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Prepared for the U.S. Army Corps of Engineers, Portland District,
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Contract DE-AC05-76RL01830

Sensor Fish Characterization of Fish Passage Conditions through John Day Dam Spillbay 20 with a Modified Flow Deflector

Final Report

JP Duncan

April 2011

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Fish passage conditions over a modified deflector in Spillbay 20 at John Day Dam were evaluated by Pacific Northwest National Laboratory for the U.S. Army Corps of Engineers (USACE), Portland District, using Sensor Fish devices. The objectives of the study were to describe and compare passage exposure conditions at two spill discharges, 2.4 and 4.0 thousand cubic feet per second (kcfs), identifying potential fish injury regions within the routes, and to evaluate a low-tailwater condition at the 2.4-kcfs discharge. The study was performed in April 2010 concurrent with HI-Z balloon-tag studies by Normandeau Associates, Inc.

Sensor Fish and live fish were released upriver of the spillbay gate at an elevation of 215 ft above mean sea level, determined using a computational fluid dynamics model. Release depth and position were established to introduce the fish and sensors into flows of approximately 5 to 8 feet per second (fps); fish and Sensor Fish were projected to pass 4 ft above the crest of Spillbay 20.

Sensor Fish data were analyzed to estimate 1) exposure conditions, particularly exposure to severe collision and shear events; 2) differences in passage conditions between treatments; and 3) relationships to live-fish injury and mortality data estimates.

Nearly 79% (n = 47) of all Sensor Fish released experienced a significant event, as determined from acceleration magnitude data; the greatest percentage was observed for the 2.4-kcfs low-tailwater condition (88%; n = 17). Event severity was also highest for Sensor Fish passing the 2.4-kcfs discharge at low tailwater, with a mean impulse peak value of 141.76 g for the most severe event per release and 134.87 g for Sensor Fish experiencing more than one event (multiple events) per release for that condition. Multiple events for the 2.4-kcfs discharge at low-tailwater conditions averaged 1.53 events per release. For normal tailwater levels at the same discharge, there were 1.27 events per release; 0.93 event per release was measured for the 4.0-kcfs discharge.

The acceleration magnitudes for the most severe significant event observed during normal tailwater conditions at the 2.4-kcfs and 4.0-kcfs discharges averaged 125.9 g and 123.3 g, respectively. Live-fish estimates during normal tailwater conditions for both mortality and malady-free metrics were determined to not be significantly different.

Nearly all Sensor Fish significant events were classified as collisions; the most severe occurred at the gate, on the spillbay chute, or at the deflector transition. Collisions in the gate region were observed only during the 2.4-kcfs discharge, when the tainter gate was open 1.2 ft. One shear event was observed during the evaluation, occurring at the deflector transition during passage at the 2.4-kcfs discharge at low tailwater. Flow quality, computed using the Sensor Fish turbulence index, was best for passage at the low-flow low-tailwater condition as well. The worst flow quality was observed for the 4.0-kcfs test condition.

Contrasting the passage exposure conditions, the 2.4-kcfs low-tailwater treatment would be most deleterious to fish survival and well-being.

Acronyms and Abbreviations

cfs	cubic feet per second
fps	feet per second
ft	foot, feet
g	average acceleration produced by gravity at the Earth's surface (sea level); used in this report as a measure of event magnitude
g	gram(s)
hr	hour(s)
Hz	hertz
in.	inch(es)
kcfs	thousand cubic feet per second
min	minute(s)
mm	millimeter(s)
MSL	mean sea level
MW	megawatt(s)
psia	pounds per square inch absolute
RM	river mile
RSW	removable spillway weir
s	second(s)
TSW	top spillway weir
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

During the past several years, strategies to improve downstream passage of juvenile salmonids have resulted in spillway modifications including weir inserts and surface bypass channels, as well as structural modifications such as deflectors and walls, with the intention of decreasing passage time, reducing risk of injury or mortality, optimizing water used for spill passage, and managing dissolved gas concentrations. Recent focus has been on inserts that pass water from the upper portion of the water column rather than through a submerged gate opening, improving fish passage efficiency and survival. These top spillbay weirs (TSWs) and/or removable spillway weirs (RSWs) have been successfully deployed and evaluated at several U.S. Army Corps of Engineers (USACE) projects on the Columbia and Snake rivers. The TSWs originally installed in Spillbays 16 and 17 at John Day Dam were moved in 2010 to Spillbays 18 and 19 to enhance migrant passage by utilizing the powerhouse attraction flows to direct fish away from the more detrimental turbine passage route. A new 50-ft-long deflector with a 50-degree radius was installed in Spillbay 20 to function as a flow guidance mechanism, deterring fish from being caught in a powerhouse eddy in the tailrace, and to aid in total dissolved gas reduction. The powerhouse eddy has contributed to delayed egress, allowing increased predation of summer migrants by birds and piscivorous fish.

This report documents an evaluation of the newly installed deflector in Spillbay 20 at John Day Dam, contrasting conditions for two flow discharges at normal tailwater levels and one flow discharge at a low tailwater level. The study was conducted by Pacific Northwest National Laboratory for the USACE, Portland District, and was performed concurrently with HI-Z balloon-tag studies of passage survival for juvenile spring Chinook salmon (*Oncorhynchus tshawytscha)* conducted by Normandeau Associates, Inc. (Normandeau 2011).

1.1 Objectives

The objectives of this study were

- to describe and compare passage exposure conditions at two spill discharges, 2.4 and 4.0 thousand cubic feet per second (kcfs) during normal tailwater levels
- to describe and compare passage exposure conditions during 2.4-kcfs spill at low tailwater levels to those at normal tailwater levels
- to identify regions within the passage route where conditions are potentially injurious to fish.

1.2 Report Overview

Chapter 2 describes the study site, the Sensor Fish device, and the data collection and analysis procedures used in the research. Chapter 3 presents the results of the study, followed by a discussion in Chapter 4. Conclusions are offered in Chapter 5, followed by Chapter 6, the sources cited in this report.

Appendix A contains field log data that provide dam operating conditions, release elevations, and deployment and recovery times for each Sensor Fish release. Appendix B provides summary data tables for each Sensor Fish release, including exposure event descriptions, acceleration magnitude at gate passage, and rates of change in pressure. Appendices C and D present graphics showing pressure, acceleration magnitude, and angular-rate-of-change magnitude time histories for each Sensor Fish release.

2.0 Methods

2.1 Study Site

John Day Dam, located on the Columbia River at river mile (RM) 215.6, is the third dam upstream from the mouth of the Columbia River, approximately 100 miles east of Portland, Oregon. The project, built and operated by the USACE, was completed in 1971 and consists of a navigation lock with a total lift height of 113 ft; 20 spillbays, each with a 50-ft-wide tainter gate; a powerhouse containing 16 Kaplan turbine units capable of producing a combined power capacity of 2,160 megawatts (MW), and 4 skeleton bays for future hydroelectric generation expansion; and fish passage facilities (Figure 2.1).

Figure 2.1. John Day Dam.

2.2 Sensor Fish Device

The Sensor Fish housing is constructed of clear polycarbonate plastic (Figure 2.2). It is 24.5 mm in diameter and 90 mm long and weighs 43 g. The Sensor Fish is nearly neutrally buoyant in fresh water. The Sensor Fish measures the three components of linear acceleration, the three components of angular velocity (these together comprise the six degrees of freedom), absolute pressure, and temperature, at a sampling frequency of 2,000 Hz per sensor channel over a user-programmable recording time of about 4 min.

Figure 2.2. Six-degree-of-freedom Sensor Fish device.

The Sensor Fish consists of modules that charge its internal battery, program the sensor settings, acquire data, and convert from analog signal to digital form. The acquired data are stored in an internal memory card and transferred to a computer via a wireless infrared link using an external infrared link modem. Sensor Fish are deployed, acquiring data in response to hydraulic conditions and interaction with structure; units are retrieved; and the data are downloaded, analyzed, and interpreted.

Retrieval of the Sensor Fish is aided by the attachment of a micro-radio transmitter (Advanced Telemetry Systems, Isanti, Minnesota) and HI-Z balloon tags (Normandeau Associates, Inc., Bedford, New Hampshire), which are identical to those used for live test fish (Heisey et al. 1992). HI-Z tags contain a water-soluble capsule filled with a chemical that produces gas when activated with water, a process that takes approximately 3 min following initiation. The balloons inflate sufficiently to bring the Sensor Fish to the surface for recovery, and a directional radio receiver antenna used by boaters in the tailrace homes in on the radio transmitter attached to the Sensor Fish.

2.3 Procedures

Sensor Fish releases were interspersed with releases of HI-Z balloon-tagged live fish through the same release pipes used by Normandeau Associates, Inc. During the low-tailwater 2.4-kcfs spill treatment, only Sensor Fish were released; no live fish were released during this condition.

Sensor Fish were injected into the Spillbay 20 approach flow, passing through 1.2-ft and 2.0-ft gate openings discharging spill volumes of 2.4 kcfs and 4.0 kcfs, respectively. Releases were made through an induction system consisting of a large-diameter (4-in.) stainless steel pipe with a flexible hose attachment, installed approximately 2.5 ft upstream, mid-bay. Flexible hosing (4-in.-diameter) connected the terminus of the steel pipe to the outlet of the modified head tanks where live fish and Sensor Fish were introduced into the injection systems.

A computational fluid dynamics model was used identify elevations for introduction of live fish and Sensor Fish so that they would enter the spillbay approach flow at approximately 4 ft above the spillway crest (214 ft above mean sea level [MSL]) into water velocities of approximately 5 to 8 feet per second (fps).

2.4 Data Analysis

Sensor Fish data sets consist of time histories of angular motion (pitch, roll, and yaw), pressure, acceleration (x, y, and z axes), temperature, and battery status extending from the time of release through the period of data acquisition programmed into the Sensor Fish (Deng et al. 2007a). Data time histories contain a data point for each transducer every 0.0005 s. This time interval between digital samples corresponds to a 2,000-Hz sampling rate for each of the analog outputs from Sensor Fish acceleration, rotation, and pressure sensors. Sampling of all analog data streams occurs simultaneously within each sampling interval.

Water depth in feet is estimated, when appropriate, from absolute pressure at various points along each Sensor Fish route by subtracting atmospheric pressure, determined at the time of the release of each Sensor Fish, and dividing the resulting gauge pressure by 0.4335, the pressure in pounds per square inch of 12 in. of fresh (distilled) water at 39.2ºF (4ºC). Acceleration vector magnitude is computed for each sampling interval using triaxial accelerometer output and is one of the variables analyzed and reported to characterize Sensor Fish response to turbulence, contact with structure (strike or collision), and shear. Triaxial angular rate-of-change data are processed similarly to triaxial acceleration data to provide further information about the response of the Sensor Fish to flow conditions.

Analysis of the raw data from the Sensor Fish begins with preparation of plots showing absolute pressure, triaxial acceleration, and triaxial rotation. These records are visually inspected to identify prospective strike, collision, and shear events and to obtain a general overview of the passage conditions present for each test treatment. Changes in pressure during passage include features that are consistently present that result from the design of passageway structures and the dynamics of water flow through the passageway. These features in the pressure time history permit acceleration and rotation data to be divided into segments corresponding to specific locations (zones) that extend from Sensor Fish injection to exit from the stilling basin. Each zone is identified by characteristic features in the Sensor Fish pressure time history and characteristics in triaxial acceleration and rotation data. For each Sensor Fish data set, events of interest, such as rapid pressure changes, strikes, collisions, shear, and severe turbulence, are identified and quantified. Quantification of events includes the time of occurrence, location by zone, and extraction of information describing severity, as well as additional information to separate collisions from shear exposure.

3.0 Results

Detailed data on which this chapter is based are provided in the appendices. Appendix A contains study data that include the release and recovery times for each Sensor Fish, flow discharge, and other project information for the study period. Appendix B contains tables of observed significant event magnitudes, acceleration magnitudes acquired during passage under the tainter gate, and pressure rates of change for all Sensor Fish releases. Graphs with plots of pressure and acceleration magnitude for each successful Sensor Fish release are located in Appendix C, and those for pressure and angular rate-of-change magnitude are in Appendix D.

3.1 Release Data

A total of 52 Sensor Fish were released through Spillbay 20 at John Day Dam between April 3 and April 12, 2010, with 47 data sets acquired (Table 3.1). A successful release requires both the recovery of the unit and successful download of acquired data. Four Sensor Fish were not recovered, and one data set could not be downloaded due to damage during passage. The injection pipe terminus elevation was confirmed to be approximately 215 ft MSL, and the forebay elevation averaged 263.9 ft MSL during the study.

Table 3.1. Number of Sensor Fish releases by study treatment during the April 2010 spillway evaluation.

Spillbay 20 Flow (kcfs)	Mean Forebay Elevation (ft MSL)	Mean Tailwater Elevation (ft MSL)	Mean Total Spill (kcfs)	Mean Turbine Flow (kcfs)	Mean Total Project Flow (kcfs)	Total Number Released	Number of Sensor Fish Lost	Number of Sensor Fish Damaged/ Unusable	Number of Usable Data Sets
2.4	263.9	160.4	12.1	93.1	105.2	16	1	0	15
4.0	263.3	159.7	30.5	69.3	99.8	16	1	0	15
2.4	264.4	158.0	11.0	82.1	93.1	20	2	1	17
					Total	**52**	**4**	**1**	**47**

3.2 Data Analysis

Sensor Fish data analysis included reviewing time histories, computing acceleration and rotational magnitudes, and examining pressure records. Collision and/or shear events appear as high-amplitude impulses in acceleration magnitude time histories. To qualify as a significant event, a high-amplitude acceleration impulse must have a peak value equal to or greater than 95 *g* (Deng et al. 2007b). Significant events frequently also show concurrent high-amplitude pressure and rotation magnitude values, which aid in identifying the location of the event in time and space and in distinguishing collisions and strike events from shear events.

The location of a significant event is determined by the location of the impulse relative to distinctive, consistent features observed in the pressure time histories. Timing marks used to locate significant events and identify regions of spillway passage include

1. passage through the tainter gate opening
2. passage along the spillway chute

3. passage at the deflector transition (the region of flow redirection from the spillway chute to the spillway deflector)
4. the deflector region
5. passage through the walled region between the extended piernose and powerhouse
6. passage through the stilling basin to the tailrace surface.

Examples of pressure timing marks used for the spillway study are shown in Figure 3.1. A large drop in pressure (shown by the blue line) occurs as the Sensor Fish passes under the tainter gate. During passage down the spillway chute, pressure is nearly atmospheric, increasing as the flow is redirected over the deflector. Pressure again approaches atmospheric as it passes through the walled area between the piernose and the powerhouse before increasing as the Sensor Fish enters the deeper waters of the stilling basin and is carried to the surface by the increased buoyancy of the inflating balloons. Acceleration magnitude (shown by the red line) shows three significant events (impulses with magnitudes ≥ 95 *g*), identified as collisions with the tainter gate, on the spillway chute, and in the walled area between the powerhouse and piernose extension. Turbulence in the deflector region and at entrance to the stilling basin is also shown. A second data set is shown in Figure 3.2, further describing passage regions.

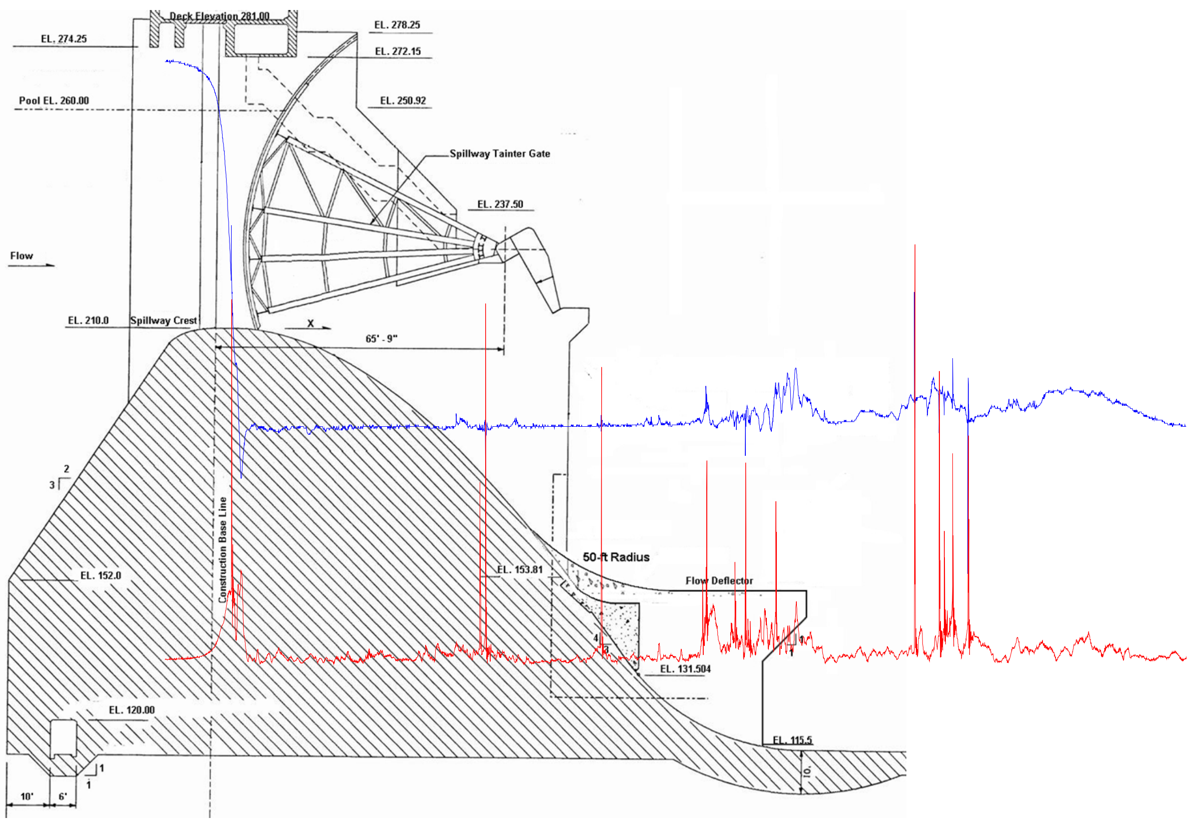


Figure 3.1. Sensor Fish data overlaid on a cross section of John Day Dam showing the approximate locations for major timing marks during spillway passage. The blue line is pressure; the red line is acceleration vector magnitude in *g*.

