TONGUE RIVER WATERSHED PLAN

Appendix D-8: Project Benefits Report

Spring 2016 Image of Renwick Reservoir/Icelandic State Park

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Table of Contents

Figures

Tables

The proposed river channel stabilization project will provide flood control, water quality, recreation, fish and wildlife, and infrastructure benefits. The following information supplements and summarizes analyses utilized to determine project benefits. Monetization of benefits is documented in Appendix D-5 Economics Evaluation.

Flood Control Benefits

Renwick Reservoir Sedimentation/ Project Flood Control Benefits Downstream of Renwick

Renwick Dam construction was completed in 1962, with a designed sediment pool of 303 acre-feet and permanent pool of 1,225 acre-feet. Renwick Dam rehabilitation was completed in 2013, with a new designed sediment pool of 508 acre-feet and a permanent pool of 1,440 acre-feet. In 1990 a reservoir sediment study was completed, which documented a total 96.5 acre-feet of sediment storage, equating to 3.45 acre-feet/year of sediment deposition. In 2002, a sediment survey was completed in preparation for the Renwick Dam rehabilitation project, and six bathymetric cross sections of the reservoir were surveyed by NRCS staff utilizing RTK GPS survey equipment through drilled holes in the ice. For a more complete bathymetric survey on the reservoir NRCS hired Specialty Devices, Inc (SDI) to complete acoustic imaging in order to estimate both the pre-reservoir ground elevation and the accumulated sediment to that date. The 2003 SDI summary concluded an "estimate of total sediment volume in the reservoir to be between 115 and 150 acre-feet." The 1990-2003 sedimentation rate of 3.45 acre-feet/year was validated by the SDI survey and subsequent analysis; yielding a final determination of 141.5 acre-feet of accumulated sediment out of the originally designed sediment pool capacity of 303 acre-feet. Planning and design of the rehabilitation project was completed on the basis of that sediment accumulation rate, for a 100-year lifespan.

Eleven cross sections from the 2002 survey were repeated in 2020, to evaluate the extent to which upstream river channel incision and widening had impacted the reservoir. NRCS completed the survey on cross sections A through E, and cross section 1 on foot with RTK GPS, and Houston Engineering completed the survey of cross sections 2-6 utilizing barge mounted acoustic imaging equipment. Figures 1 through 3 depict the location of the surveyed cross sections and overlays the 2020 versus 2002 sediment. River erosion through the project reach was noted as a major concern in 2013, which was the year of a major basin flood event. Therefore, 2013 is considered initiation of extreme project reach erosion. The total sediment accumulation is estimated to be 255.4 acre-feet over the 8 years of major erosion, for an average of 27.2 acre-feet/year. This is a sharp increase in comparison to the 3.45 acre-feet/year for prior 51 years. Aerial views of the significant reservoir delta expansion can be found in Appendix D-1, Figure 6. Note that the north arm of the reservoir was not included, nor was the entire delta expansion area, so the 255.4 acre-feet is somewhat of an underestimate. The estimated reservoir sedimentation due to river incision and widening is 23.8 acre-feet/year, as the difference between the 2002-2020 rate (27.2 acre-feet/year) and natural watershed sedimentation (3.45 acre-feet/year). Reservoir sediments originating from river incision and widening are predominately from the bed of the river (incised up to 8 ft in some locations, channel widening (up to 40 ft in some locations), erosion on outer meander bends, and landslides on steep upland slopes that have been undercut. The project reach (General Reaches 4 and 5) was identified to have much greater erosion potential compared to other reaches, as documented in Appendix D-1; therefore the project reach accounts for majority of sediment delivered to Renwick in the 2003-2020 time period. As noted in Appendix D-1, the floods of 2009 and 2013 would have dramatically increased the rate of that incision process, therefore the majority of the sediment was likely delivered in the latter half of that time period.

In order to translate watershed erosion to reservoir sedimentation there are two important parameters: reservoir sedimentation trap efficiency and unit weight of sediment. National Engineering Handbook (NEH) Section 3, Chapter 8 (NRCS 1982) adopted the Brune method for trap efficiency, which is based on reservoir Capacity-Inflow ratio (C/I). The capacity, or active storage between principle and auxiliary spillways, is 4,071 acre-feet at Renwick, while annual inflow volume is 19,276 acre-feet from USGS gauge 05101000. Therefore, C/I = 2.1 with median curve resulting in Trap efficiency (T) ~94% as shown in Figure 4. The volume-weight relationship range for reservoir sediment, which is dependent on grain size and submerged/aerated, was determined from Table 1 (NRCS, 1982). The 2003 SDI core samples identified that ~75% of sedimentation was clay, and ~25% silts. Each of the sedimentation and survey analyses indicated that the large majority of sediment is deposited in the reservoir, in comparison to inlet above normal water level; therefore the sediment is considered always submerged or nearly submerged as the reservoir has minor annual drawdowns. A more detailed method (Lane, 1943), which was a collaborative study including the USDA, identified a density equation considering grain size, reservoir operation, and time of consolidation as shown in Table 2 below. The resulting typical sedimentation density is ~50 lb/ft^3, with slightly higher values for longer periods of years and slightly less for shorter sedimentation durations. The original 1955 Work Plan, assuming 303 acre-feet of reservoir storage for 6,233 ton/year of watershed erosion, and 94% trap efficiency, also estimated a density of ~50 lb/ft^3. The International Water Institute has developed a calibrated water quality model, based on hydro-conditioned LiDAR data, land use, and basin wide averages for water quality constituents, called PTMApp. The current PTMApp model prediction for the sediment load at Renwick reservoir lines up with these results at a resulting range of 5,600 and 6,800 tons/year. Additionally, the selected 50 lb/ft^3 typical unit weight of reservoir sediment falls within the NEH criteria outlined in Table 2 (NRCS, 1982).

Table 1: NEH Sec. 3, Ch. 8, Table 8-1 Volume-weight of reservoir sediments

	Volume Weight of Sediment	
Grain Size	Submerged-lb/ft^2	Aerated-lb/ft^2
Clay	35-55	55-75
Silt	55-75	75-85
Clay-silt mixtures (equal parts)	40-65	65-85
Sand-silt mixtures (equal parts)	75-95	95-110
Clay-silt-sand mixtures (equal parts)	50-80	80-100
Sand	85-100	85-100
Gravel	85-125	85-125
Poorly sorted sand and gravel	95-130	95-130

Table 2: Lane (1943), Table 10 Density value for use in reservoir design

	Density Values for Use in Design		
Reservoir Operation	Sand	Silt	Clay
	W_1/K.	W_1/K.	W_1/K.
Sediment always submerged or nearly submerged	93/0	65/5.7	30/16.0
Normally a moderate reservoir drawdown	93/0	74/2.7	46/10.7
Normally a considerable reservoir drawdown	93/0	79/1.0	60/6.0
Reservoir normally empty	93/0	82/0.0	78/0.0

As discussed previously, the estimated reservoir sedimentation due to river incision and widening is 23.8 acre-feet/year. Due to trap efficiency, the actual erosion occurring along the river is then estimated to be 25.3 acre-feet/year. Erosion from the outer banks on meander bends through the project reach was estimated to be 3,689 ton/year, from Appendix D-1, Figure 12; which results in an estimated volume of 3.4 acre-feet/year. Incision is estimated to be 3.5 acre-feet/year, based on the preliminary project design channel fill of 101,500 cy back to the natural bankfull elevation. There is also erosion throughout the project reach due to widening that is not along outside of meander bends, and is located above the bankfull elevation, which also needs to be considered; widening was considered "extensive" through project reach and this type of inside bend erosion can be seen on cross section 14. In addition, the south slope of the river through the project reach is a steep forested slope, with numerous translational landslides that have occurred due to the toe of the slope being undercut. As large, mature, trees fail during those landslides their rootwads also bring large quantities of sediment into the river. Quantifying this additional input that is not from the outer banks at meander bends and is above bankfull was an approximation based on practical dimension and lesser erosion outside the project reach resulting in 15.0 acre-feet/year. Therefore, the resulting estimate for Renwick sediment load from reaches outside the project reach is 3.2 acre-feet/year, which is 12% of the project reach erosion and appears reasonable due to much better stability ratings identified in Appendix D-1.

Using the available Renwick sediment surveys (1990, 2003, and 2020), the historic sediment storage is plotted with predicted/designed storage from original dam construction (1962) and rehabilitation (2013) in Figure 5. Figure 6 shows the current rate of sedimentation (27.2 acre-feet/year) extrapolated as the “No project” condition if the channel incision is allowed to continue working upstream. The “With Project” condition assumes the project reach is stabilized, through either Alternative 1 or 2 of the plan, and incision is not allowed to progress upstream, reducing sediment delivery to the historic watershed rate plus the current beyond project river erosion (6.7 acre-feet/year). Those estimates are similar and slightly more than original design sedimentation rate of 6.1 acre-feet/year (303 acre-feet / 50-years). Results are detailed in Table 3 below and summarized in Figure 7. Key findings are as follows:

- The designed sediment pool, which was planned to have capacity through 2113, filled 72% between 2003 and 2020.
- If the upstream channel is not stabilized, the sediment pool is projected to be full in ~2027, after which sediment will begin to encroach upon the permanent pool design volume intended for recreation.
- If the proposed channel stabilization project is completed, the sediment pool will still fill prior to the designed lifespan of the rehab project (2113), however that would not occur until 2043.
- Without the project the permanent pool, i.e. the “lake” that supports a fishery and recreation use, would be 24% filled by 2040 and 40% filled by 2050.
- Without the proposed project, the permanent pool would conceivably be full in ~2086, eliminating the presence of all recreation storage volume in the reservoir.
- Downstream flood control benefits will steadily decline if the proposed project is not constructed; by 2113 they would be reduced by an estimated 33%.

Table 3: Renwick historic and predicted sediment loading, plus filling of sediment, permanent, and flood pools

Year	Total Sediment Deposits (acre-ft) Existing &		New Sediment Pool filled (%) Existing &		New Permanent Pool filled (%) Existing &		New Flood Pool filled (%) Existing &	
	No project	W/ project	No project	W/ project	No project	W/ project	No project	W/ project
1962	0.0	0.0	0%	0%	0%	0%	0%	0%
1990	96.5	96.5	19%	19%	0%	0%	0%	0%
2002	138.0	138.0	27%	27%	0%	0%	0%	0%
2003	141.5	141.5	28%	28%	0%	0%	0%	0%
2013	176.0	176.0	35%	35%	0%	0%	0%	0%
2020	365.3	365.3	72%	72%	0%	0%	1%	1%
2025	486.3	395.0	96%	78%	0%	0%	1%	1%
2030	607.2	424.7	120%	84%	7%	0%	2%	1%
2035	728.2	454.4	143%	89%	15%	0%	2%	1%
2040	849.1	484.1	167%	95%	24%	0%	2%	1%
2045	970.1	513.8	191%	101%	32%	0%	3%	1%
2050	1091.0	543.5	215%	107%	40%	2%	3%	1%
2055	1212.0	573.2	239%	113%	49%	5%	3%	1%
2060	1333.0	602.9	262%	119%	57%	7%	4%	2%
2065	1453.9	632.7	286%	125%	66%	9%	4%	2%

2070	1574.9	662.4	310%	130%	74%	11%	5%	2%
2075	1695.8	692.1	334%	136%	82%	13%	5%	2%
2080	1816.8	721.8	358%	142%	91%	15%	5%	2%
2085	1937.7	751.5	381%	148%	99%	17%	6%	2%
2090	2058.7	781.2	405%	154%	108%	19%	15%	2%
2095	2179.7	810.9	429%	160%	116%	21%	19%	2%
2100	2300.6	840.6	453%	165%	124%	23%	23%	2%
2105	2421.6	870.3	477%	171%	133%	25%	27%	2%
2110	2542.5	900.0	500%	177%	141%	27%	31%	3%
2113	2615.1	917.8	515%	181%	146%	28%	33%	3%

Assumptions:

1. 89% sediment loading applied to sediment pool, 11% sediment loading applied to flood storage based on 2020 survey distribution between submerged and inlet deposits above permanent pool (971.0), respectively.

2. Sediment loading applied to sediment pool until full (508 acre-feet), then applied to permanent pool until full (1,440 acre-feet), then applied to flood pool (3,850 acre-feet).

Flood Control Benefits Hwy 89 to Renwick

To analyze the performance of restoration alternatives, synthetic rainfall events were simulated using HEC-HMS (USACE, 2020) and routed through the HEC-RAS (USACE, 2019) hydraulic models described in *Appendix D-2: Existing Conditions Hydrology and Hydraulics Report*. The events include 2-year through 100-year return periods based on NOAA Atlas 14 rainfall depths with a 4-day duration. The 4-day duration was found to be critical for economic analysis of the Tongue River Watershed. The 500-year event was not modeled as there are no urban areas or structures inundated with greater than 3 feet of depth, or 4 feet^2/second Depth*Velocity. Runoff Curve Numbers were adjusted from a 24-hour Curve Number to a 4-day Curve Number based on guidance from *NEH, Part 630, Chapter 21* and were set to average antecedent moisture condition (AMC II). The rainfall distribution used for the synthetic events was developed using a "nesting" technique described in *NEH, Part 630, Chapter 4* (NRCS, 2015). *(Note: The existing conditions model was modified to incorporate the restoration alternative project components. Inundated acreages were updated for this report and may not match the Existing Conditions Hydrology and Hydraulics Report and the Alternative Screening Report).*

The existing conditions includes the severely incised Tongue River channel, where all events modeled do not access the natural floodplain. Both Alternatives 1 and 2 take into account the river restoration project in which the bankfull flow remains in the channel, but all greater events activating the floodplain. The floodplain in the project reach is forest, conservation easement, grassland, or hayfields which makes it an ideal area for temporary inundation. Alternative 1 includes incorporates river restoration with large floodplain excavations on both sides of Hwy 89 to maximize off-channel flood volume storage. Alternative 2 includes river restoration with smaller floodplain depressions on both sides of Hwy 89, that are only large enough to generate the earthfill necessary for the restoration project. Floodwaters that flow through the floodplain, instead of the incised channel, have lower velocities and attenuate peak flows. Additionally, floodplain excavations further attenuate peak flood flows as off-channel storage.

Multiple reporting locations are selected at geographically significant locations, these locations include North Dakota State Highways, township roads, and inflow and outflow from the main stem Tongue River at Renwick Reservoir. Reporting locations are shown in Figure 8. Flow reductions are most significant immediately downstream of the project and are lower further downstream, full results are shown in Table 4.

The inundation for the 2-year through 100-year events are shown in Figures 9 through 14. Inundation for each existing conditions (red), the proposed Alternative 2 condition (yellow), and proposed Alternative 1 condition (blue) are shown on the figures. The red and yellow represents lands that are no longer flooded with the project for that event. Blue represents lands that are flooded for all conditions. In addition to inundation extents, critical structures that are affected by the existing conditions inundation are shown on the inundation figures. The figures show the maximum inundation extent that occurs during the event; however the full benefit of the project is not apparent on the inundation figures. Flood damages, especially damages to agricultural lands, are caused both by the extent of the inundation and, almost equally as important, the duration of inundation. The total inundated acres and cropland inundated acres for the analyzed events based on duration are shown in Table 5. Cropland acres were estimated using the National Agricultural Statistics Service (NASS) data from 2020 (USDA, 2020).

Typical crops within the North Branch Watershed include wheat, soybeans, corn, dry beans, potatoes, and sunflowers. Flood inundation durations greater than four days generally represents the maximum anticipated damages, or total loss, for the crop types in the study area. Table 6 shows total inundated acres for durations less than 4-days. To provide benefit to agricultural lands, flood durations between 0 and 4 days should be reduced. Zero to 4 days represents the time between no inundation and total crop loss inundation. The total area with reduced inundations is less than cropland due to floodplain re-activation and inundation of non-cropland through the project reach.

During the existing conditions 10-year event, there are 326 cropland acres inundated for less than 4-days. With the impoundment site, the same event would inundate 285 cropland acres for less than 4-days. This results in a reduction of 40 acres or 12%. Restoration with large excavations reduces the cropland inundation for durations less than 4-days by 3% to 18% for the 2-year through 100-year events.

