Upper Deschutes River Bank Stability Characterization

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Abstract

The Upper Deschutes River Bank Stability Characterization is designed to assess streambank erosion on the Upper Deschutes River along approximately 60 miles between Wickiup Reservoir and the City of Bend, Oregon. Many previous studies conducted by local, state and federal resource agencies have previously identified elevated levels of erosion and in-stream sedimentation and turbidity as a primary factor in water quality, riparian health and fish habitat concerns in the region. This characterization provides previously unavailable information about the extent of streambank erosion to help prioritize future efforts in streambank restoration, water quality restoration and fish habitat enhancement. Using the Bank Erosion Hazard Index (BEHI) methodology, bank height, bank angle, vegetation cover, root density, root depth, and bank materials was evaluated for a total of 130 reaches throughout the study area. Results indicated that 47 of the streambank reaches are classified as having high, very high, or extreme erodability; 45 are classified as moderate, 37 are classified as low and 6 are classified as very low. Maps showing the extent and distribution of the sites are included and strategies to address the erosion problems are discussed.

Introduction

The stream banks of the Upper Deschutes River downstream from Wickiup Reservoir are heavily eroded. While the geologic processes that define river channels in some areas might result in bedrock banks or channels lined with large boulders that are resistant to erosion, the Deschutes River channel between Wickiup Reservoir and Fall River contains loose sediments deposited from the combination of volcanic activity and alluvial processes. These sediments are relatively fine and provide little natural resistance to the erosive forces present. The erosion of bank materials has been linked to the combination of lower than natural winter flows and higher than natural summer flows. Bank erosion and subsequent turbidity is exacerbated by the combination of regulated winter flows below Wickiup Reservoir that drop substantially lower than the levels of natural flows that occurred prior to the management of water out of Wickiup Reservoir and summer flows that are significantly higher than natural flows (see complete discussion under 'Flow Regime').

The Upper Deschutes Watershed Council (UDWC) is collaborating with a broad range of local partners to complete a watershed assessment of the entire Upper Deschutes subbasin. Local agencies and partners including the Deschutes Resources Conservancy (DRC), Oregon Department of Fish and Wildlife (ODFW), Oregon Water Resources Department (OWRD), Oregon Department of Environmental Quality (DEQ), and the United States Forest Service (USFS) have long recognized and identified the need for a comprehensive assessment focused on the stream bank conditions above Bend. In addition to the larger community need for a comprehensive characterization of the current and potential rates of erosion on the Upper Deschutes, UDWC's subbasin assessment identified a need to rank eroding stream banks and prioritize potential restoration project areas. There have been no previous primary data collection projects prioritizing restoration opportunities along this reach of the Deschutes River.

The objectives of the stream bank stability characterization are to:

1) Inventory bank conditions between Wickiup Reservoir and the City of Bend.
2) Identify sediment source locations.
3) Rank relative bank erosion hazard and erodability among stream banks.
4) Assess priorities for bank restoration projects.
5) Create a characterization map depicting the erosion conditions between Wickiup and the City of Bend.
6) Supply local resource managers with comprehensive stream bank erosion data for restoration project prioritization and implementation.

Study Area

The study area includes approximately 60 miles of the Deschutes River corridor downstream from Wickiup Reservoir (near river mile 226) to the upstream edge of the City of Bend (near river mile 171). This portion of the Deschutes River is within the area of interest for the Upper Deschutes Watershed Council and it includes a majority of the upstream sections of the Upper Deschutes Subbasin Assessment. Due to the mix of private, state, and federally owned lands, the river corridor along the Upper Deschutes is managed for a variety of interests and uses.

Wickiup Dam was constructed by the Bureau of Reclamation and was completed in 1949. The dam is an earthfill structure that is used to store water during the winter for irrigation uses in the summer. The water releases from Wickiup are currently managed by the Oregon Water Resources Department (OWRD). The reservoir water is not part of the municipal water supply and the dam serves no hydropower functions. The reservoir's sole purpose is to store water for irrigation use in the summer. The current annual flow regime released out of Wickiup Reservoir is defined by the quantity of water rights held by irrigation districts in the area. In order to fulfill the requirements of irrigation districts' water rights, Wickiup Reservoir must be filled to a certain level every winter. Consequently, winter flows in the Deschutes are suppressed until sufficient water is stored for the upcoming irrigation season. As a result of winter water storage, the current levels of water flow below Wickiup have been substantially altered from the natural stable annual hydrograph of the river. While the natural flows of the Upper Deschutes River were historically stable year round, the current regulated hydrograph can swing between 20 cubic feet per second (cfs) to over 2,100 cfs (USDA 1996). The modifications and extreme fluctuations of flow have contributed to conditions that have destabilized the stream banks, increased stream bank erosion, and reduced water clarity, thereby decreasing water quality for fisheries and humans (USDA 1996).

The riparian zones between Wickiup Reservoir and the City of Bend consist of an overstory of stands of lodgepole pine and ponderosa pine, a shrub understory of spirea, snowberry, alder, or willow, and a herbaceous layer of forbs and sedges. There are several large willow/sedge meadows scattered along the area. In addition to meadow, the lodgepole (wet) plant association group is also included in the riparian classification. Lodgepole (wet) plant association is typically associated with high water tables or partially or frequently inundated soils. Approximately 1,850 acres of meadow and 5,070 acres of lodgepole (wet) habitat occur along the Deschutes River above Bend. In general, the root systems of riparian vegetation plays a critical role in stabilizing the erosive potential of streambanks. Flow regulation of the water from Wickiup Reservoir has resulted in the reduction of riparian vegetation at the outside bends of the river and an increase in the width of the point bars and associated vegetation on the inside of the bends (USDA 1996).

Flow Regime

Since Wickiup Reservoir's construction in the 1949, water storage and release schedules have significantly modified the flows in the Deschutes River, subsequently affecting the channel morphology including erosion and sedimentation. While the natural flows historically remained very stable year-round, the regulated flows below Wickiup rise and plunge dramatically through the course of a given year (Figure 1). During the winter storage season the minimum regulated river flow below Wickiup Reservoir is 20 cfs, which represents and 95% reduction the natural unregulated flows (minimum natural unregulated flows were approximately 419 cfs prior to the construction of the reservoir) and during the summer irrigation season, the maximum daily river flows have been recorded at 2,280 cfs, which is approximately 162% of the natural unregulated flows (maximum natural unregulated flows in the summer were approximately 1400 prior to the construction of the reservoir) (Table 1) (USDA 1996).

Tributaries and springs augment the flow of the main stem Deschutes between Fall River and the north boundary of Sunriver (USDA 1996). The perennial streams that feed the Upper Deschutes are Fall River, the Little Deschutes River, and the Spring River complex which includes significant accretion from springs and seeps in addition to Spring River itself. These tributaries slightly moderate the downstream effects of the highs and lows of regulated flows Table 2 presents the location and mean flows of Upper Deschutes tributaries.

Figure 1: Median Natural and Regulated Flows Below Wickiup Reservoir (OWRD 2002)

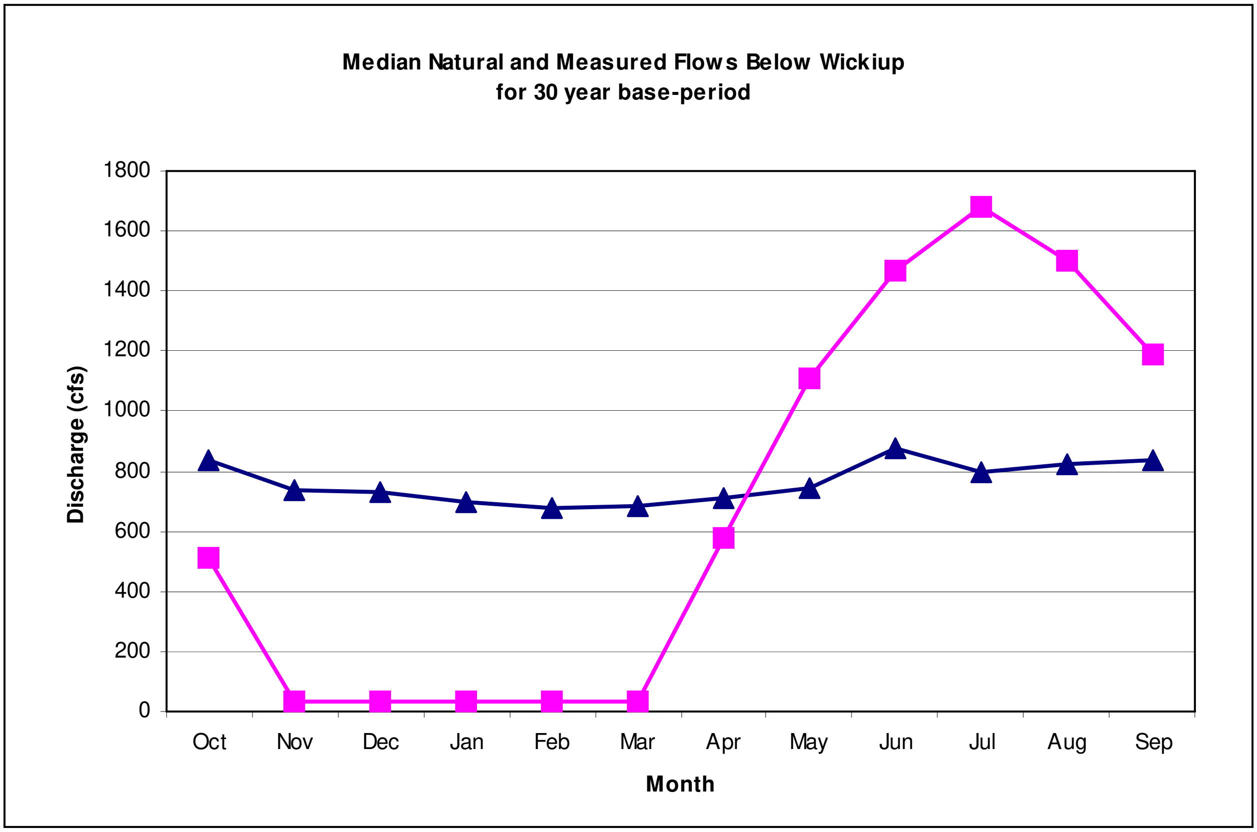


Table 1: Maximum and Minimum Mean Daily Flows Below Wickiup Reservoir (USDA 1996)		
	Minimum Daily Flow (winter)	Maximum Daily Flow (summer)
Regulated Flow (1943-1987)	20 cfs	2280 cfs
Natural (unregulated) flow (1925-1941)	419 cfs	1400 cfs

Comparison between regulated and unregulated flows	95% decrease in flow under regulated conditions	162% increase in flow under regulated conditions

Table 2: Perennial Tributaries to the Upper Deschutes (USFS 1994)			
		Mean Annual Flow	Mean Annual Flow
Tributary	River Mile	Low	High
Fall River	205	140	160
Little Deschutes River	193	160	350
Spring River complex	190	220	220

The management of flows has created the equivalent of a 25-year flood event sustained for the six-month irrigation season since the construction of Wickiup in 1949 (USDA 1996). Artificial flood stages from irrigation releases have accelerated lateral erosion on the outside banks of bends in the river and increased deposition on the inside of river bends. Evidence of these stream bank changes was gathered by comparing contemporary and historic photographs. The results from the comparison include a 20% increase in the width of the channel between 1943 and 1991 and an increase in the number of meander cutoffs from 2 to 12 from 1943 to 1991 (USDA 1996). The type of bank material present plays a key role in the greater or lesser impact that the hydraulic force of the water exerts on a stream bank. While in some sections of the river such as the Benham Falls area, geologic processes have constructed hard bedrock channels that resist erosion, the Deschutes River channel between Wickiup Reservoir and Fall River is composed primarily of highly erodable fine sediments deposited from successive volcanic activity. The high springtime flows released from Wickiup erode the fine sediments that are not held in place by either the roots of riparian vegetation or large woody material (USDA 1996).

Turbidity and Sediment

In areas between Wickiup Reservoir and the City of Bend (RM 168.2 to 222.2), the Deschutes River is on the Department of Environmental Quality (DEQ) Draft 2002 303(d) list for both turbidity and sediment. DEQ's 2001 Draft Upper and Little Deschutes

TMDL Water Quality Monitoring Study identified streambank erosion as the primary cause for increased sedimentation along this reach. Turbidity, one parameter used to measure water quality, can increase with increased erosion and sediment release (Harden-Davis 1991). Increases in levels of turbidity and sediment in the Upper Deschutes have been linked to the regulation and release of flows from upstream reservoirs (USDA 1996). From spring until midsummer in the upper reaches of the Deschutes, water quality is very good as it first leaves Wickiup Reservoir. However, the quality of the water rapidly deteriorates in the first few miles below the dam. The turbidity of the river below the dam increases as much as 30 times the levels found in Wickiup Reservoir when irrigation water is first released from storage in early spring (USDA 1996). Turbidity levels peak once flows reach 800 cfs and at that point can range between two to five times background levels until the end of July (USDA 1996). In this case, the background levels are the quantities of sediment and turbidity present in the water stored in Wickiup Reservoir.

