10. Infrastructure Impacts of Dam Removal Alternative

Immediate impacts of reservoir drawdown to infrastructure located within the reservoir areas are identified and analyzed.

10.1. Yreka Pipeline Crossing

The City of Yreka water supply pipeline crosses at the upstream end of Iron Gate Reservoir. Upon removal of the reservoir, the pipeline will be exposed to faster river flows that could damage the exposed pipeline. The pipeline will need to be relocated and this section analyzes the flood flows, hydraulics, and scour at this location to support the design of the new crossing. An aerial view of the reach at the pipelines crossing is given in Figure 10-1. The pipeline may be placed on a bridge over the river or it may be buried beneath the river bed. This section is intended to provided hydraulic and scour analysis for both alternatives.

The peak flows on the Klamath River are given in Table 2-4. The peak flows at the pipeline crossing were computed by developing a relationship between drainage area and peak flow at various return periods. The relationship between peak flows and drainage area is given in Figure 10-2. The estimated peak flows at the Yreka Pipeline Crossing are shown in Table 10-1.

A HEC-RAS model as described in section 4.1.1 is used to estimate the hydraulic properties at the pipe crossing after dam removal. Based upon the drill measurements, there is little deposition of material at the upper end of Iron Gate Reservoir. However, there is some uncertainty because no drill holes were at the pipeline location. Future studies should collect sediment information at the location of the pipe crossing before final designs are prepared. For the purposes of generating water surfaces, it is assumed that no significant erosion of the cross section will occur after dam removal. This will give a higher estimate for the water surface elevations. For the purposes of scour estimates, it is assumed that 2 feet of the channel bottom will eroded after dam removal. This will give a conservative estimate on scour.

The predicted water surface elevations are given in Table 10-2 and shown in Figure 10-3. These should be conservative estimates, but it is still recommended that any bridge or pipe crossing should be at least 3 feet above the 100-year water surface elevation.

Table 10-1. Flood flows at the Yreka pipeline crossing on the Klamath River.

Location	Drainage Area (mi^2)	10 yr (cfs)	25 yr (cfs)	50 yr (cfs)	100 yr (cfs)
Klamath River at Yreka Pipeline	4396	11,000	13,800	16,000	18,300

Table 10-2. Hydraulic properties at Yreka pipeline crossing

Profile	Q Total	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Hydr Depth C	Top Width
	(cfs)	(ft)	(ft)	(ft/ft)	(ft/s)	(ft)	(ft)
100-yr	18300	2321.0	2323.1	0.00923	11.4	5.7	280
50-yr	16000	2320.4	2322.3	0.00972	11.2	5.4	267

10.1.1. SCOUR METHODS

If the pipeline is placed underneath the river bed, it should be placed at an elevation below the potential scour elevation. The scour elevations were estimated using several methods. It was assumed that the pipeline is on a moderate bend for the methods where a bend type is needed. The median bed material size at the site is computed based upon the average of the median bed material size from Iron Gate Dam to Cottonwood Creek.

Lacey

The scour equation of Lacey (1930) as reported in Reclamation (1984) is:

$$d_s = Z0.47\left(\frac{Q}{f}\right)^{1/3}$$

where:

Q = Flow rate in channel at design discharge (ft^3/s or m^3/s)

f = $1.76\sqrt{d_{50}}$

Z = 0.25 for straight reach, 0.5 for moderate bend, 1.25 for vertical rock bank

d_{50} = mean grain size in mm

Z = 1.25 was chosen for vertical rock bank.

Blench

The scour equation of Blench (1969) as reported in Reclamation (1984) is:

$$d_s = Z\frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

where:

q_f = design discharge per unit width
F_{bo} = $1.75 d_{50}^{0.25}$
d_{50} = mean grain size in mm
Z = 0.6 for straight, 1.0 for moderate bend, 1.25 for vertical rock bank or wall.

Z = 1 was chosen for bends as recommended in Reclamation (1984).

10.1.2. Limiting Velocity

The limiting velocity method as reported in Reclamation (1984) is:

$$d_s = d_m \left(\frac{V_m}{V_c} - 1 \right)$$

where:

d_m = mean depth
V_m = mean channel velocity
V_c = minimum competent velocity

The competent velocity can be estimated using a shear stress based incipient motion criteria:

$$u_\tau = \theta_c \sqrt{g(s-1)D_c}$$

where:

u_τ = friction velocity = $nV_c\sqrt{g} \Big/ \left(C_m R^{\frac{1}{6}}\right)$
V_c = minimum competent average channel velocity
n = Manning's roughness coefficient
g = acceleration of gravity
R = hydraulic radius
C_m = Manning's constant (1.0 for SI, 1.486 for English units)
θ_c = critical non-dimensional shear stress (often between 0.03 to 0.05)
s = specific weight of bed material
D_c = d_{50} of surface bed material

Alternatively, one could use the competent bottom velocity method as recommended in Reclamation (1984) Eq (3). That equation can be rewritten to be dimensionally consistent as:

$$V_c = 0.57\sqrt{g(s-1)D_c}$$

and this equation is used in the analysis in this report.

EM1601

The COE manual EM1601 (COE, 1994) recommends using the following equation:

$$d_s = S_f Z d_m - d_f$$

where:

d_m = average depth in the crossing upstream of the bend.
d_f = depth of thalweg at bend
S_f = Safety Factor = 1.14
Z = factor based upon radius of curvature to width ratio
= $3.37 - 0.66\ln(R/W)$ for sand bed
= $3.37 - 0.7\ln(R/W)$ for gravel bed

The correlation between *Z* and *R*/*W* for gravel bed rivers is very weak based upon Plate B-42 in Appendix B of EM1601. We recommend using the upper value of 3.37 for this design.

HEC 11

The scour method proposed by HEC-11 (Federal Highway Administration, 1989) is only a function of bed particle size:

$$d_s = \min\left(12, 6.5 d_{50}^{-.11}\right)$$

10.1.3. SCOUR RESULTS

The results for each method are given in Table 10-3. The predicted scour ranges from 5 to 10 feet. There is considerable uncertainty regarding the site conditions because the site is currently within the reservoir. Therefore, the bed material and channel dimensions that will occur after dam removal are uncertain. There is also some uncertainty regarding the amount of sediment that will be eroded from the site after dam removal material. Therefore, the maximum scour depths are used in the recommendations. This equates to a scour elevation of 2399.5 feet.

Table 10-3. Reach scour estimates from each method at the Yreka pipeline crossing.

Bed Erosion (ft)	Design Scour (ft)					Final Design Scour Recommendation (ft)
	Lacey (1930)	Blench (1969)	Limiting Velocity	EM1601	HEC11	
2	6.4	9.5	5	9.8	9.7	10