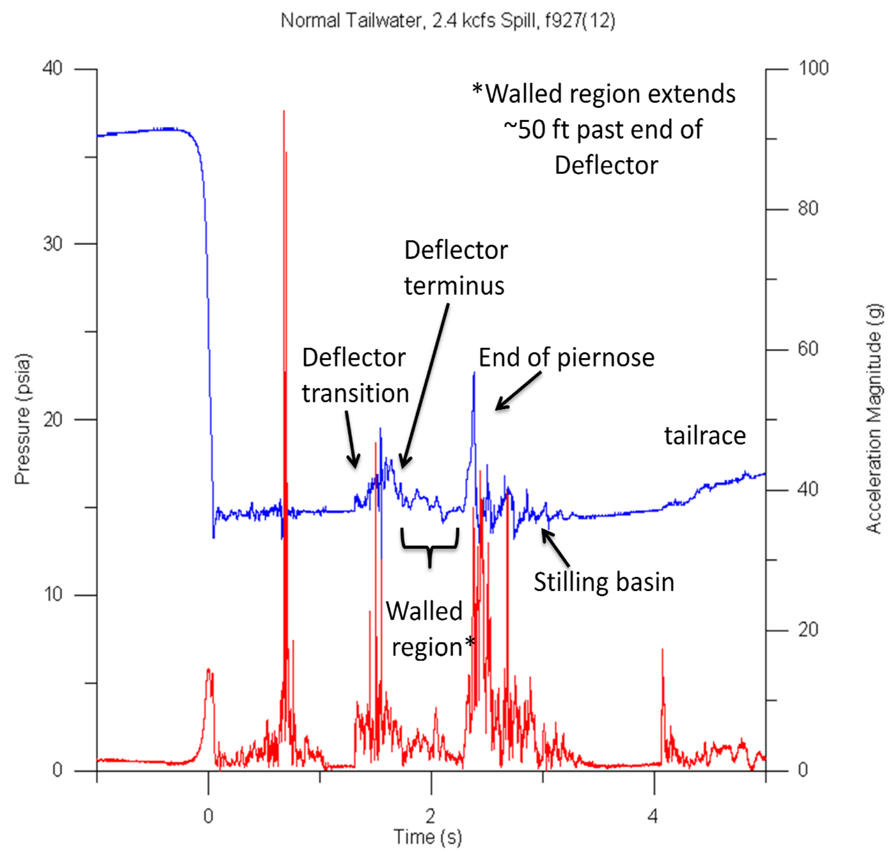


Figure 3.2. Sensor Fish pressure and acceleration magnitude time histories displaying spillway passage regions. "Walled region" refers to the region past the deflector and prior to entrance to the stilling basin between the powerhouse and the extended piernose.

The majority (78.7%) of Sensor Fish experienced at least one significant event, regardless of treatment during passage at John Day Dam; nearly 30% of the Sensor Fish experienced more than one significant event. We define a significant event as an impulse in acceleration magnitude greater than or equal to 95 *g*. Significant events are caused by strike, collision on structure, or exposure to shear. Approximately 10% of the Sensor Fish were damaged or lost during spillway passage.

Table 3.2 summarizes Sensor Fish data by release condition and type and location of occurrence of the most severe significant event observed. No significant events were observed in the stilling basin or tailrace during the evaluation. The most frequently observed severe significant events for the 2.4-kcfs discharge at the low-tailwater condition were collisions at the deflector transition (60%); 27% of the most severe significant event collisions occurred in the gate region and 13% at the deflector (Figure 3.3). No significant events were observed on the spillway chute or the walled region for this treatment. For Sensor Fish released into the 2.4-kcfs discharge at normal tailwater levels, 30% of the most severe significant events were collisions at the deflector transition; 30% were observed on the spillbay chute, 20% at the gate, and 20% in the walled region. At the 4.0-kcfs discharge, collisions on the spillbay chute were the most frequently observed severe significant event (50%), followed by events on the deflector (25%) and at the deflector transition (25%). No significant events were observed in the gate or walled regions at the 4.0-kcfs discharge.

Table 3.2. Sensor Fish releases for each treatment showing location and type of most severe significant event observed.

Spillbay 20 Discharge (kcfs)	Tailwater Level	Number of Releases	Number of Sensor Fish Having at Least 1 Event |a| > 95 *g*	Frequency of Occurrence of All Most Severe Events by Region: Gate	Spillbay Chute	Deflector Transition	Deflector	Piernose/ Powerhouse Wall
2.4	Normal	15	10	2	3	3	0	2
			66.7%	20%	30%	30%	0%	20%
Significant event mean magnitude		125.9 *g*		141.2 *g*	109.3 *g*	131.9 *g*		126.6 *g*
4.0	Normal	15	12	0	6	3	3	0
			80%	0%	50%	25%	25%	0%
Significant event mean magnitude		123.3*g*			130.6 *g*	126.7 *g*	105.4 *g*	
2.4	Low	17	15	4	0	9	2	0
			88.2%	26.7%	0%	60%	13.3%	0.0%
Significant event mean magnitude		141.8 *g*		128.6 *g*		145.3 *g*	152.4 *g*	

		Frequency of Occurrence of the Most Severe Collision Events by Region					Frequency of Occurrence of the Most Severe Shear Events by Region				
Spillbay 20 Discharge (kcfs)	Tailwater Level	Gate	Chute	Deflector Transition	Deflector	Piernose/ Powerhouse Wall	Gate	Spillbay Chute	Deflector Transition	Deflector	Piernose/ Powerhouse Wall
2.4	Normal	2	3	3	0	2	0	0	0	0	0
		20%	30%	30%	0%	20%	0%	0%	0%	0%	0%
4.0	Normal	0	6	3	3	0	0	0	0	0	0
		0%	50%	25%	25.0%	0%	0%	0%	0%	0%	0%
2.4	Low	4	0	8	2	0	0	0	1	0	0
		26.7%	0%	53.3%	13.3%	0%	0%	0%	6.7%	0%	0%

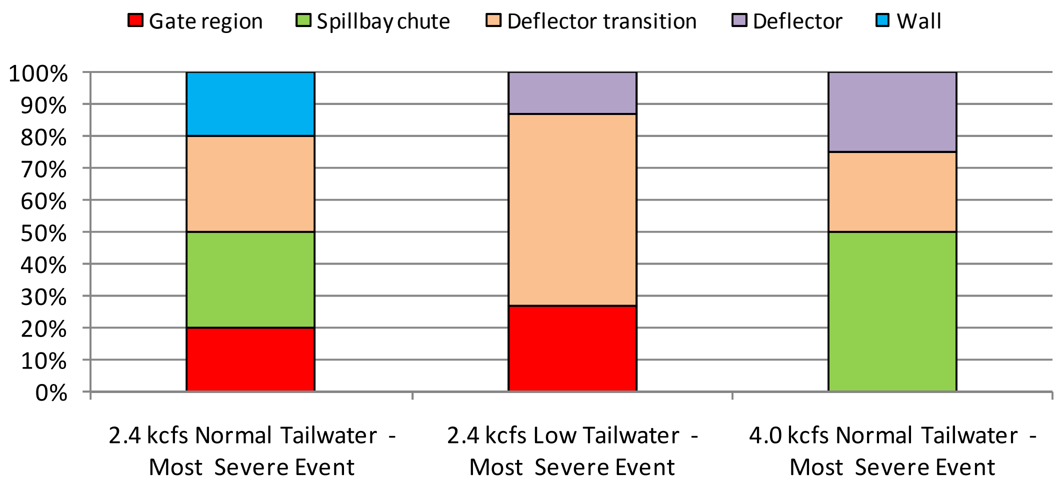


Figure 3.3. Location of the most severe Sensor Fish significant events by passage region. "Gate region" refers to any event immediately prior to, at, or just beyond the gate. "Deflector transition" is the region of flow redirection from the spillbay chute to the spillbay deflector. "Wall" refers to the region past the deflector and prior to entrance to the stilling basin between the powerhouse and the extended piernose.

Table 3.3 summarizes the total number of significant collision and shear events by event type and location of occurrence. For these multiple-event occurrences, the average number of significant events per release was 1.53 events for Sensor Fish passing Spillbay 20 at 2.4-kcfs discharge and low tailwater levels. The fewest events per release, averaging 0.93, occurred during passage at 4.0-kcfs spill at normal tailwater conditions.

No significant events were observed during spillway discharge entry into the stilling basin or tailrace for any Sensor Fish. Multiple significant events were observed most frequently on the spillbay chute following passage at normal tailwater levels and at the deflector transition during low-tailwater passage (Figure 3.4). Collisions in the gate region and the walled section between the piernose and powerhouse were observed during the 2.4-kcfs spill discharge only.

Frequency of shear events observed during the study was low; only one Sensor Fish experienced shear, which occurred at the deflector transition during passage at the 2.4-kcfs discharge low-tailwater condition.

Table 3.3. Location, type, and frequency of occurrence of all Sensor Fish significant events by passage condition.

Sensor Fish Event Summary													
Spillbay 20 Discharge (kcfs)	Tailwater Level	Number of Releases	Number of SF having at Least 1 Event $\lvert a\rvert >95$ *g*	No Event	Single Event	>1 Event	Total No. of Events	Avg. Events per Release	Gate Region	Spillbay Chute	Deflector Transition	Deflector	Piernose/ Powerhouse Walled Region
2.4	Normal	15	10	5	5	5	19	1.27	3	7	6	0	3
			66.7%	33.3%	50%	50%			15.8%	36.8%	31.6%	0	15.8%
			Significant event mean magnitude			125.9 *g* (most severe event)	119.9 *g* (all events)		131.4 *g*	111.4 *g*	124.4 *g*		118.9 *g*
4.0	Normal	15	12	3	11	1	14	0.93	0	7	3	4	0
			80%	20%	91.7%	8.3%			0%	50%	21.4%	28.6%	0%
			Significant event mean magnitude			123.3 *g* (most severe event)	119.6 *g* (all events)			125.8 *g*	126.7 *g*	103.6 *g*	
2.4	Low	17	15	2	7	8	23	1.53	4	3	12	2	2
			88.2%	11.8%	46.7%	53.3%			17.4%	13%	52.2%	8.7%	8.7%
			Significant event mean magnitude			141.8 *g* (most severe event)	134.9 *g* (all events)		141.8 *g*	122.4 *g*	137.5 *g*	152.4 *g*	132.8 *g*

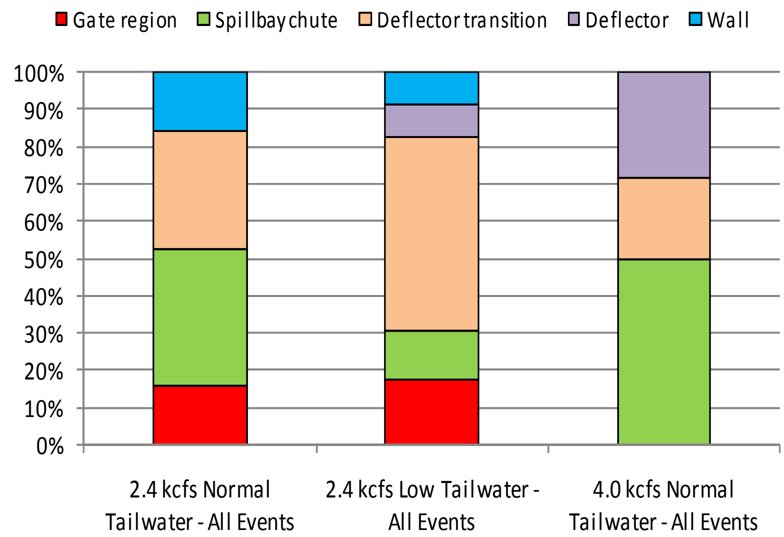


Figure 3.4. Location of all Sensor Fish significant events by passage region.

The mean, maximum, and minimum acceleration magnitude values for the most severe events contrasted with the percentage of Sensor Fish experiencing at least one significant event during passage are shown in Figure 3.5. Sensor Fish significant event magnitudes for passage through Spillbay 20 at both spill discharges at normal tailwater levels were essentially equal; however, the proportion of Sensor Fish experiencing a significant event was higher for the 4.0-kcfs discharge. The highest percentage of Sensor Fish experiencing a significant event and greatest magnitudes were observed for passage through the 2.4-kcfs discharge at the low-tailwater condition.

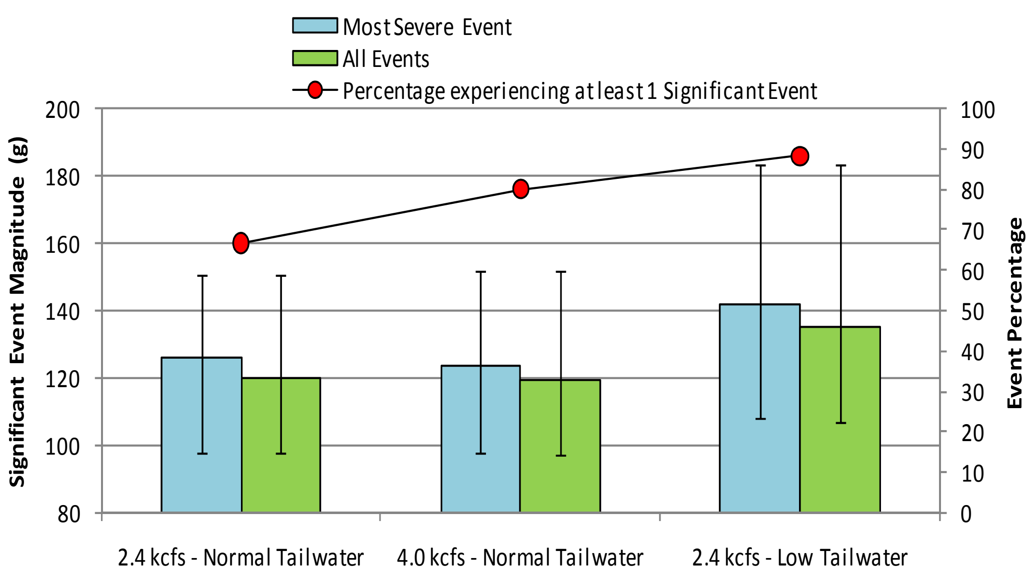


Figure 3.5. Mean, maximum, and minimum peak acceleration magnitudes for the most severe and multiple significant events observed per Sensor Fish release for each treatment condition compared with the percentage of Sensor Fish experiencing at least one significant event.

During the study, operational head was maintained at approximately 104 ft for normal tailwater levels and 106 ft during the low-tailwater condition. Gate openings were 1.2 ft and 2.0 ft for the 2.4-kcfs and 4.0-kcfs discharge, respectively. The pressure reported by Sensor Fish decreased rapidly to near atmospheric following passage under the tainter gate. Pressure rate of change during passage under the gate at normal tailwater conditions averaged –346 psia/s at the 1.2-ft gate opening and −240 psia/s at the 4.0-ft gate opening; rate of change at the 1.2-ft opening at low-tailwater levels averaged –411 psia/s (Figure 3.6). Observed differences between the low and normal tailwater values for the 2.4-kcfs spill discharge are discussed in Chapter 4.

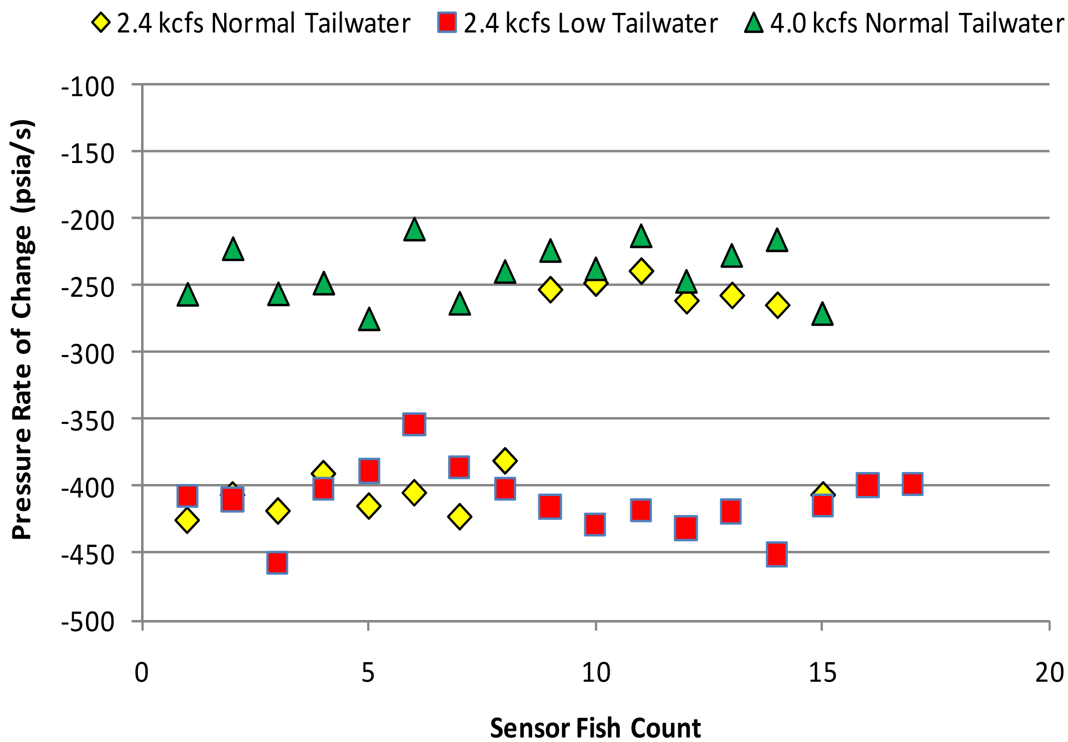


Figure 3.6. Pressure rate of change observed during Sensor Fish passage for each flow discharge and tailwater condition.

3.3 Turbulence Index

The turbulence index as it is used here is a subjective measure developed by computing the area (integrating) under the acceleration magnitude and angular rate-of-change magnitude curves for a given time period, with the premise that larger area equates to greater turbulence. The first 3 s following passage under the tainter gate were used for computations. Computed areas were normalized to seconds for evaluation purposes.

Turbulence index values were highest for passage through the 4.0-kcfs discharge, normal-tailwater condition; lowest values were observed following passage through the 2.4-kcfs discharge at low-tailwater levels (Table 3.4).

Table 3.4. Computed area under the curve for angular rate-of-change and acceleration magnitudes for each treatment condition.

Spill Discharge (kcfs)	Tailwater Condition	Area – Acceleration Magnitude per Second	Area – Angular Rate-of-Change Magnitude per Second	Combined Area per Second
2.4	Normal	5.46	1035.78	1041.24
4.0	Normal	6.04	1065.61	1071.64
2.4	Low	5.02	922.03	927.05

3.4 Comparison of Sensor Fish and Live-Fish Data

Live-fish HI-Z–tag studies were conducted by Normandeau Associates, Inc., concurrently with the Sensor Fish studies. Normandeau scientists released live fish through the same injection system as the Sensor Fish and under the same test conditions with the exception of the low-tailwater scenario, during which only Sensor Fish were released. Sensor Fish releases were interspersed with live-fish releases.

Approximately 600 juvenile Chinook salmon (119–164 mm; mean 135 mm total length [Normandeau 2011]) and 52 Sensor Fish were released during the spillway evaluation at John Day Dam in April 2010. Table 3.5 shows fish release and recapture rates, estimated survival rate, and malady-free rate for live fish (Normandeau 2011).

Table 3.5. Survival and malady-free rates (with 95% confidence intervals) for juvenile Chinook salmon passage at John Day Dam, April 2010 (Normandeau 2011).

