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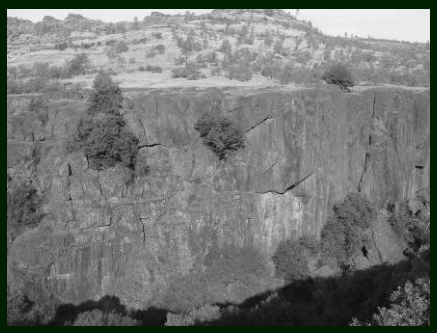

Evaluation of Iron Canyon

For Proposed Fish Ladder Structure Repair and Construction

Final Report

May 2006

SAGE HDR

Evaluation of Iron Canyon For Proposed Fish Ladder Structure Repair and Construction

May 24, 2006

U.S. Fish and Wildlife Service
Chico, California

Forward

This report presents the findings of an evaluation by HDR Engineering, Inc. and Sanders & Associates Geostructural Engineering, Inc. for the proposed fish ladder structure repair and construction in Iron Canyon. Included in this report are discussions of the investigations, interviews, and analyses performed during the course of this evaluation. Based on the information collected and the analyses performed, the report addresses the geologic hazards, constructability, design considerations, operations and maintenance, structure lifespan, and safety issues associated with the repair and construction of the fish ladder. Attached appendices include full size drawings illustrating geologic and project features discussed in the report, and laboratory test results.

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Introduction

HDR Engineering, Inc. (HDR), along with our geostructural subconsultant Sanders & Associates Geostructural Engineering, Inc. (SAGE), presents herein an evaluation report of Iron Canyon that focuses on geological, seismic, structural, hydraulic and hydrological factors as they relate to the proposed fish ladder structure repair and construction.

Specifically, this document reports the results of a geologic review, reconnaissance, and analyses to identify significant geologic constraints that could adversely impact the project and the selected fish ladder alternatives. An evaluation of the general risk posed by the identified constraints, if the existing ladder is repaired and/or removed and new segments are constructed, is also included. The primary geological issues identified include stability of the western canyon wall (i.e., rock fall potential) above the fish ladder and stability of various sized rock blocks along the creek channel adjacent to or supporting the fish ladder structure. Hydraulics and its effect on block stability is also included. We also evaluated the stability and suitability of the west canyon rim for construction staging, as well as the existing rock blocks in the creek channel for the use as a foundation for the proposed fish ladder structure repair and construction.

This evaluation report is intended to supplement prior studies by focusing on geological, structural, and hydraulic factors related to the design, construction, maintenance and long term performance of the proposed fish ladder repair. It is not intended to judge the merits of the project from a fisheries perspective.

Project Background

The Iron Canyon fish ladder is located in Big Chico Creek, northeast of Chico, California (Figure 1). Big Chico Creek flows through Butte and Tehama Counties, and is encompassed by an approximately 72-square-mile watershed. The creek originates on Colby Mountain's western slope and flows approximately 45 miles to its confluence with the Sacramento River.

Declining numbers of salmon and steelhead trout have created a need for restoration activities to preserve and promote these populations. Toward this end, the U.S. Fish and Wildlife Service (USFWS), the California Department of Fish and Game (DFG), the California Department of Water Resources (DWR), and other interested stakeholders are working to improve fish passage via the Iron Canyon fish ladder on Big Chico Creek. The overall intent of this improvement is to repair the fish ladder to allow fish passage to approximately nine miles of upstream habitat over a broader range of flows for spring-run Chinook salmon and steelhead trout.

Figure 1 – Site Vicinity Map

The existing fish ladder was constructed by the DFG in 1958 with assistance from the Magalia Honor Camp of the State Division of Forestry. The seventeen weirs that comprise the ladder were reportedly constructed to bypass a 14-foot-high waterfall created by debris deposited by a rock slide that occurred in the early 1900s, possibly as a result of the 1906 San Francisco earthquake (DFG, 1958).

Fish passage through the existing ladder at low flows is currently difficult if not impossible, due to pool leakage, weir deterioration, and inadequate contact between weir bases and underlying creek bed. Currently, the upper portion of the ladder is not passable at low flows, while the lower portion is marginally passable. Damage to the structure has been reported, and erosion and weathering of the existing concrete ladder structure has resulted in exposed rebar in some locations.

The DWR Northern District prepared a *Preliminary Engineering Technical Report* for the Iron Canyon and Bear Hole Fish Passage Project on Big Chico Creek in April of 2002. The report discusses project alternatives and presents preliminary engineering drawings for these alternatives. The report includes a Geological Feasibility Study, dated March 28, 2001, however, potential impacts of rock slope failures (e.g., rock falls) were not considered. The report also includes a cultural resources study (September, 2000) and a preliminary environmental inspection (September, 2000).

In the *Preliminary Engineering Technical Report*, the fish ladder was divided into lower and upper sections. The lower section was defined as the area downstream of Pool (Weir) 8, and the upper section was defined as the area upstream of Pool 8. For the purposes of clarity between this evaluation report and the *Preliminary Engineering Technical Report*, we have adopted the same nomenclature.

Scope of Services

The technical scope of services consisted of the following tasks and subtasks:

1. Literature and Aerial Photograph Review
   a) Geologic Literature Review
   b) Aerial Photograph Review
   c) Digital Photograph Mosaic of Canyon Walls.
   d) Hydrologic Data Review
2. Geologic Reconnaissance
   a) Geologic Reconnaissance of Fish Ladder
   b) Geologic Reconnaissance of Canyon Rim/Walls.
3. Laboratory Testing

4. Geological Analyses
5. Rock Fall Risk Assessment
6. Foundation Stability (Creek Channel) Assessment
7. Hydrodynamic Evaluation
8. Constructability Evaluation
9. Evaluation Report
10. Public Outreach

This evaluation report serves as the deliverable associated with Task 9, and addresses the topics of Tasks 1 through 8.

Investigations

The following tasks were performed as part of our evaluation of Iron Canyon for the proposed fish ladder structure repair and construction.

Interviews

A number of individuals were interviewed regarding the geologic and hydrologic conditions in Iron Canyon, past rock fall events, the availability of vertical and oblique historic photos covering the site, and the suitability of specific construction equipment for the project. A list of individuals who provided pertinent information is included in the references.

Geologic Literature and Aerial Photograph Review

Available published and unpublished geologic data covering the site vicinity were reviewed, including reports, maps, and theses on-file at California State University, Chico; University of California, Davis (UCD); and the U.S. Geological Survey (USGS) in Menlo Park. We also reviewed the Geological Feasibility Study report included in the *Preliminary Engineering Technical Report*. We compiled pertinent geological data on rectified aerial photograph base maps provided by DWR. These maps are attached as oversize Drawings 1 and 2 in Appendix A.

Also reviewed were 11 sets of historic stereo-paired aerial photographs gathered from various public and private sources. The photographs were flown between 1937 and 2000. Standard aerial photogeologic interpretation techniques were used to map geologic features. The most recent set of photographs reviewed (2000) were flown at a scale of approximately 1:2,400 (1 inch = 200 feet) specifically for use during preparation of the *Preliminary Engineering Technical Report*. The photographs from 1937 to 1990 were flown by federal agencies or private suppliers at smaller scales ranging from 1:20,000 (1 inch = 1,667 feet) to 1:31,680 (1 inch = 2,640 feet).

To supplement the aerial photographs, we reviewed three historical topographic maps dated 1895, 1953, and 1980 on-file at the UCD Shields Library. A list of aerial photographs and topographic maps reviewed is included in the references.

Digital Photograph Mosaic of Canyon Walls

Due to vertical to near vertical slopes, the western canyon wall above the fish ladder was not visible on the rectified aerial photograph base maps. To record and present geologic data for this canyon wall, we prepared two digital photograph mosaics (photomosaics) of the canyon wall by digitally "stitching" overlapping photographs taken from inside Iron Canyon. These photomosaics are attached as oversize Drawings 3 and 4 in Appendix A. The point of view and extent of the photomosaics are shown on Drawings 1 and 2. No scale is shown on the photomosaics due to displacement and distortion errors common to using uncorrected photographs.

Hydrologic Data Review

Hydrologic data for the project location was obtained from two gages. Data from water years 1931 to 1986 are from the USGS gaging station #11384000, which was located approximately 3/4 miles downstream of Bear Hole (now abandoned). Data from water years 1996 to 1998 are from the DWR gaging station #A04250 located approximately 1-1/2 miles downstream of the abandoned USGS gage. The USGS gage data is as follows:

- Butte County, California
- Hydrologic Unit Code 18020119
- Latitude 39°46'35", Longitude 121°45'10" NAD27
- Drainage area: 72.4 square miles
- Gage datum 300.00 feet above sea level NGVD29

The DWR gaging station is only capable of recording flows up to about 3,300 cfs, and was not recording during the 1997 storms. The flow data for 1997 (maximum flow from which hydraulic modeling was performed) was developed by the Flood Study Unit of the USGS in 1997 and is based on direct measurements (Tom Haltrom, Public Information Officer of the California Water Science Center of the USGS). Figure 2 shows the historic flows in Big Chico Creek for the water years 1931 to 1998.

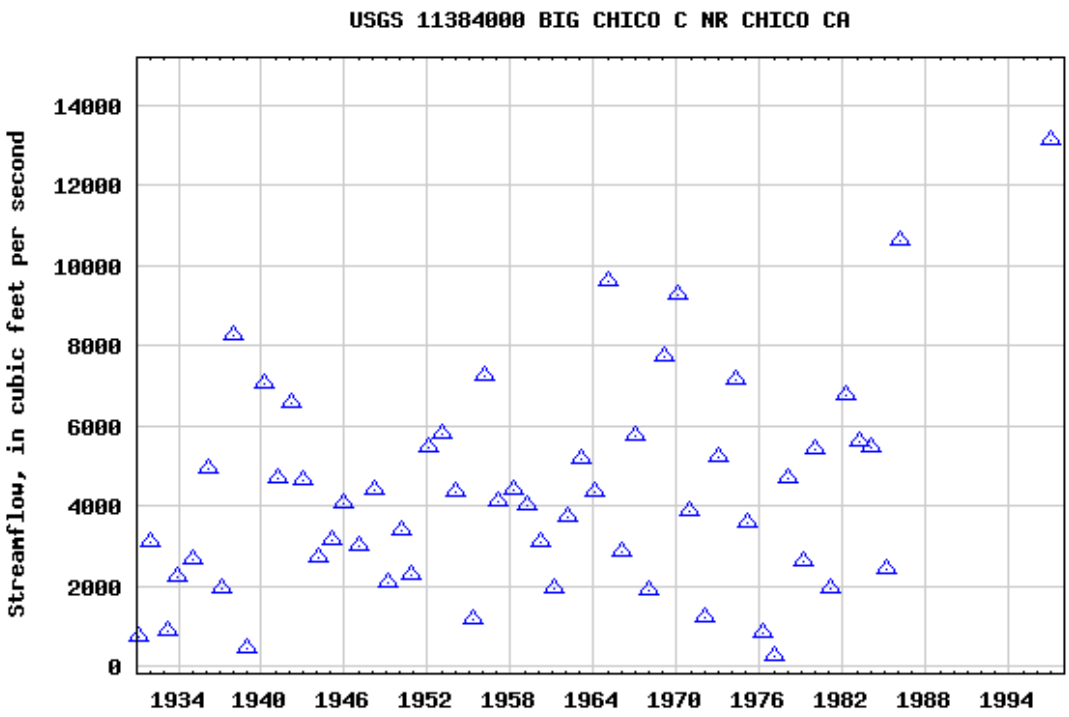


Figure 2 - Historic Flows in Big Chico Creek.

Geologic Reconnaissance

Geologic reconnaissance mapping of the site and immediate vicinity was performed from December 12 through 15, 2005. Supplemental mapping and field checking was performed on February 22, May 11, and May 21, 2006. The primary objectives of the mapping were to identify geologic features, characterize bedrock units and their structural discontinuities (i.e., bedding, joints, and faults), and identify areas of potential instability (i.e., unstable blocks). Geologic data was recorded on the rectified aerial photograph base maps and photomosaics (Drawings 1 through 4 in Appendix A).