The elevated turbidity levels that follow the initial spring irrigation release are largely a result of the dramatic fluctuations in flow levels on the Upper Deschutes. During the winter storage season little water is released from upstream reservoirs, leaving much of the channel exposed. Weathering and frost action loosens the exposed channel and its bank material which is later eroded by the increased flows in the spring. After the initial spring water releases, turbidity levels eventually decrease gradually through the summer. As a result, neither the turbidity nor the sediment levels of 54 miles of the Upper Deschutes meet the state water quality standard, which defines a water quality violation for turbidity as an increase in excess of 10 % over background (USDA 1996).

The 1994 Upper Deschutes River Instream Flow Assessment completed by the Deschutes National Forest documented the following features and erosion conditions that are the product of regulated flow regimes in the Upper Deschutes:

- Nearly 15% of the channel banks are bare and badly eroding.
- A comparison of 1943 and 1991 photographs reveals that the Deschutes River between Wickiup Reservoir and Benham Falls widened an average of 20% during this 48-year period.
- In 1943, two cutoff meanders existed. In 1991, twelve existed.
- From Wickiup Reservoir to Fall River there is a "drawdown" area in the river channel that lacks vegetation. This area is between the levels of about 30 and 1000 cfs flows.
- Turbidity increases downstream from Wickiup to peak levels that exceed 10 ntu's when irrigation water is initially released then reduces to near 2.5 ntu's even though flows continue to increase and level off at much higher levels than initial releases.

According to the Instream Flow Assessment, the previously listed erosion conditions are linked to the following characteristics of the Upper Deschutes:

- The ash and streamborne sediments of the river channel are the fine-grained materials that have low bulk density, lack cohesion, and are highly erodable.
- The gradient of the river between Wickiup and Benham Falls is low--a drop of 132 feet in 44 river miles.
- In the early years of this century much of the large woody material between Wickiup and Bend was removed from the channel to facilitate the transportation of logs down the river from Wickiup to ½ mile above Benham Falls.
- There is a large amount of private and a lesser amount of public development adjacent to the river.

Methods

UDWC project manager, Kolleen Yake, collaborated with representatives from Deschutes National Forest, Bureau of Land Management, Oregon Department of Fish and Wildlife, and the Oregon Department of Environmental Quality to determine the scope, location, and methodology for the project. The project manager then assembled an assessment team including OSU-Cascades Riparian Studies Professor, Bob Ehrhart, and two interns, Alasia Heinritz and Matt Maloney. The assessment team surveyed and characterized approximately 60 river miles between Wickiup Reservoir and the City of Bend.

In order to identify and rank relative rates of erosion, the assessment utilized the Bank Erosion Hazard Index (BEHI) methodology created by David Rosgen (Wildland Hydrology) for assessing relative rates of erosion. BEHI is a quantitative prediction of stream bank erosion rate uses an estimation, process-integration approach. The prediction model applies a stream bank erodability index that combines a variety of stream bank characteristics and integrates their cumulative impact. Stream bank characteristics involving bank heights, bank angles, bank materials, presence of layers, rooting depth, rooting density, and percent of bank protection are used to develop the stream bank erodability index (Rosgen 2001).

The BEHI stream bank erosion model attempts to predict the erodability of a bank by combining and integrating all of the different factors affecting the stream bank erosion processes. Rosgen (2001) defines the BEHI methodology as "an expert system was used to transfer field observations of potential erodability to relative rankings. Field experience from direct observations of stream bank instability was used to document stream bank conditions associated with active erosion and various modes of failure. The field measured variables assembled as predictors of erodability (BEHI) were converted to a risk rating of 1-10 (10 being the highest level of risk)." The risk ratings from 1 to 10 indicate corresponding adjective values of risk of very low, low, moderate, high, very high, and extreme potential erodability. The total points are obtained by converting the measured bank variables of the stream bank characteristics to risk rating values. The BEHI characteristics, values, and indices are shown in Table 3.

The field team conducted the primary data collection portion of the characterization between August 12 and August 23, 2002 and on February 28, 2003. In order to assess all

60 miles of stream banks in the area, 80% of the assessment was completed from a raft and 20% of the stream banks were assessed from hiking trails paralleling the river. 130 total sites were assessed.

Table 3. Streambank characteristics used in the Bank Erosion Hazard Index (BEHI) (Rosgen 2001)

Adjective Hazard or risk rating categories		Root Depth/ Bank Height	% Root Density	Bank Angle (degrees)	% Surface Protection	Totals
VERY LOW	Value	1.0-.9	100-80	0-20	100-80	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	4-7.6
LOW	Value	.89-.5	79-55	21-60	79-55	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	8-15.6
MODERATE	Value	.49-.3	54-30	61-80	54-30	
	Index	4.0-5.9	4.0-4.9	4.0-4.9	4.0-4.9	16-19.6
HIGH	Value	.29-.15	29-15	81-90	29-15	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	24-31.6
VERY HIGH	Value	.14-.05	14-5.0	91-119	14-10	
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	32-36
EXTREME	Value	<.05	<5	<119	<10	
	Index	10	10	10	10	37-40

GPS readings were taken at the beginning and end points of each stream reach. In order to capture current erosion conditions, two downstream photos and two upstream photos were taken at the beginning and end points of each reach. The bank materials, vegetation type, and percentage of vegetative cover were visually estimated by the UDWC assessment team. Professor Ehrhart analyzed the vegetation type to estimate root depth and root density. A range finder was used to calculate bank height and a clinometer was used to measure bank angle. Narrative notations documented visually apparent land use impacts, land ownership, roads, bridges, restoration project sites, instream structures, recreation areas, trails, tributaries, seeps, and noxious weeds.

Located at the end of the report, table 3 presents the BEHI index values and calculations for all of the stream bank reaches characterized on the Upper Deschutes. Each stream bank condition was quantified with a corresponding index value based on the BEHI's geomorphological assumptions. The index values were summed and multiplied to compute a score for each stream reach. Adjustments based on bank materials were made to the score to then reach a total score that corresponded with a relative erosion/ erodability rating of extreme, very high, high, moderate, low, or very low. The stream bank reaches are ranked in descending order from extreme down to very low.

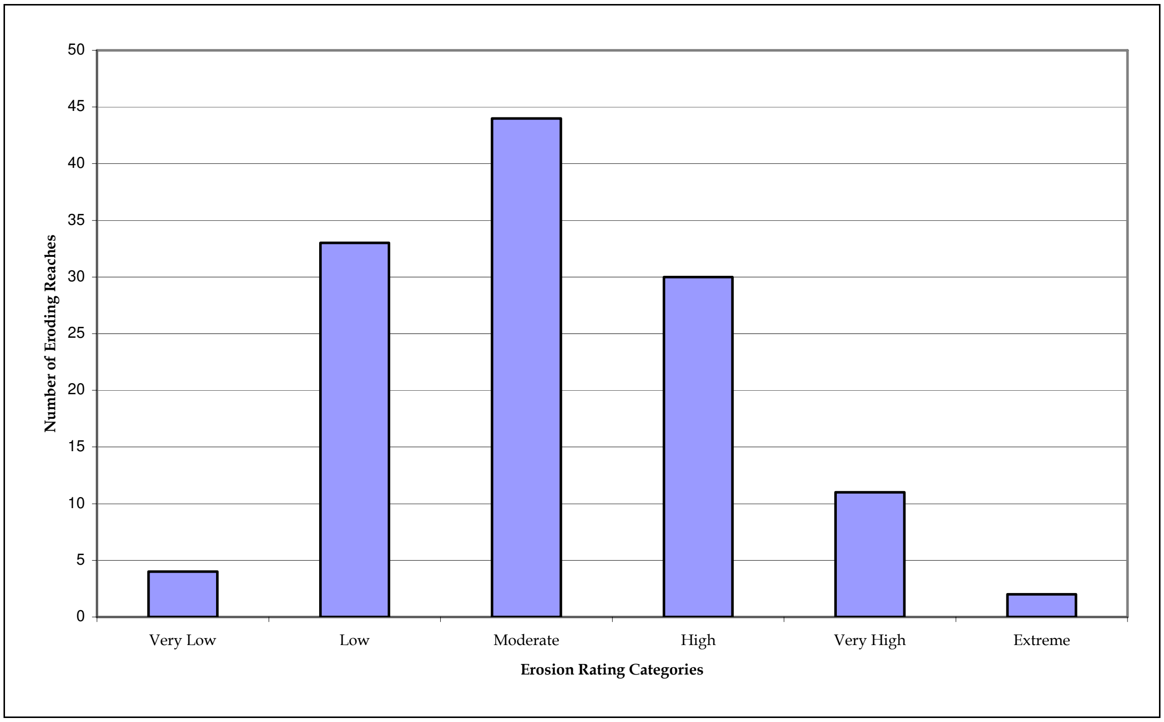
Several modifications of the BEHI method were used in order to adapt the protocol to the specific site conditions. The BEHI methodology also measures bankfull height and uses the ratio of bank height/ bankfull height as an erodability index value. Bankfull levels play a critical role in assessing the erosion potential of many rivers; however, the regulated flow regime of the Upper Deschutes creates predictable annual flows that never exceed certain levels. The Deschutes River does not flood the way that free-flowing rivers do. The bankfull level of the Upper Deschutes is annual and predictable as it is released and regulated out of Wickiup Reservoir. Therefore, the Upper Deschutes River Bank Stability Characterization project did not integrate bankfull measurements into the erosion and erodability assessment.

When faced with time and budget constraints, the UDWC chose not to characterize the entirety of the stream banks between Wickiup and Bend. Stream reaches where banks on both sides were exhibiting no apparent erosion were not characterized. Instead, the characterization includes all of the stream banks that appeared to have had previously eroded or were currently eroding. For every eroding stream bank that was assessed and characterized, so too were the opposite banks. The opposing banks often had no active erosion occurring, but they provide representation for the different types of systemic responses downstream from the dam.

<u>Results</u>

The data for the BEHI values of each stream reach assessed are presented at the end of this document in Table 4. Next to each stream bank condition value is the corresponding index value from the BEHI ranking system presented in Table 3. Of the 130 reaches assessed, 2 were rated as extreme, 13 were rated as very high, 32 were rated high, 45 received moderate ratings, 37 were rated low, and 6 were rated very low. Figure 2 presents a graphical comparison of the eroded stream reaches. The digital photos taken of each stream reach are located on the compact disc included with this report. The physical locations for each stream reach are depicted in the Upper Deschutes River Bank Stability Characterization Map book.

Figure 2: Streambank Erosion Ratings for the Upper Deschutes River



Discussion

The results indicate that 47 reaches on the Upper Deschutes are currently eroding at high, very high, or extreme rates. Analysis of the methodology for assessing the bank heights of stream sections has revealed that there may in fact be a greater number of high, very high, and extreme banks than the study indicates due to the fact that bank height and surface protection were both measured to the very top of the bank instead of to the top of the eroding portion of the bank. Therefore, it might appear that there is a greater percentage of surface cover protecting the bank from eroding than currently exists.

As mentioned in the introduction, some sections of the Upper Deschutes are naturally resistant to erosion due to the geology of the area. Taken from the overlook at Benham Falls, photograph 1 displays the bedrock that is remnant from the Lava Butte Flow from the eruption of Newberry Volcano. The lava rock remains and lines the channel at Benham Falls. Although the gradient and velocity are high in this reach, the erosion potential is very low.

Photograph 1: Reach 104, Benham Falls

Distinctly different from the banks at Benham Falls, the stream reach in photograph 2 consists of primarily silt and clay fine sediments. This reach is located at river mile 209 near La Pine State Park. The bank received a BEHI rating of moderate due to the combination of loose bank materials, moderate vegetation, and a 45 degree bank angle. The sedges and other herbaceous material at the water's edge combined with some surface protection from the pine roots to prevent a higher erosion rating.

Photograph 2: Reach 51, La Pine State Park

Taken just below river mile 213, photograph 3 presents a stream bank that received a BEHI rating of extreme. On this bank there is vegetation at the top portions of the bank but it is serving no protective service to the erosion or erodability of the bank at the water's edge.

Photograph 3: Reach 30, Tetherow Log Jam

The land use notations documented by the assessment team included information regarding past stream bank restoration sites. The assessment team observed a variety of project sites that consisted of unsuccessful willow plantings and large woody material that appeared to be exacerbating erosion.

The assessment team documented the use of rip-rap or revetments as attempted methods to cease erosion in private riverfront property locations. Occasionally, the rip-rap appeared to exacerbate erosion downstream from the site; however, the bulk of the heavily eroded areas occurred on public forest service land and not on privately owned lands.

The relatively small number of banks receiving a very low BEHI rating is due to the fact that a large percentage of the banks that appeared to have no erosion problem were not included in the assessment. Reach 62 shown in photograph 4 is a bank that was assessed in order provide a representative sample of banks that, due to high levels of surface protection and low height, have very low or no erodability potential. Photograph 4 is representative of the majority of inside meander bends on the Upper Deschutes. As in the photo, the inside of meanders were typically deposition areas that had well established sedge meadow and willow vegetation.

Photograph 4: Reach 62, Fall River Area

Photograph 5 shows a substantial patch of knapweed located right on the river trail. This patch of knapweed is between the trail and the water's edge. As knapweed sends down a single deep taproot, the weed can exacerbate erosion but edging out other native riparian vegetation that would more effectively hold soil in place.