	Spill Discharge	
	2.4 kcfs	4.0 kcfs
Number released	300	302
Used for survival calculations[(a)]	294 (99.3%)	296 (98.3%)
Number recaptured alive	292 (97.3%)	291 (96.4%)
Number recaptured dead	1 (0.3%)	2 (0.7%)
Number assigned dead[(b)]	1 (0.3%)	3 (1.0%)
Number undetermined	6 (2.0%)	6 (2.1%)
48-hour survival	**99.3%**	**98.3%**
95% confidence interval (±)	97.3–99.9%	95.9–99.4%
Number examined for maladies	293 (97.7%)	293 (97.0%)
Number without maladies	277 (94.5%)	275 (93.9%)
Number with maladies	16 (5.5%)	18 (6.1%)
Malady-free rate[(c)]	**94.5%**	**93.9%**
95% confidence interval (±)	91.1–96.7%	90.3–96.2%

(a) Number excludes undetermined fish.
(b) Includes dislodged tags and stationary signals.
(c) Percentage based on number alive/ (number released minus number undetermined); not significantly different (Z-statistic).

Figure 3.7 shows live-fish malady and mortality rates compared to Sensor Fish average significant event magnitudes (± standard error of the mean) for all evaluated passage treatments. The reciprocal of the malady-free rate is reported as the injury or malady rate; the reciprocal of survival is reported as mortality. Mean exposure severity for the normal tailwater treatments were nearly equivalent, as shown by the magnitudes of severe and multiple significant events; magnitudes were higher for the 2.4-kcfs low-tailwater condition. Both the live fish and Sensor Fish data indicated that passage conditions were not considerably different for the 2.4-kcfs and 4.0-kcfs discharges at normal tailwater levels.

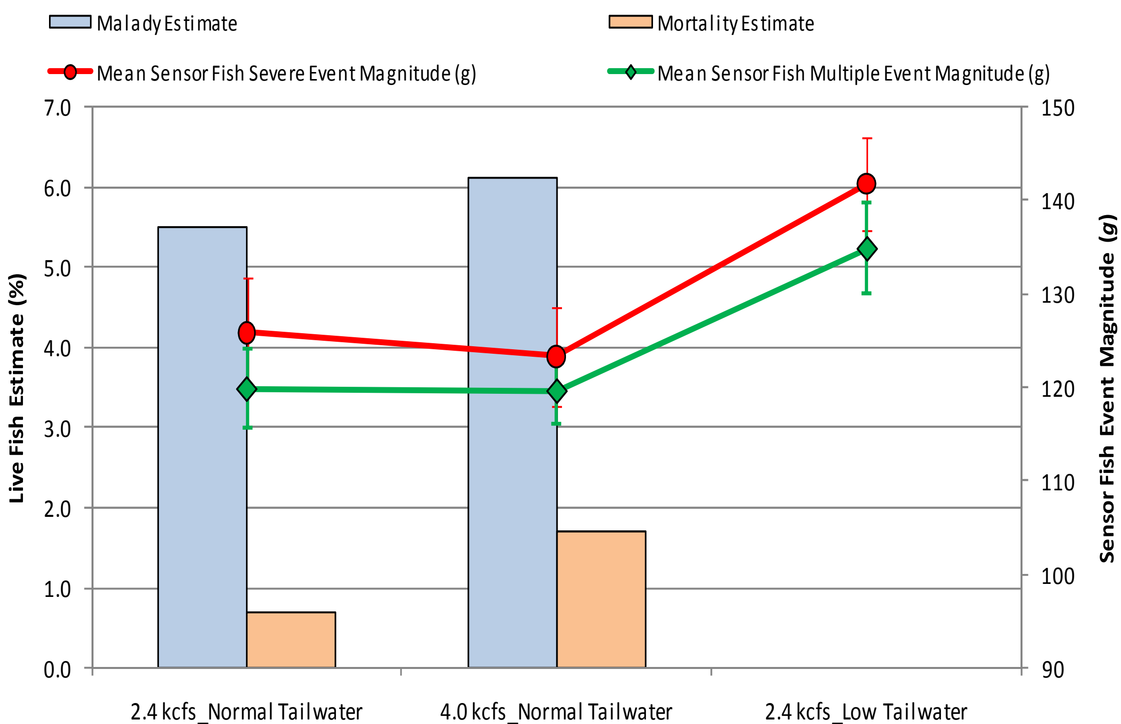


Figure 3.7. Live-fish mortality and malady estimates contrasted with Sensor Fish significant event magnitudes (± standard error of the mean) for all evaluated passage routes.

4.0 Discussion

The objective of this study was to describe and compare passage exposure conditions through the newly installed extended-length 50-degree-radius deflector in Spillbay 20 at John Day Dam, contrasting conditions for two flow discharges at normal tailwater levels and one flow discharge at a low tailwater level, and to compare Sensor Fish observations of passage conditions with observations of the injury and mortality rates for live fish.

Spill volume and associated pressures during Sensor Fish passage through the tainter gates is affected by forebay elevation and tainter gate opening. During the study, forebay elevation averaged 263.9 ft MSL, ranging from 263.2 to 264.5 ft MSL; normal tailwater elevation averaged 160.0 ft MSL (159.3 to 161.0 ft), and low tailwater elevation averaged 158.0 ft (157.9 to 158.1 ft).

Sensor Fish were used to evaluate passage conditions for discharge flow rates of 2.4 kcfs and 4.0 kcfs at normal tailwater levels and 2.4-kcfs discharge at low tailwater levels. Nearly 67% of the Sensor Fish passing through the 2.4-kcfs discharge during normal tailwater conditions experienced a significant event, and 50% of these experienced more than one event. The majority of significant events were observed at the deflector transition and on the spillbay chute (30% each); all were collisions. Approximately 88% of the Sensor Fish passing at the same spill discharge and low tailwater levels had significant events, with 53% of these experiencing multiple events. The majority of significant events occurred at the deflector transition, and all but one were collisions. During 2.4-kcfs spill, the tainter gate at Spillbay 20 was open approximately 1.2 ft; nearly 30% of the Sensor Fish experienced a significant collision event in the gate region at this opening. Injuries to live fish in the head, snout, gills, operculum, and isthmus were somewhat higher for passage through the 1.2-ft gate opening compared with the 2.0-ft opening (Normandeau 2011).

During 4.0-kcfs spill discharge, generated by opening the tainter gate 2.0 ft, and normal tailwater conditions, 80% of the Sensor Fish experienced a significant event, and only one sensor unit had more than one event (less than 10%). All the significant events were collisions, and the majority occurred on the spillbay chute (50%). None of the Sensor Fish passing under the 2.0-ft opening experienced a significant event in the tainter gate region.

In 2008, Battelle–Pacific Northwest Division and Normandeau Associates, Inc. conducted an evaluation of passage conditions through Spillbay 17 at John Day Dam at 6.2-kcfs spill discharge using the same release pipe depth and horizontal position as used during the current study (Carlson and Duncan 2009; Normandeau et al. 2008). The deflector at Spillbay 17 is located at an elevation of 146 ft MSL, has a 15-ft radius, and is 12.5 ft long. In contrast, the newly installed deflector in Spillbay 20 is located at an elevation of 150 ft MSL, has a 50-ft radius, and is 50 ft long (Figure 4.1). The north powerhouse wall extends past Spillbay 20 on the Oregon side of the Columbia River, and the Spillbay 19 extended piernose borders the Washington side (Figure 4.2). This bordered region extends approximately 50 ft past the end of the deflector; the area beyond the deflector at Spillbay 17 has no walls. During the 2008 study, approximately 55% of the Sensor Fish experienced a significant event following passage through the 6.2-kcfs spill discharge; 31% of these experienced more than one event. The majority of significant events were collisions at the deflector transition, although shear was observed more frequently than during the 2.4-kcfs and 4.0-kcfs discharges, approximately 23% of the time. Approximately 31% of the

Spillbay 17 Sensor Fish collided with the spillway chute, and there were no significant events in the tainter gate region, which was open approximately 3.1 ft during the 6.2-kcfs discharge.

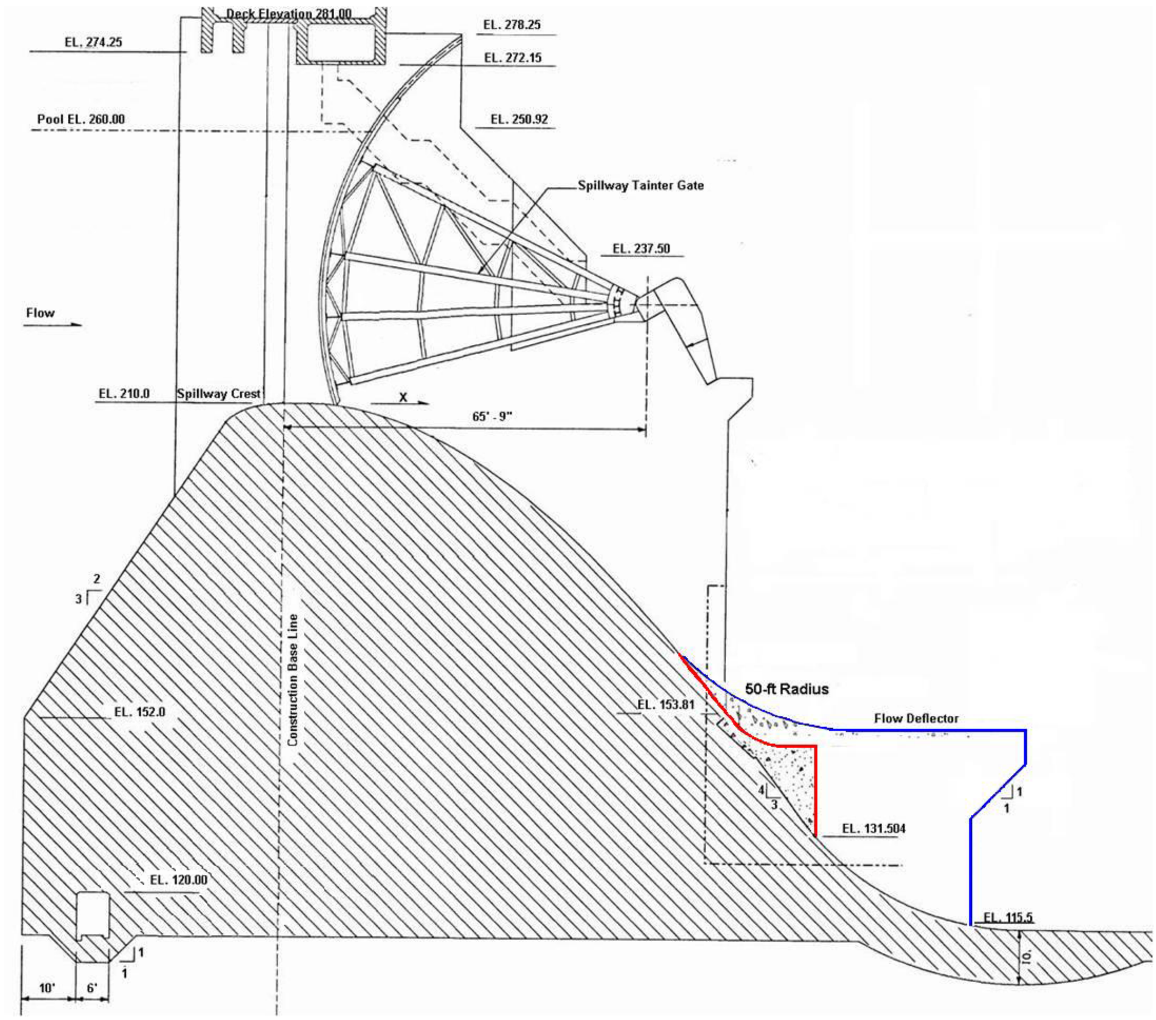


Figure 4.1. Comparison of the existing flow deflector in Spillbay 17 (red line) and the new 50-ft-radius flow deflector in Spillbay 20 (blue line) at John Day Dam.

The influence of flow discharge and elevation of entry (elevation of injection) into spillway approach flow on Sensor Fish and live-fish passage assessment metrics has been examined for several USACE projects (Carlson and Duncan 2004; Carlson et al. 2006, 2008; Normandeau 2004, 2006; Normandeau and Skalski 2005, 2006a, 2006b). These studies show that elevation of entry and flow volume influence the frequency of occurrence, location of occurrence, and type of significant event for Sensor Fish. They also show that elevation of entry influences the survival and injury rates of balloon-tagged juvenile Chinook salmon. Sensor Fish and balloon-tagged fish entering spill approach flow at deeper depths (lower elevations) have been found to have a higher probability of exposure to injurious or fatal events and higher exposure severity. The implication is that Sensor Fish and live fish that enter approach flow at lower elevations are nearer the spillway structure during spillway passage and are therefore more likely to experience collision. Also, tainter gate opening and resultant flow discharge affect passage depth; reduced depth suggests the fish and Sensor Fish would also be closer to structure.

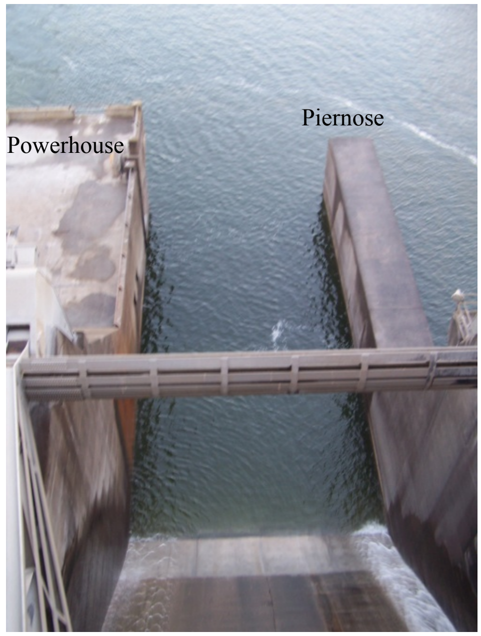


Figure 4.2. Spillbay 20 showing the bottom of the chute and deflector transition, bordered by the powerhouse wall and the Spillbay 19 extended piernose.

During the current study, all fish and Sensor Fish were released from the same injection pipe (elevation 215 ft MSL) positioned to pass the fish 4 ft above the spillway crest. The release point for the 2008 study was 4 ft directly above the spillway crest at an elevation of approximately 214 ft MSL. Primary collisions (the most severe event for the release) on the spillbay chute were greatest for the 4.0-kcfs discharge at 50%; 31% of the Sensor Fish collided on the chute during passage in the 6.2-kcfs discharge in Spillbay 17, 30% collided at the 2.4-kcfs discharge at normal tailwater conditions, and no Sensor Fish collided during 2.4-kcfs low-tailwater passage. Taking into account multiple events per release, similar percentages were observed for all treatments with the exception of passage during 2.4-kcfs low tailwater, where 13% of the Sensor Fish collided with the spillbay chute. Observed values are counterintuitive to what one might expect, considering flow depth and adjacent concrete structure.

Approximately 62% of the most severe significant events observed during passage over the standard 12.5-ft-long deflector in Spillbay 17 during the 2008 study occurred at the deflector transition; 31% experienced an event on the spillbay chute, and 6% at the deflector (Figure 4.3). Shear was more prevalent at the 6.2-kcfs discharge, with 25% of the most severe significant events being of this type, compared with less than 3% shear events during the current study for all conditions. Severe events observed during Sensor Fish passage at normal tailwater levels were primarily on the spillbay chute and at the deflector transition; at low tailwater levels, significant events were more frequent at the deflector transition (60%). Fewer significant events at the deflector transition were observed for the new deflector in Spillbay 20 (50-ft radius, 50-ft extended length) during normal tailwater conditions compared with those at the standard deflector in Spillbay 17. The extended length likely contributed to a greater frequency of events on the deflector as well.

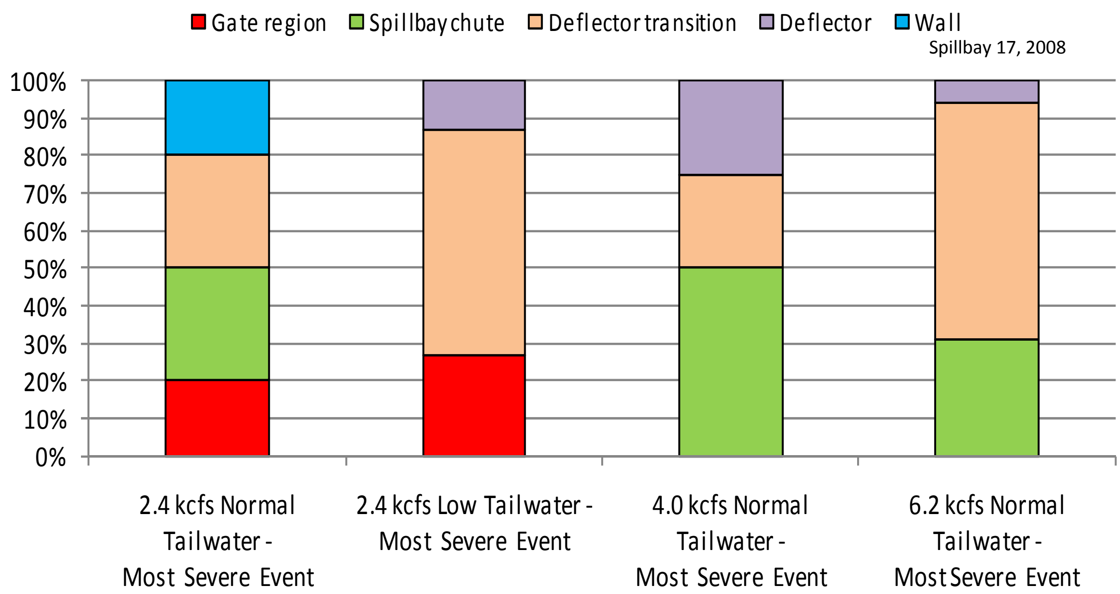


Figure 4.3. Location of the most severe Sensor Fish significant events by passage region at John Day Dam, 2008 and 2010.

Significant event magnitudes observed during normal tailwater conditions at the 2.4-kcfs and 4.0-kcfs discharges averaged 125.9 *g* and 123.3 *g*, respectively, for the most severe event per release. For multiple events, the average significant event magnitudes were 119.9 *g* and 119.6 *g*, respectively, values that are essentially equivalent. Results from the 2008 study examining passage through Spillbay 17, at a 6.2-kcfs discharge and normal tailwater conditions, resulted in average significant event magnitudes of 134.1 *g* for the most severe event per release and 127.0 *g* for multiple events.

Significant event magnitudes were highest for the 2.4-kcfs low-tailwater condition, averaging 141.8 *g* for the most severe event per release and 134.9 *g* for multiple events. For the most severe event per release, collision severity was greatest at the gate and deflector transition regions for the normal-tailwater 2.4-kcfs discharge and on the spillbay chute for the 4.0-kcfs discharge. Event severity during low-tailwater passage (2.4-kcfs flow) was greatest on the deflector and at the deflector transition. Examining multiple events per release, the most severe events occurred at the gate region for the 2.4 kcfs normal tailwater condition; at the 4.0 kcfs treatment the highest magnitude values were observed at the deflector transition region, and at the 2.4 kcfs low tailwater condition highest magnitude events were at the deflector region.