Laboratory Testing

Laboratory testing was performed on four selected rock samples collected during the geologic reconnaissance to develop representative rock strength parameters for design and construction. In addition, we performed laboratory testing on one soil sample to determine its plasticity index. Laboratory tests performed include:

- Atterberg Limits (Plasticity Index) per ASTM D4318
- Rock Bulk Density
- Rock Uniaxial Compressive Strength per ASTM D7012-04-Modified

Laboratory test results are included in Appendix B.

Monitoring Points

During the course of our investigation, we requested that DWR Northern District personnel establish monitoring points on selected rock blocks along the fish ladder to measure movement associated with winter stream flows, if any. Nine monitoring points were established during low creek flows (approximately 100 cfs) on February 22, 2006, using a total station (combination electronic transit and electronic distance measuring device). The estimated dimensions of blocks selected for monitoring ranged from 3x3x7 feet to 10x20x20 feet. The monitoring points were generally established on the smaller sized blocks that would be more likely to move during high creek flows. However, two monitoring points were established on two large blocks that might have moved in the past according to Mr. Paul Ward of DFG. The locations of the monitoring points are shown on Drawing 2.

Monitoring Point 1 was established on an inaccessible block in the creek channel using reflectorless surveying methods, and, therefore, was used to evaluate large-scale movements. Monitoring Points 2 through 8 were established using lead and tack methods. Lead was tamped into an existing crack or small notched chipped into the basalt block, and then a steel tack was hammered into the lead.

The monitoring points were resurveyed by DWR personnel on May 11, 2006. The results of the resurvey indicated that no detectable movement occurred over the 78-day period between the date the monitoring points were established and resurveyed. Figure 3 shows the flows in Big Chico Creek measured at the downstream DWR gaging station during this period.

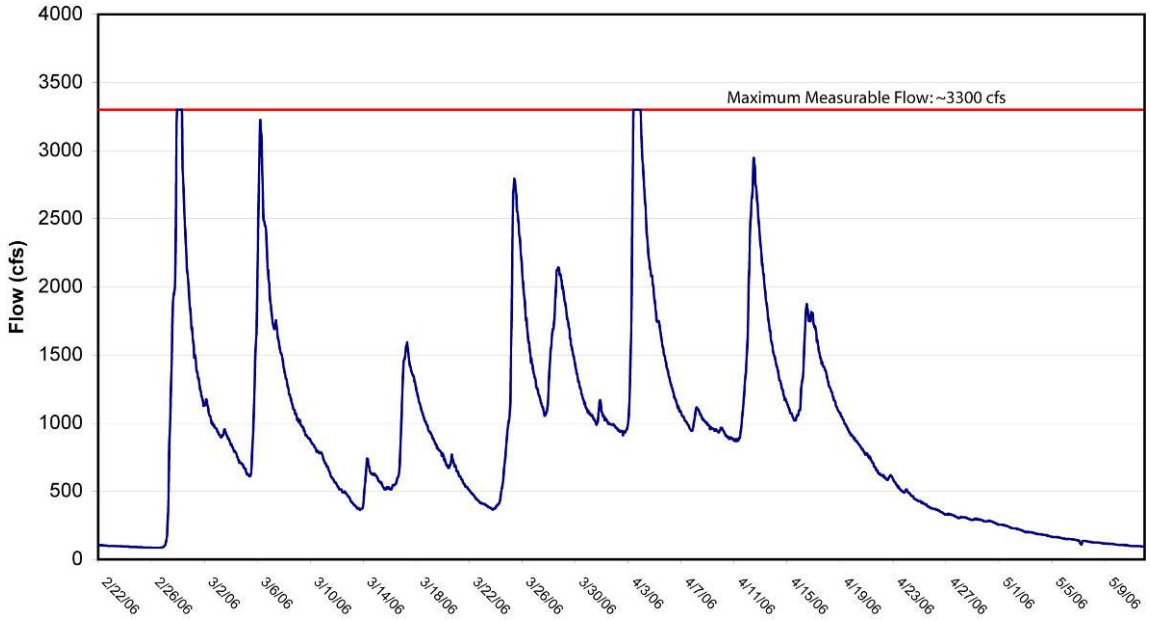


Figure 3 – Big Chico Creek flows during the block monitoring period - February 22, 2006 to May 11, 2006.

Regional Geologic Setting

The site is located in the southernmost portion of the Cascade Range geomorphic province. The Great Valley geomorphic province lies to the west and the Sierra Nevada geomorphic province lies to the east and south. Rocks from the Cascade Range and Great Valley provinces are exposed along Big Chico Creek, and include Upper Cretaceous marine sedimentary[1] rocks of the Chico Formation, Miocene volcanic[2] rocks of the Lovejoy Basalt, and Pliocene volcanic and sedimentary rocks of the Tuscan Formation. A regional geologic map showing the distribution of these formations is presented as Figure 4. A brief description of these stratigraphic units and the geologic history of the Big Chico Creek area, modified from Doukas (1983), are provided below.

The Chico Formation consists of fossiliferous marine sandstone with siltstone and conglomerate interbeds that accumulated in a shallow sea that covered the area about 75 to 90 million years ago. The sandstone is generally friable with some cemented beds locally, particularly along fossiliferous horizons (Creely, 1965; Doukas, 1983).

Subsequent to deposition of the Chico Formation, the area was uplifted above sea level and exposed to weathering and erosion. About 16 million years ago, large volumes of Lovejoy Basalt flowed across the area, preferentially filling low areas and drainages in the pre-existing topography (Page et al., 1995). The eruptive source of the Lovejoy Basalt is thought to be east of the Sierra Nevada (Durrell, 1959), and recent paleomagnetic work by Coe et al. (2005) suggests that a volcanic "hotspot", currently associated with Yellowstone National Park, may have produced the Lovejoy Basalt before migrating to its current position in Wyoming.

Approximately 4 million years ago, the Lovejoy Basalt was covered by the Tuscan Formation, which consists of a series of interbedded lahars (volcanic mud flows), volcanic conglomerate, and volcanic sandstone deposits. The likely source for these deposits was several volcanoes near Mt. Lassen, approximately 40 miles northeast of Chico (Guyton and DeCourten, 1978).

After deposition of the Tuscan Formation, the area was subject to uplift and faulting during formation of the Chico Monocline. The Chico Monocline is a northwest-trending flexure that extends about 47 miles along the northeast side of the Sacramento Valley from Chico to Red Bluff (Harwood et al., 1981). The monocline formed between 1.0 and 2.6 million years ago from uplift of the northern Sierra Nevada and rupture along a concealed fault beneath the monocline, referred to as the Chico Monocline fault (Figure 4; Harwood and Helley, 1987). Bedding in the Tuscan Formation east of the monocline dips less than 5 degrees to the southwest, but steepens to 20 degrees or more along the monoclinal flexure (Harwood and Helley, 1987). The trace of the monocline is characterized at the surface by a series of short, generally northwest-trending anastomosing fault segments (Figure 4).

1. Sedimentary rocks are formed by the consolidation and compaction of loose fluvial sediment or by chemical precipitation.
2. Volcanic rocks are formed by crystallization of magma at or near the surface of the earth.

Figure 4 – Regional Geologic Map

In response to tectonic uplift and tilting, Big Chico Creek eroded through the Tuscan Formation and exposed the older Lovejoy Basalt. Continued downcutting through the very hard and resistant basalt resulted in the formation of a steep-sided, narrow canyon (Figure 5), primarily oriented along two primary joint sets within the basalt. Where the creek has cut entirely through the basalt into the softer Chico Formation, the steep canyon walls have been prone to instability due to undercutting and the loss of support (Guyton and DeCourten, 1978).

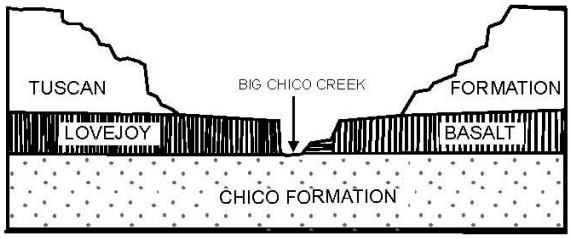


Figure 5 – Generalized profile across Big Chico Creek in Upper Bidwell Park showing the primary stratigraphic units. Modified from Guyton and DeCourten (1978). Not to scale.

Regional Seismic Setting

Historically, the area has been one of relatively low earthquake activity compared to other parts of California. The major active fault[3] systems that might affect the site are the San Andreas fault system located in the Coast Range, the Cascadia subduction zone offshore of northwestern California, and the Eastern California Shear Zone along the eastern side of the Sierra Nevada. Because of their distance from the site, these active fault zones are generally considered less significant sources of ground shaking than the nearby potentially active[4] Chico Monocline fault and the Foothills fault system.

The concealed trace of the Chico Monocline fault is mapped by Helley and Harwood (1987) approximately 2.5 miles southwest of the site (Figure 4), making this the closest potentially active fault. The estimated minimum long-term slip rate for the fault is 0.2 mm/year (McPherson and Garvin, 1999). Harwood and Helley (1987) indicate that movement has occurred along the monoclinal fault system within the past million years, and suggest that two aftershocks of the 1975 Oroville earthquake may have occurred on this fault. The Chico Monocline fault is not currently zoned as active under the State of California Alquist-Priolo Earthquake Fault Zoning Act (Hart and Bryant, 1997).

The Foothills fault system is a group of northwest-trending faults that tectonically separate distinctive belts of Paleozoic and Mesozoic rocks for more than 200 miles along the western foothills of the Sierra Nevada (Clark, 1960). The fault system terminates near Lake Oroville, approximately 12 miles southeast of the site. Major tectonic activity along the Foothills fault

3. Active faults are defined as those exhibiting either surface ruptures, topographic features created by faulting, surface displacements of Holocene (younger than about 11,000 years old) deposits, tectonic creep along fault lines, and/or close proximity to linear concentrations or trends of earthquake epicenters.

4. Potentially active faults displace geologic deposits of Pleistocene age (about 2 million to 11,000 years old).

system is thought to have occurred in the Late Jurassic. During the last five million years, the Sierra Nevada has been uplifted as a tilted block by active faults along the steep eastern escarpment of the mountain range. In response to this uplift, microseismicity and small fault displacements have occurred along the Foothills fault system. On August 1, 1975, a magnitude 5.7 earthquake and associated surface ruptures occurred near Oroville (Sherburne and Hauge, 1975), focusing attention on the Foothills fault system as a potential area of active faulting (Harwood et al., 1981). However, the general absence of Quaternary age deposits in the Sierra Nevada foothills has made it difficult to assess the recency of fault activity along the fault system. Where investigated, fault displacement rates appear to be low during the past 100,000 years (Schwartz et al., 1996).

The Foothills fault system is not currently zoned as active under the State of California Alquist-Priolo Earthquake Fault Zoning Act, expect for the Cleveland Hill fault which experienced ground rupture during the 1975 Oroville earthquake (Hart and Bryant, 1997; CDMG, 1977). The Cleveland Hill fault is located approximately 25 miles southeast of the site. The maximum moment magnitude[5] earthquake estimated for the Foothill fault system is M_w 6.5, with a recurrence interval of about 12,500 years (CDMG, 1996).

Site Conditions

The fish ladder is located on Big Chico Creek where it flows through Iron Canyon in Upper Bidwell Park. Iron Canyon is a steep-sided canyon approximately 170 feet deep and 480 feet wide. The canyon is flanked on either side by a prominent topographic bench which marks the approximate top of the Lovejoy Basalt (Drawing 1).

For the purposes of clarity in this report, the surface features within Iron Canyon have been subdivided into six distinct zones. The zones are described below moving from the west rim to the east rim of Iron Canyon, and are shown on a schematic cross section presented as Figure 6.

- The *western canyon wall* is a near vertical to vertical rock cliff approximately 140 feet high.
- The *lower western canyon slope* is a steep, approximately 30-foot-high, slope that extends down from the base of the western canyon wall to the Big Chico Creek channel. The slope is characterized by a chaotic assemblage of slope debris and large basalt blocks.
- The *Big Chico Creek channel* is an approximately 80-foot-wide channel filled with various sized basalt blocks with granular alluvium locally filling the voids between the blocks.

5. Moment magnitude (M_w) is directly related to average slip and rupture fault area, while the Richter magnitude scale reflects the amplitude of a particular type of seismic wave.