Photograph 5: Reach 108, ¼ mile downstream from Slough campground

There were a relatively low number of visible noxious weed infestations along the river corridor. The notable exceptions included mullein and bull thistle on a large patch of private property just downstream from Foster Bridge, small periodic patches of bull thistle in the Sunriver area, and knapweed in a variety of small patches along the west river trail between Dillon Falls and Bend's urban growth boundary. The trail receives high use from hikers, runners, and cyclists and the parking lots located adjacent to the trail are a prime avenue for noxious weeds to be transported from infected outside areas. In the Upper Deschutes area infestations of knapweed and other noxious weeds are most often found along roads or other locations where humans import the seeds (Grenier, 2002).

Photograph 6 was taken at Slough campground near river mile 180. There is an overnight campground, a dirt road, and a boat launch located here and the river trail runs from Bend up through the campground. Although the campground receives high levels of use, the erosion is low. The low erosion is probably due to low bank heights and lower water velocity.

Photograph 6: Reach 107, Slough

There are many areas along the Upper Deschutes River that see high levels of human use. The recreation sites, boat launches, dispersed camping, campgrounds, and day use areas along the river all exhibit trampled and degraded riparian vegetation and eroding stream banks. However, the eroding banks are located in areas that are primarily receiving high-density, concentrated impact. The banks are primarily very low height and are, consequently, losing very little sediment. Generally, the areas of high erosion and erodability were not located on or adjacent to human use areas. Most likely, this is due to the fact that recreation areas are located at sites that are close to the river with very low stream banks. Areas such as these tend to be on inside meander bends where there are sedge meadows and low banks.

Recommendations

UDWC recommends that the following steps be taken in response to the current levels of erosion in the Upper Deschutes. UDWC recommends that:

1) Stream channel cross sections of each extreme, very high, and high reaches are completed and overlain upon the data from the Bank Stability Characterization. The Deschutes National Forest has already completed stream channel cross sections for a small number of sections on the Upper Deschutes; these comprehensive cross sections provide valuable information regarding the widening of the stream channel and the corresponding loss of sediment quantities. When combined with the stream bank characterization data, the cross sections would reveal which areas are simply shifting and which areas are in fact widening.

2) Additional field work and research be directed toward using the bank stability characterization data to complete further calculations and analyses of sediment sources and quantity of sediment eroding from each bank section.

3) The Upper Deschutes River Bank Stability data and characterization map be distributed and used among resource managers as an informative tool for choosing and prioritizing restoration project sites.

4) Resource managers considering stream bank restoration projects communicate and collaborate with other interested groups and agencies doing restoration work in the watershed.

5) Restoration projects are prioritized based on the impact and benefit to the system as a whole.

6) Erosion levels and erodability rankings are taken into consideration when prioritizing projects.

7) Stream bank stabilization and restoration projects are consistently and accurately monitored to determine project effectiveness and downstream impact.

8) Additional examination and research be directed toward stream bank stabilization and restoration methods appropriate and effective within the unique modified flow regime of the Upper Deschutes.

9) A pilot project applying methodology specific to the Upper Deschutes flow regime will be researched, implemented, and monitored for effectiveness and success. As there are currently very few, if any, models for stabilization and restoration projects in systems with channel types, bank materials, and flow regimes such as in the Upper Deschutes, it should be a priority for resource managers in the area to pioneer a pilot project that accurately represents the unique characteristics at work. The pilot project can stand as a model for future stabilization and restoration projects on the Upper Deschutes.

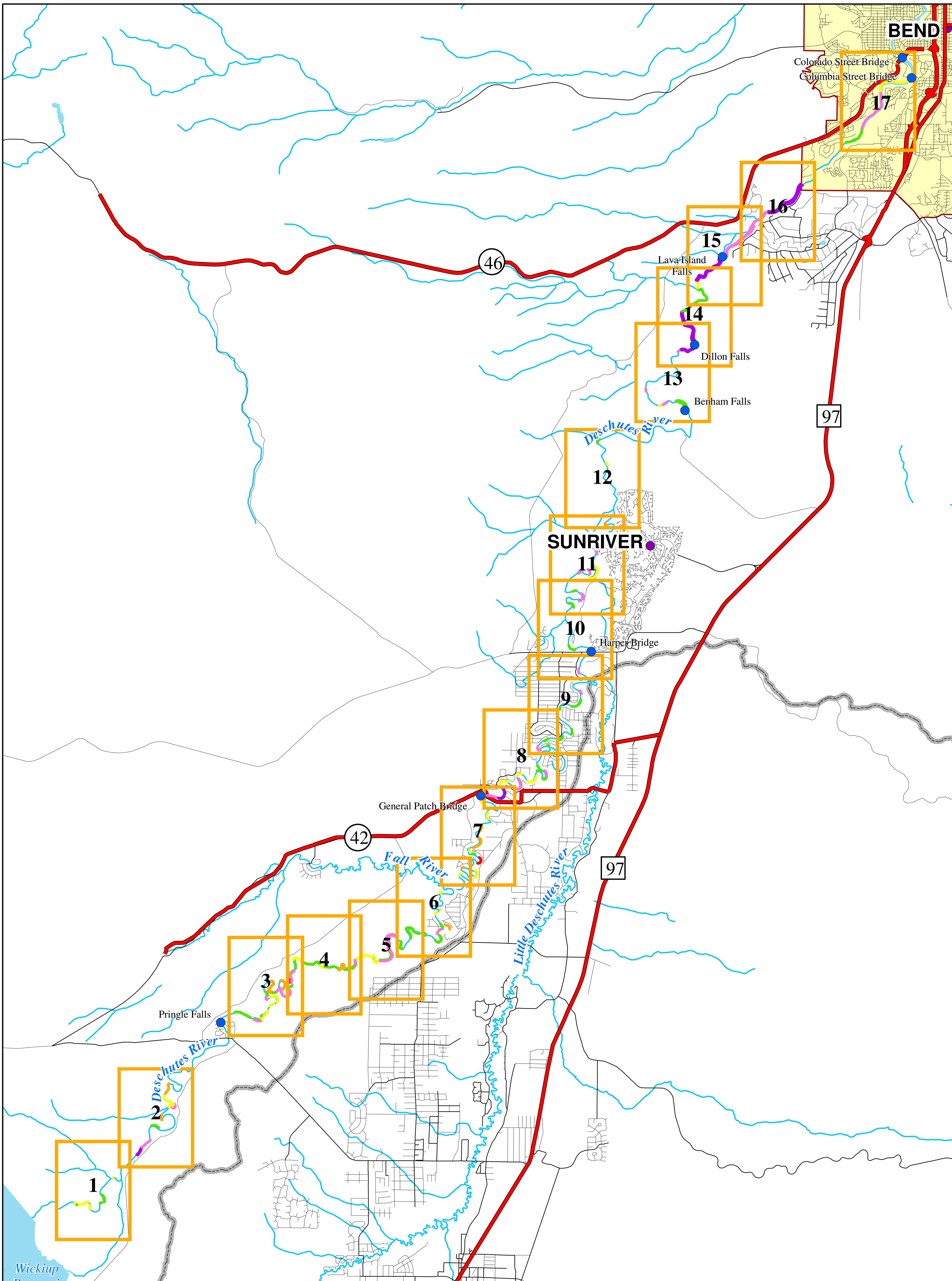
Table 4: Stream Bank Stability Index Values for the Upper Deschutes River From Tenino to Columbia Street Bridge in Bend, Oregon. August 12-23, 2002 and February 28, 2003

Reach	Name	Bank Side	Angle (degrees)	Angle Index	Surface Protection (%)	Surface Protection Index	Height (BH) (ft)	Root Depth (RD) (ft)	RD/BH Ratio	RD/BH Index	Root Density (%)	Root Density Index	Sum of Indices	Adjust .	Total Score	Rating
65	Fall River Area	Right	50	3.0	10	9.0	25	2	0.08	7.0	2	10.0	29.0	10	9.75	extreme
30	Log Jam	Left	90	8.0	0	10.0	26	0	0.00	10.0	0	10.0	38.0	0	9.50	extreme
38	Tetherow	Right	60	4.0	5	10.0	33.6	0	0.00	10.0	1	10.0	34.0	2	9.00	very high
12C	Wyeth	left	80	6.0	0	10.0	25	0	0.00	10.0	0	10.0	36.0	0	9.00	very high
31	Tetherow	Right	80	6.0	5	10.0	4	5	1.25	10.0	5	9.0	35.0	0	8.75	very high
57	La Pine State Park	Right	90	8.0	5	10.0	5	5	1.00	1.0	10	8.5	27.5	7	8.63	very high
11	Bull Bend	left	90	9.0	5	10.0	45	10	0.22	7.0	10	8.0	34.0	0	8.50	very high
68	Fall River Area	Right	45	3.0	30	6.0	29	3	0.10	7.0	15	8.0	24.0	10	8.50	very high
69	Fall River Area	Right	45	3.0	15	8.0	12	3	0.25	7.0	15	8.0	26.0	8	8.50	very high
101	Sun River	Left	90	8.0	15	8.0	4	1	0.25	7.0	10	8.5	31.5	2	8.38	very high
24	Tetherow Burn	Right	85	7.0	15	8.0	13	2	0.15	8.0	10	8.5	31.5	1	8.13	very high
23	Tetherow Burn	Left	50	3.0	10	9.0	14.22	1	0.07	10.0	15	8.0	30.0	2	8.00	very high
27	Tetherow Burn	Left	80	6.0	10	9.0	48	3	0.06	8.5	10	8.5	32.0	0	8.00	very high
39	Tetherow	Left	55	3.0	5	10.0	35	3	0.09	7.0	5	10.0	30.0	2	8.00	very high
63	Fall River Area	Left	45	3.0	20	7.0	6	3	0.50	4.0	15	8.0	22.0	10	8.00	very high
43	La Pine	Left	50	3.0	10	9.0	21	3	0.14	8.5	5	9.0	29.5	2	7.88	High
12B	Wyeth	left	80	6.0	10	9.0	45	10	0.22	7.0	10	9.0	31.0	0	7.75	high
44	La Pine	Right	55	3.0	10	9.0	24	3	0.13	8.5	10	8.5	29.0	2	7.75	High
111	Big Eddy	Left	90	8.0	90	3.0	15	3	0.20	7.0	45	3.0	21.0	10	7.75	High
1	Tenino	Left	50	3.0	5	10.0	40.75	8	0.20	7.0	2	10.0	30.0	0	7.50	High
60	Foster Bridge	right	45	3.0	10	9.0	8	2	0.25	7.0	5	9.0	28.0	2	7.50	High
62	Fall River Area	Left	90	8.0	50	3.0	7	5	0.71	3.0	15	8.0	22.0	8	7.50	High
42	La Pine	right	45	3.0	10	9.0	26	5	0.19	7.0	10	8.5	27.5	2	7.38	High
59	Foster Bridge	Left	45	3.0	10	9.0	15	3	0.20	7.0	10	8.5	27.5	2	7.38	High
70	Fall River Area	right	45	3.0	15	8.0	5	2	0.40	5.0	10	8.5	24.5	5	7.38	High
34	Tetherow	Left	50	3.0	10	9.0	92	10	0.11	8.5	10	8.5	29.0	0	7.25	High
64	Fall River Area	right	50	3.0	80	2.0	22	10	0.45	7.0	20	7.0	19.0	10	7.25	High
67	Fall River Area	right	50	3.0	40	5.0	20	8	0.40	5.0	30	6.0	19.0	10	7.25	High
76	Big River	Left	90	8.0	20	7.0	12	10	0.83	3.0	10	8.5	26.5	2	7.13	High
3	Tenino	Left	60	4.0	30	7.0	38	5	0.13	8.5	15	8.5	28.0	0	7.00	High
20	Tetherow Burn	right	70	5.0	20	7.0	61	10	0.16	7.0	20	7.0	26.0	2	7.00	High
61	Foster Bridge	Left	90	8.0	80	2.0	3	1	0.33	6.0	20	7.0	23.0	5	7.00	High
36	Tetherow	right	50	3.0	5	10.0	35	10	0.29	7.0	20	7.0	27.0	0	6.75	High