Table 4: Peak Flow Changes

Location	Event	Existing Conditions	Alternative 1: Stable Channel w/ large floodplain excavations		Alternative 2: Stable Channel w/ small floodplain excavations	
		Flow (cfs)	Flow (cfs)	% Change	Flow (cfs)	% Change
Tongue River - Hwy 32	2-year	415	379	-9%	379	-9%
	5-year	603	513	-15%	542	-10%
	10-year	845	585	-31%	680	-20%
	25-year	1,225	809	-34%	1,111	-9%
	50-year	1,494	1,267	-15%	1,481	-1%
	100-year	1,812	1,722	-5%	1,807	0%
Tongue River - 131st Ave NE	2-year	399	387	-3%	387	-3%
	5-year	615	528	-14%	553	-10%
	10-year	863	606	-30%	697	-19%
	25-year	1,236	825	-33%	1,125	-9%
	50-year	1,393	1,257	-10%	1,385	-1%
	100-year	1,462	1,451	-1%	1,461	0%
Tongue River - Hwy 5	2-year	397	389	-2%	389	-2%
	5-year	612	529	-14%	554	-9%
	10-year	816	607	-26%	686	-16%
	25-year	1,031	792	-23%	988	-4%
	50-year	1,130	1,027	-9%	1,106	-2%
	100-year	1,153	1,136	-1%	1,150	0%
	2-year	483	480	-1%	481	0%

Tongue River - 133rd Ave NE	5-year	700	663	-5%	677	-3%
	10-year	993	865	-13%	924	-7%
	25-year	1,454	1,231	-15%	1,395	-4%
	50-year	1,786	1,664	-7%	1,742	-2%
	100-year	2,302	2,037	-12%	2,141	-7%
Tongue River - Renwick Inflow	2-year	523	519	-1%	520	-1%
	5-year	758	725	-4%	737	-3%
	10-year	1,141	1,018	-11%	1,076	-6%
	25-year	2,230	1,824	-18%	2,094	-6%
	50-year	3,529	3,151	-11%	3,260	-8%
	100-year	6,733	6,114	-9%	6,390	-5%
Tongue River - Renwick Outflow	2-year	308	305	-1%	305	-1%
	5-year	425	419	-1%	421	-1%
	10-year	520	512	-2%	517	-1%
	25-year	753	716	-5%	737	-2%
	50-year	1,169	1,112	-5%	1,133	-3%
	100-year	2,119	2,021	-5%	2,049	-3%

Table 5: Flood Duration Acreage by Flood Recurrence Interval

Scenario	Duration (hours)	2-year Cropland	2-year Total	5-year Cropland	5-year Total	10-year Cropland	10-year Total	25-year Cropland	25-year Total	50-year Cropland	50-year Total	100-year Cropland	100-year Total
Existing Conditions	0-24	19	61	95	235	197	399	390	700	475	799	491	834
	24-48	19	59	43	103	68	154	116	227	276	494	344	555
	48-72	16	61	36	84	45	102	61	138	102	232	299	601
	72-96	13	79	17	43	15	33	17	35	18	42	29	69
	96-120	5	46	9	37	14	33	12	27	13	30	14	34
	>120	40	414	62	583	88	673	116	747	129	778	135	794
	Total	113	721	261	1,084	428	1,394	712	1,875	1,012	2,374	1,312	2,887
Alt. 1 Stable Channel w/ Large Floodplain Excavations	0-24	20	62	86	226	158	351	290	554	353	588	430	714
	24-48	19	59	43	103	68	155	117	240	226	448	318	530
	48-72	15	57	36	84	45	103	57	137	99	248	255	582
	72-96	12	79	14	36	14	32	16	35	18	45	29	73
	96-120	5	45	8	32	15	34	12	30	12	30	15	37
	>120	40	423	64	617	84	697	113	775	126	811	134	830
	Total	111	723	251	1,098	384	1,371	605	1,771	835	2,171	1,181	2,766
Alt 1 % Change Stable Channel w/ Large Floodplain Excavations	0-24	2%	0%	-10%	-4%	-20%	-12%	-26%	-21%	-26%	-26%	-12%	-14%
	24-48	0%	0%	1%	0%	0%	0%	1%	6%	-18%	-9%	-7%	-4%
	48-72	-8%	-7%	-1%	0%	-1%	2%	-5%	-1%	-3%	7%	-15%	-3%
	72-96	-4%	-1%	-18%	-16%	-8%	-6%	-5%	-2%	-2%	6%	2%	7%
	96-120	-2%	-3%	-14%	-14%	8%	2%	2%	10%	-2%	1%	4%	8%
	>120	-1%	2%	4%	6%	-5%	4%	-3%	4%	-2%	4%	-1%	5%
	Total	-2%	0%	-4%	1%	-10%	-2%	-15%	-6%	-18%	-9%	-10%	-4%
Alt 2 Stable Channel w/ Small Floodplain Excavations	0-24	20	62	89	248	172	400	334	655	426	723	494	832
	24-48	22	61	41	103	66	155	115	238	251	493	323	529
	48-72	15	58	36	87	45	100	58	137	97	243	275	624
	72-96	12	80	15	39	14	32	16	35	16	41	29	73
	96-120	5	44	7	30	15	37	10	25	11	27	14	37
	>120	39	421	66	611	87	696	115	772	142	843	133	817
	Total	114	726	254	1119	398	1421	648	1862	944	2369	1269	2911
Alt 2 % Change Stable Channel w/ Small Floodplain Excavations	0-24	6%	1%	-6%	6%	-13%	0%	-14%	-6%	-10%	-10%	1%	0%
	24-48	11%	4%	-5%	0%	-3%	0%	-1%	5%	-9%	0%	-6%	-5%
	48-72	-6%	-6%	1%	4%	-1%	-1%	-4%	-1%	-5%	5%	-8%	4%
	72-96	-7%	1%	-8%	-8%	-10%	-5%	-4%	-1%	-11%	-3%	1%	6%
	96-120	3%	-4%	-24%	-19%	7%	13%	-10%	-8%	-10%	-10%	2%	6%
	>120	-2%	2%	6%	5%	-1%	3%	-1%	3%	10%	8%	-2%	3%
	Total	1%	1%	-3%	3%	-7%	2%	-9%	-1%	-7%	0%	-3%	1%

Table 6: Inundated Acreage Less than 4-Days

Scenario	Duration (hours)	2-year		5-year		10-year		25-year		50-year		100-year	
		Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total
Existing Conditions	Less than 4-days (0-96 Hours)	67	261	191	464	326	688	584	1101	871	1566	1163	2059
Alt 1 Stable Channel w/ Large Excvtn		66	256	179	449	285	640	481	966	696	1330	1033	1899
Difference		-2	-5	-12	-15	-40	-48	-103	-135	-175	-237	-130	-159
% Change		-2%	-2%	-6%	-3%	-12%	-7%	-18%	-12%	-20%	-15%	-11%	-8%

Scenario	Duration (hours)	2-year		5-year		10-year		25-year		50-year		100-year	
		Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total
Existing Conditions	Less than 4-days (0-96 Hours)	67	261	191	464	326	688	584	1101	871	1566	1163	2059
Alt 2 Stable Channel w/ Small Excvtn		69	261	182	477	297	687	523	1065	790	1499	1121	2057
Difference		1	0	-9	13	-29	-1	-61	-36	-81	-67	-42	-1
% Change		2%	0%	-5%	3%	-9%	0%	-10%	-3%	-9%	-4%	-4%	0%

Water Quality/Recreation Benefits

Water Quality Monitoring Data

The 26.4 miles of the Tongue River from it's origin upstream of Senator Young Dam to Renwick Dam was listed in the ND Section 303(d) list as "Fully Supported but Threatened" for Fish and other Aquatic Biota due to Combined Biota/Habitat Assessments. The 14.6 miles downstream of Renwick Dam had the same designation but with added impairments for selenium and sedimentation/siltation. Limited data is available with regards to water quality in the Tongue River. The only currently active USGS gauge in the watershed is #05101000 Tongue River at Akra, located immediately below the principle spillway outlet of Renwick Dam. It has recorded daily flow data from 1950 to the present and has included sporadic water quality sampling since 1971. Flow out the spillway is from the top of the reservoir, therefore is primarily made up of dissolved phosphorus (DP) and particulate phosphorus (PP) bound to fine grained suspended sediments. Given the location of the gauge, typical correlations between flow rate and water quality constituents such as total suspended solids and total phosphorus (TP) are not present. As a result, annual TP loads cannot be computed, however concentrations in the 10 water years sampled do illustrate trends as summarized in Table 7. With the initiation of the severe channel incision in the project reach in 2013, TP concentrations approximately doubled in the discharge downstream of the dam. Although 2018-2020 have seen very low peak flows, TP concentrations have remained high due to the ongoing channel incision process.

Table 7: Available Total Phosphorus Data from USGS #05101000 Below Renwick Dam

Water Year	# Samples	Peak Q (cfs)	Min TP (mg/L)	Max TP (mg/L)	Mean TP (mg/L)	Median TP (mg/L)
1980	8	180	0.05	0.63	0.22	0.18
2004	13	630	0.07	0.39	0.19	0.15
2013-2015	12	1,550	0.08	1.07	0.41	0.36
2016-2017	8	552	0.08	0.89	0.43	0.42
2018-2020	11	279	0.08	0.81	0.36	0.34

In 2004 the Pembina Soil and Water Conservation District collected samples at several sites upstream of Renwick, which are summarized in Table 8.

Table 8: 2004 Total Phosphorus Data Collected Upstream of Renwick Dam

Location	# Samples	Min TP (mg/L)	Max TP (mg/L)	Mean TP (mg/L)	Median TP (mg/L)
Herzog Dam outlet	20	0.06	0.92	0.30	0.49
Highway 32	21	0.12	0.64	0.27	0.38
Olson Dam outlet	14	0.06	0.33	0.20	0.19

As demonstrated by the fact that upstream TP concentrations in 2004 were up to 3 times higher than those downstream of Renwick, the reservoir does act as a phosphorus trap. While that result may appear obvious, given typical assumptions that approximately 75% of TP exported from agriculturally dominated Upper Midwest watersheds is in particulate bound form (Huisman et al, 2013), that would not necessarily be expected in the Red River Basin. Long term water quality data indicates that DP accounts for an average of 85% of TP on tributaries to the Red River, due to the combination of long inundation floods resulting from the low relief landscape, very fine silt and clay lacustrine soils, high contribution of labile phosphorus to DP during spring runoff flooding over dead vegetation (McCullough et al, 2012). Sediment cores collected for the Renwick dam rehabilitation project planning effort indicate in 2003 that "phosphorus and nitrate level were low", with concentrations from the four cores averaging 11.6 mg/kg for nitrate and 66.4 mg/kg for phosphorus (Higley, 2004). The Environmental Assessment for the rehabilitation project concluded that the reservoir water quality was "adequate and static" at that time (USDA-NRCS, 2006).

The Renwick reservoir was listed as a Section 303(d) TMDL water as “Fully Supporting but Threatened” for Fish and Other Aquatic Biota due to sedimentation/siltation and “Fully Supported but Threatened” for Recreation due to Nutrient/Eutrophication Biological Indicators (ND DEQ, 2018). A TMDL has not been developed for the reservoir at this point in time. Water quality data within the reservoir was last collected by ND DEQ in 2015-2016. The reservoir was found to stratify in the summer with warm, well-oxygenated water at the top of the water column and cold, low-oxygen water near the bottom (ND DEQ, 2019). It is typical for small reservoirs in the Red River Basin to stratify rapidly after the spring and fall turnovers, as warm water in the bottom moves to the surface and vice versa. The spring turnover can cause fish kills due mixing which causes overall oxygen depletion through the reservoir however no fish kills have been reported in this particular reservoir to date. The overall reservoir trophic state index is considered eutrophic (DEQ, 2019), which has high nutrient concentrations and moderate algal and plant growth. Based on the TP index, the reservoir is categorized as hypereutrophic, which is considered impaired due to excessive plant and algal growth from high supply of nutrients. The reservoir nutrient concentrations indicate TP is greater than the median of other lakes in the ecoregion, while Total Nitrogen (TN) is less than median ecoregion lakes. TP is the critical nutrient driving water quality and associated beneficial uses, i.e. recreation and aquatic biota, in the Renwick reservoir.

From 1997 to 2020, the ND Game and Fish (NDG&F) collected water quality data twice a year, once in the summer (typically early August) and once in the winter (typically early February) in the Renwick reservoir. Sampling for turbidity, dissolved oxygen, and temperature was completed at various depths and lake locations, and the presence of algae noted. Prior to 1997 some less intensive sampling was done, mainly in the winter months and the testing frequency was somewhat sporadic. A comparison of data prior to initiation of major channel incision in 2013, versus after that point is shown in Table 9, and indicates a slight increase in turbidity, surface dissolved oxygen, and bottom dissolved oxygen. Warmwater fish such as perch and northern pike have Measurements taken once a year, however, are likely not reliable data for comparison.

Table 9: Renwick Reservoir Summer NDG&F Water Quality Data (mid-lake)

Parameter		1997-2012	2013-2020
Number Samples		15	8
Turbidity- Secci (m)	Range	0.3-1.5	0.5 – 1.5
	Average	0.6	0.8
DO @ 1m (mg/L)	Range	5.7 – 13.7	7.5 – 12.1
	Average	8.8	9.8
DO @ bottom (mg/L)	Range	2.5 – 11.4	2.8 – 9.5
	Average	5.7	6.4
Algal Blooms[1]	Number	3	4
	% of years	20%	50%
Harmful Algal[1] Blooms	Number	0	2
	% of years	0%	25%

[1] Algal bloom data augmented with ND DEQ data as well.

Algal blooms were recorded either in the NDG&F data and/or in ND DEQ records in 2008, 2011, 2012, 2015, 2017, 2019, and 2020. Those reflect only that single day of the survey that year, however, and likely seriously under-represent the frequency of algal blooms. Cyanobacteria, or blue-green algae, are naturally present in the reservoir. Likely cynobacteria species present are Aphanizomenon or Microcystis, given they are common in ND. The combination of a phosphorus rich lake and high temperatures can generate rapid reproduction of the bacteria, causing extensive blooms that have the potential to release cyanotoxins. ND DEQ sampled for cyanotoxin in the Renwick reservoir in both 2017 and 2020, prompting a Harmful Algal Bloom (HAB) declaration and public warnings in those years. It is unknown whether other algal bloom events had cyanotoxin release as well.

Phosphorus Modeling and Projections

As previously noted, the International Water Institute has developed a calibrated water quality model, based on hydro-conditioned LiDAR data, land use, and basin wide averages for water quality constituents, called PTMApp for the Pembina River Basin which includes the Tongue River. The PTMApp modeled TP load to Renwick reservoir is estimated to be between 13,000 and 15,000 lb/year (International Water Institute, 2021); this does not consider the additional inputs from an actively incising river. As previously noted, the Red River Basin is unique in its high percentage of dissolved phosphorus. A ratio analysis of dissolved to particulate form phosphorus was completed for the adjacent Park River using USGS Gauge #5090000 records. The result was an average of 73% dissolved and 27% particulate phosphorus ratios. Therefore, the expected base watershed TP loading to Renwick is ~14,000 lb/year, with dissolved contributing ~10,000 lb/year and particulate contributing ~4,000 lb/year.

In order to derive an estimate of TP delivered from upstream channel incision and widening, six borings were taken on riverbanks through the project reach as identified in Figure 15. A total of 29 samples were collected at various depths, the results of which indicate the average TP concentration to be ~750 ppm with generally decreasing concentration with depth. Concentration plots by depth are shown in Figure 16. Based on the 21.9 ac-ft per year of erosion due to channel banks (3.4), channel thalweg (3.5) and widening beyond channel (15.0), which were described in the previous Flood Control Benefits section; annual TP transport volume due to channel incision and widening is estimated at 70,000 lbs as show in Table 10.

Table 10: Annual Phosphorus Delivery Due to Project Reach Channel Incision and Widening

Sediment Erosion	Area Conversion	Unit Weight of Soil	TP attached to Sediment	TP Erosion
(acre-feet)	(ft^2/acre)	(lb/ft^3)	(lb/lb)	(lb)
21.9	43,560	~100	0.00075	~70,000

The amount of the project reach erosion generated TP that reaches Renwick Reservoir is difficult to estimate, given the challenges of determining bedload and suspended load ratios, equilibrium concentrations, and fluxes through river and reservoir. Given that the eroded TP from project reach is ~5 times that of the natural watershed load, however, even a fraction of that load delivered to the reservoir would be a substantial increase above base conditions. The significant increase in sediment from channel incision also increases the likelihood of DP binding to suspended sediment particles in the river, as they are transported downstream. Likewise, depending on equilibrium phosphorus concentration, DP in the reservoir can bind to suspended sediments that have a higher likelihood of depositing in the reservoir.

Recreation Impacts

Icelandic State Park encompasses 900 acres located on the north shore of Renwick Reservoir and includes a swim beach, boat launch, watercraft rentals, playground, amphitheater, museum, visitor center, 4 miles of hiking trails, 140 modern, 10 primitive, and 7 group camp sites. In the 2009-2011 time period, the average annual visitation was recorded as 114,906 people, with 29,963 of those staying overnight (Bangsund, 2013). From 2012 to 2020, the number of vehicles visiting the parks has averaged 66,121 per year, with the majority of that in June, July, and August (NDSP, 2021). The closest campgrounds with similar amenities would be on Devils Lake, which is a two hour drive to the southeast.

The reservoir is one of the key features of the state park and is also utilized by residents in the nearby communities of Cavalier, Walhalla, and Langdon for swimming, boating, and fishing. Within Pembina and Cavalier Counties, the only lakes stocked by ND Game and Fish are Renwick, the Langdon City Pond, and Mount Carmel Dam. ND DEQ classifies Renwick Dam as a Class III warm-water fishery, which are "capable of supporting natural reproduction and growth of warm water fishes and associated aquatic biota." It is managed by ND Game and Fish for northern pike and perch, with some fingerlings stocked on an intermittent basis. The most recent fish survey, via netting, was completed in 2019 by NDG&F and yielded the results shown in Table 11.

Table 11: 2019 Fish Survey, Renwick Reservoir

Species	Catch %	Length Range (in)	Average Length (in)	Weight Range (lbs)	Average Weight (lbs)
Yellow Perch	50.9	5.9-7.5	6.3	0.1-0.1	0.1
Black Bullhead	26.6	6.9-10.8	9.0	0.2-0.9	0.4
White Sucker	20.1	10.8-20.7	16.8	0.5-3.8	2.1
Northern Pike	1.8	17.7-36.6	26.5	1.3-12.1	5.7
Black Crappie	0.6	4.3-4.3	4.3	----	---

Fish appear to be undersized in the lake, which would be logical given the measured dissolved oxygen ranges. Optimum fish growth and reproduction for warmwater fish species such as perch, walleye, and northern pike occurs at dissolved oxygen concentrations over 5 mg/L and delayed hatching and size reduction occurs at concentrations less than 3.4 mg/L. Due to the high phosphorus loading, conditions less than 3.4 mg/L have been regularly reported (MPCA, 2005). The NDG&F water quality surveys discussed earlier included notes on recreational use beginning in 1991. Ice fishing houses are noted in most of the winters, ranging in number from 4 to 20 on the date of the sampling. In addition, spearing holes were also noted. Notes on summer recreational use in the NDG&F surveys are more sporadic. In years when algal blooms were noted in the month of August, as discussed previously, there was little to no summer recreational use noted. Summer recreational use seemed to only be sporadically noted by the NDG&F, and likely would be dependent on the time of day and the weather during the visit. Common summer recreational activities noted included swimming, boating, tubing, and jet skiing. Summer angling was only noted in one year, which is consistent with personal accounts which indicate summer recreation revolves around water sports and angling is a minor summer recreational activity. The more recent notes document recreational kayaking and paddle boarding activities. Regional participation in these sports has recently increased and that the demand for these summer recreational activities is increasing in the region. State Parks personnel noted the high volume of public phone calls and concerns raised in

The original (1962) surface area of Renwick reservoir was estimated to be 220 acres, while navigable area during 2003 survey was 145 acres (Higley, 2004). Surface area based on the 2020 ortho image perimeter was estimated at 154 acres, a reduction of 30% from original pool area. As discussed in the earlier flood control section, the accelerated infill of sediment has not yet impacted the permanent pool, which was the design volume intended for recreation. Local residents are well aware of the sediment infill, however, and have raised the issue as a concern in various public forums. As discussed in previous sedimentation section, without a restoration project the permanent pool will likely fill 24% by 2040, 40% by 2050, and 100% by 2086. Near ~2030 it would be expected that water depths would have dropped to the point that a fishery could not be maintained due to high temperatures and low dissolved oxygen levels. The frequency and severity of algal blooms would continue to increase with high phosphorus loading from upstream channel erosion, reducing recreational opportunities for both state park users and local residents.