- The *lower eastern canyon slope* is a steep, approximately 90-foot-high slope that extends from the Big Chico Creek channel to an intermediate topographic bench. The slope is characterized by a chaotic assemblage of slope debris and large basalt blocks.
- The *intermediate eastern bench* is a prominent topographic bench that extends along the eastern side of Iron Canyon and continues upstream. The bench terminates downstream of the fish ladder near the abrupt bend in Big Chico Creek (Drawing 1). The surface of the bench is highly irregular with a large open fissure up to 30 feet deep present along a portion of the bench (Drawing 1). A slope is located along the eastern (back) edge of the bench, sloping steeply up to the eastern canyon wall. The slope is characterized by a chaotic assemblage of slope debris and large basalt blocks.
- The *eastern canyon wall* is a near vertical to vertical rock cliff about 50 to 80 feet high.

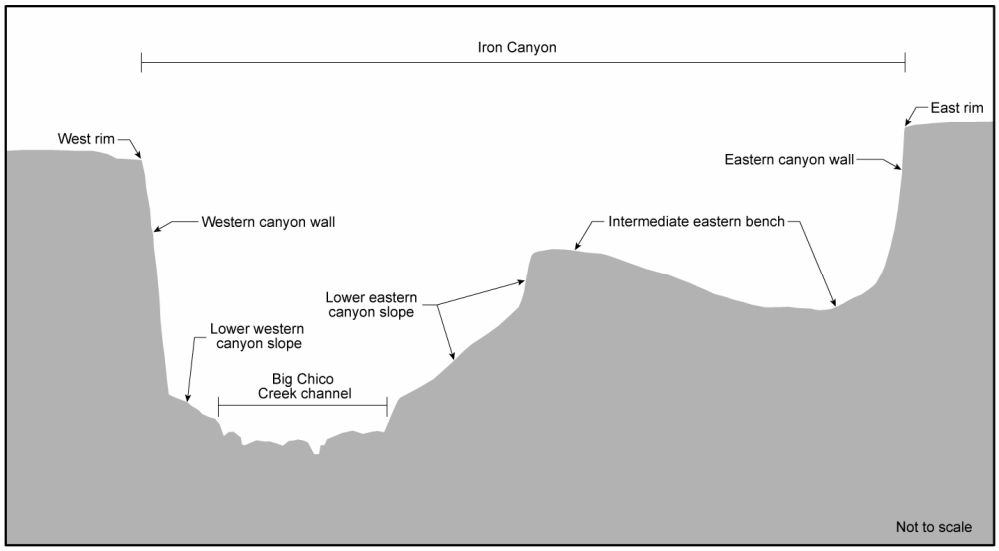


Figure 6 – Schematic cross section across Iron Canyon. View looking upstream.

Site Geology

Geologic conditions at the site are generally similar to those described and/or depicted by Burnett (1961 and 1967), Guyton and DeCourten (1978), Harwood et al. (1981), Doukas (1983), and Saucedo and Wagner (1992). The primary bedrock unit present at the site is the Lovejoy Basalt, which forms the resistant cliffs of Iron Canyon (Drawing 1).

Surficial deposits locally blanket the Lovejoy Basalt (Tl) bedrock, and include rock fall/landslide deposits (Qd/Qls) and undifferentiated alluvium and rock fall deposits (Quad). The approximate limits of the bedrock and surficial deposits are shown on Drawings 1 and 2. Schematic geologic cross sections A-A' and B-B', oriented across Iron Canyon, are included as Drawings 5 and 6. These cross sections are based on limited spot elevations, and therefore, should be considered schematic for the purposes of this report.

The geologic units (map symbols shown in parentheses) mapped at the site are discussed in further detail below, from oldest to youngest. The physical properties criteria used to describe the rock fracturing, hardness, strength, and degree of weathering are included on Figure 7.

Chico Formation (Kc)

Geologic mapping by Harwood et al. (1981) shows the Chico Formation cropping out along Big Chico Creek approximately ¾-mile upstream (northeast) of the site (Figure 4). The unit may be present immediately below the creek at the location of the fish ladder. However, significant rock block debris along the base of the canyon conceal the underlying units, and therefore, the presence of the Chico Formation cannot be confirmed by surface exposures.

Where exposed in Big Chico Creek upstream of the site, this unit consists of friable sandstone that is easily eroded, resulting in progressive undercutting of the Lovejoy Basalt. The undercutting has locally triggered instability of the Lovejoy Basalt, with large basalt blocks having toppled or slid into the creek channel.

Lithic Tuff (no map symbol)

An unnamed lithic tuff unit is visible at creek level immediately upstream of the fish ladder and at two locations downstream of the fish ladder (Drawing 1). The tuff underlies the Lovejoy Basalt at the furthest downstream exposure located at the abrupt bend in Big Chico Creek. This unit may have been deposited during the early stages of volcanic activity prior to the arrival of the overlying basalt flows.

Where visible, the tuff is generally a deeply weathered soil-like material. Laboratory testing of a representative sample indicates that the material is highly plastic silt. Furthermore, a seep is present at the downstream exposure closest to the fish ladder (Drawing 1). Tobia (1997) described a similar tuff or tuffaceous sandstone unit underlying the Lovejoy Basalt in Coal Canyon at Table Mountain near Oroville. In addition, Creely (1965) described a volcanic conglomerate unit below the Lovejoy Basalt at several localities in the Oroville 15-minute quadrangle. Creely estimated the unit thickness at 15 to 20 feet.

The presence of the lithic tuff unit both upstream and downstream of the fish ladder suggests that Big Chico Creek has cut through the Lovejoy Basalt in Iron Canyon, and depending on the thickness of the lithic tuff, may have cut into the underlying Chico Formation (Drawings 5 and 6).

Lovejoy Basalt (Tl)

The Lovejoy Basalt consists of a series of basalt flows that generally dip approximately four to five degrees to the southwest (Burnett, 1961 and 1967; Doukas, 1983). It is likely the basalt was deposited horizontally and that this dip is related to regional uplift associated with the Chico Monocline.

Figure 7 – Rock Description Chart

The basalt is characterized by dark gray to black, dense, microcrystalline to extremely fine-grained crystalline rock. The rock is generally moderately fractured, very hard, very strong, and little weathered. Basalt is generally extremely resistant to weathering because the very dense, highly interlocked texture of very small crystalline particles makes the rock impenetrable to water (Goodman, 1993). Weathering typically is limited to joints and fractures along which water can flow.

Four representative samples of the Lovejoy Basalt were collected from the site. Because of the density and strength of the rock and limited equipment that could be packed in, the samples consisted of relatively small, loose blocks lying on the ground. We were unable to collect suitable rock samples for direct shear testing of the bedrock joints. Therefore, we estimated what we considered to be reasonable, but conservative, values for joint friction angles for our analyses.

The results of rock uniaxial compressive strength tests performed on the four basalt samples are included in Appendix B, and are summarized below in Table 1.

Table 1 – Rock Uniaxial Compressive Strength Tests

Sample No.	Density (pcf)*	Unconfined Compressive Strength (psi)**	Style of Failure
1	177.5	31,360	Failed along pre-existing joint
2	177.9	63,970	Brittle failure
3	177.5	7,280	Failed along pre-existing joint
4	176.9	33,280	Failed along pre-existing joint

* Units in pounds per cubic foot (pcf)
** Units in pounds per square inch (psi)

Test 2 indicated a rock compressive strength of nearly 64,000 psi before brittle failure occurred. The remaining tests exhibiting lower strengths failed partially or entirely along pre-existing joint surfaces.

Three distinct systems of fracturing and jointing are present in the Lovejoy Basalt. The first system is a series of subhorizontal and low angle joints that may be related to cooling and/or flow unit boundaries. These joints range in orientation, with dips of up to approximately 30 degrees. These joints often form small benches or overhangs on the steep canyon walls. Joint spacing between flows ranges from 2 to 25 feet.

The second system is a vertical columnar jointing that is poorly to moderately developed in the upper portion of the Lovejoy Basalt. The columnar jointing forms parallel columns that have four to seven sides and are generally 5 to 10 inches in diameter. The joints form as a result of contraction of an individual basalt flow during cooling. Columnar jointing is generally not present in the lower portion of the Lovejoy Basalt, where the basalt tends to be massive with more widely spaced joints.

The third system is a pair of vertical joints, which are informally referred to as the primary (master) joints in this report. The joints are generally orthogonal, and form vertically stacked rectangular blocks. These joints differ from the columnar jointing in that they pass continuously through two or more basalt flows, and many can be traced through the entire thickness of the formation (Burnett et al., 1969). The joints do not extend into the underlying Chico Formation or overlying Tuscan Formation (Creely, 1965).

The primary joints generally trend approximately N15E and N85E, although there is a natural variation in orientation of about 15 degrees. The joint spacing is about 5 to 12 feet. The joints are discernable at the ground surface outside of Iron Canyon where they are typically expressed as linear depressions in the ground surface in which a thin cover of soil and grass has developed. Between the joints, basalt rock is typically exposed and forms small linear ridges. These surface features are visible in the aerial photograph base on Drawing 1. A similar style of primary jointing in the Lovejoy Basalt was described by Creely (1965), Burnett el al. (1969), and Doukas (1983).

The trend of the primary joints strongly influences the course of Big Chico Creek, with the Iron Canyon segment of the creek roughly oriented along the N15E joints, and the downstream creek segment near Salmon Hole roughly oriented along the N85E joints (Drawing 1). In addition, these joints generally control the mode and size of rock slope failures in Iron Canyon.

Tuscan Formation (Tta)

The Tuscan Formation consists of a series of interbedded lahar, volcanic conglomerate, and volcanic sandstone, siltstone, and tuff deposits. The unit is mapped in the site vicinity along Upper Park Road (Drawing 1).

Rock Fall/Landslide Deposits (Qd/Qls)

Rock fall/landslide deposits are present throughout Iron Canyon, and consist of various sized basalt blocks generated by past canyon wall instability. The rock fall/landslide deposits are typically easily recognized because the columnar joints, where visible in the blocks, are no longer vertical as they would be if they were in place. Blocks size ranges from less than one foot to over 80 feet in maximum dimension (usually parallel to the columnar jointing).

As described by Doukas (1983), the eastern side of Iron Canyon consists of a large landslide complex most likely related to sliding along the underlying highly plastic lithic tuff unit that dips about 2 to 3 degrees out of slope (Drawings 1, 5, and 6). The overall morphological characteristics of the eastern side of the canyon are consistent with a large landslide complex, including the intermediate eastern bench, irregular topography, and open fissures up to 30 feet deep. The landslide mass is characterized by a chaotic mass of rigid blocks. Large blocks at the toe of the landslide mass appear to have dilated and back-rotated, while blocks armoring the topographic bench generally appear to have toppled forward. In response to movement of the landslide mass into the canyon, it appears that the entire creek channel has shifted to the west to

near the base of the western canyon wall. Big Chico Creek is located closer to the center of the canyon both upstream and downstream of Iron Canyon.

The timing of landsliding along the eastern side of the canyon is uncertain. The landslide complex is visible in the earliest aerial photographs reviewed (1937), but the scale of the 1895 topographic map covering the site area was insufficient to discern any detail regarding site conditions. Therefore, the landslide complex initiated at least 70 years ago, but may be much older. Stability of the landslide mass is discussed below under "Geologic Hazards – Canyon Stability – Potential Areas of Future Instability".

Undifferentiated Alluvium and Rock Fall Debris (Quad)

The Big Chico Creek channel is filled with various sized basalt blocks that have accumulated as an interlocking mass of randomly orientated rocks (Photo 1). The size of the basalt blocks generally exceeds the transport capacity of the creek, and therefore, most of the large blocks are likely the result of rock falls and topples along the canyon walls.

The blocks range up to 80 feet in maximum dimension, although the actual dimension of some of the largest blocks is unknown because they extend below the surficial debris and/or the water surface at the time of our reconnaissance. The blocks strongly influence the rate and direction of water flow in the Big Chico Creek channel, and also provide foundation support for the existing fish ladder.

Granular alluvium locally fills the voids between the blocks. Other voids are open and act as pathways for creek flow. Rather than attempt to map the alluvium and rock fall debris separately, these materials were grouped into one unit.

Photo 1 – Photo showing the range of basalt block sizes in the Big Chico Creek channel at the fish ladder.