77	Big River	right	60	4.0	40	5.0	12	3	0.25	7.0	5	9.0	25.0	2	6.75	High
97	Sun River Marina	right	90	8.0	20	7.0	3	2	0.67	3.0	20	7.0	25.0	2	6.75	High
99	Sun River Bridge	Left	90	8.0	30	6.0	4	2	0.50	4.0	20	7.0	25.0	2	6.75	High
106	Benham Falls	Left	90	8.0	20	7.0	32	10	0.31	6.0	30	6.0	27.0	0	6.75	High
71	Fall River	Left	45	3.0	30	6.0	8	5	0.63	3.0	20	7.0	19.0	7	6.50	high
4	Tenino	right	60	5.0	50	5.0	45	5	0.11	8.5	25	7.0	25.5	0	6.38	high
7	Dillman	Left	50	3.0	30	6.0	35	5	0.14	8.5	15	8.0	25.5	0	6.38	high
18	Tetherow Burn	right	45	3.0	40	5.0	21	3	0.14	8.5	20	7.0	23.5	2	6.38	high
74	Big River	Left	50	3.0	15	8.0	10	5	0.50	4.0	10	8.5	23.5	2	6.38	high
19	Tetherow Burn	Left	47	3.0	30	6.0	9	3	0.33	5.0	10	8.5	22.5	2	6.13	high
12	Bull Bend	left	60	5.0	5	10.0	10	10	1.00	1.0	10	8.0	24.0	0	6.00	high
16	Pringle Falls	right	52	3.0	50	5.0	62	10	0.16	7.0	20	7.0	22.0	2	6.00	high
102	Sun River	right	30	3.0	25	7.0	10	2	0.20	7.0	20	7.0	24.0	0	6.00	high
121	Columbia Bridge	Left	45	3.0	50	5.0	3	1	0.33	6.0	50	5.0	19.0	5	6.00	high
29	Tetherow Log Jam	Left	50	3.0	20	7.0	6	3	0.50	4.0	10	8.5	22.5	1	5.88	moderate
92	Sun River	right	75	5.0	40	5.0	4	3	0.75	3.0	10	8.5	21.5	2	5.88	moderate
10	Dillman	left	55	5.0	20	7.0	30	10	0.33	6.0	40	5.0	23.0	0	5.75	moderate
6	Tenino	right	50	3.0	50	5.0	20	3	0.15	8.0	25	7.0	23.0	0	5.75	moderate
33	Tetherow	right	50	3.0	60	3.0	25	10	0.40	7.0	50	5.0	18.0	5	5.75	moderate
55	La Pine State Park	right	60	4.0	40	5.0	47	10	0.21	7.0	20	7.0	23.0	0	5.75	moderate
54	La Pine State Park	Left	50	3.0	15	8.0	8	5	0.63	3.0	10	8.5	22.5	0	5.63	moderate
87	Water Wonderland	right	40	3.0	20	7.0	4	5	1.25	1.0	10	8.5	19.5	3	5.63	moderate
104	Benham Falls	right	90	8.0	100	1.0	80	5	0.06	8.5	50	5.0	22.5	0	5.63	moderate
104	Benham Falls	Left	90	8.0	100	1.0	60	5	0.08	8.5	50	5.0	22.5	0	5.63	moderate
17	Pringle Falls	Left	75	5.0	60	3.0	10	2	0.20	7.0	35	5.0	20.0	2	5.50	moderate
22	Tetherow Burn	right	80	6.0	60	3.0	8.7	3	0.34	5.0	30	6.0	20.0	2	5.50	moderate
41	Tetherow	right	90	8.0	80	2.0	4	2	0.50	4.0	70	3.0	17.0	5	5.50	moderate
85	Big River	right	60	4.0	70	3.0	30	5	0.17	7.0	30	6.0	20.0	2	5.50	moderate
91	Harper Bridge	Left	45	3.0	30	6.0	15	3	0.20	5.0	20	6.0	20.0	2	5.50	moderate
35	Tetherow	Left	50	3.0	20	7.0	20	10	0.50	4.0	20	7.0	21.0	0	5.25	moderate
52	La Pine State Park	Left	75	5.0	40	5.0	44	10	0.23	5.0	30	6.0	21.0	0	5.25	moderate
53	La Pine State Park	right	40	3.0	15	8.0	7	10	1.43	1.0	10	8.5	20.5	0	5.13	moderate
2	Tenino	right	50	3.0	50	5.0	21.56	5	0.23	5.0	25	7.0	20.0	0	5.00	moderate
50	La Pine Bridge	right	65	5.0	80	2.0	62	10	0.16	7.0	30	6.0	20.0	0	5.00	moderate
66	Fall River Area	right	45	3.0	40	5.0	15	5	0.33	6.0	30	6.0	20.0	0	5.00	moderate
78	Big River	Left	40	3.0	40	5.0	8	5	0.63	3.0	20	7.0	18.0	2	5.00	moderate
5	Tenino	Left	58	5.0	25	7.0	16.6	7	0.42	5.0	80	2.0	19.0	0	4.75	moderate
13	Pringle Falls	Left	50	3.0	80	2.0	35	7	0.20	7.0	40	5.0	17.0	2	4.75	moderate
37	Tetherow	Left	40	3.0	20	7.0	18	10	0.56	3.0	15	6.0	19.0	0	4.75	moderate
58	Foster Bridge	Left	90	8.0	80	2.0	3	3	1.00	1.0	30	6.0	17.0	2	4.75	moderate
79	Big River	right	60	4.0	60	3.0	6	3	0.50	4.0	30	6.0	17.0	2	4.75	moderate
82	Big River	right	45	3.0	50	5.0	5	3	0.60	3.0	30	6.0	17.0	2	4.75	moderate
94	Sun River	right	35	2.5	40	5.0	4	3	0.75	3.0	30	6.0	16.5	2	4.63	moderate
14	Pringle Falls	Left	40	3.0	70	3.0	40	8	0.20	7.0	50	3.0	16.0	2	4.50	moderate

15	Pringle Falls	Left	30	3.0	60	3.0	17	10	0.59	3.0	20	7.0	16.0	2	4.50	moderate
40	Tetherow	right	75	5.0	70	3.0	32	10	0.31	5.0	60	3.0	16.0	2	4.50	moderate
40	Tetherow	Left	45	3.0	20	7.0	10	10	1.00	1.0	20	7.0	18.0	0	4.50	moderate
25	Tetherow Burn	right	45	3.0	90	3.0	57	10	0.18	7.0	60	3.0	16.0	1	4.25	moderate
81	Big River	Left	50	3.0	30	6.0	8	5	0.63	3.0	70	3.0	15.0	2	4.25	moderate
84	Big River	right	45	3.0	50	5.0	4	10	2.50	1.0	30	6.0	15.0	2	4.25	moderate
86	Water Wonderland	right	35	3.0	60	3.0	30	10	0.33	6.0	60	3.0	15.0	2	4.25	moderate
88	Water Wonderland	right	60	4.0	60	3.0	15	10	0.67	3.0	40	5.0	15.0	2	4.25	moderate
32	Tetherow	Left	50	3.0	80	2.0	44	5	0.11	8.5	70	3.0	16.5	0	4.13	moderate
45	La Pine	Left	45	3.0	60	3.0	14	10	0.71	3.0	50	5.0	14.0	2	4.00	moderate
49	La Pine Bridge	Left	80	6.0	80	2.0	17	10	0.59	3.0	50	5.0	16.0	0	4.00	moderate
51	La Pine State Park	right	45	3.0	60	3.0	17	10	0.59	5.0	50	5.0	16.0	0	4.00	moderate
103	Benham Falls	Left	30	3.0	60	3.0	27	10	0.37	5.0	40	5.0	16.0	0	4.00	moderate
110	Aspen Camp	Left	45	3.0	60	3.0	2	2	1.00	1.0	30	6.0	13.0	3	4.00	moderate
118	Meadow Camp	Left	45	3.0	100	1.0	12	3	0.25	7.0	50	5.0	16.0	0	4.00	moderate
56	La Pine State Park	Left	45	3.0	50	5.0	11	10	0.91	1.5	30	6.0	15.5	0	3.88	low
113	Lava Falls	Left	90	8.0	95	1.5	1	1	1.00	1.0	80	2.0	12.5	3	3.88	low
9	Dillman	left	50	4.0	80	2.0	30	10	0.33	6.0	60	3.0	15.0	0	3.75	low
41	Tetherow	Left	40	3.0	90	3.0	21	10	0.48	5.0	80	2.0	13.0	2	3.75	low
46	La Pine	Left	20	2.0	80	2.0	16	10	0.63	3.0	60	3.0	10.0	5	3.75	low
48	La Pine	right	50	3.0	70	3.0	11	10	0.91	2.0	50	5.0	13.0	2	3.75	low
72	Big River	right	60	4.0	50	3.0	5	5	1.00	1.0	40	5.0	13.0	2	3.75	low
83	Big River	Left	30	3.0	30	6.0	10	10	1.00	1.0	70	3.0	13.0	2	3.75	low
90	Harper Bridge	Left	40	3.0	80	2.0	15	10	0.67	3.0	50	5.0	13.0	2	3.75	low
93	Sun River	right	45	3.0	70	3.0	4	5	1.25	1.0	30	6.0	13.0	2	3.75	low
95	Sun River	right	45	3.0	70	3.0	3	5	1.67	1.0	30	6.0	13.0	2	3.75	low
15	Pringle Falls	right	50	3.0	95	1.5	23	10	0.43	5.0	60	3.0	12.5	2	3.63	low
96	Sun River	Left	90	8.0	90	1.5	2	2	1.00	1.0	80	2.0	12.5	2	3.63	low
21	Tetherow Burn	Left	45	3.0	80	2.0	11	3	0.27	5.0	80	2.0	12.0	2	3.50	low
30	Log Jam	right	45	3.0	60	3.0	30	10	0.33	5.0	60	3.0	14.0	0	3.50	low
45	La Pine	right	45	3.0	60	3.0	13	10	0.77	3.0	60	3.0	12.0	2	3.50	low
46	La Pine	right	45	3.0	70	3.0	15	10	0.67	3.0	60	3.0	12.0	2	3.50	low
89	Water Wonderland	right	60	4.0	80	2.0	5	10	2.00	1.0	40	5.0	12.0	2	3.50	low
98	Sun River Marina	right	55	3.0	80	2.0	4	10	2.50	1.0	40	5.0	11.0	3	3.50	low
115	Meadow Camp	Left	90	8.0	100	1.0	1	2	2.00	1.0	80	2.0	12.0	2	3.50	low
120	Mt Bachelor Trail	Left	35	3.0	90	1.5	2	3	1.50	1.0	70	3.0	8.5	5	3.38	low
12A	Bull Bend	right	40	3.0	60	3.0	20	10	0.50	4.0	60	3.0	13.0	0	3.25	low
80	Big River	right	30	3.0	80	2.0	4	10	2.50	1.0	50	5.0	11.0	2	3.25	low
114	Lava Falls	right/left	45	3.0	100	1.0	30	5	0.17	7.0	80	2.0	13.0	0	3.25	low
116	Meadow Camp	Left	20	2.0	60	3.0	1	3	3.00	1.0	80	2.0	8.0	5	3.25	low
26	Tetherow Burn	right	45	3.0	60	3.0	10.6	10	0.94	1.5	40	5.0	12.5	0	3.13	low
28	Tetherow Log Jam	right	45	3.0	70	3.0	12	10	0.83	3.0	60	3.0	12.0	0	3.00	low
75	Big River	right	65	5.0	70	3.0	5	5	1.00	1.0	60	3.0	12.0	0	3.00	low
47	La Pine	Left	40	3.0	80	2.0	16	10	0.63	3.0	60	3.0	11.0	0	2.75	low

48	La Pine	Left	30	3.0	80	2.0	6	10	1.67	1.0	60	3.0	9.0	2	2.75	low
47	La Pine	right	40	3.0	85	1.5	15	10	0.67	3.0	60	3.0	10.5	0	2.63	low
100	Sun River	right	45	3.0	90	1.5	2	2	1.00	1.0	70	3.0	8.5	2	2.63	low
105	Benham Falls	Left	45	3.0	95	1.5	3	2	0.67	3.0	70	3.0	10.5	0	2.63	low
32	Tetherow	right	40	3.0	90	3.0	10	10	1.00	1.0	70	3.0	10.0	0	2.50	low
107	Slough	Left	40	3.0	75	3.0	2	2	1.00	1.0	80	2.0	9.0	0	2.25	low
108	Dillon	Left	40	3.0	90	3.0	1	1	1.00	1.0	80	2.0	9.0	0	2.25	low
119	Meadow Camp	Left	30	3.0	100	1.0	2	2	1.00	1.0	75	3.0	8.0	0	2.00	low
73	Big River	right	45	3.0	95	1.5	5	15	3.00	1.0	70	1.5	7.0	0	1.75	very low
8	Dillman	right	30	3.0	90	1.0	2	2	1.00	1.0	90	1.0	6.0	0	1.50	very low
8	Dillman	left	30	3.0	90	1.0	2	2	1.00	1.0	90	1.0	6.0	0	1.50	very low
109	Dillon	left/right	variable	1.0	100	1.0	1	1	1.00	1.0	80	2.0	5.0	0	1.25	very low
112	Big Eddy	left/right	variable	1.0	100	1.0	1	1	1.00	1.0	80	2.0	5.0	0	1.25	very low
117	Meadow Camp	right/left	variable	1.0	100	1.0	1	1	1.00	1.0	80	2.0	5.0	0	1.25	very low