Fish and Wildlife Benefits

Instream Habitat

Northern Pearl Dace (*Margariscus margarita*) is a small, native minnow known to inhabit cool, small headwater streams and the pools of beaver dams. They spawn in clear water at depths of 1-2 feet over a gravel or sand substrate, and males establish and defend territories during the spawning season. They do not migrate extensively and tend to be residents of a series of permanent pools (MTNHP, 2021). They are considered to be an indicator species of the Coolwater Northern Glaciated Plains Fish Assemblage and are identified as a Level I Species of Conservation Priority in North Dakota (NDGF, 2021). Fish surveys over the past three decades in North Dakota have documented the Upper Tongue River as the last stronghold of the species in the state. Degradation of habitat due to land use practices, destruction of riparian habitat, decline in water quality, and flow regime changes due to the addition of dams are considered to the causal factors in population decline (NDGF, 2021).

During monitoring surveys completed for channel stability assessments in 2015-2020, NRCS staff have consistently observed high numbers of dace (species unknown) above Sta 100+00 of the proposed project where limited channel incision has occurred to date. Between Sta 70+00 and Sta 100+00 dace have been observed occasionally as well. They are often observed in beaver dam pools or those formed by large woody debris jams in the channel, likely seeking the cooler water and nutrients available. Downstream of Sta 100+00 where there is minimal tree canopy cover over the river, limited large woody debris, and a higher component of fine-grained sediment from bank erosion; dace have not been observed. These observations match with the descriptions of desirable habitat for the species given that they are frequenting reaches with the following conditions:

- Cleaner, less turbid water conditions due to non-incised river banks with only natural levels of erosion.
- High percentage of tree canopy cover over the channel, which maintains lower water temperatures in the summer.
- Narrower and deeper channel width, with deep pools, which also helps to create temperature refugia during summer low flow conditions.
- Floodplain connectivity, which allows beaver dams to be maintained for natural lifespans, providing additional pool habitat/temperature refugia.

Construction of either Alternative 1 or 2 will restore natural channel dimensions, deep pools, gravel substrate, floodplain connectivity, and riparian tree planting; all of which will be beneficial to northern pearl dace. In addition, the project will put a stop to the upstream movement of channel incision threatening the existing high-quality habitat from Sta 100+00 to the 92nd Street NE bridge (upstream of there the river channel has very little shade, and is therefore not high quality habitat).

Historical accounts of trappers and explorers from the 19th century detail the ubiquity of beaver across much of North America and a report from the Hudson Bay Company in 1783 describes the Red River Valley being full of beaver dams to the extent that the resulting marshes, mudholes, and sinkholes prevented passage (Bluemle, 2016). The fur trade was established in the northeastern Red River Valley in the late 1700s, with a trading post near the project site on the Park River that averaged 800 beaver pelts per year. Known impacts of declining beaver populations include decreased physical complexity and simplification of instream habitat, decreased channel-floodplain connectivity; increased peak flows and reduction in baseflow, channel incision, decreased groundwater tables and water storage, and conversion of multi-threaded channels to single threaded channels (Wohl, 2013). As described in Appendix D-1, the dramatic decline in beaver populations was a likely a minor contributing factor in the ongoing river channel incision process in the Tongue River.

Albeit much less than pre-nineteenth century levels, beaver activity remains present on the Tongue River. Longtime local residents describe pre-incision beaver dams as having lifespans of 3-6 years and being at a far greater density. Over the last five years, when NRCS has been conducting fall monitoring surveys, beaver dams have been often been present in the project reach; most often near 53+00, 60+00, 80+00, 95+00, and 98+00. Although there have been no flood events exceeding the 2-yr recurrence interval, none of the dams has survived a spring runoff event due to the high shear stresses within the incised channel. This is a concern, because beaver kits typically remain at their home lodge for at least 2 years before venturing out on their own. Appendix D-3 includes an evaluation of utilizing beaver dam analogues as a restoration technique, the stability analysis for which makes clear why current hydraulic conditions within the project reach are not congruent with more than a seasonal dam. Upstream of the project reach, where the rate of incision progressively declines, beaver dams have been observed to survive for several years near 101+00 and 116+00. Beavers prefer aquatic vegetation as a food source in summer given it has higher digestibility, higher mineral/protein content, and lower cellulose, lignin, and secondary metabolites than terrestrial vegetation. Woody species are of high importance as well, given that they engage in communal food caching, storing stems and branches below the ice to sustain themselves through the winter. Trees and shrubs of salicaceous riparian species (aspen, willow, and cottonwood) are their strong preference, and foraging range from a dam is typically ~200 feet. Revegetation planning for the project has been done with this in mind, to provide adequate food supplies in the future to ensure a reliable presence of dams in the reach.

The proposed project will restore 9,650 ft (1.8 miles) of river channel from 4+50 to 101+00 to natural conditions that will benefit northern pearl dace, beavers, and other aquatic species. It will also protect 28,800 ft (5.5 miles) of existing high-quality habitat from 101+00 to the 92nd St NE bridge from deteriorating due to the channel incision that would progress upstream otherwise. Although additional 5.4 river miles are present from the 92nd St

NE bridge up to Senator Young dam, the silt and boulder bed and lack of riparian forest adjacent to the channel make it less suitable habitat for northern pearl dace and other cool water aquatic species.

Floodplain and Riparian Zone

Assessment of riparian zone and floodplain vegetation in the project area was completed in 2020 and is documented in detail within Appendix D-7. Detailed revegetation plans are outlined in Appendix D-4. Overall improvements to these areas, as a result of the project, include:

- Current condition of the old cropland fields in the floodplain upstream of 37+00 is invasive bromegrass and tansy pasture. Much of that vegetation will be lost to construction staging and stockpile areas, as well as excavation of the planned floodplain depressions. Remaining vegetation will be sprayed out, areas compacted from construction tilled, and the area will be reseeded to deep-rooted native warm season grasses and forbs. The area of improved floodplain habitat will be 15 acres on the west side of Hwy 89 and 20 acres on the east, for a total of 35 acres.
- As noted previously, riparian forest is critical to maintaining natural ecosystem functions on the Tongue River. Due to incision, bank collapse, and widening, the forested riparian area on the north bank has been lost as the channel eroded into old hayfields from 37+00 to 43+00, 47+00 to 49+00, and 52+00 to 69+50. With the project, 2,550 feet of channel will have a natural riparian area with native trees and shrubs restored.
- Raised water surface levels, due to the restoration project, will accelerate productivity and growth rates of native riparian and floodplain vegetation benefiting a variety of aquatic and terrestrial species adjacent to the 9,650 feet of channel to be restored and protect 5.5 miles of upstream floodplain forests.
- The floodplain will remain in hayfields downstream of 37+00, and production of those fields will be restored with the combination of a raised water table in summer and increased frequency of flood events that provide nutrient and sediment resupply to the soils. Acreage in hayfields upstream of 4+50 (top of the rock arch rapids) that will benefit is approximately 21 acres.

Wetlands

The restoration project will raise the river thalweg to re-connect baseflow between channel and abandoned oxbow wetlands. Wetland restoration and creation areas are identified in Figure 17. There is one existing oxbow wetland (ID16 – 0.03 acres) that will be expanded, plus five additional that will be restored (ID22-26). The total restored oxbow wetland area is 0.6 acres, plus variable wetland function improvements, see Tables 12 and 13 for a summary of wetland oxbow benefits. Wetland functional improvements are calculated using the Riverine HGM developed by NRCS-South Dakota, as depressional riverine floodplain wetlands. Improvements are calculated as Functional Capacity Units (FCU), which is product of functional index and area.

The floodplain excavations described in flood control benefits section, to further attenuate peak flood flows, also provide wetland benefits. There is one wetland that will be lost (ID9 – 0.03 acres) due to the excavations, therefore this area and functions are mitigated for with improvements. Alternative 1 and 2 benefits are also summarized in Tables 12 and 13. Alternative 1 include larger excavations and therefore larger area of wetland creation than Alternative 2. Negative values in mitigation required represents benefits gained beyond existing conditions.

Table 12: Wetland acreage improvements

Alternative 1

RIVERINE ACREAGE			
Wetland ID	Pre-project (ac)	Post-Project (ac)	Mitigation Required (ac)
9	0.03	0.00	0.03
16	0.03	0.11	-0.08
22	0.00	0.07	-0.07
23	0.00	0.03	-0.03
24	0.00	0.05	-0.05

Alternative 2

RIVERINE ACREAGE			
Wetland ID	Pre-project (ac)	Post-Project (ac)	Mitigation Required (ac)
9	0.03	0.00	0.03
16	0.03	0.11	-0.08
22	0.00	0.07	-0.07
23	0.00	0.03	-0.03
24	0.00	0.05	-0.05

	25	0.00	0.01	-0.01		25	0.00	0.01	-0.01
	26	0.00	0.33	-0.33		26	0.00	0.33	-0.33
	27	0.00	4.69	-4.69		27	0.00	2.6	-2.6
	28	0.00	8.20	-8.20		28	0.00	3.5	-3.5
	Net	0.06	13.49	-13.43			0.06	6.7	-6.6

Table 13: Wetland functional improvements

	RIVERINE FUNCTIONS			
Alternative 1		Pre-project	Post-Project	Mitigation Required
		(FCU)	(FCU)	(FCU)
	Storage of Surface Water	0.01	9.84	-9.83
	Velocity Reduction Surface Water	0.03	10.75	-10.73
	Storage & Release Subsurface Water	0.02	8.67	-8.66
	Removal Imported Elements & Compounds	0.02	8.64	-8.61
	Retention of Particulates & Organic Materials	0.02	10.64	-10.62
	Organic Carbon Export	0.03	9.73	-9.70
	Maintains Plant Community	0.01	10.06	-10.04
	Maintains Habitat Structure	0.04	11.03	-10.99
	Habitat Structure & Connectivity Among Wetlands	0.03	9.95	-9.92
	RIVERINE FUNCTIONS			
Alternative 2		Pre-project	Post-Project	Mitigation Required
		(FCU)	(FCU)	(FCU)
	Storage of Surface Water	0.01	4.94	-4.93
	Velocity Reduction Surface Water	0.03	5.37	-5.34
	Storage & Release Subsurface Water	0.02	4.34	-4.32
	Removal Imported Elements & Compounds	0.02	4.3	-4.27
	Retention of Particulates & Organic Materials	0.02	5.32	-5.3
	Organic Carbon Export	0.03	4.85	-4.82
	Maintains Plant Community	0.01	5.01	-4.99
	Maintains Habitat Structure	0.04	5.48	-5.44
	Habitat Structure & Connectivity Among Wetlands	0.03	4.95	-4.93

Forest Resources

As described in Appendix D-7, the overstory of forest areas along the project reach consists of 50to 80-year old basswood, oak, elm, and ash trees. The forest stands are managed to supply a private lumber mill owned by one of the major landowners involved in the project. The active channel incision on the Tongue River, and resulting widening, has caused the loss of mature hardwood trees due to nearly continuous riverbank collapse and terrace landslides. Riverbank collapse alternates along outside bends, but also typically includes both sides of straighter riffle sections between pools. LiDAR topographic data published in 2010 was subtracted from LiDAR published in 2018, which indicated erosion depths greater than ten feet in many sections; these erosion depths are shown in callouts for each of Figures 18, 19, and 20. There was very slight aggradation along inside bends, which means sediment was moving through the system. Offsetting natural regeneration of trees within the active channel is negligeable at this point but would be expected in the future. Erosion widths vary, but the average is ~30 feet; slightly wider west of Hwy 89 and slightly narrower east of Hwy 89.

The upstream river length protected by the proposed stabilization project is ~19,000 feet, which starts at downstream project location and extends to 92nd Street NE. The project reactivates the floodplain to limit erosive currents throughout the project reach and will halt progression incision upstream. The incision wedge moving upstream of 92nd Street NE would be limited due to larger boulders in the stream bed, which holds grade better than finer material below 92nd Street NE, therefore that was not considered in these estimates. The product of nearly continuous stream length (19,000 feet) and average erosion width (30 feet) results in ~13 acres of forestland lost in the past eight years; or an average forest resource loss of ~1.6 acres/year due to channel widening and bank collapse.

River meanders that abut the valley terrace are resulting in landslides and loss of forest resources, which are exacerbated by ongoing river incision as direct streambank erosion and undercutting of banks. The landslide heights are significant, varying from 20 to 50 feet from floodplain to top of terrace. The forest resource loss includes mature trees and attached sediment; these large root systems include considerable sediment mass failures that also degrade riverine pool habitats. The majority of forest resource losses are along the southern terrace. There are five landslide areas within the project extents, which are identified as 6 – 10 in Figures 19 and 20. There are five areas identified as 1 – 5 in the mile upstream of the project that have current forest erosion due to moderate channel incision, plus further future potential as incision wedge continues to move upstream without stabilization. There are also callouts with drone imagery from 2018 that show one landslide in each section. The total area of recent and potential landslides are 8.3 acres. The potential landslide areas were delineated by land slopes greater than 15 degrees from 2018 LiDAR, and likely future extents along outside river bend that abut the terrace.

Riverbank erosion in the past 8 years has been significant, which is estimated to be ~1.6 acres/year with typical depths greater than 7 feet, and many bends eroding more than 10 feet vertically. As forest areas fall into the river the trees die and sediment moves downstream filling pools and eventually Renwick Reservoir. Landslide potential is also significant issue as there are ten currently eroding landslides along terrace bluffs. The potential for future forested landslide area loss is 8.3 acres, however timeframe or annual estimate for these was not completed due to lack of suitable assumptions. In summary, in the next ten years the loss of forest resources will range from 16 – 25 acres. Beyond that, loss of forest resources will remain even though annual losses may become less as active incision wedge works through this less stable reach.

Infrastructure Benefits

If the channel incision process on the Tongue River is not halted, through implementation of either Alternative 1 or Alternative 2 of the plan, two existing bridges will be impacted. Unlike the existing bridges downstream of the currently incised reach, both are short span bridges due to their location on low daily traffic load township roads. As a result, each would require replacement with longer span bridges and/or specially designed abutments and wingwalls. A private farm road bridge downstream of Hwy 89, failed due to channel incision and widening in approximately 2014 (rough recollection of the owner) and was never rebuilt. Another private farm road bridge in that reach has just long enough span to maintain stability. The Highway 89 bridge construction project was partially funded by the U.S. Air Force, as it is the access to the Cavalier Air Station, hence the reason it is a very long span bridge with significant clear height from the channel. While the footings have been exposed due to the channel incision process, they do not appear to be in danger of undercutting. Highway 32 is a major state highway, therefore that bridge has a relatively long span as well. The two bridge crossings upstream of Hwy 89, however, are short span bridges that would be in jeopardy of failure from incision and related widening. Figure 21 shows the locations of the bridges and includes photos.

The Tongue River crossing on 127th Ave NE (County Road 6) is approximately 1 river mile above the end of the proposed river restoration/stabilization project. The existing bridge is a ~34 ft span steel girder bridge, with unknown decking (likely corrugated steel) covered by gravel. The abutments and wingwalls consist of round timber piles with timber plank backing. Original design drawings for the bridge could not be located, but it is in good condition. As described in Appendix D-1, monitoring indicates that this 1-mile reach has already experienced 1-2 feet of incision. Over the course of the next 5-15 years, depending on the occurrence and magnitude of larger peak flow events, the channel would be expected to cut another 6 feet at the bridge. Similar to the downstream channel, it would widen in the process as well. This would have the effect of destabilizing the road fill and undercutting the existing timber abutment and wingwalls. Figure 22 shows the estimated projected profile and typical downstream cross section superimposed over the current channel and bridge section. Redesign of the bridge could be accomplished in a number of ways, however a mechanically stabilized earth wall (example: Hilfiker welded wire retaining wall) , with rock foundation excavated below the anticipated scour depth, would be a rationale choice to reduce the span length required for a new bridge to limit construction costs. An approximate layout for a new 54 ft modular steel bridge is shown on Figure 22, and a construction cost estimate is provided in Table 14.

Table 14: Bridge Replacement Cost Estimate: Tongue River @ 127th Ave NE

No.	Item	Unit	Quantity	Unit Price	Total Price
1	Mobilization, Traffic Control	LS	1	$50,000.00	$50,000
2	Demolition- existing bridge & timber pilings	LS	1	$20,000.00	$20,000
3	Excavate foundation for MSE wall, endhaul material	CY	240	$5.00	$1,200
4	Riprap purchase/placement for reinforced foundation	CY	240	$60.00	$14,400
5	MSE wall materials and construction	SQFT	2688	$55.00	$147,840
6	Purchase & delivery for 21 ft x 54 ft HS20 prefabricated modular A588 weathering steel modular bridge package. Corrugated sheet pile deck configured for 4.5" of gravel, bulkheads, backwalls, bearing pads.	FT	54	$1,741.30	$94,030
7	Reinforced concrete bridge footings	CY	12	$440.00	$5,280
8	Modular bridge placement, finish road grading	LS	1	$50,000.00	$50,000
9	Erosion Control, seeding & mulching	LS	1	$10,000.00	$10,000
10	Construction Contingency (20%)				$78,550
11	Design & Construction Engineering (25% Construction)				$117,825
12	Legal Administration and Bonding (5% Construction)				$23,565
Total Estimated Project Cost					**$612,690**

Sources: True North Steel Estimate (2020), U.S. Forest Service Northern Region Cost Estimating Guide for Road Construction (2020), RSMeans Heavy Construction Costs (2017).

The Tongue River crossing on 92nd Street NE is a 15 ft span steel girder bridge with timber plank decking, with an 8 ft clear height to the current river channel. The decking is in poor condition, and the steel girders appear undersized for standard HS20 traffic loads. It is currently used largely for light vehicles, snowmobiles, and off highway recreational vehicles. The abutments and wingwalls are reinforced concrete and would likely need replacement to meet HS20 traffic loads as well. The bridge is the legal access to the Olson Dam, which is currently undergoing an NRCS dam rehabilitation plan. Construction of that dam rehabilitation project would be projected to occur in the 2025-2027 time period and will need to include replacement of the bridge. If it does not appear that the downstream channel will be stabilized, the design of that bridge replacement would need to take projected incision in the future into account. The following is a rough estimate of only the difference of the "with project" river channel condition, for either Alternative 1 or 2, versus the "without project" conditions, assuming a similar type bridge as was described above.