At least one Sensor Fish appeared to be recirculated in the walled region between the powerhouse wall and the extended piernose during passage at the 2.4-kcfs discharge normal-tailwater condition (Figure 4.4). This Sensor Fish is assumed to have been caught in the discharge jet, which rolled back on itself and created an area of turbulence on the deflector that was not evident on the shorter (12.5-ft) Spillbay 17 deflector. Although an area of repeated turbulence is evident, no significant events were observed in this region.

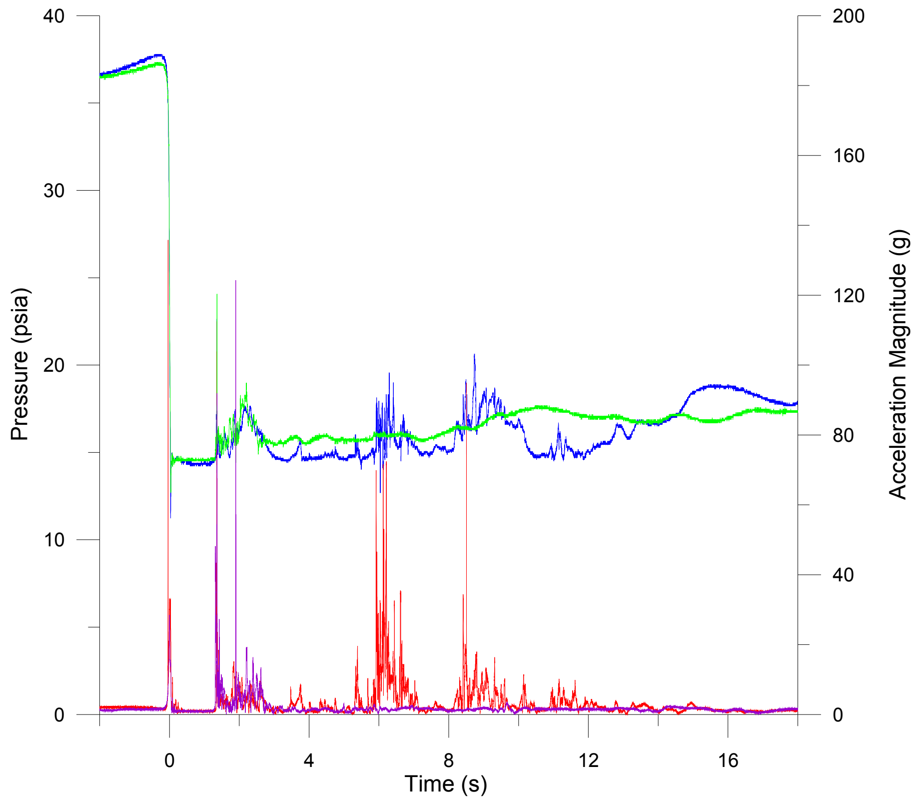


Figure 4.4. Sensor Fish pressure and acceleration magnitude time history illustrating recirculation in the walled region between the powerhouse and extended piernose. Recycled pressure is shown in blue; normal passage pressure in green. Recycled acceleration magnitude is shown in red; normal passage acceleration in purple.

The pressure rate of change during passage under the tainter gate as determined from Sensor Fish data was greatest for the lower gate openings, with the exception of a few 2.4-kcfs normal tailwater releases (Figure 4.5). Data from the 2008 Spillbay 17 evaluation at 6.2-kcfs normal tailwater are also shown and demonstrate very little variation as compared to the current study. One would expect characteristic flow data in the gate passage region for each discharge to be analogous, regardless of tailwater elevation, allowing for slight variances in forebay elevation. Close inspection reveals divergent results for pressure rates of change at gate passage during the second day of 2.4-kcfs normal tailwater testing. Average pressure rate of change for the 2.4-kcfs normal tailwater releases was –346.1 psia/s and mean acceleration magnitude was 21.9 *g* (*n* = 15; standard deviation – 79.5; standard error – 20.5); for the low tailwater elevation, the pressure rate of change was –410.6 psia/s and acceleration magnitude was 29.3 *g* (*n* = 17; standard deviation – 24.4; standard error – 5.9) (Table 4.1).

Partitioning the second day of 2.4-kcfs normal tailwater data from the data set and averaging the first 5 s of pressure data for each flow discharge during passage prior to the tainter gate reveals similar paths for day 1 of the 2.4-kcfs discharge normal tailwater condition and the same discharge at low tailwater (Figure 4.6). Graphic representation of Sensor Fish acceleration magnitude and pressure rate of change data also suggest the second day of data collection for the 2.4-kcfs normal tailwater is related to the 4.0-kcfs normal tailwater treatment (Figure 4.7).

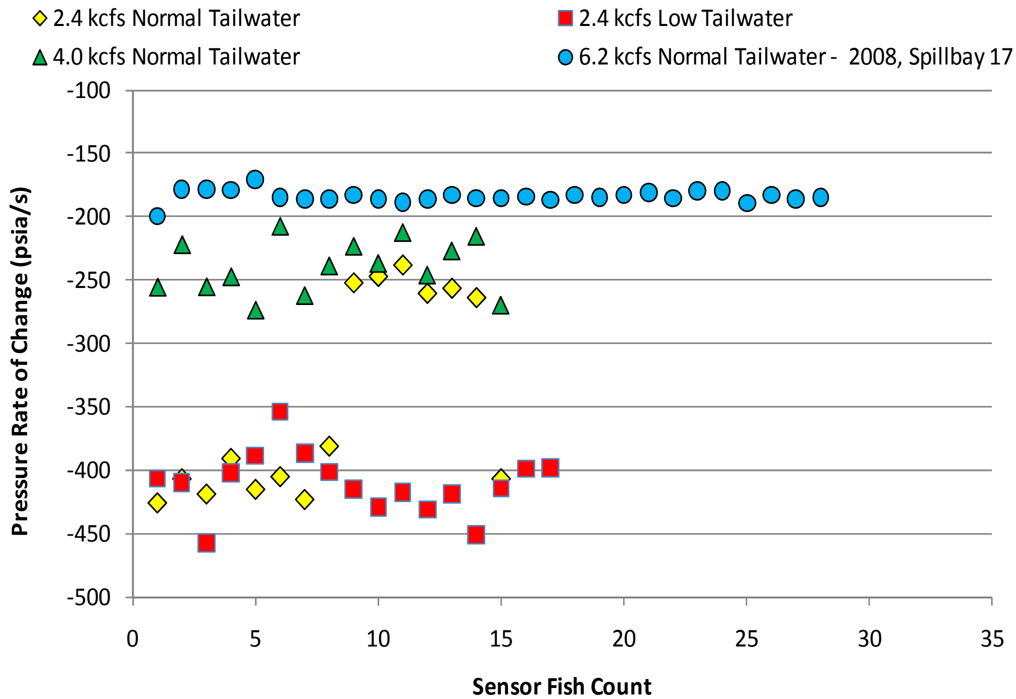


Figure 4.5. Pressure rate of change for passage under the tainter gate at John Day Dam, 2008 and 2010.

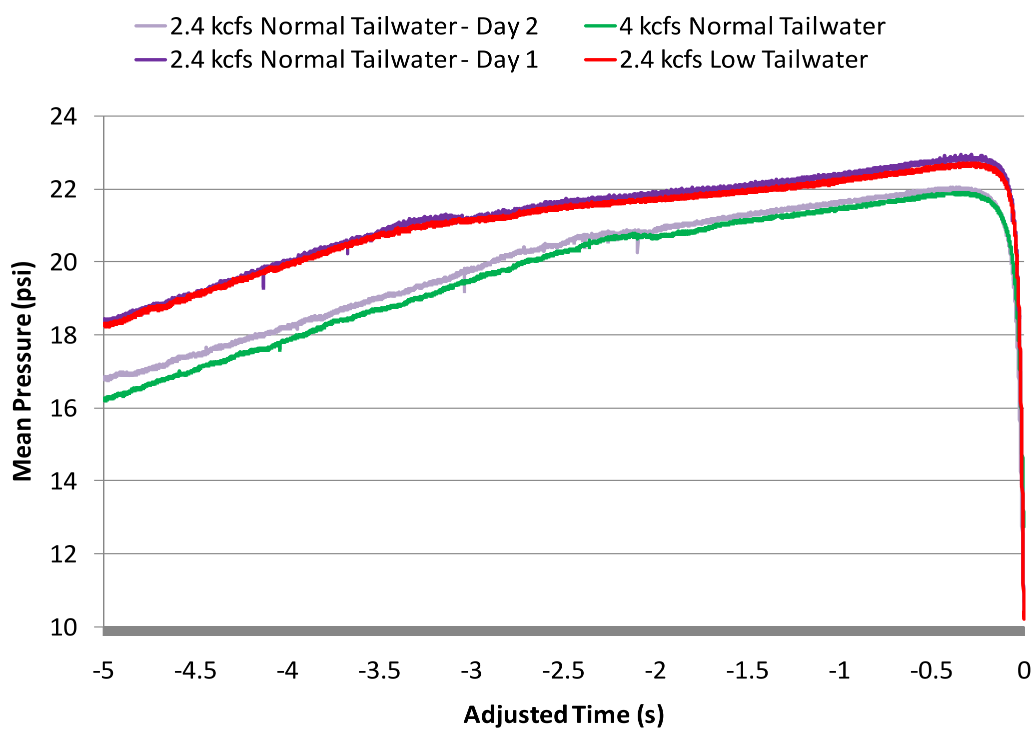


Figure 4.6. Tainter gate approach pressures showing similar paths for 4.0-kcfs flows and day 2, 2.4-kcfs discharge.

Table 4.1. Pressure rate of change and acceleration magnitude during passage under the tainter gate as determined from Sensor Fish. Day 2 of the 2.4 kcfs spill, normal tailwater condition is highlighted.

2.4-kcfs Normal Tailwater (psia/s)	Gate Acceleration	2.4-kcfs Low Tailwater (psia/s)	Gate Acceleration	4.0-kcfs Normal Tailwater (psia/s)	Gate Acceleration	6.2-kcfs Normal Tailwater (psia/s)	Gate Acceleration
–425.67	28.5	–406.67	28.6	–256	14.9	–199.33	11.9
–406.67	26.4	–409.67	29.9	–222	13.7	–178.00	10.3
–418.67	23.0	–457.33	32.8	–255.67	23.4	–178.67	10
–390.67	27.3	–402.33	33.6	–247.67	16.3	–179.00	14.8
–415.00	32.9	–388.67	24.9	–274.33	16.2	–171.00	11.8
–405.00	28	–353.67	26.8	–207.33	13.7	–184.33	10.7
–423.00	24.9	–386.33	26.5	–262.67	14.6	–186.00	10.4
–381.00	22.6	–401.33	24.7	–239.00	13.9	–186.00	10.9
–252.33	14.7	–-415.33	23.8	–223.33	15.7	–183.00	10.3
–247.33	14.5	–429.00	35.2	–237.00	16.6	–186.00	14.1
–238.33	13.5	–417.33	31.2	–212.33	14.9	–189.00	11.5
–260.67	14.5	–431.00	36.4	–246.33	15	–185.67	9.9
–256.67	15.7	–418.67	26.7	–227.00	15.3	–183.00	11.5
–264.00	15.4	–451.00	30.1	–215.33	15.6	–185.33	15.1
–406.67	26.3	–414.33	28.1	–270.33	17.1	–185.33	15.2
Mean – 346.11	**21.88**	–399.00	32.0	**Mean –239.76**	**15.79**	–184.00	9.9
Std Dev. 79.49	6.51	–398.00	27.4	Std Dev. 21.44	2.34	–186.67	11.8
Std Err. 20.52	1.68	**Mean –410.57**	**29.34**	Std Err. 5.54	0.61	–182.67	9.8
		Std Dev. 24.36	3.75			–184.33	12
		Std Err. 5.91	0.92			–182.67	10.4
						–181.00	14.5
						–185.33	11.2
						–179.67	10.9
						–179.33	10.5
						–189.33	9
						–182.67	10.9
						–185.67	10.8
						–184.33	12.8
						–179.67	11.6
						Mean 183.69	**11.53**
						Std Dev. 4.82	1.70
						Std Error 0.89	0.32

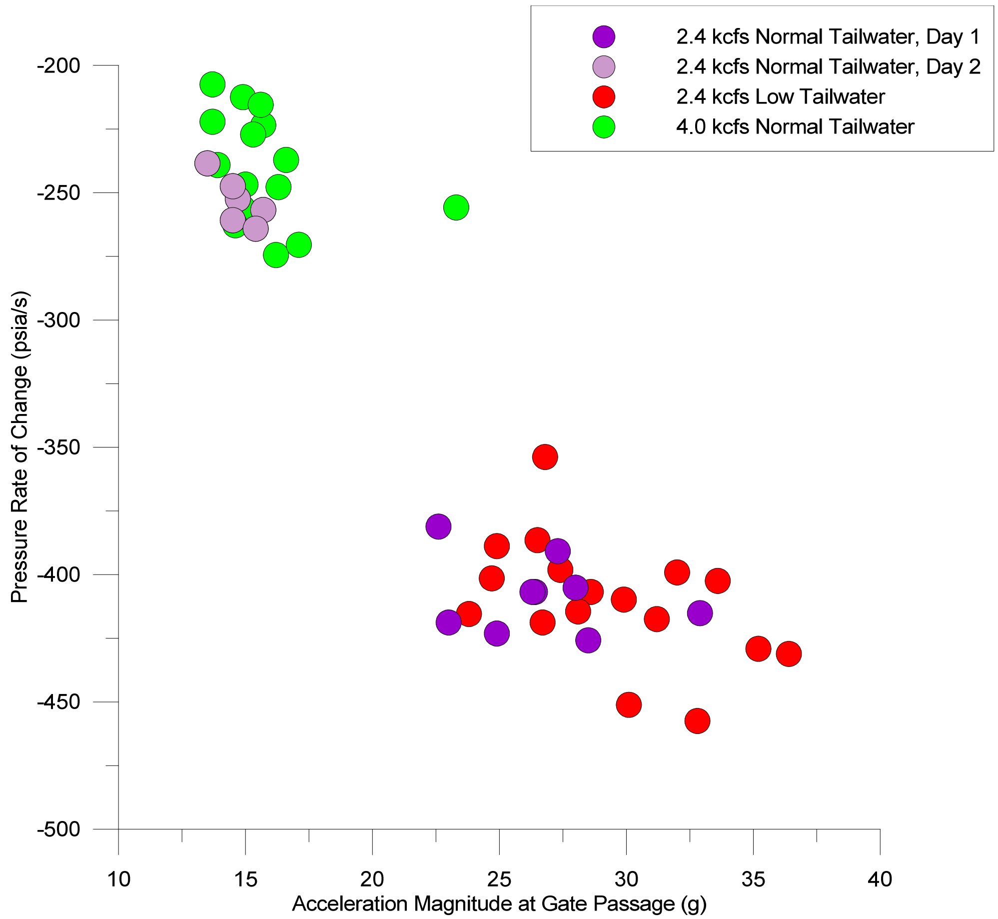


Figure 4.7. Sensor Fish data illustrating a relationship between the second day of 2.4-kcfs discharge and 4.0-kcfs discharge.

Several factors could be responsible for the differences noted between day 1 and day 2 results for the 2.4 kcfs normal tailwater condition. Table 4.2 shows the rate-of-change values with associated dam operations information and acceleration magnitudes during gate passage. Forebay levels change frequently on a run-of-the-river dam; however, there does not appear to be a correlation between acceleration magnitude or pressure rate-of-change values with forebay elevation (Figure 4.8 and Figure 4.9, respectively). A second factor may be the flows in the adjacent spillbays; however, these also do not appear to impact acceleration magnitude or pressure rate of change values during tainter gate passage.

Sensor Fish data collected during the second day of testing for the 2.4-kcfs normal tailwater condition suggest the gate settings during the testing period were incorrect. Data analysis disclosed the inconsistency following fieldwork completion. However, reanalysis of the data assuming the second day of 2.4-kcfs spill was actually 4.0 kcfs does not significantly change the data. The average significant event magnitude for the 2.4-kcfs normal tailwater treatment decreased slightly (125.9 to 125.4 *g*), and the 4.0-kcfs normal tailwater condition increased from 123.3 to 124.1 *g*, still fundamentally the same. Live-fish mortality and malady-free estimates for the testing period were determined to not be significantly different as well. Verification of dam operations data from USACE personnel indicated the gate settings were correct as reported, so the results reported here are based on those settings.

Table 4.2. Rate of change, gate acceleration, and associated dam operations criteria for passage at John Day Dam, 2010. Highlighted rows distinguish levels of Spillbay 19 flow discharge.

