POWELL FALLS DAM REMOVAL SEDIMENT STUDY EVALUATION

RIVER FALLS HYDROELECTRIC PROJECT

FERC NO. 10489

SUBMITTED BY:

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Powell Falls Dam Removal Sediment Study Evaluation

The City of River Falls Municipal Utilities (RFMU) is proposing to decommission the Powell Falls Development of the River Falls Hydroelectric Project (Federal Energy Regulatory Commission (FERC) Project No. 10489) by removing the Powell Falls Dam. Powell Falls Development is located on the Kinnickinnic River in River Falls, Wisconsin. Removing the dam will involve the drawdown and draining of Lake Louise, the impoundment created by Powell Falls Dam.

On May 26, 2020 FERC issued a Determination on Request for Study Modifications for the River Falls Hydroelectric Project.[1] This determination included a staff recommendation to conduct a sediment study to evaluate the impact of the removal of the Powell Falls Dam. FERC requested two study objectives be addressed: "1) compare the amount of sediment that could be released downstream of Powell Falls Dam to the average annual sediment yield in the Kinnickinnic and St. Croix Rivers to determine the level of ecological risk to downstream geomorphology and aquatic resources; and 2) assess the potential effects on geomorphology and aquatic resources based on the predicted level of ecological risk." Part 1 of this report, "Kinnickinnic River Sediment Analysis for Proposed Powell Falls Dam Removal", addresses Objective 1 of the FERC study request. Part 2 of this report, the sediment study ecological risk assessment, addresses Objective 2 of the FERC study request.

To address Objective 1, Ayres compared the overall sediment influx from storage within the impoundment to yearly rates and depositional features within the Kinnickinnic and St. Croix Rivers. The sediment storage of Lake Louise was compared to other system altering events. River reaches in which sediment transport and deposition relative to other reaches were determined. Short-term processes and responses were determined in each geographic reach. Finally, areas for monitoring vulnerable habitat were identified in the Kinnickinnic River.

To address Objective 2, TRC addressed the combined list of ecological risk assessment requirements found in "Dam Removal Analysis Guidelines for Sediment" (Randle and Bounty 2017) and "Guidelines for Dam Decommissioning Projects" (USSD 2015). An opinion of the removal of the Powell Falls Dam was produced that addresses the following ecological risks and benefits to the Kinnickinnic River ecosystem:

1) Water quality deterioration due to increased suspended sediment levels or contaminants;
2) Burial of downstream aquatic spawning, rearing, and holding areas for threatened or endangered species or species of concern;
3) Burial of downstream aquatic species or life stages that cannot find refuge or quickly mobilize out of sediment impact areas (e. g., mussels and fish eggs);
4) Increased deposition in floodplains that could result in change in riparian vegetation when existing species are not tolerant of burial;
5) Sediment deposition blocking aquatic species migration routes;

[1] FERC accession number 20200526-3005

6) Restoration of riverine habitat in reservoir area;
7) Restoration of heterogeneous grain sizes and sediment bars that support development of more diverse channel processes such as channel migration;
8) Increase in physical habitat features that provide ecosystem benefits, such as channel spawning gravels, bars, islands, large wood features, and side channel activation;
9) Facilitate growth of invertebrate communities;
10) Natural disturbance and sedimentation required for riparian vegetation.
11) Increased exposure to ice jams whose impact are currently mitigated by the dam and reservoir; and
12) Deposition along recreational use areas including navigation channels and fishing areas.

Study Overview

This report contains two parts that address the two objectives in the FERC study determination. Part 1, *Kinnickinnic River Sediment Analysis for Proposed Powell Falls Dam Removal*, addresses Objective 1 by comparing the amount of sediment that could be released downstream of Powell Falls Dam to the average annual sediment yield in the Kinnickinnic and St. Croix Rivers to determine the level of ecological risk to downstream geomorphology and aquatic resources. Part 2, *Powell Falls Dam Removal Sediment Study Ecological Risk Evaluation*, addresses Objective 2 by assessing the potential effects on geomorphology and aquatic resources based on the predicted level of ecological risk. Part 1 used field data collected by Ayres in the lower Kinnickinnic River prior to the October 2020 drawdown, with conclusions edited to reflect preliminary observations from the drawdown. Part 2 also utilized recently collected water data related to the October 2020 drawdown event, including RFMU water quality measurements and drone imagery from the Kinnickinnic Corridor Collaborative. Part 2 reflects heavily on the analysis provided in Part 1, while at the same time comparing the Powell Falls Dam setting with other pertinent information derived from literature-based research.

Part 1.

Kinnickinnic River Sediment Analysis for Proposed Powell Falls Dam Removal

Kinnickinnic River Sediment Analysis for Proposed Powell Falls Dam Removal

Prepared for:

TRC Environmental Corporation &
City of River Falls

1/15/2021

Kinnickinnic River Sediment Analysis for Proposed Powell Falls Dam Removal

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Project Background

The City of River Falls Municipal Utilities (RFMU) is proposing to relicense the Junction Falls Development and decommission the Powell Falls Development with dam removal. Both developments are located on the Kinnickinnic River and licensed by the Federal Energy Regulatory Commission (FERC). This sediment study is based on the premise that Junction Falls, with its upstream impoundment Lake George, will remain in place for the foreseeable future, while the Powell Falls Dam will be removed around 2024 (Ayres, 2020).

Powel Falls Dam is a concrete gravity dam, 110 feet long and 22 feet high, with an uncontrolled overflow spillway. The impoundment, Lake Louise, is 15.4 acres with a normal capacity of 37 acre-feet and a normal water surface elevation of 821.8 feet mean sea level. The decommissioning and removal of the Powell Falls Dam will involve the drawdown and draining of Lake Louise which is impounded by the Dam.

The Draft Decommissioning Plan (authored by Ayres, appended to the January 2020 Initial Study Report to FERC, and as revised throughout 2020) presumes a slow stage drawdown over multiple years to naturally stabilize the fine-grained sediments within the no conveyance portions of the impoundment area. This proposed drawdown is dependent on the reestablishment of natural vegetation on banks of the newly formed channel within the impoundment (Ayres, 2020).

The Initial Study Report proposed a slow drawdown to limit the amount of sediment excavation and transport downstream into the system. The goal is to release sediment gradually over a period of years following the drawdown. The first year expects to see an increase (beyond the 5,000 CY of average annual release) of about 10,000 tons (5,000 CY), or at most 100% of the yearly sediment yield tapering off to 2,000 tons (1,000 CY) an increase of at most 20% of the yearly average sediment yield in the sixth year following removal (Ayres, 2020).

This report's field observations and desktop analyses were completed prior the October 2-15, 2020, drawdown of Lake Louise for a dam safety inspection. However, this report's conclusions have been edited to reflect updated understandings (based on preliminary information as the October drawdown's effects on the impoundment and downstream reach are still being studied) about how lessons learned during the October 2020 drawdown are indicative of future drawdown impacts.

FERC Study Request

Commission staff request that the City of River Falls conduct a desktop sediment study to assess the ecological risks and potential effects of releasing approximately 25,100 cubic yards of sediment on geomorphology and aquatic resources in the Kinnickinnic and St. Croix Rivers. The specific objectives of this study are to:

1. Compare the amount of sediment that could be released downstream of Powell Falls Dam to the average annual sediment yield in the Kinnickinnic and St. Croix Rivers to determine the level of ecological risk to downstream geomorphology and aquatic resources

2. Assess the potential effects on geomorphology and aquatic resources based on the predicted level of ecological risk.

Purpose and Objectives

The Draft Decommissioning Plan details the proposed timing, logistics, sequencing, and potential issues within the dam structure. However, the proposed removal of the Powell Falls Dam represents a marked change in the short-term sediment regime of the downstream system.

The purpose of this study is to understand the potential effect of additional short-term sediment influx from the impoundment during decommissioning on the downstream reaches of the Kinnickinnic River (Figure 1). This will include:

- Comparing the overall sediment influx from storage within the impoundment to yearly rates and depositional features within the Kinninkinnic River and St. Croix River.
- Placing the sediment storage within Lake Louise in context with other system altering events.
- Determining reaches in which sediment will be transported and deposited relative to other reaches
- Determining short-term processes and responses of each geomorphic reach
- Identifying areas for monitoring and vulnerable habitat within the Kinnickinnic River.

This report will rely on estimates of sediment volume within the impoundment, average sediment yield of the Kinnickinnic River, flow estimates of the Kinnickinnic River, and impoundment sediment characteristics calculated and determined within the Decommission Plan (Ayres, 2020).

No numerical modeling was done as a part of this study and conclusions are based on conceptual channel evolution models, field visits, and methods from the Dam Removal Analysis Guideline for Sediment (Randle and Bountry, 2017). A site visit to verify the desktop analysis and examine flood impacts was conducted on September 23rd and 24th, 2020.

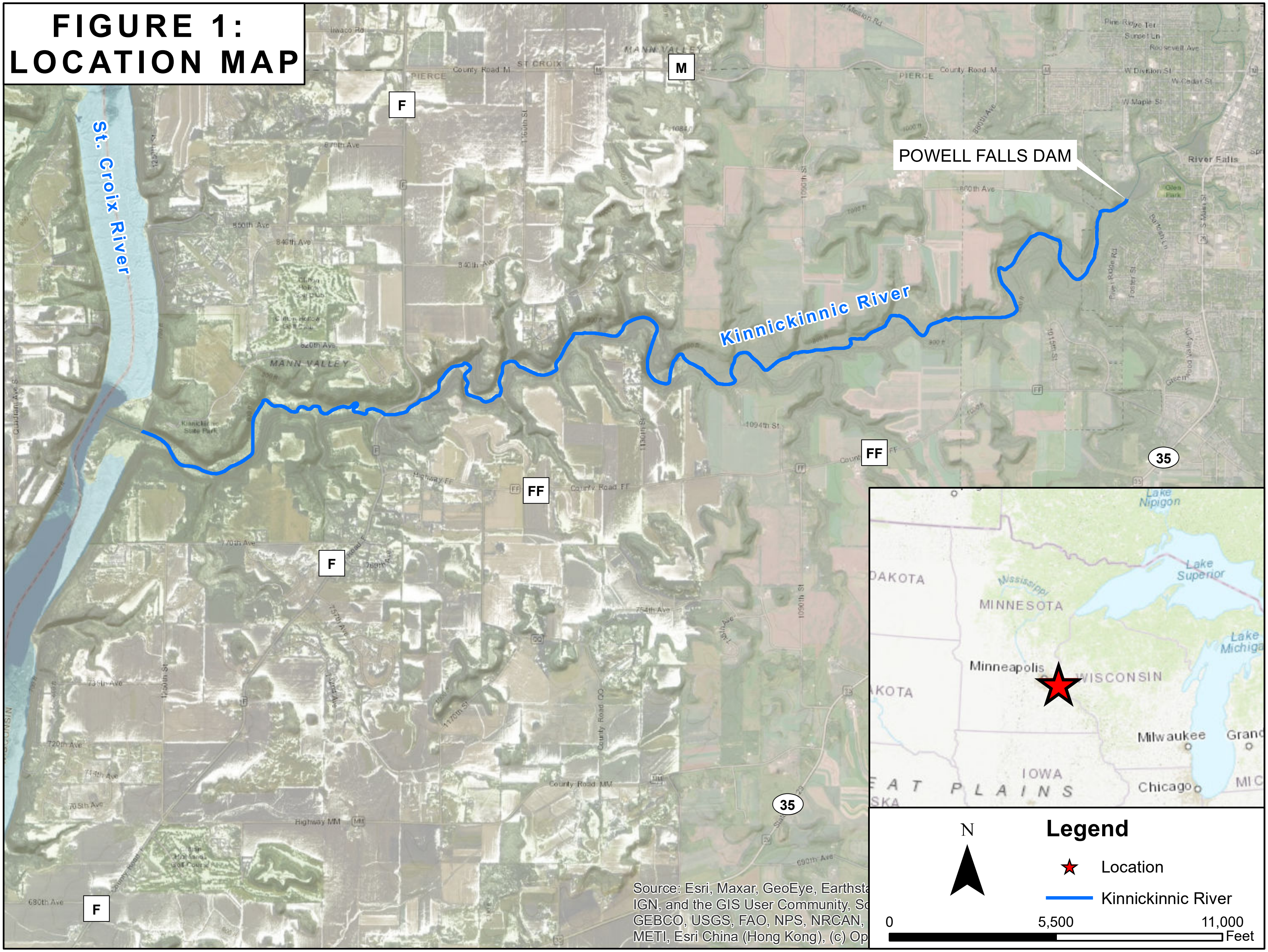
FIGURE 1:
LOCATION MAP
POWELL FALLS DAM
St. Croix River
Kinnickinnic River
River Falls
M
F
FF
35
MINNESOTA
WISCONSIN
Minneapolis
Milwaukee
Chicago
IOWA
Lake Superior
Lake Michigan
Lake Nipigon
Legend
Location
Kinnickinnic River
N
0
5,500
11,000
Feet
Source: Esri, Maxar, GeoEye, Earthsta
IGN, and the GIS User Community, Sc
GEBCO, USGS, FAO, NPS, NRCAN,
METI, Esri China (Hong Kong), (c) Op

Kinnickinnic River Existing Conditions

This study focused on 10 miles of the Kinnickinnic River bounded upstream by the Powell Falls Development and downstream by the confluence with the St. Croix River. This section of river is entrenched within a large valley complex formed by an Early Ordovician sandstone dolomite (Evan et. al, 2007) with the thalweg approximately 125 feet below the top of the valley margin. The watershed of the Kinnickinnic River is located within the extent of the North American continental glaciers, meaning that surficial geology is dominated by extensive surficial deposits of sand, gravel, and glacial till (Kostka, 2004). The Kinnickinnic River watershed specifically is located primarily within the River Falls diamicton, a poorly sorted sand and gravel deposit beneath less than 3 feet of topsoil. The abundant supply of sand in gravel in the upper watershed is responsible for relatively high sediment yield of the Kinnickinnic River. The Decommission Plan estimated that the predicted total sediment yield to the Kinnickinnic River at the Powell Falls Dam is more than 10,000 tons (5,000 CY) per year using USGS gage data (Ayres, 2020). The yearly sediment influx is predominately coarse-grained sandy sediment based on the surficial geology of the watershed.

An intense rainfall event occurred along this reach with approximately seven inches of rain falling within a few hours on June 29, 2020.[1] Based on the gage data, this event is estimated to be a 10-year event with flows reaching approximately 6,000 cfs. This event altered the study reach, which will take several years to recover to pre-flood conditions. The channel response to this flood event offers insight into the anticipated response following removal of the Powell Falls Dam. The flood affected the channel differently depending on the proximity to the dam and the St. Croix. In general, sand was transported from the impoundment and tributary influxes, especially Rocky Branch which is known for large sediment yields, downstream and stored in inundated overbank areas and eddies. It is possible that the impoundment sediment volume was altered[2] in composition and volume during this event, however a reexamination of the impoundment sediment would be needed to accurately calculate changes since the 2015 survey was completed[3]. More of these effects will be discussed in detail within the reach descriptions. The insights provided on channel response and how they relate to the increase in sediment yield resulting from the removal of the Powell Falls Dam will be discussed in the post-removal sections of this report.