Table 15: Differential Bridge Replacement Costs: Tongue River @ 92nd Street NE

No.	Item	Unit	Quantity	Unit Price	Total Price
1	Difference in height and length of MSE wall	SQFT	896	$55.00	$ 49,280
2	Difference in bridge span	FT	22	$1,741.30	$ 38,309
Total Estimated Construction Cost Differential					**$ 87,589**

Summary of Project Benefits

The following table provides a summary of quantitative, non-monetized benefits of the project.

Table 16: Summary of Project Benefits

Item	No Action Alternative	Alternative #1 Max Flood Damage Reduction	Alternative #2 Balanced Onsite Earthwork
Renwick Annual Sediment Load	55,000 tons/year	7,500 tons/year	7,500 tons/year
Renwick Annual Phosphorus Load	84,000 lbs/year	14,000 lbs/year	14,000 lbs/year
Renwick Sediment Pool	Full- 2027	Full- 2043	Full- 2043
Renwick Permanent (Recreation) Pool	24% - 2040 40% - 2050 Full - 2086	2% - 2050 11% - 2070 28% - 2113	2% - 2050 11% - 2070 28% - 2113
Renwick Flood Pool (flood damage reduction downstream of Renwick)	4% - 2060 5% - 2080 23% - 2100 33% - 2113	2% - 2060 2% - 2080 2% - 2100 3% - 2113	2% - 2060 2% - 2080 2% - 2100 3% - 2113
4-day Cropland Flood Inundation (Hwy 89 to Renwick)	2-yr – 67 acres 10-yr – 326 acres 25-yr – 584 acres 100-yr – 1163 acres	2-yr – 66 acres 10-yr – 285 acres 25-yr – 481 acres 100-yr – 1033 acres	2-yr – 69 acres 10-yr – 297 acres 25-yr – 523 acres 100-yr – 1121 acres
Project Reach Hayfields with Restored Hydrology	0 acres	21 acres	21 acres
Natural Channel & Riparian Area Function	2020 – 5.5 miles 2040 – 2.8 miles 2060 – 0 miles	1.8 miles restored 5.5 miles protected	1.8 miles restored 5.5 miles protected
Floodplains w/native perennial vegetation and hydrologic conditions	0 acres	35 acres	35 acres
Wetlands	0.1 acres 0.01-0.04 FCY	13.5 acres 8.6-11.0 FCU	6.6 acres 4.3-5.4 FCU
Forest Resources at Risk Due to Landslides	16-25 acres	0 acres	0 acres

Monetized benefits of project alternatives, resulting from maintenance of the current recreational use of Renwick Dam and reduced cropland damages, are presented in *Appendix D-5 Economics Evaluation*.

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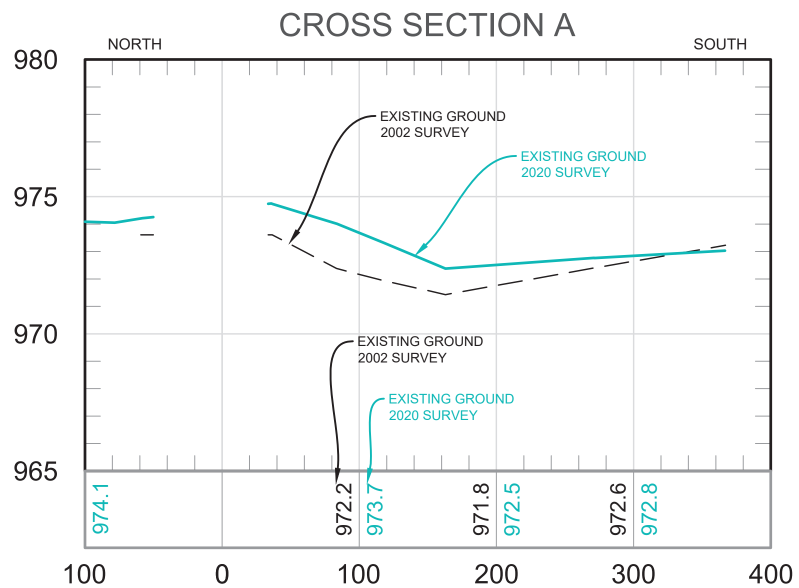
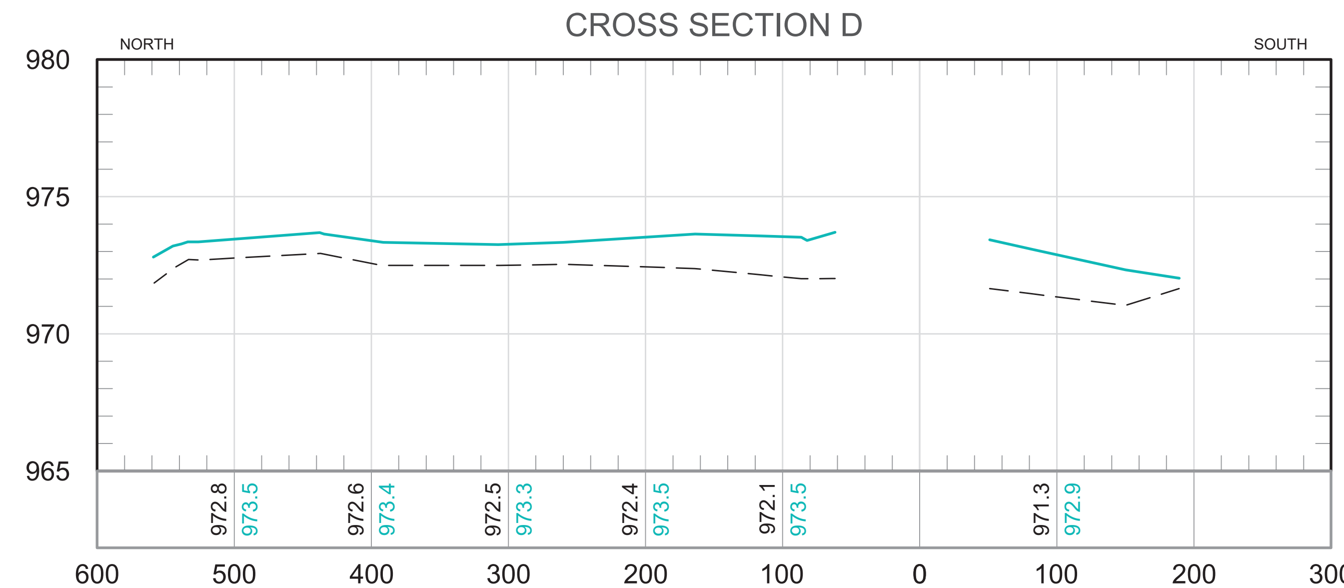
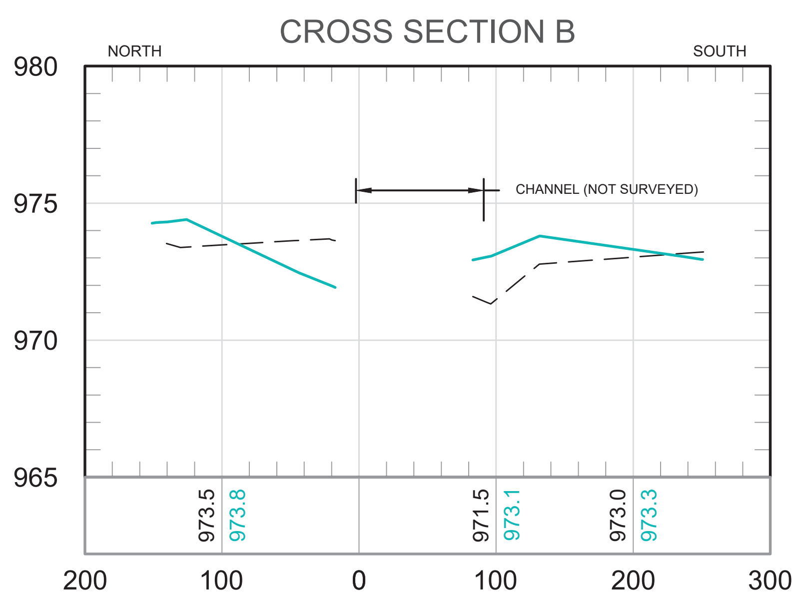
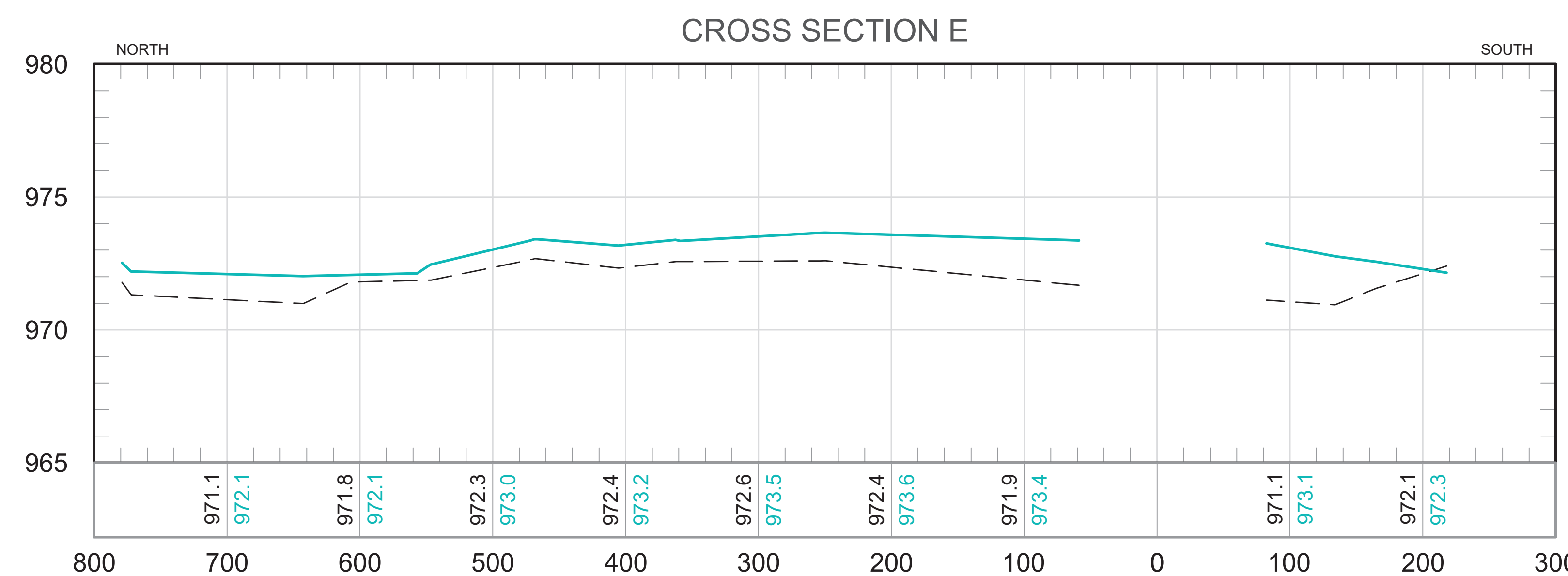
RENWICK DAM SEDIMENT SURVEY
PLAN VIEW

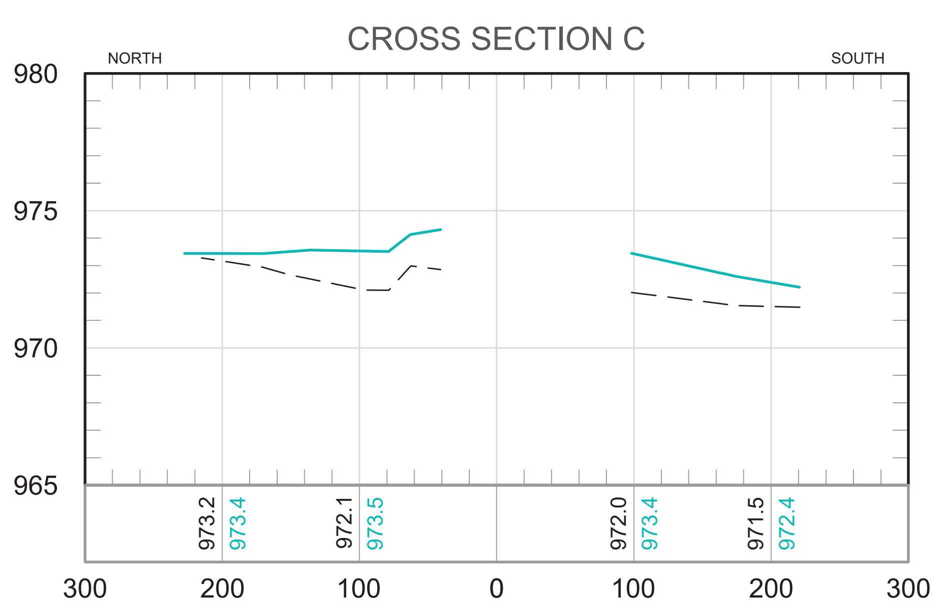
TONGUE RIVER PLAN/EA
APPENDIX D-8 FIGURE 1











Note: "0" station on cross section views are relative to the centerline of the alignment as shown on the plan view sheet.

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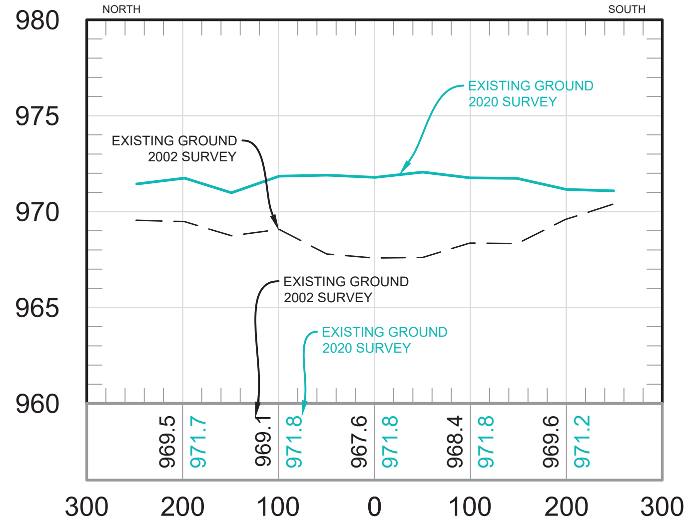
Natural Resources Conservation Service

RENWICK DAM SEDIMENT SURVEY
CROSS SECTIONS - INLET DELTA

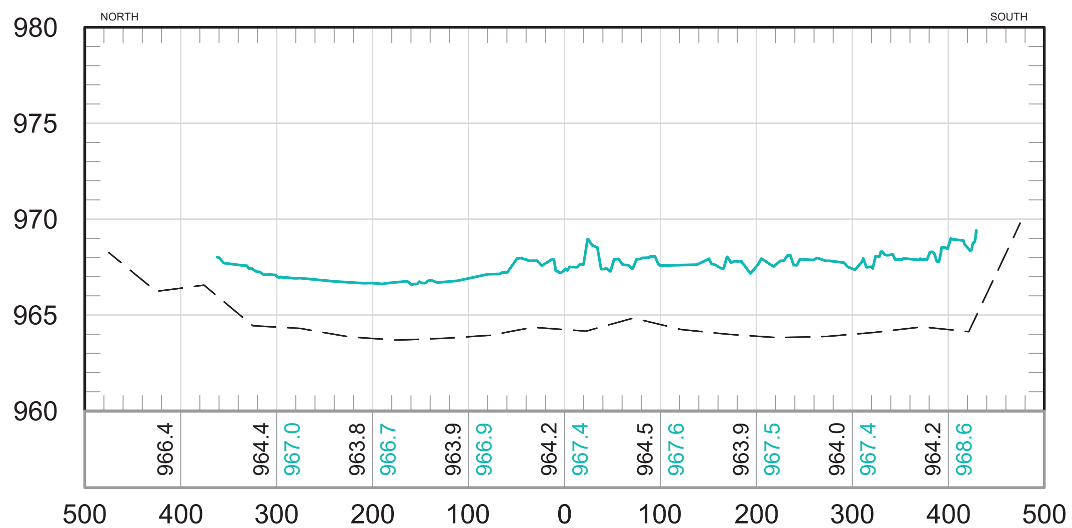
TONGUE RIVER PLAN/EA
APPENDIX D-8 FIGURE 2

CROSS SECTION 1



Note: "0" station on cross section views are relative to the centerline of the alignment as shown on the plan view sheet.

