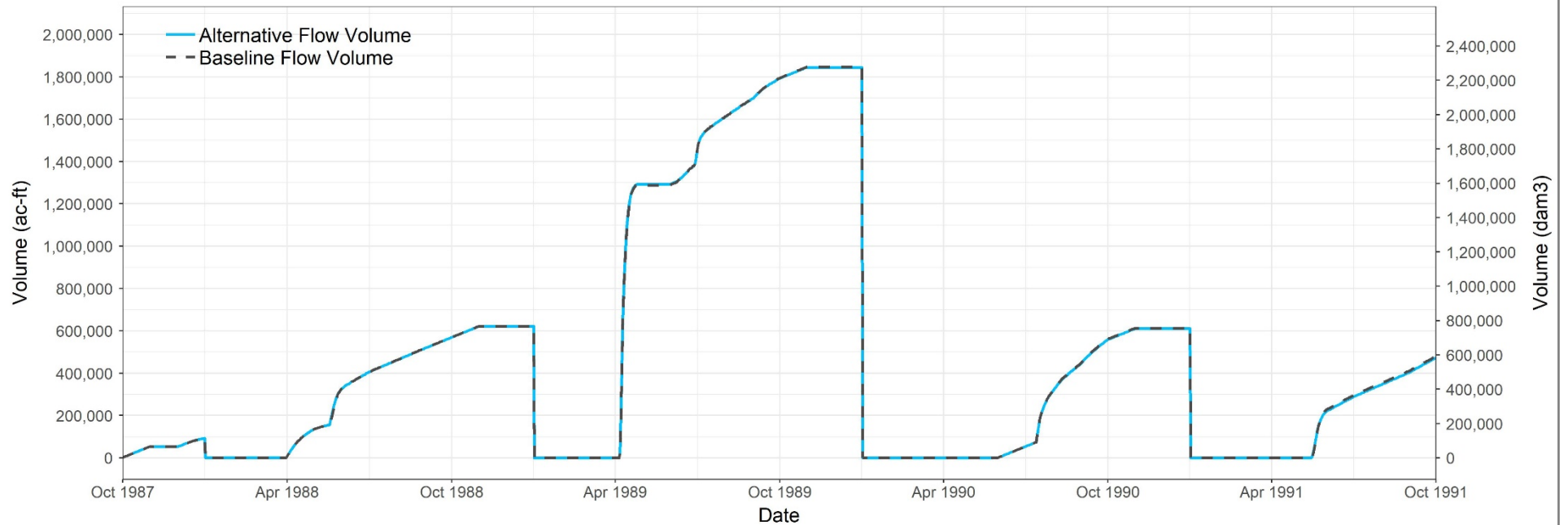
Souris River at Verendrye, ND - Cumulative Volume