2.4-kcfs Normal Tailwater					
Rate of Change	Gate Acceleration	Forebay El (ft)	Spillbay 20	Spillbay 19	Total Spill
–425.67	28.5	263.9	2.4	1.2	3.6
–406.67	26.4	264.0	2.4	4.7	7.1
–394.33	23.9	264.1	2.4	6.9	9.3
–390.67	27.3	264.2	2.4	9.7	12.1
–415.00	32.9	264.2	2.4	9.7	12.1
–405.00	28	264.2	2.4	9.7	12.1
–466.67	26.1	264.1	2.4	9.7	12.1
–381.00	22.6	264.1	2.4	9.7	12.1
–252.33	14.7	263.9	2.4	6.2	8.6
–247.33	14.5	263.9	2.4	6.2	8.6
–238.33	13.5	264	2.4	11.3	13.7
–260.67	14.5	263.5	2.4	11.3	13.7
–256.67	15.7	263.5	2.4	11.3	13.7
–264.00	15.4	263.5	2.4	11.2	13.6
–406.67	26.3	263.4	2.4	9.7	12.1

2.4-kcfs Low Tailwater					
Rate of Change	Gate Acceleration	Forebay El (ft)	Spillbay 20	Spillbay 19	Total Spill
–406.67	28.6	264.4	2.4	7.3	9.7
–409.67	29.9	264.4	2.4	7.3	9.7
–457.33	32.8	264.4	2.4	7.3	9.7
–402.33	33.6	264.4	2.4	7.3	9.7
–388.67	24.9	264.5	2.4	8.2	10.6
–319.33	27.3	264.5	2.4	8.2	10.6
–386.33	26.5	264.5	2.4	8.2	10.6
–401.33	24.7	264.5	2.4	8.2	10.6
–362.33	24.2	264.3	2.4	9.7	12.1
–429.00	35.2	264.3	2.4	9.7	12.1
–417.33	31.2	264.3	2.4	9.7	12.1
–431.00	36.4	264.3	2.4	9.7	12.1
–418.67	26.7	264.3	2.4	9.7	12.1
–460.67	30.4	264.3	2.4	9.7	12.1
–414.33	28.1	264.3	2.4	9.7	12.1
–373.67	34.2	264.3	2.4	9.7	12.1
–367.33	28.6	264.4	2.4	7.3	9.7

Table 4.2. (contd)

4.0-kcfs Normal Tailwater						
Rate of Change	Gate Acceleration	Forebay El (ft)	Spillbay 20	Spillbay 19	Spillbay 18	Total Spill
–256.00	14.9	263.3	4.0	9.7	16	29.7
–222.00	13.7	263.4	4.0	9.7	16	29.7
–265.00	23.4	263.4	4.0	9.7	16	29.7
–247.67	16.3	263.4	4.0	9.7	16	29.7
–274.33	16.2	263.4	4.0	9.7	16	29.7
–207.33	13.7	263.4	4.0	9.7	16	29.7
–262.67	14.6	263.3	4.0	9.7	18	31.7
–239.00	13.9	263.3	4.0	9.7	18	31.7
–223.33	15.7	263.3	4.0	9.7	18	31.7
–237.00	16.6	263.3	4.0	9.7	18	31.7
–212.33	14.9	263.3	4.0	9.7	18	31.7
–246.67	15	263.3	4.0	9.7	18	31.7
–227.00	15.3	263.3	4.0	9.7	18	31.7
–215.33	15.6	263.2	4.0	9.7	18	31.7
–270.33	17.1	263.3	4.0	9.7	18	31.7

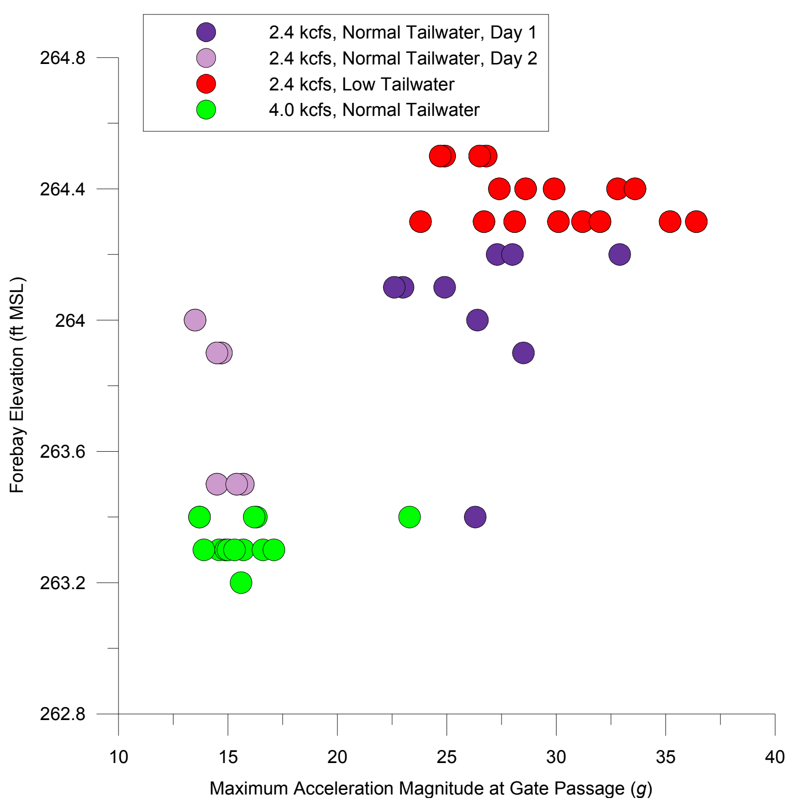


Figure 4.8. Acceleration magnitude at gate passage contrasted with forebay elevation.

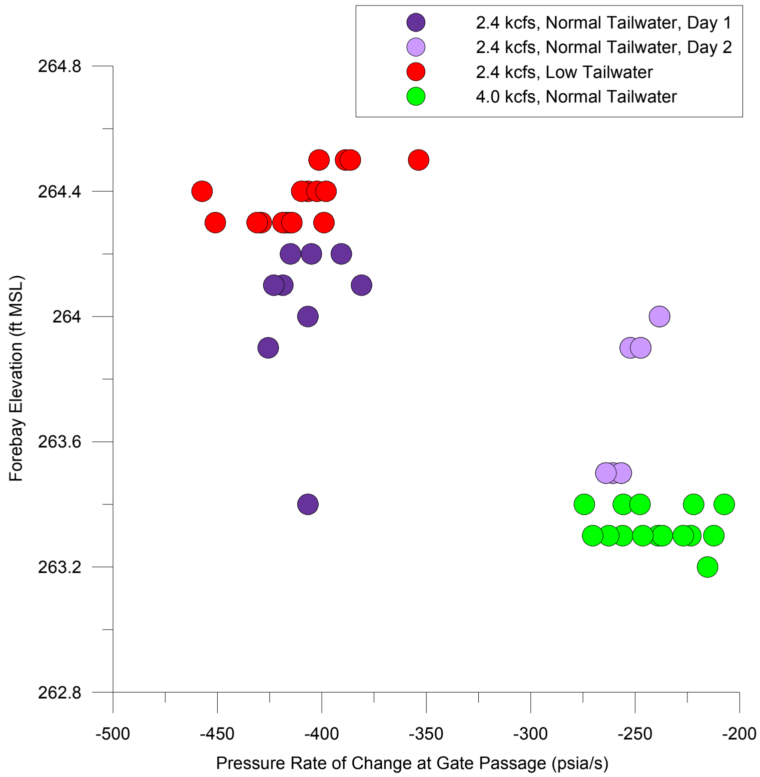


Figure 4.9. Pressure rate of change at gate passage contrasted with forebay elevation.

Comparison of Sensor Fish data with live-fish mortality and malady estimates from the current study and passage through Spillbay 17 with a standard deflector indicate there is a relationship between live-fish mortality and malady estimates and the percentage of Sensor Fish experiencing an event (Figure 4.10). Figure 4.11 and Figure 4.12 show estimated live-fish mortality and maladies, respectively, based on the percentage of Sensor Fish experiencing a severe event during passage, assuming a linear relationship. Using this metric, an approximation of 2.3% mortality and maladies of 7.3% for live-fish passage through the 2.4-kcfs discharge low-tailwater condition can be estimated. However, based on the trajectory shown in Figure 4.10, these estimates may be slightly elevated; nevertheless, the mortality and malady estimates are relatively benign.

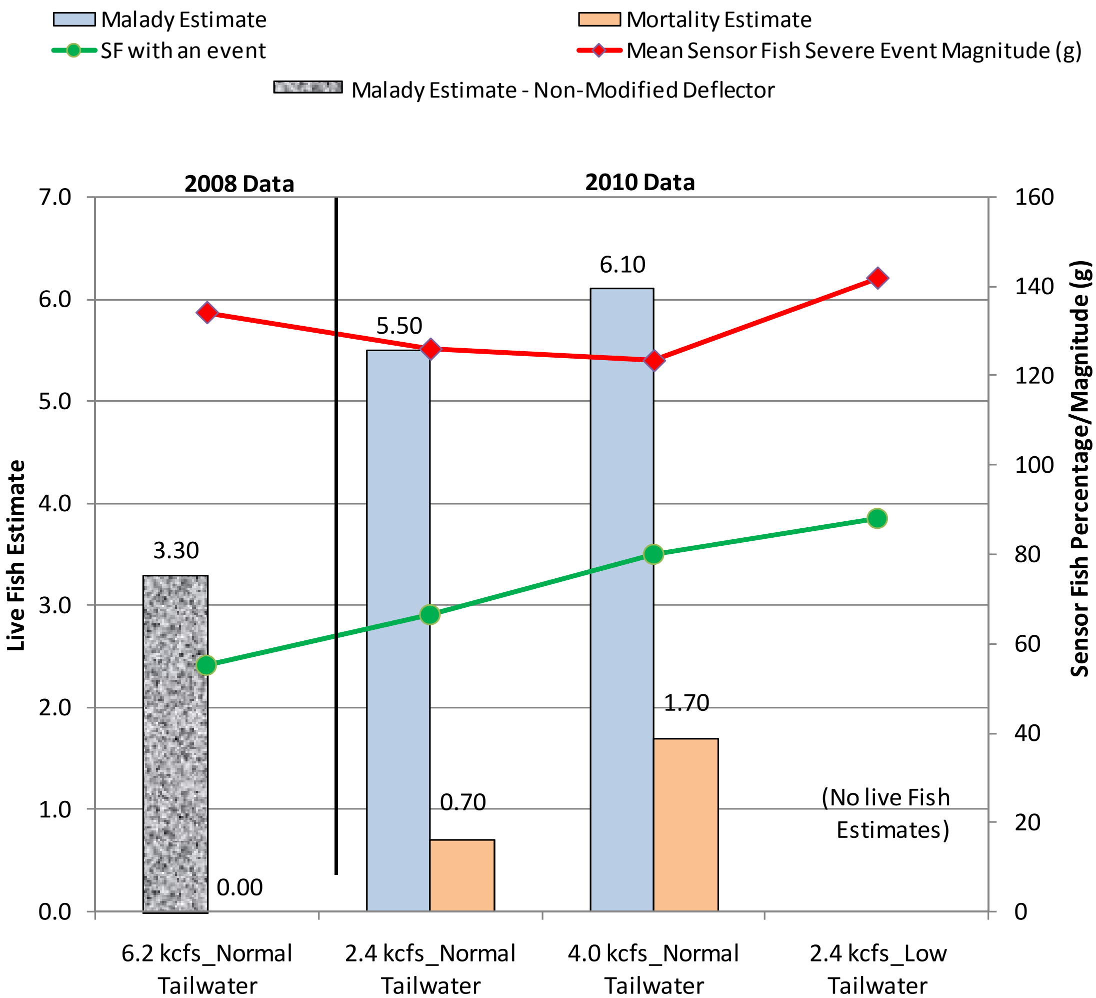
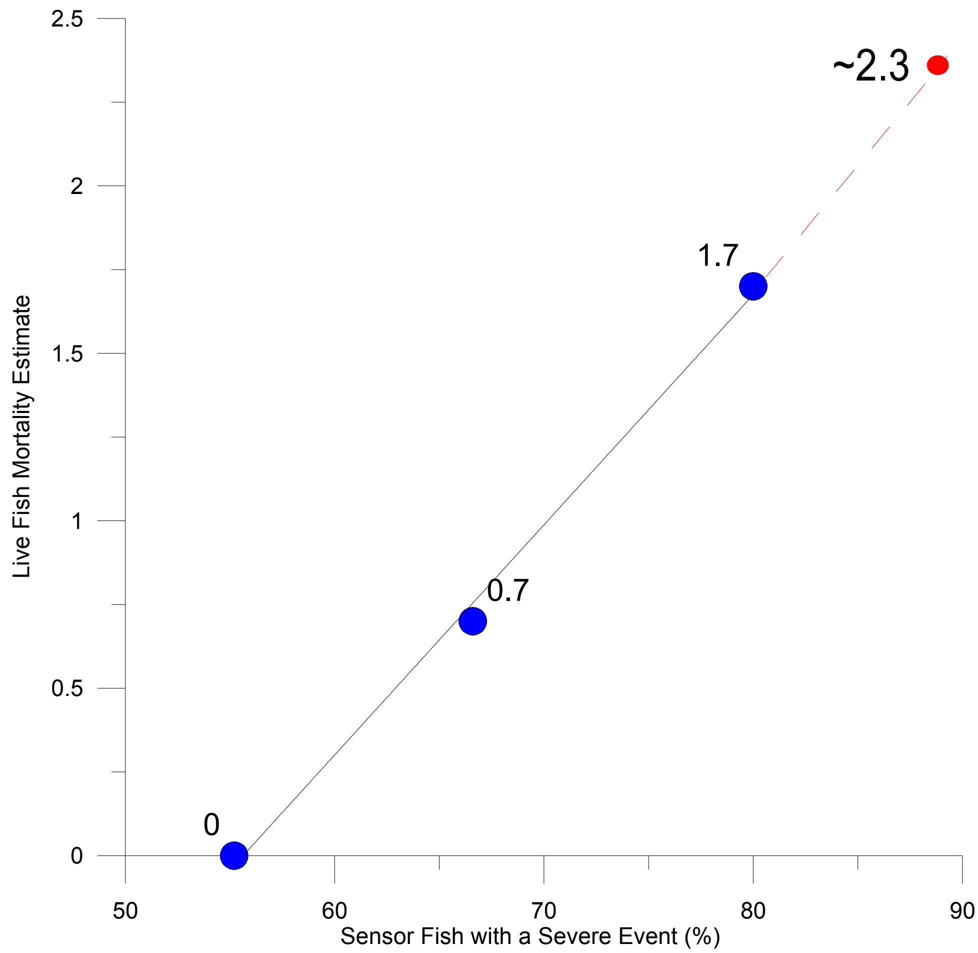
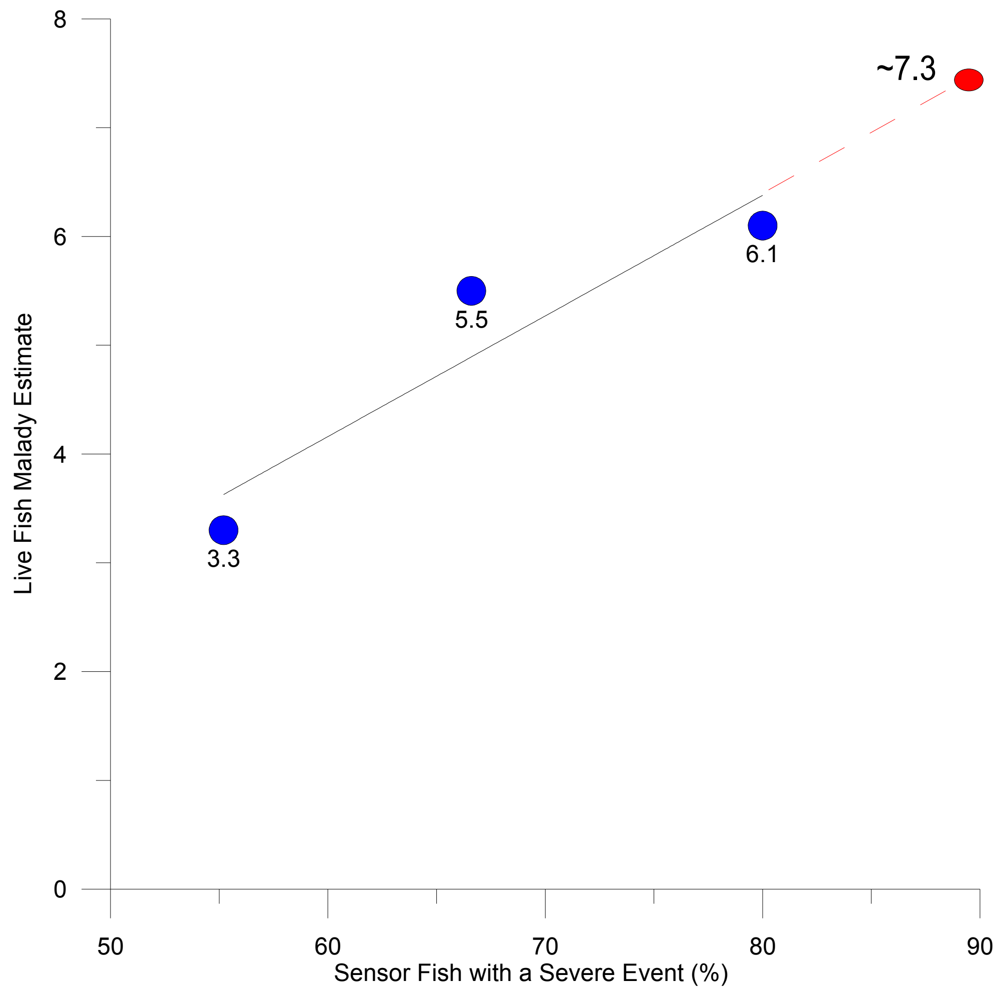


Figure 4.10. Live-fish mortality and malady estimates contrasted with the Sensor Fish severe event magnitude and the percentage of Sensor Fish experiencing a significant event.



Y = 0.0687245825 * X - 3.822873583
Number of data points used = 3
Average X = 67.2667
Average Y = 0.8
Residual sum of squares = 0.00441334
Regression sum of squares = 1.45559
Coef of determination, R-squared = 0.996977
Residual mean square, sigma-hat-sq'd = 0.00441334

Figure 4.11. Fit of linear model between live fish estimated 48-hr mortality and Sensor Fish severe event percentage for John Day Dam spillway evaluations. The red dashed line and point estimate the 48-hr mortality for live fish passage at 2.4-kcfs spill discharge and low-tailwater conditions.



Y = 0.1109284416 * X - 2.495119841
Number of data points used = 3
Average X = 67.2667
Average Y = 4.96667
Residual sum of squares = 0.554393
Regression sum of squares = 3.79227
Coef of determination, R-squared = 0.872456
Residual mean square, sigma-hat-sq'd = 0.554393

Figure 4.12. Fit of linear model between live fish malady estimates and Sensor Fish severe event percentage for John Day Dam spillway evaluations. The red dashed line and point estimate the 48-hr mortality for live fish passage at 2.4-kcfs spill discharge and low-tailwater conditions.

5.0 Conclusions

Exposure conditions observed from Sensor Fish time histories following passage through Spillbay 20 at John Day Dam in April 2010 indicate the overall impact of the large radius extended flow deflector appears to be minimal at normal tailwater levels. However, Sensor Fish data acquired during passage at 2.4-kcfs discharge at low tailwater levels exhibit conditions that would be slightly more deleterious to live fish.

The percentage of Sensor Fish experiencing a significant event during passage during normal tailwater levels increased with spill discharge—67% at the 2.4-kcfs discharge and 80% at the 4.0-kcfs discharge. In addition, more Sensor Fish experienced a significant event during the 2.4-kcfs discharge low-tailwater condition (88%).

The occurrence of multiple events (more than one event during a single release) was highest for the 2.4-kcfs discharge at low-tailwater conditions, averaging 1.53 events per release; for normal tailwater levels at the same discharge, there were 1.27 events per release. The fewest events per release occurred at the 4.0-kcfs discharge.

The mean acceleration magnitude for significant events observed during normal tailwater conditions at the 2.4-kcfs and 4.0-kcfs discharge averaged 125.9 *g* and 123.3 *g*, respectively, values that are essentially equivalent. Live-fish estimates for both mortality and malady-free metrics for the same conditions were determined to not be significantly different (Normandeau 2011).

Nearly all Sensor Fish significant events were classified as collisions; the most severe occurred at the deflector transition, spillbay chute, and at the gate. One shear event was observed during the evaluation, occurring at the deflector transition during passage at the 2.4-kcfs discharge at low tailwater. Flow quality, computed using the Sensor Fish turbulence index, was best for passage at the low-flow low-tailwater condition as well. The worst flow quality was observed for the 4.0-kcfs test condition.

Pressure rate of change during passage under the tainter gate, as determined using Sensor Fish data, was relatively low and would not likely contribute to additional injury.

Sensor Fish data suggest that the long extension on the flow deflector at Spillbay 20, along with the walls on either side, can add to increased turbulence and possible rollback of the jet discharge. Although no significant events were observed during the current study, such conditions could contribute to loss of equilibrium in fish.

Injury and mortality estimates for low-tailwater passage using Sensor Fish data suggest that there would be an increase in both mortality and maladies. However, values are considered to be relatively low—nearly 98% survival and 93% malady-free.

Sensor Fish data revealed an ambiguity concerning gate settings during one day of the study. Although no significant difference in overall results was observed in this case, the value of using the Sensor Fish to substantiate dam operations is noteworthy.

6.0 References

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Appendix A

Field Log Data Sheets

Appendix A contains field log data sheets showing dam operating conditions, deployment and recovery times for each Sensor Fish release, and other project information for each study period.