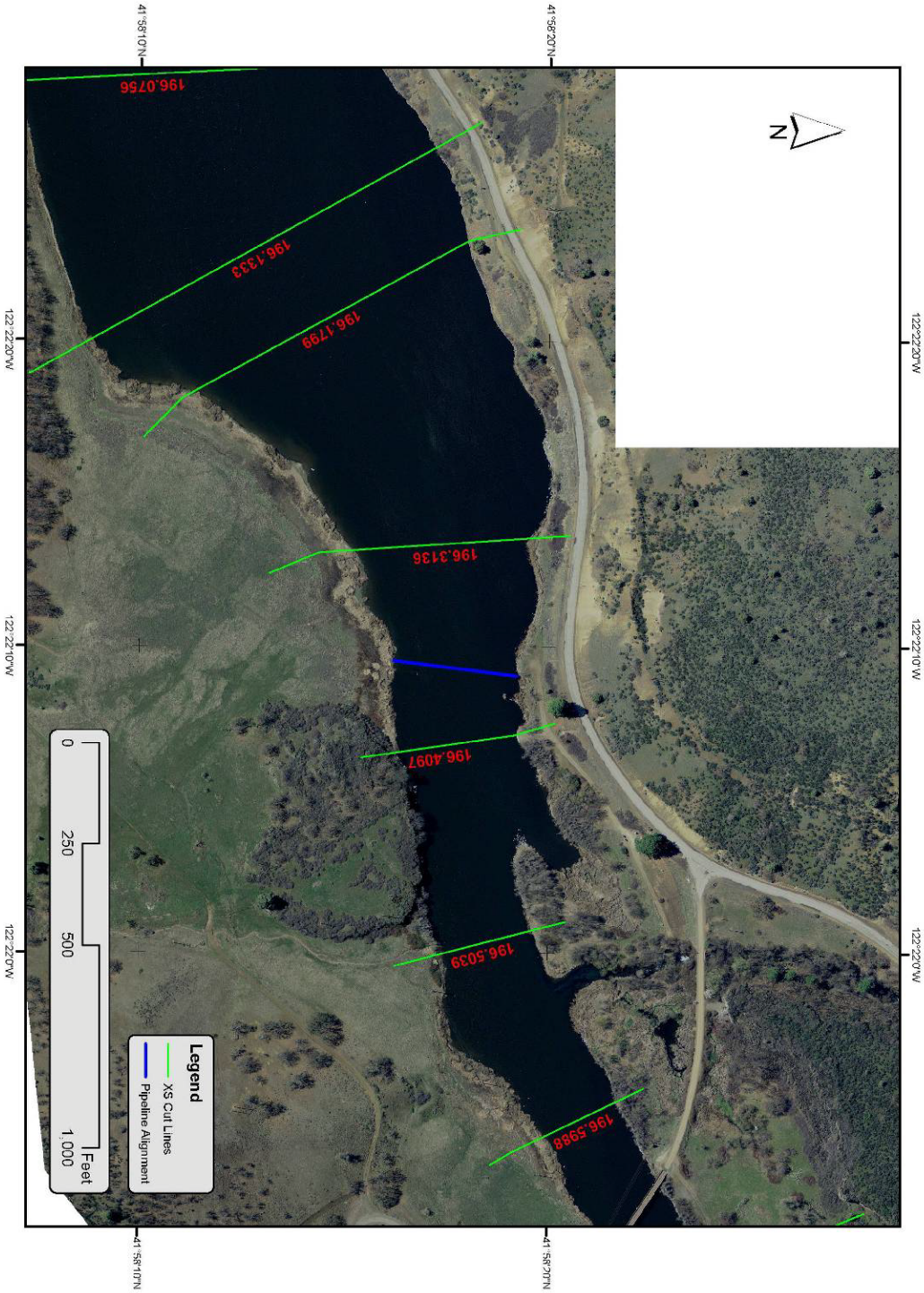

Figure 10-1. Overview map of the Yreka pipeline crossing.

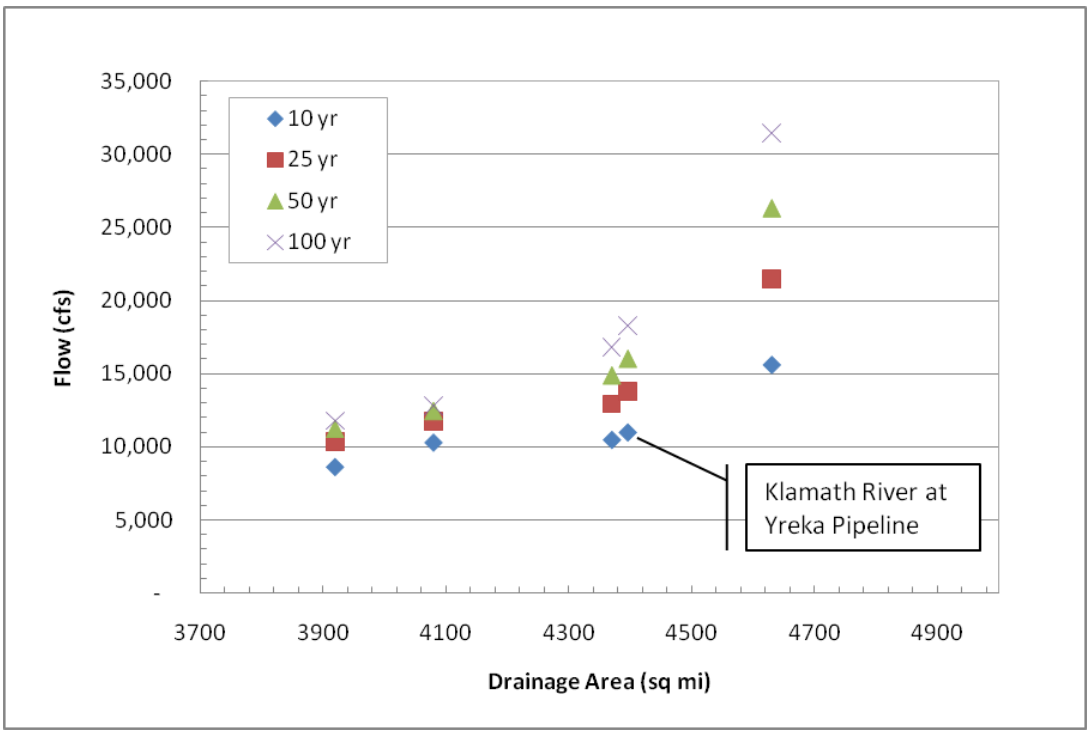

Figure 10-2. Drainage area and flood frequency at Yreka pipeline crossing on Klamath River.

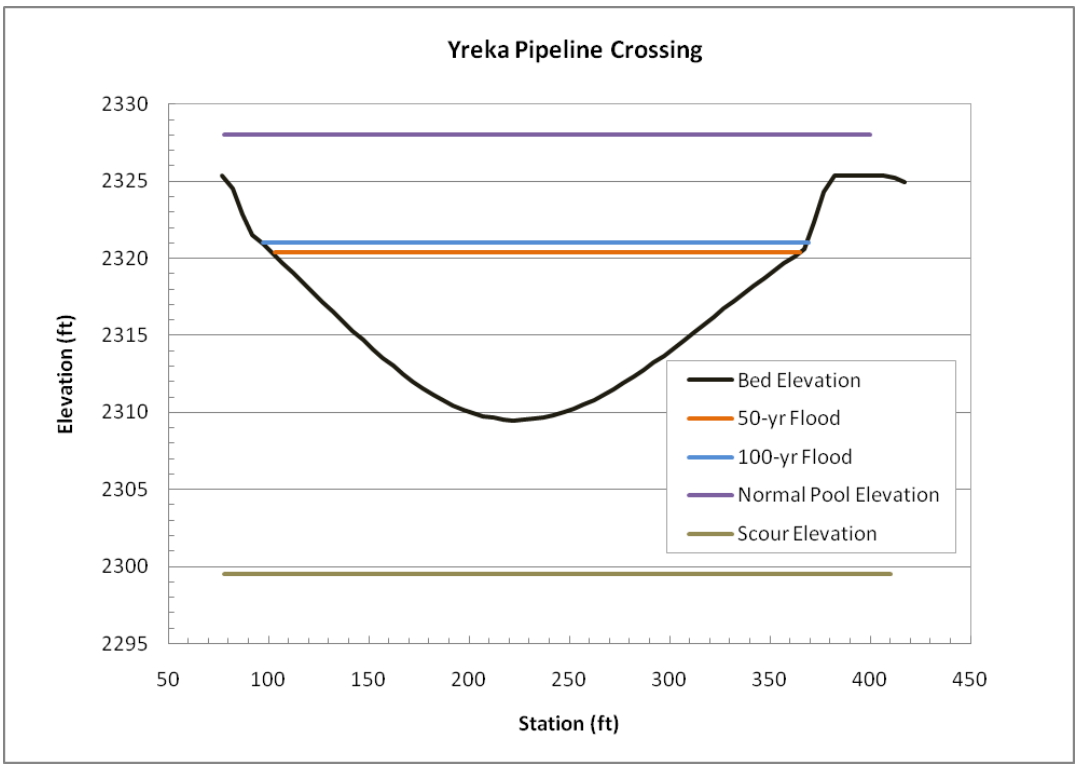

Figure 10-3. Cross section at Yreka pipeline crossing.