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1 https://mesonet.agron.iastate.edu/sites/hist.phtml?station=RVFW3&network=WI_COOP&year=2020&month=6

2 The question of whether the impounded sediment volume within Lake Louise increased or decreased is still under future evaluation. Preliminary aerial photography of the drawn down lake bed does indicate that coarser sand (light brown) may have been added on top of the darker black silts of Lake Louise; however, closer to the spillway it appears the lake bed may have been scoured by floodwaters. In short, the impacts of the July 2020 flood on sediment conditions within Lake Louise are not fully understood yet.

3 "Lake George and Lake Louise Sediment Assessment Report." Inter-Fluve, Inc. 14 March 2016.

Channel Morphology

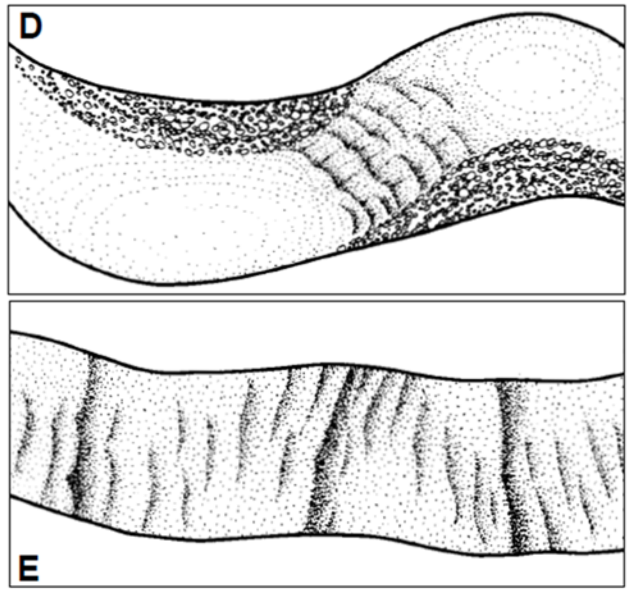

Figure 2: An idealized diagram of a pool-riffle (D) and dune-ripple (E) channel from Montgomery and Buffington, 1997

Channel and bed morphology provide the basis to understand the dominate processes, linkages within the channel network, and overall response to disturbances (Montgomery and Buffington, 1997). Any significant alterations to the channel morphology within a reach are likely the result of a disturbance to or shift in the sediment or hydrologic regime of the reach. The dominate channel morphology is pool-riffle sequences based on the overall channel slope (0.0033 ft/ft) and field investigations.

Pool-riffle channels are characterized by regularly spaced deeps with fine sediment and coarse-grained shallows that create an undulating longitudinal profile at the reach scale, as shown in Figure 2 (Montgomery and Buffington, 1997). These types of channels are extremely common in meandering stream systems. These systems self-maintain with the location and spacing of pools remaining relatively fixed temporally. Typically, these pool-riffle sequences are formed by either an influx of sediment from a tributary, which forms a riffle just downstream or velocity-reversals which occur at high flows (Wohl, 2014). Relative velocities of pools and riffles, where pools are areas of low velocities and riffles areas of high velocities during low flows, reverse during high flow events so that pools become areas of high velocities and riffles experience lower velocities due to friction along the stream bed and turbulence. During these events, bed load in the pools are entrained and transported downstream. As the velocities subside towards the downstream end of the pools, sediment is deposited forming and maintaining the next downstream riffle (Wohl, 2014). Riffles are typically wider and shallower than pools at all flow regimes. This process means that sediment is likely to move in a step-wise fashion downstream, filling pools during low-flow periods and scouring them during flood events (Wohl, 2014).

Roughly at station 60+00 (see Appendix A, page 1), the channel morphology shifts from pool-riffle to dune-ripple due to a reduction in channel slope from the backwater of the St. Croix River. Dune-ripples are a much more uniform channel type with less heterogeneity within the channel (Figure 2). Dune-ripple channels are not stable temporally and will have significant mobility of bed load at all flow regimes, adapting as needed to be most efficient at sediment transport (Montgomery and Buffington, 1997).

The significance of these differing channel morphologies related to the removal of the Powell Falls Dam will be discussed later in this report.

Geomorphic Reach Delineations and Descriptions

Variations in channel confinement, slope, width, valley width, and stream power are the result of changes in underlying geology, boundary conditions, and influxes within a system. Separating reaches based on these variations helps to better understand the response of the overall system and identify specific areas for any disturbance.

Understanding channel interaction with the overbanks and floodplain is essential to analyzing the riparian system. To properly estimate confinement of the active stream channel, a relative elevation model (REM) was generated using GIS software to better evaluate the changes in elevation moving from the thalweg to the overbanks (Figure 3). Fluvial signatures, such as meander scars, cutoff channels, and bars, indicate active stream processes are influencing and shaping overbank areas. By using the corresponding elevations of these features on the REM, the active stream corridor can be delineated within the larger river valley. The width of the active stream corridor can then be used in local hydraulic calculations, like unit stream power.

Unit stream power is an important proxy for the driving forces with a reach. It indicates the capacity of flow to erode and transport sediment throughout a fluvial system (Blazewicz et al., 2020). Lower unit stream power points to more sediment storage while higher values indicate a transport reach with limited opportunity for sediment storage. The variations in unit stream power are a function of the channel confinement (a type of stream width) and channel slope. Figure 4 shows a plot of unit stream power along the Kinnickinnic River calculated using a 10% annual exceedance probability (AEP) storm event. Overall shifts in unit stream power was used heavily in determining reach breaks through the study reach.

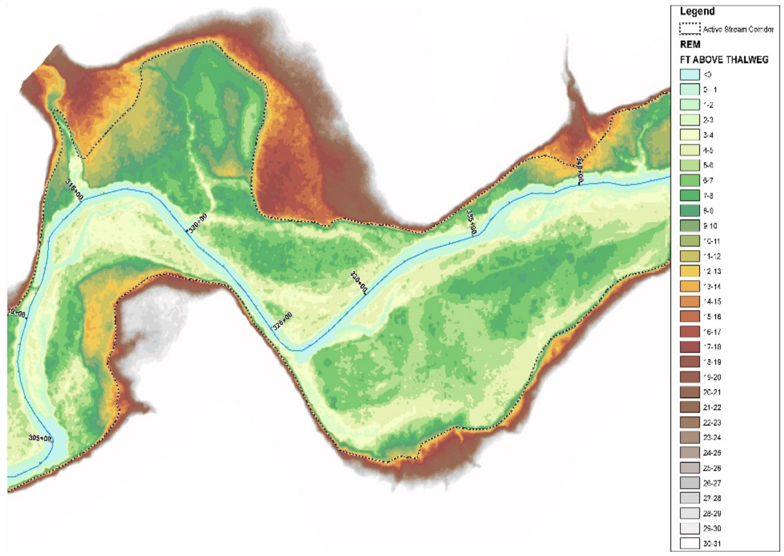

Figure 3: An example of the relative elevation model (REM) used to delineate the active stream corridor and in turn the width for unit stream power calculations.

Table 1 lists the variations in physical characteristics across each of the four reaches. Note that these reaches are numbered and stationed from confluence and heading upstream, according to the standard

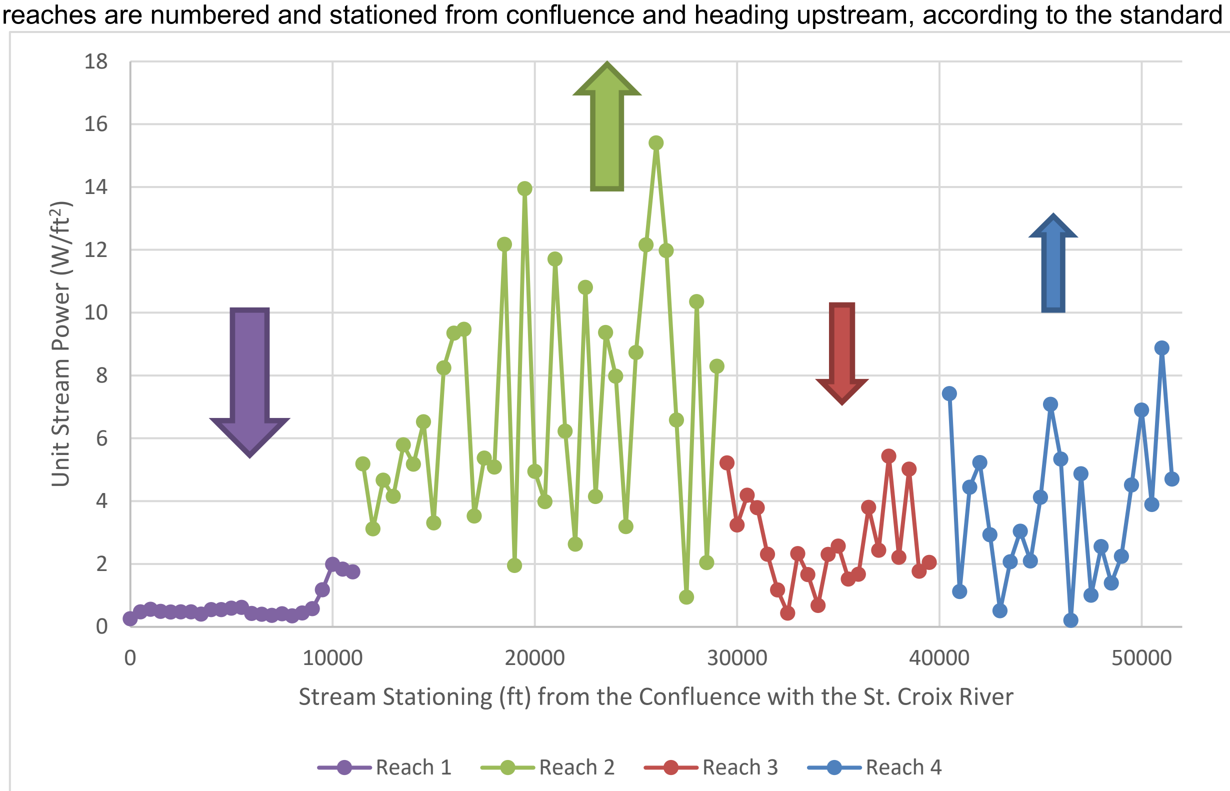

Figure 4: A plot of unit stream power along the study reach of the Kinnickinnic River. The different colors represent the reach breaks within the study reach. The arrows indicate relative change and magnitude compared to adjacent reaches.

convention of hydraulic engineers.[4] The existing conditions of each reach are described in detail below and will determine the response to the removal of the Powell Falls Dam.

Table 1: Reach characteristics for the four reaches delineated along the Kinnickinnic River downstream of the Powell Falls Dam. Figure below table shows reach locations on a Google Earth Pro aerial photograph.

	Channel Slope (ft/ft)	Valley Slope (ft/ft)	Avg Unit Stream Power (Watts/ft^2)	Bankfull Width (ft)	Valley Width (ft)	Alluvial Channel Type
Reach 1	0.0007	0.0008	0.68	73	469	Dune - Ripple / Pool - Riffle
Reach 2	0.0031	0.0035	6.86	57	242	Pool - Riffle
Reach 3	0.0027	0.0032	2.53	48	464	Pool - Riffle
Reach 4	0.0031	0.0035	3.86	52	359	Pool - Riffle

[4] To clarify, the "River Falls Hydroelectric Project Riverine Habitat Evaluation below Powell Falls" report by Inter-fluve, Inc and dated November 2020, uses reach numbers starting at the dam and proceeding downstream. Ayres' Reach 1 is Inter-fluve's Reach 5; Ayres' Reach 2 is Inter-fluve's Reach 4, Ayres' and Interfluve have the same Reach 3; and Ayres' Reach 4 is Inter-fluve's Reach 1 and 2 combined.

Reach 1

Length: 2.1 miles

Station Extents: 0+00 to 113+24

Average Slope (ft/ft): 0.0008

Average Unit Stream Power (Watts/ft^2): 0.68

Channel Morphology: Dune - Ripple / Pool -Riffle

Channel Description:

Reach 1 is the most downstream channel reach of the Kinnickinnic River, extending from the confluence of the St. Croix River (0+00) to the crossing along County Rd. F (113+24). This reach has been altered overtime by the permanent water surface at the St. Croix River upstream of the confluence with the Mississippi River. The increase in water surface elevation has caused a severe reduction in slope to 0.0008 ft/ft and stream power. These reductions have caused the sediment transported by the Kinnickinnic River to aggrade along this reach causing channel widening and a channel morphology shift near 60+00. The lack of energy and abundant sediment supply has caused the river to shift from a pool-riffle to a dune-ripple channel (Wohl, 2014). The shift to a dune-ripple channel reduces roughness and turbulence allowing the channel to maintain sediment transport capacity at a wider range of flow regimes, however these planforms offer less ecological function and habitat heterogeneity than pool-riffle sequences (Wohl, 2014).

Figure 5: A sand deposit (~2,600 CY) in the shadow of a log jam deposited during the large 2020 flood.

2020 Flood Impact:

The recent 2020 flood event has resulted in large amounts of deposition 200 feet past the mouth of the Kinnickinnic River into the St. Croix River, including sand and large wood. The dune-ripple portions of the Kinnickinnic River channel did not appear impacted by flood flows, with minimal log jams and very little scour or channel variations. This reach of the Kinnickinnic River stores significant amounts of sand transported from upstream. Above 60+00, sand has been deposited in at least six areas in velocity shadows and eddies during the flood (Figure 5). The channel was also realigned and diverted back into a cutoff channel following the event.

Reach 2

Length: 3.4 miles

Station Extents: 113+24 to 295+00

Slope (ft/ft): 0.0031

Average Unit Stream Power (W/ft^2): 6.86

Channel Morphology: Pool - Riffle

Channel Description:

Reach 2 extends about 3.4 miles from the crossing of County Rd. F (113+24) to just upstream of 1130th St. (295+00). Valley width has reduced along this reach, likely as a response to more resistant rock comprising the valley margins. This has resulted in an increased slope, confinement (242 ft), and, in turn, stream power. County Rd. F crosses at the downstream boundary of this reach.

2020 Flood Impact:

Similarly, to the upper portions of Reach 1, sand deposits formed during the flood event are present primarily in eddies and on point bars. These bars vary in size and tend to be narrower than the deposits seen downstream. Most of the large wood in this reach is located on the overbanks and wrapped on mature trees. This pool-riffle channel shows evidence of scour on the outside of meander bends, but the positioning of the pool-riffle sequences throughout this reach appear to be stable with very little movement post-flood based on historical imagery.

Reach 3

Length: 2.0 miles

Station Extents: 295+00 to 400+00

Slope (ft/ft): 0.0027

Average Unit Stream Power (W/ft^2): 2.53

Channel Morphology: Pool – Riffle

Channel Description:

Reach 3 is begins upstream of 1130th St. (295+00) and continues 2 miles to station 400+00. This reach is the shortest segment defined by a decrease in confinement leading to a reduction in channel slope and stream power. The valley margins have likely widened because of less resistant margins and the confluence of two large tributary channels.