Test Date	Test Condition	Flow (kcfs)	Fish ID	Tag Number	Deployment Time	Recovery Time	File Name	Barometric Pressure (in Hg)	Notes	Barometric Pressure (psi)
4/3/2010	Normal TW	2.4	635	9 781	10:35	10:47	f635_2_NT_1	29.56	TW EL ~161.0 MSL	14.5
			930	8 821	11:52	12:01	f930_2_NT_2	29.5	11-ft deflector submergence	14.5
			926	9 194	12:50	12:57	f926_2_NT_3	29.47		14.5
			927	8 290	13:40	13:49	f927_2_NT_4	29.47		14.5
			115	8 101	14:22	14:57	f115_2_NT_5	29.45		14.5
			729	9 602	14:35	14:43	f729_2_NT_6	29.45		14.5
			117	8 851	15:32	15:52	f117_2_NT_7	29.45		14.5
			931	8 610	15:18	15:26	f931_2_NT_8	29.44		14.5
4/5/2010	Low TW	2.4	926	9 194	9:52	9:59	f926_2_LTW_1	29.31	TW EL ~158.1 MSL	14.4
			927	8 290	9:53	10:03	f927_2_LTW_2	29.31	8.1-ft deflector submergence	14.4
			931	8 610	9:54	10:01	f931_2_LTW_3	29.31		14.4
			115	8 101	9:54	10:13	f115_2_LTW_4	29.31		14.4
			729	9 602	9:55	8:00	f729_2_LTW_17	29.31	Recovered next morning	14.4
			635	9 781	10:18	10:29	f635_2_LTW_5	29.3		14.4
			900	9 630	10:19	10:27	f900_2_LTW_6	29.3		14.4
			698	8 971	10:30	10:39		29.31	Data interrupt	14.4
			117	8 851	10:31			29.31	In front of SB?	14.4
			930	8 821	10:31	10:39	f930_2_LTW_7	29.31		14.4

Test Date	Test Condition	Flow (kcfs)	Fish ID	Tag Number	Deployment Time	Recovery Time	File Name	Barometric Pressure (in Hg)	Notes	Barometric Pressure (psi)
4/5/2010	Low TW	2.4	121	9 004	10:32			29.31		14.4
			640	9 084	10:32	10:38	f640_2_ltw_8	29.32		14.4
			664	9 571	11:09	11:22	f664_2_LTW_9	29.32		14.4
			901	8 500	11:10	11:17	f901_2_LTW_10	29.32		14.4
			908	8 131	11:11	11:18	f908_2_LTW_11	29.32		14.4
			923	8 450	11:11	11:19	f923_2_LTW_12	29.32		14.4
			926	9 194	11:21	11:27	f926_2_LTW_13	29.32		14.4
			927	8 290	11:22	11:35	f927_2_LTW_14	29.32		14.4
			931	8 610	11:23	11:29	f931_2_LTW_15	29.32		14.4
			115	8 101	11:23	11:33	f115_2_LTW_16	29.32		14.4
4/6/2010	Normal TW	2.4	635	9 781	8:07	8:12	f635_2_NT_9	29.78	Windy; TW EL ~160.0 ft MSL; 10-ft deflector submergence	14.6
			930	8 821	8:54	9:04	f930_2_NT_10	29.79	Windy	14.6
			926	9 194	9:41			29.81	Windy	14.6
			931	8 610	10:38	10:44	f931_2_NT_11	29.85	Windy	14.7
			927	8 290	11:58	12:08	f927_2_NT_12	29.87	Windy	14.7
			908	8 131	12:51	12:57	f908_2_NT_13	29.87	Windy	14.7
			901	8 500	13:50	14:05	f901_2_NT_14	29.84	Windy	14.7

Test Date	Test Condition	Flow (kcfs)	Fish ID	Tag Number	Deployment Time	Recovery Time	File Name	Barometric Pressure (in Hg)	Notes	Barometric Pressure (psi)
4/11/2010	Normal TW	4.0	635	9 781	8:03	8:21	f635_4_NT_1	29.5	TW EL~159.9 ft; 9.9-ft deflector submergence; both TSWs open, plus 17	14.5
			729	9 602	8:54			29.5	Trapped at PH/SB20 edge flow	14.5
			931	8 610	10:03	10:14	f931_4_NT_2	29.49		14.5
			115	8 101	12:00	12:12	f115_4_NT_3	29.47		14.5
			901	8 500	13:03	13:09	f901_4_NT_4	29.41		14.4
			930	8 821	14:07	14:15	f930_4_NT_5	29.38		14.4
			640	9 084	14:53	14:59	f640_4_NT_6	29.34		14.4
	Normal TW	2.4	927	8 290	16:04	16:10	f927_2_NT_15	29.32		14.4
4/12/2010	Normal TW	4.0	635	9 781	8:12	8:20	f635_4_NT_7	29.31	TW EL ~159.4 ft; 9.4-ft deflector submergence; both TSWs open, plus 17	14.4
			664	9 571	8:59	9:36	f664_4_NT_8	29.32		14.4
			901	8 500	9:43	15:31	f901_4_NT_15	29.33	Trapped at PH/SB20 edge flow – flushed at end of day	14.4
			115	8 101	10:36	10:45	f115_4_NT_9	29.33		14.4
			923	8 450	11:18	11:29	f923_4_NT_10	29.33		14.4
			931	8 610	12:17	12:27	f931_4_NT_11	29.34		14.4
			908	8 131	12:56	13:08	f908_4_NT_12	29.34		14.4
			930	8 821	13:40	13:53	f930_4_NT_13	29.35		14.4
			931	8 610	14:30	15:07	f931_4_NT_14	29.34		14.4

Test Date	Test Condition	Flow (kcfs)	File Name	Mean Forebay (ft)	Mean Tailwater (ft)	Total Turbine (kcfs)	Spillbay Q (kcfs) 18	19	20	Total Spill (kcfs)
4/3/2010	Normal TW	2.4	f635_2_NT_1	263.9	160.9	99.4		1.2	2.4	3.6
			f930_2_NT_2	264.0	160.9	100.6		4.7	2.4	7.1
			f926_2_NT_3	264.1	160.8	99.7		6.9	2.4	9.3
			f927_2_NT_4	264.2	161.0	93.0		9.7	2.4	12.1
			f115_2_NT_5	264.2	161.0	91.8		9.7	2.4	12.1
			f729_2_NT_6	264.2	161.0	91.8		9.7	2.4	12.1
			f117_2_NT_7	264.1	161.0	96.1		9.7	2.4	12.1
			f931_2_NT_8	264.1	161.0	96.1		9.7	2.4	12.1
4/5/2010	Low TW	2.4	f926_2_LTW_1	264.4	158.0	90.7		7.3	2.4	9.7
			f927_2_LTW_2	264.4	158.0	90.7		7.3	2.4	9.7
			f931_2_LTW_3	264.4	158.0	90.7		7.3	2.4	9.7
			f115_2_LTW_4	264.4	158.0	90.7		7.3	2.4	9.7
			f729_2_LTW_17	264.4	158.0	90.7		7.3	2.4	9.7
			f635_2_LTW_5	264.5	158.1	80.6		8.2	2.4	10.6
			f900_2_LTW_6	264.5	158.1	80.6		8.2	2.4	10.6
			f930_2_LTW_7	264.5	158.1	80.6		8.2	2.4	10.6
			f640_2_LTW_8	264.5	158.1	80.6		8.2	2.4	10.6
			f664_2_LTW_9	264.3	157.9	78.0		9.7	2.4	12.1
			f901_2_LTW_10	264.3	157.9	78.0		9.7	2.4	12.1
			f908_2_LTW_11	264.3	157.9	78.0		9.7	2.4	12.1
			f923_2_LTW_12	264.3	157.9	78.0		9.7	2.4	12.1
			f926_2_LTW_13	264.3	157.9	78.0		9.7	2.4	12.1
			f927_2_LTW_14	264.3	157.9	78.0		9.7	2.4	12.1
			f931_2_LTW_15	264.3	157.9	78.0		9.7	2.4	12.1
			f115_2_LTW_16	264.3	157.9	78.0		9.7	2.4	12.1

Test Date	Test Condition	Flow (kcfs)	File Name	Mean Forebay (ft)	Mean Tailwater (ft)	Total Turbine (kcfs)	Spillbay Q (kcfs) 18	19	20	Total Spill (kcfs)
4/6/2010	Normal TW	2.4	f635_2_NT_9	263.9	159.9	109.0		6.2	2.4	8.6
			f930_2_NT_10	263.9	159.9	109.0		6.2	2.4	8.6
				264.1	159.8	91.6		11.3	2.4	13.7
			f931_2_NT_11	264.0	159.7	80.8		11.3	2.4	13.7
			f927_2_NT_12	263.5	159.5	89.5		11.3	2.4	13.7
			f908_2_NT_13	263.5	159.5	89.5		11.3	2.4	13.7
			f901_2_NT_14	263.5	160.0	88.4		11.2	2.4	13.6
4/11/2010	Normal TW	4	f635_4_NT_1	263.3	160.1	64.8	14.4	9.7	4.0	28.1
			f931_4_NT_2	263.4	160.0	64.1	14.4	9.7	4.0	28.1
			f115_4_NT_3	263.4	160.0	62.6	14.4	9.7	4.0	28.1
			f901_4_NT_4	263.4	159.9	63.4	14.4	9.7	4.0	28.1
			f930_4_NT_5	263.4	159.9	63.1	14.4	9.7	4.0	28.1
			f640_4_NT_6	263.4	159.9	63.1	14.4	9.7	4.0	28.1
	Normal TW	2.4	f927_2_NT_15	263.4	159.9	63.2	16.0	9.7	2.4	28.1
4/12/2010	Normal TW	4	f635_4_NT_7	263.3	159.4	74.2	18.6	9.7	4.0	32.3
			f664_4_NT_8	263.3	159.5	73.8	18.6	9.7	4.0	32.3
			f901_4_NT_15	263.3	159.5	73.8	18.6	9.7	4.0	32.3
			f115_4_NT_9	263.3	159.5	74.1	18.6	9.7	4.0	32.3
			f923_4_NT_10	263.3	159.6	73.5	18.6	9.7	4.0	32.3
			f931_4_NT_11	263.3	159.5	73.5	18.6	9.7	4.0	32.3
			f908_4_NT_12	263.3	159.4	73.1	18.6	9.7	4.0	32.3
			f930_4_NT_13	263.3	159.4	73.1	18.6	9.7	4.0	32.3
			f931_4_NT_14	263.2	159.3	73.4	18.6	9.7	4.0	32.3

Appendix B

Data Summary Tables for Each Sensor Fish Release

File Name	Number of Events	Time (s)	Event Magnitude (*g*)	Event Type	Location
f635_2_NT_1	1	26.7985	124.3	Collision	Wall
f930_2_NT_2	1	34.7165	97.6	Collision	Spillway chute
f926_2_NT_3	0	22.26			
f927_2_NT_4	1	26.0985	127.9	Collision	Deflector transition
f115_2_NT_5	2	24.101	135.8	Collision	Just prior to gate
		25.5035	112.5	Collision	Deflector transition
f729_2_NT_6	1	24.0005	116.8	Collision	Deflector transition
f117_2_NT_7	2	22.2705	146.5	Collision	Just past gate
		23.5965	129.1	Collision	Deflector transition
f931_2_NT_8	3	25.135	128.8	Collision	Wall
		22.994	112	Collision	Gate
		23.79	110.7	Collision	Spillway chute
f635_2_NT_9	0	20.751			
f930_2_NT_10	3	19.833	125	Collision	Spillway chute
		19.7845	110.6	Collision	Spillway chute
		20.6805	109.1	Collision	Deflector transition
f931_2_NT_11	4	22.3155	150.9	Collision	Deflector transition
		21.1845	130.3	Collision	Spillway chute
		22.9695	103.5	Collision	Wall
		21.114	100.5	Collision	Spillway chute
f927_2_NT_12	0	23.5965			
f908_2_NT_13	1	22.2965	105.2	Collision	Spillway chute
f901_2_NT_14	0	24.0625			
f927_2_NT_15	0	23.3765			
Average number of events per release	**1.27**	Mean	**125.88**	All Events:	**119.85**
		Max	150.9		150.9
		Min	97.6		97.6
		Std. Dev.	16.58		15.05
		SE	5.24		3.45

File Name	Number of Events	Time (s)	Event Magnitude (*g*)	Event Type	Location
f926_2_LTW_1	0	29.8205			
f927_2_LTW_2	0	21.3195			
f931_2_LTW_3	1	22.1205	117.3	Collision	Deflector transition
f115_2_LTW_4	1	22.2315	149	Collision	Prior to gate
f635_2_LTW_5	1	21.9675	151.4	Collision	Deflector transition
f900_2_LTW_6	2	22.652	125.9	Collision	Deflector transition
		21.463	115.3	Collision	Spillway chute
f930_2_LTW_7	2	23.0565	154.6	Collision	Deflector transition
		21.918	129.5	Collision	Spillway chute
f640_2_ltw_8	1	20.053	126.9	Collision	After gate
f664_2_LTW_9	1	21.3075	108	Collision	Gate
f901_2_LTW_10	1	22.8775	127.6	Collision	Deflector transition
f908_2_LTW_11	1	22.503	183.6	Collision	Deflector
f923_2_LTW_12	2	24.015	170.8	Collision	Deflector transition
		24.298	128.4	Collision	Wall
f926_2_LTW_13	2	22.2505	128.3	Shear	Deflector transition
		20.9255	122.5	Collision	Spillway chute
f927_2_LTW_14	2	21.5775	161.8	Collision	Deflector transition
		21.5425	128.1	Collision	Deflector transition
f931_2_LTW_15	2	25.6475	121.1	Collision	Deflector
		25.2595	107.1	Collision	Deflector transition
f115_2_LTW_16	2	21.6015	169.6	Collision	Deflector transition
		22.071	137.2	Collision	Wall
f729_2_LTW_17	2	22.2045	130.5	Collision	Gate
		23.5845	107.6	Collision	Deflector transition
Average number of events per release	**1.35**	Mean	**141.76**	All Events:	**134.87**
		Max	183.6		183.6
		Min	108		107.1
		Std. Dev.	22.72		21.44
		SE	5.87		4.47

File Name	Number of Events	Time (s)	Event Magnitude (*g*)	Event Type	Location
f635_4_NT_1	1	28.309	109.3	Collision	Deflector
f931_4_NT_2	1	20.3435	112.1	Collision	Spillway chute
f115_4_NT_3	0	22.6695			
f901_4_NT_4	1	20.497	151.6	Collision	Spillway chute
f930_4_NT_5	1	20.6625	130.7	Collision	Deflector transition
f640_4_NT_6	1	20.292	114.4	Collision	Spillway chute
f635_4_NT_7	1	20.9235	109.2	Collision	Deflector
f664_4_NT_8	3	22.8325	122.8	Collision	Spillway chute
		24.417	98.1	Collision	Deflector
		23.289	97	Collision	Spillway chute
f115_4_NT_9	0	21.7855			
f923_4_NT_10	0	23.607			
f931_4_NT_11	1	21.0705	135.1	Collision	Spillway chute
f908_4_NT_12	1	23.2365	110.3	Collision	Deflector transition
f930_4_NT_13	1	21.7035	147.3	Collision	Spillway chute
f931_4_NT_14	1	24.252	97.7	Collision	Deflector
f901_4_NT_15	1	21.361	139.2	Collision	Deflector transition
Average number of events per release	**0.93**	Mean	**123.31**		All Events:
		Max	151.6		
		Min	97.7		
		Std. Dev.	17.18		
		SE	4.96		

File Name	Acceleration Under Gate (*g*)	File Name	Acceleration Under Gate (*g*)	File Name	Acceleration Under Gate (*g*)
f635_2_NT_1	28.5	f926_2_LTW_1	28.6	f635_4_NT_1	14.9
f930_2_NT_2	26.4	f927_2_LTW_2	29.9	f931_4_NT_2	13.7
f926_2_NT_3	23.0	f931_2_LTW_3	32.8	f115_4_NT_3	23.3
f927_2_NT_4	27.3	f115_2_LTW_4	33.6	f901_4_NT_4	16.3
f115_2_NT_5	32.9	f635_2_LTW_5	24.9	f930_4_NT_5	16.2
f729_2_NT_6	28	f900_2_LTW_6	26.8	f640_4_NT_6	13.7
f117_2_NT_7	24.9	f930_2_LTW_7	26.5	f635_4_NT_7	14.6
f931_2_NT_8	22.6	f640_2_LTW_8	24.7	f664_4_NT_8	13.9
f635_2_NT_9	14.7	f664_2_LTW_9	23.8	f115_4_NT_9	15.7
f930_2_NT_10	14.5	f901_2_LTW_10	35.2	f923_4_NT_10	16.6
f931_2_NT_11	13.5	f908_2_LTW_11	31.2	f931_4_NT_11	14.9
f927_2_NT_12	14.5	f923_2_LTW_12	36.4	f908_4_NT_12	15
f908_2_NT_13	15.7	f926_2_LTW_13	26.7	f930_4_NT_13	15.3
f901_2_NT_14	15.4	f927_2_LTW_14	30.1	f931_4_NT_14	15.6
f927_2_NT_15	26.3	f931_2_LTW_15	28.1	f901_4_NT_15	17.1
Mean	**21.9**	f115_2_LTW_16	32.0	Mean	**15.8**
Std. Dev.	6.51	f729_2_LTW_17	27.4	Std. Dev.	2.32
SE	1.68	Mean	**29.3**	SE	0.60
		Std. Dev.	3.75		
		SE	0.92		