10.2. Jenny Creek Bridge

Jenny Creek Bridge is located on Iron Gate Reservoir. PWA (2008) identified this bridge as one that may be impacted by dam removal. The approach road and abutments are built upon material deposited since the construction of Iron Gate Dam (see Figure 5-7 of PWA, 2008). After dam removal, the channel will incise through the deposits and is expected to undermine the abutments of the bridge. To prevent this, a new bridge will be need upstream of the current bridge. The current alignment and a potential new alignment are shown in Figure 10-4 with the 2010 aerial photograph as a background. The same information is shown in Figure 10-5 with the 1960 (pre-dam) aerial photograph as a background.

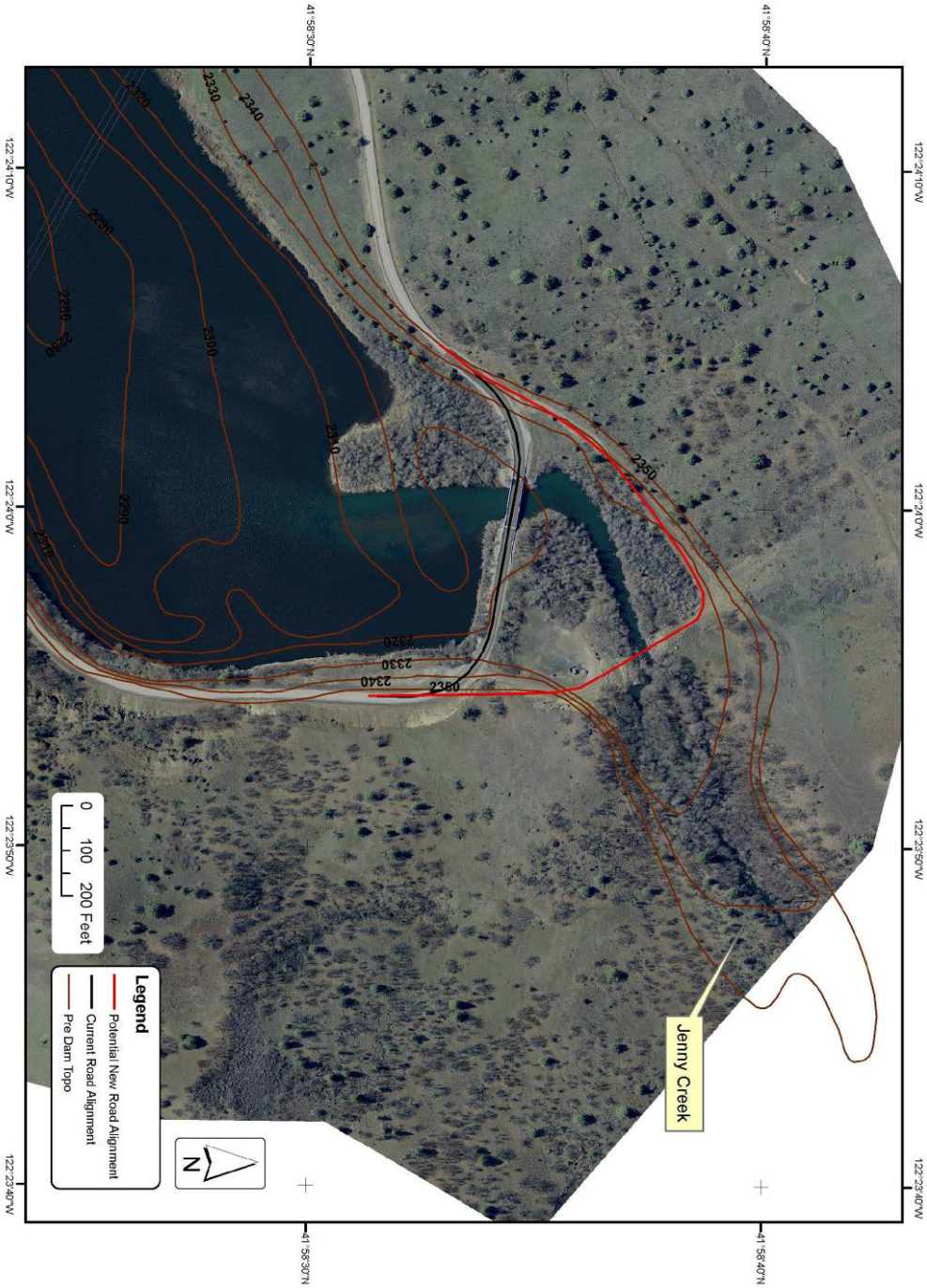

Figure 10-4. 2009 Aerial view of Jenny Creek Bridge on Iron Gate Reservoir with pre-dam topography shown.