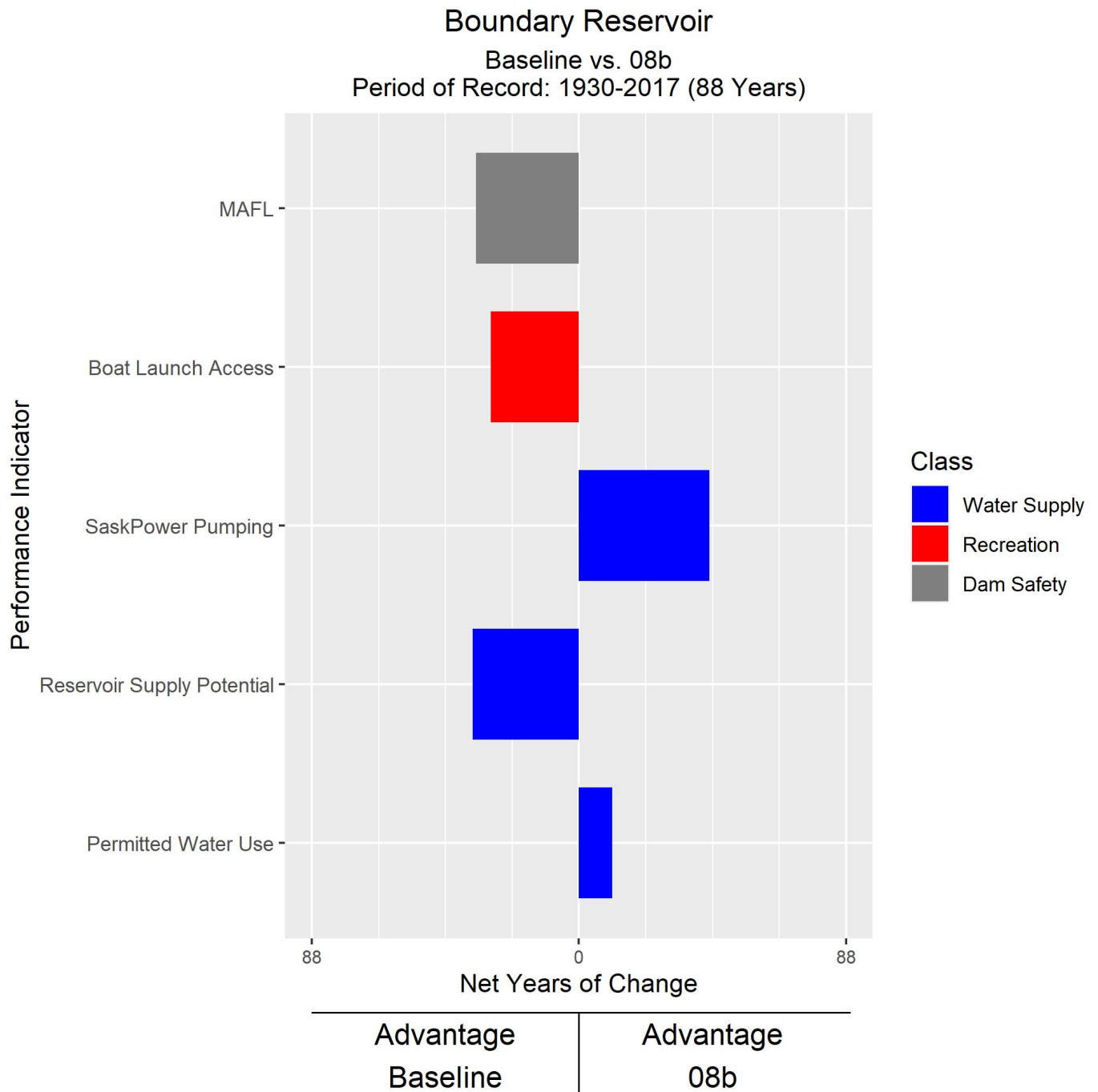


Souris River at Bantry, ND - Cumulative Volume

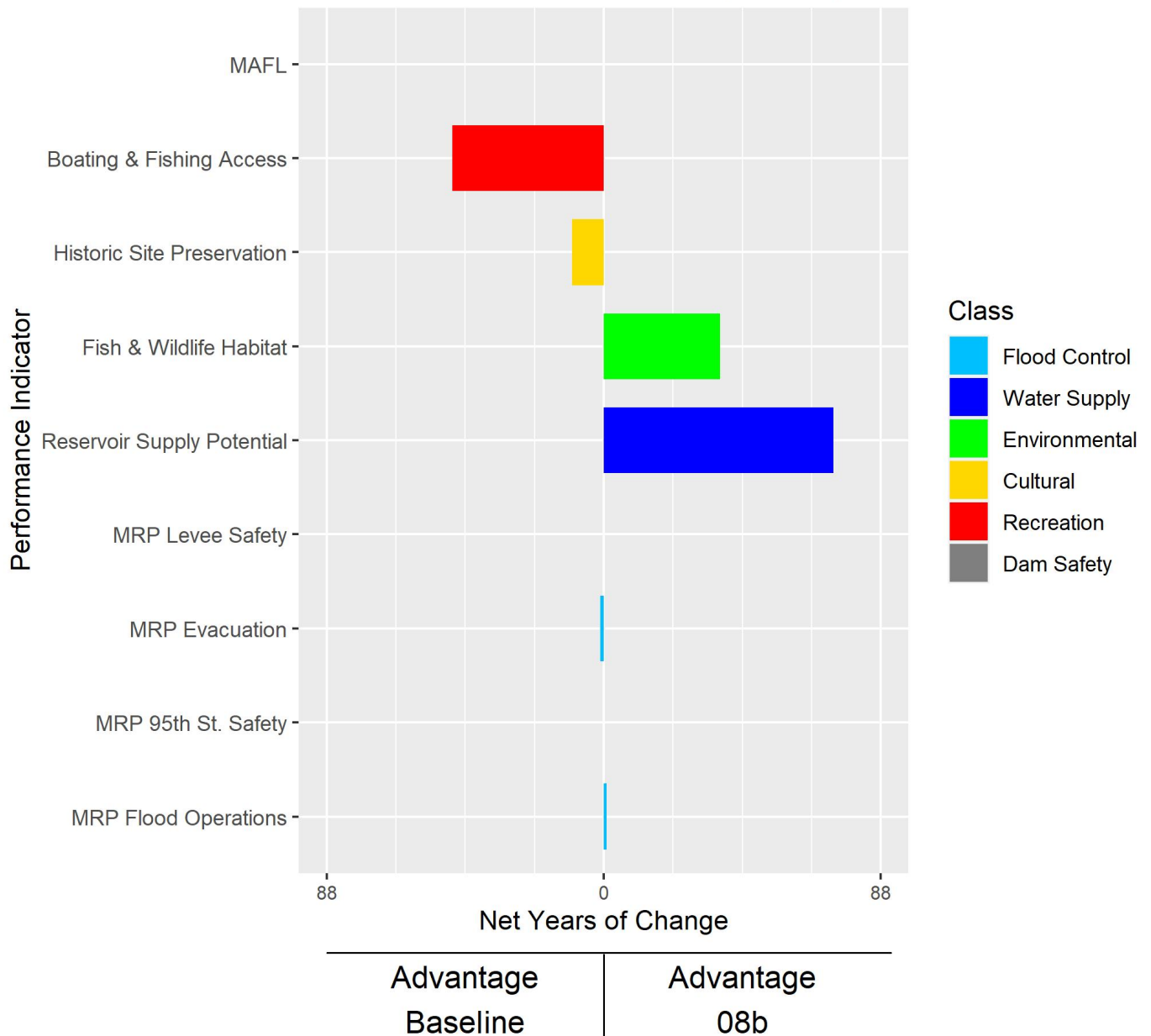


Souris River at Westhope, ND - Cumulative Volume

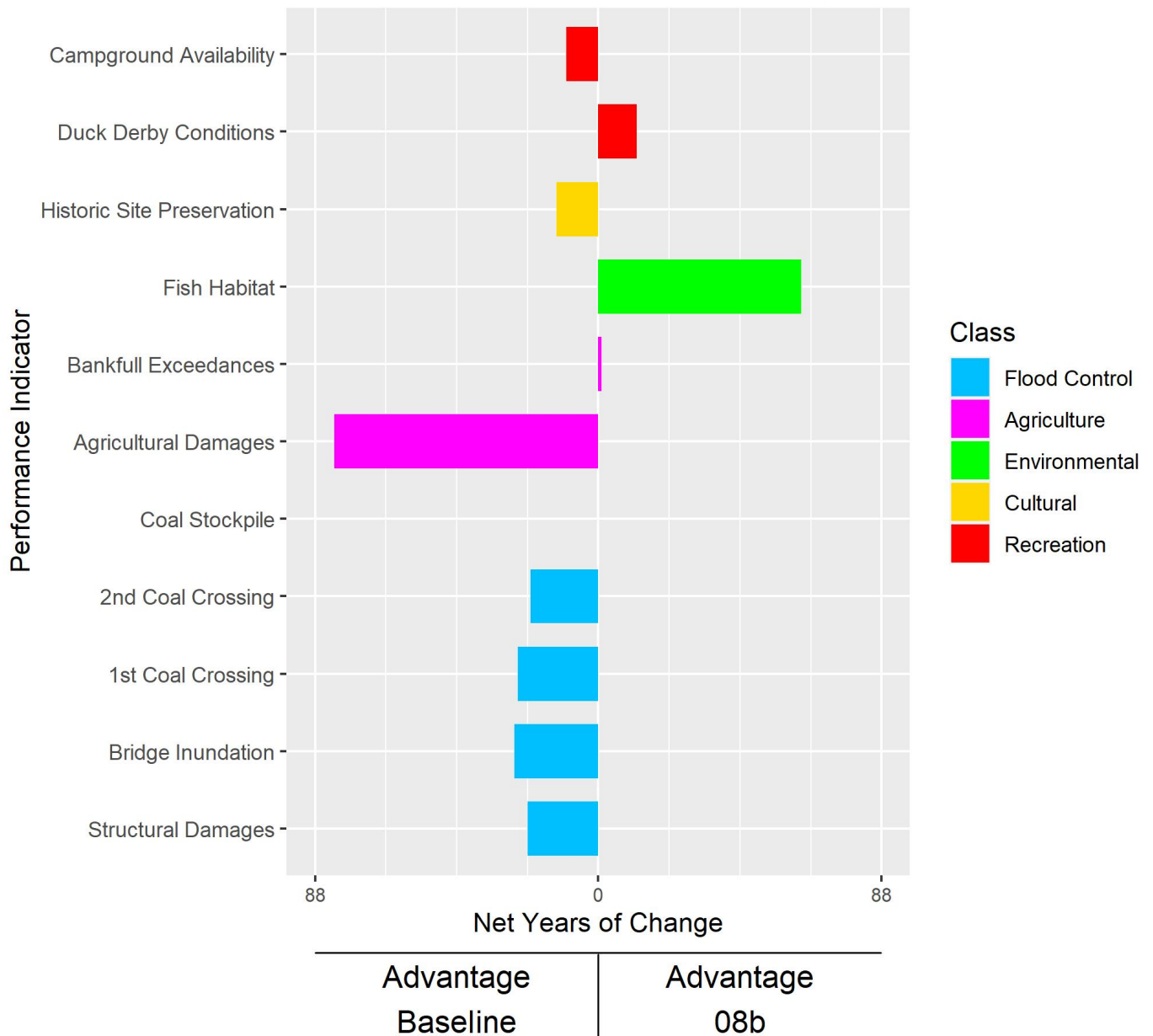




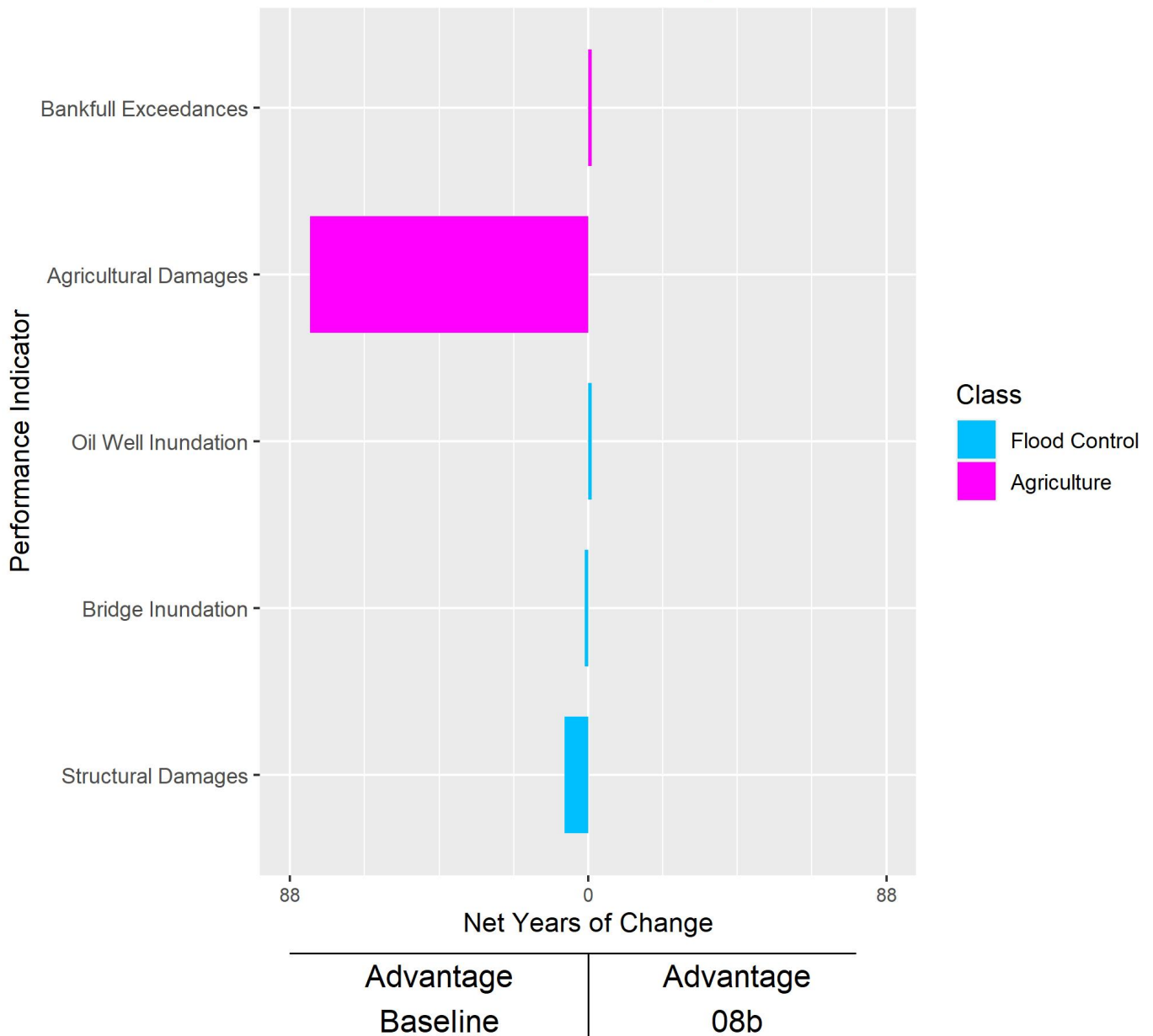
Lake Darling
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