CROSS SECTION 2



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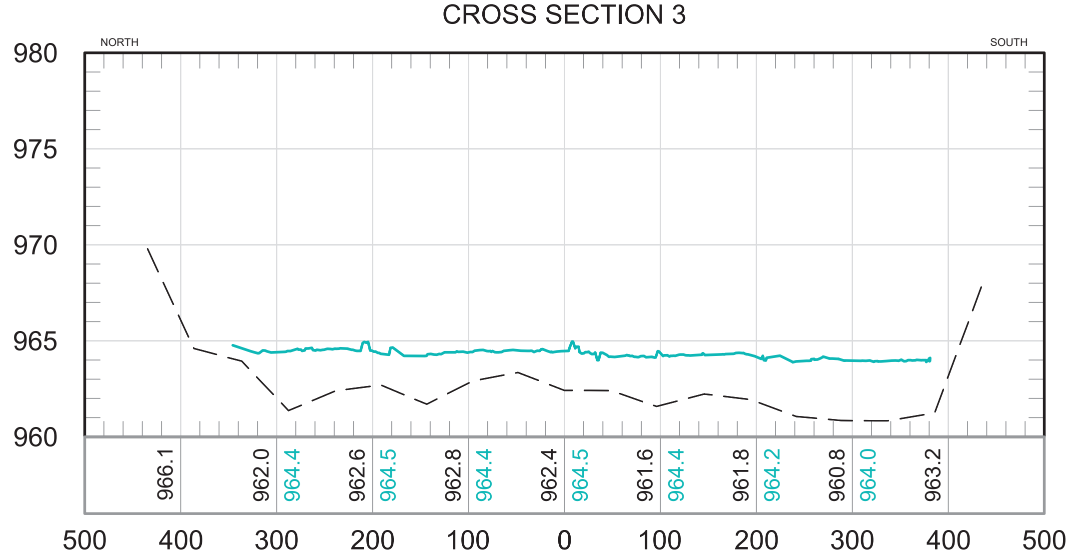

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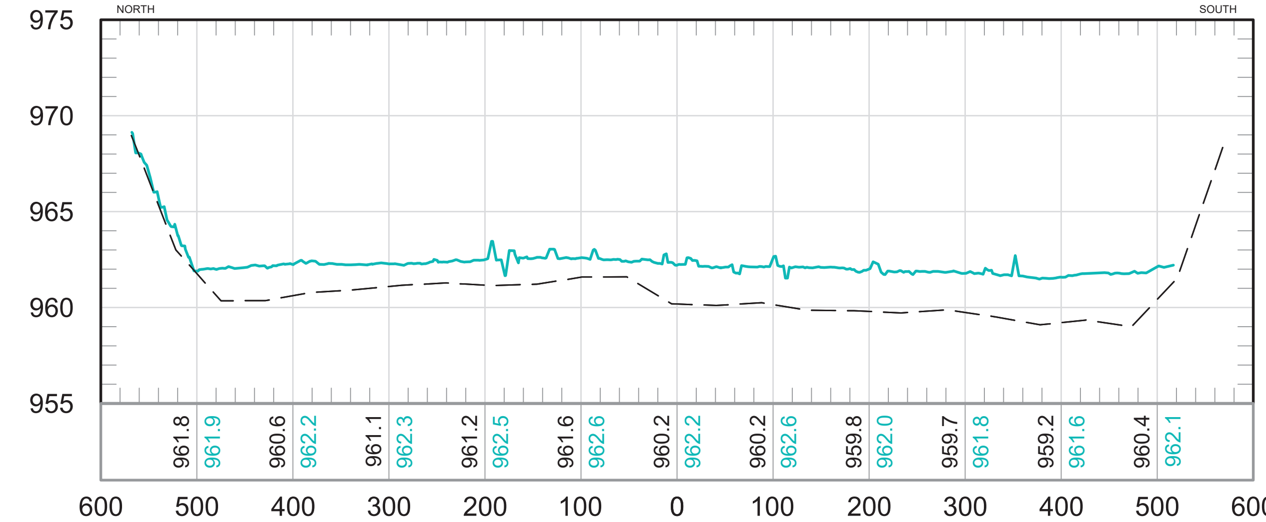

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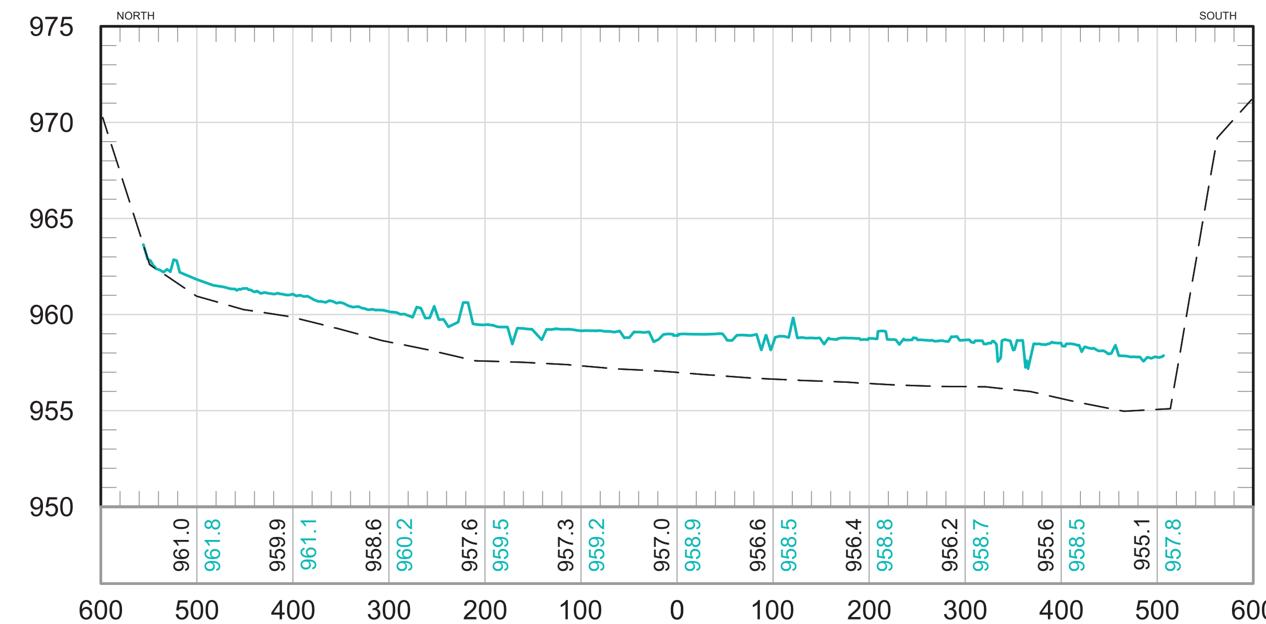

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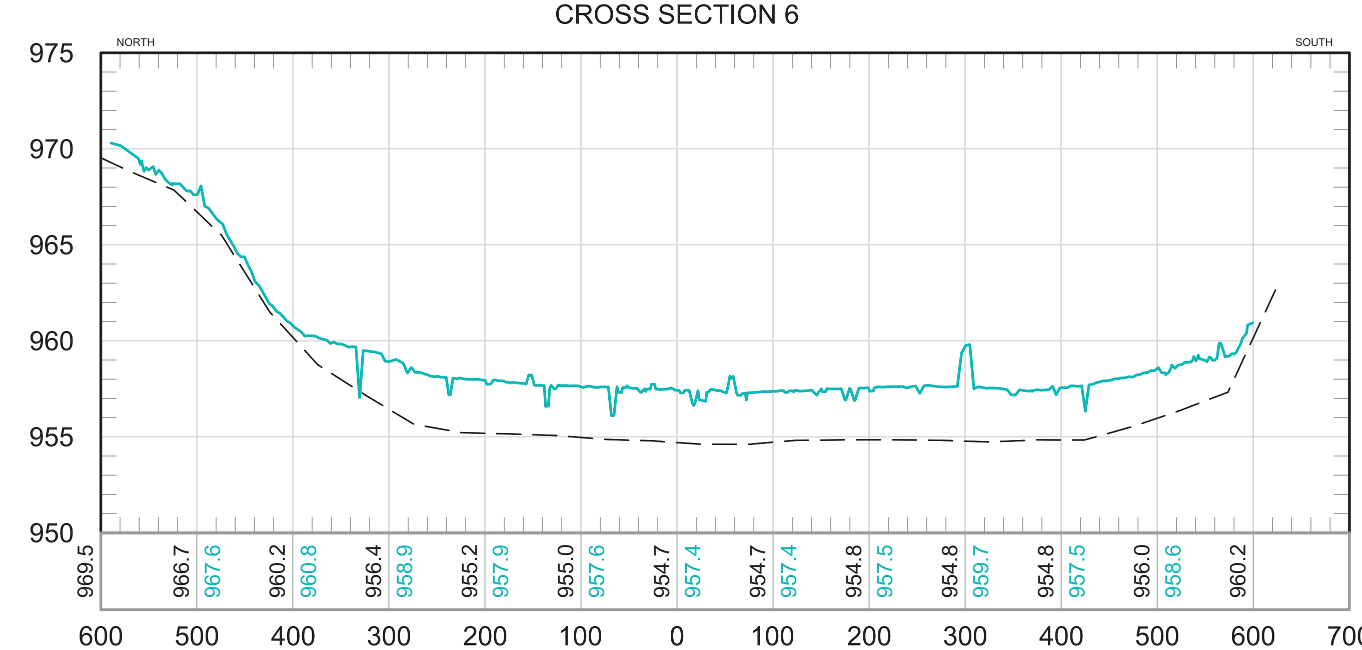

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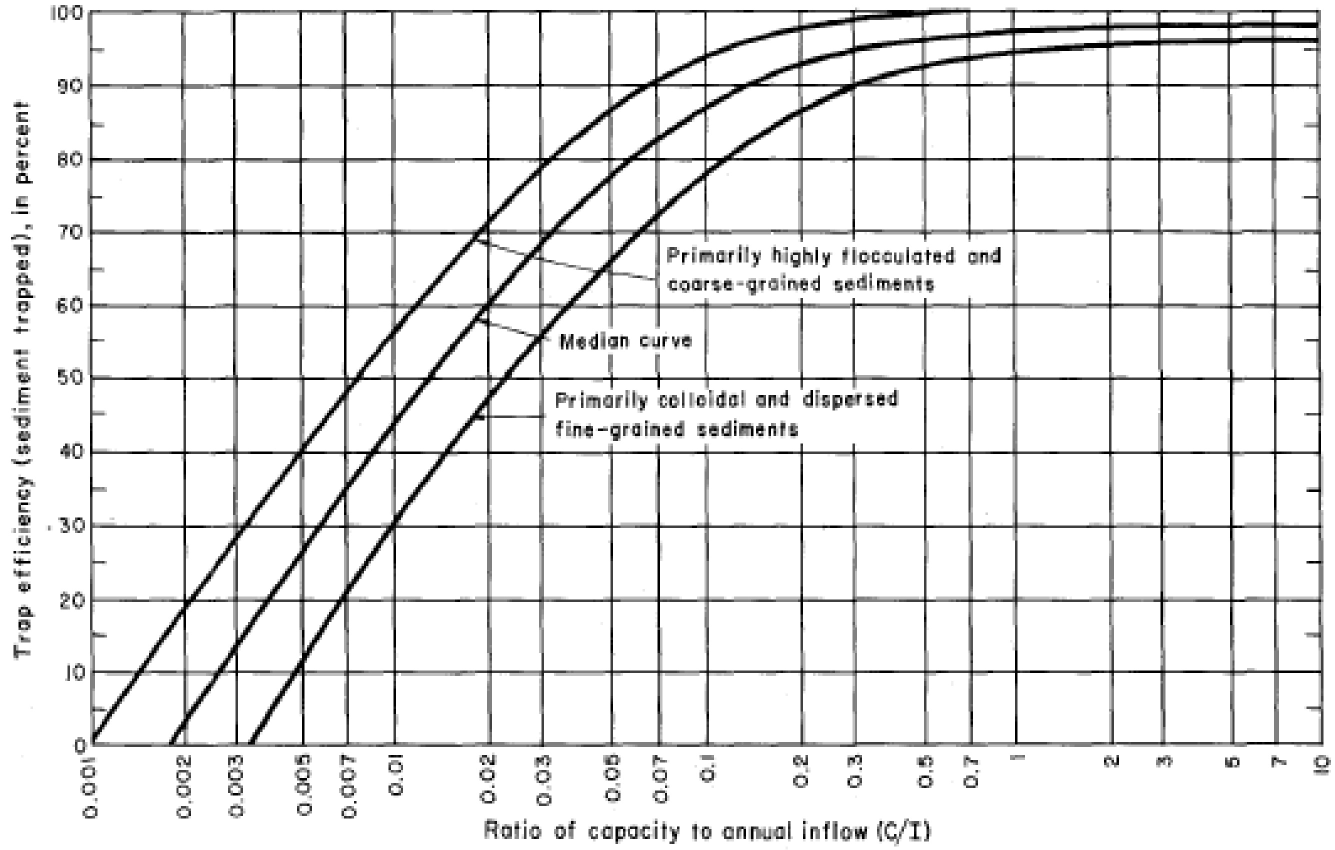
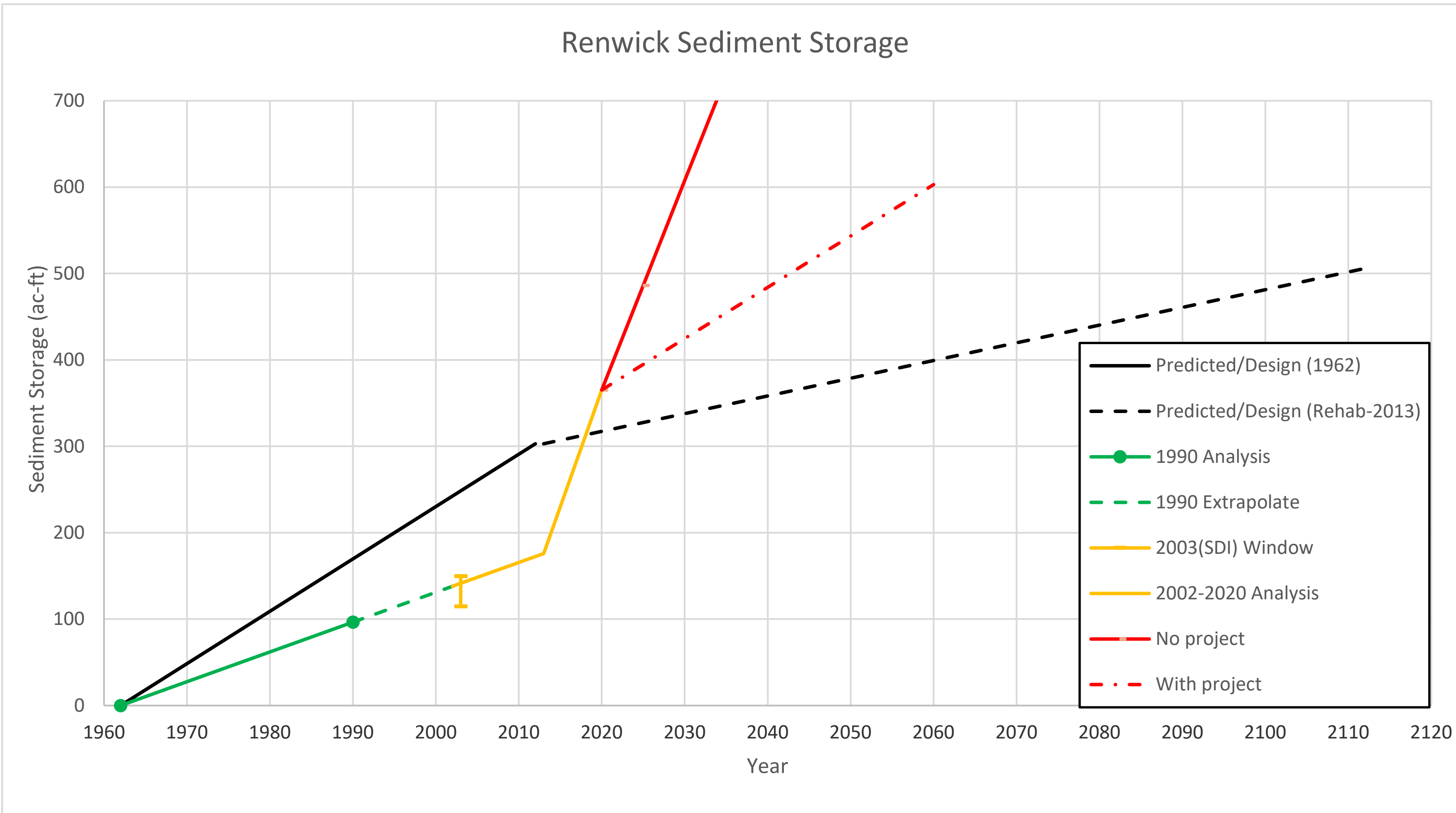
RENWICK DAM SEDIMENT SURVEY
CROSS SECTIONS - RESERVOIR

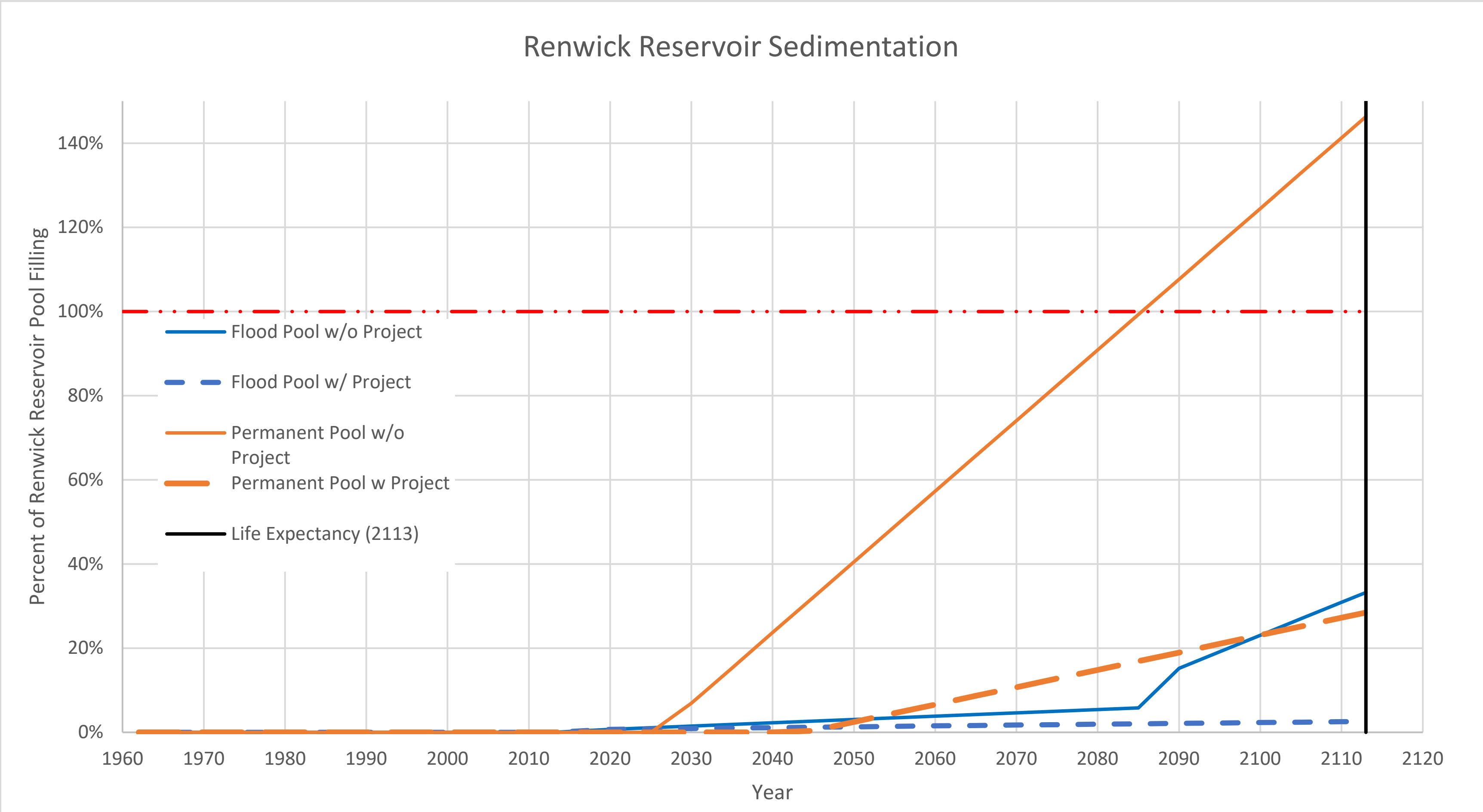
TONGUE RIVER PLAN/EA
APPENDIX D-8 FIGURE 3