Geologic Hazards

On the basis of our evaluation, we conclude the principal geologic hazards that could impact the fish ladder are potential instability of the western canyon wall and the individual blocks within the Big Chico Creek channel. However, no geologic hazards were identified that would preclude construction of the proposed project. The following sections discuss the stability of Iron Canyon in the immediate vicinity of the fish ladder, and the stability of the western canyon rim for construction staging. Channel stability is discussed below under "Foundation (Creek Channel) Stability".

Canyon Stability

Past Rock Slope Failures

The extent of rock debris throughout Iron Canyon indicates that rock falls resulting from canyon wall instability have occurred over time. Large-scale landsliding along the eastern side of the canyon has also contributed to rock block debris in the canyon. We attempted to estimate an approximate recurrence interval for past episodes of canyon wall instability from historical aerial photographs, but the scale and availability of the aerial photographs flown prior to 2000 was not sufficient to identify and establish a timeline of individual failure events. In addition, the scale of the 1895 topographic map covering the site area was insufficient to discern any detail regarding site conditions.

Outdoor California Magazine (1958), which is published by DFG, reported that a rock slide during, or about, the time of the 1906 San Francisco earthquake had blocked Big Chico Creek at Iron Canyon. The migrating salmon were unable to leap over a 14-foot-high water fall created by the slide. The location of the rock slide and resulting barrier to fish passage were not provided in the article. The article did note that a significant portion of the fish ladder that was constructed around the falls was "subterranean" in nature. We assume this to be the upper section of the fish ladder (Drawing 2).

The overall condition of the fish ladder suggests that there has not been any significant rock falls that have adversely impacted the fish ladder since it was constructed in 1958.

Primary Factors Affecting Canyon Stability

The formation of Iron Canyon has been largely driven by the processes of rock slope failure combined with stream erosion. As previously discussed, there are two primary sets of vertical joints in the Lovejoy Basalt. The importance of these joints is that they have fundamental control over the creek and canyon morphology. The trend of the primary joints strongly influences the course of Big Chico Creek. In addition, the primary joints generally control the mode and size of rock slope failures on the canyon walls. The orthogonal vertical joints generally form large, vertically stacked prismatic blocks.

Geological observations, together with kinematic and limit equilibrium analyses, suggest that blocks exposed in the canyon walls are generally stable under existing static conditions. However, changes in boundary conditions related to erosion and undercutting, and/or seismic shaking have the potential to induce failure of select blocks.

Undercutting and Loss of Support

Although undercutting of blocks could potentially induce instability under static loading conditions, this erosional process would require neighboring buttressing blocks to fail and/or involve downcutting and lateral migration of the creek channel. While Big Chico Creek appears to have cut through the Lovejoy Basalt, locally exposing the lithic tuff unit upstream and downstream of the fish ladder, the creek channel is now naturally armored with large, resistant basalt blocks that substantially limit the rate of further erosive downcutting.

Downcutting by Big Chico Creek through the Lovejoy Basalt into the underlying stratum appears to have been a very slow process occurring over the last one to two million years. Slope failure associated with downcutting and/or undercutting of the Lovejoy Basalt is a cyclic process wherein fallen blocks naturally armor the channel, thus slowing the rate at which downcutting and/or undercutting takes place. Over time (on a geologic scale), the armoring may be stripped away, resulting in a new episode of downcutting and canyon wall instability. Given the prolonged nature of this process and existing creek channel conditions, it is our opinion that destabilization due to undercutting is a minor concern in Iron Canyon during the project design life.

Site Seismicity

Earthquake induced ground shaking is another mechanism by which select blocks may be destabilized. If subjected to seismic shaking during the project design life, we expect low to moderate ground accelerations. The intensity of ground shaking at the site depends on many factors, including the size of the fault generating an earthquake event, the distance from the fault rupture to the site, and the duration of strong ground shaking. As previously discussed, the Chico Monocline fault and Foothills fault system are located approximately 2.5 miles southwest and 12 miles southeast of the site, respectively. The Foothills fault system is recognized by the California Geological Survey (CGS) as being an active, "Type C"[6] fault with a maximum M_w of 6.5 (Cao et al., 2003). The Chico Monocline fault is not recognized as an active fault by the CGS and has not been assigned a maximum moment magnitude. Therefore, for the purposes of our evaluation, we have assumed the Foothills fault system is the controlling fault with respect to site seismicity.

Using published attenuation formulas (Boore, et al., 1997; Sadigh, et al., 1997; Spudich, et al., 1997), we estimated the peak ground acceleration (PGA) that may be felt at the site during a M_w 6.5 event on the Foothills fault system. Using this deterministic evaluation procedure, we

6. A Type C fault has an $M_w \leq 6.5$ and an average slip rate ≤ 2 mm/year. Type C faults are considered relatively low activity faults in the building code and do not require the use of near-source amplification factors.

estimate the mean (50th percentile) PGA would range from 0.1 to 0.2 g, and the mean plus one standard deviation (84th percentile) values would likely range from 0.17 to 0.32 g. However, the CGS probabilistic seismic hazards mapping program (2002) estimate of the PGA at the site for a 10 percent probability of exceedance in 50 years is about 0.13 g. For reference, the accelerations of commonly known California earthquakes and the damage expected in urbanized areas is shown in Figure 8 below.

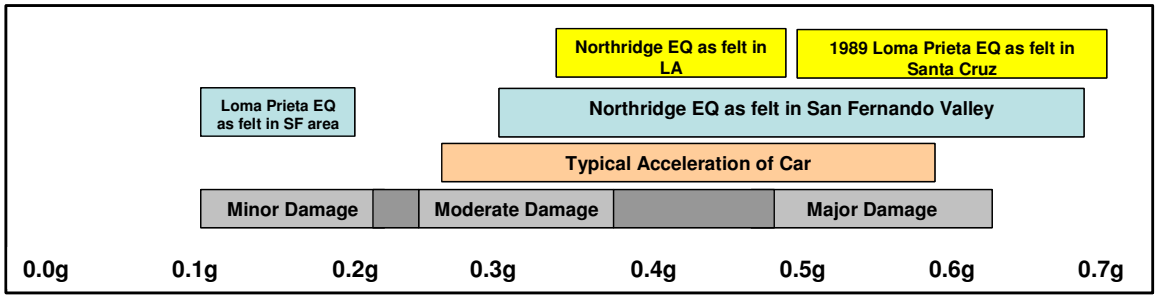


Figure 8 – Accelerations (g) ranges and typical expected damage for recent California earthquakes.

In our opinion, deterministic attenuation formulas are generally conservative for relatively low activity faults as the regression relationships used to develop the formulas are generally based on higher activity faults. We believe that for low activity faults, a probabilistic value, which incorporates the likelihood of faulting, as well as the influence of poorly defined, regional "background" seismic sources (e.g., the Chico Monocline fault), provide a better indicator of likely degree of ground shaking at the site. As a result, we believe a value of 0.15 g is a reasonable estimate of the design PGA for project design purposes and this value has been considered in our evaluations. We estimate there is only about a 10 percent probability that an earthquake generating a higher PGA will occur during the 50-year life of the project.

Areas of Potential Future Instability

Due to its overall height, steepness, jointing, and close proximity to the fish ladder, we anticipate that the western canyon wall represents the most likely source of future rock falls that could potentially adversely impact the project. We identified and evaluated seven overhanging blocks and/or blocks with open joints along the western canyon wall that are considered the most likely to be destabilized in the future. These blocks are typically characterized by vertical prisms resting on subhorizontal to moderately steep basal joints. Although these blocks have likely remained stable for many years, perturbation of the blocks related to long term weathering processes, changes in boundary conditions, and/or seismic shaking may potentially result in instability. These blocks, numbered 1 through 7, are depicted graphically on the photomosaics (Drawings 3 and 4). In addition, the approximate limits of Blocks 3, 6, and 7 are shown on Drawing 2.

Factors of safety and yield accelerations for the seven blocks were estimated either analytically or based on engineering and geologic judgment. Because the scope of the field investigation

was limited to surficial mapping, not all necessary geologic and geometric parameters could be measured accurately in order to perform detailed evaluations, and thus assumptions regarding key input parameters were required. As a result, relative values of the factors of safety estimated are considered useful for guiding engineering judgment, but the absolute values are not necessarily considered meaningful. As a result, we have elected to designate block stability and risks in qualitative relative terms, such as *very low, low, moderate, and high, and very high*, rather than report factor of safety values. Table 2 presents a summary of the block stability evaluations and assessment of project risk levels. The risk levels stated in this table have been established by considering the estimated stability characteristics of each block, combined with the impact to the project should block failure occur.

Table 2 – Summary of stability evaluations, project impacts, and project risk levels for the most critical blocks identified along the western canyon wall. Blocks are depicted graphically on Drawings 3 and 4.

Block No.	Description*	Failure Mode	Static Stability	Seismic Stability	Project Impact	Project Risk
1	Three blocks at canyon rim. Open vertical joint along back of blocks about 12 ft. from canyon rim. Open joint is at least 25 ft. high and 40 ft. wide. Basal joint appears to dip moderately steeply out of slope. Block partially overhanging.	Block Topple	Low to Moderate	Low	Low	Low
2	Block at canyon rim. Approx. 9 ft. wide, 10 ft. deep, and 10 ft. high. Joint is partially open at back of block. Basal joint appears to dip moderately steeply out of slope.	Wedge Slide	Low	Very Low	Moderate	Moderate
3	Large overhanging block. Approx. 70 ft. wide and 74 ft. high. Depth estimated to be 17 ft. Overhang estimated to range from 2 to 17 ft. wide. Buttressed by underlying block along upstream edge.	Compressive Failure of Buttress or Block Torsion	Moderate to High	Moderate	Very High	Low
4	Block at canyon rim. Approx. 15 ft. wide and 30 ft. high. Estimated depth of 14 ft. Basal joint dips moderately steeply out of slope.	Block Topple or Block Slide	Moderate to High	Moderate	High	Low to Moderate
5	Block at canyon rim. Approx. 23 ft. wide, 13 ft. deep, and 13 feet high. Basal joint dips moderately steeply out of slope.	Block Slide	Moderate to High	Moderate	High	Low to Moderate
6	Large block extending upwards from base of wall. Marked by open vertical joints along back of block. Lower portion of block appears to be buttressed by several large blocks. Unbuttressed height estimated to be 80 to 90 ft., and average depth of 20 ft.	Block Topple	High	Moderate to High	Very High	Low
7	Large overhanging block. Approx. 32 ft. wide and 85 ft. high. Depth estimated to be 16 ft. Overhang estimated to be up to 8 ft. wide. Dilated joint around most of block.	Block Topple or Block Slide	Low	Very Low	High	Moderate to High

* Estimated block dimensions are reported as width (parallel to wall face), depth (perpendicular to wall face), and height (vertical along wall face).

The lower western and eastern canyon slopes, characterized by a chaotic assemblage of slope debris and large basalt blocks, also represent potential sources of rock falls. However, it is our judgment that the potential for these blocks to become dislodged and transported significant distances is low.

While rock falls will likely continue to occur along the near vertical to vertical eastern canyon wall, the overall topography and the distance of the east canyon rim from the creek channel suggests that the potential for rock falls to reach the fish ladder is very low and the overall project risk is considered very low.

The scope of work undertaken for this project has not been sufficient to evaluate the potential for future movement of the large landslide complex along the eastern side of Iron Canyon. Doukas (1983) suggested that this mass "may still be moving downhill." Should this be the case, we would expect that on-going movement would have resulted in deformation along the toe of the eastern slope, which would be expected to damage the existing fish ladder. The overall condition of the fish ladder suggests distress related to toe deformation of the landslide complex has not occurred since its construction in 1958, and in general, we would expect similar conditions to persist for the project under consideration. Although we would expect similar performance over the next 50 years, the potential for future static creep or seismic movement cannot be precluded.

We consider the potential for global failure of the western canyon wall (similar to large scale landsliding along the eastern side of the canyon) to pose a very low risk to the project, as this would likely require further downcutting and lateral migration of the creek channel. As discussed previously, the potential for this to occur is considered low due to the natural block armor in the creek channel.

Mitigation Measures

In our judgment, Block 7 poses the highest potential risk to the project due to its relatively low stability characteristics and potential for adverse project impacts. Considering the large block volume (estimated to be on the order of 1,600 cubic yards) and relatively low stability characteristics, block reinforcement using rock bolts would not be cost effective and would pose a risk to construction personnel during installation. Alternatively, if it is desired to mitigate the risk prior to new construction, the block can be removed using controlled blasting techniques. It must be emphasized that this could potentially damage the existing weirs in the upper section of the fish ladder and/or result in significant alteration of the channel morphology, requiring reconfiguration of the fish ladder.