City of Estevan
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



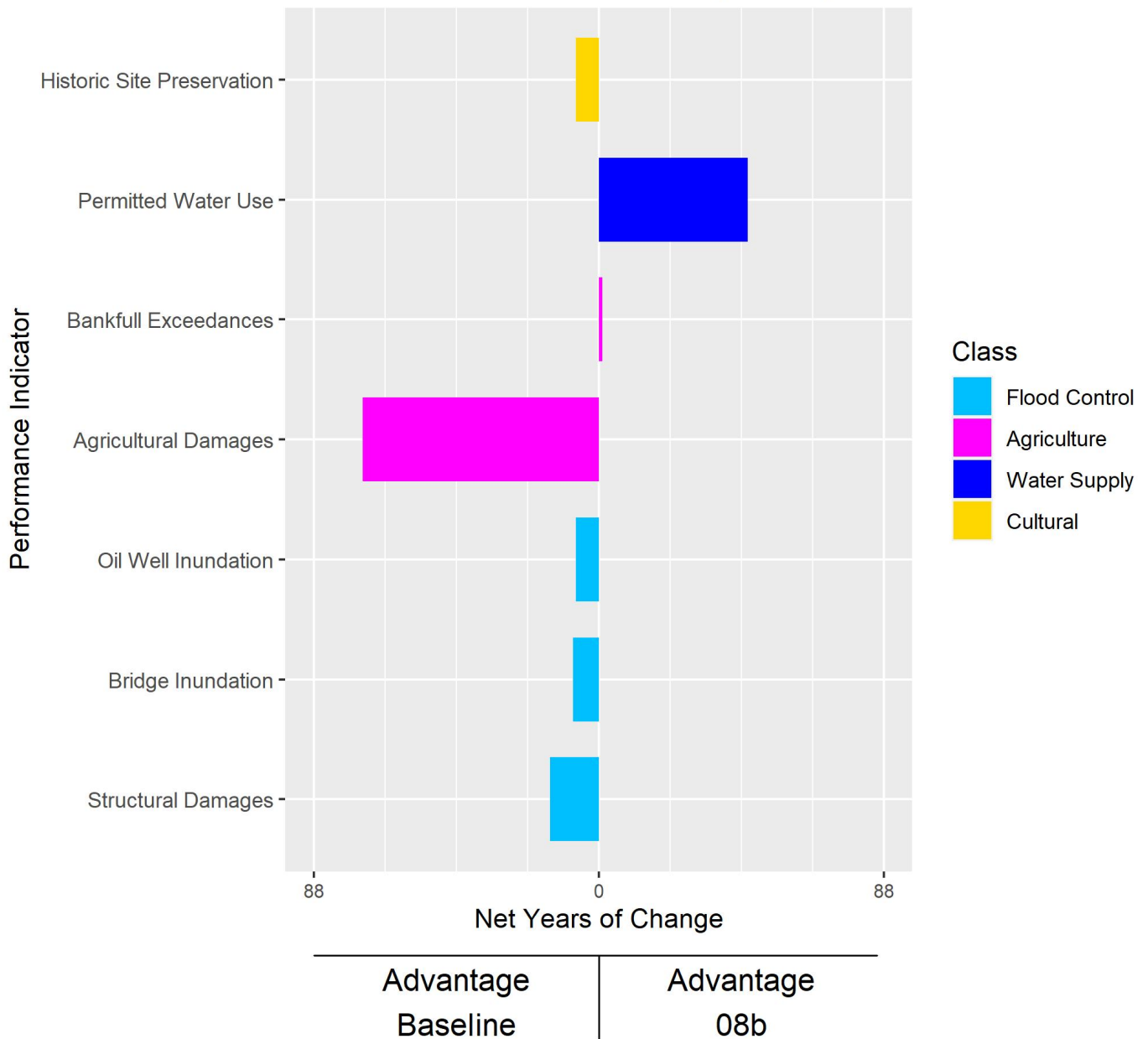
City of Roche Percee
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



Roche Percee to Moose Mountain Creek

Baseline vs. 08b

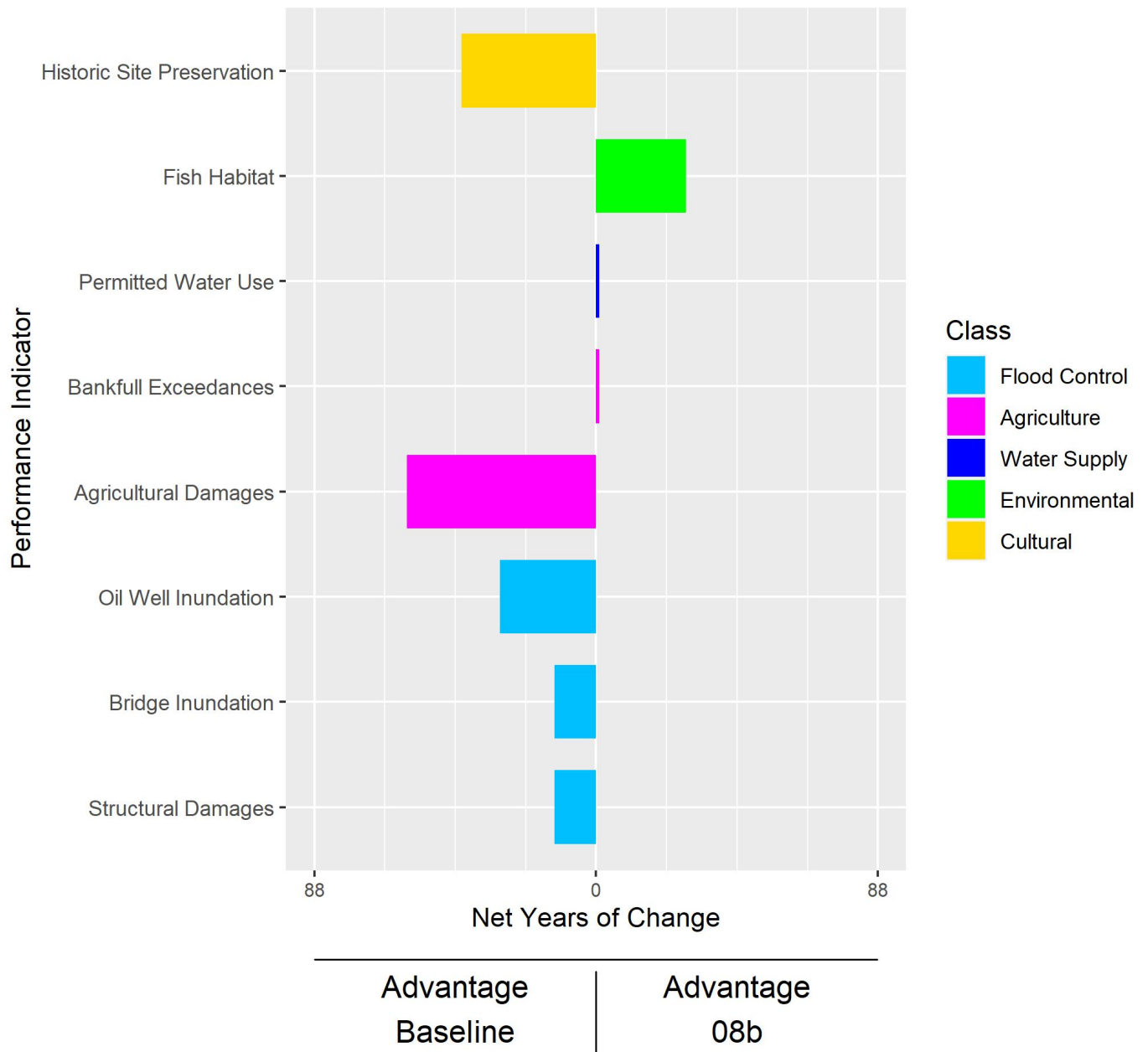
Period of Record: 1930-2017 (88 Years)