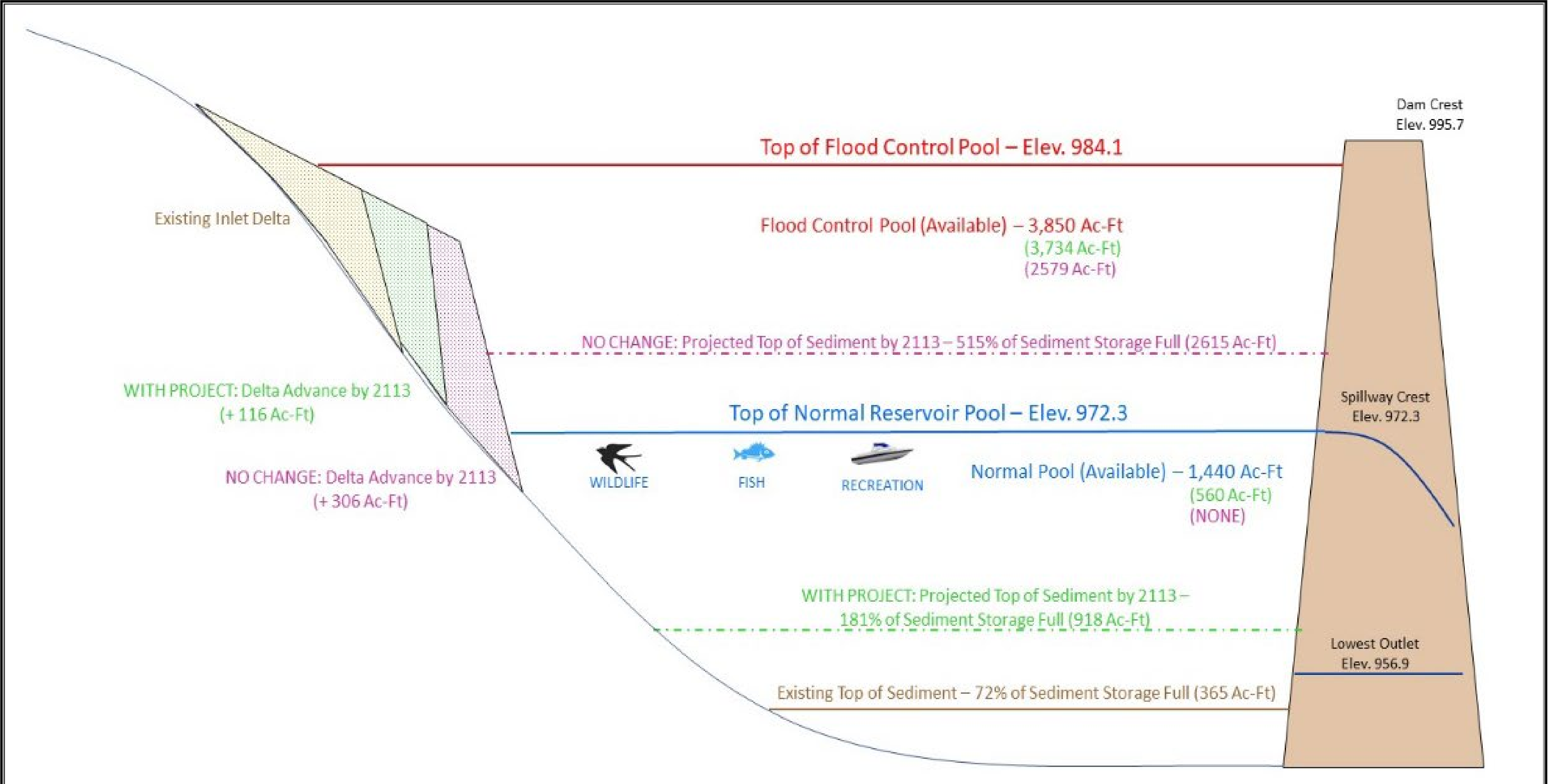
Appendix D-8 Figure 4: NEH Sec. 3, Ch. 8, Fig 8-2 Trap efficiency of reservoirs, including Renwick reservoir point



Appendix D-8 Figure 5: Renwick sediment storage design, historic, and projected (with and without project)

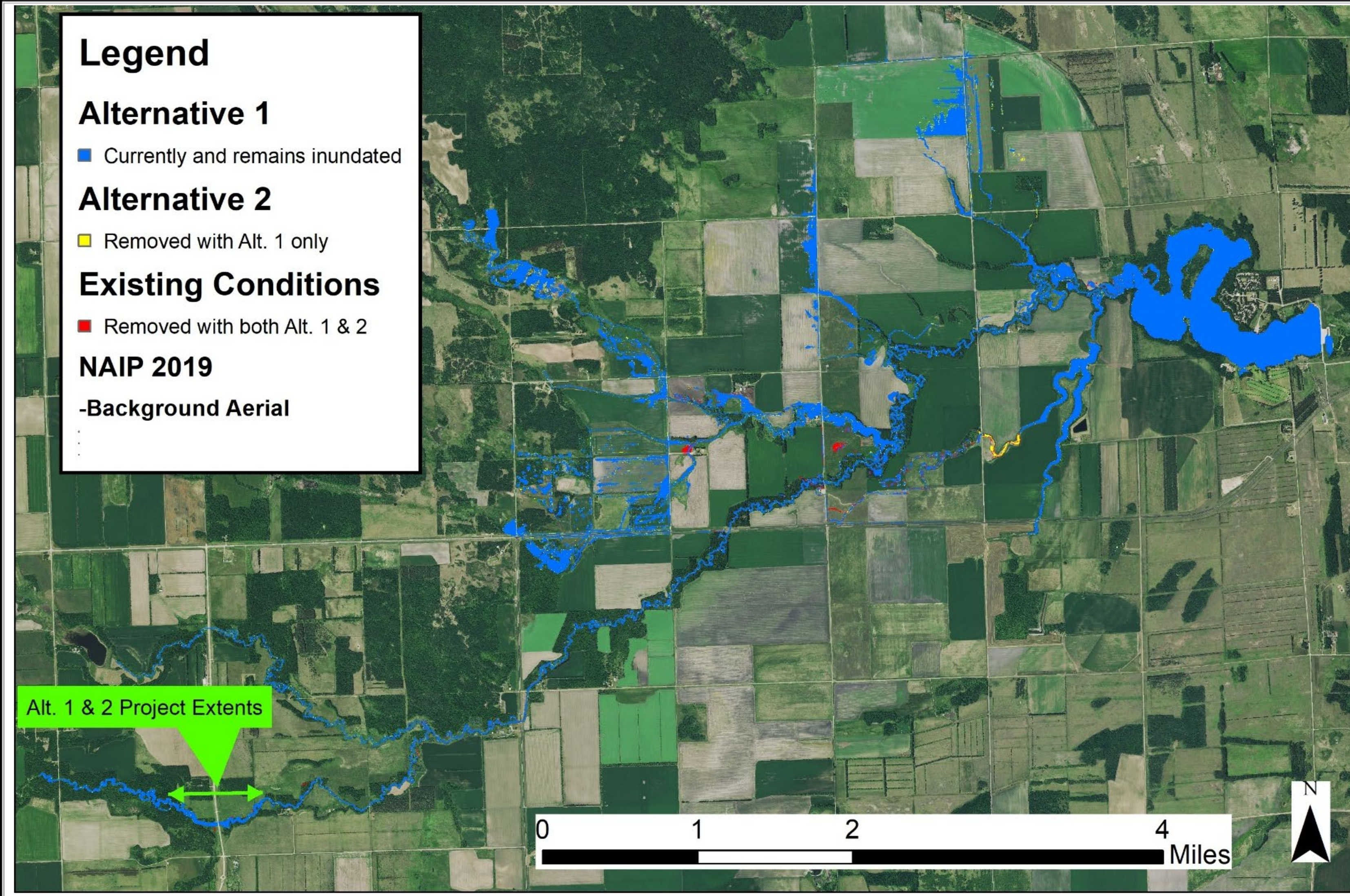


Appendix D-8 Figure 6: Renwick sediment filling design space (Flood and permanent pools), historic, and projected (with and without project)

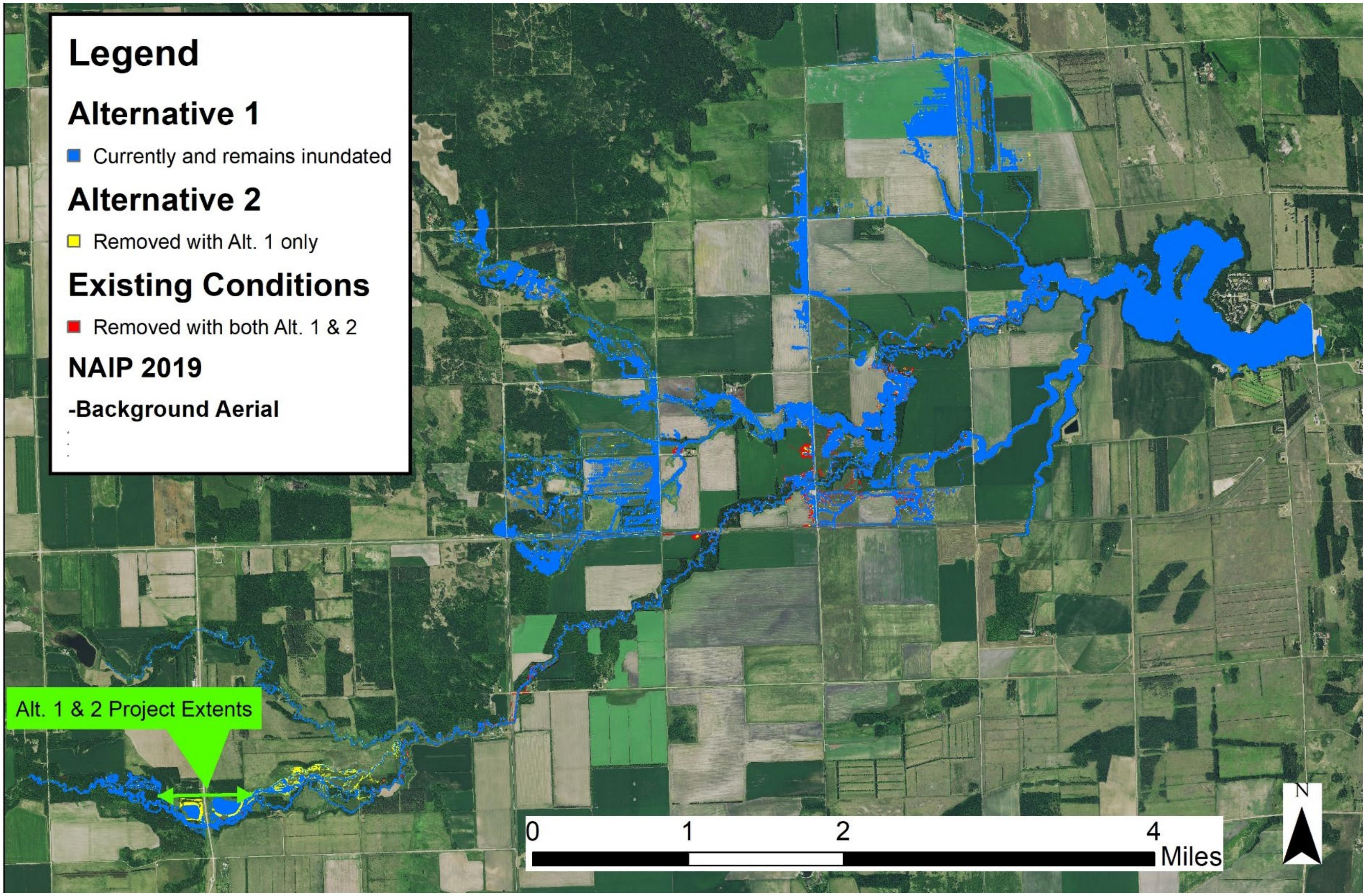


Appendix D-8 Figure 7: Renwick available storage due to sediment filling design space (with and without project)

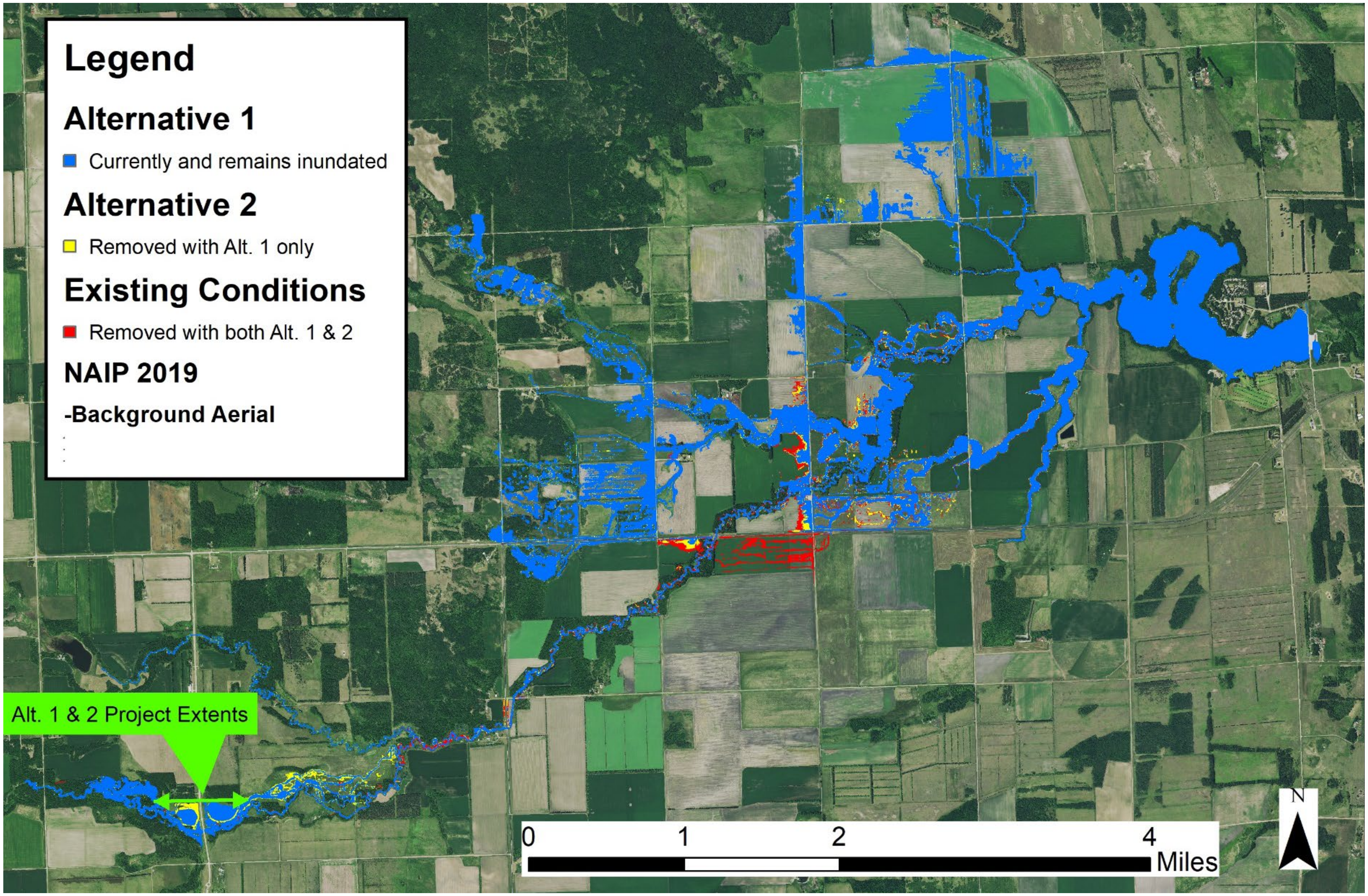
Appendix D-8 Fig. 8: Flood Control Benefits Reporting Locations



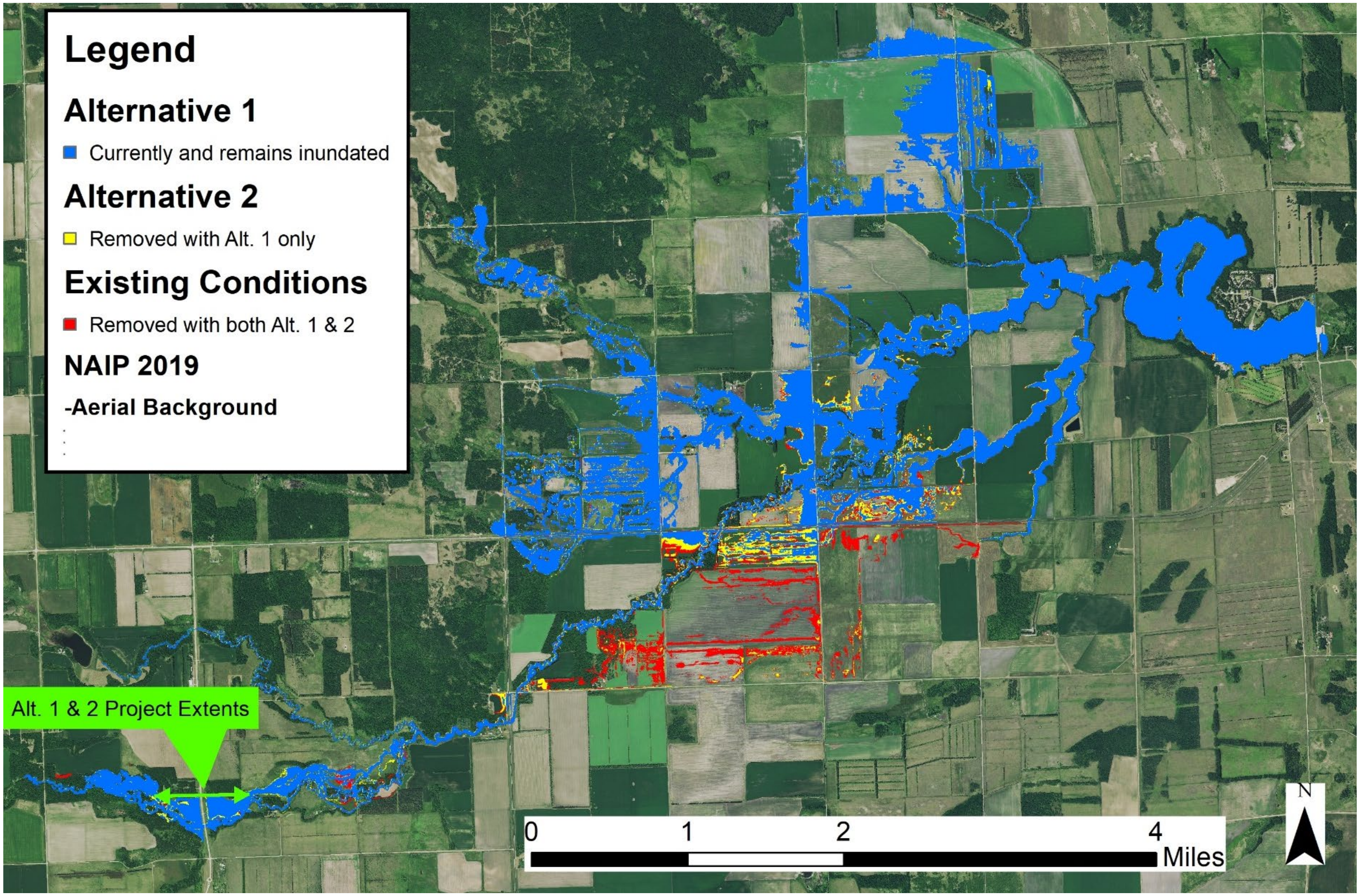
Appendix D-8 Fig. 9: Existing vs. Proposed Alternative Inundation Extents, 2-year, 4-Day