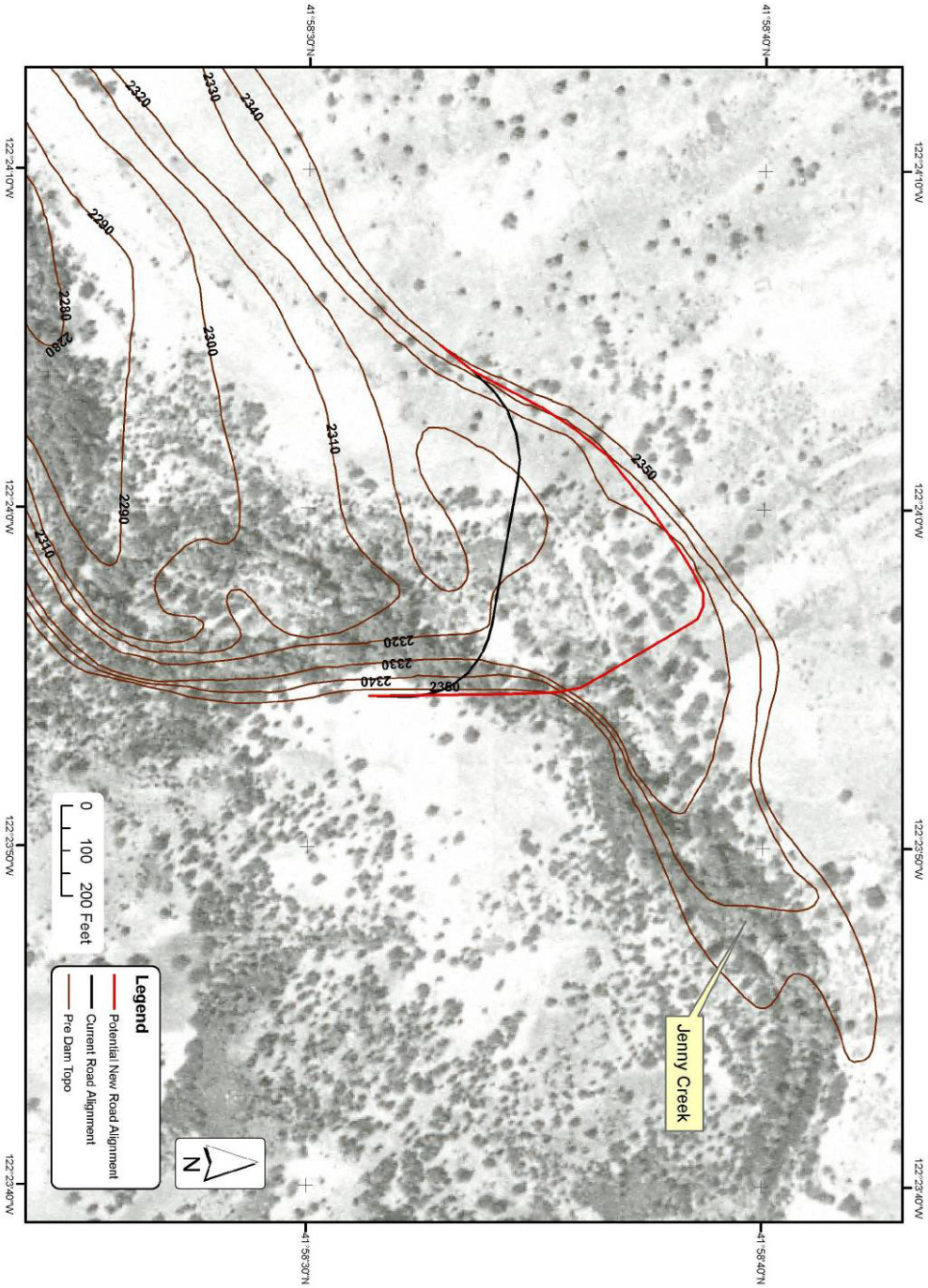

Figure 10-5. 1960 Aerial view of Jenny Creek Bridge site with pre-dam topography shown.

10.3. Highway 66 Bridge

State Highway 66 Bridge is located within J.C. Boyle Reservoir (Figure 10-6). Figure 10-7 shows the 2010 aerial photograph and the 1952 pre-dam photograph with the highway alignment shown on both. The left abutment and middle pier are located in the historical river channel, as evidenced by the 1952 aerial photograph. The sediment sampling holes are also shown in the figure. The reservoir sediment thicknesses vary between 0 and 1.5 feet in the holes shown in the figure (Reclamation, 2010). The minimum bed elevation according to the bathymetry information from Eilers and Gubala bathymetry survey is 3781.8 feet (NAVD 88). Therefore, the minimum pre-dam elevation could be as low as 3780 feet.

The historic river channel will quickly reestablish itself after dam removal. The bridge piers and east abutment will be subject to higher velocities and therefore subject to greater scour potential.

To determine the required protection at the pier, the as-built drawings were obtained from Oregon Department of Transportation. The bottom elevation of the 2 east piers is at 3763 feet and the bottom of the casing is at 3775.3 feet. The bottom elevations of the 2 west piers were 3768.7 feet and the bottom elevation of the casing around the pier was 3779.2 feet. The elevation of layer termed “Basalt B” at the east pier was approximately 3765.8 feet and the elevation at the west pier was 3775.6 feet.

Therefore, the minimum pier elevations are expected to be between 17 and 11.3 feet of the bed elevation after dam removal. The minimum pier elevations are about 3 feet below the “Basalt B” layer and about 8 feet below the top of the “Basalt A” layer. The descriptions of the Basalt Layers are below:

> *BASALT FLOW TOP - BASALT, gray. brown. and yellow brown. Moderately Weathered to Predominantly Decomposed. Very Soft to Soft (R1 to R2), Very Close to Close joints. RQD=O to 36, vesicular with vesicles forming planes of weakness, a few brecciated zones with green to green gray clay infilling up to 10 mm. This unit grades into Basalt A.*
>
> *BASALT UNIT A - BASALT - dark gray to brown gray, mostly Moderately Weathered but varies from Predominantly Decomposed to Slightly Weathered. Soft to Medium Hard (R2-R3), Very Close to Moderately Close joints, vesicles in very close near horizontal layers creating zones of weakness, joints near horizontal to 30 degrees and 45-60 degrees, light gray to green gray joint infilling up to 3 mm thick. RQD 47 to 83. Laboratory UCS is 19.4 to 45.1 MPa. This unit grades into Basalt B at the lower surface, and Basalt Flow Top at the upper contact.*
>
> *BASALT UNIT B - BASALT, dark gray to brown gray, mostly Slightly Weathered to Fresh, minor Moderately Weathered zones, mostly Medium Hard to Hard (R3 to R4) with minor Soft (R2) zones. Close to Wide*

jointing, joints stained and some have up to 2 mm of green gray clay infilling. RQD 62-100, Lab UCS is 88.4 MPa This unit is a local basalt flow and has a gradational upper contact with Basalt A.

Based upon these classifications, pier scour should not extend below the Basalt Unit A layer and therefore the pier would have approximately 8 feet buried beneath into the basalt layer.

The abutment is located on the outside of a mild bend in the river and the river will create a scour pool at the left abutment. There is already a riprap along the east abutment and it is classified as "Riprap Class 1000", which according to the Oregon Department of Transportation, has the gradations shown in Table 10-4. The size of material is sufficient to protect the abutment from scour, but it is uncertain if the riprap was place below grade to account for scour that can occur at the base of the riprap.

Table 10-4. Riprap size on east abutment of Highway 66 Bridge based upon as-built drawings from Oregon DOT.

Mass (kg)	**% by mass**
1000 – 650	20
650 – 300	30
300 – 20	40
20 -0	10

Figure 10-6. Spencer Bridge on State Highway 66 in J.C. Boyle Reservoir. Picture taken from the downstream side east abutment.