Moose Mountain Creek to Sherwood

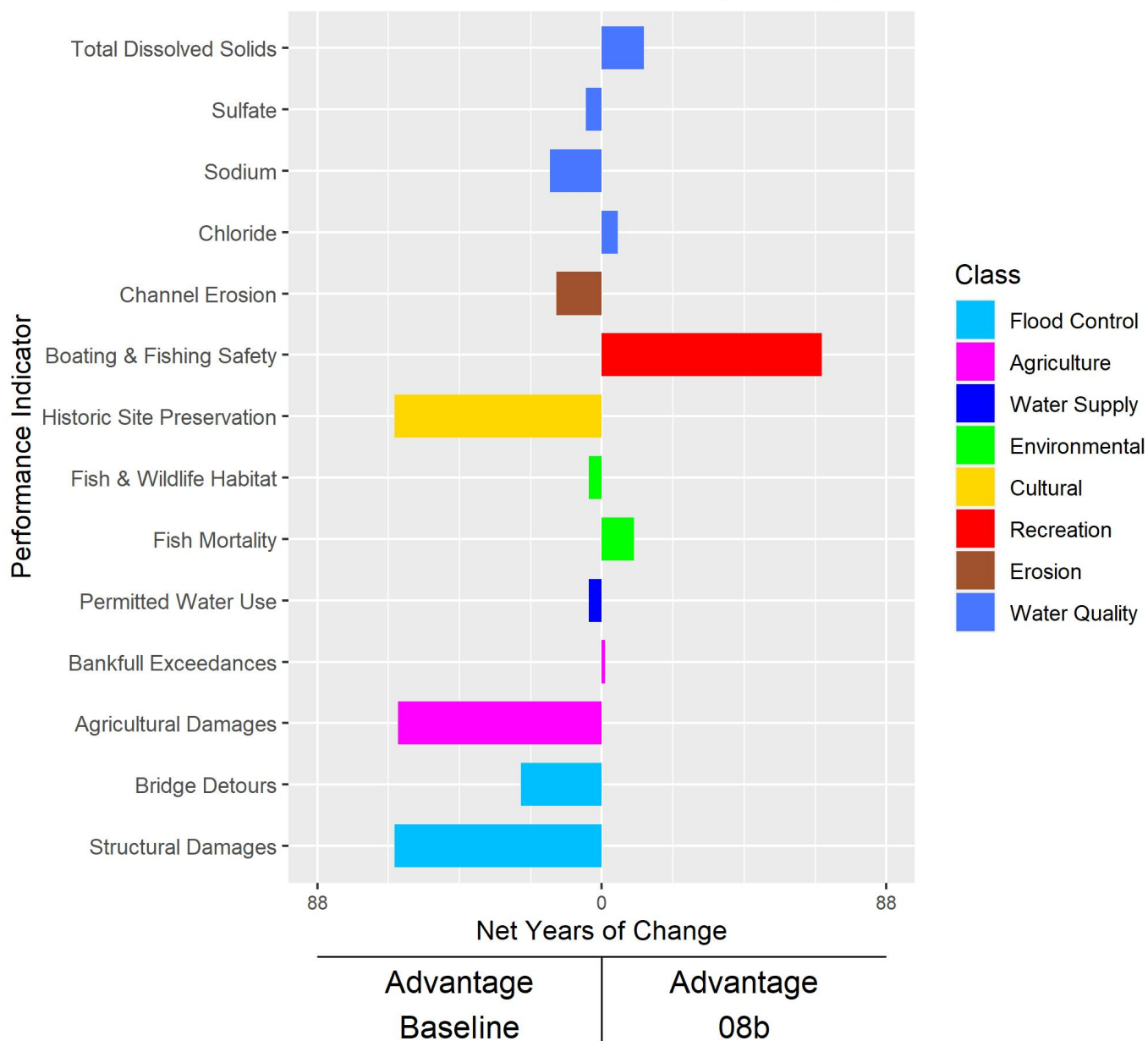
Baseline vs. 08b

Period of Record: 1930-2017 (88 Years)

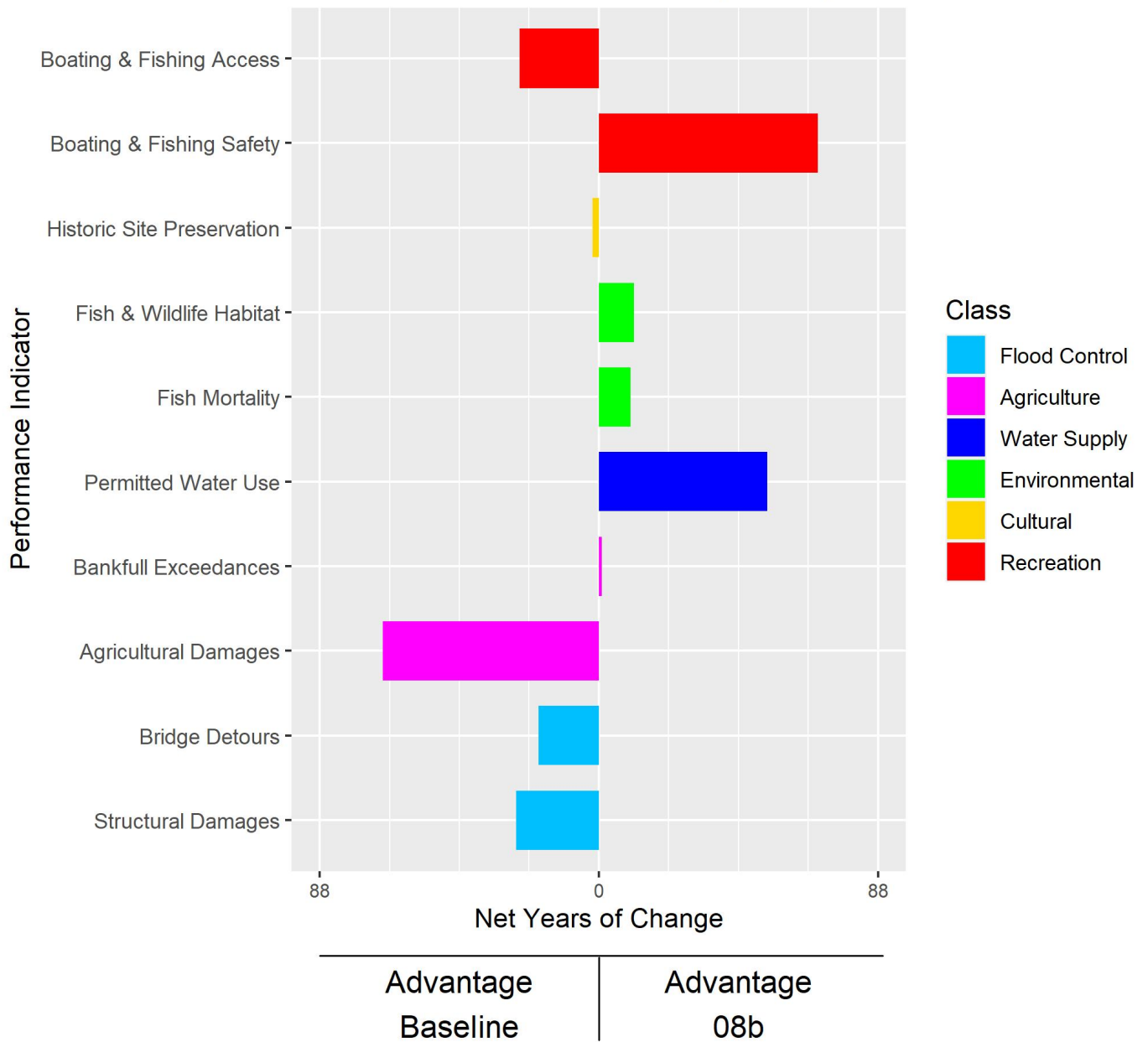


Sherwood to Mouse River Park

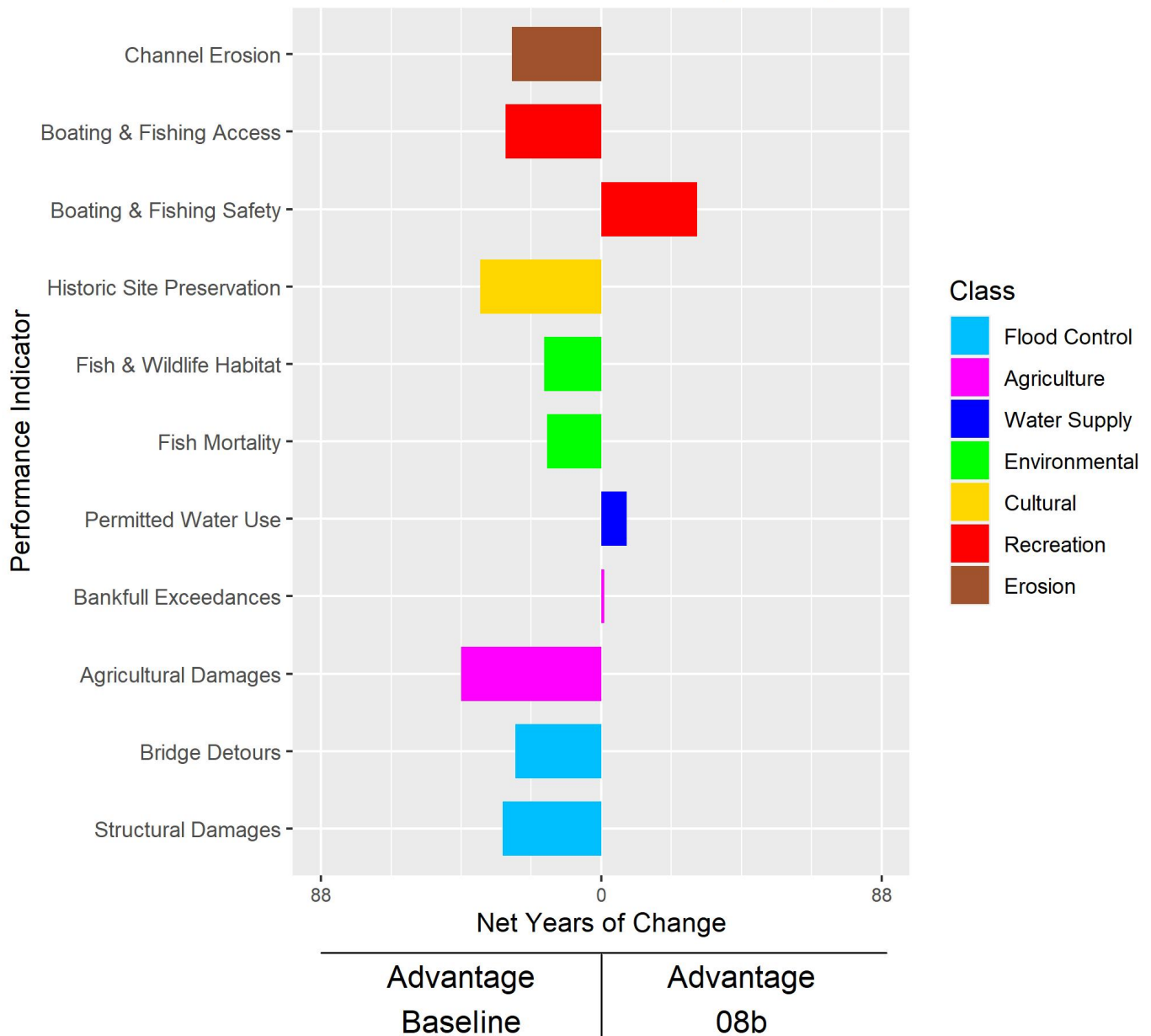
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