UPPER DESCHUTES RIVER

Bank Stability Characterization

Map Index

Project Manager Kolleen Yake

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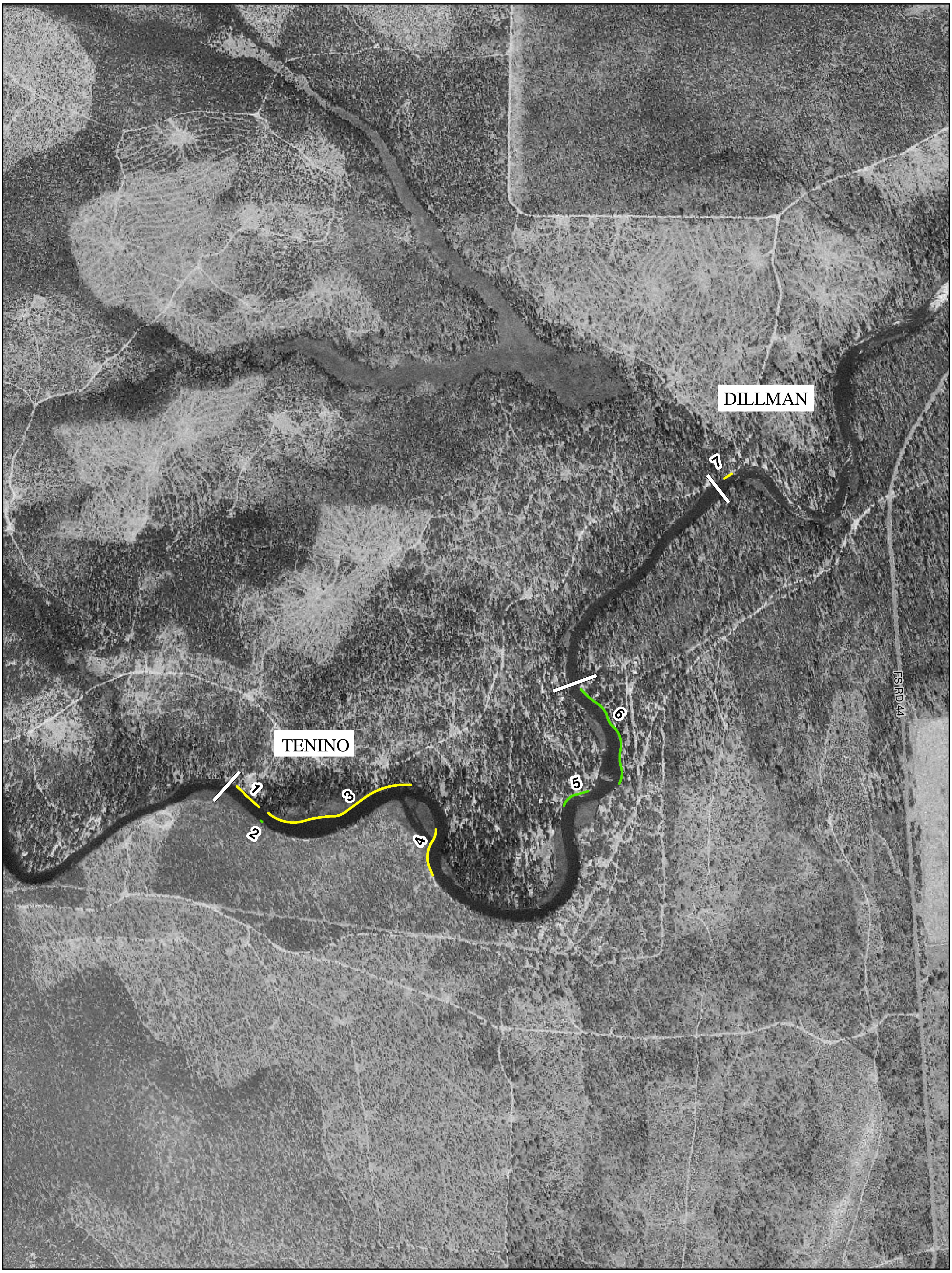

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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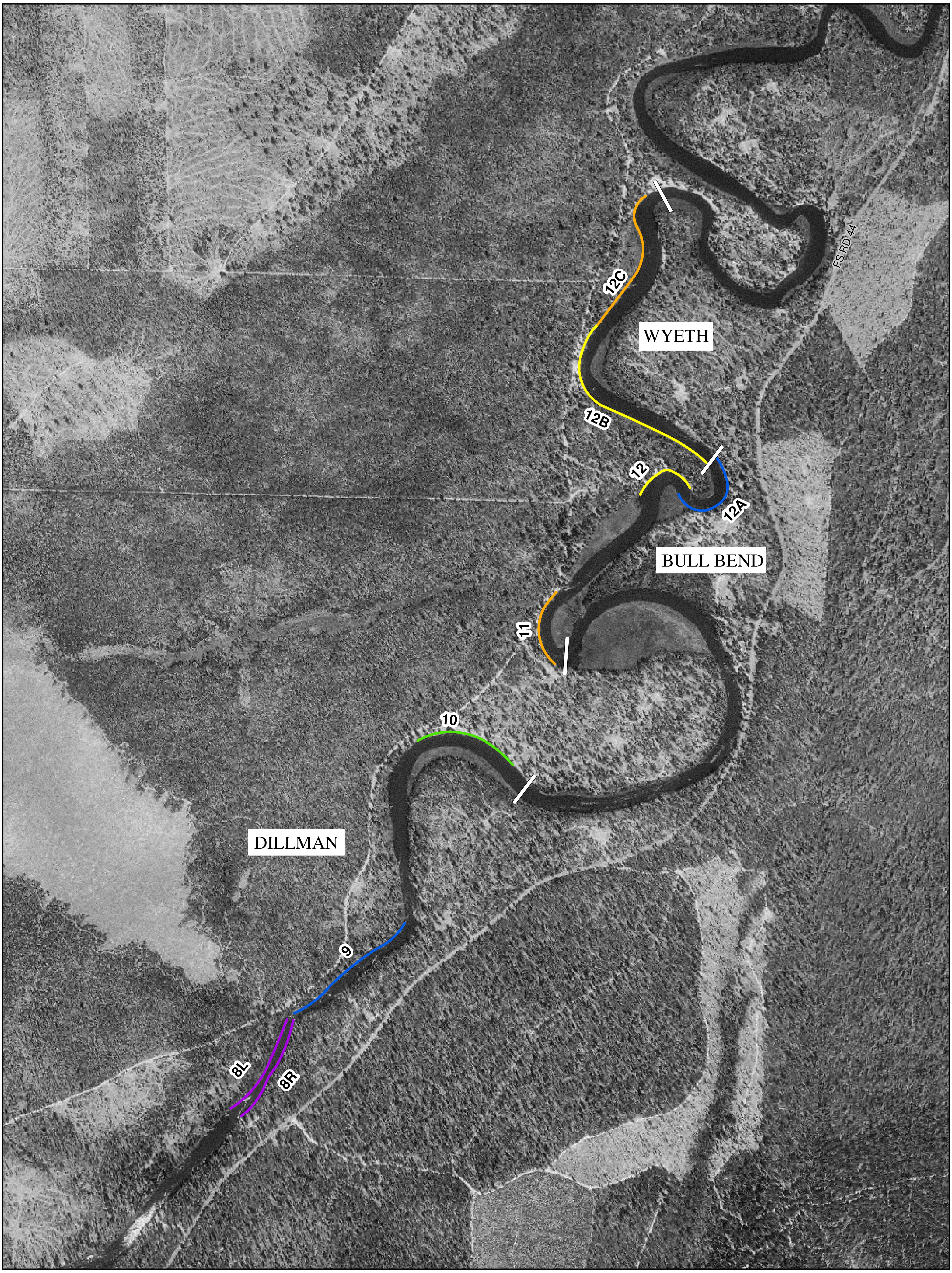

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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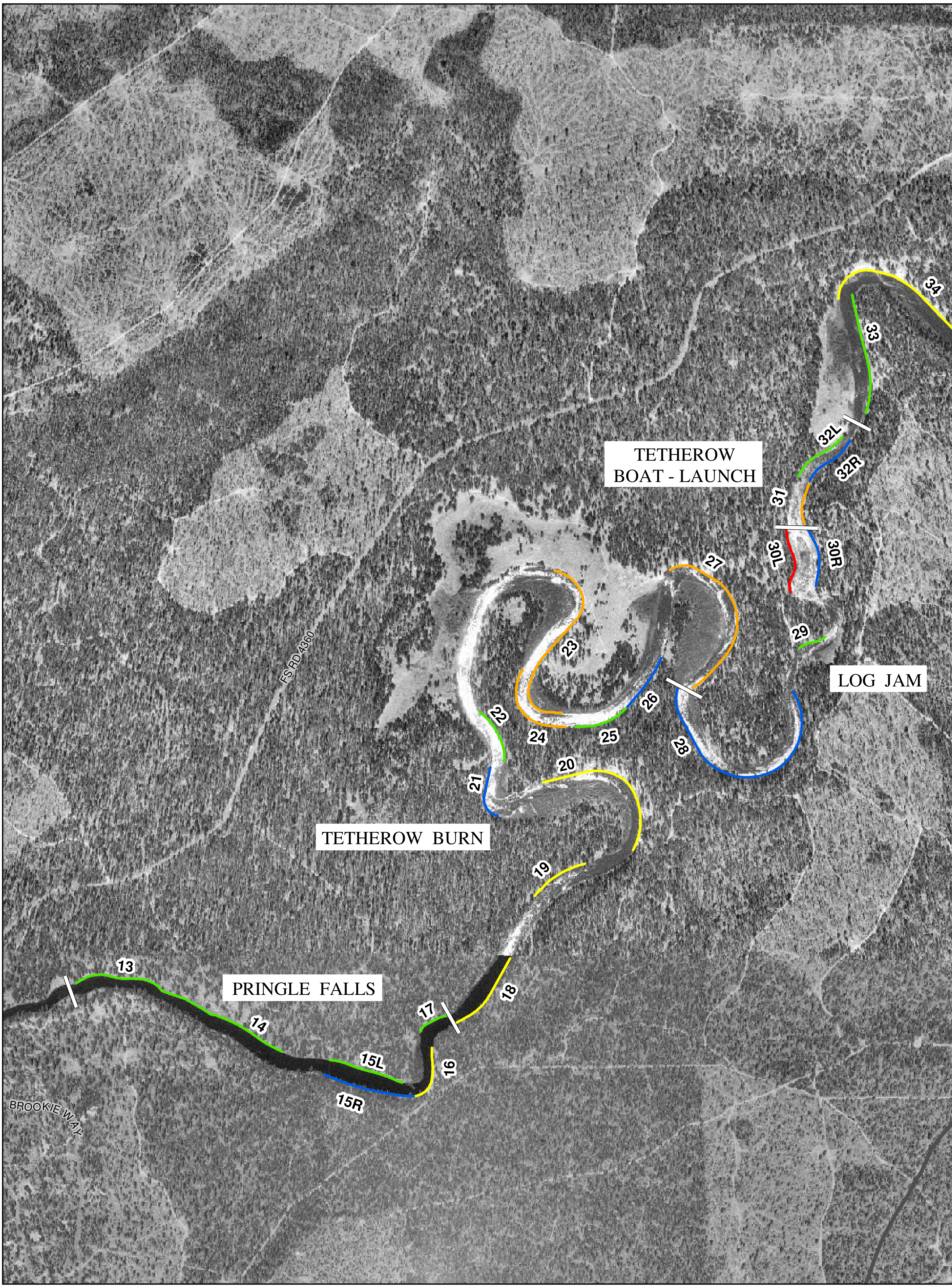

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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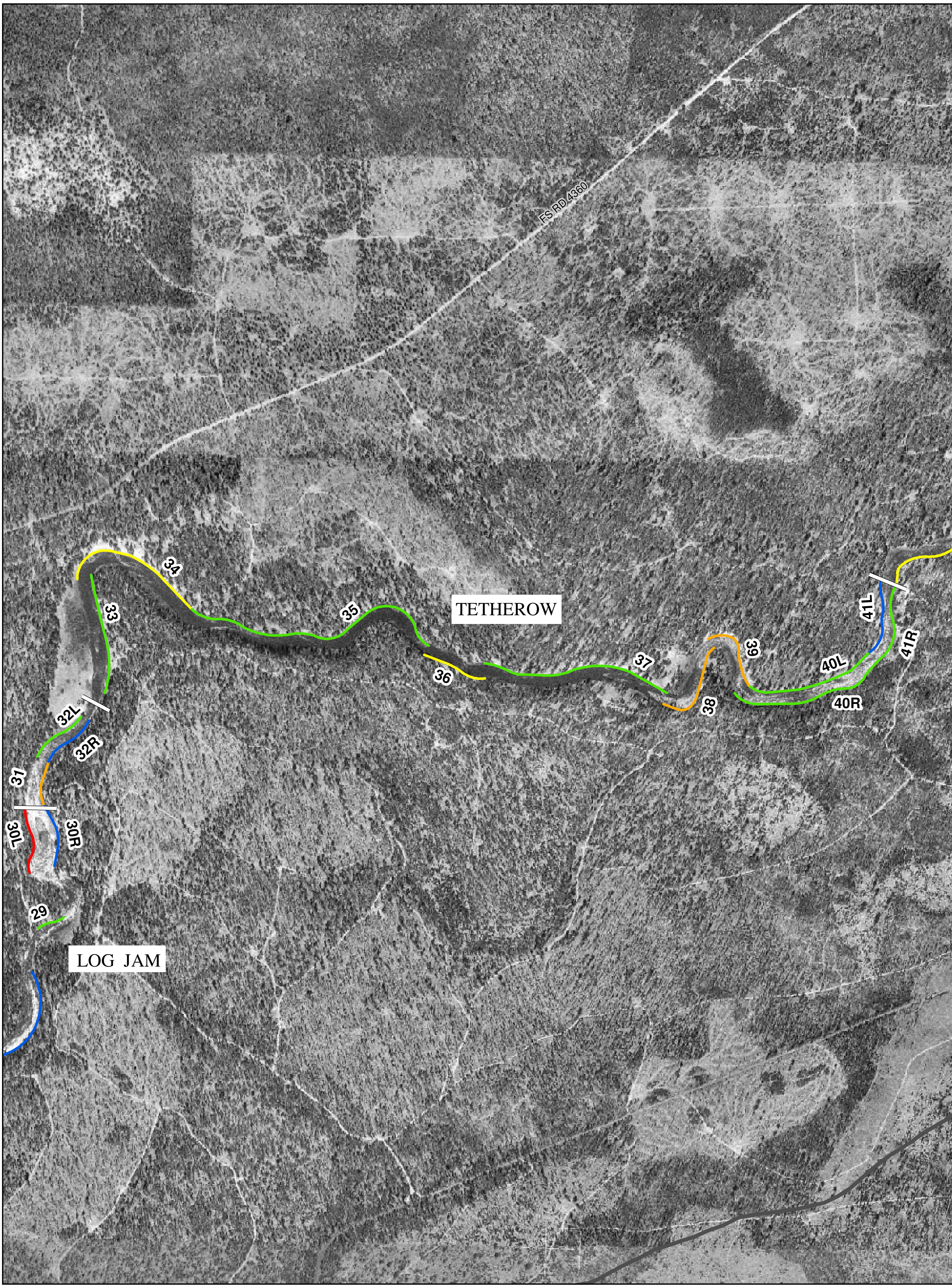