Block 2 is judged to pose a moderate risk to the project, and due to its relatively small volume (estimated to be on the order of 30 cubic yards), we recommend that the block be removed by mechanical scaling (e.g., excavator with rock breaker) or controlled light blasting.

Although other slope processes (including instability of other blocks and movement of the eastern canyon landside complex) may potentially adversely impact the project, it is our opinion that the overall project risk levels are typically low, and implementing mitigation measures would therefore not likely be justifiable from an economic perspective.

Hydraulic Evaluation

In order to determine creek depth and velocity ranges, a simplified hydrodynamic evaluation was performed by modeling three cross sections in HEC-RAS[7] (Figure 9). Cross Section 530 was partially constructed using survey data provided by DWR during the February, 2006 survey. The remainder of the section and Cross Section 760 was estimated using a limited number of hand-held altimeter points. The downstream cross section "0" was estimated by measuring the channel width off an aerial photograph and the channel depth from a point survey (Figures 10 – 12, HEC-RAS modeled cross sections)

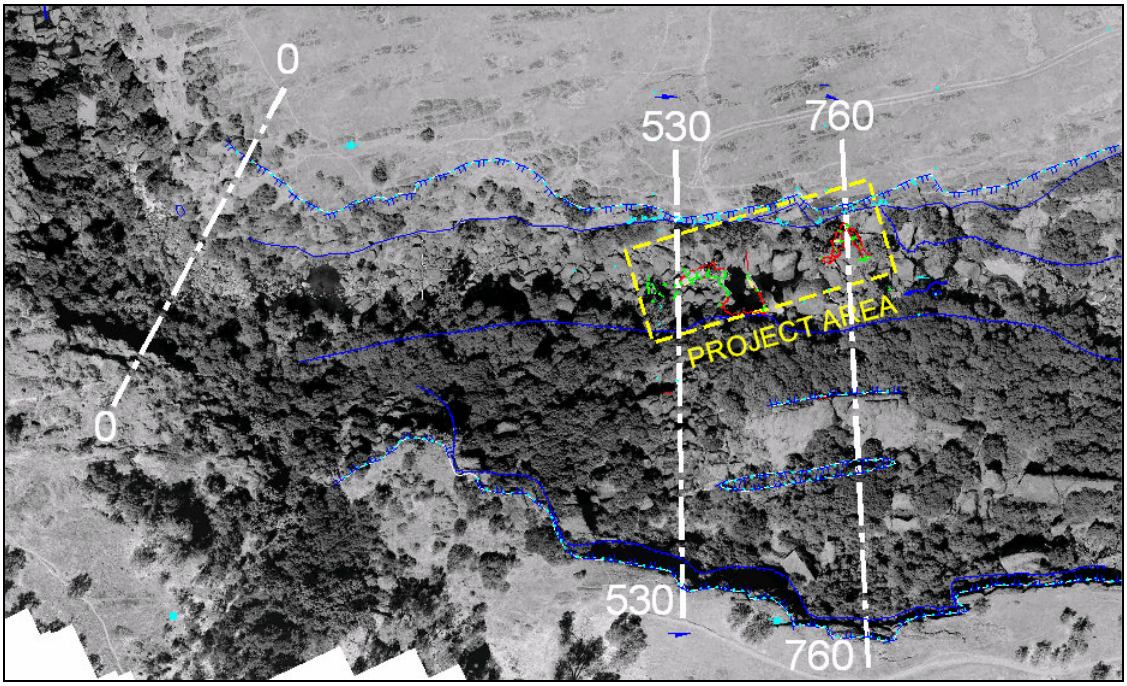


Figure 9 - Locations of modeled cross sections

7 It is recognized that three inadequately surveyed cross sections are insufficient to accurately model a canyon of this size and complexity, however, for the information needed, (depths and velocity of water in order to determine boulder movement) an order-of-magnitude approach was appropriate. Furthermore, the ultimate calibration, debris lines for water depth and historical photos and existing site conditions for boulder movement, confirmed the range of values developed.

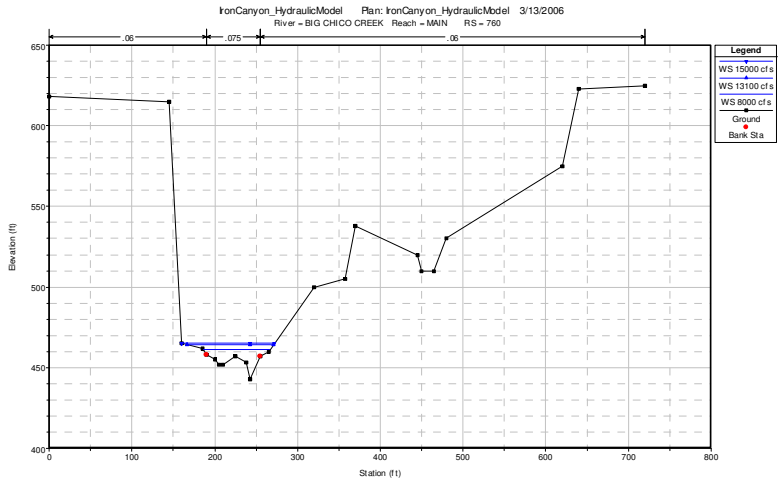


Figure 10 – HEC-RAS Cross Section 760

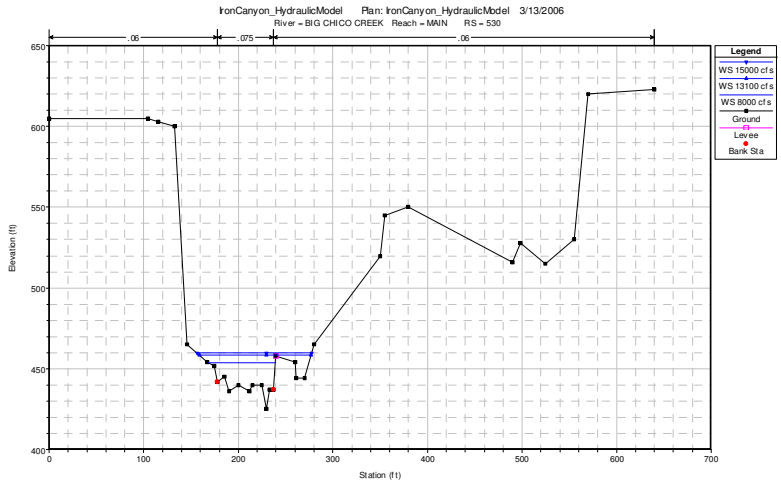


Figure 11 – HEC-RAS Cross Section 530

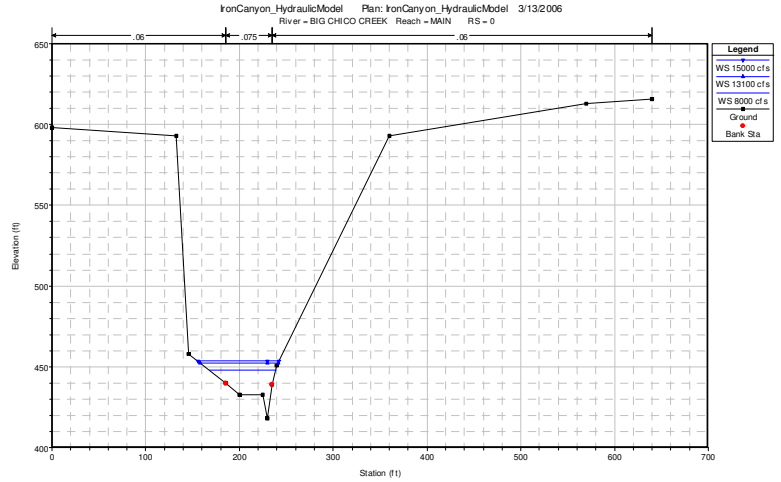


Figure 12 – HEC-RAS Cross Section 0

The upstream and downstream boundary conditions were defined in the steady flow data menu. Critical depth was set as the upstream boundary condition, and normal depth, with an estimated channel bottom slope of 0.013, was used for the downstream boundary condition. To provide upper and lower boundaries and determine sensitivity, the HEC-RAS model was run with two flow profiles (8,000 cfs and 15,000 cfs) in addition to the 1997 data of 13,100 cfs. The HEC-RAS model was run as a mixed flow regime.

Manning's n-values were estimated as 0.060-0.075 for the channel and 0.060 for both the left and right overbank. Channel Manning's n-values were then varied to test sensitivity of varying roughness coefficients within the model. At a peak discharge of 13,100 cfs, roughness coefficients of 0.075 for channel and 0.060 for overbanks produced the worst-case scenario. At cross-section 760, a depth of 21.44 ft and channel velocity of 16.79 ft/s were computed. At cross section 530, a depth of 33.25 ft and a channel velocity of 9.66 ft/s were computed. At cross section "0", a depth of 34.25 ft and a channel of velocity of 11.92 ft/s were computed.

Table 3 summarizes the ranges of water depths and channel velocities possible at peak discharges between 8,000 cfs to 15,000 cfs.

Table 3 – Flow depth and velocity for modeled cross sections

Cross-Section	Water Depth (ft)	Channel Velocity (ft/s)
760	18.4 - 22.2	15.1 - 17.0
530	28.8 - 34.3	8.6 - 10.0
0	29.9 - 35.6	10.1 - 12.5

Foundation (Creek Channel) Stability

As discussed previously, the fish ladder is founded on an interlocking mass of randomly orientated and variously sized basalt blocks in the Big Chico Creek channel. Granular alluvium locally fills voids between the blocks and also forms part of the foundation material. Because the fish ladder is structurally connected to the basalt blocks, ladder stability ultimately depends on the stability of the basalt blocks, and could be adversely impacted by block movement. Condition assessments of each weir to evaluate past block movement were limited by creek flows at the time of this evaluation. To the extent possible, field observations were supplemented using weir photos and descriptions contained in the *Preliminary Engineering Technical Report*.

Where visible during our investigations, the type of distress to the fish ladder does not suggest that movement of the foundation blocks has occurred since the fish ladder construction. Observed or reported distress appears to primarily consist of concrete wear, concrete deterioration, and structural failure of pool floors. One possible exception is the left wall of Weir 6, which the *Preliminary Engineering Technical Report* notes is leaking where the wall meets the basalt block.

Although we did not observe any evidence to suggest that the foundation blocks for the weirs have moved, there is evidence that localized blocks in the creek channel have shifted slightly as depicted in Photos 2 and 3.

Photos 2 and 3 – Original construction photo of the fish ladder from 1958 (California Department of Fish and Game). Photo on the right was taken from roughly the same vantage point in May 2006. Note that the overall configuration of the large foundation blocks is generally the same in both photos. The red arrows point to a block that appears to have shifted.

Block Movement Monitoring

To monitor block movement during this evaluation, DWR personnel established monitoring points on selected basalt blocks along the fish ladder. The locations of the monitoring points are shown on Drawing 2. The monitoring points were resurveyed by DWR personnel after a period of 78 days, and no detectable movement was measured.

Two monitoring points were also established on two large blocks that may have moved per discussions with Mr. Paul Ward of DFG. These blocks include:

- A large block on the east side of Weir Group 1 has fractured into two smaller blocks (Drawing 2). Fracturing and block movement reportedly may have caused or contributed to a recent change in the local creek flow pattern where Weir Group 1 was bypassed. Close inspection of the fractured block and Weir Group 1 was limited by creek flows at the time of this evaluation. However, where visible, there was no separation or distress where the concrete weir was cast against the fractured or neighboring block. In addition, there was no detectable movement of a monitoring point established on the downstream end of the fractured block. The recent change in

flow patterns away from Weir Group 1 may be related to movement of smaller blocks immediately upstream of the larger blocks. Monitoring points established on two of these smaller blocks (Drawing 2) did not detect any movement, but past movement may have shifted the blocks into a more stable configuration.