2020 Flood Impact:

This reach was not walked during the site visit due to access and time constraints.[5] However, based on observation of the adjacent reaches and the relative values of stream power, we can infer that the reach was likely net depositional during the recent flood events. Sand was likely deposited in eddies and velocity shadows, increasing in occurrence with distance downstream from the Powell Falls Dam.

Reach 4

Length: 2.2 miles

Station Extents: 400+00 to 515+81

Slope (ft/ft): 0.0031

Average Unit Stream Power (W/ft^2): 3.86

Channel Morphology: Pool - Riffle

Channel Description:

Figure 6: A photo taken looking downstream at the first meander bend where sands and fines have been removed and logs have been wrapped on trees.

The upper most reach extends from station 400+00 to the Powell Falls Dam (515+81), about 2.2 miles. This reach has a similar slope to Reach 2 but has slightly less stream power due to wider valley margins resulting from two large tributary confluences on the north and south side. Rocky Brach Tributary confluences within this reach as well, however the reach separated at this location due to lack of geomorphic channel difference upstream and downstream of the tributary.

2020 Flood Impact:

This reach appears to be historically starved of sandy bed load due the impoundments upstream, as much of the Kinnickinnic River sediment supply to the lower reaches is thought to originate from the Rocky Reach Branch. During the 2020 flood event, a large amount of bed load within the impoundment was is suspected to have been transported downstream, however, due to magnitude of the flow and corresponding velocities, these flood waters were supply limited rather than transport limited, resulting in mobilization of almost all the sands and fines in the reach. It is likely that a large amount of sediment was delivered to the system from the Rocky Branch Tributary, however there was little evidence of this influx during field investigations. The more gradual increase in depositional features is indicative of sediment starved waters coming over the Powell Falls Dam and slowly reaching carrying capacity as they entrain sediment from the channel rather than a sudden shift in sediment yield typical of a tributary influx. Sand deposits within this reach are limited to the overbanks areas.

Expected Removal Impacts

The proposed drawdown approach anticipates releasing sediment gradually over several years following the drawdown. After dam removal, the first year expects to see an increase of about 10,000 tons (5,000

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[5] Note that this report was originally intended (requested by FERC and committed contractually) to be only a desktop study, but Ayres' staff felt it was important to walk selected portions of the Kinnickinnic after the 2020 flood to confirm key points of the desktop study.

CY), or at most 100% of the yearly sediment yield; the sixth year expects to see an increase of about 2,000 tons (1,000 CY), or an increase of at most 20% of the yearly average sediment yield (Ayres, 2020). The worst-case scenario for sediment releases downstream is expected to be a plug of 45,000 CY mobilized within a single event. Both scenarios will be discussed regarding the relative impact to the channel; but the specific reach responses, overall risk, and required monitoring are similar with variations in magnitude and timing. An exhibit summarizing the existing conditions, channel morphology, field investigation, and secondary channel areas is available in Appendix A.

Lane's Balance and Overall Transport Dynamics

Generalized impacts to the Kinnickinnic River can be theorized using simple concepts and fundamentals of sediment transport. We can expect river processes to work towards maintaining an equilibrium between discharge and sediment yield. Figure 7 shows Lane's balance, a simple conceptual model for understanding the feedbacks within a river system (Pollock, 2014). Generally, Lane's Balance states that there is a proportional balance between sediment load and sediment size on one side and discharge and slope on the other ($Q_w*S \alpha Q_s*d_{50}$). For example, an increase in sediment load (▲Q_s) with no change in discharge will cause the channel to steepen (▲S) and the average sediment grain size to increase (▲d_{50}). The steepening of the channel will increase the sediment transport capacity in order to maintain equilibrium and enabling fine-grain sediments to be entrained more easily while larger sediment sizes remain. Additionally, the river is expected to decrease in sinuosity and bedform height, again increasing sediment transport to maintain equilibrium (Wohl, 2014).

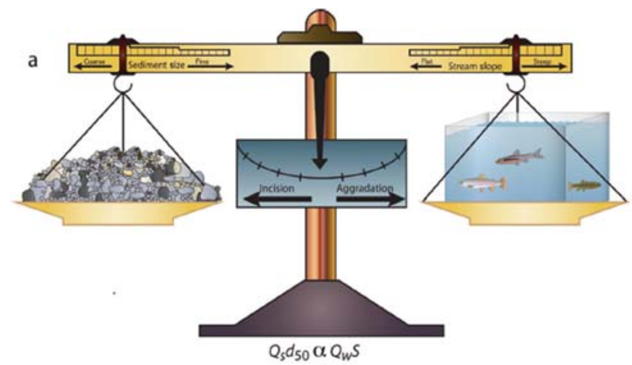

Figure 7: Lane's Balance showing the conceptual response to changes in slope, sediment input, discharge, and sediment size from Pollock, 2014.

In the anticipated drawdown scenario, between 5,000 CY and 2,000 CY would be released from Lake Louise yearly for an estimated period of six years. This sediment would travel as a wave with initially large impacts closest to the source reducing with distance downstream due to the attenuation and storage of sediment (Greiman et. al, 2006). Figure 8 highlights the accumulation that can occur in the upper portions of a reach. This is especially true in a pool-riffle channel where the movement of sediment is limited by the stream's transport capacity rather than the sediment supply (Wohl, 2014). Ayres expects the sediment to accumulate in the upper reaches, occupying all available channel storage before continuing downstream. The proposed scenario will occur in a normal hydrologic regime meaning that storage and transport will be limited to the bankfull channel. We expect preferential filling of pools, compared to riffles during base flows, which is already evident following the most recent flood event. Scouring and degradation required to maintain pools would depend on high-flow events occurring within this reach (Wohl, 2014).

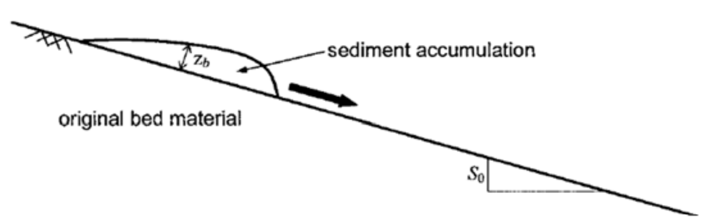

Figure 8: Illustration of a sediment influx moving as a wave along a slope from Greiman et. al, 2006.

The worst-case release scenario is a high flow event that overwhelms the construction site during the Powell Falls Dam removal. Ayres expects the final dam removal activities to accommodate up to a 10-yr flood event, meaning this worst-case scenario would require flows greater than 6,000 cfs. In this scenario, the magnitude of sediment influx to the Kinnickinnic River below the Powell Falls Dam would be much greater, but the long-term effect on the channel would likely be similar in filling and transport activity, though with greater magnitude of effects than expected for the anticipated drawdown scenario. During the worst-case scenario, flow overtops the channel and inundates overbank areas. These areas have little transport capacity causing sediment to deposit on the floodplain (Figure 9 top). Furthermore, deep eddies offer abundant sediment storage vertically (Figure 9 bottom). The sediment entrained in main conveyance portions of the channel will be carried through and out of the system to the lower portions of Reach 1 and the St. Croix. The increased sediment capacity and storage means that the worst-case scenario for sediment release from the impoundment may actually not negatively impact the Kinnickinnic River more than the anticipated drawdown scenario due to magnitude of flows required to overwhelm the sediment mitigation measures installed during the drawdown of the impoundment. In short, either scenario (anticipated drawdown or worst-case) will create temporary impacts on the downstream Kinnickinnic River that could take a decade to equilibrate post-removal sediment deposits with post-removal river transport capacity. This is similar to observations that Ayres has made at other large dam removals such as Grimh Dam (2011 removal; this delta and downstream reach have already reached equilibrium because this dam was half drawn down in 2000) and Gordon Dam (2017 removal; this delta and downstream reach have nearly reached equilibrium because this dam was half drawn down in 2010).

Figure 9: Sand deposited on overbanks and vertically in eddies.

Normally in dam removal scenarios, there is a risk of avulsion, or river realignment to an area that is outside the active stream corridor (Blazewicz et al., 2020). Avulsion occurs when a large influx of sediment fills the existing channel to the extent that the channel is forced into an alignment with a lower elevation than the filled channel. Along the Kinnickinnic River, the risk of avulsion is extremely low because the river is not capable of escaping the entrenched valley which the river occupies. Instead, the Kinnickinnic River is more likely to migrate laterally and occupy secondary channels and meander cutoffs within the entrenched valley for a limited longitudinal extent before rejoining the main channel. This, while not as destructive and uncontrollable as an avulsion, could still pose challenges to the community (especially if the avulsion areas are under private land ownership). Therefore, areas with potential for this to happen have been marked in the *Summarizing Exhibit* in Appendix A. These specific areas will be discussed in the reach specific impacts.

Relative Size of the Sediment Influx

Comparing the relative increase in the sediment input into the system is an important first step in understanding the magnitude of the impact to the downstream systems. Overall, the proposed drawdown and sediment release plan is estimated to initially increase the yearly sediment input into the Kinnickinnic River downstream of the Powell Falls Dam by 100% in the year following drawdown before tapering off to a 20% increase by the sixth year.

The St. Croix is a much larger system with a drainage area of 8,570 mi^2 at nearby Prescott (USGS, 1986). Estimates of sediment loads are difficult, but rough estimates by the USGS at St. Croix Falls

(6,240 mi^2 watershed) is 10,000 CY (25,000 tons) per year of suspended sediment (USGS, 1986). The additional sediment from the removal of the Powell Falls Dam will end up adding to the large depositional bar that has already formed along the St. Croix River. The bar has formed over many years from sand inputs from the Kinnickinnic River that have been pushed along the east bank of the St. Croix by the St. Croix's larger flow and currents. The 2020 flood event in the Kinnickinnic River pushed a large quantity of sediment and debris roughly 200 ft out into the St. Croix channel where it may take years to be pushed downstream and deposited as an extension of this existing sandbar. The effect of this additional Kinnickinnic River sediment on a system as large as the St. Croix is likely to be limited spatially and temporally.

Average Bar Volume Comparison

The Dam Removal Analysis Guideline for Sediment (2016) suggests comparing the sediment volume released to common depositional features within the river to gain an understanding of the impact to the riparian system. This is also helpful in evaluating the abundant depositional features existing within the channel and on the overbanks following the 2020 flood event. The guideline recommends estimating average bar size using the following equation,

*Average Bar Volume = Average Bankfull Depth * Average Bankfull Width*^{2}

So, for the Kinnickinnic River, $7\ ft * (57.3\ ft)^2 = 23{,}000\ ft^3$ *or 854 CY.*

Figure 10: A typical sand bar deposit with dimensions approximately 80 ft x 30 ft x 7 ft (622 CY).

This estimate was confirmed by observations of many depositional bars during the field investigation. Based on the field investigation, these bars typically occur every 1,500 linear feet within Reach 1, 2, and 3 equating to approximately 23 bars. The maximum yearly volume release in the proposed conditions, 5,000 CY, is equivalent to approximately six depositional bars observed within bankfull channel.

In additional to the bars, the backwater from the St. Croix River has created a storage sink for sand. Conservatively, assuming the sand bed is 3 feet deep, the channel is actively storing approximately 50,000 CY of sand within the dune-ripple channel portion. Additionally, high flow events, which inundate the overbanks, can lock large amount of sediment within the overbank soils and vegetation. The sediment stored during the most recent flood event cannot be easily estimated, but likely exceeds 25,000 CY.

Reach Response and Recommended Actions

Consistent monitoring during the removal and continuing at least 10 years after removal ends is the first recommended step to sustaining high ecological function of the Kinnickinnic River. Pools have been identified in the *Summarizing Exhibit* (Appendix A) for monitoring throughout the study area because these bed forms will be at the highest risk for filling during baseflow periods. Filling of the pools is expected, especially in the upper reaches. However, with yearly high flow events, these pools should eventually scour and continue transporting sediment downstream. In addition to the temporary filling of pools, the overall location of the pool-riffle sequences should remain relatively stable and can be monitored using the estimates presented in the *Summarizing Exhibit* (Appendix A). If a reduction in number or extent persists, especially following high-flow events, this may indicate a more large-scale shift in the channel morphology, affecting the ecological function, transport capacity, and sensitivity of the system overall (Wohl, 2014). Additional actions, such as the trapping of sediment from the impoundment or flushing events (if even practicable), should potentially be employed if the high flow periods are inadequate to scour the pools or maintain pool-riffle morphology.

Preliminary visual estimates during the October 2020 dam safety inspection drawdown indicate that between 3500 and 8000 CY of sediment was released from the impoundment; but less than two weeks after the drawdown ended, the turbidity was back down below 60 mg/L. This indicates the rate of downward cutting has slowed in the impoundment, though minor cutting may continue overwinter at a slower pace. Ayres believes the spring floods will initiate the future channel forming events within Lake Louise, though additional field monitoring is needed to confirm how the reservoir fluctuations correlate with channel and bank stability.

St. Croix River Sensitivity, Risk, & Response

Sensitivity & Response to Removal:

Ayres anticipates the impact to the St. Croix to be delayed and limited. The storage and attenuation of sediment within the Kinnickinnic River will delay and dampen in peak influx of sediment to a point that the increase will not be detectable above yearly averages. Most likely sand will be transported just past the confluence with the St. Croix before moving downstream and depositing on the existing sand bar. The bar is unlikely to extend further out into the channel due to the equilibrium between increased channel velocities due to confinement and sediment transport capacity. As the bar extends into the river, the cross-sectional area of the St. Croix decreases resulting in increased velocities and sediment transport capacity. The increased sediment transport capacity will facilitate downstream movement of sand and deposition on the existing bar.

Reach 1 Sensitivity, Risk, & Response

Sensitivity & Response to Removal:

Reach 1 is the least sensitive reach in the Kinnickinnic River because, for most of this reach, a channel morphology shift has already occurred from a natural pool-riffle channel to a dune-ripple channel. There is little evidence that this sediment influx will further degrade the function of this reach.

Upstream of station 60+00, the stream will respond like the other pool-riffle reaches within the river with pools filling during low-flow intervals and deposition and widening of riffles during high flow events. The sediment from the removal will take many years to be transport down to this reach, due to attenuation and storage within the upper reaches. It will be difficult to decern the provenance of the sediment within this reach because of the abundant sediment stored in eddies and overbanks during the most recent flood event.

Figure 11: A pool filling with sand during low flow periods.

Monitoring Pools:

Two pools have been denoted in *Summarizing Exhibit* (Appendix A) for potential monitoring[6].

Secondary Channel Areas:

Only one region has been flagged as having concern for limited channel relocation in an existing meadow adjacent to several tributary channels.

Infrastructure:

There is no known infrastructure at risk within the active stream corridor within this reach.

