PROJECT 184:
CANAL FAILURE FREQUENCY AND ANALYSIS

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INTRODUCTION

Project 184 conveys water from the main diversion dam located near Kyburz to the El Dorado Forebay over a 22-mile system of canals, flumes and tunnels. Much of the current improvements have been in relatively continuous operation for over 65 years in an alignment for an even earlier canal system that dates from the Nineteenth Century. Tat the terminus, the El Dorado Forebay regulates water that flows into a surge tank and through a penstock into the El Dorado Powerhouse where power is generated. The forebay also regulates approximately 15,080 acre-feet per year of water for consumptive use into El Dorado Irrigation District's main canal.

The total length of the canal system is 115,790 feet, or approximately 22 miles. It presently consists of a combination of structures as follows:

Table 1: Canal System

Lined ditches	86,592
Flumes (wood and concrete)	19,800
Pipe (primarily siphons)	3,590
Existing tunnel	5,808
New tunnel (replacing canal and flumes)	10,500
Total	**115,790**

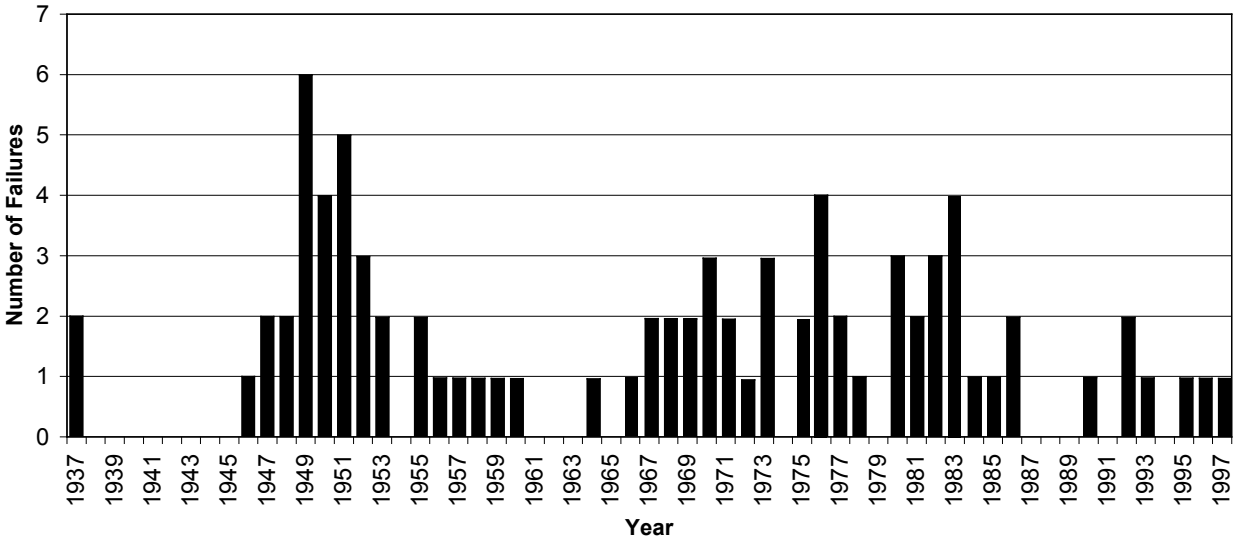
The majority of the canal system is constructed on a bench occupying a relatively steep, north-facing slope. This exposed location has been subject to failure, primarily due to natural events including occasional disasters caused by fire and landslide. Over the 65-year record, the canal has experienced an average failure incidence rate of 1.4 per year. Certain portions of the canal have had a much higher frequency of failure than others. This analysis documents the historic pattern of canal failure over that period.

ANALYSIS

A total of 83 failures occurred between the years 1937 and 1997, the last year in which the system was operational. Although there have been impacts to the canal since then, there have been no operational failures. Table 2 shows the annual incidence of failures of all magnitudes during that period. On average, approximately 1.4 canal failures occur each year, although the distribution of failures has not been constant with the years 1937 through 1946 having no incident of failure while other years experienced multiple

failures. These often correspond to wet cycles in the weather pattern but are also affected by fires and human activity.