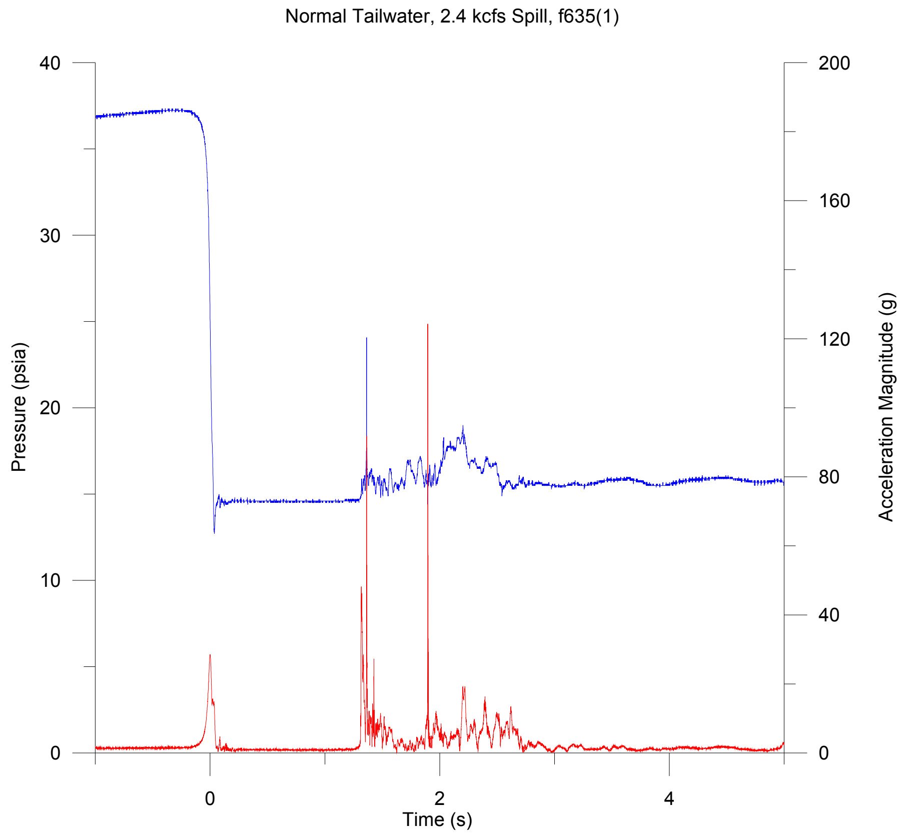
File Name	Pressure Rate of Change (psia/s)	File Name	Pressure Rate of Change (psia/s)	File Name	Pressure Rate of Change (psia/s)
f635_2_NT_1	-425.67	f926_2_LTW_1	-406.67	f635_4_NT_1	-256.00
f930_2_NT_2	-406.67	f927_2_LTW_2	-409.67	f931_4_NT_2	-222.00
f926_2_NT_3	-418.67	f931_2_LTW_3	-457.33	f115_4_NT_3	-255.67
f927_2_NT_4	-390.67	f115_2_LTW_4	-402.33	f901_4_NT_4	-247.67
f115_2_NT_5	-415.00	f635_2_LTW_5	-388.67	f930_4_NT_5	-274.33
f729_2_NT_6	-405.00	f900_2_LTW_6	-353.67	f640_4_NT_6	-207.33
f117_2_NT_7	-423.00	f930_2_LTW_7	-386.33	f635_4_NT_7	-262.67
f931_2_NT_8	-381.00	f640_2_LTW_8	-401.33	f664_4_NT_8	-239.00
f635_2_NT_9	-252.33	f664_2_LTW_9	-415.33	f115_4_NT_9	-223.33
f930_2_NT_10	-247.33	f901_2_LTW_10	-429.00	f923_4_NT_10	-237.00
f931_2_NT_11	-238.33	f908_2_LTW_11	-417.33	f931_4_NT_11	-212.33
f927_2_NT_12	-260.67	f923_2_LTW_12	-431.00	f908_4_NT_12	-246.33
f908_2_NT_13	-256.67	f926_2_LTW_13	-418.67	f930_4_NT_13	-227.00
f901_2_NT_14	-264.00	f927_2_LTW_14	-451.00	f931_4_NT_14	-215.33
f927_2_NT_15	-406.67	f931_2_LTW_15	-414.33	f901_4_NT_15	-270.33
Mean	**-346.11**	f115_2_LTW_16	-399.00	Mean	**-239.76**
Std. Dev.	79.49	f729_2_LTW_17	-398.00	Std. Dev.	21.44
SE	20.52	Mean	**-410.57**	SE	5.54
		Std. Dev.	24.36		
		SE	5.91		

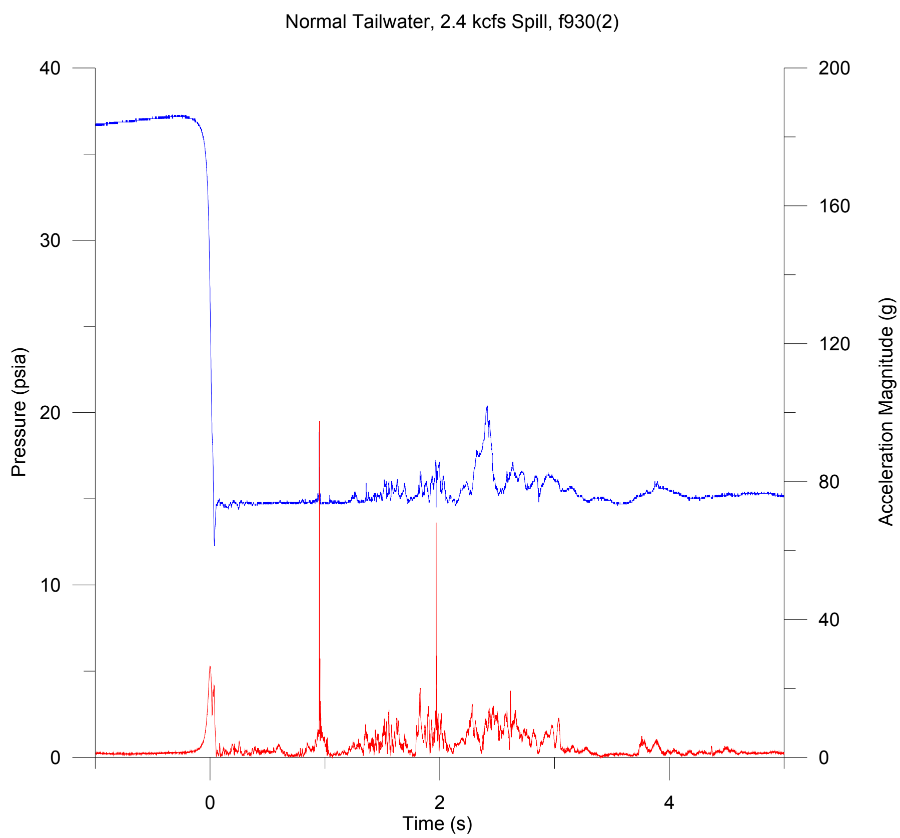
Appendix C

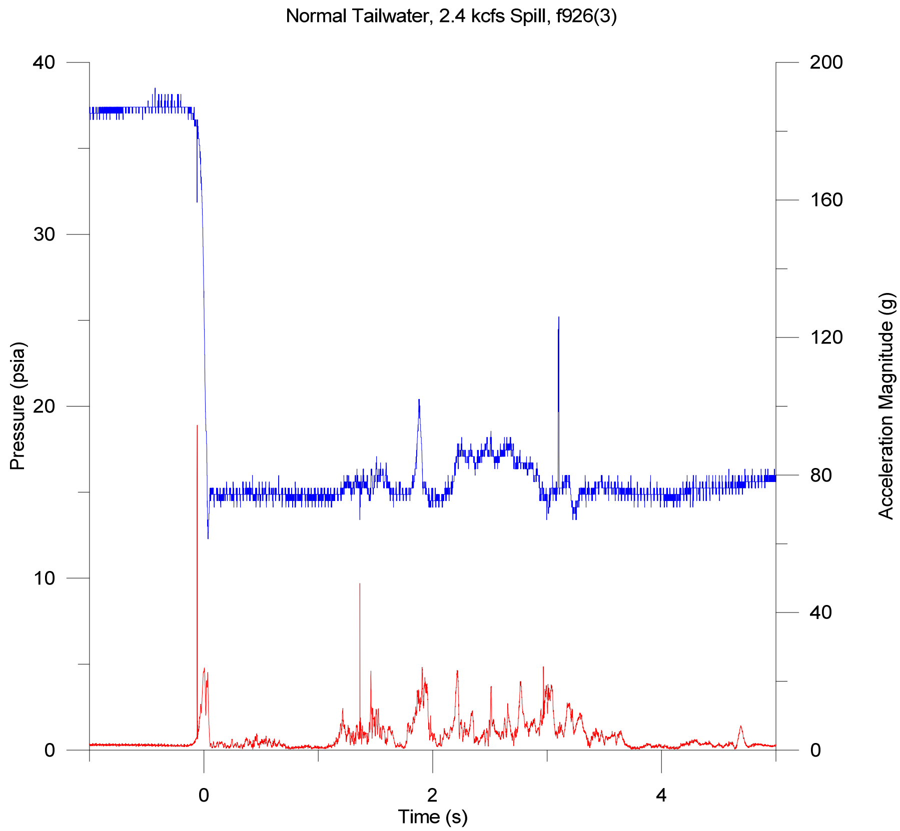
Pressure and Acceleration Magnitude Time Histories of Each Sensor Fish Release

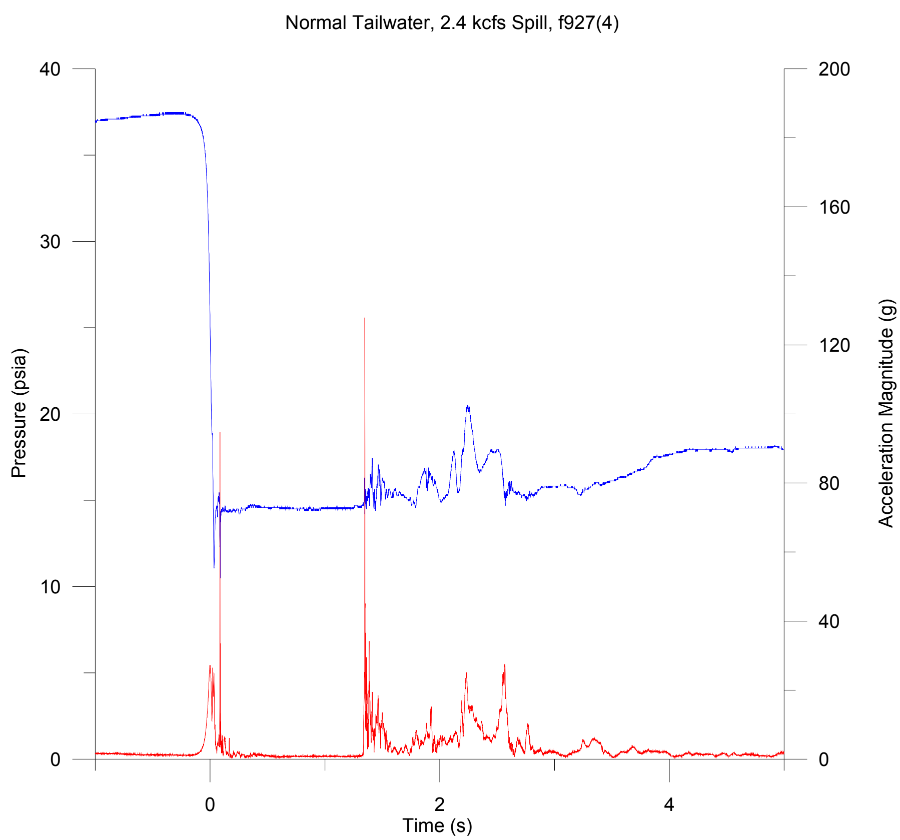
John Day Dam Spillbay 20

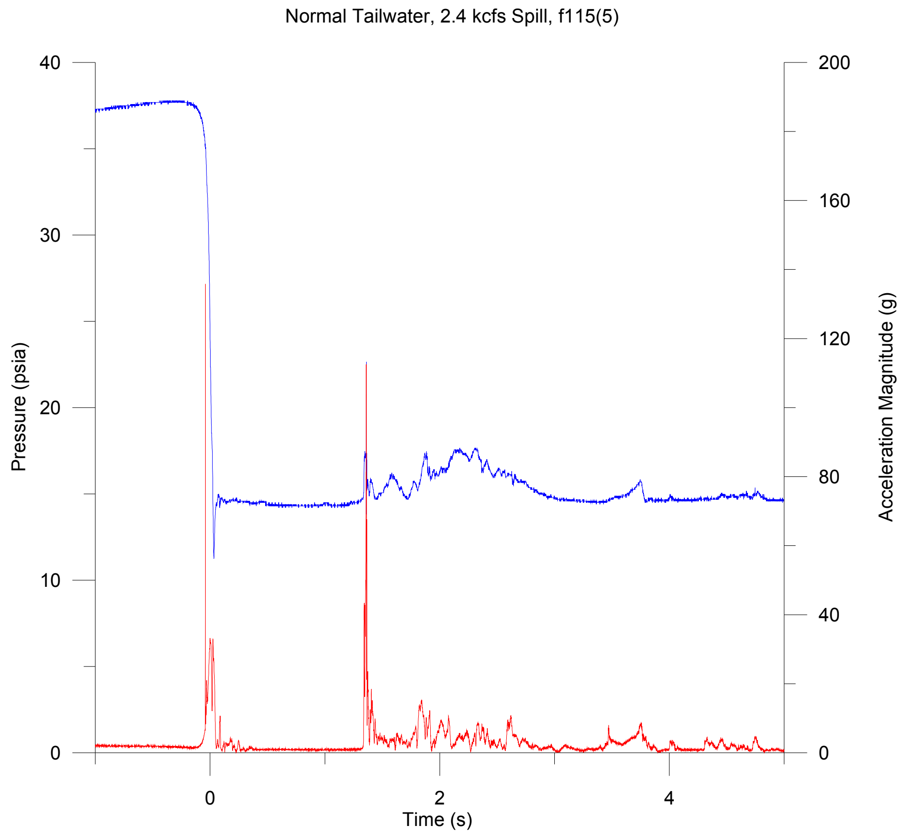
2.4-kcfs Discharge, Normal Tailwater

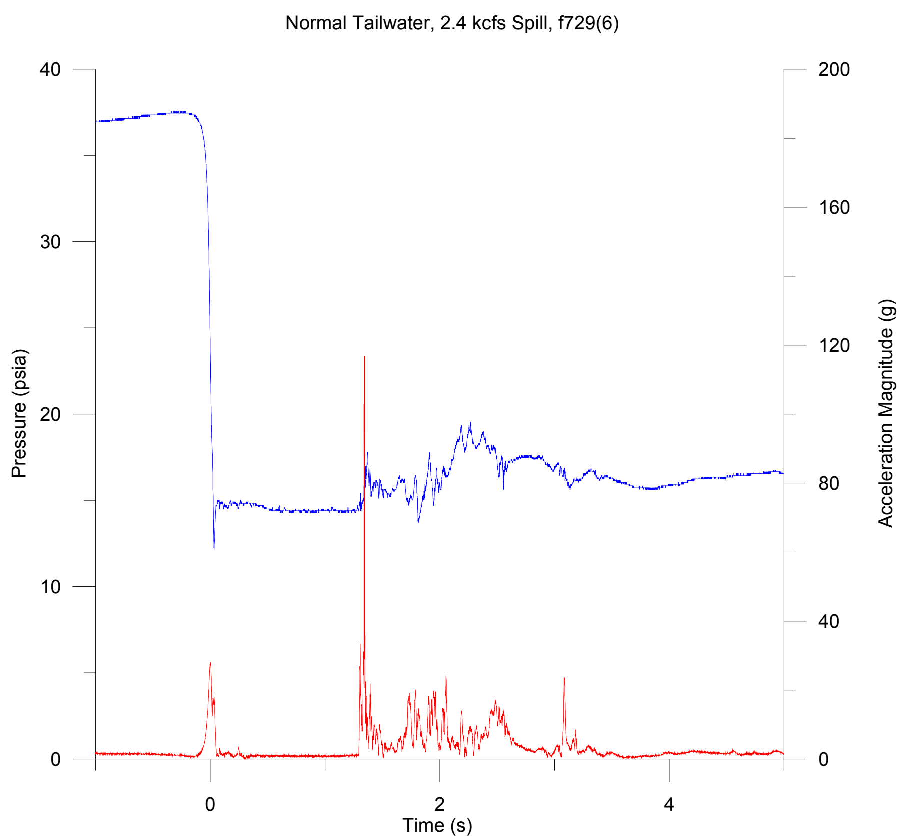

Normal Tailwater, 2.4 kcfs Spill, f635(1)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Normal Tailwater, 2.4 kcfs Spill, f930(2)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

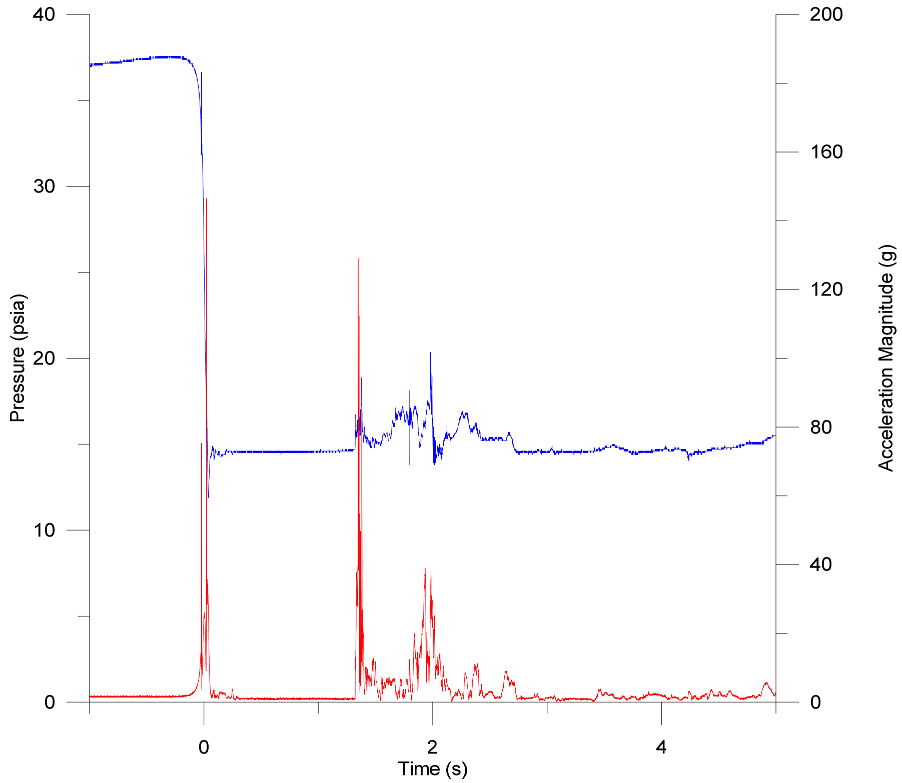

Normal Tailwater, 2.4 kcfs Spill, f926(3)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Normal Tailwater, 2.4 kcfs Spill, f927(4)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

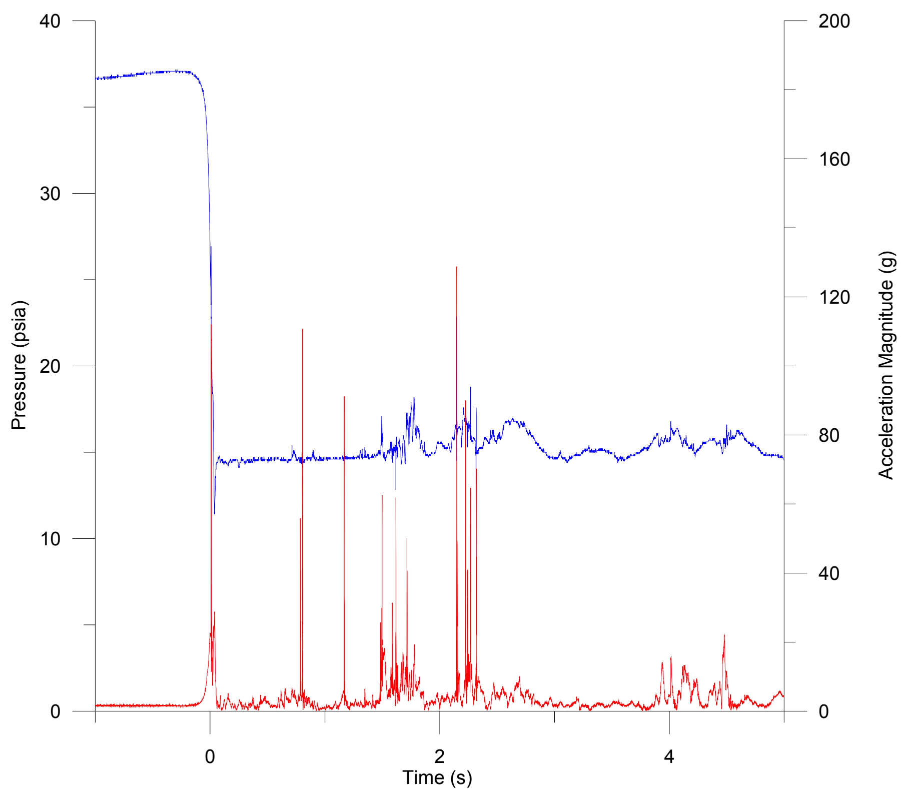

Normal Tailwater, 2.4 kcfs Spill, f115(5)
40
30
20
10
0
200
160
120
80
40
0
Pressure (psia)
Acceleration Magnitude (g)
0
2
4
Time (s)