Reach 2 Sensitivity, Risk, & Response

Sensitivity & Response to Removal:

Based on the relative stream power, this reach is a transport reach. This reach is a pool-riffle channel throughout with many depositional bars and habitat heterogeneity. Despite the high stream power, this reach has abundant sand in storage, on the overbanks and in eddies. This suggests that while this reach has a higher transport capacity, it is still transport limited, which is indicative of a pool-riffle channel.

Normally, as described previously, pools will fill during low-flow periods and scour during high-flow periods. With an increased in sediment influx, these pools are likely to fill further than normal which will cause a decrease roughness and create a more uniform flow-depth and bed-gradient (Wohl, 2014). This will increase the ability of the stream to transport sediment during moderate- and low-flow periods while reducing channel heterogeneity and, potentially habitat. While the higher stream power makes this reach relatively less sensitive, it is also home to many high-functioning pool habitats and channel heterogeneity that may be at increased risk.

Monitoring Pools:

Eight pools were identified within this reach for monitoring following the removal of the Powell Falls Dam.

Secondary Channel Areas:

Two small areas have been identified as having potentially for channel realignment within secondary channel or cutoff channels. The confinement of the channel limits to overall extents and number of these areas.

Infrastructure:

The County Rd F crossing should be monitored regularly, especially following high flow events. Any shift in channel alignment following filling of the channel might increase the overall risk of bridge instability (depending on the bridge foundation design, to be confirmed with the bridge design documents).

---

[6] In previous large dam removal permits that Ayres has reviewed, the WDNR conditions the permit upon requiring a three- to five-year period of "monitoring" reaches above and below dam removal sites. To Ayres' knowledge, the "monitoring" has been done by the WDNR as an informal visual inspection by regional engineers, not as a formal process funded by and reported by the permittee. The WDNR permit language implies the WDNR reserves the right to require the permittee to undertake mitigation measures for excessive changes to the upstream or downstream reaches.

Reach 3 Sensitivity, Risk, & Response

Sensitivity & Response to Removal:

Due to access and time allowed, this reach was not walked during the field visit in September 2020. However, Ayres expects this reach to respond similarly to the adjacent reaches. This reach has the second lowest overall stream power along the Kinnickinnic River meaning the sediment transport capacity is lower. Reach 3 likely has large amounts of sand deposited by the recent flood event, especially in the larger overbank areas and floodplains.

Monitoring Pools:

Three pools for monitoring have been identified within this reach, however these areas were not visited in the field.

Secondary Channel Areas:

The risk of channel realignment into a secondary channel is high in this reach due to the wider valley margins and increased number of tributaries. The wide valley and tributaries increase the ability to the stream to migrate laterally which creates more relic channels and meander scars for the existing channel to reoccupy.

Infrastructure:

There is no known infrastructure at risk within the active stream corridor within this reach.

Reach 4 Sensitivity, Risk, & Response

Sensitivity & Response to Removal:

Reach 4 is the highest risk reach due to its proximity to the sediment influx and the pool-riffle channel morphology. Any sediment released from the impoundment will travel as a wave through the system, filling storage and attenuating in the upper reach before traveling downstream, meaning that pools in Reach 4 will fill first and with the most sediment. This is especially true during low-flow periods when the stream has no ability to store sediment on the floodplain.

Whatever sediment was passed through Lake George and Lake Louise to the downstream Kinnickinnic River during the 2020 flood was quickly scoured as the floodwaters receded, at least in the first 500 feet below the Powell Falls Dam. Downstream further, this reach still appears to be depleted of sand and fine sediment until the Rocky Branch. The Kinnickinnic River upstream of Rocky Branch is a cobble and gravel system that has not had the sediment supply fully replenished following the flood. Initially, the influx of some sand following dam removal will likely create temporary benefits for this reach; but excessive releases of sand (such as the worst-case scenario during dam removal) could negatively affect this reach more than the other three reaches.

Update: After the October 2020 drawdown, sediment has been deposited by the drawdown activities within Reach 4. During the first week of the drawdown, a couple inches of fine silt was deposited within slower pool areas from Powell Falls Dam downstream about 600 feet (to the first major riffle). After a 2-inch rain event on October 12, Lake Louise water levels rose six feet and fell six feet within a day. This lake bounce initiated rapid headcutting and upstream bank instabilities within the impoundment, causing significant sediment movement for the next four or so days. On October 16, sediment cutting appeared to slow again to pre-bounce conditions, but silty sand had nearly filled the pool between Powell Falls Dam and the first major riffle. During a follow-up inspection of the first pool below Powell Falls Dam on November 2, a new channel had been scoured through the new sediment, reaching down to original bedrock grade in several places. In short, the Reach 4 received 3500 cubic yards deposited in 4 days below the dam; but during normal flow conditions that followed, the river had sufficient stream power to reform a channel. At the time of this report's writing, the pool below Powell Falls does have sediment still in the pool, but the new channel has recut to bedrock within this sediment deposit.

Monitoring Pools:

Three pool were identified for monitoring along Reach 4.

Secondary Channel Areas:

Two secondary channel areas were identified along this reach at meander bends and through meander cutoffs.

Infrastructure:

Reach 4 is the most visible portion of the channel with a community trail following the river through most of the reach. It will be important to preserve the trail and historical features along the trail. Kayakers launch on the left bank below the Powell Falls development, and this launch may need to be moved downstream to accommodate sediment movement during decommissioning efforts.

Conclusion

Overall, Ayres expects the impact of the increase sediment load to the Kinnickinnic River downstream of the Powell Falls Dam after dam removal to be on the scale of the impact of the most recent flooding event. The Kinnickinnic River has an abundant sediment supply (~5,000 CY per year) and sediment storage which it transports to the St. Croix while sustaining high-functioning riparian habitat. Ayres estimates that more sediment[7] was stored within the channel and on the overbanks during the most recent flood event than is expected to be released during dam removal efforts. In Ayres' opinion, and especially in the lower reaches, sand stored during the recent flood will pose a larger risk to the channel equilibrium once it is mobilized than the sediment from the impoundment.

Based on time scales of geomorphologic adjustments, the sediment released from Lake Louise will have a disproportional impact on the upper reaches of the Kinnickinnic River. The sediment will likely be released during typical flow regimes which will limit storage to the bankfull channel filling pools in the upper reach more severely and continuously than the lower reaches. This process (albeit currently confined to the first 600 feet downstream of Powell Falls Dam) was confirmed during the October 2020 drawdown.

Monitoring of these pools, especially in the upper reaches, for several years following the dam removal is prudent and a normal expectation of a WDNR dam removal permit. From a hydraulic engineering and river stability viewpoint, monitoring would ideally check for large-scale, long-term, negative geomorphological impacts such as permanent or continuous filling, reduction in volume, or reduction in aquatic biota. For any excessively detrimental impacts noted, the dam removal permits issued by the state usually include a requirement to mitigate impacts (repairs of bank instabilities, sediment removal, check dams, etc.), and therefore, continued state agency involvement is expected for several years after dam removal is complete.

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[7] However, the source of this July 2020 flood sediment is uncertain. Ayres understands that the Rocky Run and other tributaries below Powell Falls Dam are significant sediment contributors, but how these downstream sources compare to sediment volumes coming from Junction Falls and the South Fork is uncertain.

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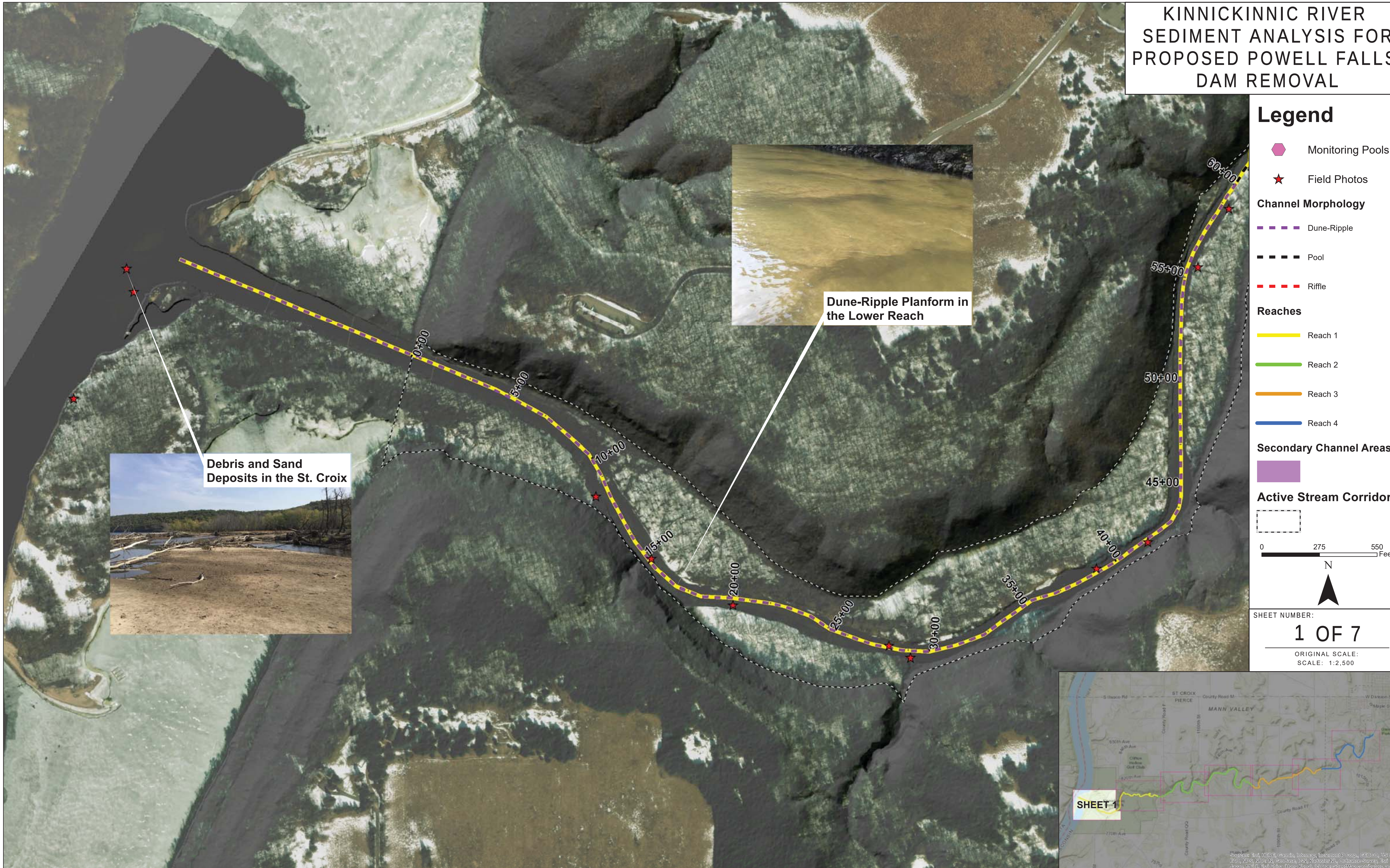
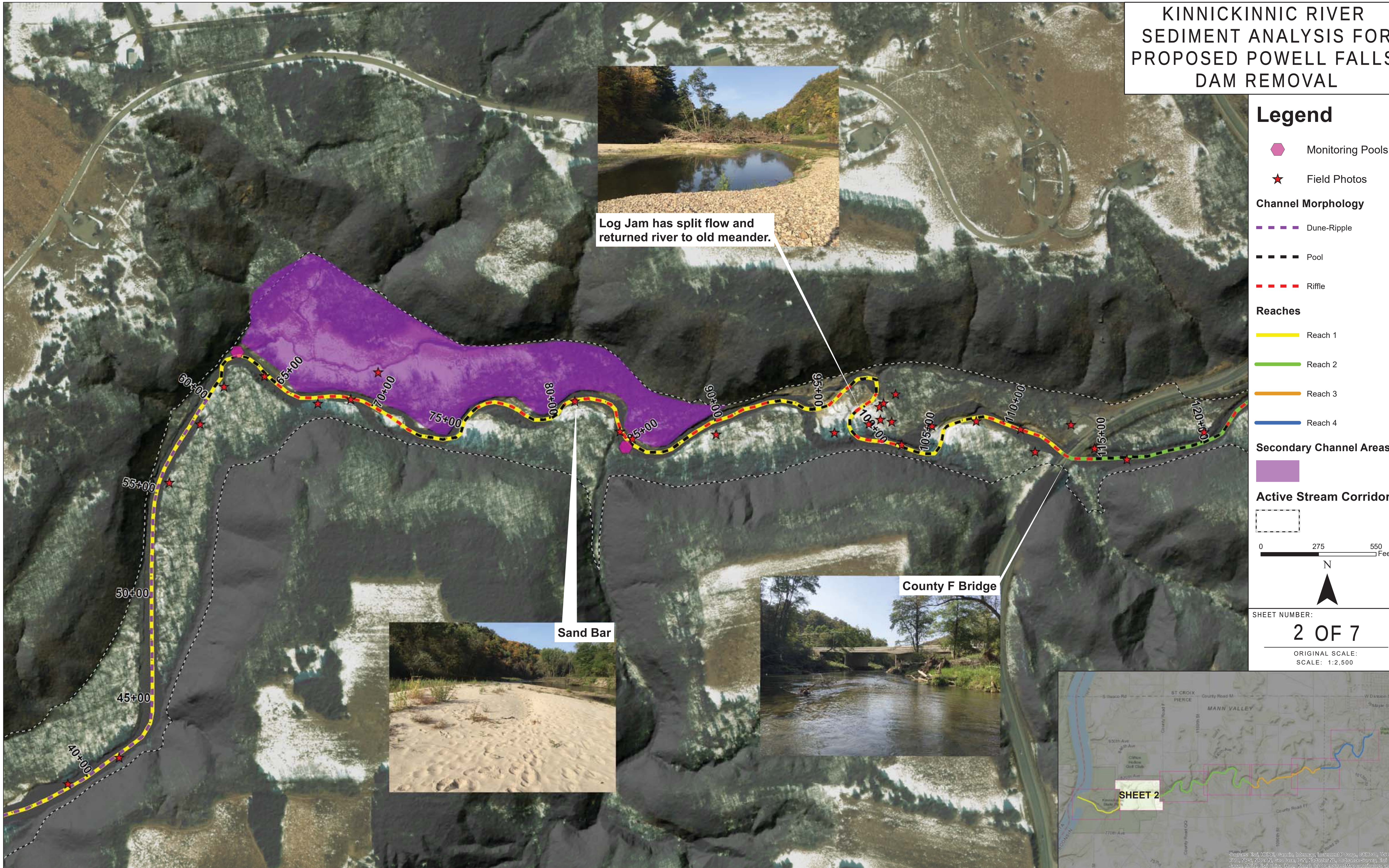
Appendix A