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Bank Stability Characterization

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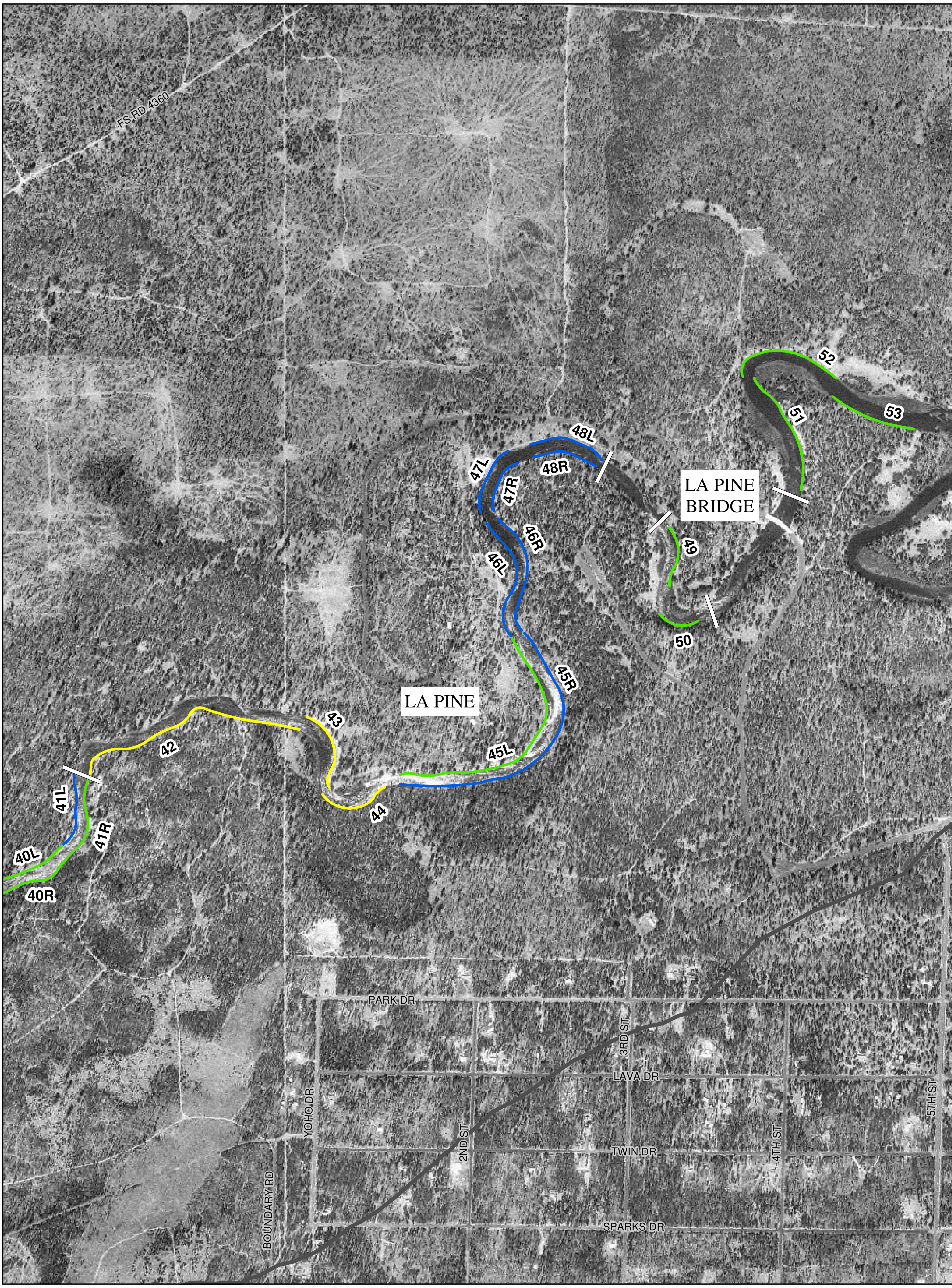

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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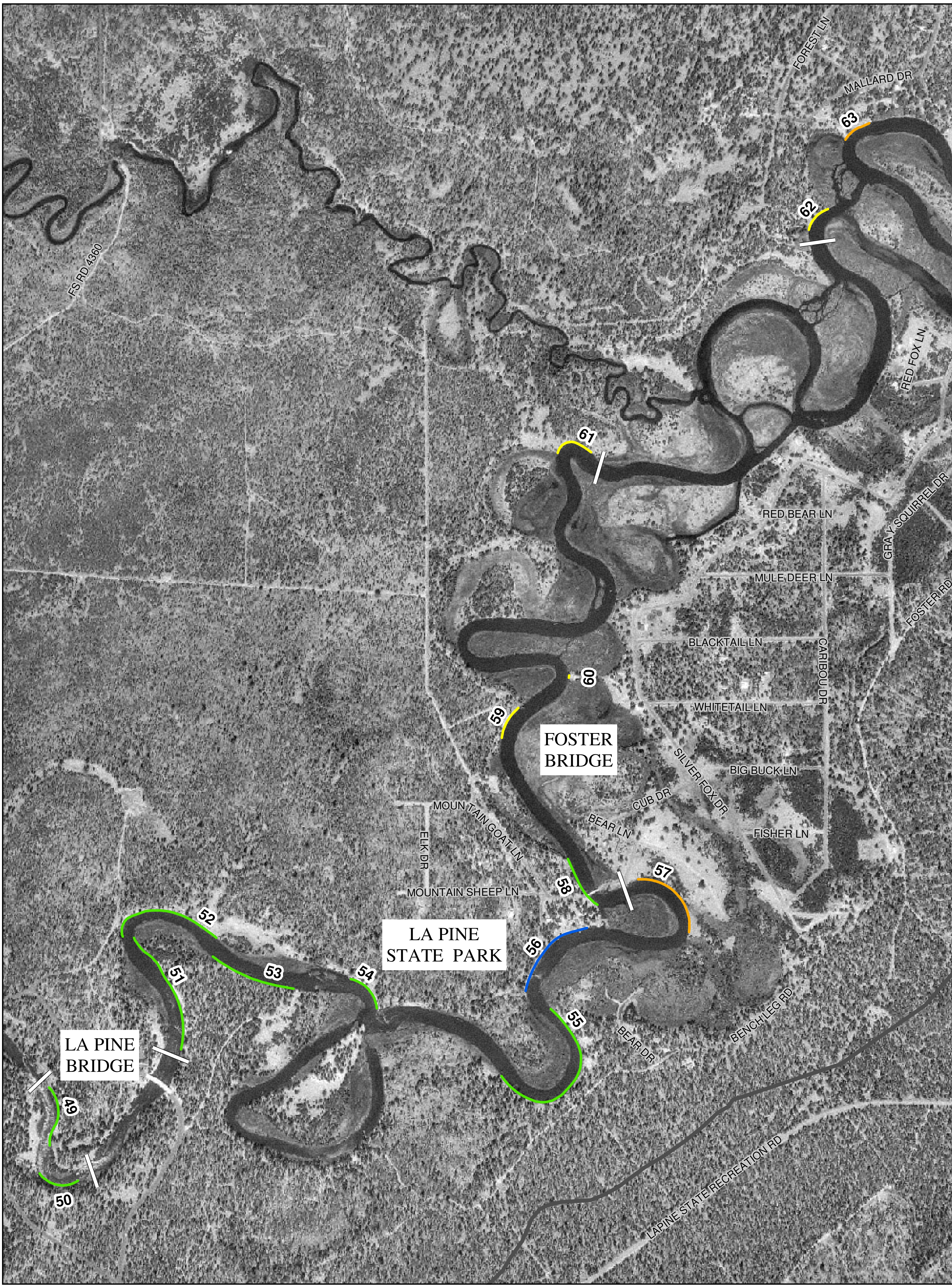

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UPPER DESCHUTES RIVER

Bank Stability Characterization

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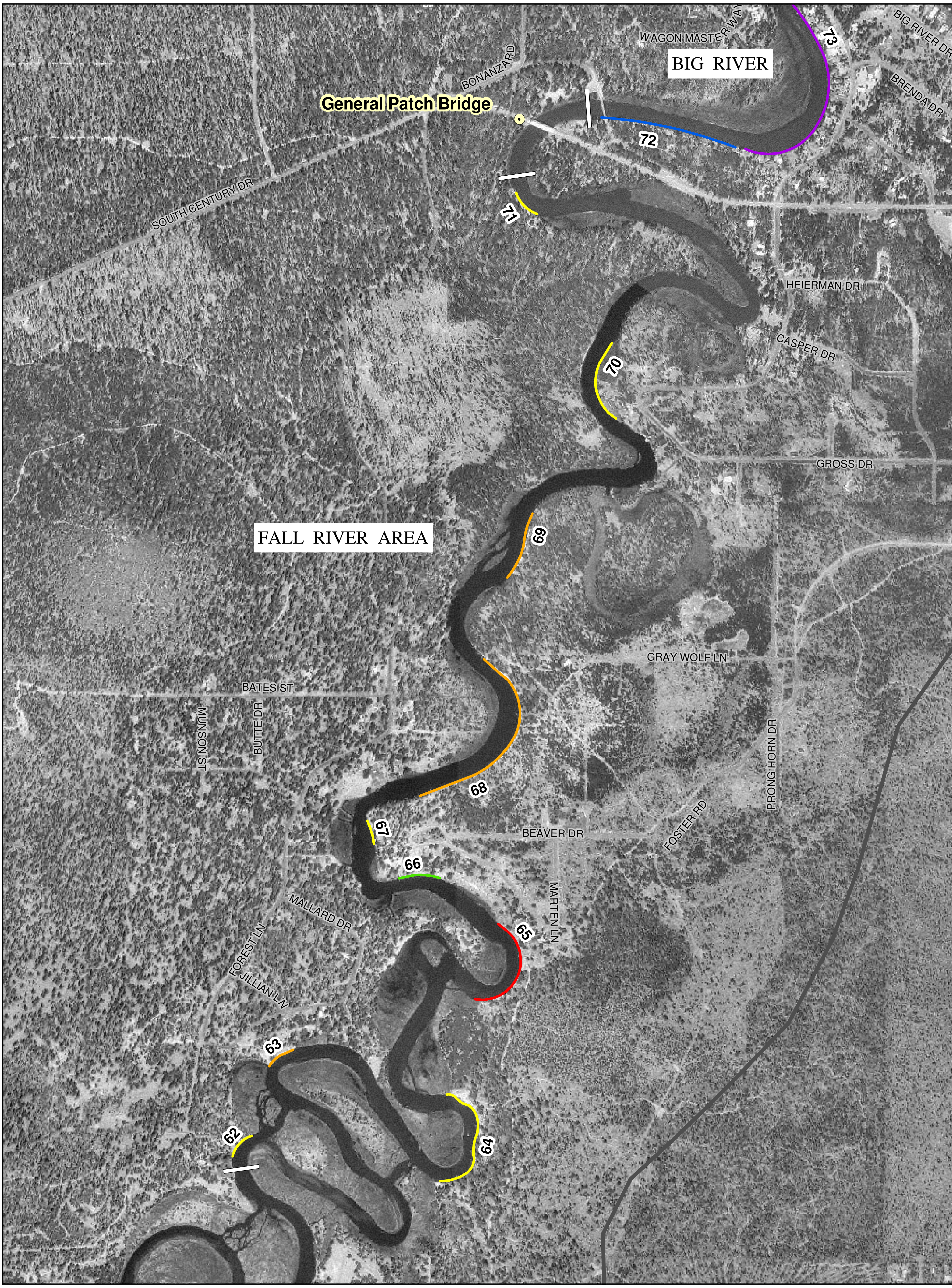

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Bank Stability Characterization