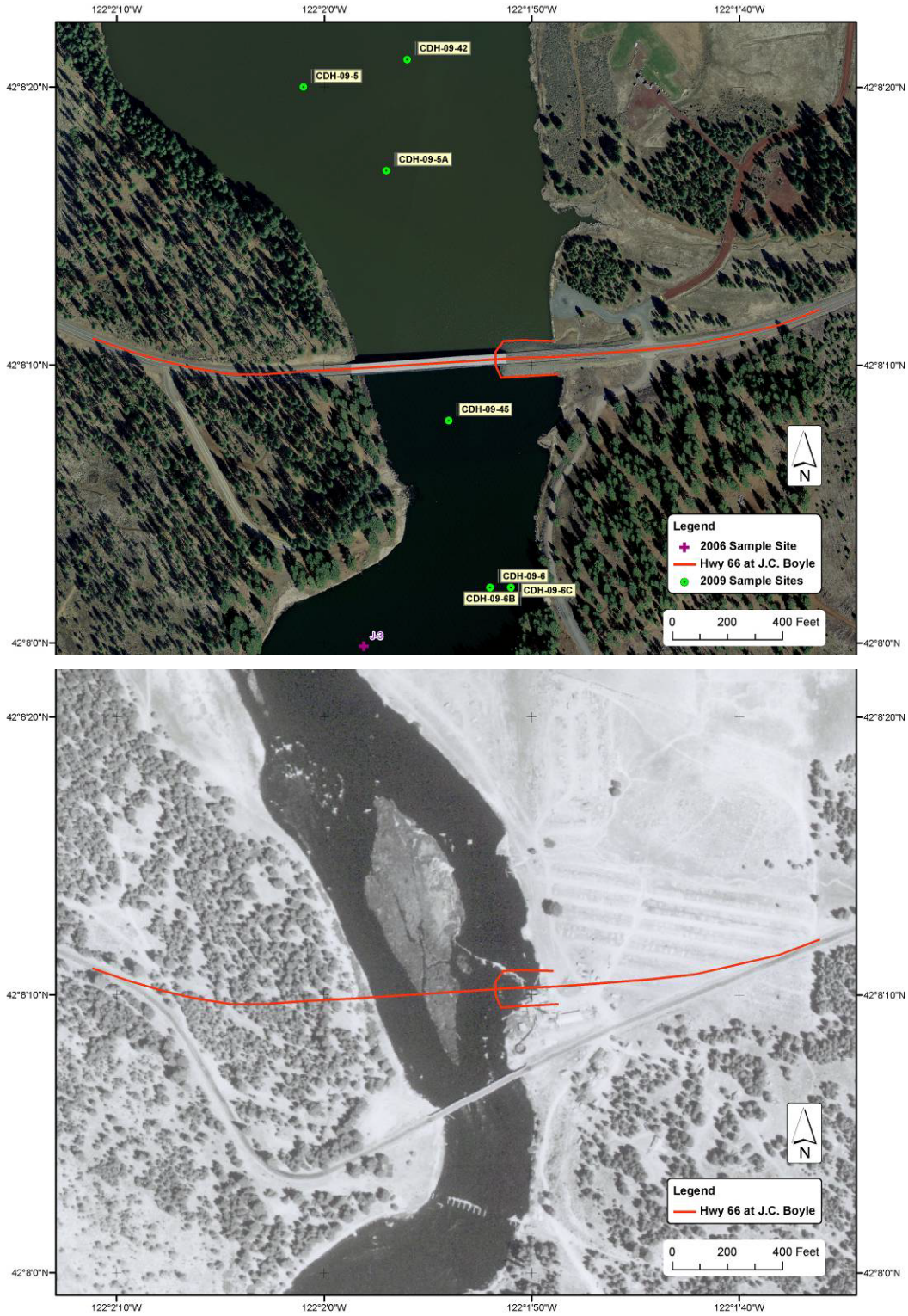

Figure 10-7. 2010 (above) and 1952 (below) Aerial photograph of State Highway 66 Bridge in J.C. Boyle Reservoir. The dam was complete in 1958.

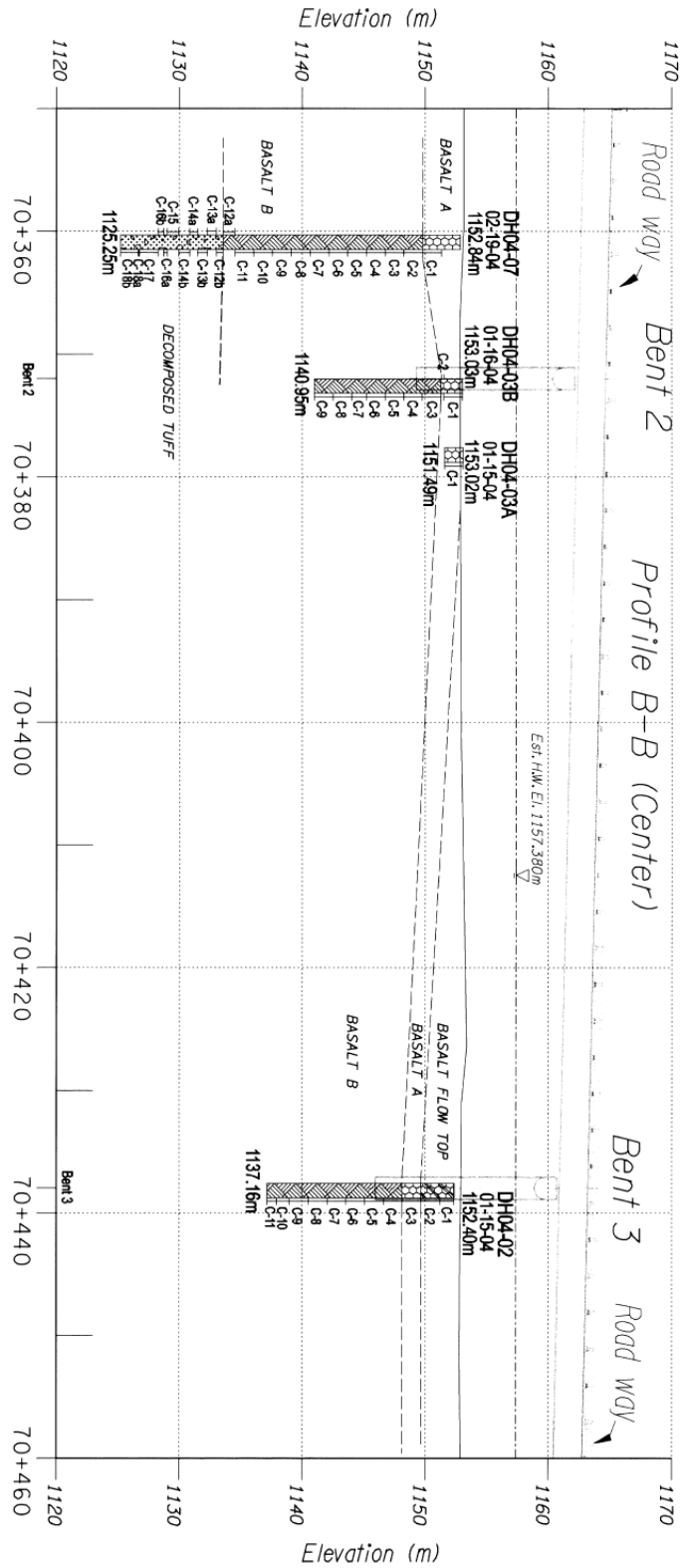

Figure 10-8. Pier location and drill log information from Oregon Department of Transportation.

10.4. J.C. Boyle Bypass Reach Bridge

The J.C. Boyle Bypass Reach Bridge is shown in Figure 10-9. The 2010 LiDAR information shows the bridge elevation as 3735 feet (NAVD88). The 100-year flood at J.C. Boyle Dam is 13,150 cfs (Table 2-4). The 100-year flood in the bypass reach under the No Action Alternative calculation assumes the powerhouse is at full capacity of 2,800 cfs is 10,350 cfs. A summary of the hydraulic characteristics for the bridge under No Action and Dam Removal Alternatives is given in Table 10-5. The 100-year water surface elevation for the No Action or Dam Removal Alternative will be below the bridge soffit elevation, and therefore, it will not be necessary to raise the bridge deck.

The median flow will increase substantially from the current minimum flow release of 100 cfs to 930 cfs under the Dam Removal Alternative. In addition, the river stage and velocities will be commonly higher under the Dam Removal Alternatives. The abutments consist of rock held in place by a wood crib structure (Figure 10-10). The abutment will experience higher flows for longer duration which may affect the lifespan of the current cribbing structure.

Table 10-5. Hydraulic conditions under No Action and Dam Removal Alternatives for J.C. Boyle Bypass Reach Bridge.

Item	**No Action**	**Dam Removal**
100-yr flood (cfs)	10,350	13,150
Median Flow (cfs)	100	930
Approximate 100-yr WSE (ft)	3726	3727
Approximate median flow WSE (ft)	3717.5	3720
Bridge Deck	3735	3735
Bridge Soffit	3731	3731

Figure 10-9. J.C. Boyle Bypass Reach Bridge.

Figure 10-10. Abutment of J.C. Boyle Bypass Reach Bridge.

10.5. Copco Bridge

Copco Bridge is located at the upstream end of Copco Reservoir. The cross section of the bridge is shown in Figure 10-11. The middle pier is located in the historical stream channel and extends to an elevation of 2560 feet. The bed elevation is at 2587.3 feet according to the drawings provided by Siskiyou County. After dam removal, there will be additional scour at this pier, but the pier rests upon bedrock and the additional scour will not destabilize the pier. There may be more exposure of the pier, so the pier may require additional protection from abrasion.