Table 2: Canal Failure Frequency



The causes of these failures include landslides, snow, ice, fire, trees, normal wear, vandals, and loggers. The number and type of failures are shown in Table 3 below. Failures can occur over a series of years if the weather pattern is experiencing a wet cycle. Of the 83 failures occurring over 60 years, 7 were due to snow loading the canal and snow-laden trees falling on the canal, 8 were due to ice jams causing flume breaks or overtopping of the canal, 3 were due to fires causing damage to the canal, and 8 were due to trees falling on the canal.

Table 3. Causes of Canal Failures

Type of Failure	Number of Failures
Slide	30
Rain	13
Snow	7
Ice	8
Fire	3
Tree	8
Wear	12
Vandals	1
Loggers	1
Total	**83**

Over half of the failures (43) were due to landslides or rockfalls. Translational/rotational landslides, debris slides, earthflows, and debris flows occur in this area. Translational/rotational landslides are relatively slow moving slides characterized by a cohesive slide mass and a deep failure plane. Large masses are shifted downward in a

translational slide, and rotational slides are similar except the mass is rotated to a certain degree. Debris slides typically consist of unconsolidated rock, colluvium, and soil that move along a relatively shallow failure plane. Earthflows occur when saturated soil and debris become semi-plastic and highly viscous, resulting in mass movement. Debris flows occur along stream banks that have been scoured and eroded by the stream. They commonly occur along bare streambanks, and originate in steep, intermittent and first and second order channels during high intensity precipitation events. Landslides occur due to multiple factors, including slope inclination, bedrock geology, geologic structure, geomorphology, weathering, vegetation, and precipitation.

High intensity rain events, rain-on-snow events, and rapid snowmelt often fully saturate the soil, thus decreasing slope stability. When the soil becomes saturated in a short amount of time, the water cannot drain from pore spaces and pore pressures elevate. Elevated pore pressures often result in a landslide. Of the 43 failures, 13 were identified during times of heavy rains. These landslides cause trees and/or debris to slide into the canal and damage it. More landslides may have been due to precipitation, but it cannot be determined with the available data.

The January 1997 failure, which was the most expensive and caused the largest magnitude of damage, corresponds to the sixth highest monthly rainfall for the 129-year period of record (1873 to the present). This month ranks third for monthly rainfall during the period of analysis, 1937 to 1997. The December 1955 failure corresponds to the third highest monthly rainfall for the 129-year period of record, and the highest monthly rainfall for the period of analysis. The February 1986 failure corresponds to the ninth highest monthly rainfall for the 129-year period of record, and the fourth highest monthly rainfall for the period of analysis. A clear correlation exists between major canal failure and peak storm periods over the project record.

Additional correlations can be made with daily rainfall data. A single storm event that lasts one day or less may cause a landslide depending on its intensity. Since only monthly rainfall data is available, it is not possible to identify single storm events.

Table 2 also shows that 86% of the total number of failures were due to naturally occurring factors. An additional 12 failures were due to normal wear, specifically leaks and tears in the canal lining. The remainder of the failures were random or deliberate events caused by the actions of people, including vandalism and logging accidents.

The longest duration impaired operation of the system, caused by a canal failure was 13 months. This failure was due to a massive earth slide on April 9, 1983, which destroyed 3,610 lineal feet (lf) of the canal and major portions of State Highway 50. The combination of extensive damage and interrupted highway access was a major local disaster during that year affecting more than just Project operations.

The average duration of impairment due to failure was 11.7 days. Several failures occurred that were repaired quickly. These include a flume break due to ice on January 1,

1949 and a rock damaging the flume on April 3, 1972, which were the shortest duration failures and were repaired in one hour.

The severity of canal failures are classified as small, moderate, or severe. Severe failures include those that lasted more than a day, caused significant damage to the system in more than one location, or caused significant erosion of the hillslope. Moderate failures include those that lasted more than a couple of hours, caused some erosion, or caused an interruption in operations. Small failures include those that lasted a couple of hours or less, caused little or no erosion, or caused minimal damage to the canal.