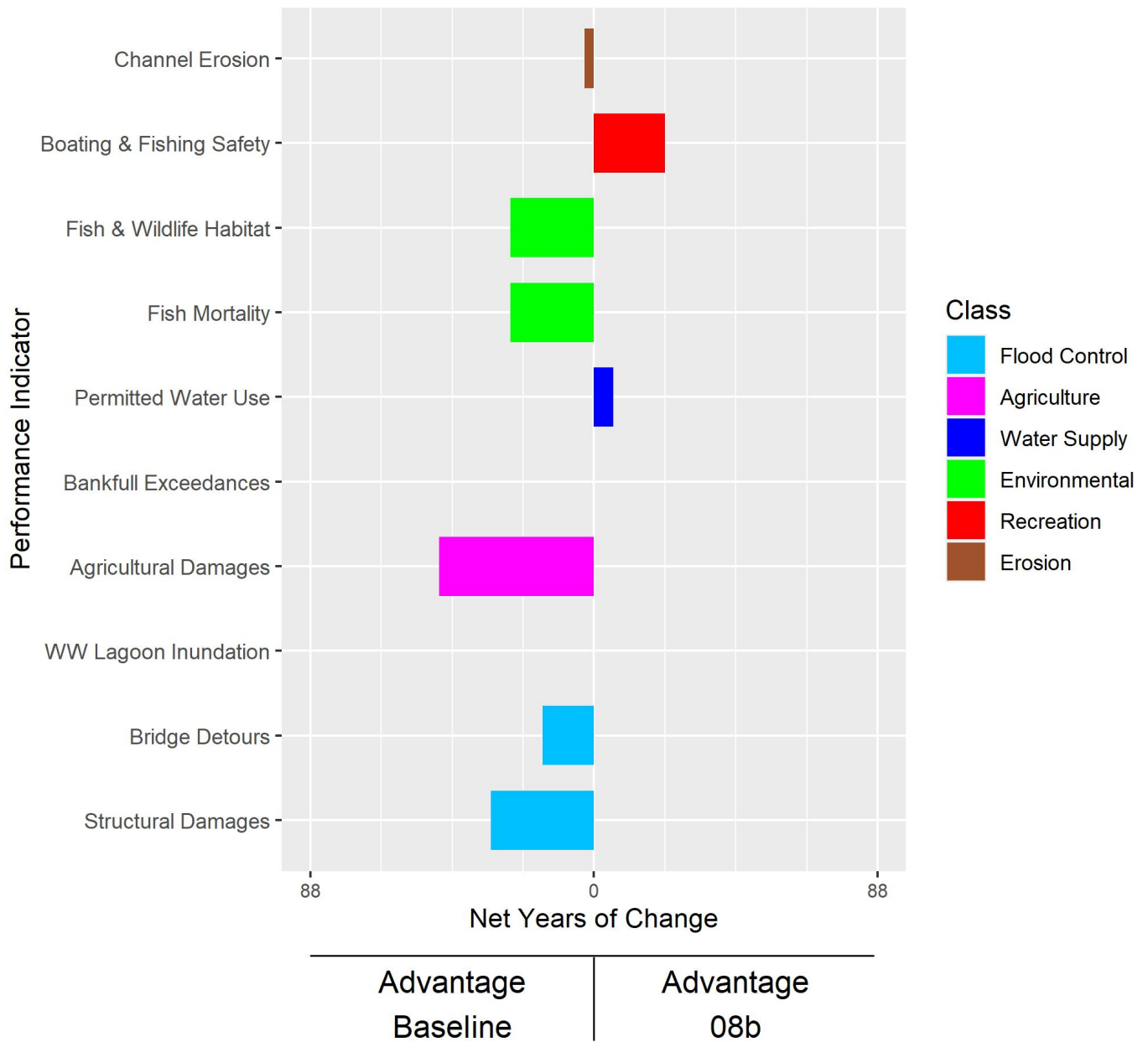
Mouse River Park
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



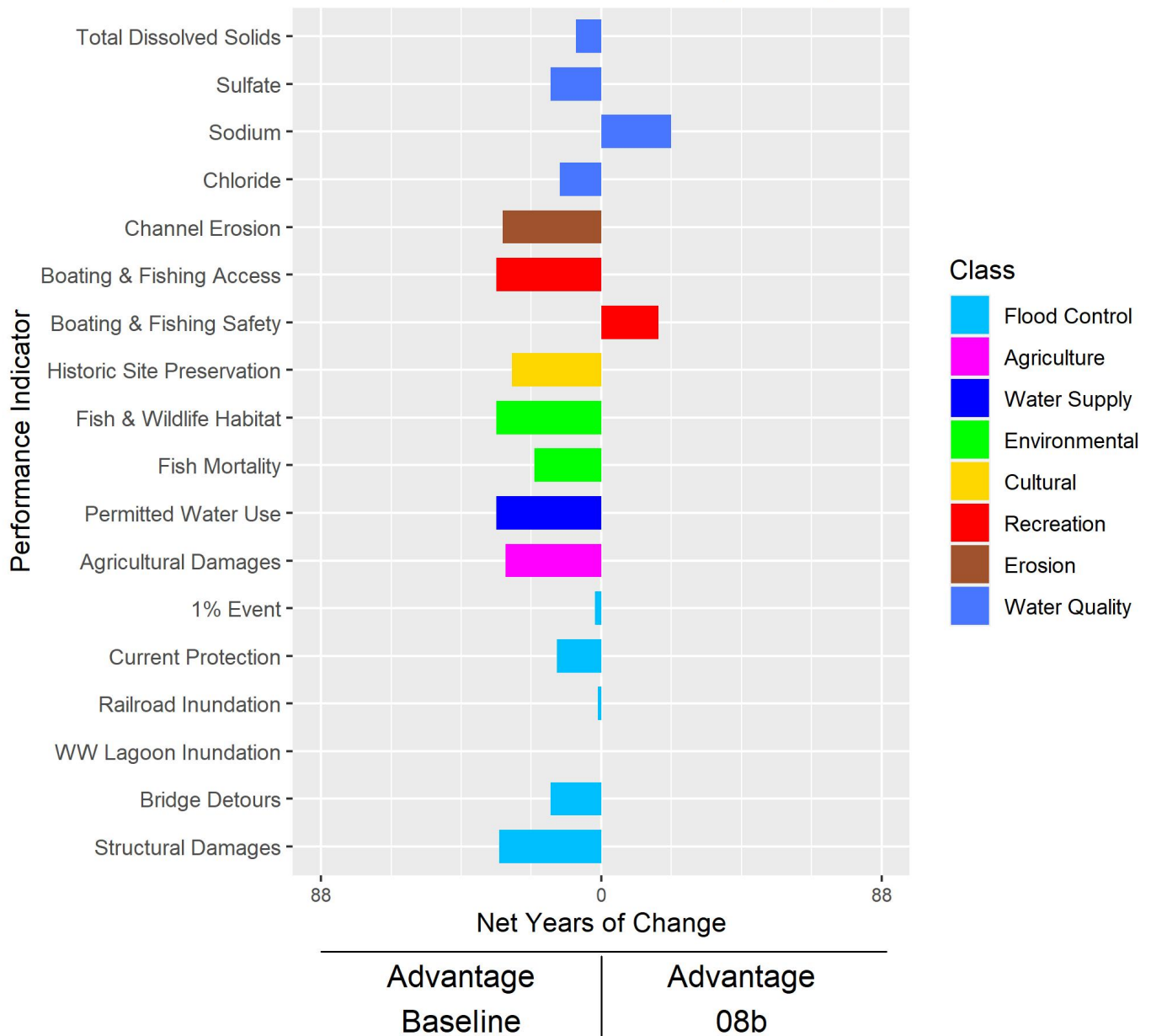
Lake Darling to Burlington
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