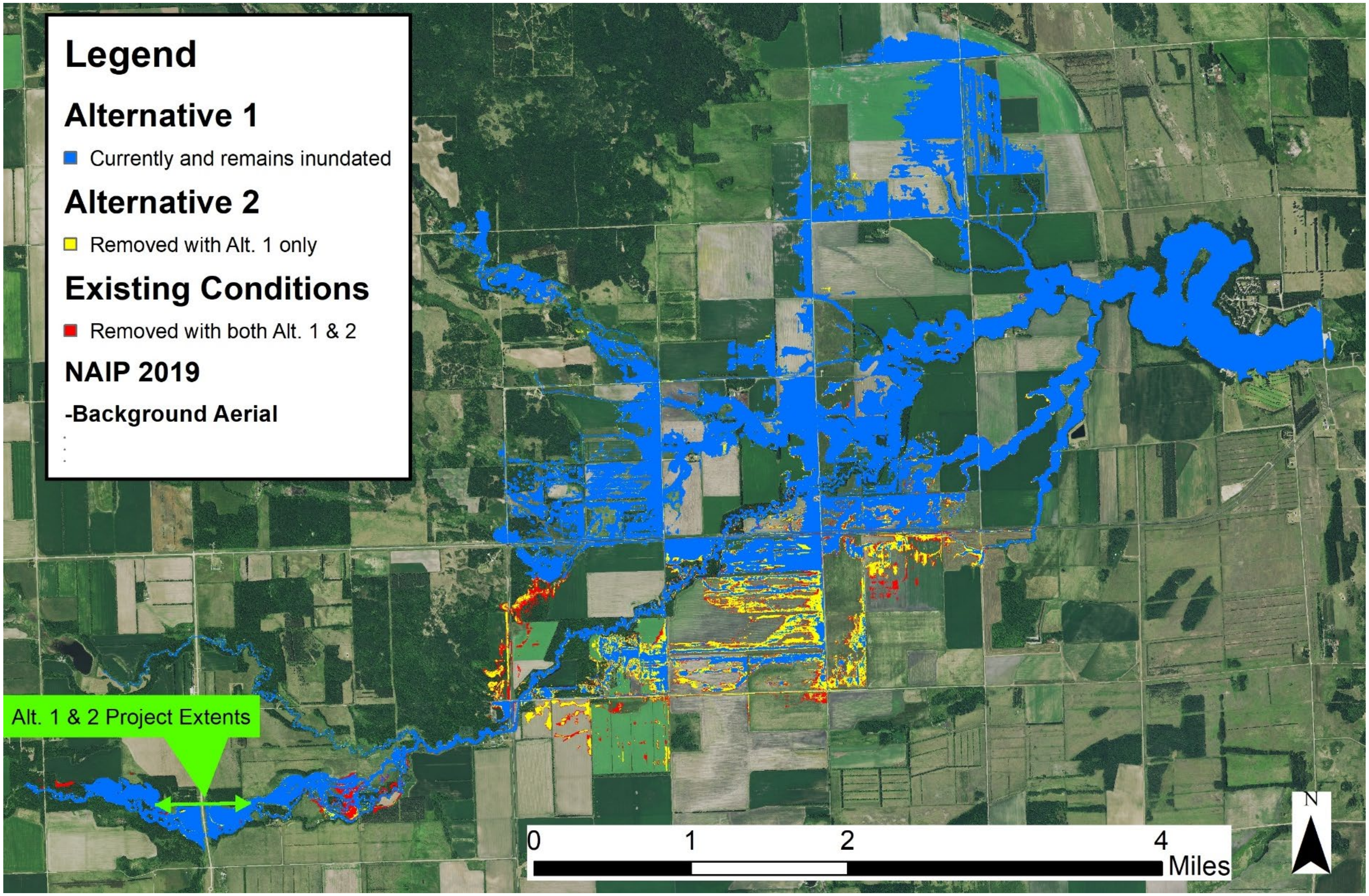
Appendix D-8 Fig. 10: Existing vs. Proposed Alternative Inundation Extents, 5-year, 4-Day



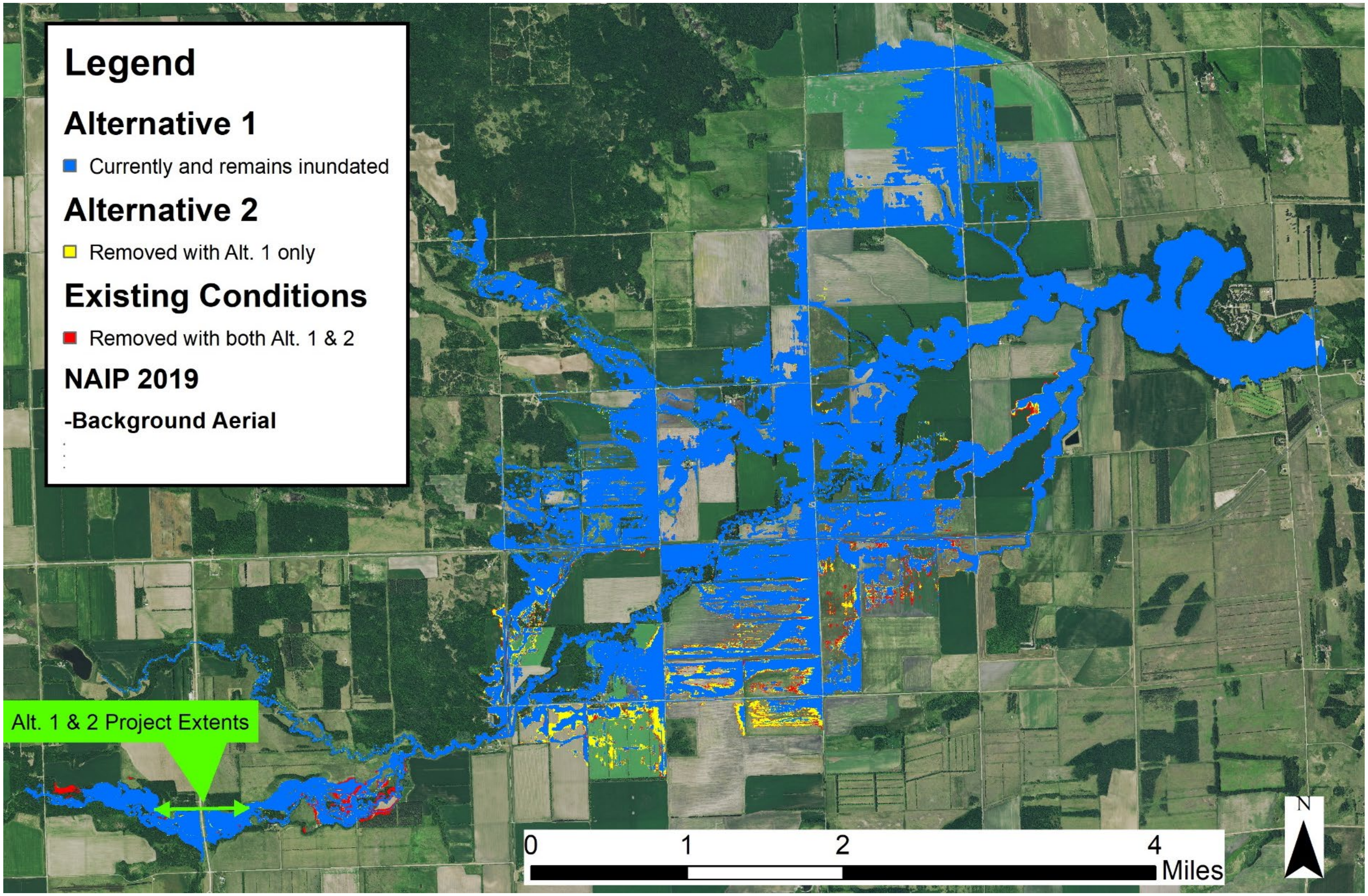
Appendix D-8 Fig. 11: Existing vs. Proposed Alternative Inundation Extents, 10-year, 4-Day



Appendix D-8 Fig. 12: Existing vs. Proposed Alternative Inundation Extents, 25-year, 4-Day



Appendix D-8 Fig. 13: Existing vs. Proposed Alternative Inundation Extents, 50-year, 4-Day



Appendix D-8 Fig. 14: Existing vs. Proposed Alternative Inundation Extents, 100-year, 4-Day

Figure D-8-15 Sediment Core with Total Phosphorus Concentration Locations

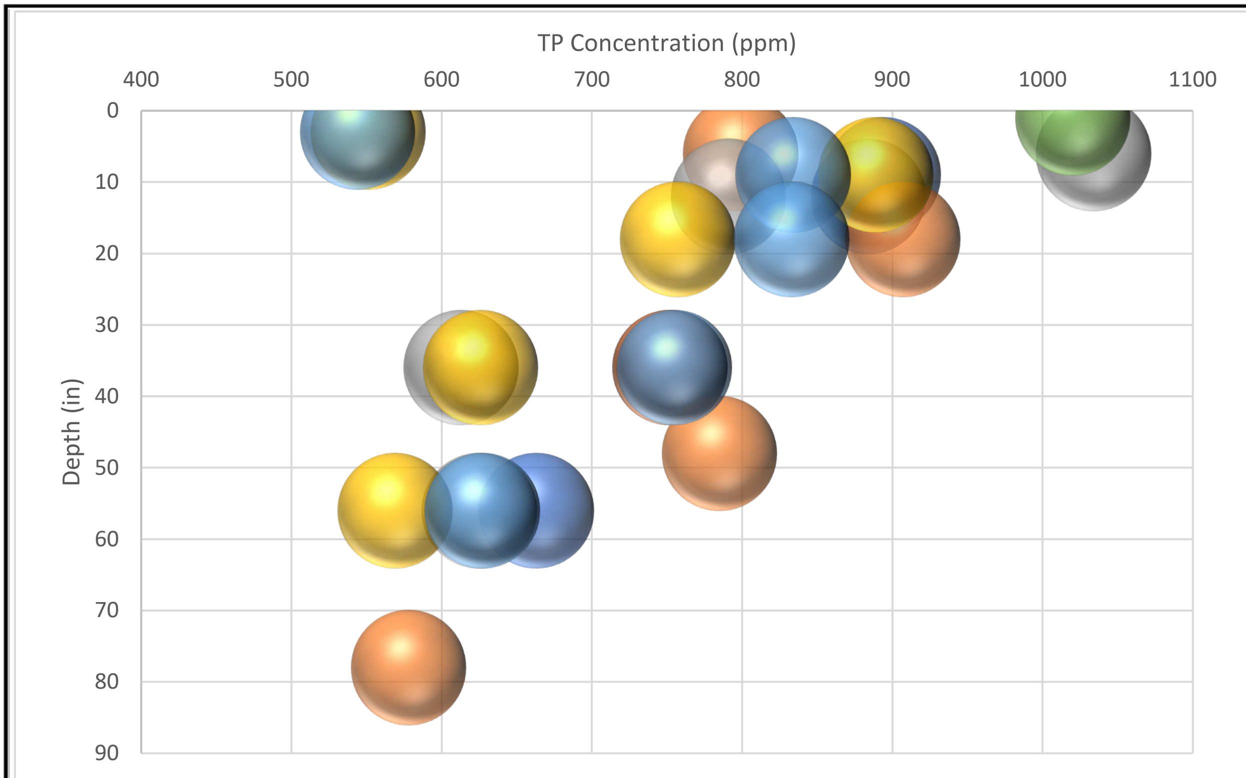
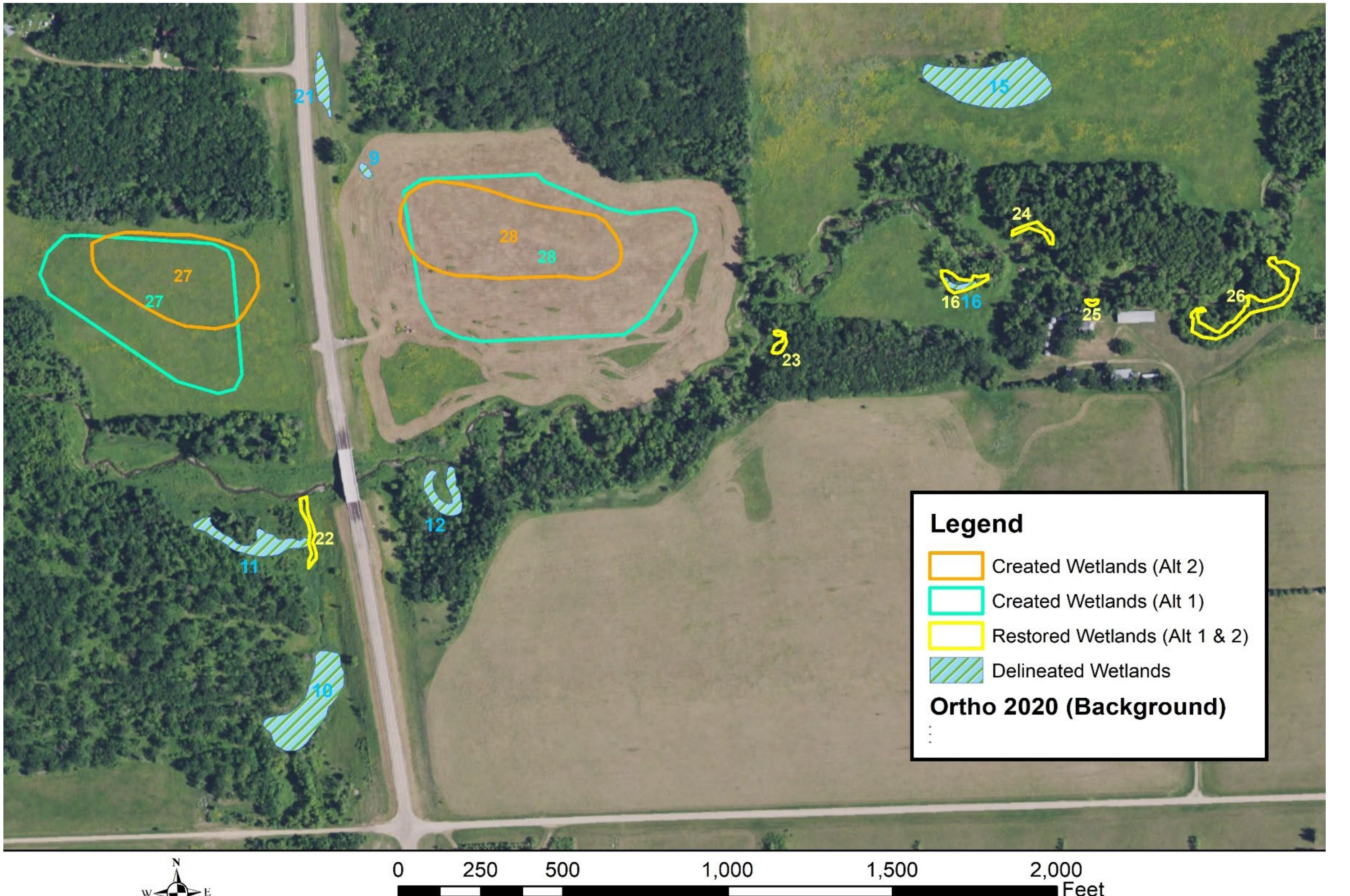
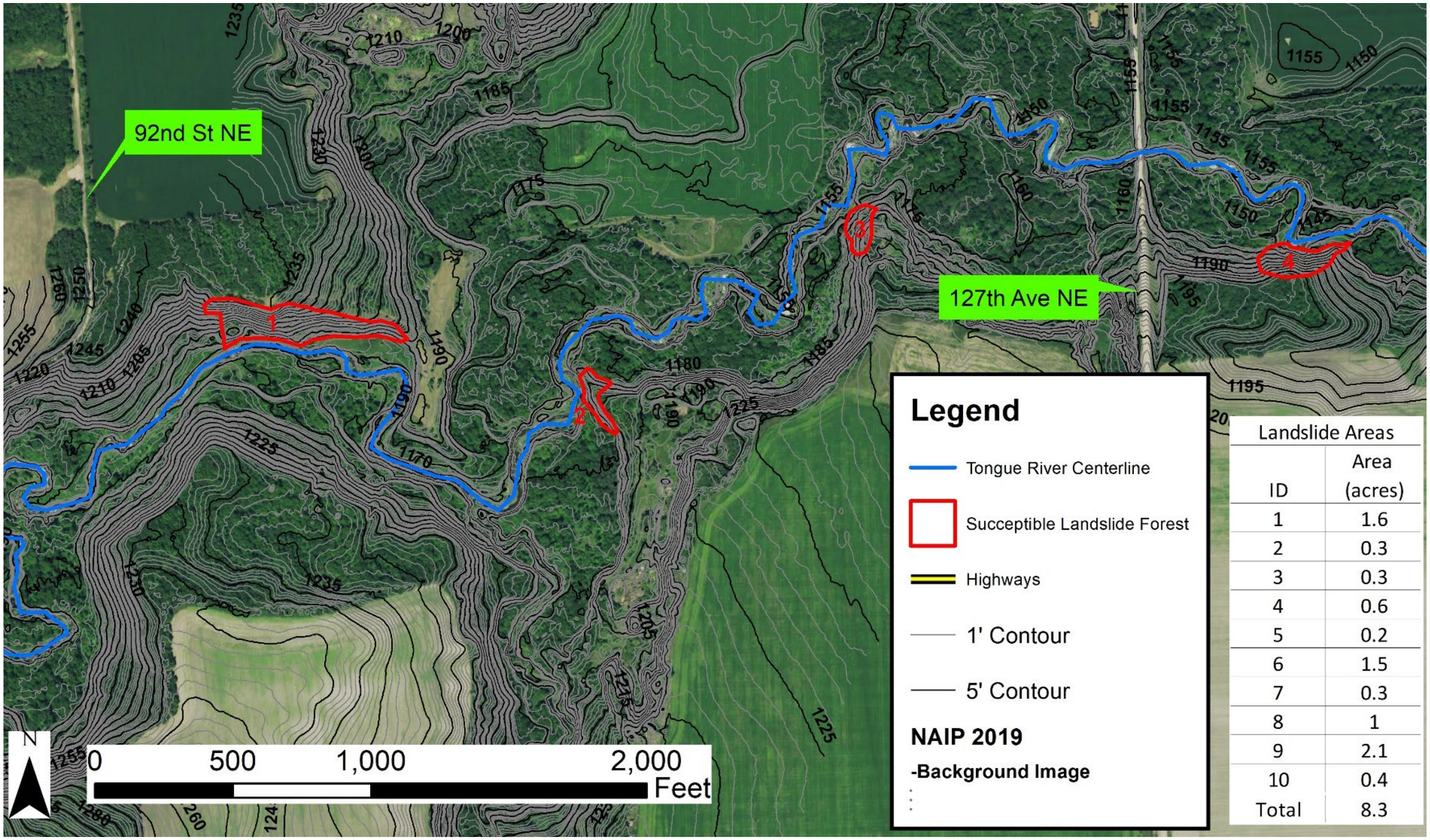