Summarizing Exhibit



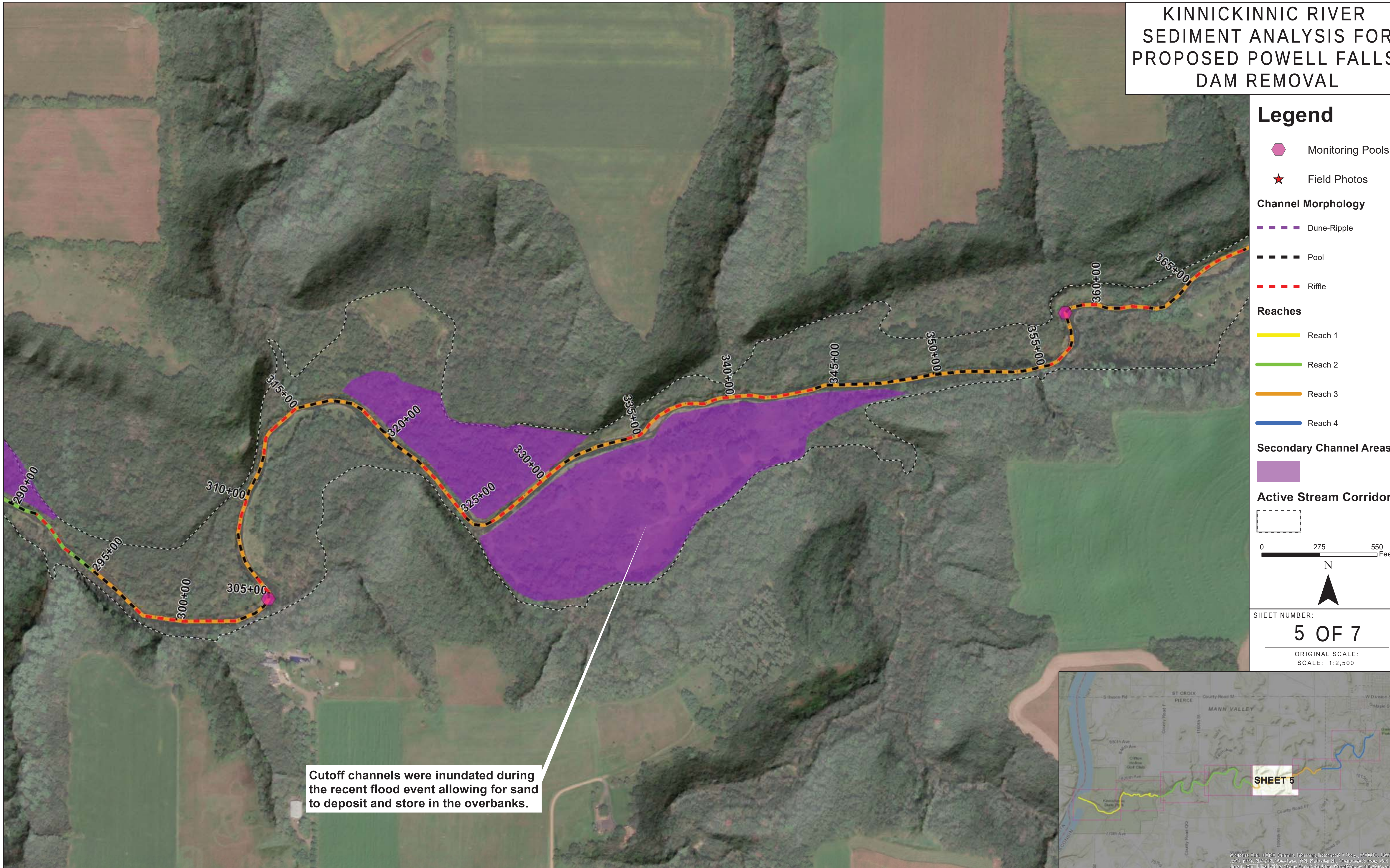
KINNICKINNIC RIVER SEDIMENT ANALYSIS FOR PROPOSED POWELL FALLS DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
1 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
Debris and Sand Deposits in the St. Croix
Dune-Ripple Planform in the Lower Reach
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00
55+00
60+00
SHEET 1



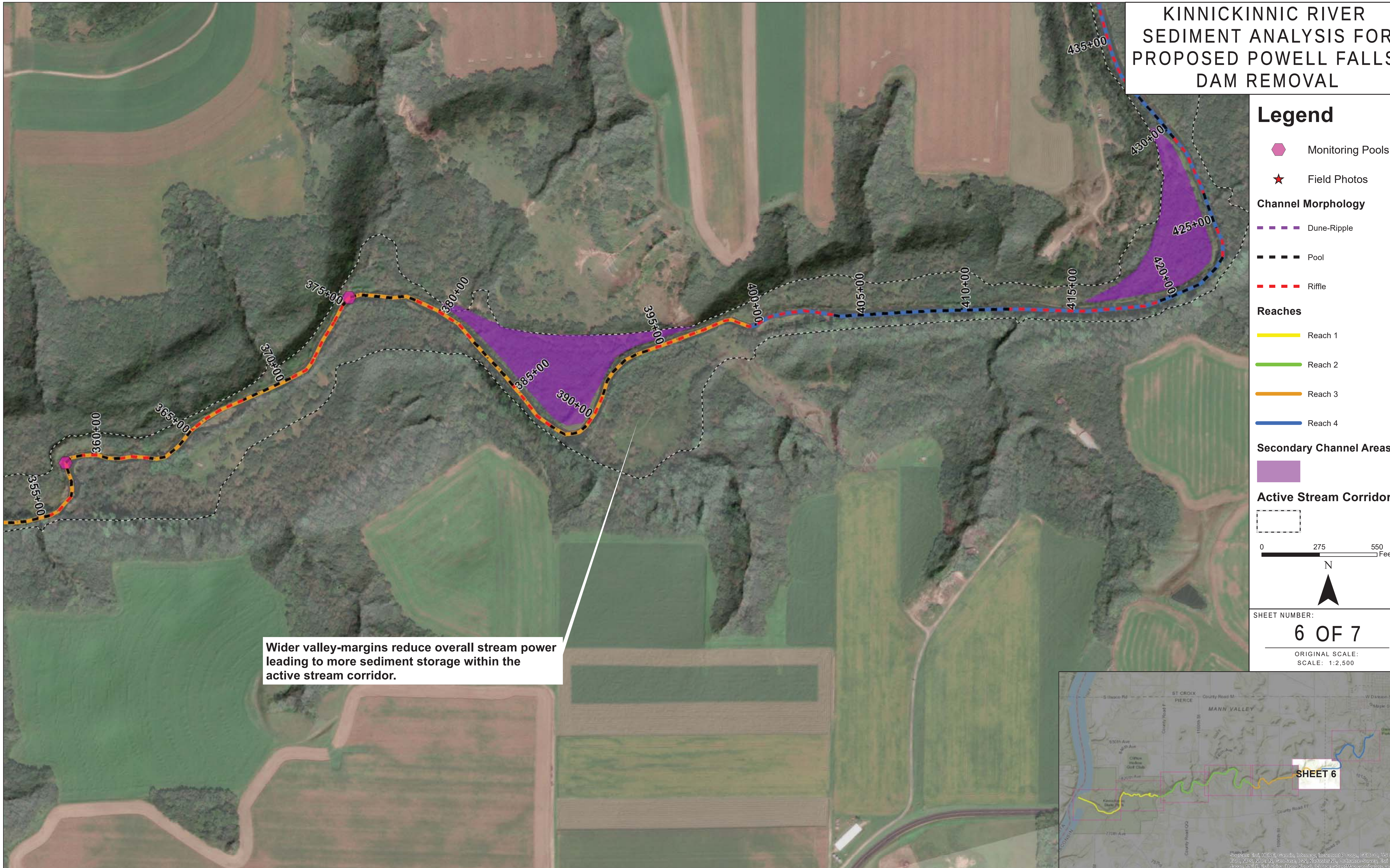
KINNICKINNIC RIVER
SEDIMENT ANALYSIS FOR
PROPOSED POWELL FALLS
DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
2 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
Log Jam has split flow and
returned river to old meander.
Sand Bar
County F Bridge
SHEET 2
MANN VALLEY
40+00
45+00
50+00
55+00
60+00
65+00
70+00
75+00
80+00
85+00
90+00
95+00
100+00
105+00
110+00
115+00
120+00

KINNICKINNIC RIVER SEDIMENT ANALYSIS FOR PROPOSED POWELL FALLS DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
3 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
Structure Storing Sand
Sand Bar in Eddy
Sand Bar in Eddy
115+00
120+00
125+00
130+00
135+00
140+00
145+00
150+00
155+00
160+00
165+00
170+00
175+00
180+00
185+00
190+00
195+00
200+00
205+00
SHEET 3
MANN VALLEY

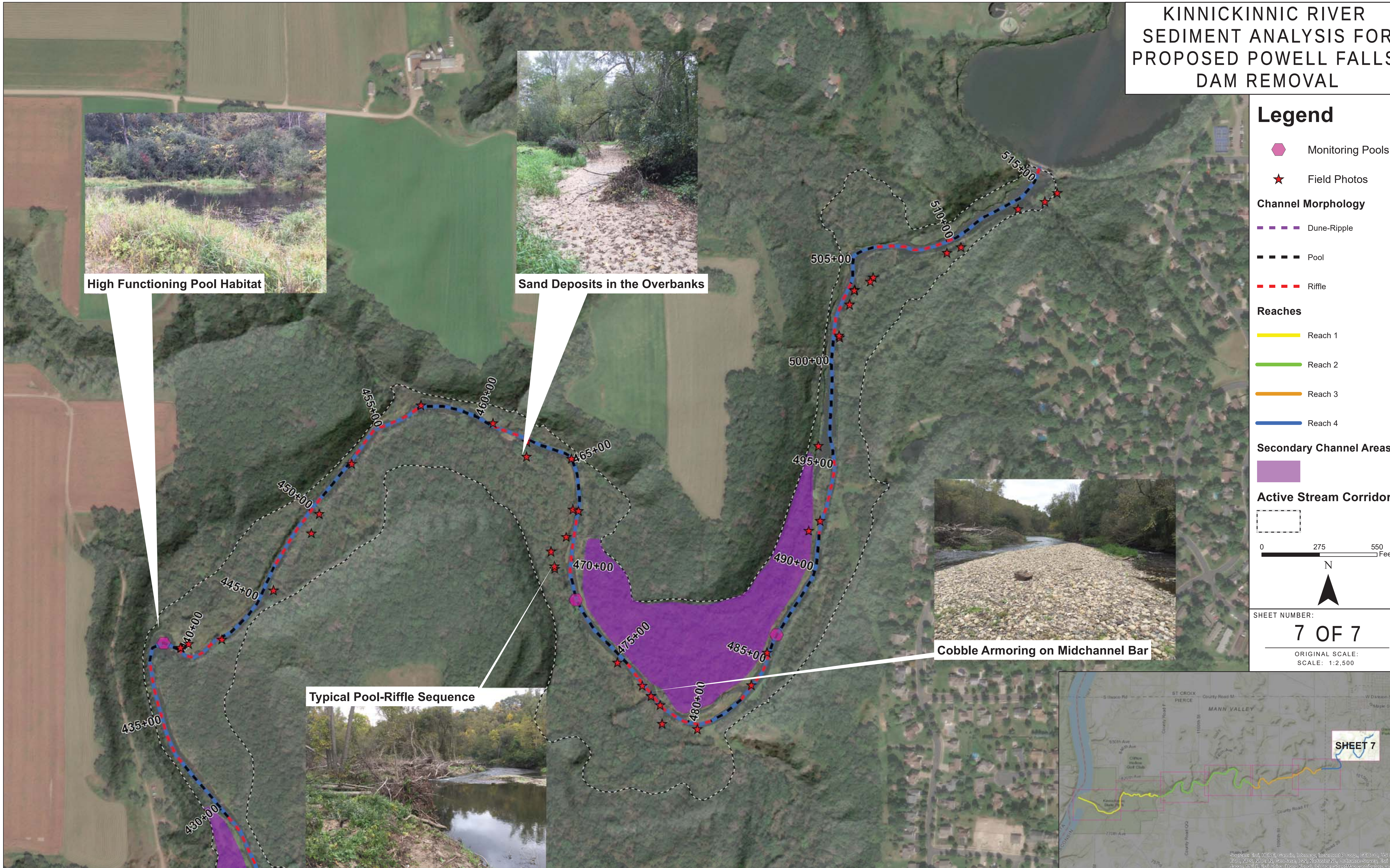

KINNICKINNIC RIVER SEDIMENT ANALYSIS FOR PROPOSED POWELL FALLS DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
4 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
Pool Habitat
200+00
205+00
210+00
215+00
220+00
225+00
230+00
235+00
245+00
250+00
255+00
260+00
265+00
270+00
275+00
280+00
285+00
290+00
295+00
SHEET 4
MANN VALLEY



KINNICKINNIC RIVER SEDIMENT ANALYSIS FOR PROPOSED POWELL FALLS DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
5 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
Cutoff channels were inundated during the recent flood event allowing for sand to deposit and store in the overbanks.
290+00
295+00
300+00
305+00
310+00
315+00
320+00
325+00
330+00
335+00
340+00
345+00
350+00
355+00
360+00
365+00
SHEET 5
MANN VALLEY



KINNICKINNIC RIVER SEDIMENT ANALYSIS FOR PROPOSED POWELL FALLS DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
6 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
355+00
360+00
365+00
370+00
375+00
380+00
385+00
390+00
395+00
400+00
405+00
410+00
415+00
420+00
425+00
430+00
435+00
Wider valley-margins reduce overall stream power leading to more sediment storage within the active stream corridor.
SHEET 6
MANN VALLEY



KINNICKINNIC RIVER SEDIMENT ANALYSIS FOR PROPOSED POWELL FALLS DAM REMOVAL
Legend
Monitoring Pools
Field Photos
Channel Morphology
Dune-Ripple
Pool
Riffle
Reaches
Reach 1
Reach 2
Reach 3
Reach 4
Secondary Channel Areas
Active Stream Corridor
0
275
550
Feet
N
SHEET NUMBER:
7 OF 7
ORIGINAL SCALE:
SCALE: 1:2,500
High Functioning Pool Habitat
Sand Deposits in the Overbanks
Typical Pool-Riffle Sequence
Cobble Armoring on Midchannel Bar
430+00
435+00
440+00
445+00
450+00
455+00
460+00
465+00
470+00
475+00
480+00
485+00
490+00
495+00
500+00
505+00
510+00
515+00
SHEET 7
MANN VALLEY

Part 2.

Powell Falls Dam Removal Sediment Study Ecological Risk Evaluation

POWELL FALLS DAM REMOVAL SEDIMENT STUDY ECOLOGICAL RISK EVALUATION

RIVER FALLS HYDROELECTRIC PROJECT

FERC NO. 10489

SUBMITTED BY:

CITY OF RIVER FALLS MUNICIPAL UTILITIES
222 LEWIS STREET
RIVER FALLS, WI 54022

PREPARED BY:

TRC
150 NORTH PATRICK BOULEVARD
BROOKFIELD, WI 53045

JANUARY 2021

CITY OF RIVER FALLS MUNICIPAL UTILITIES

RIVER FALLS HYDROELECTRIC PROJECT

FERC NO. 10489

Powell Falls Dam Removal Sediment Study Ecological Risk Evaluation

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1.0 INTRODUCTION

The City of River Falls Municipal Utilities (RFMU) is proposing to decommission the Powell Falls Development of the River Falls Hydroelectric Project (Federal Energy Regulatory Commission (FERC) Project No. 10489) by removing the Powell Falls Dam. Powell Falls Development is located on the Kinnickinnic River in River Falls, Wisconsin. Removing the dam will involve the drawdown and draining of Lake Louise, the impoundment created by Powell Falls Dam.