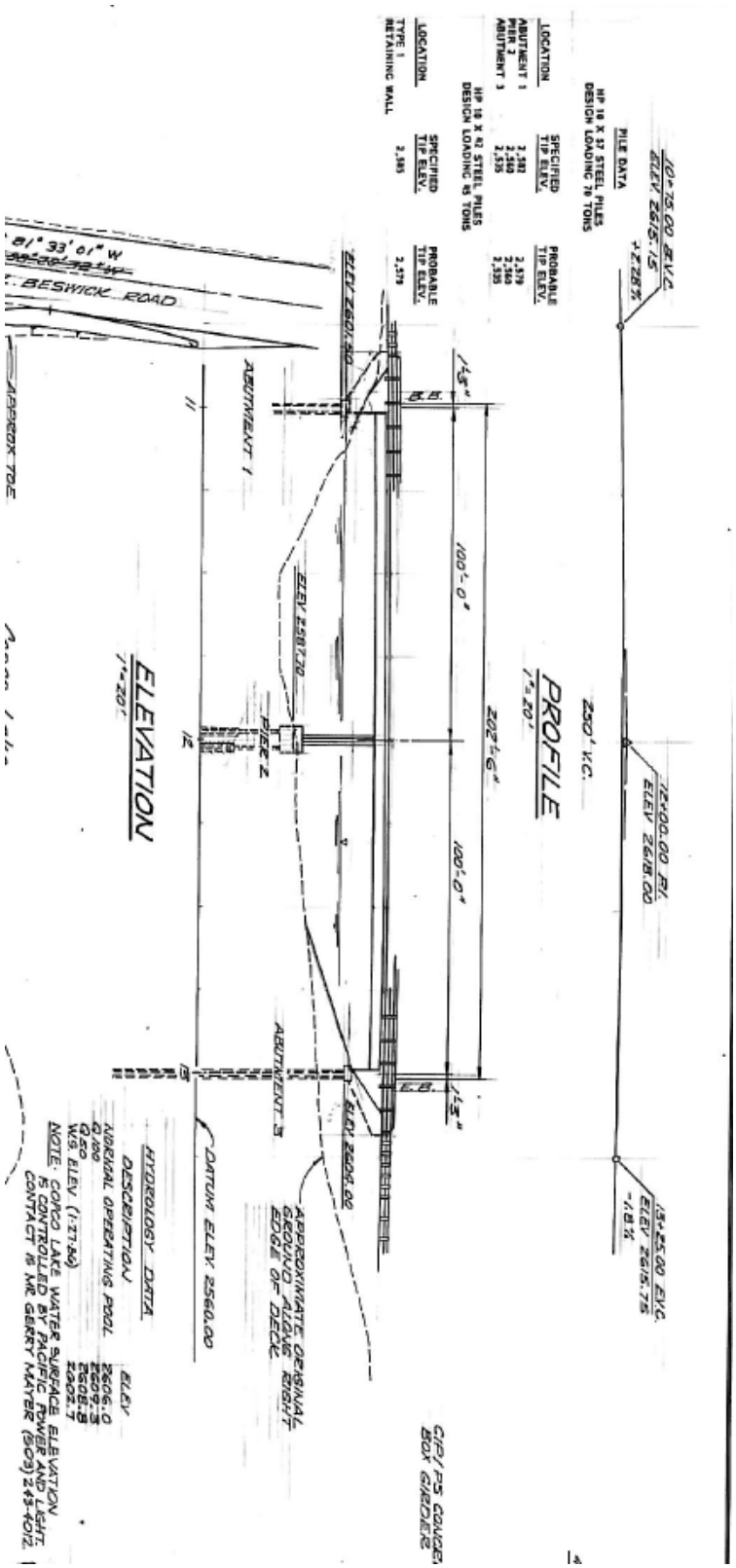

Figure 10-11. Pier elevations at Copco Bridge in upstream of Copco Reservoir.

10.6. Copco No. 2 Access Bridge

Copco No. 2 Access Bridge crosses the Klamath River in the upstream end of Iron Gate Reservoir. Information on the hydraulic conditions at the bridge for the No Action and Dam Removal Alternatives is given in Table 10-6. The 100-year flood information is from Table 2-4. The median flow is computed based upon the results listed in Appendix F. Exceedance Flows for No Action and Dam Removal Alternatives Based Upon Index Sequential Hydrology. The bridge deck elevation is taken from the 2010 LiDAR information. Based upon drawings from PacifiCorp, the bridge sofit is approximately 4 feet below the bridge deck. The bridge soffit is approximately 5 feet above the No Action Alternative 100-year WSE and 10 feet above the Dam Removal Alternative 100-year WSE. The hydraulic calculations are based upon the Iron Gate pre-dam survey having a 10-foot contour so the hydraulic calculations are expected to have a relatively large error associated with them. However, it is certain that the 100-year WSE under the Dam Removal Alternative conditions will be substantially lower than under the No Action Alternative. The bridge is shown in Figure 10-12 in the 2010 aerial photograph along with the pre-dam topography contours.

Because the water surface will decrease under the Dam Removal Alternative, the bridge will be exposed to higher velocities and greater scour potential. There are three piers located in the 100-year floodway. However, the bridge was built prior to the construction of Iron Gate reservoir and therefore would have been exposed to these high velocities at that time. The bridge and piers should be inspected to ensure they are in good condition. If they are in acceptable condition, additional protection should not be necessary.

Table 10-6. Hydraulic conditions under No Action and Dam Removal Alternatives for Copco No. 2 Access Bridge.

Item	**No Action**	**Dam Removal**
100-yr flood (cfs)	14,470	14,470
Median Flow (cfs)	1,390	1,360
Approximate 100-yr WSE (ft)	2,332	2,329
Approximate median flow WSE (ft)	2,328	2,323
Minimum Bridge Deck	2,341	2,341
Bridge Soffit	2,337	2,337

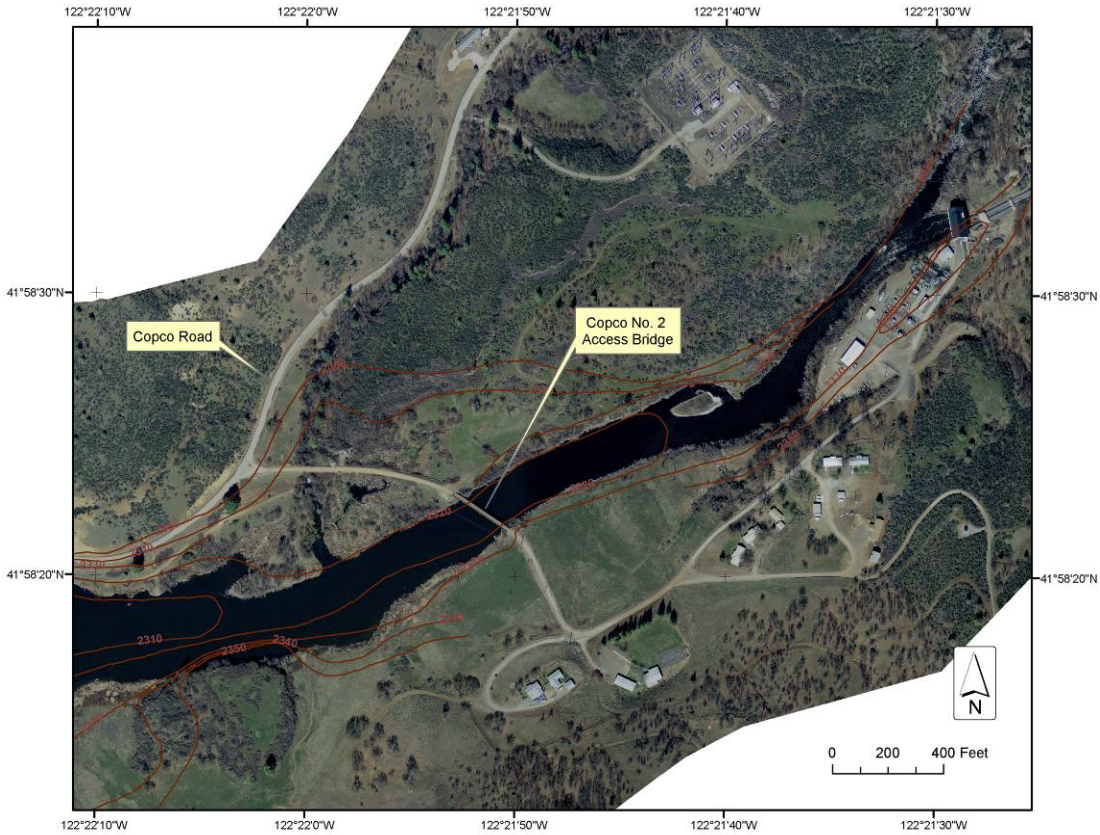

Figure 10-12. Copco No. 2 Access Bridge shown on 2010 aerial with pre-dam Iron Gate Reservoir survey contours.