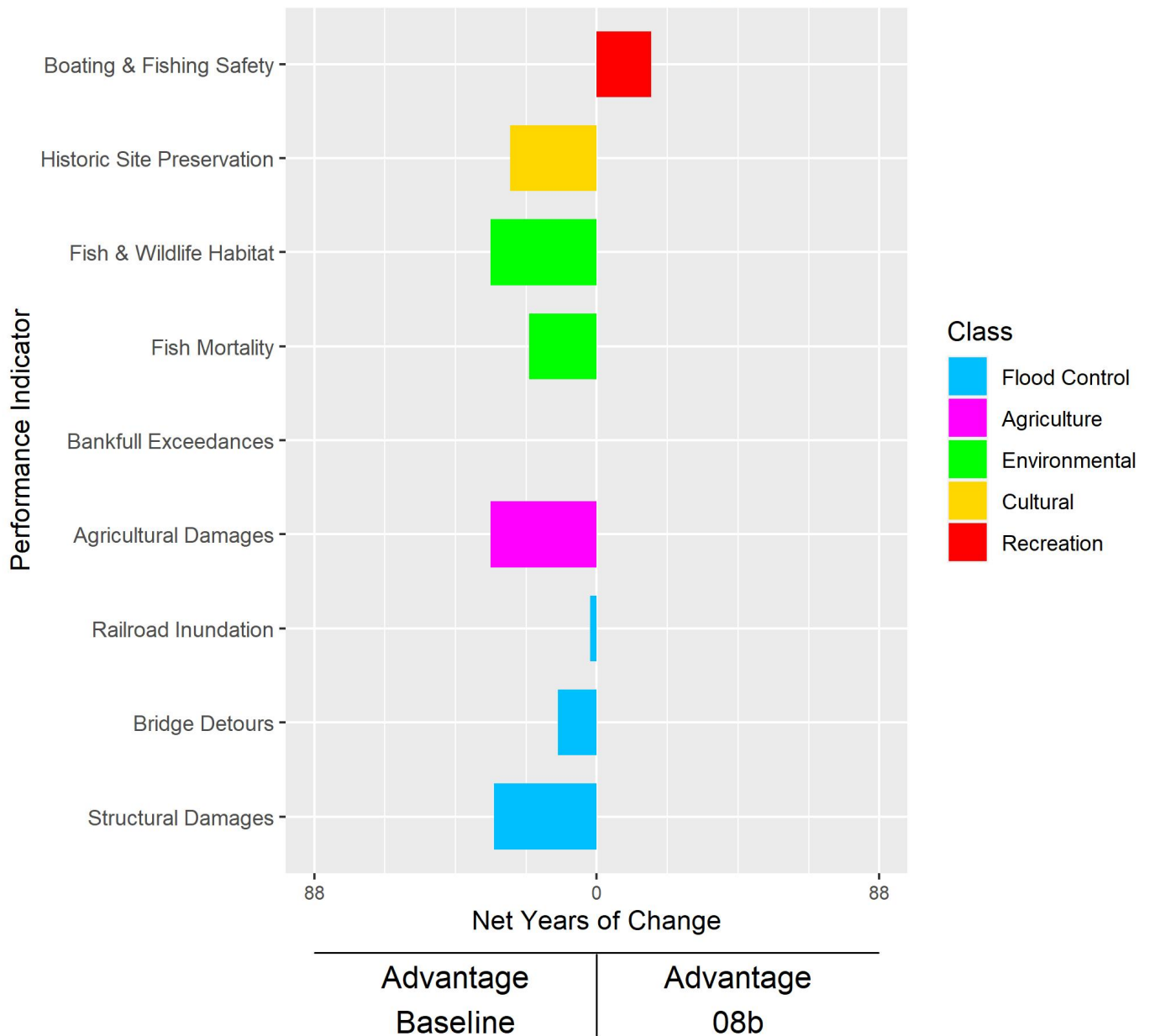
City of Burlington
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



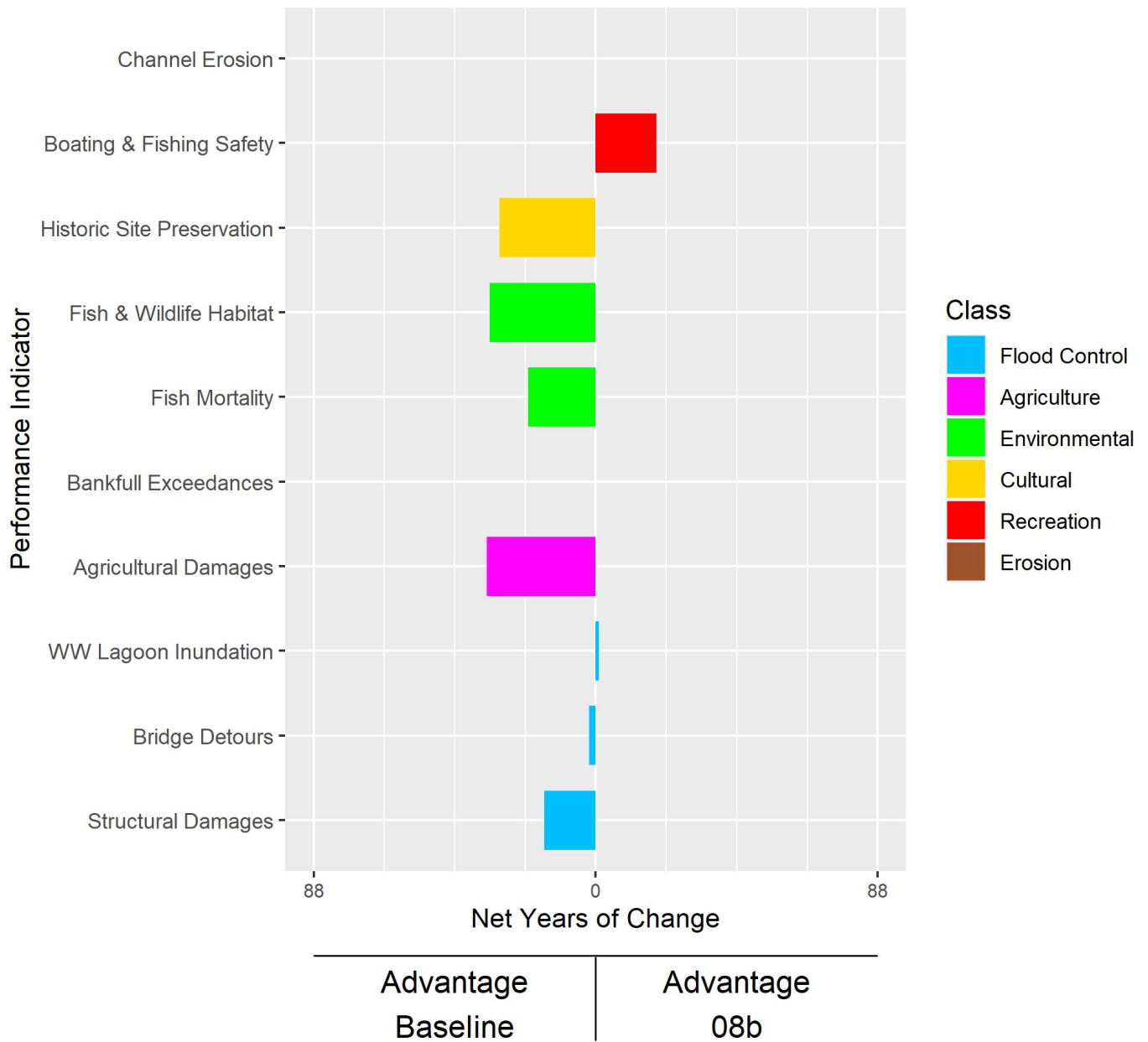
City of Minot
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