On May 26, 2020 FERC requested a sediment study be performed to evaluate the impact of the removal of the Powell Falls Dam. FERC requested two study objectives be addressed: "1) compare the amount of sediment that could be released downstream of Powell Falls Dam to the average annual sediment yield in the Kinnickinnic and St. Croix Rivers to determine the level of ecological risk to downstream geomorphology and aquatic resources; and 2) assess the potential effects on geomorphology and aquatic resources based on the predicted level of ecological risk." Part 1 of this report, "Kinnickinnic River Sediment Analysis for Proposed Powell Falls Dam Removal", addresses Objective 1 of the FERC study request. Part 2 of this report, the sediment study ecological risk assessment, addresses Objective 2 of the FERC study request.

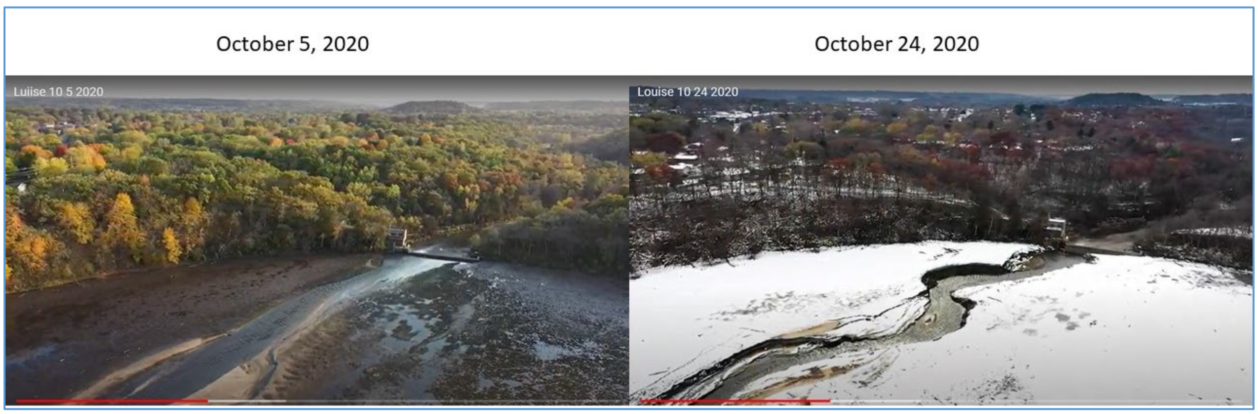
2.0 Background

The sediment analysis used to address Objective 1 of this study builds upon the material presented in the draft "Powell Falls Decommissioning Plan" authored by Ayres (January 30, 2020). Included in this plan is the methodology used to estimate the amount of sediment that will be released downstream of Powell Falls Dam post-removal. This estimate of 25,100 cubic yards was produced prior to the 10-year flood event that occurred on June 29, 2020 and the current drawdown that started on October 2, 2020. The drawdown occurred to evaluate the structural damage to Powell Falls Dam from the June 29, 2020 flood (FERC approved the drawdown on October 1, 2020). The amount of sediment that moved downstream of Powell Falls Dam during the June 29 flood and drawdown events is undetermined. However, the remaining channel sediment (that volume naturally incised in the lakebed during a prolonged drawdown period[1]) in Lake Louise is likely less than 25,100 cubic yards, the original estimated amount that would be displaced by the Powell Falls Dam removal referenced in the FERC May 26, 2020 sediment study request (Ayres 2020; Figure 1).

[1] A letter dated 10 November 2020 from Ayres to RFMU explains the sediment volumes in more detail by itemizing them into fouring categories: 1) sediment released in October and November 2020 during and after drawdown ≈8000 CY, 2) maximum sediment expected to be released between now and 2024 if drawdown continues and sediment is not actively dredged ≈25000 CY, 3) sediment necessary to be removed to complete the dam removal and channel stabilization ≈25000 CY, and 4) sediment expected to be caught in turbidity barriers during 2.5 years of construction activities ≈22000 CY. In short, the 8000 CY is an upper end estimate of released sediment already in the Kinnikinnic River below the dam, and the 25000 CY is an upper estimate of what may be naturally released over the next three to four years of drawdown. The last two numbers (25000 + 22000 = 47000 CY) is what Ayres has budgeted for the contractor to remove during the dam removal construction period. The red numbers are the same as the 25,100 number listed in this report, just rounded to acknowledge the appropriate significant digits.

Field data collected during September 21-24, 2020 provided empirical evidence of the June 29, 2020 flood impact to the riverine habitat downstream of Powell Falls Dam. This evidence is presented in Part 1. Supplemental data related to the post-flood habitat conditions were collected and are presented in the draft "River Falls Hydroelectric Project Riverine Habitat Evaluation below Powell Falls" relicensing study report. The field data collection activities for this relicensing study were postponed from 2019 to September 2020. The data from these two sources are used in conjunction to address Objective 2 of this study, predicting the level of ecological risk of removing Powell Falls Dam by assessing the potential effects on geomorphology and aquatic resources.

Figure 1. Aerial images of the Kinnickinnic River channel formation in the bed of Lake Louise during the Powell Falls Dam drawdown event of October 2020.



Source: Kinnickinnic Corridor Collaborative, https://www.youtube.com/channel/UCB-jCo-8r4iQVowaFzC1UhQ

2.1 Objectives

The following are a list of items to be addressed in this report, which cumulatively present an opinion of the level of ecological risk to the geomorphology and aquatic natural resources by removing Powell Falls Dam. This list combines the ecological risk assessment requirements found in "Dam Removal Analysis Guidelines for Sediment" (Randle and Bounty 2017) and "Guidelines for Dam Decommissioning Projects" (USSD 2015). The assessment will address the following Powell Falls Dam removal ecological risks and benefits to the Kinnickinnic River ecosystem:

1) Water quality deterioration due to increased suspended sediment levels or contaminants;

2) Burial of downstream aquatic spawning, rearing, and holding areas for threatened or endangered species or species of concern;

3) Burial of downstream aquatic species or life stages that cannot find refuge or quickly mobilize out of sediment impact areas (e. g., mussels and fish eggs);

4) Increased deposition in floodplains that could result in change in riparian vegetation when existing species are not tolerant of burial;

5) Sediment deposition blocking aquatic species migration routes;

6) Restoration of riverine habitat in reservoir area;

7) Restoration of heterogeneous grain sizes and sediment bars that support development of more diverse channel processes such as channel migration;

8) Increase in physical habitat features that provide ecosystem benefits, such as channel spawning gravels, bars, islands, large wood features, and side channel activation;

9) Facilitate growth of invertebrate communities;

10) Natural disturbance and sedimentation required for riparian vegetation.

11) Increased exposure to ice jams whose impact are currently mitigated by the dam and reservoir; and

12) Deposition along recreational use areas including navigation channels and fishing areas.

2.2 Methods

This desktop study evaluates the potential effects on geomorphology and aquatic resources of removing Powell Falls Dam. The framework of this study utilizes guidance provided in “The Dam Removal Analysis Guidelines for Sediment” (Randle and Bountry 2017) and the “Guidelines for Dam Decommissioning Projects” (USSD 2015). These documents contain methods to evaluate the level of ecological risk and potential effects of sediment on geomorphology and aquatic resources downstream of a dam removal site.

The information collected and analyzed for the Powell Falls Decommissioning Plan (Ayres 2020), Part 1 of this study, the concurrent Riverine Habitat Evaluation (Interfluve and GSRC 2020), and Lower Kinnickinnic River Mussel Survey (Kelner 2020) will be used to fulfill the informational needs described in the Randle and Bounty (2017) and USSD (2015) guidelines. The results of Part 1 of this study provide essential baseline description of the existing geomorphic conditions and potential impact to them by removing Powell Falls Dam. The effort to address Objective 2 of this study is to evaluate the impact described in Objective 1 on existing aquatic natural resources. The site-specific information gathered during the current relicensing and drawdown monitoring studies are used to describe the existing aquatic natural resources. Monitoring of abiotic water quality and habitat conditions during the ongoing Lake Louise drawdown are also used as direct observations of expected conditions during the continuation of Powell Falls Dam removal activities. The library of site-specific information is also compared to the existing body of scientific literature related to this subject. A summary table that qualitatively assigns levels of ecological risk and benefit as low, medium and high for varying timespans, (short-term equal to 1-yr or less, and long-term greater than 1-yr), that reflect the results and discussion for all of the study objectives was produced. This table is a comprehensive summary of the risk-benefit analysis of the Powell Falls Dam removal.

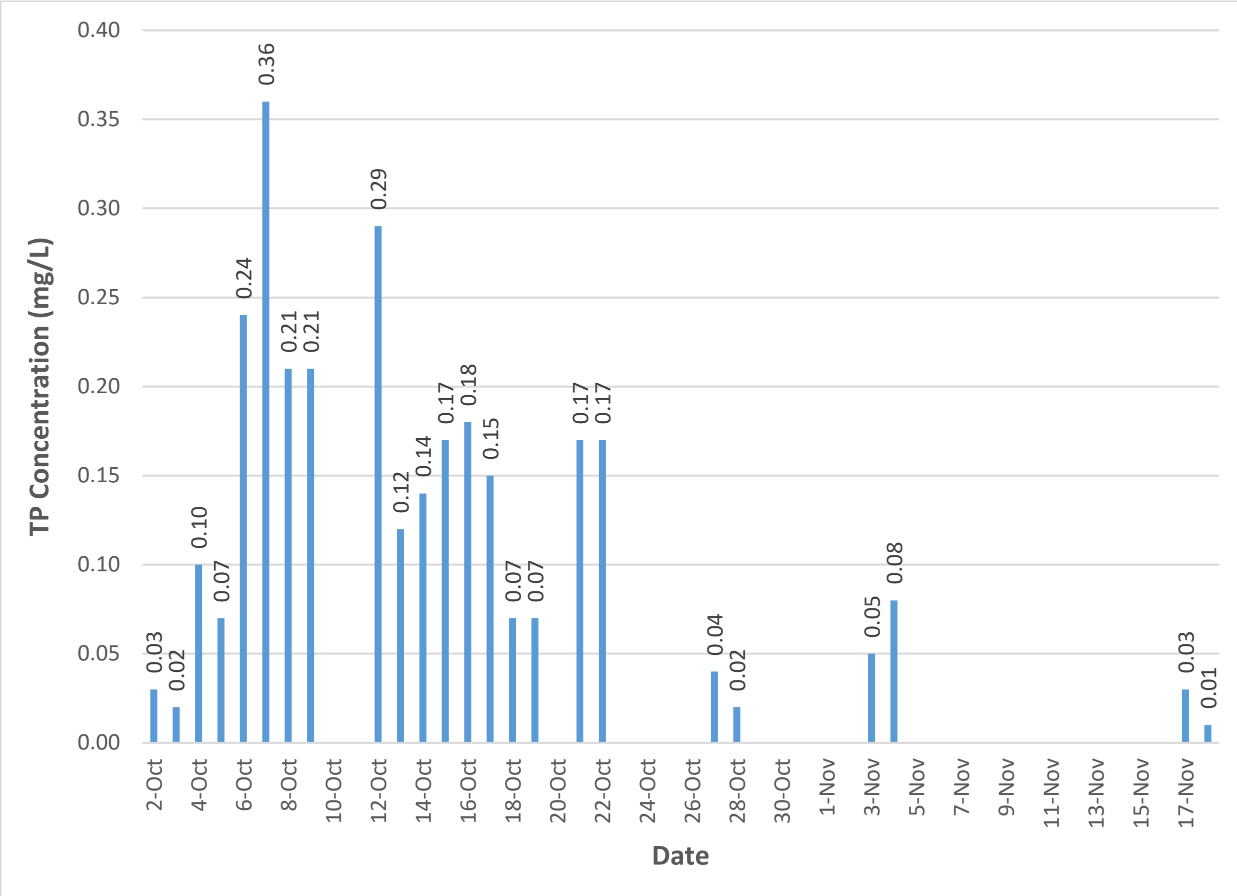
3.0 RESULTS AND DISCUSSION

3.1 Water Quality

Restoring impounded rivers to free-flowing conditions can improve water quality. By removing the Powell Falls Dam, the impoundment reservoir, Lake Louise, will change from lentic to lotic habitat. This alteration will reduce the amount of time surface water is pooled and exposed to solar radiation, which will change the thermal regime of this waterbody. The lack of increased exposure to solar energy will result in a decrease in water temperatures below Powell Falls and in the re-established river channel in the Lake Louise bed after dam removal. Reduced water temperature will be beneficial to the popular recreational Brown and Brook Trout (*Salmo trutta* and *Salvelinus fontinalis*, respectively) fisheries that require cold water and exist in the Kinnickinnic River downstream of Powell Falls and in the re-established river channel through the Lake Louise bed.

Dam removal activities can impact water quality conditions by increasing suspended solids and releasing contaminants that were previously stored in the impoundment sediment. Given this concern, RFMU collected two parameters, total phosphorus concentration and total suspended solids, during the Lake Louise drawdown initiated on October 2, 2020 to monitor water quality impacts (results are depicted in Figure 2). Total phosphorus concentration was above the state of Wisconsin standard 13 of the 24 sampling dates. The highest value, 0.36 mg/L, occurred on October 7. The dates when total phosphorus concentrations were above state standard occurred on or before October 22. Total phosphorus concentrations were below state standard on all sampling dates after October 22.

Figure 2. Total Phosphorus (TP) Concentrations (mg/L) in the Kinnickinnic River downstream of Powell Falls Dam



Note: State of Wisconsin total phosphorus water quality standard for streams is 0.075 mg/L (WDNR 2017).
Source: City of River Falls Municipal Utilities.

Increased levels of phosphorus can impact water quality by increasing primary productivity in a water body. Increased levels of this essential plant nutrient can set off a chain of undesirable events in a waterbody including accelerated plant growth, algae blooms, low dissolved oxygen, and the death of certain fish, invertebrates, and other aquatic animals (EPA 2012). There are many sources of phosphorus in the Kinnickinnic River basin, one of which is the point-source wastewater treatment plant that discharges into the Kinnickinnic River upstream of Powell Falls Dam. As a monitoring requirement of this facility's discharge permit, RFMU regularly records total phosphorus concentrations in the wastewater facility outfall. The increased levels of phosphorus during the first week of the drawdown are a result of its resuspension in surface water after being stored in the sediment that composed the substrate of Lake Louise. The rapid decline in total phosphorus after the first two weeks of the drawdown reflects the amount of time it took for the erosive forces of the river channel formation to alleviate. Now that the river channel is present in Lake Louise, continued erosion of the lakebed outside of the channel will be limited, and phosphorus that remains stored in the substrate will not be released into the Kinnickinnic River.