10.7. Road Crossings with Culverts

Culverts are used to pass low flows under roads from several smaller tributaries into Iron Gate and Copco reservoirs. In some cases, these tributaries have created deltas perched above the pre-dam channel. After the reservoirs are emptied, the tributary channels will return to their pre-dam elevations and could possibly undermine the existing road crossings at these tributaries. At these road crossings, there would be two options to restore road access:

1. Prior to dam removal, move the crossing further upstream on the tributary.

2. Immediately after reservoir drawdown, grade a new road down to the elevation of the pre-dam channel. There may be a temporary interruption of access.

Scotch and Camp Creek at Iron Gate Reservoir

Copco Road intersects Scotch and Camp creeks and the crossings are shown in Figure 10-13 along with the pre-dam contours. The normal pool elevation of Iron Gate is 2328 feet and this can be compared against the pre-dam contours in the figure.

The current road elevation of the crossing at Scotch Creek is at an elevation of 2346 feet and the stream bed is currently at an elevation of 2336 feet based upon the 2010 LiDAR (NAVD88). The pre-dam elevation of the bed at this location was approximately 2334 feet (NAVD88). This indicates the bed should incise only a couple feet at this location. The current road alignment does not need to be altered, but a larger culvert will need to be installed to account for potential drop in bed elevation.

At Camp Creek, the current road elevation is at 2340 feet and the water surface elevation is at 2329.5 feet (NAVD88). The pre-dam bed elevation was approximately 2310 (NAVD88). Substantial erosion is expected at this location.

Fall Creek at Iron Gate Reservoir

The road crossing at Fall Creek at Iron Gate Reservoir is shown in Figure 10-14. The current road elevation at this crossing is 2348 feet and the water surface elevation is 2333 feet (NAVD88). The pre-dam elevation is estimated to be at approximately a normal pool elevation of 2331 feet (NAVD 88). Therefore, the incision expected at this site should be a couple feet.

Beaver Creek at Copco

Copco Rd crosses East Fork Beaver Creek and Beaver Creek along the north side of the reservoir (Figure 10-15). The road elevation is at approximately 2623 feet (NAVD88) and the gulch is at elevation 2616 feet just downstream of the crossing

(NAVD88). The normal pool elevation is at about 2606 feet (NAVD88) and the shoreline is about 430 feet from the road crossing. There is evidence of a substantial delta at this location and several feet of incision at the road crossing is possible.

Raymond Gulch at Copco

Figure 10-16 shows the crossing of Copco Rd over Raymond Gulch. The road elevation is at approximately 2631 feet (NAVD88) and the gulch is at elevation 2625 feet (NAVD88). The normal pool elevation is at 2606 feet (NAVD88) and the shoreline is about 450 feet from the road crossing. This crossing is elevated far enough above the reservoir, so that there should be no significant erosion at the crossing.

Tributary crossing Topsy Grade Road near J.C. Boyle Dam

Topsy Grade Road crosses an un-named tributary near J.C Boyle Dam. The watershed area of the tributary is approximately 5 square miles. The 2010 aerial photography and the pre-dam contours are shown in Figure 10-17. The elevation contour of 3793 feet (NAVD29) is the normal maximum pool elevation and defines the extent of the reservoir. A small delta has formed upstream of the road crossing, but this delta has not reached the road.

According to the pre-dam topographic map from PacifiCorp, there were three 24 inch culverts that pass flow underneath the road. The culverts are not aligned with the historical river channel and the road would act as a dam when high flows occur. The culverts will need to be aligned with the historical stream channel. The same number and size of culverts will be sufficient to maintain the same level of access for the road. The road will need armoring with riprap on the downstream face so that it does not erode away when overtopped. .

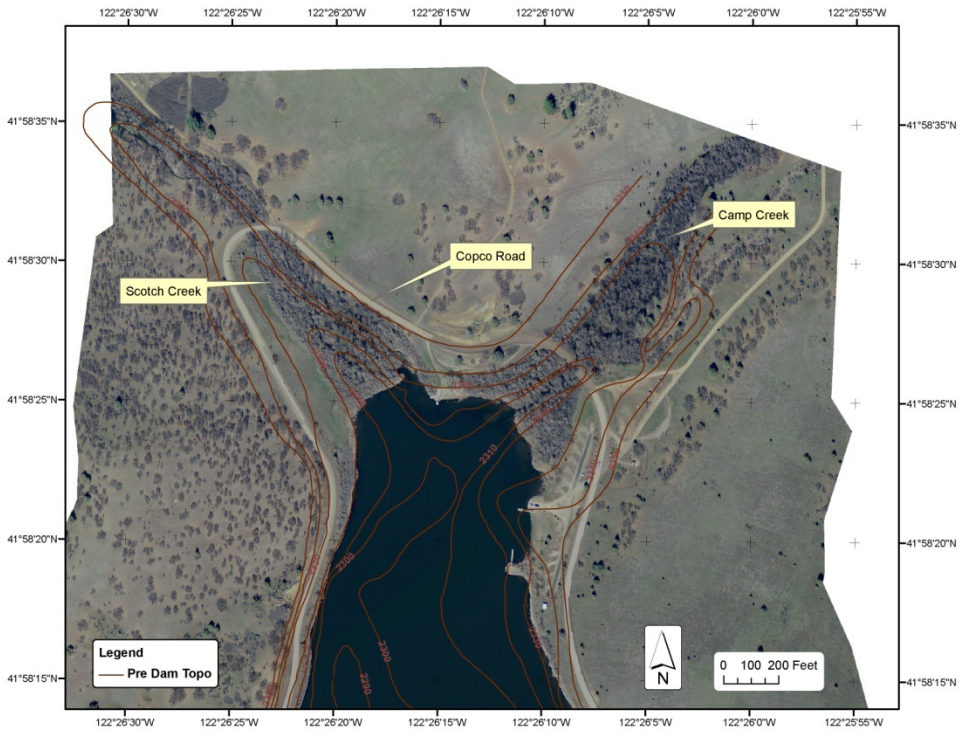

Figure 10-13. Road crossings at Scotch and Camp creeks. Pre-dam contours are in NGVD29 vertical datum.