- A large block located over Weir 17 (Drawing 2) has reportedly moved downward and is presently within several inches of the top of the concrete weir (Photo 4). Mr. Ward reported that flashboards had been periodically installed in a vertical slot in the weir during past years, but there is now insufficient clearance between the ceiling formed by the block and the weir to install the flashboards. Visual assessment of the large block above Weir 17 indicates that the block appears to be supported by similarly sized blocks beneath it at three points, and the block is within several inches of coming into contact with another large block at its eastern end. The block may have not been in contact at these three points when the weir was originally constructed, and thus, some downward movement may have occurred. However, there was no detectable movement of a monitoring point established on the top of the block and significant additional movement of this block downward onto the weir appears unlikely.

Photo 4 – Photograph of Weir 17 and basalt block that forms ceiling. Note the vertical slot in the concrete to install flashboards between the two weir sections.

Potential Future Block Movement

Mechanisms of potential future block movement along the fish ladder include: creek downcutting, seismic activity, hydrodynamic forces on larger blocks, or erosion and bed transport of underlying material. These mechanisms are further discussed below.

Creek Downcutting

As discussed previously, it appears that Big Chico Creek has cut into the lithic tuff below the Lovejoy Basalt, and may have cut into the underlying Chico Formation (Drawings 5 and 6). However, the creek channel is naturally armored with resistant basalt blocks that will likely impede significant downcutting.

Localized downcutting has occurred upstream of the fish ladder, as evidenced by a large 10-foot-diameter block overlying the lithic tuff exposure upstream of the fish ladder. This block has been partially undermined by erosion of the tuff. Failure of this block into the creek channel could change the local creek flow dynamics. However, we do not believe that this will adversely affect the proposed project.

Seismic Settlement

The estimated maximum PGA at the site is only about 0.15 g, and therefore, only low to moderate ground shaking is anticipated over the lifetime of the project. As discussed previously, we estimate there is only about a 10 percent chance that an earthquake generating a higher PGA will occur over the 50-year life of the project. Because the blocks are relatively stable in their current configuration and future ground accelerations are expected to be low, the potential for large seismic movements is considered low.

Hydrodynamic Movement of Blocks and Boulders

Hydrodynamic induced movement of blocks and boulders can potentially damage the rebuilt fish ladder via three modes; 1) loss of support or confinement if a large boulder to which the ladder is connected moves; 2) loss of supporting boulders beneath a pool or weir; 3) impact damage from bedload transport.

Using results from the hydraulic model, we performed calculations to determine the size of boulders likely to be hydraulically moved or transported based on the 1997 flows. Calculations were performed based on the USACE ERDC TN-EMRRP-SR-11 (Boulder Clusters, February, 2002) and take into account the channel flow depth, the friction slope (hydraulic grade line), and the mass (specific gravity) of the boulders. The calculations do not take into account the interlocking nature of the larger boulders and blocks in the stream. The resulting values will therefore tend to be conservative for boulders and blocks greater than 4 to 5 feet in diameter which rarely exist in isolation in the canyon. The calculations indicated that for Section 760 (furthest upstream), isolated blocks as large as 8 to 9 feet in diameter could be moved by a flow of 13,100 cfs. At Section 530 the maximum sized boulder the same flow should be capable of moving was calculated at approximately 3 feet in diameter. At Section “0” the maximum sized boulder the same flow should be capable of moving was calculated at 4 to 5 feet in diameter. Table 4 shows the maximum sized boulder that the calculations indicated could move for each section at the potential range of depths.

Table 4 – Boulder sizes which could be hydraulically moved

Cross-Section	Water Depth (ft)	Boulder Diameter (ft)
760 / "B"	18.4	7.7
	21.4	8.9
	22.0	9.2
530 / "A"	28.8	2.3
	33.3	2.7
	34.3	2.7
0	29.9	4.1
	34.3	4.7
	35.6	4.9

Possibly the best indicator of what size blocks a 1997 type event could move is empirical in nature. The existing fish ladder endured the 1986 and 1997 flows, the highest on record since 1931, with very little apparent shifting of the blocks and boulders to which they are attached.

The possible movement of small boulders and cobble-sized material supporting the weirs and pools can best be addressed structurally. Permeation grouting and the construction of new structural slabs for the pools is discussed in the Constructability portion of this report. Permeation grouting can also be used to help stabilize critical boulders of any size with obvious voids beneath them.

The transportation of boulders up to 2 feet in diameter which are not interlocked with the surrounding blocks is unavoidable at high flows and some impact damage can be expected during a 1997-like event. The best approach to minimize this type of damage is to seasonally remove debris and rocks from the pools. This would be particularly important for pools with new structural bottom slabs where there is little chance of a boulder becoming wedged in place.

Erosion and Bed Transport

Due to the flows in the creek at the time of this evaluation, the foundation material for most of the basalt blocks was obscured. However, where the blocks are founded on granular alluvium (e.g., sand and gravel), the potential exists for erosion and bed scour to undermine the blocks and result in block movement. During construction, the foundation conditions for each block should be evaluated. Where foundation materials prone to erosion and scour are encountered, it will be necessary to construct concrete slabs at the base of the pools to act as scour protection. Specific construction requirements for construction of these slabs are discussed below under "Constructability – Specific Construction Methods – Sealing Pools."

Constructability

The proposed fish ladder repair and construction includes repairing and capping the existing damaged weirs, replacing damaged or missing weir sections, adding new weirs, sealing leaks, and excavating pools. Construction issues are discussed below.

Site Access

Project access improvements, both to the top of the canyon and from the west canyon rim to the bottom, will be required to perform the proposed construction. The existing gravel roads leading to the western canyon rim (presumed upper staging area) are insufficient for heavy construction traffic in terms of both width and grading. A minimum amount of re-grading, widening, and tree trimming will be required for heavy equipment, including concrete trucks, a crane capable of reaching into the canyon, and other material delivery trucks, to access the site. If maintaining two-way traffic to the upper areas of the canyon rim is required during construction, additional widening will likely be required.

Construction Setback from Western Canyon Rim

Based on the geologic reconnaissance and evaluation, we recommend construction activities not be performed within 30 feet of the western canyon rim. This includes vehicle parking, construction staging, and crane operation. Crane outriggers should be centered between observable primary joints typically visible at the ground surface.

Prior to start of construction activities, temporary fencing should be erected and a work exclusion zone established. This zone should be checked for newly opened joints or tension cracks prior to the start of construction activities each day. Should newly opened joints or tension cracks be observed, construction activities in the canyon should be immediately suspended and the workers evacuated to the staging area. Construction activities should not resume until a licensed engineering geologist has evaluated the features and determined that construction can safely continue. It is further recommended that wire extensometers or survey pins across select existing joints along the canyon wall and/or rim, particularly at Block 7 be installed prior to construction.

Scaling of Western Canyon Wall

Prior to the start of construction activities within Iron Canyon, the western canyon wall should be scaled by experienced personnel using pry bars and other hand tools to remove loose blocks and debris above the planned work zone. Scaling personnel should be properly secured by ropes anchored at least 30 feet back from the canyon rim. A platform suspended from a crane is an alternative to using ropes.

Transporting Material and Personnel to Site

Transporting material and personnel to the site presents unique challenges. The existing trails leading from the canyon rim to the project site should not be considered as safe access routes to the fish ladder. As anyone who has hiked into the canyon via these routes can attest, the potential for "slip, trip & fall" injuries is too great for day-to-day use by construction personnel. Additionally the lost time alone spent walking in makes these routes undesirable.

The most likely option for transporting personnel, equipment and material into the canyon from the rim is by use of a self-erecting crane (Figure 13). A short tower crane was also considered, but rental durations are typically for one year or more. Several models of self-erecting cranes are available that would likely serve the project's needs.

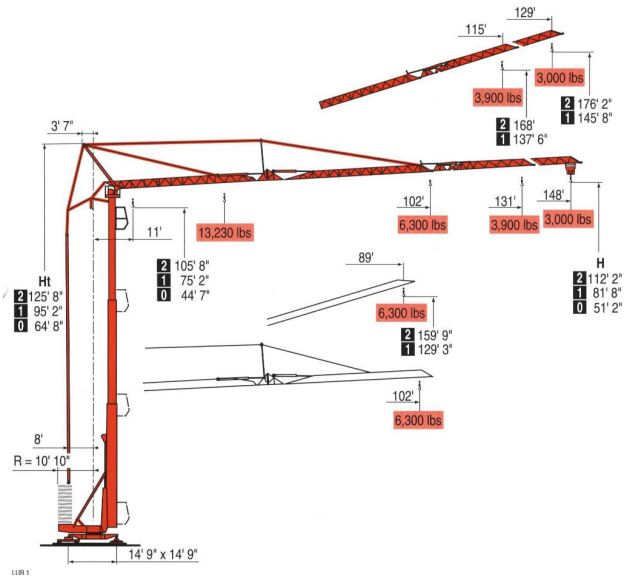


Figure 13 – Self-erecting crane suitable for transporting material into the canyon.

The crane shown in Figure 13 is the Manitowoc Potain HDT 80, with a boom length of almost 150 feet and a 3,000-pound capacity at maximum boom length. With a minimum 30-foot setback from the western canyon rim, the most desirable staging areas on the canyon floor are estimated at approximately 75 feet from the canyon rim, well within the boom reach (Figure 14). With a boom reach of 102 feet, the capacity of the crane is 6,300 pounds (a typical loaded concrete bucket is approximately 5,000 pounds). It should be noted that the crane's load capacity increases even further as the boom length decreases if heavier equipment were required in the canyon.

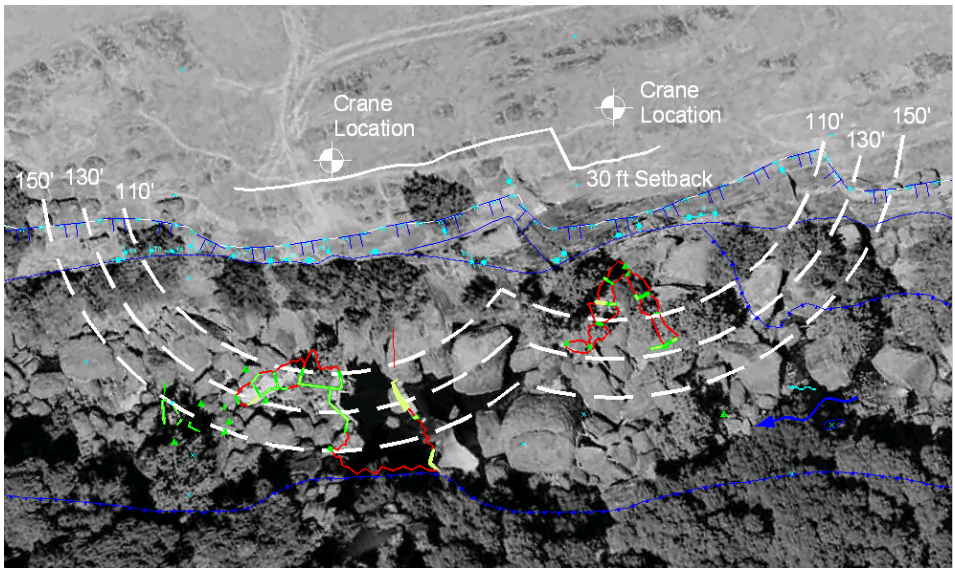


Figure 14 – Boom reach for self-erecting crane at two locations.

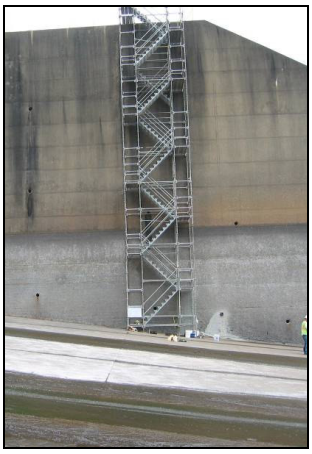
Travel speeds for crane trolleys are typically faster than the rotating speed of the crane. Therefore, limiting the crane's movement as much as possible to primarily back and forth trolley motion instead of swinging motions would reduce the overall delivery time from the canyon rim to the canyon floor. This could be accomplished by moving the trolley back from the edge of the canyon rim and loading underneath the crane. Limiting the crane's movement in this way would make less of an impact on the construction schedule and would likely reduce the need for concrete admixtures to prolong setting. A typical rental cost for such a crane for 4 months duration would be in the range of $60,000 to $70,000.