Approximately 48% of the failures were small, 16% were moderate, and 36% were severe. All of the severe failures had a significant operational impact, since it was not possible to deliver water to the forebay for more than one day. Sixteen of the moderate and severe failures (19% of all failures) caused significant amounts of erosion to occur on the hillslope, and 22 of the failures (26% of all failures) were repaired at a significant cost. Erosion varied from washing away topsoil to bedrock for a limited distance below the canal, to significant erosion that reached the mainstem.. Failure incidents that caused significant damage comprise 19% of the total failures occurring in the last 60 years. A significant percentage of major failures, including the 1983 landslide, the 1995 Cleveland Fire, and the 1997 flood event, occurred in the reach from Mill Creek to Bull Creek. Efforts to replace this section of the canal with tunnels in 1994 (El Dorado Tunnel) and 2001-2002 (current tunnel project) will significantly improve system reliability and reduce failure rates, particularly in the area that has been the most subject to catastrophic failure in the past.

Approximately 3,610 lf of canal was replaced with the El Dorado Tunnel after the April 9, 1983 landslide. Approximately 75% of the failures that occurred in the canal replaced by the El Dorado Tunnel were classified as severe. No failures in this section have occurred since the installation of the tunnel. The Mill to Bull Creek Tunnel replaces flume sections that were damaged during the 1997 landslides. Both tunnels eliminate problem areas that previously took long periods of time to repair. Not including the sections that were replaced with the tunnels, the longest duration of a canal failure decreases to 60 days. This failure occurred on November 12, 1985, and was due to a snowstorm that blew a tree over the canal. The Esmeralda Tunnel, which was installed in 1931, most likely eliminated failures that occurred before 1931. Since we only have records from 1937, however, it is not possible to determine how this tunnel decreased the number of failures. With the replacement of the canal with the El Dorado Tunnel in 1984 and the Mill to Bull Creek Tunnel in 2002, the average number of canal failures is statistically reduced to 1.0 per year and the average duration of canal failure is decreased to 4.3 days.

CONCLUSIONS

The Project 184 canal delivery system is vulnerable to periodic damage and interruption due to natural processes and fire. The likelihood of such failure is higher in wet years and major storm events. The system is also vulnerable to occasional and sometimes severe damage due to forest fire and occasional minor damage due to the acts of man.

Tunnel projects undertaken by PG&E and its successor, the El Dorado Irrigation District, have significantly reduced the likelihood of failure in the most vulnerable reach. The remaining wooden flume sections will continue to represent potential failure points which can be reduced by an incremental program of repair, lining and replacement by pre-cast concrete flume, where indicated.