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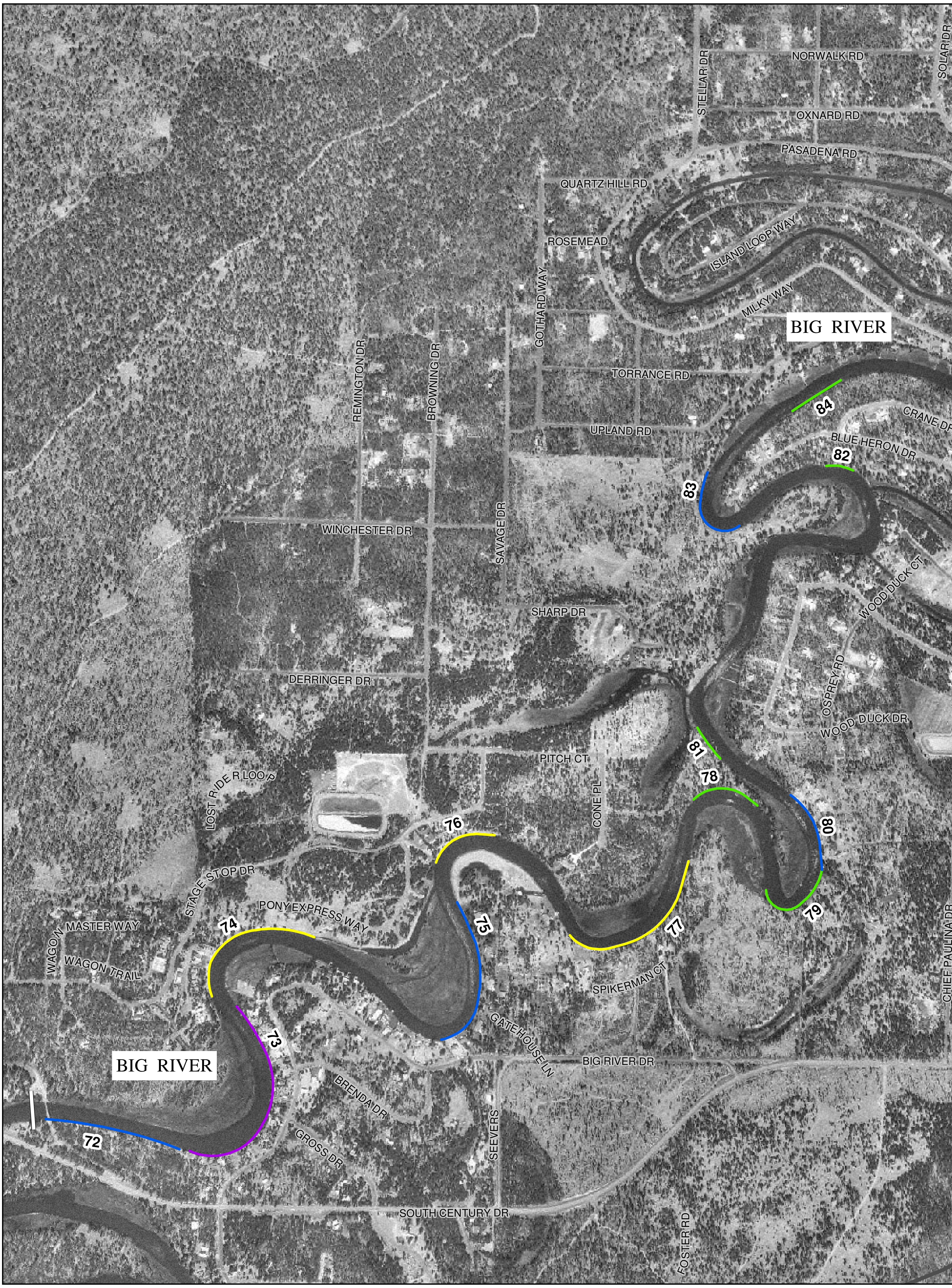

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UPPER DESCHUTES RIVER

Bank Stability Characterization

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Bank Stability Characterization

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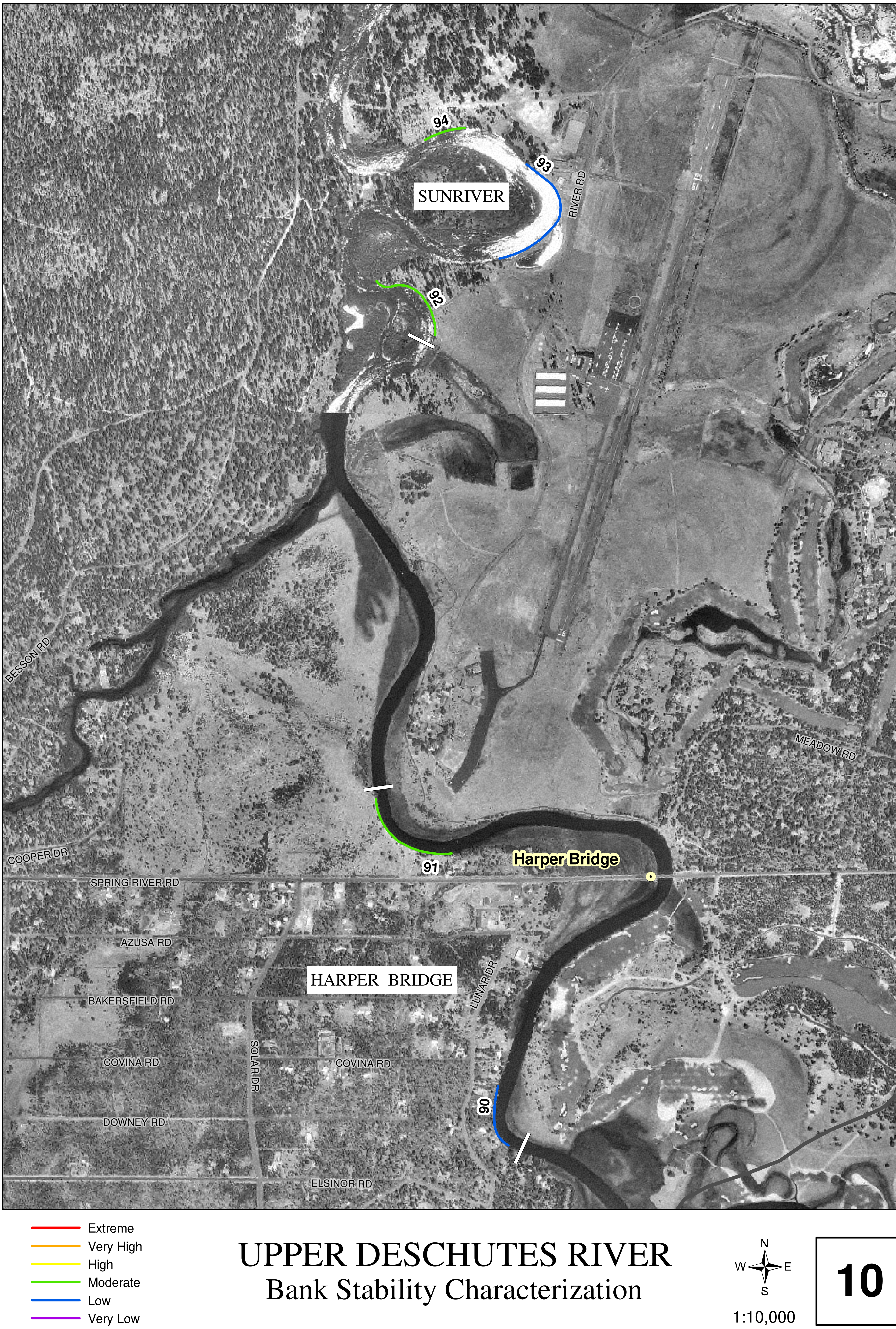

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Bank Stability Characterization

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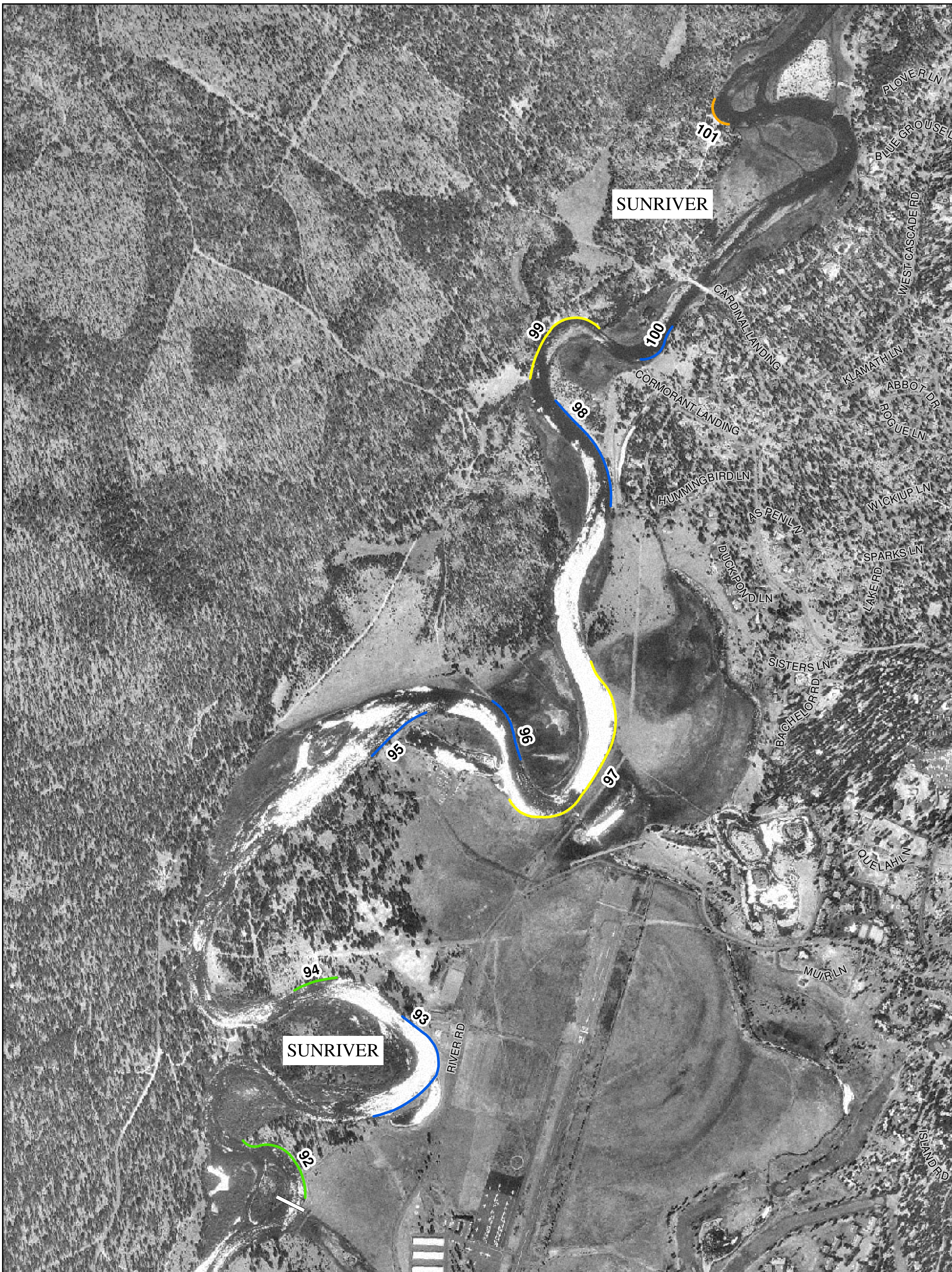

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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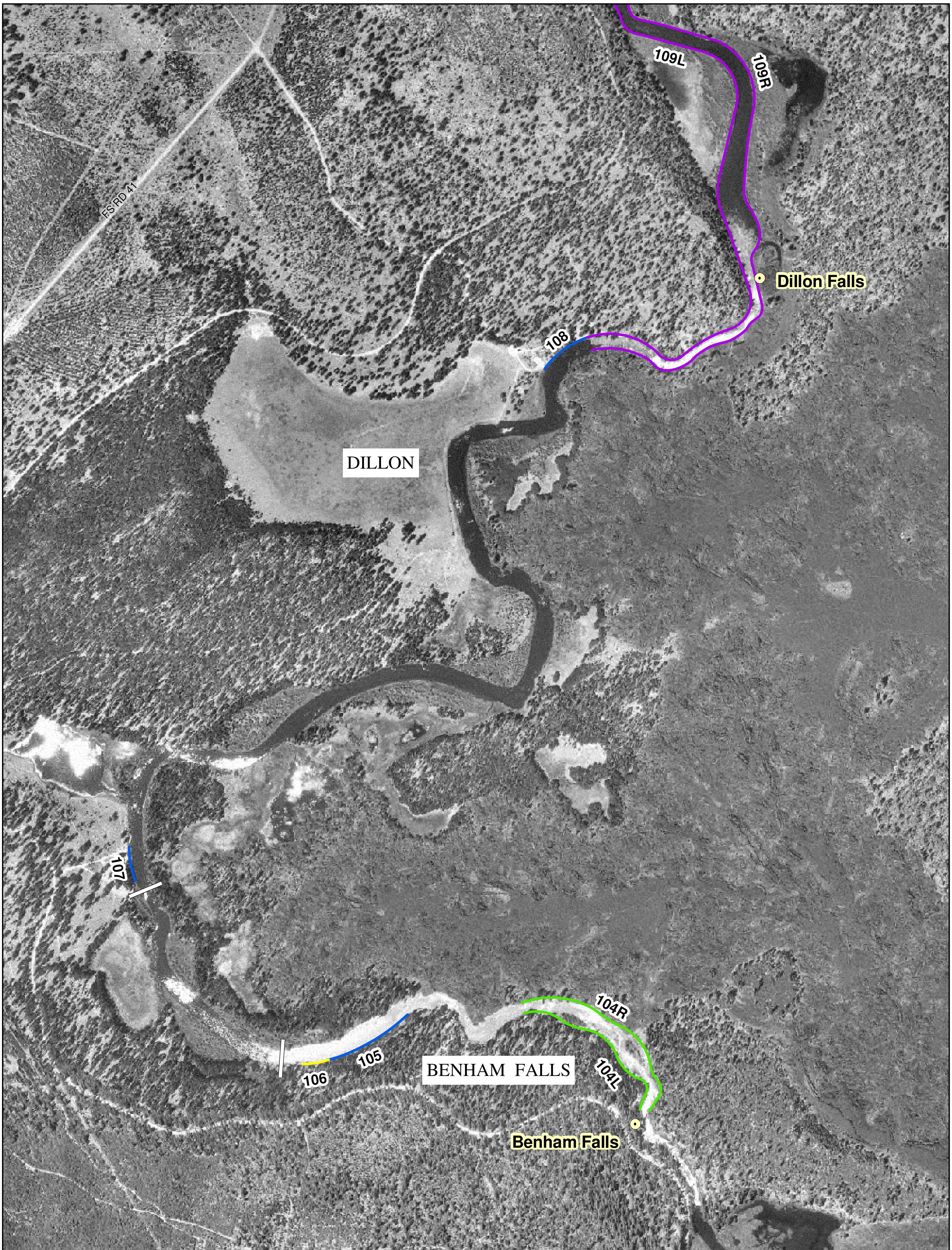