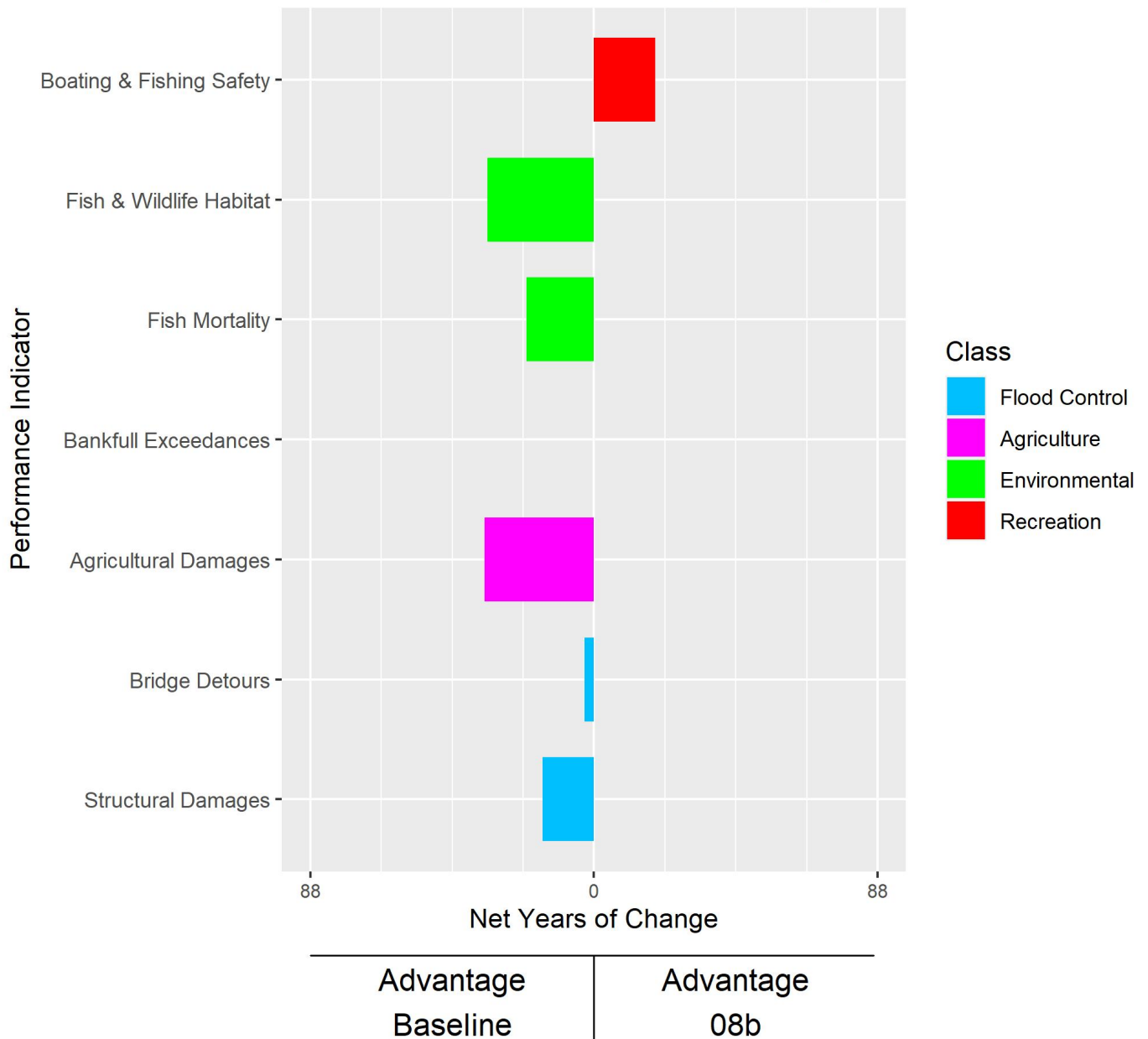
Minot to Sawyer
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



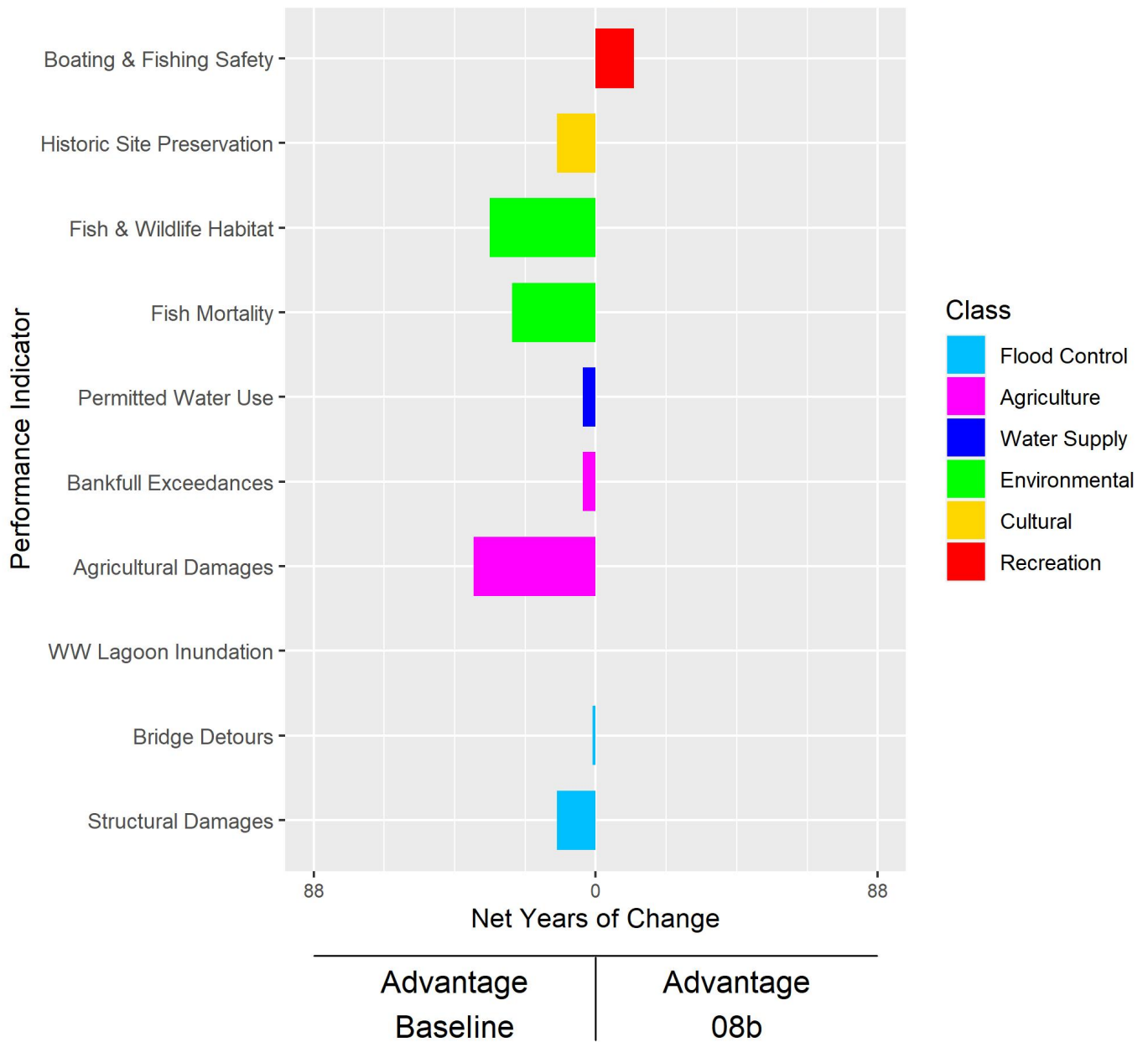
City of Sawyer
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



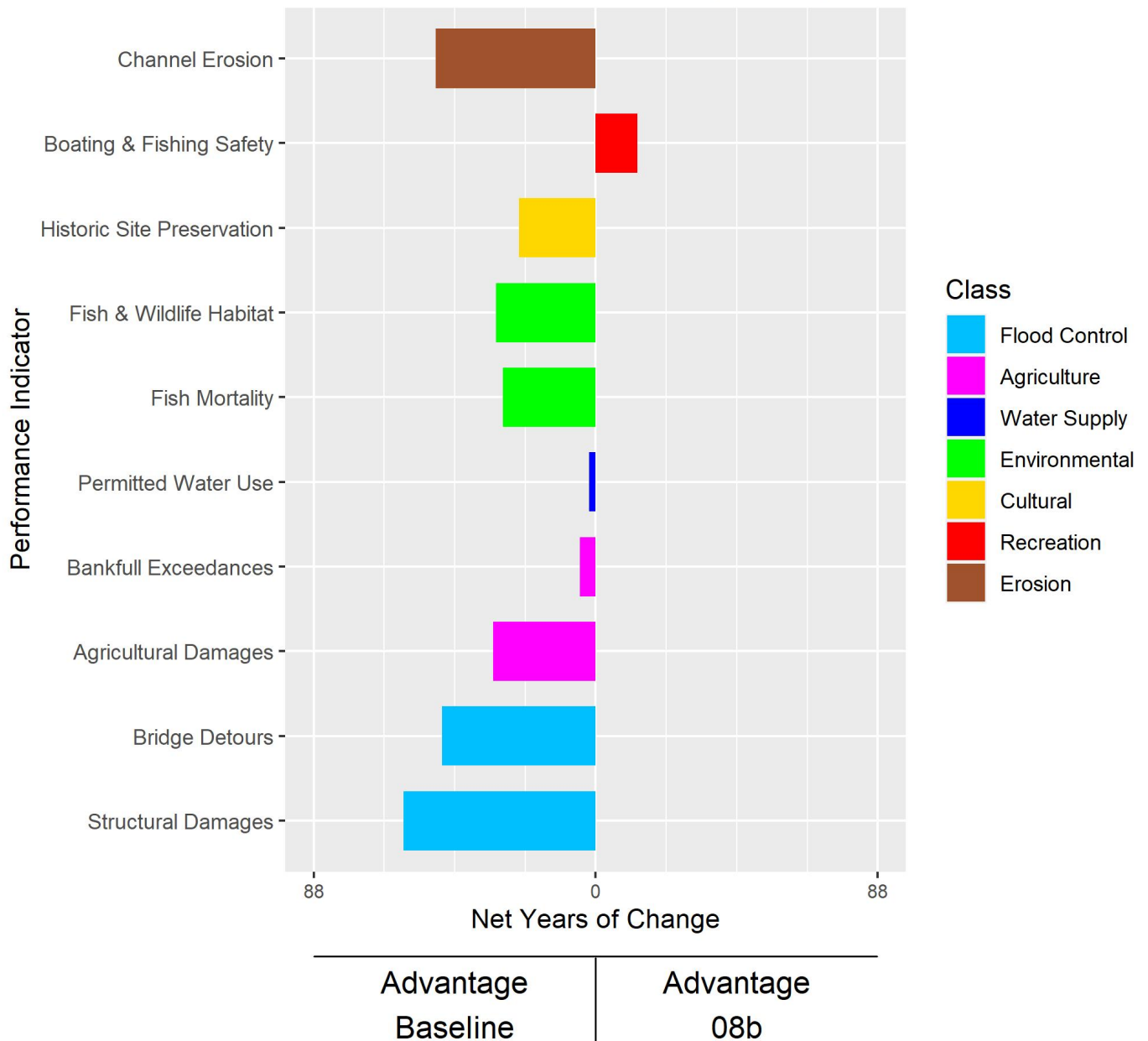
Sawyer to Velva
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