Appendix I: **Canal Failure Record 1937 to 1997**

DATE	DATE	DURATION	LOCATION	CAUSE	SEVERITY
June 15, 1937	6/15/37	6 Days	Station 21+07	Canal Break - Slide	severe
February 1, 1937	2/1/37		Station 229+20	Canal Break - Slide	small
June 15, 1946	6/15/46	1 Day	Flume 4	Flume Break - Lining	moderate
January 2, 1947	1/2/47	2 Days	Station 152+83	Flume Break - Tree	severe
February 26, 1947	2/26/47		Station 1053+	Canal Break - Leak	small
December 15, 1948	12/15/48		Station 784+50	Canal Break - Snow	small
December 25, 1948	12/25/48	5 Days	Station 407+97	Flume Break - Ice Jam (Flume 31)	severe
January 1, 1949	1/1/49	1 Hour	Station 1068+58	Flume Break - Ice (Flume 49 & 50)	small
February 22, 1949	2/22/49		Station 1162+00	Canal Break - Slide	small
February 14, 1949	2/14/49		Station 1016+00	Canal Break - Ice	small
March 4, 1949	3/4/49		Station 1092+62	Canal Break - Slide	small
March 13, 1949	3/13/49		Station 245+70	Flume Break - Slide (Flume 31)	small
July 22, 1949	7/22/49	1 Day	Station 289+00	Flume Break - Leak in lining (Flume 24 & 25)	moderate
June 30, 1950	6/30/50	3 Hour	Station 365+	Flume Break - Leak (Flume 29)	small
November 12, 1950	11/12/50		Station 350+45	Canal Break - Leak	small
November 18, 1950	11/18/50		Misc	Flood Damage - Rain (Flume 2)	small
December 4, 1950	12/4/50		Station 615+40	Canal Break - Slide	small
January 19, 1951	1/19/51		Station 608+25	Flume Break - Tree (Flume 46)	small
March 13, 1951	3/13/51		Station 41+75	Canal Break - Slide	small
November 14, 1951	11/14/51		Station 284+17	Canal Break - Leak	small
December 12, 1951	12/12/51	5 Days	Station 415+90	Flume Break - D/S Slide backed up water to overflow Flume 31-A	severe
December 29, 1951	12/29/51		Station 408+15	Canal Break - Slide (Flume 31-A)	small
January 13, 1952	1/13/52		Station 620+00	Flume Break - Snow/Tree (Flume 46)	small
January 14, 1952	1/14/52		Station 406+00	Flume Break - Snow/Tree (Flume 30)	small
August 18, 1952	8/18/52	1 Day	Station 318+00	Flume Break - Slide	moderate
October 30, 1953	10/30/53	2 Days	Station 1185+03	Canal Break - Leak	severe
November 7, 1953	11/7/53		Station 1182+00	Canal Break - Leak	small
November 24, 1955	11/24/55	1 Day	Station 1029+50	Flume Break - Snow/Tree (Flume 49 +50)	severe
December 22, 1955	12/22/55		Various	Flume Breaks - Rain	small
January 27, 1956	1/27/56	2 Days	Station 150+10	Flume Break - Tree	severe
March 7, 1957	3/7/57		Station 34+00	Canal Break - Slide	small
April 4, 1958	4/4/58	13 Days	Station 408+55	Flume Break - Tree (Flume 31)	severe
February 12, 1959	2/12/59	10 Days	Station 288+70	Flume Break - Tree (Flume 24 & 25)	severe
February 6, 1960	2/6/60	5 Hours	Station 1069+70	Flume Break - Slide (Flume 41)	moderate
December 22, 1964	12/22/64	22 Days	Station 995+06	Flume Break - Slide (Flume 48)	severe
May 30, 1966	5/30/66	6 Days	Station 744+65	Canal Break - Slide	severe
March 11, 1967	3/11/67	17 Days	Station 366+57	Tree in ditch caused over topping of Flume 29	severe
December 13, 1967	12/13/67		Station 610+40	Flume Break - Ice (Flume 46)	small
January 16, 1968	1/16/68	3 - 4 Hours	Station 519+45	Rock & earth slide knocking out substructure at Flume 44	moderate
December 16, 1968	12/16/68		Station 518+75	Flume Break - Slide	small
January 18, 1969	1/18/69	2 Days	Station 365+11	Flume Break - Slide (U/S Flume 29)	severe
May 9, 1969	5/9/69	12 Days	Station 407+25	Flume Break - Slide	small
			D/S Flume 31	Wood paneling fell into ditch caused by landslide. Water backed up causing over topping of flume.	severe
January 22, 1970	1/22/70	8 Hours	Flume 46	Boulder knocked a large hole in flume loosened by heavy rains.	moderate
January 24, 1970	1/24/70	4 Hours	Flume 46	Tree fell against flume and broke 4 flume boards.	small