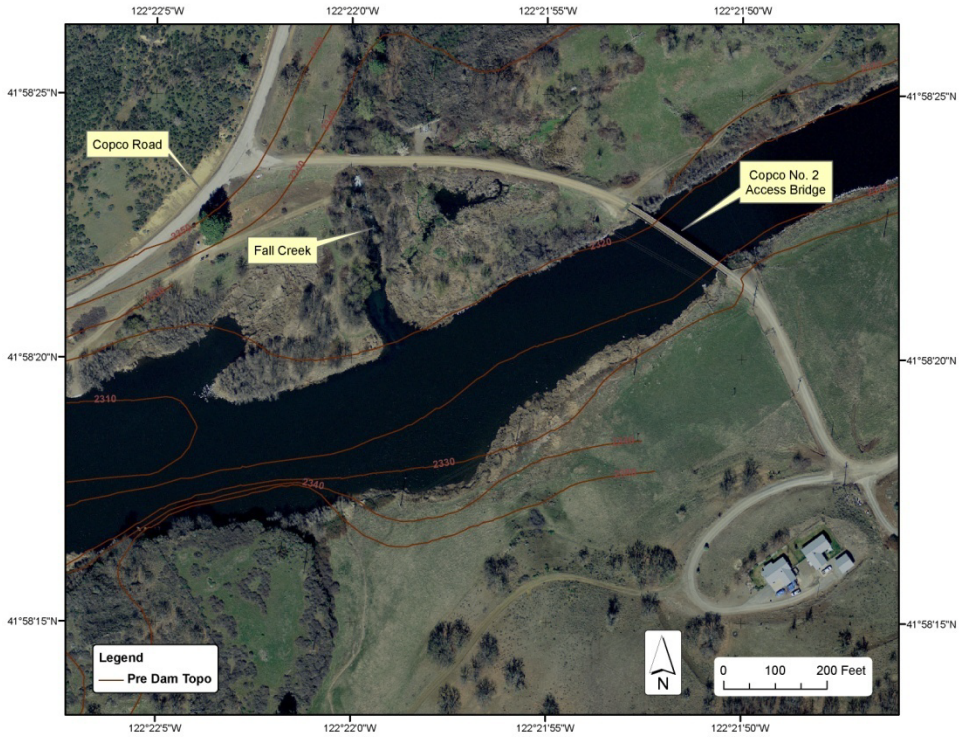

Figure 10-14. Fall Creek Road crossing at Iron Gate Reservoir. Pre-dam contours are in NGVD29 vertical datum.

Figure 10-15. Beaver Creek Road crossing at Copco Reservoir.

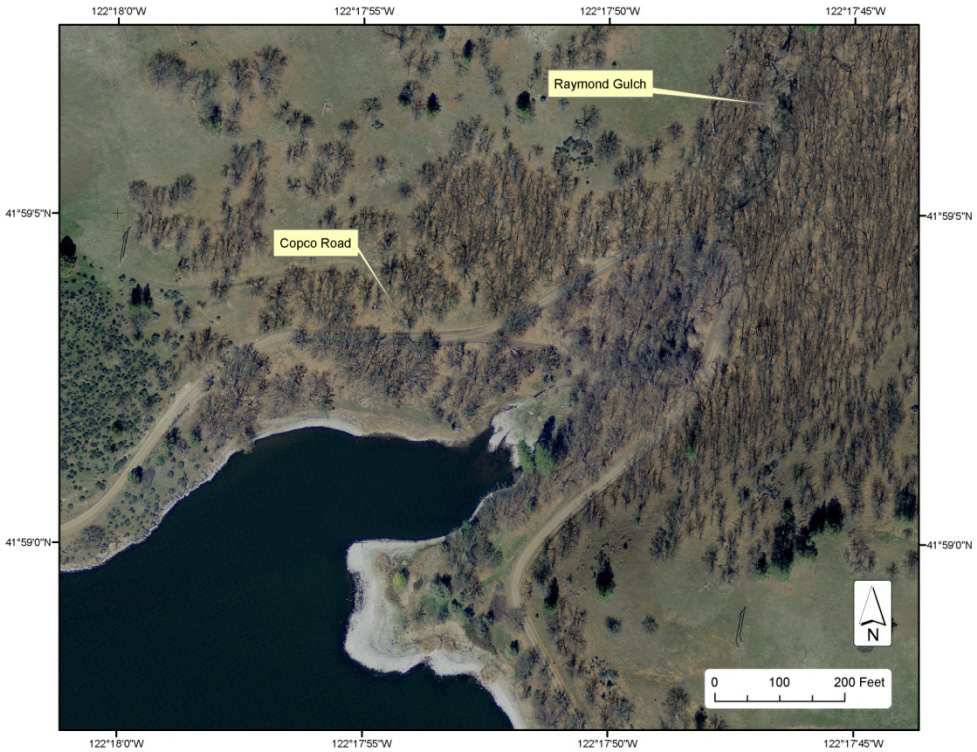

Figure 10-16. Raymond Gulch Road crossing at Copco Reservoir.

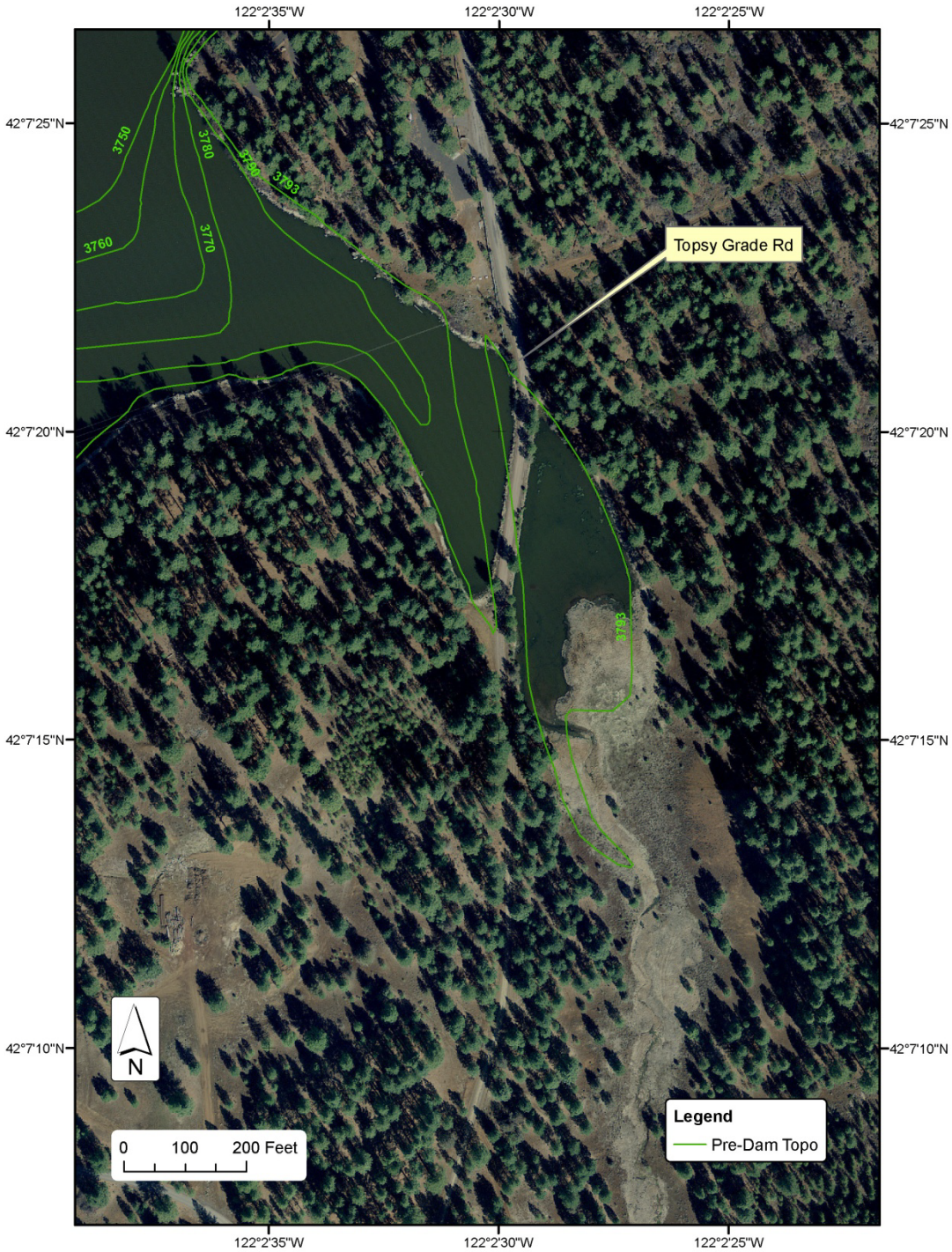

Figure 10-17. Crossing at Topsy Grade Road near J.C. Boyle Dam.