Figure D-8-16 Sediment Core with Total Phosphorus Concentration by Depth

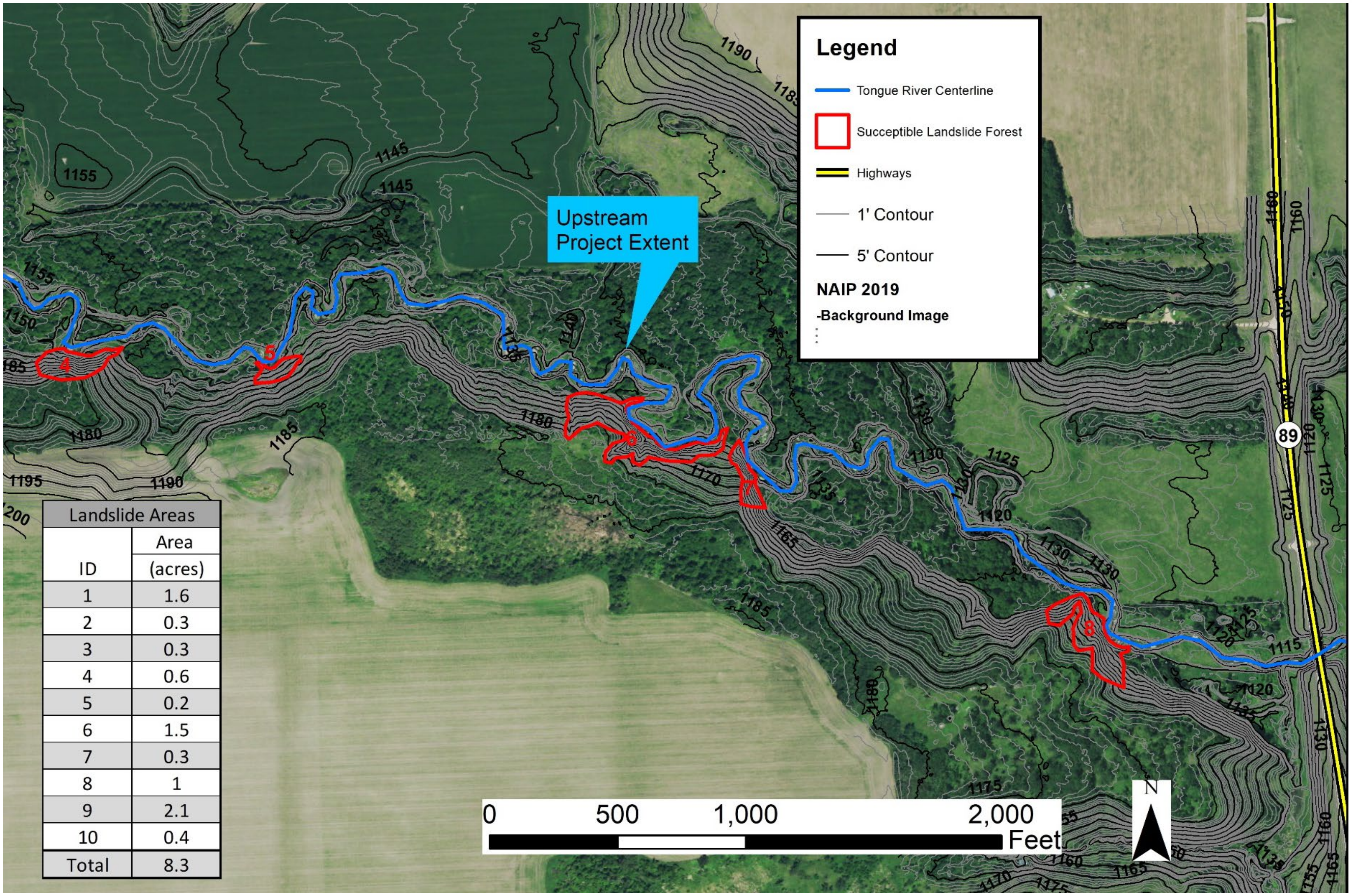


Appendix D-8 Fig. 17: Wetland Benefit Map, including Delineated Wetlands



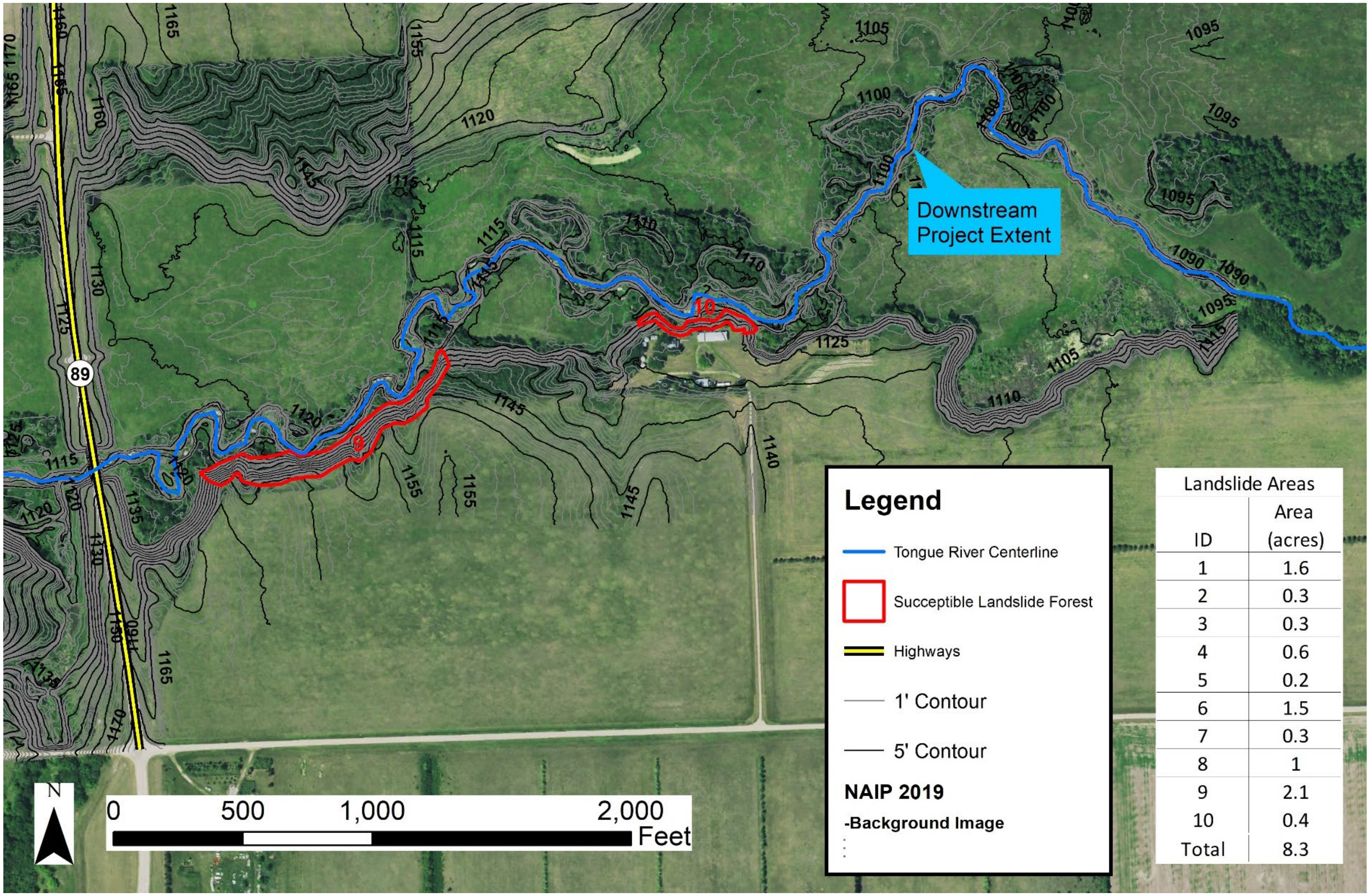
ID	Area (acres)
1	1.6
2	0.3
3	0.3
4	0.6
5	0.2
6	1.5
7	0.3
8	1
9	2.1
10	0.4
Total	8.3

Appendix D-8 Fig. 18: Susceptible Forest Erosion Areas (92nd St. to 127th Ave.)



Landslide Areas	
ID	Area (acres)
1	1.6
2	0.3
3	0.3
4	0.6
5	0.2
6	1.5
7	0.3
8	1
9	2.1
10	0.4
Total	8.3

Appendix D-8 Fig. 19: Susceptible Forest Erosion Areas (West of Hwy 89)



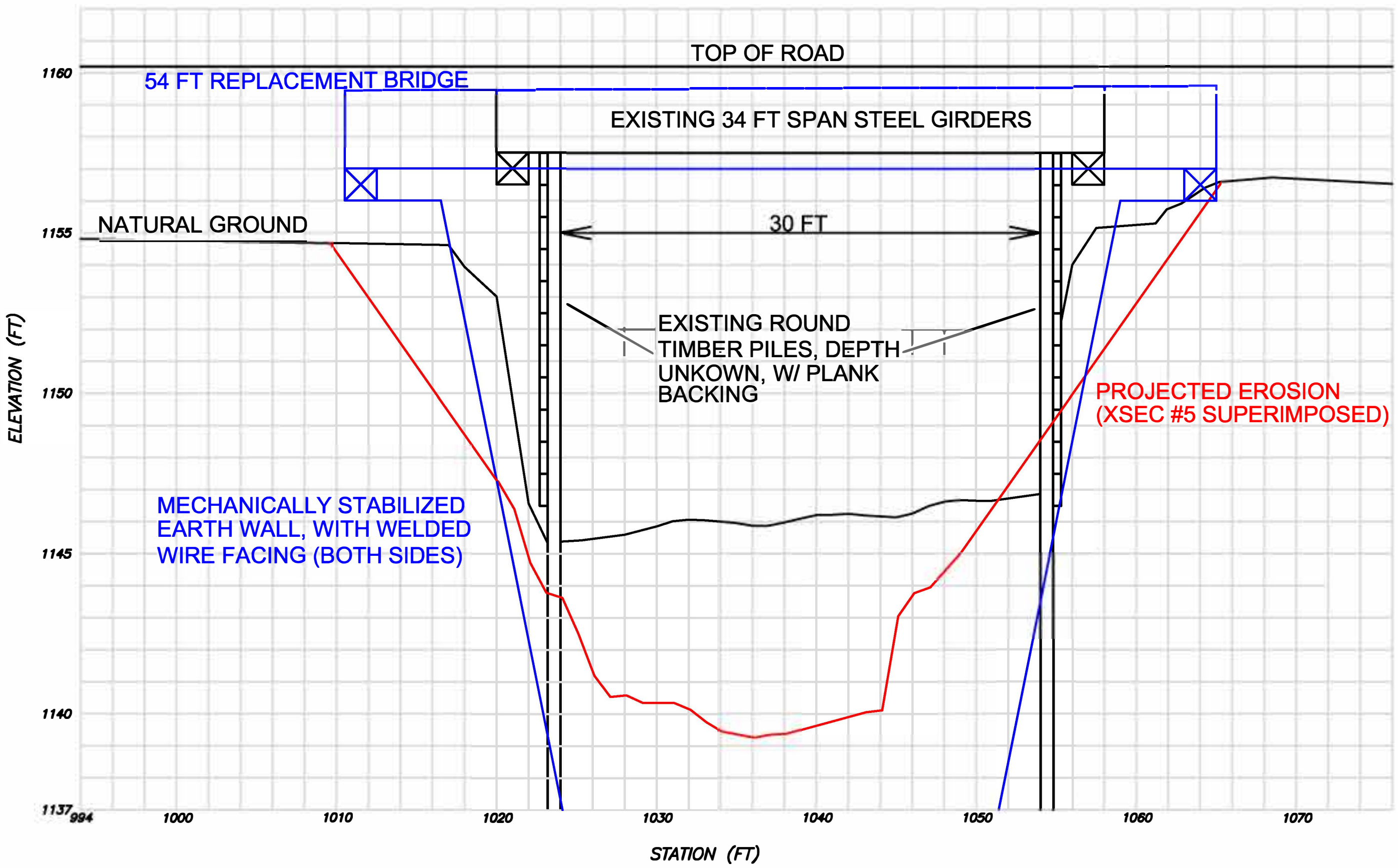
Landslide Areas	
ID	Area (acres)
1	1.6
2	0.3
3	0.3
4	0.6
5	0.2
6	1.5
7	0.3
8	1
9	2.1
10	0.4
Total	8.3

Appendix D-8 Fig. 20: Susceptible Forest Erosion Areas (East of Hwy 89)

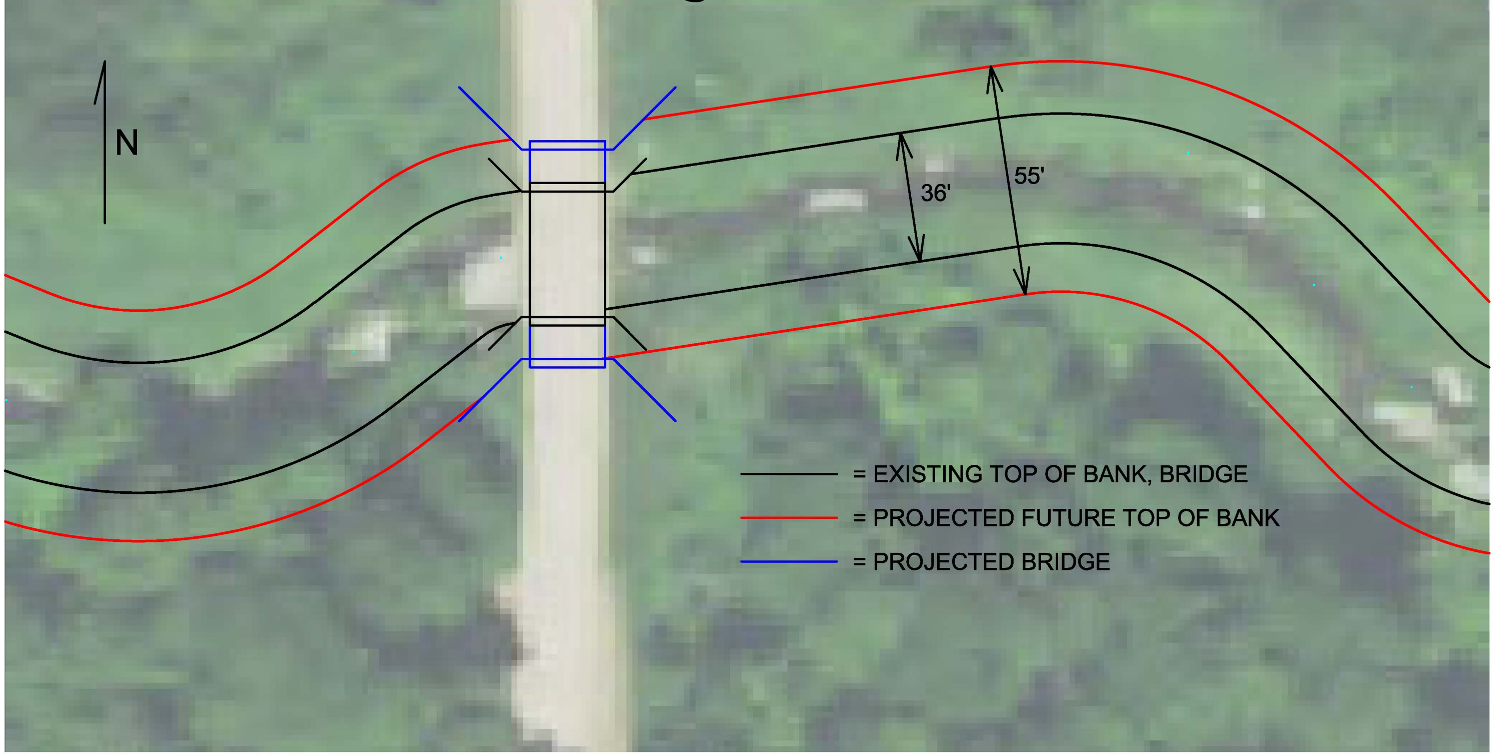
TONGUE RIVER BRIDGES
HIGHWAY 32 TO SENATOR YOUNG DAM

TONGUE RIVER PLAN/EA
APPENDIX D-8 FIGURE 21

RIVER / BRIDGE CROSS SECTION @ 127TH AVE NE



RIVER / BRIDGE PLAN VIEW @ 127TH AVE NE



TONGUE RIVER PLAN/EA APPENDIX D-8 FIGURE 22	127TH AVE NE BRIDGE DETAILS	NRCS Natural Resources Conservation Service