December 16, 1970	12/16/70	4 Hours	Flume 27 & 28	Trees loosened by heavy rains caused 2 trees to fall and break 6" wide x 18" long hole in flume.	small
January 6, 1971	1/6/71	12 Days	U/S Flume 12	Ice jammed in spillway 10 causing over topping of gunnite ditch	severe
			Station 175+37		
December 6, 1971	12/6/71	5 Hours	Flume 24 & 25	Rock went through the bottom of flume	small
April 3, 1972	4/3/72	1 Hour	Flume 46	Rock went through the bottom of flume	small
January 12, 1973	1/12/73	2.5 Hours	Alarm 11	Stump slid into canal from heavy rainfall; canal blocked.	small
January 15, 1973	1/15/73	2.5 Hours	Esmeralda Tunnel	2 Cedar stumps slid into canal, floated downstream lodged in tunnel.	small
August 18, 1973	8/18/73	8 Days		Fire broke out along Iron Mountain Road (Pelican Fire). The wind spread the fire in a Northeasterly direction causing damage to the canal.	severe
			Station 97+82	11'x7'x7' Rock rolled into concrete lined canal. A 20' section had to be replaced after the rock was removed.	
			Flume 5	Fire destroyed 4 sections of flume, approximately 64'	
			Flume 8 & 9	Rock rolled into canal and broke a 20"x20" hole in the bottom of the flume.	
			Flume 10	Fire destroyed 2 sections of flume, approximately 32'	
			Flume 20	Fire destroyed 3 sections of wood flume, approximately 48'	
			Flume 22	Fire destroyed 2 sections for wood flume, approximately 32'	
February 11, 1975	2/11/75	5 Days	Flume 5	Hillside above canal had slipped causing trees to fall and pushed 3 - 10' sections of concrete lining into the canal.	severe
March 21, 1975	3/21/75	2 Days	Flume 49 & 50	Tree fell into flume due to heavy snowfall causing major washing below flume.	severe
January 5, 1976	1/5/76	1.5 Hours	Flume 24 & 25	Spline groove at corner special had ruptured causing leak in bottom of the flume.	small
January 10, 1976	1/10/76	2.75 Hours	Flume 13	Large rock had rolled into flume 13 causing board to break in the bottom of the flume.	small
February 8, 1976	2/8/76	6 Hours	Flume 45	Severe leak in bottom of flume; flume board had split.	moderate
February 13, 1976	2/13/76	4.5 Hours	Flume 23	Rock came down hill breaking 4 top boards	moderate
January 18, 1977	1/18/77	3 Hours	Flume 1	Ice caused the spline grooves to enlarge, leaks caused erosion under flume.	moderate
July 30, 1977	7/30/77	1.5 Hours	30 Mile Summer Track	12" Wide x 6" long hole developed in concrete lining section	small
August 14, 1978	8/14/78	1.5 Hours	Flume 46	Rock dislodged and went through flume. Replaced 6 boards 2' wide.	small
January 14, 1980	1/14/80	6 Days	Flume 5	Due to slide, replaced 32' upper side of wood flume	severe
			Flume 20	Removed mud slide	
			Flume 22	Removed slide and trees. Replaced 5 support posts.	
			Flume 23	Washed out wood flume supports	
			Camp 3 Section	Numerous locations - removed rocks, mud, trees, and re-position various wood panel boards, at various locations.	
August 11, 1980	8/11/80	2.25 Hours	Flume 46	Rock dislodged and went through wooden flume.	small
August 23, 1980	8/23/80	4 Hours	Spillway 40	Vandals opened spillway 40, broke U-bolt holding gate in place	small
November 14, 1981	11/14/81	4 Hours		Heavy rains caused the following damage to the El Dorado Canal:	moderate
			Flume 4	Tree top fell through flume, replaced 4' of upper side of flume	
			Flume 30	Tree top fell across flume backing water up. No damage to flume.	
			Station 582+60	Rock, trees, etc., mud slide backing up canal flows	
			Station 586+18 to 587+30	112' of panel board lining collapsed into canal.	