Suspended sediment can alter water quality by causing temperature decreases and turbidity increases (Ryan 1991). To monitor sediment concentration downstream of Powell Falls Dam, RFMU recorded total suspended solids (TSS) during the drawdown of Lake Louise (Figure 3). Soon after lowering the water elevation of the impoundment formed by Powell Falls Dam on October 2, 2020, its bed substrate began to erode as the Kinnickinnic River channel formed (Figure 1). Total suspended solids concentrations remained at low levels for the first four days before a rapid increase occurred on October 7, 2020. Fluctuations in TSS occurred as avulsive episodes released sediment during river channel formation in the bed of Lake Louise until a precipitation event of approximately 2 inches[2] of rain on October 12, 2020 raised TSS to the highest concentration recorded, 3081 mg/L, during the monitoring period. TSS concentrations rapidly declined after the heavy rainfall caused increased erosion of the exposed Lake Louise substrate and returned to levels similar to those prior to the drawdown (Figure 3).

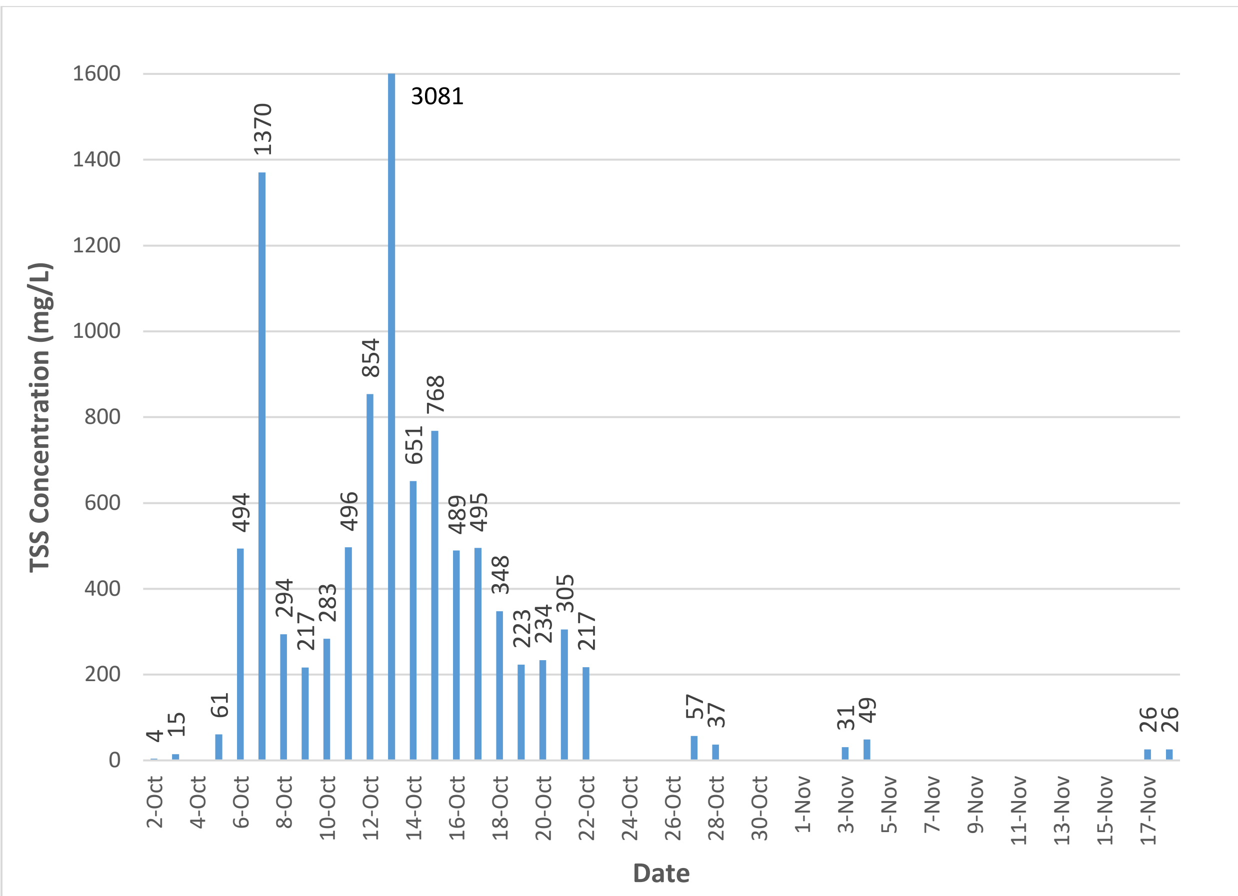
Short-term impacts to water quality of the Kinnickinnic River were observed during the drawdown of Lake Louise created by Powell Falls Dam. Phosphorus concentrations increased for a short period of time during the formation of the river channel in Lake Louise but have decreased to concentrations below the criteria for this nutrient established by the state of Wisconsin. Given that this brief increase in phosphorus occurred during late Fall when primary productivity is diminished, it is unlikely it upset the trophic structure of the lower Kinnickinnic River. Since the phosphorus was not utilized by algae or plants for growth, it likely precipitated and amalgamated with the fine sediment that was conjointly transported downstream during the 2-week time period after the drawdown was initiated. If the drawdown had occurred during a period of increased primary productivity (i.e., Spring or Summer), the increase in the nutrient phosphorus may have caused increased algal blooms and plant growth. Similarly, the increase in suspended solids caused intense yet brief increases in turbidity. Any impacts to water temperature were negligible as the 2-week period when the addition of suspended sediment occurred was late Fall when water temperatures are normally rapidly declining. The degradation of water quality by increased suspended sediment concentrations and the nutrient phosphorus would likely have been of greater consequence if it had occurred during Spring or Summer months.

A contaminant analysis of the sediment in Lake Louise consisting of collecting samples at six locations was performed in 2016. Parameters tested were metals (As, Cd, Cr, Cu, Pb, Ni, Zn, and Hg), organics (polycholorinated biphenyl (PCB), polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides, and petroleum residues), and physical (particle size and percent total

[2] https://mesonet.agron.iastate.edu/sites/hist.phtml?station=RVFW3&network=WI_COOP&year=2020&month=10

organic carbon). PCBs were not detected. Threshold effects concentrations (TEC) of trace metals were not exceeded. Arsenic was found above the probable effects concentration (PEC) in one sampling location. Dichlorodiphenyldichloroethane (DDD) values above TEC were detected at one sampling location. Ten PAH compounds were above TEC at one sampling location. Four PAH compounds were above PEC at one sampling location. All other PAH compounds detected were below TEC. The resulting determination of the Lake Louise contaminant study was the sediment is relatively clean and represented a low risk to the aquatic organisms residing in the Kinnickinnic River downstream of Powell Falls Dam; a critical element in the decision-making to move forward with dam removal (Interfluve 2016).

Figure 3. Total Suspended Solids (TSS) (mg/L) in the Kinnickinnic River downstream of Powell Falls Dam



Source: City of River Falls Municipal Utilities.

3.2 Aquatic Habitat Sedimentation Risks and Benefits

Burial of some of the Brown and Brook Trout available spawning habitat in the lower Kinnickinnic River is a short-term risk due to the removal of Powell Falls Dam. Excess sediment can profoundly affect the productivity of a trout stream by burying the spawning beds (Cordone and Kelly, 1961). Increased fine sediment in spawning gravels cause decreased survival and emergence of salmonid eggs and alevin (Lisle 1989; Tappel and Bjornn 1983). Brown Trout use clean gravel substrate in October and November to spawn. Brook Trout use similar substrate but often migrate to headwater streams to spawn during the same time period. Both trout species find cold clear water to excavate spawning nests or redds by rapidly moving their tails to push aside substrate, which results in a circular or oval depression in the river bottom (Werner 2004). Ideal conditions for Brown and Brook Trout to build redds are often associated with upwellings of groundwater or hyporheic flow (Baxter and Hauer 2000). Cold water seeps or springs adjacent to the mainstem Kinnickinnic River and riffle habitats provide optimum conditions for Brown and Brook Trout spawning. The combination of the upward movement of groundwater and/or hyporheic discharge with the lateral mainstem flow flushes sediment up and away from a trout spawning redd. Additionally, the initial excavation of the redd cleans the substrate of fine sediment and exposes the coarser gravel.

The brief intense pulse of suspended sediment experienced during the October 2020 drawdown occurred at a sub-optimal time to avoid impacts to Brown and Brook Trout spawning. During consultation with Wisconsin DNR, it was noted that trout spawning in the Kinnickinnic River starts by late October and peaks in early November.[3] To minimize risk to trout, it was recommended to initiate the draw down as soon as possible so turbidity would have a chance to clear prior to the start of spawning. It is possible, however, that both species may have initiated spawning activities when the drawdown occurred; however it's more likely that the drawdown occurred early enough in the spawning season that eggs had not yet been deposited. If this is the case, sediment released and transported downstream during the Lake Louise drawdown could have been removed by favorable hydraulic conditions that are associated with trout spawning habitat and by the redd maintenance activities by spawning adults.

Increased sediment transport downstream resulting from dam removals has been documented (Burroughs et al. 2009). The initial movement of finer sediments moving downstream following a dam removal results in a reduction in bed sediment caliber (Wohl and Cenderelli 2000). High stream discharge events driven by precipitation or snowmelt will increase the rate of transport rate and caliber of sediment (Pearson et al. 2011). Aerial imagery collected prior to and after the initial 2-week period of the Lake Louise drawdown provides insight into where the sediment deposited downstream of Powell Falls Dam. A qualitative evaluation of this imagery collected by photographic equipped drone flown at varying elevations above the Kinnickinnic River shows that the bulk of the transported fine sediments settled in the lower velocity pool habitats located

[3] RFMU consulted with Wisconsin Department of Natural Resources on September 23rd and 24th, 2020 when it was determined that the drawdown should be completed by October 15, 2020 to minimize impacts to trout and overwintering herptiles. These meeting summaries were included with the *River Falls Hydroelectric Project, FERC Project No. 10489 Plan and Schedule Response to September 10, 2020 letter regarding June 2020 Flooding Damage* filed with FERC on September 25, 2020. FERC accession number 20200925-5137.

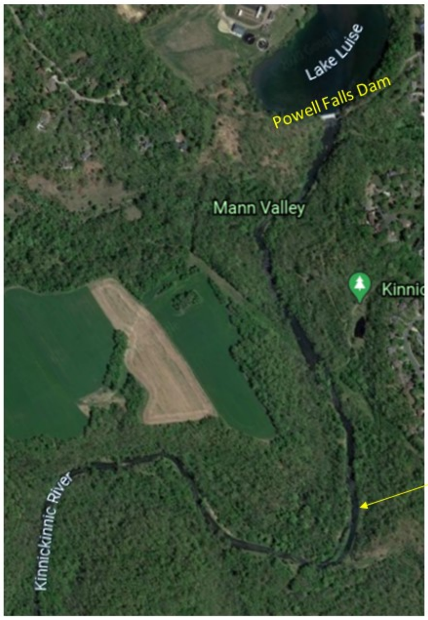
within 6,000 ft downstream of Powell Falls Dam. This length of river corresponds with Reach 1 of the Riverine Habitat Evaluation draft report that describes it as a "pool-riffle morphology with large gravels and cobbles in riffles being 20% embedded" (Interfluve and GSRC 2020). Undoubtedly, the embeddedness of the coarser substrates in pool habitat has increased in Reach 1 post-drawdown (Figure 4). Riffle habitats, however, were less susceptible to sediment settling released during the drawdown. The hydraulic conditions associated with riffles inhibit deposition by continuously flushing suspended sediment to lower velocity habitat features such as adjoining pools (Figure 5). Since the eggs deposited by Brook and Brown Trout in redds are more likely to occur in riffle habitats, their susceptibility to the increased sediment deposition of the Lake Louise drawdown is lessened. Similarly, larval life stages that remain in riffle habitats are less likely to suffer the effects of increased sediment deposition associated with dam removal activities.

Figure 4. Aerial images of the Kinnickinnic River 200 feet downstream of Powell Falls Dam before and after the drawdown event of October 2020.

Source: GoogleEarth, imagery collection date prior to October 2, 2020

Source: Source: Kinnickinnic Corridor Collaborative, https://www.youtube.com/channel/UCB-jCo-8r4iQVowaFzC1UhQ

Figure 5. Aerial images of the Kinnickinnic River 3,000 feet downstream of Powell Falls Dam before and after the drawdown event of October 2020.



Source: GoogleEarth, imagery collection date prior to October 2, 2020

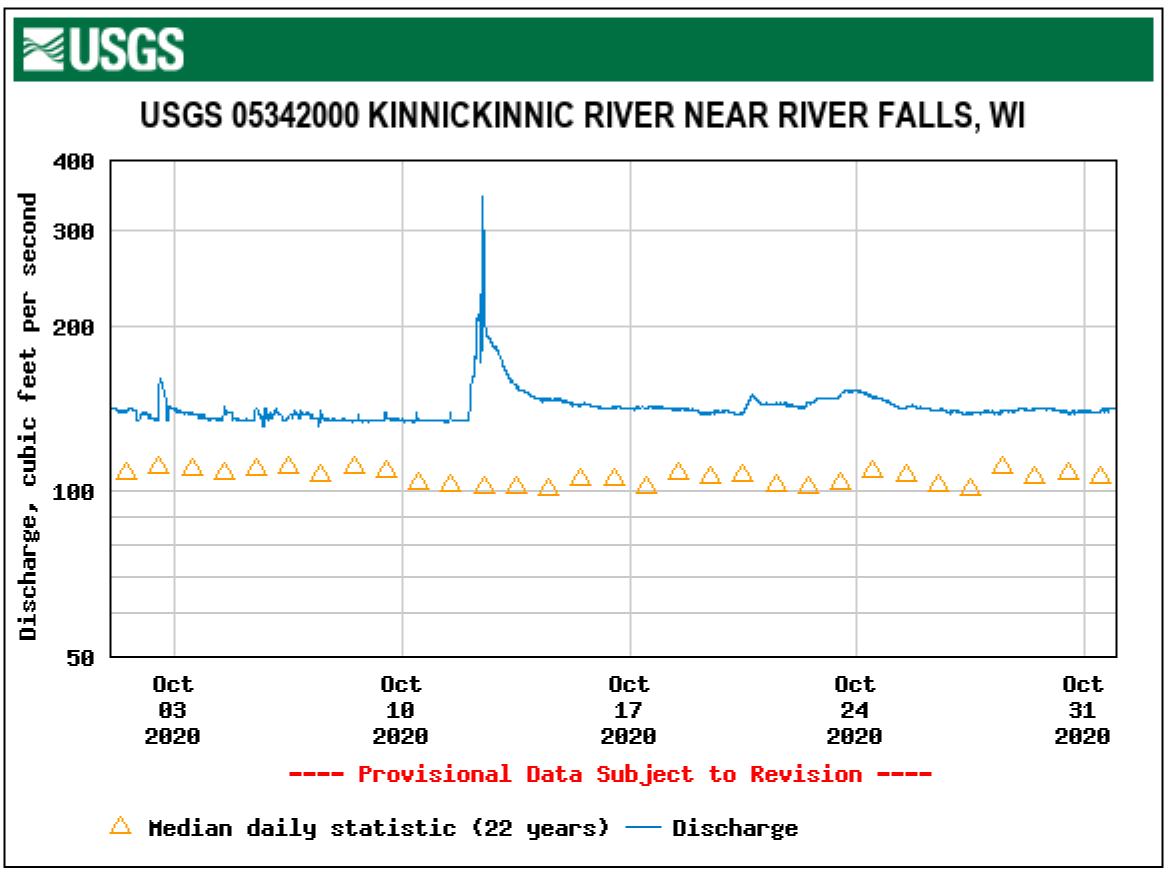
Source: Source: Kinnickinnic Corridor Collaborative, https://www.youtube.com/channel/UCB-jCo-8r4iQVowaFzC1UhQ

These observations demonstrate that the fine sediments released upstream will eventually settle in pool habitats of the Kinnickinnic River. The sediment accumulation in pools will influence the life stage specific behavior of Brown and Brook Trout that use this habitat. Decreased pool depth, i. e., raised channel bed elevation, can lead to decreased use of this habitat type as a holding location for resting or foraging for juveniles and adults. Daily peak water temperatures may increase in shallower pools because of the decrease in water volume, which could deter use by juveniles and adults. Short-term negative impacts to the life stages of Brown and Brook Trout due to increased sedimentation in pool habitats needs to be compared to the long-term advantages of dam removal.