A second option for the construction of the new ladder would be a high-line. A highline strung between the canyon rims was reportedly used for the fish ladder's original construction. A new highline will require anchor points based on the specific loads anticipated for the fish ladder repair work. Note that unlike the self-erecting crane described above, a high-line will likely produce forces on the canyon rim (perpendicular) into the canyon and may require a larger setback distance from the rim than does the crane.

While a crane or high-line will be the primary access for personnel into the canyon, an emergency access/egress should also be provided. If the crane becomes unavailable for any reason, in the event of an accident the only emergency egress from the canyon would be along the hiking trails, by rope access, or by helicopter. According to the City of Chico Fire Department, the city has agreements with Butte County and the CDF for use of a helicopter in the event of an emergency. The department also has swift water and high-angle rope rescue teams, however, these services should not be considered the primary emergency access or egress method in the event of an accident. The easiest method to provide this access would be with either a construction elevator (hoist) or scaffolding tower as shown in Photos 5 and 6.

Either would need to be 120 to 140 feet tall and anchored to the western canyon wall at several locations along its height. A bridge would also be required to span a safe distance from the canyon rim to the distance the elevator or tower was set back from the wall, estimated at 40 to 50 feet.

The tower or elevator should be sited away from the seven overhanging blocks and/or blocks with open joints on the western canyon wall that are judged to have the potential for static and/or seismic instability. A potential location is shown on Drawing 3. The final location of the tower or elevator and anchorage points on the western canyon wall should be reviewed and approved by an engineering geologist prior to installation.



Photos 5 and 6 – Construction elevator (hoist) and tower scaffolding suitable for access/egress during construction.

Another option that should be considered not only for emergency access but also long term operation and maintenance is a permanent access to the site. While possibly environmentally and aesthetically unappealing, some type of stairs, either free standing or constructed into the canyon, should at least be considered. Refer to the Operations and Maintenance section for further discussion.

Working in Creek Channel

It is anticipated that construction activities would be staged from one or possibly two platforms. A single platform can be constructed over the pool near Weir 8, providing up to approximately 1,200 square feet of space depending on the elevation above the pool and boulders upon which it is constructed. If sealing of the pool or construction of a bottom slab is required, the platform would also be constructed high enough to work beneath. The platform could be constructed from light steel beams with a wooden deck. Although more difficult to construct, a second platform could be constructed near Weirs 9 through 17 providing additional staging. Ladders,

catwalks and/or gangplanks should be constructed between staging areas and each weir being demolished or rebuilt. All staging platforms and temporary access features should be constructed according to OSHA and CAL-OSHA standards.

Specific Construction Methods

Flow Containment and Diversion

Diversion of even the summer flows (historic average June – October of 32 cfs) will be required to execute the construction of a new fish ladder. This can be accomplished with the use of aqua-dams (water filled bladders), sandbags and plastic sheets, and piping to temporarily direct the flow around the area under construction. It is likely that more than one of these methods will be required to dewater the site sufficiently. It may even be beneficial to use a naturally occurring pool or create a temporary sump and pump some or all of the flow rather than damming the creek to a height great enough to redirect it (Photo 7). If a 5-foot-high sump or cofferdam is assumed, an approximately 30 horsepower propeller pump would be required to keep the site dewatered (based on 32 cfs which equals 14,360 gallons per minute). A pump of this size is within the delivery capacity of the crane previously described.

Photo 7 – Aqua-dam and floating pump used for the dewatering of Folsom Dam Stilling Basin.

Equipment

The largest equipment required in the canyon should be an approximately 35 kVA generator weighing around 2,500 pounds and a 100 – 200 CFM air compressor weighing around 2,500 to 3,000 pounds. Each of these is within the load limits of the self-erecting crane described previously.

Demolition

Demolition of the existing concrete weirs should be performed with pneumatic chipping equipment rather than concrete saws. Breaking the concrete will create either larger blocks which can be easily removed or small enough debris to be ignored. Using a saw to cut the concrete would produce a water-cement slurry that may be difficult to contain or clean up.

Excavation

Per the *Preliminary Engineering Technical Report,* some of the pools will be excavated to add depth for leaping and to improve energy dissipation. Minimum excavation depths range from 0.1 feet in Pool 3 to 2.1 feet in Pool 11. Pool excavation could apply to the pool floors, the sidewalls, or both. Existing pool floors were generally not visible at the time of this evaluation due to creek flows; however, the *Preliminary Engineering Technical Report* suggests that most of the pools contain sand, gravel, cobbles, and boulders.

Given that relatively minor pool deepening is required, it is expected that most of the floor material will consist of loose alluvium (sand, gravel, small cobbles), and therefore, this material can most likely be easily removed. However, some larger basalt blocks may be encountered that cannot be easily removed, and many of the pool sidewalls are comprised of large basalt blocks that will require partial or complete removal. The rock can likely be broken down into manageable pieces by jack-hammering or drilling and blasting. However, breaking down blocks with jack hammers will likely be very slow and extremely difficult, as laboratory test have indicated rock compressive strengths up to about 64,000 psi. Potential contractors should be made aware of these values prior to bid.

Drilling and controlled blasting may be feasible for demolition and removal of select blocks. Blasting is expected to be light, as most of the material to be blasted will be boulder-sized and at the base of the canyon. However, even light blasting will require a blasting plan, and the blasting engineer must be made aware of hazards that could be caused by blasting-induced vibrations so that appropriate safety measures can be implemented. It is recommended that all personnel be evacuated from the canyon when blasting is performed. Prior to reoccupying the canyon after each blast, it is recommended that the western canyon rim be checked for newly opened joints or tension cracks. Installation of wire extensometers or survey pins across select existing joints along the canyon wall and/or rim, particularly at Block 7, is recommended.

Temporary / Permanent Block Support

The stability of individual basalt blocks along the open and covered sections of the fish ladder during and after construction is of critical importance. As part of the final design, the stability of individual blocks that will support new concrete ladder structures should be evaluated. In addition to structural design of the ladder structures, additional structures should be designed where temporary and/or permanent support is necessary. Stabilization measures may include the use of concrete or steel buttresses, cut-off slabs to reduce the risk of undermining, and cast-in-place concrete foundation supports.

Immediately prior to construction when the site has been dewatered, blocks in which work will be occurring near or under should be reevaluated by an engineering geologist or engineer to check that the stabilization measures determined during final design are appropriate. In addition, excavation activities should be closely monitored by an engineering geologist or engineer to evaluate the actual conditions encountered and the need for supplemental stabilization.

Placing Concrete

Whenever possible, new concrete should be placed directly from a crane delivered by bucket to the form. Since some locations have overhangs, either rock or vegetation, chutes will likely be required for placement at some weirs. Hand placement, from a wheelbarrow or other manual delivery device should be avoided. Particular attention should be paid to good consolidation of the concrete, minimizing reentrant corners and gaps, and good bonding. To improve bonding

the boulders and blocks which weirs or slabs are cast against should be well cleaned and if worn smooth, should be intentionally roughened per ACI design codes.

The new weirs should be designed such that the reinforcing bars are as small a diameter as possible. This will allow for easier on-site sizing, adjustments and bending. Since the required load carrying capacity of the weirs is not great, a larger number of smaller bars will also help increase the serviceability of the new structures.

Sealing Pools

Sealing pools will be required at a number of locations. If the location can be sufficiently dewatered, overexcavation where possible may be the most cost effective slab preparation method. Permeation grouting with cementitious materials may be also feasible. However, this will tend to increase the alkalinity of the creek water. Should alkalinity be a concern, inert chemical grouts may be considered; however, this is not anticipated to be an economically favorable solution.

After preparation of the slab subgrade, a structural bottom could then be cast-in-place. According to the *Preliminary Engineering Technical Report*, the DFG has suggested that at some pools "the repair should be flexible to account for minor geologic shifting." Depending on the site conditions, this may be accomplished with variations of hydrophobic polyurethane foams with higher tensile strengths designed to form flexible plugs and gaskets in flowing water.

Once a given pool has been sealed by permeation grouting, the best method for maintaining the invert elevation is a structural slab, drilled and bonded into the surrounding rock, and where appropriate, structurally tied to the corresponding weir. The slabs should be constructed with cast-in-place concrete and designed to span the distance between boulders to which they are tied, even in the event of the loss of supporting bed below. Given the size of pools being considered, a 12-inch thick slab, with appropriate reinforcing and anchorages should be sufficient to span the needed distances. Dental concrete should be used to fill any void between the grouted and sealed bed and the bottom of the new slab (Figure 15).

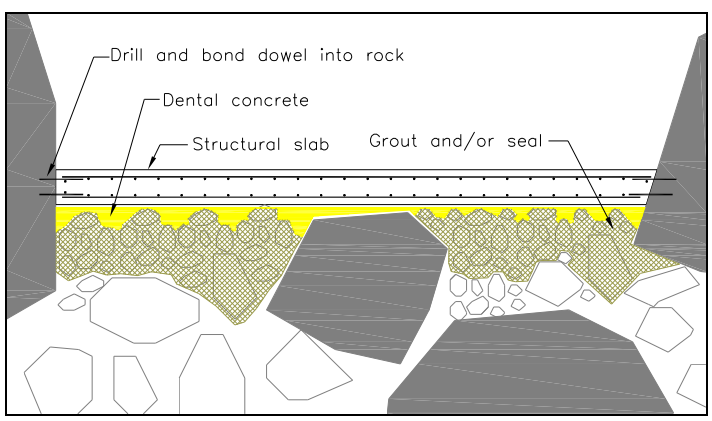


Figure 15 – Cross section through pool requiring grouting and structural bottom slab.

The surface of the structural slab within the pools should be finished to a smooth surface. This is commonly executed by grinding the surface with a rotary grinder to expose all air pockets, voids, and other imperfections. All voids should be filled with cement mortar fill.

The final or cured chemical composition of all concrete, grout or other construction products used on the site should be checked for the possibility of residual or leachable properties that could have a lingering effect on the pH of the creek.

Attachment to Existing Rock

Drilling into existing rocks for reinforcing and dowel attachments will vary from routine to extremely difficult. Laboratory test have indicated rock compressive strengths up to about 64,000 psi. Any potential contractors should be made aware of these values. However, we anticipate that all required drilling could be accomplished with a percussion-electric drill and commonly available roto-hammer, fluted bits (e.g., SDS MAX or "Rebar-eater" bits). Coring is also allowed, however, it results in smooth sided holes which have weaker bonding capacity than rough sided drilled holes and may require deeper embedment.

Construction Management

The project should have a full-time resident engineer who is familiar with the intent of the project and its goals and is qualified to direct the contractor through the multitude of decisions the site will require. An engineering geologist should also evaluate boulder stability surrounding the work area, evaluate geologic conditions as exposed during dewatering and excavation, and observe foundations to confirm loose material has been either removed or consolidated.

Design Considerations

Any design of the new fish ladder should be performed with the maximum amount of construction flexibility in mind. The design should consist of standardized or idealized design as much as possible with the exact dimensions and fit to be worked out in the field. The exception would be weir and pool elevations which would be specified precisely. For example, ideally there would be one design and reinforcing scheme respectively that works for all weirs, walls, and bottom slabs such that only the dimensions change between locations.

The *Preliminary Engineering Technical Report* lists the UBC and ACI codes as design standards. Additional relevant design parameters can also be found in the following USACE documents:

- EM 1110-2-2104 Strength Design for Reinforced Concrete Hydraulic Structures
- EM 1110-2-2000 Standard Practice for Concrete for Civil Works Structures
- ERDC TR-INP-00-1 Technologies for Positioning and Placement of Underwater Concrete

- EM 1110-1-2908 Engineering and Design Rock Foundations
- EM 1110-1-2907 Rock Reinforcement

Should aesthetics be a concern, the use of architectural rock form liners and/or colored concrete should be considered. New, grey concrete crossing a creek may have an "environmentally unfriendly" connotation, even for a fish ladder. Although it is unlikely that a "Lovejoy Basalt" form liner exists, the use of any number of readily available liners could make the rebuilt fish ladder virtually invisible to the casual observer. Similarly, a number of companies offer concrete sculpting and coloring which can achieve nearly identical appearances to existing rock. Integral coloring should be used so that chipping and abrasion that is likely to occur over time does not result in variable coloring. Photos 8, 9 and 10 show three examples of concrete walls either form lined and colored or sculpted and stained to match local native rock.