			Station 1110+00	Large deposit of rock and gravel, approximately 40 yards washed into the canal.	
			Alder & Plum Creek	Siphon gates plugged with debris, tree limbs, etc.	
			Flume 4	Repairs to flume and removal of debris on grates were made thru Nov 14, 1981. Removal of slides was scheduled to coincide with an outage scheduled for El Dorado Powerhouse.	
December 3, 1981	12/3/81	3 Hours	Flume 46	16" Of rock wall supporting Flume 46 slid away due to excessive ground saturation from heavy rainfall.	small
February 15, 1982	2/15/82	2 Days	Numerous Locations	Heavy rainfall and high winds resulted in extensive damage at numerous locations along the El Dorado Canal. Mudslides and debris plugged the Alder Creek and Plum Creek siphons and the 14 Mile Tunnel. Mudslide at Camp 4 blocked canal flow.	moderate
April 1, 1982	4/1/82	6 Days	Flume 8 & 9	Falling trees from heavy snow load blocked the canal just downstream from Flume 8 & 9 backing up the flow and over topping Flume. 4 to 16' Section washed out.	severe
September 24, 1982	9/24/82	1.5 Hours	Flume 45	Rock had slid into flume fracturing a joint section.	small
January 24, 1983	1/24/83	14 Hours	Flume 5	Earth and rockslide, repairs consisted of rebuilding 1 to 16' side section of flume.	severe
March 4, 1983	3/4/83	33 Days	Various	Heavy rain caused numerous slides, flume damage.	severe
April 9, 1983	4/9/83	13 Months	Flume 22	Massive earth slide slipped into the South Fork American River. 3,610 LF. Of tunnel constructed between Flumes 20 & 23	severe
June 24, 1983	6/24/83	3 Days	Flume 46	Loggers had fallen a large tree that slid down the hill damaging 32' of flume.	moderate
May 10, 1984	5/10/84	5.5 Hours	Stations 161+35 and 162+05	Water leaking around a weep pipe that goes under concrete section of canal. Hole was found in section.	small
November 12, 1985	11/12/85	60 Days	Flume 51-A	Heavy snow and winds caused a tree to fall over canal. Snow and debris built up on the limbs, backing up the flows and over flowing Flume 51-A. Flume replaced with steel reinforced gunnite box realigned into uphill slope.'	severe
February 16, 1986	2/16/86	3 - 4 Weeks	Numerous Locations	Earth slides due to heavy rains along the El Dorado Canal	severe
			Flume 49 & 50	Replaced 2, 16' sections of flume	
			Flume 5	Remove earth and debris from flume. Replaced 32' of side lining	
			Flume 27 & 28	2 Sides of flume pushed in.	
			Flume 39 & 40	Remove3d slide from flume.	
September 7, 1986	9/7/86	4 Days	Flume 45	Fire destroyed 4, 16' sections of the flume. Origin of fire unknown.	moderate
December 28, 1990	12/28/90	8 Hours	Open Canal U/S of Flume 20	Ice formed inside the Alder Creek Siphon, broke loose and developed a blockage about 75 feet downstream in the opened canal. About 25 LF of berm was washed out. Gunnite remained intact. Spill flow was estimated at 20 cfs. Ice as removed and canal flow was limited to 30 cfs.	severe
February 16, 1992	2/16/92	3 Days	Flume 10	4 Large rocks, 16' upstream wall fell in. 12' hole on lower side, 6 small holes in flume.	severe
September 29, 1992	9/29/92		Flume 4 - 29	Cleveland forest fire, 24, 580 acres burned. Portions of flumes 4, 5, 6, 20 & 23 were damaged and all of flumes 7, 8/9, 10, 11, 12, 23-A, 23-B, 24/25, 26, 26-A, 27/28, & 29 were destroyed.	severe
December 10, 1993	12/10/93	1 Day	Plum Creek Siphon	Large chunk of ice dislodged from inside the Plum Creek siphon and became lodged in the canal about 30' down stream, causing it to overtop.	severe
January 10, 1995	1/10/95		Flume 46	Heavy rains caused mudslide that took out a section of flume.	moderate
1996	6/18/05		Flume 10	Flume Break - Tree	small

January 2, 1997	1/2/97	Numerous Locations	Earth slides from heavy rain along the El Dorado Canal caused numerous slides, flume damage	severe
		Flume 1, 8, 9, 38-40, 45a, 46	Removed earth and debris from flumes	
		Flume 6, 23b	Berm Repair	
		Flume 2a, 12, 24, 25, 41	Lining Repair	
		Flume 29	Foundation Repair	
		Flume 2, 3, 4, 6, 7, 10, 11	Joint Repair	
		Flume 1, 10, 12	Flume Box Repair	
		Flume 39/40, 45	Replace 64 lf of wooden flume	
		Flume 24, 25, 27, 28	Replaced with tunnel	