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UPPER DESCHUTES RIVER
Bank Stability Characterization

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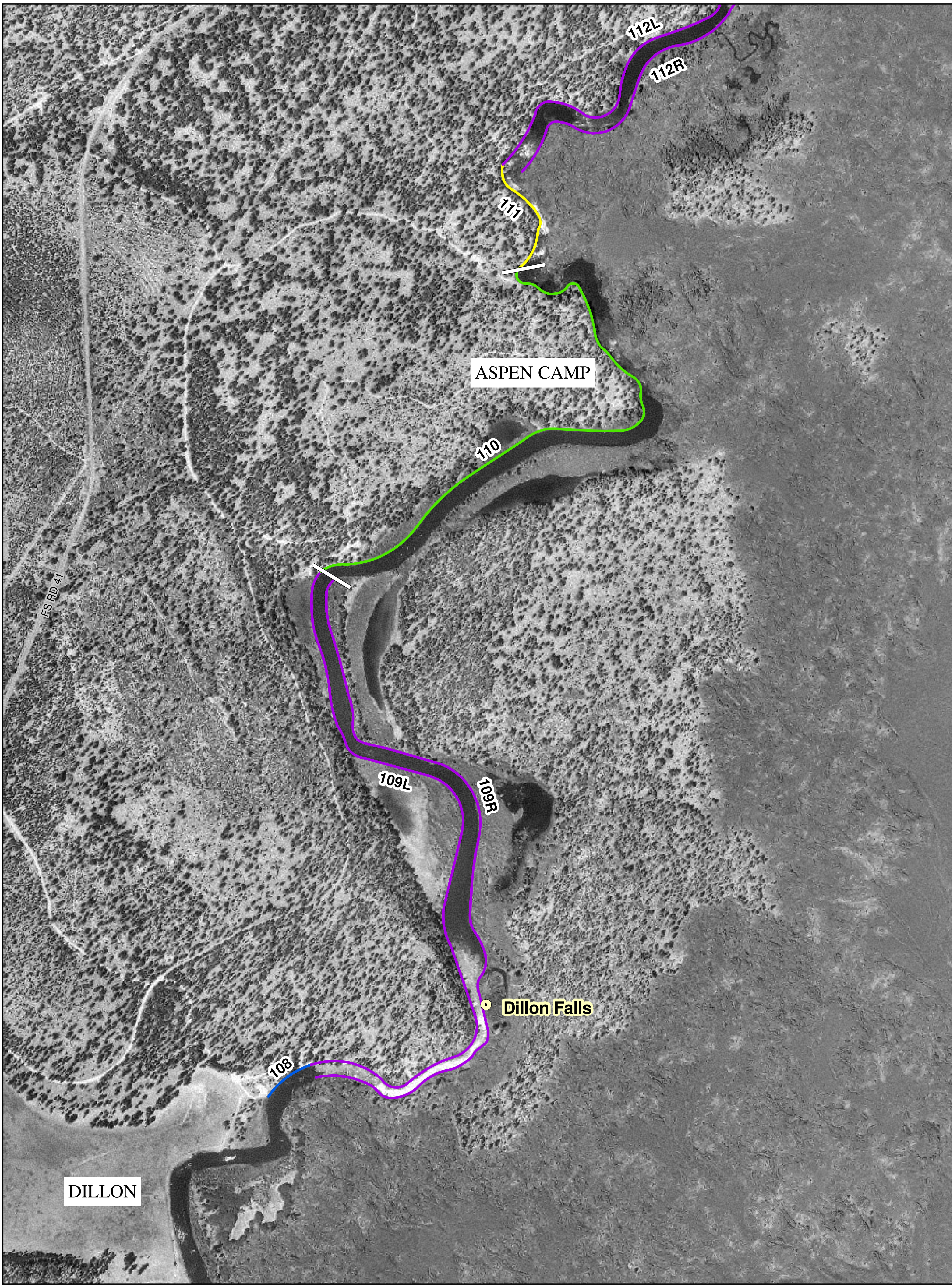

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UPPER DESCHUTES RIVER

Bank Stability Characterization

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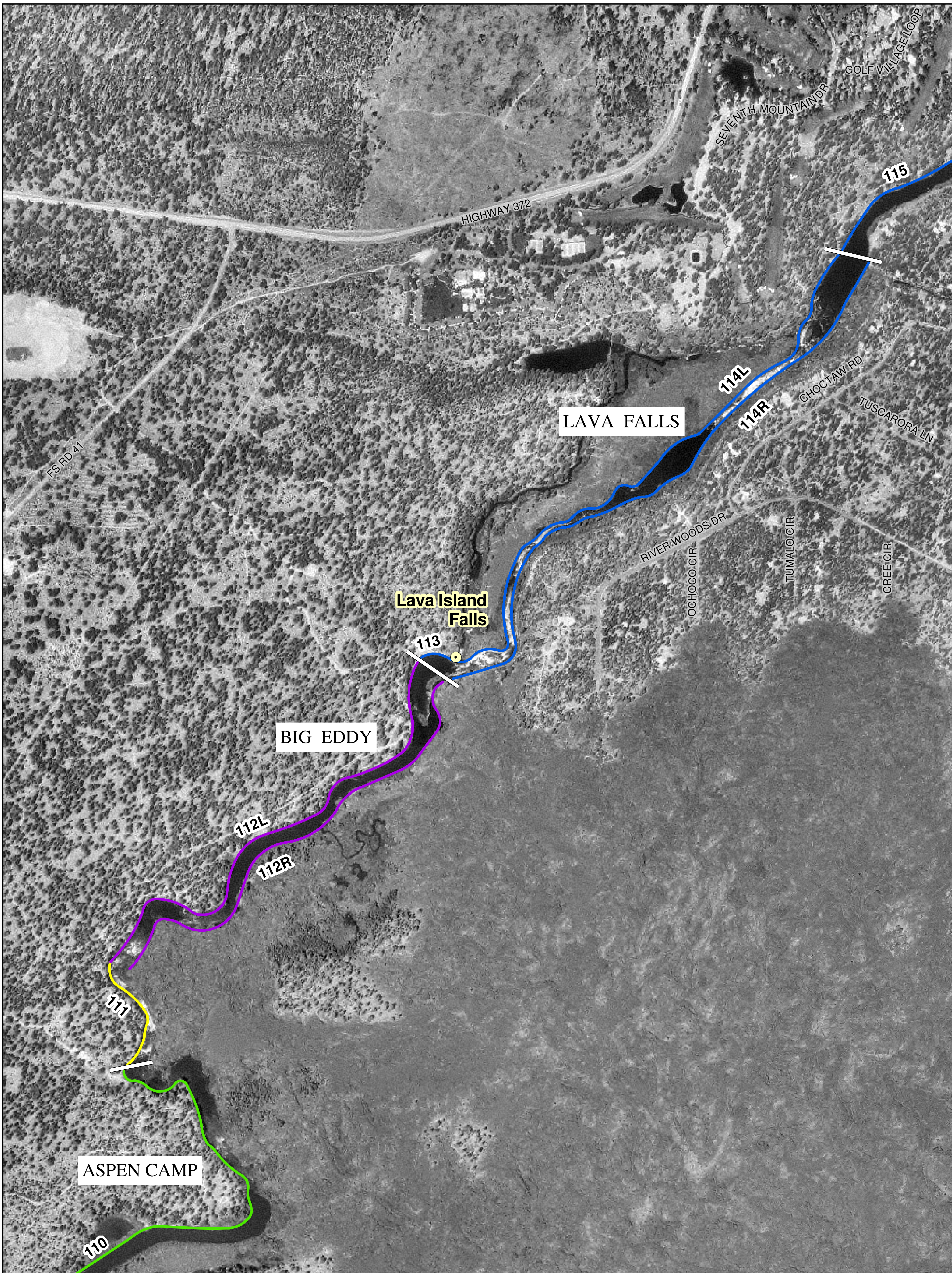

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UPPER DESCHUTES RIVER

Bank Stability Characterization

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- Very High
- High
- Moderate
- Low
- Very Low

UPPER DESCHUTES RIVER
Bank Stability Characterization

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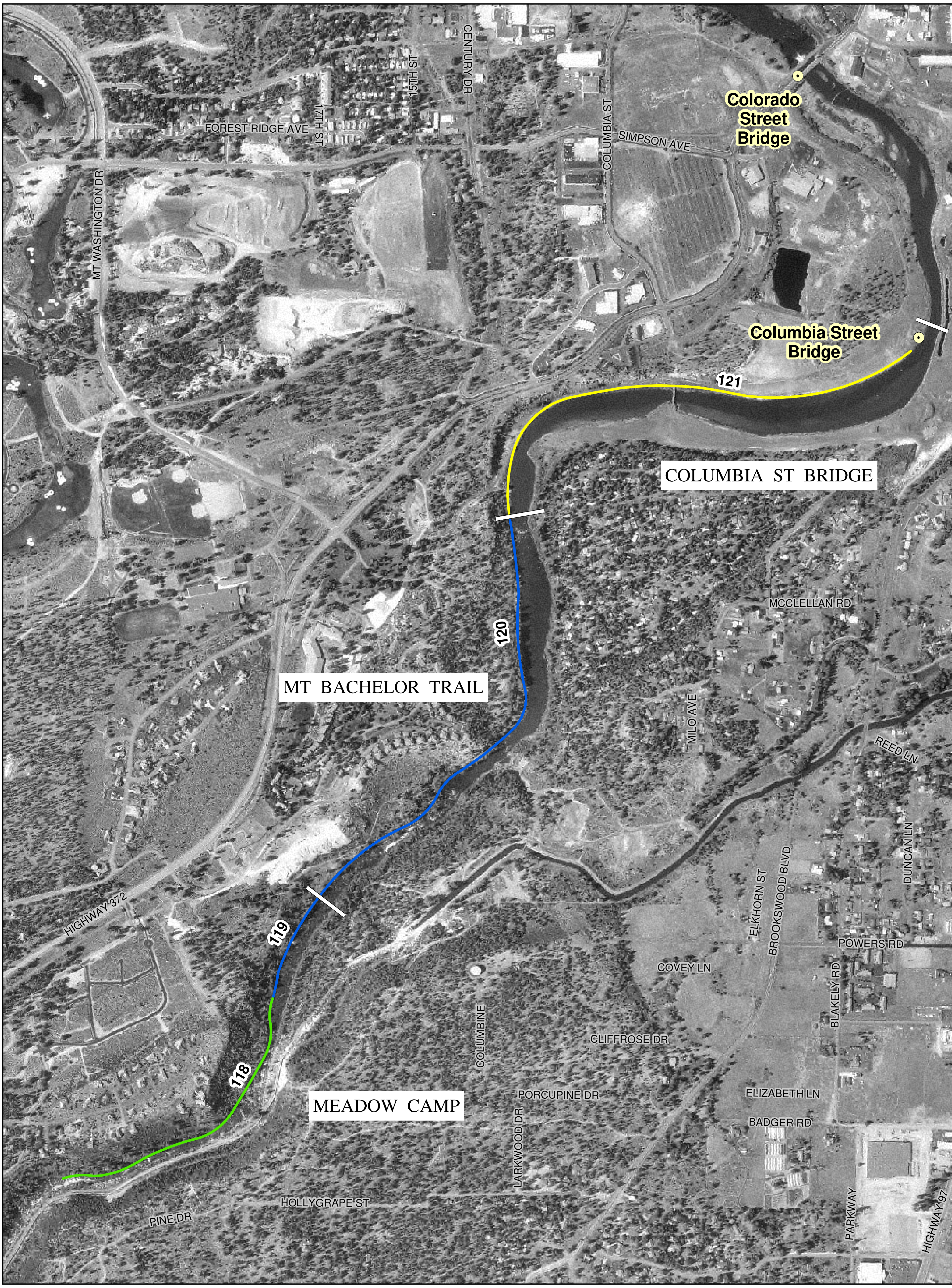

- Extreme
- Very High
- High
- Moderate
- Low
- Very Low

UPPER DESCHUTES RIVER

Bank Stability Characterization

N W E S

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