The removal of Powell Falls Dam creates a setting that could produce favorable trout spawning habitat conditions in the reach upstream of the dam. The establishment of a free-flowing stream whose increased flow velocities scour the bed of Lake Louise will benefit trout populations by uncovering the coarse substrates of the original river channel. These coarse substrates are preferred spawning habitat (Werner 2004). Trout production could increase in the years following the Powell Falls Dam removal depending on the amount of quality spawning substrate that is exposed.

The impacts from sediment deposition on pool habitats downstream of Powell Falls Dam will likely be of short duration. First, if productivity was reduced during the spawning season (Fall) of 2020, it will likely recover in following years as the two trout species use alternative spawning habitat locations including ones that are formed through the river channel creation in the bed of Lake Louise. Future dam removal activities that cause sediment releases should not overlap the time period when spawning and egg incubation occurs (approximately October through early March). Secondly, the sediment burden will continue to be transported further downstream by increased discharge events. The October 2020 drawdown occurred during the relatively low discharge conditions typically experienced during this season. Although there was a rapid increase in discharge associated with the October 12 precipitation event, it quickly returned to stable baseline flows (Figure 6). The rapid rise and decline in water elevation likely led to sediment being transported a relatively short distance downstream of Powell Falls Dam. Successive increased discharge events of longer duration and larger magnitudes, e. g., spring freshets, will continue to redistribute the sediment by enhancing scour of the recently created bed formations and transporting sediment farther downstream over extended periods of time.

Figure 6. Kinnickinnic River discharge during the month of October 2020.



Sessile organisms or life stages are more susceptible to sediment deposition. Trout eggs can suffocate from lack of dissolved oxygen as fine sediments accumulate on them in the redd

(Argent and Flebbe 1999). This risk is greatest when sediment is released after eggs are present, i. e., spawning season. Brook Trout are naturally adapted to avoid this negative impact by using habitats associated with groundwater upwelling for spawning (Alberto et al. 2017).

Freshwater mussels are a taxon that spend most of their life cycle partially buried in substrate. They respire by siphoning water across filamentous gills to extract dissolved oxygen. They have a muscular organ called a foot that allows them to move through substrate. Their mobility allows them to move vertically in substrate as well as laterally across the surface of the substrate. Chronic exposure to sedimentation and associated turbidity can negatively affect recruitment of freshwater mussel populations (Osterling et al. 2010). Episodic exposure to sedimentation such as those that occur during dam removal activities is less of a risk to mussels.

Five federally endangered species of mussels are known to occur in the lower St. Croix River- spectaclecase (*Margaritifera monodonta*), snuffbox (*Epioblasma triquetra*), Higgins eye (*Lampsilis higginsii*), sheepnose (*Plethobasus cyphyus*), and winged mapleleaf (*Quadrula fragosa*) (USFWS 2019). Extant populations of these species are known to exist in the lower St. Croix River A field survey was performed in the 0.8 miles of the Kinnickinnic River upstream of the confluence of the St. Croix River and downstream of this location to the confluence of the Mississippi River during August 2020 to document mussel habitat (location, depth, and substrate), and the occurrence density, distribution, and relative abundance of any federally listed mussel species present. The results of this survey show the lower St. Croix River harbors a species rich mussel community in the study area with at least 19 live species including the federally endangered Higgins eye in some of the sampled sites, with pockets of moderately densely populated areas that appears minimally affected by zebra mussels at this time (Kelner 2020). A total of 55 live mussels representing 11 species were observed at the sampling location closest to the Kinnickinnic River confluence. *Amblema plicata* was the most abundant, 47.3% of all live mussels, followed by *Obliquaria reflexa*, 12.7%, and *Eurynia dilatata*, 12.7% (Kelner 2020). None of the federally listed species were observed at the site closest to the Kinnickinnic River confluence (Kelner 2020).

The lower Kinnickinnic River is less suitable for use of freshwater mussels due to the presence of loose shifting sand substrate. The Kinnickinnic River is also a coldwater trout stream, which "typically do not harbor diverse mussel assemblages" (Kelner 2020). Kelner performed sampling in the lower Kinnickinnic River in July 2020 and found no evidence of live or relic mussels. No records of native mussels have been identified from the lower Kinnickinnic River (Kitchel pers. comm., as cited in Kelner 2020).

Sediment transport in the Kinnickinnic River can influence the physical characteristics of mussel habitat in the St. Croix River downstream of its confluence. Given that the greatest change in physical habitat conditions due to sediment transport from the October 2020 drawdown occurred in the reach that extends approximately 1 mile downstream of Powell Falls Dam, negative impacts from dam removal activities to the freshwater mussels found at the confluence with the St. Croix River are likely negligible (see Part 1).

Kelner noted that "the flood event that occurred immediately prior to this study provided an opportunity to evaluate the effects of dam removal and resulting increased flows on the lower Kinnickinnic River with possible impacts to mussels in the lower 6-miles of St. Croix River. Given the results from this study it appears dam removal with respect to increased and possibly irregular flows and resulting increased sedimentation into the lower St. Croix would not result in adverse impacts to mussels including federally listed species at least in the short term. However, it's recommended longer term effects to mussels in the lower St. Croix River from dam removal should be evaluated with a single repeat of this study between 10 and 20 years post dam removal." (Kelner 2020)

A risk of sediment deposition in the Kinnickinnic River floodplain changing riparian vegetation community exists. A description of the bed load change from the June 2020 flood event in the reach immediately downstream of Powell Falls Dam appears in page 10 of Ayers 2020. The Riverine Habitat Assessment described the post-flood conditions of this reach as "overbank sedimentation of fine sand varying in thickness from less than 1 inch to 4 feet." Figure 8 of the Riverine Habitat Assessment provides an image of this description (page 14 of Interfluve and GSRC 2020). This reach also experienced the sediment transport impact of the drawdown in October 2020. The flood transported sediment remained in the Kinnickinnic River channel during the drawdown, however. Newly deposited sediment forming bars downstream of Powell Falls Dam is unstable and likely will continue to be transported downstream during future increased discharge events. The magnitude and duration of these events will determine if the sediment deposited during the drawdown will move laterally from the channel to the floodplain or downstream. The dynamic nature of disturbance along the Kinnickinnic River is typical of a palustrine forest, the prevalent floodplain vegetation classification identified in the 2018 River Falls Hydroelectric Project Preliminary Application Document (PAD). This forest type is characterized by woody vegetation 18 ft or taller. It contains broad-leaved deciduous plants that are adapted to seasonally saturated organic soils (USFWS 2018). These floodplain forests consist of numerous small patches of vegetation with different species composition and successional stages. This mosaic of vegetation patches changes along a gradient of flooding frequency and duration (Cohen et al. 2020). Without the dynamic conditions that periodic flooding creates, this vegetation community may cease to exist, i. e., displays intolerance to lack of sediment deposition. Therefore, the associated sediment deposition that occurs during flood events maintains the vegetation community of the Kinnickinnic River floodplain.

Sediment transported and deposited downstream of the Powell Falls Dam during the October 2020 drawdown has not created blockages of upstream migration routes for aquatic species. Aerial imagery of the 3000 ft length of river immediately downstream where the most pronounced sediment deposition occurred post-drawdown does not show any blockages that would restrict fish movement, nor, to our knowledge, have any anecdotal reports of blockages been reported. The June 2020 flood event created or augmented gravel/cobble bars in the river channel (see Figure 3 on page 8 of Riverine Habitat Evaluation; Interfluve 2020). However, these bars were longitudinally oriented with the river channel discharge; no aquatic organism migration blockages were created. As future discharge events of greater magnitude and duration scour and redistribute the bed load that shifted downstream during the October 2020 drawdown, the likelihood of this sediment burden forming blockages will further decrease.

The October 2020 drawdown provided conditions to increase physical habitat features that provide ecosystem benefits, such as channel spawning gravels, bars, islands, large wood features, and side channel activation. In addition to the deposition bars formed immediately downstream of Powell Falls Dam (Figure 4), the continuation of dam removal activities will transport additional sediment for the formation of approximately six depositional bars within the bankfull channel in the lower Kinnickinnic River annually (see Part 1). Reach 3 is a section of the river where the wide valley margins and increased number of tributaries may allow the reconnection of relic channels and meander scars to the existing channel (Ayers 2020). RFMU staff reported having to frequently remove large woody debris that was uncovered from the Lake Louise substrate during the October 2020 drawdown. This beneficial habitat building material will progressively move downstream and once fixed, will create hydraulic conditions that add complexity to the existing habitat composition. Newly created gravel bars that were stripped of fine sediment during the June 2020 flood event will benefit from the delivery of fine sediment to anchor the large woody debris so it is not continuously transported downstream during future increased discharge events. The heterogeneous mix of coarse and fine sediments will benefit organisms that require interstitial habitat complexity to complete their life cycle.

The risk and benefit of dam removal to macroinvertebrate taxon can be subtle and thus challenging to observe. Thompson et al. (2005) recorded a temporary change in macroinvertebrate densities arising from the downstream sediment transport following a dam removal. Chiu et al. (2013) stated that downstream sedimentation following dam removal reduces macroinvertebrate density although timescales appropriate to fully interpret the long-term consequences are important yet rarely observed. Stanley et al. (2002) noted that dam removal caused minor geomorphic and ecological changes in downstream reaches, while the rapid channel formation in the impoundment reservoir created suitable habitat for a more diverse macroinvertebrate community than what existed prior. Heterogeneous habitat composed of fine and coarse substrate, varying depths, and favorable water quality conditions that benefit other aquatic taxa also benefit macroinvertebrates. The re-establishment of the Kinnickinnic River channel in the bed of Lake Louise will create an increasingly complex habitat composition in this previous homogeneous substrate. Macroinvertebrate species diversity is likely to increase in the newly formed river channel upstream of Powell Dam after removal.

3.3 Ice Jams

Ice jams are unlikely to occur during or after removal of Powell Falls Dam. The water temperature of the mainstem Kinnickinnic River is influenced by groundwater, which supplies a constant input of above freezing temperatures during winter (Interfluve 2017). Dam removal will increase flow velocities, which limits ice formation. The combination of a constant groundwater supply and increased velocities following dam removal will limit ice formation in the Kinnickinnic River below Powell Falls Dam. It is possible that ice jams that commonly form in the St. Croix River may build upstream into the downstream reach that forms the confluence with the Kinnickinnic River (https://www.startribune.com/threat-of-minor-flooding-hangs-over-cities-on-st-croix/87538387/). Increased flow velocity after dam removal may alleviate some of the backwater effect from the St. Croix that may push ice into the lowest reach of the Kinnickinnic River.

3.4 Recreational Use

Sediment deposition at recreational use areas that include navigation channels is a risk from dam removal. The informal fishing area and boat launch downstream of Powell Falls Dam experienced alterations due to sediment deposition at this site (see Figure 4 and Photo 9 on page 19 of the Recreation Facilities Inventory; TRC 2020). The pool habitat in the vicinity of this site is currently considerably shallower than prior to the October 2020 drawdown. While the sediment deposition hasn't created a blockage to recreational navigation, the shallow conditions may require in-water portaging (i. e., stepping into the river channel and floating the vessel downstream). It is also possible that this impacted site is less favorable for recreational angling pursuits. This unfavorable condition at this recreational site is expected to change as future discharge events of differing magnitude and duration scour and redistribute the bed load that shifted downstream during the October 2020 drawdown.

4.0 CONCLUSIONS

The primary goal of most dam removal projects is to improve the ecology of the aquatic ecosystem of the developed water course. The ecological benefits of restoring connectivity to upstream reaches of the Kinnickinnic River is a desired outcome of the Powell Falls Dam removal. Understanding the short-term risks to the lower Kinnickinnic River assists in managing the entire dam removal project from start-to-finish by establishing criteria to avoid substantial negative impacts. Recognizing long-term benefits as the established goals of performing the Powell Falls Dam removal can assist in determining acceptable levels of risk. Table 1 provides a summary of that qualitatively assigns levels of ecological risk and benefit that reflect the results and discussion for all the identified impacts of removing the Powell Falls Dam. The most recognizable short-term risks are to trout habitat used by multiple life stages from sedimentation, reduction in substrate complexity in reaches immediately downstream of Powell Falls Dam, and adverse effects on recreational use of the Kinnickinnic River as a navigable corridor. However, the long-term risk for all the identified impacts is low. The long-term benefits are high for many of the impacts identified. The long-term benefits are considered low for freshwater mussels primarily because the Kinnickinnic River has not historically provided preferred habitat for this taxon. Given that long-term benefits are more numerous than short-term risks, the Powell Falls Dam removal is likely to be successful in achieving its restoration goal of the Kinnickinnic River.

Table 1. Ecological risk and benefit analysis of removing Powell Falls Dam.

Impact	Risk		Benefit	
	Short-term	*Long-term*	*Short-term*	*Long-term*
Water quality	M	L	L	H
Sedimentation				
Trout habitat	H	L	L	H
Freshwater mussels	L	L	L	L
Floodplain vegetation	M	L	L	H
Fish movement	L	L	L	H
Impoundment				
Riverine conditions	L	L	M	H
Instream Habitat				
Substrate complexity	H	L	M	M
Invertebrate taxa	M	L	M	M
Ice Jams	L	L	L	M
Recreation	H	L	L	H

Short-term = ≤1 year; Long-term = ≥ 1 year
L = low, M = medium, H = high

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