Photos 8, 9 and 10 – Examples of architecturally sculpted and colored concrete.

Permitting and Seasonal Constraints

As any construction on the fish ladder will take place in the creek, certain permitting processes are unavoidable. NEPA, CEQA, the Endangered Species Act (ESA), Sections 1601-1603 of the California Fish and Game Code, Sections 401 and 404 of the Clean Water Act, as well as other permit processes will likely be considered.

Engineering solutions that provide minimal impact to the creek and surrounding area should be pursued, not only for obvious benefits to the environment, but for the minimized and shortened permitting processes they might allow. Generally, considering impacts to the creek during design and construction may allow for fewer environmental obstacles, and therefore fewer scheduling impacts. It should be noted that ESA permitting related to salmon or steelhead life cycles may also dictate construction windows for the times of year fish ladder construction can occur (typically June through September).

Consideration should also be given to construction during times of the year when the flows in the creek are historically lowest. If the flows are low enough, the contractor may not need to divert or contain water from the creek. However, precipitation and runoff within the watershed

can cause rapid increases in the flows in Big Chico Creek, and the construction contract should include clauses specifying contractor responsibility for water diversion, dewatering, pumping, cofferdams, or other water containment or diversion systems. The contract documents should include the average historical flow data (Table 5) as well as links to internet sites where the contractor should be encouraged to do his or her own research.

Table 5 - Historic average monthly flow data for Big Chico Creek.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Max	6140	7070	5300	4880	1250	366	83	51	201	3330	3270	7190
Avg.	328	409	321	221	93	46	29	25	25	35	83	214
Min	21	18	28	17	20	17	14	14	15	16	17	18

Contracting Considerations

Additional Insurance

The USFWS (or other agency anticipated to procure and administer the construction contract) should consider the benefits and costs of requiring the contractor to carry more than a standard amount of Worker's Compensation and Employer's Liability insurance as well as General Liability insurance for the project. More coverage may be warranted in this case than for typical projects due the hazardous work environment.

Safety

It should be noted in the contract that the contractor would be responsible for all design and construction of access and safety measures. All contractor designs should be stamped by a licensed engineer in the state of California, and submitted for 'informational purposes only' to the USFWS prior to the start of construction.

Risk- and Location-Based Construction Costs

It should be noted that due to the difficulty of access and the somewhat remote nature of the project, unit costs in the Engineer's Estimate as well as the contractor bids will likely be higher than similar projects without these impediments. Because the scope of construction work is difficult to define accurately, it is recommended that a construction contract based on *Unit Prices* and/or a *Lump Sum* with fixed unit prices above the anticipated quantities, be considered. A strictly *Lump Sum* (firm fixed price) contract may expose the USFWS to significant change orders and/or construction claims.

Operations and Maintenance

Structure Lifespan

Properly constructed, a new fish ladder should have very low maintenance needs for an estimated 50-year life span. The most significant gains in performance will be realized with good construction practices, such as adequately anchoring the weirs and slabs to stable blocks, using well consolidated (high strength) concrete and regular removal of rocks and debris from

the pools. Seasonal operation and maintenance of the ladder will likely consist of cleaning accumulated debris and sediment from the pools, installing and uninstalling flashboards, and monitoring movement or deterioration.

Site access, both in terms of personnel and supplies, is the biggest deterrent to maintenance. As discussed in the "Transporting Material and Personnel to the Site" section, permanent access to the site should be considered if the upkeep of the ladder is a long term goal of the stakeholders. In fact, a newly rebuilt fish ladder could attract more interested parties to the area, increasing the possibility of a serious accident. As mentioned previously, a permanent access route is likely to be considered environmentally or aesthetically undesirable; however, similar access routes are often constructed at state and national parks to reach remote areas safely. Other anticipated objections to a permanent access would include upkeep and liability of the stairway. While a permanent access would add maintenance costs for the City of Chico (or other jurisdictional organization), extremely unsafe access is already being (implicitly) provided to the site via a near-vertical path downstream of the fish ladder.

Conclusions

1. There is nothing from a geological, seismic, structural, hydraulic or hydrological perspective which would preclude the construction of the proposed fish ladder structure in Iron Canyon.
2. A properly constructed fish ladder in Iron Canyon should be expected to perform better than the existing structure has over a 50-year life span while having low maintenance needs.
3. We expect that most future potential instability concerns will be related to the western canyon wall and individual blocks within the Big Chico Creek channel.
4. We have identified seven overhanging blocks and/or blocks with open joints on the western canyon wall that are judged to have the potential for static and/or seismic instability.
5. In our judgment, Block 7 poses the highest potential risk to the project due to its relatively low stability characteristics and potential for adverse project impacts.
6. Block 2 is judged to pose a moderate risk to the project.
7. A large landslide complex exists along the eastern side of Iron Canyon. The overall condition of the fish ladder suggests distress related to toe deformation of the landslide complex has not occurred since its construction. Although we would expect similar performance over the next 50 years, the potential for future for static creep or seismic movement cannot be precluded.
8. We consider the potential for global failure of the western canyon wall (similar to large scale landsliding along the eastern side of the canyon) to pose a very low risk to the project, as this would likely require further downcutting and lateral migration of the

creek channel. The potential for this to occur is considered low due to the natural block armor in the creek channel.

9. Although other slope failure processes may potentially adversely impact the project, it is our opinion that the overall project risk levels are typically low, and implementing mitigation measures would therefore not likely be justifiable from an economic perspective.
10. Water depths in the canyon from a 13,100 cfs flow (1997-like event) will be from 18 to 35 feet deep with velocities from 8 to 17 feet per second.
11. Two large basalt blocks along the fish ladder have reportedly moved and caused local creek flow changes at Weir Group 1 and reduced serviceability of Weir 17. However, monitoring points were established to evaluate block movement and no movement was measured during the 78-day period monitored. In addition, the block above Weir 17 indicates that the block appears to be supported by similarly sized blocks beneath it at three points, and significant additional movement of this block downward onto the weir appears unlikely.
12. Isolated boulders up to approximately 9 feet in diameter could be hydraulically transported by a flow of 13,100 cfs, however, few boulders that size are present without significant interlocking with other blocks.
13. Project access to both the top and bottom of the canyon will require improvements to complete the project.
14. The most likely option for transporting personnel, equipment and material into the canyon from the rim is by use of a self-erecting crane
15. The use of a high-line for transporting personnel, equipment and material into the canyon may require larger setbacks due to the horizontal forces it exerts.

Recommendations

1. Any design for the new fish ladder should be performed with the maximum construction flexibility possible. The design should consist of standardized or idealized design with the exact dimensions and fit to be worked out in the field. The exception would be weir and pool elevations which would be specified precisely in advance.

2. The long-term pH effects of grout, concrete or other construction chemicals should be considered during design.

3. As part of final design, the stability of selected foundation blocks, sidewalls, and pool bottoms should be evaluated during low flows for excavatability, long-term stability, and the possible need for stabilization. Additional structures may also be required where temporary and/or permanent support is necessary.

4. Construction activities should not occur within 30 feet of the western canyon rim.

5. Prior to start of construction activities, temporary fencing should be erected and a work exclusion zone established. This zone should be checked for newly open joints or tension cracks prior to the start of construction activities each day.

6. Installation of wire extensometers or survey pins across select existing joints along the canyon wall and/or rim, particularly at Block 7, is recommended.

7. Should newly opened joints or tension cracks be observed, construction activities in the canyon should be immediately suspended and the workers evacuated to the staging area. Construction activities should not resume until an engineering geologist has evaluated the features and determined that construction can safely continue.

8. Crane outriggers should be centered between the observable primary joints typically visible at the ground surface.

9. Prior to the start of construction activities within Iron Canyon, the western canyon wall should be scaled by experienced personnel to remove loose blocks and debris above the planned work zone.

10. Considering the large volume of Block 7 and its relatively low stability characteristics, it is recommended that consideration be given to removing the block using controlled blasting techniques. It must be emphasized that this could potentially damage the existing upper weirs or result in significant alteration of the channel morphology, requiring reconfiguration of the fish ladder.

11. Block 2 should be removed by mechanical scaling (e.g., excavator with rock breaker) or controlled light blasting prior to the start of construction activities within Iron Canyon.

12. The existing trails leading from the canyon rim to the project site should not be considered as safe construction access routes to the fish ladder.

13. A secondary form of access and egress should be provided for construction. This could include either a tower scaffold or a construction elevator (hoist). The tower or elevator should be sited away from the seven overhanging blocks and/or blocks with open joints on the western canyon wall that are judged to have the potential for static and/or seismic instability. A potential location is shown on Drawing 3. The final location of the tower or elevator and anchorage points on the western canyon wall should be reviewed and approved by an engineering geologist prior to installation.

14. If the fish ladder is to be rebuilt or remain in operation, a permanent safe access to the site should be considered for future O&M. It is not specifically recommended that one be built, but rather that a discussion between all the stakeholders regarding a permanent access would be worthwhile.

15. All staging platforms and temporary access features should be constructed according to OSHA and CAL-OSHA standards.

16. Contractors should be made aware of the high rock strengths they are likely to encounter on the site.

17. Immediately prior to construction when the site has been dewatered, blocks in which work will be occurring near or under should be reevaluated by an engineering geologist or engineer to check that the stabilization measures determined during final design are appropriate.

18. Demolition of the existing concrete weirs and basalt blocks should be performed with pneumatic chipping equipment rather than concrete saws.

19. While rock can likely be broken down into manageable pieces by jack-hammering, light blasting may be required in some instances. Blasting will require a blasting plan so that appropriate safety measures can be implemented. It is recommended that all personnel be evacuated from the canyon when blasting is performed. Prior to reoccupying the canyon after each blast, it is recommended that the western canyon rim be checked for newly opened joints or tension cracks. Installation of wire extensometers or survey pins across select existing joints along the canyon wall and/or rim, particularly at Block 7, should be considered.

20. Excavation activities should be closely monitored by an engineering geologist or engineer to evaluate the actual conditions encountered and the need for supplemental stabilization.

21. New pool bottom slabs should be constructed with cast-in-place concrete and designed to span the distance between boulders to which they are tied, even in the event of the loss of supporting bed below.

22. To improve bonding the boulders and blocks which weirs or slabs are cast against should be well cleaned and if worn smooth, should be intentionally roughened per ACI design codes.

23. The use of architectural form liners or sculpted and colored concrete should be considered for the construction of new concrete weirs and appurtenant structures. Integral coloring should be used so that chipping and abrasion does not result in variable coloring.

24. The project should have a full time resident engineer who is familiar with the intent of the project and its goals and is qualified to direct the contractor through the multitude of decisions the site will require.

25. Debris and rocks should be removed seasonally from newly constructed pools.

26. All future personnel on official visits to the fish ladder should be in possession of a satellite phone.

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Aerial Photographs

Date	Photo Number	Scale	Flown By
6/30/00	WR-BPK-C 1-1 to 1-10	1:2,400	American Aerial Surveys for Dept. of Water Resources
6/11/90	Flight line 8, photos 21 and 22	1:24,000	Cartwright Aerial Surveys
4/22/84	WAC-84C 20-6, 20-7	1:31,680	Western Aerial Corporation
8/26/75	5147 2-212, 213	1:24,000	Cartwright Aerial Surveys
6/28/64	AAX-2EE-53, 54	1:20,000	U.S. Dept. of Agriculture
7/8/62	BUT-5-16, 17	1:20,000	U.S. Dept. of Agriculture
6/28/62	BUT-2-37, 38	1:20,000	U.S. Dept. of Agriculture
7/14/58	AAX-3V-63, 64, 103, 104	1:20,000	U.S. Dept. of Agriculture
7/22/52	AAX-10K-162, 163	1:20,000	U.S. Dept. of Agriculture
6/13/47	GS-EJ 1-74, 1-75	1:20,000	U.S. Geological Survey
11/27/37	AAX-125-31, 32, 33	1:20,000	U.S. Dept. of Agriculture

Topographic Maps

Date	Map*	Scale	Prepared By
1980	Paradise West 7.5-minute quadrangle	1:24,000	U.S. Geological Survey
1953	Paradise 15-minute quadrangle	1:62,500	U.S. Geological Survey
1895	Chico quadrangle	1:125,000	U.S. Geological Survey

* Maps on-file in Map Collection, Shields Library, University of California, Davis.

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Appendix A

Appendix B