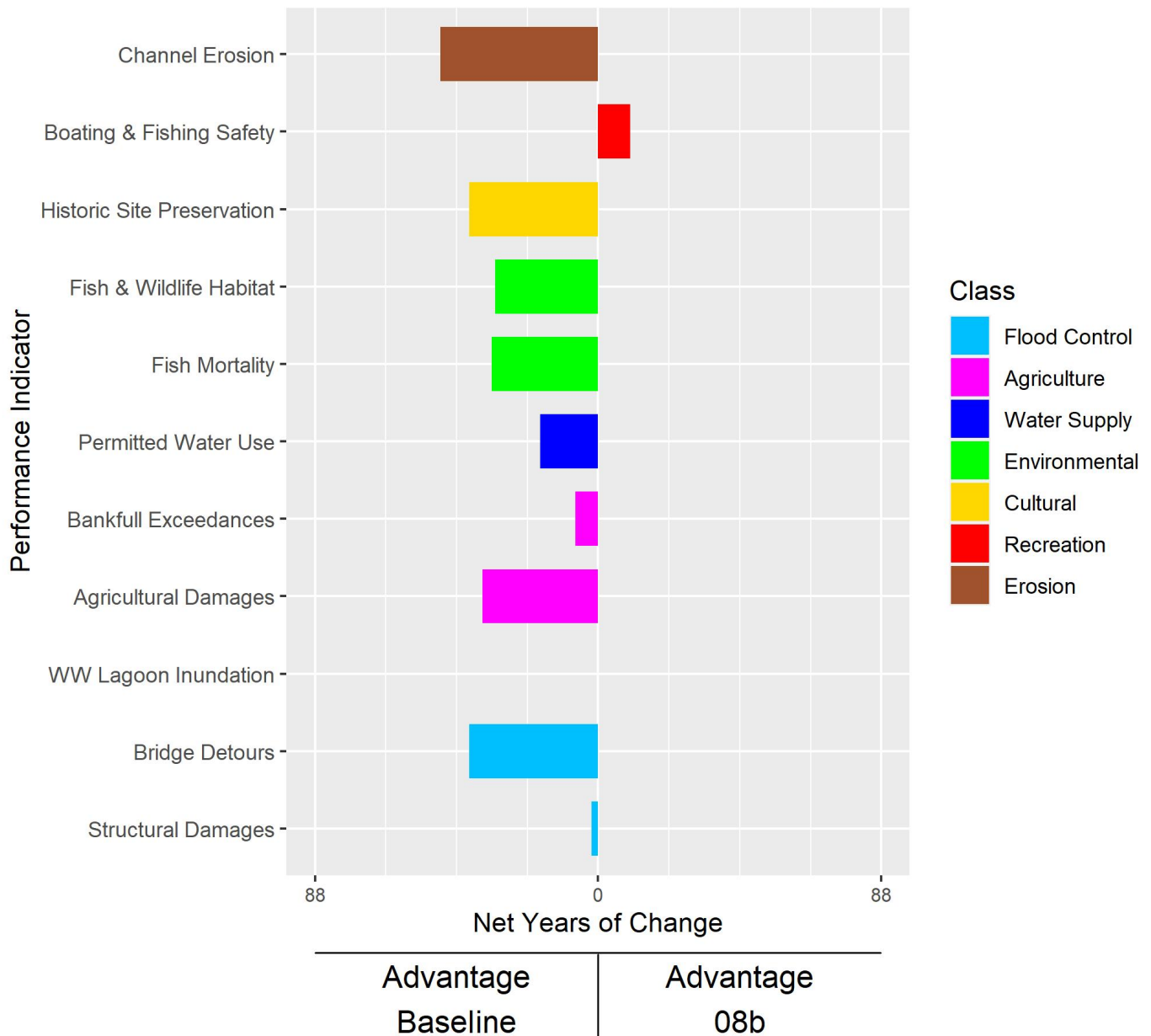
City of Velva
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



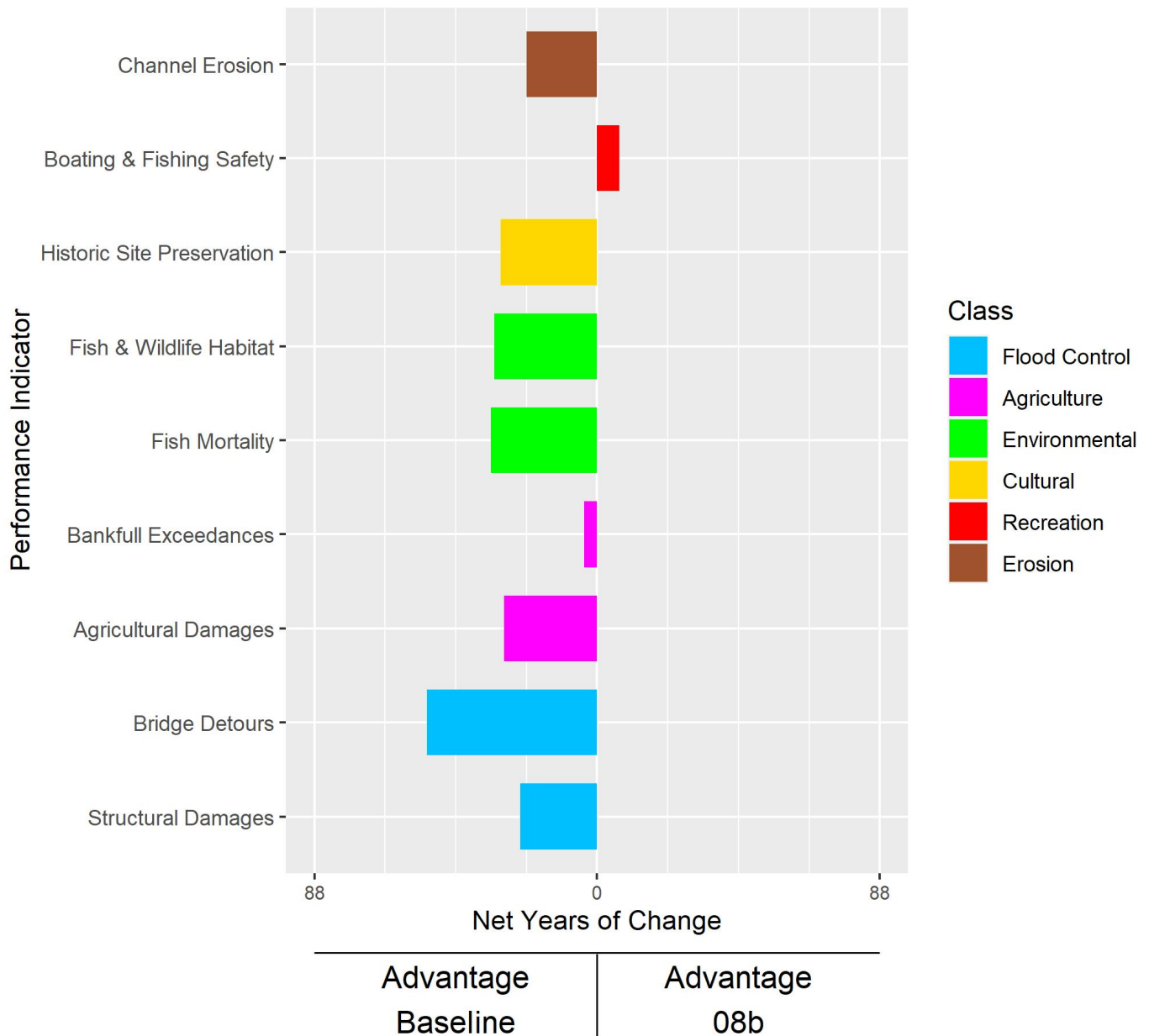
Velva to Eaton Irrigation
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



Eaton Irrigation District
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



Downstream of Towner
Baseline vs. 08b
Period of Record: 1930-2017 (88 Years)



J. Clark Salyer National Wildlife Refuge

Baseline vs. 08b

Period of Record: 1930-2017 (88 Years)