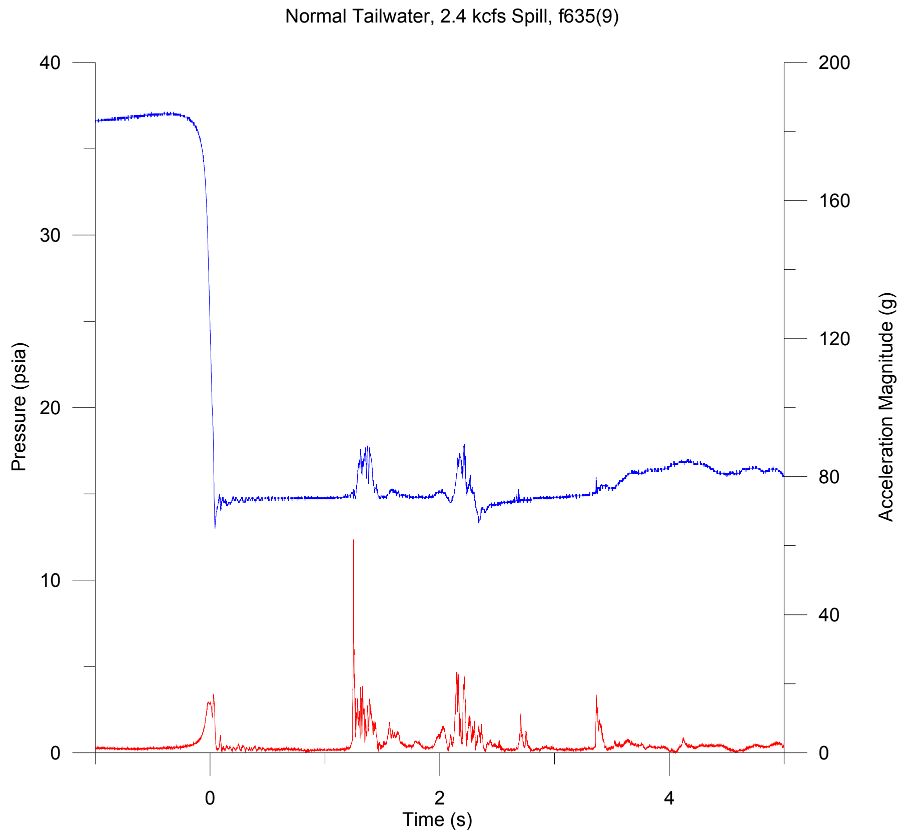

Normal Tailwater, 2.4 kcfs Spill, f729(6)
40
30
20
10
0
200
160
120
80
40
0
Pressure (psia)
Acceleration Magnitude (g)
0
2
4
Time (s)

Normal Tailwater, 2.4 kcfs Spill, f117(7)

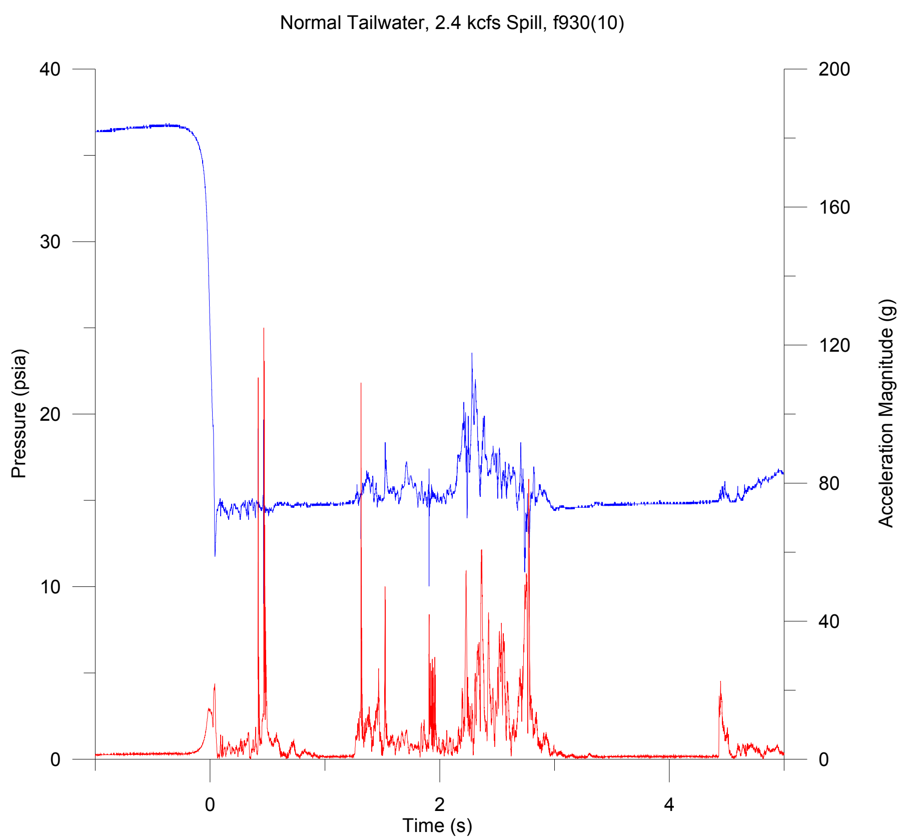


Normal Tailwater, 2.4 kcfs Spill, f931(8)

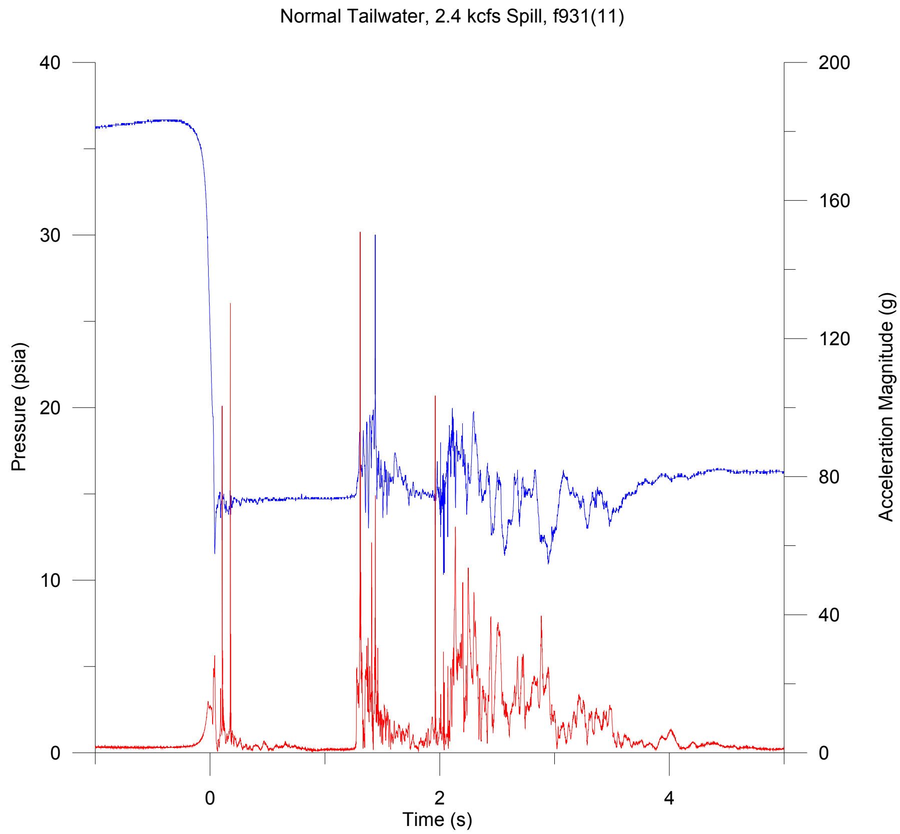


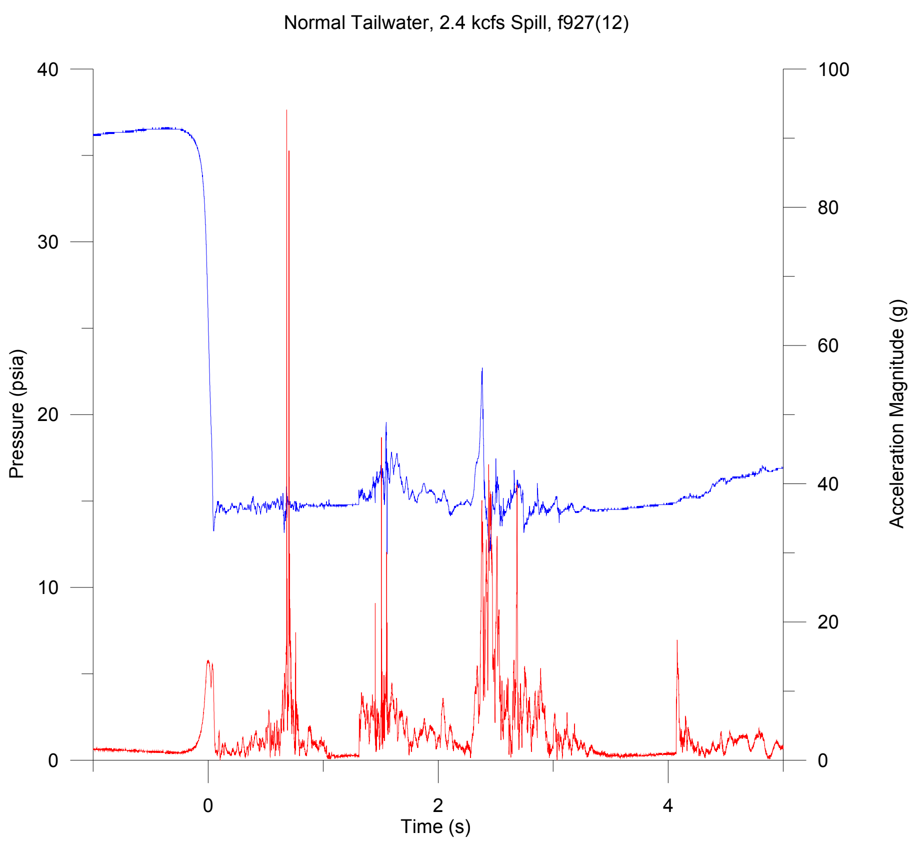


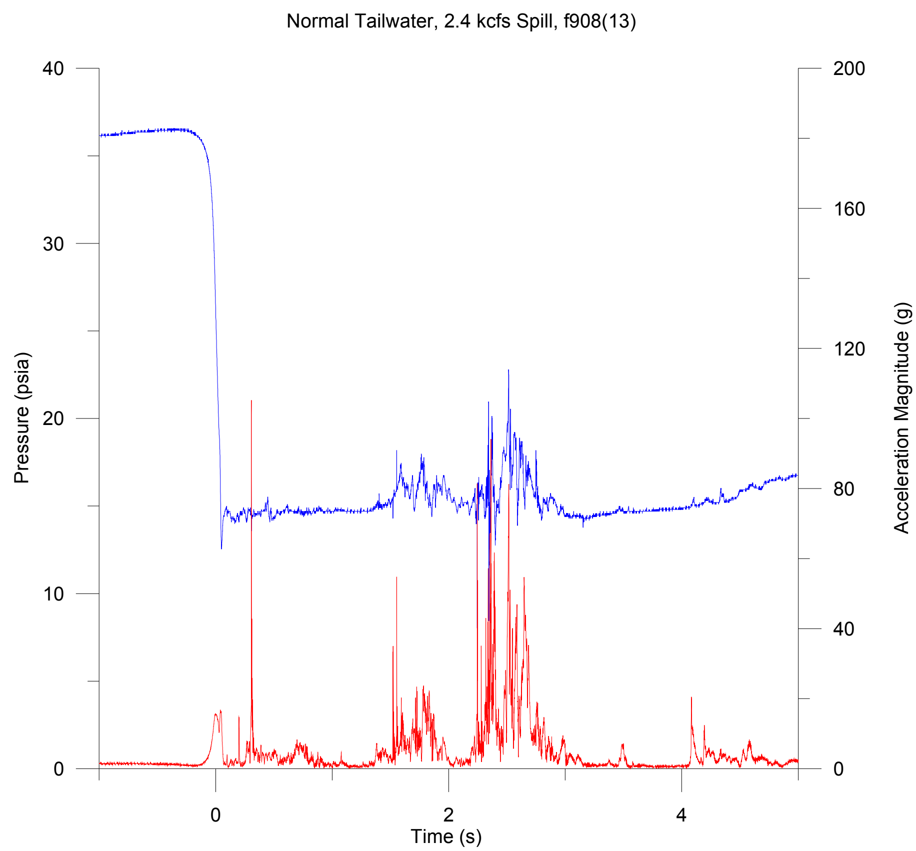
Normal Tailwater, 2.4 kcfs Spill, f635(9)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4



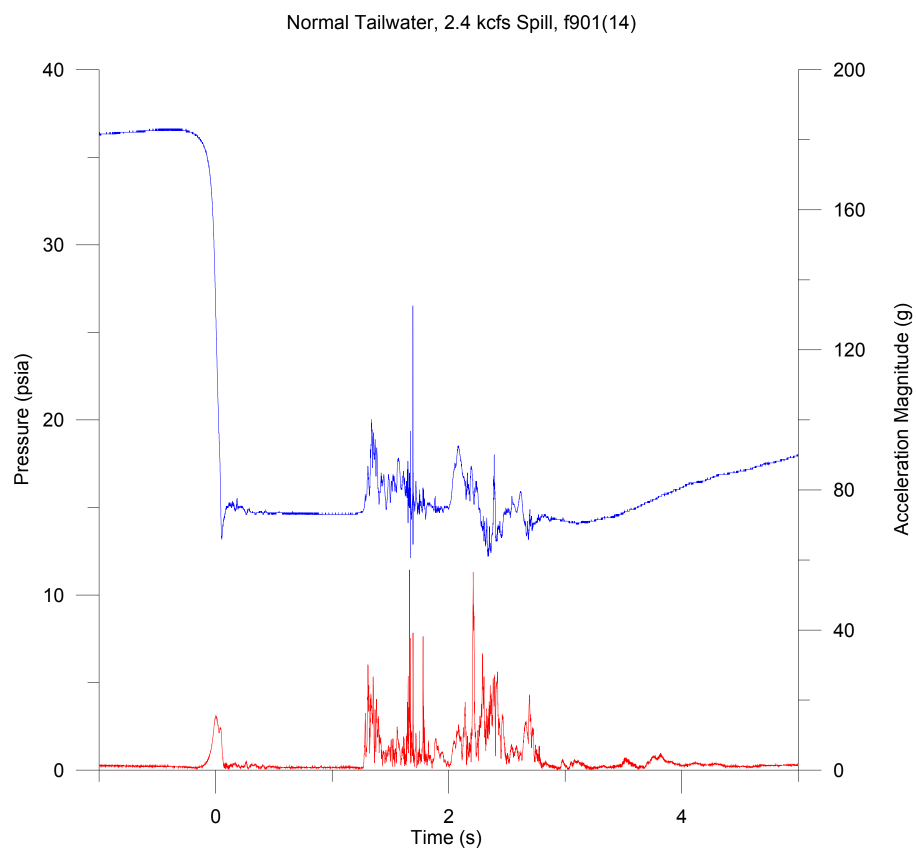
Normal Tailwater, 2.4 kcfs Spill, f930(10)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Normal Tailwater, 2.4 kcfs Spill, f931(11)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

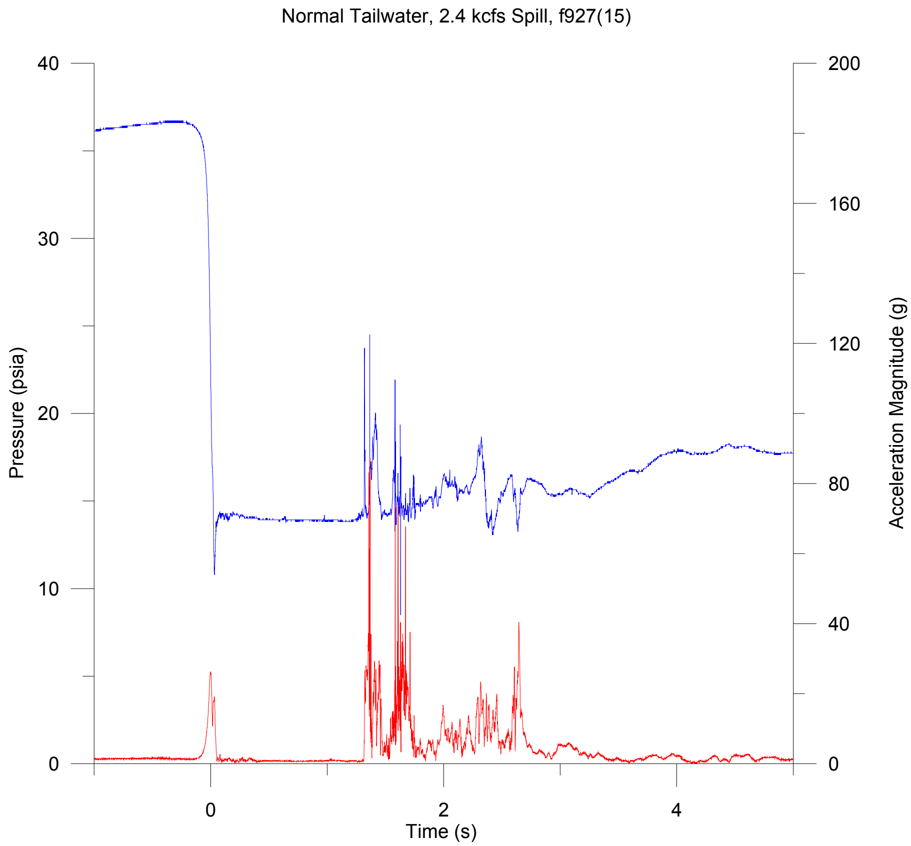

Normal Tailwater, 2.4 kcfs Spill, f927(12)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
100
80
60
40
20
0
0
2
4



Normal Tailwater, 2.4 kcfs Spill, f908(13)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

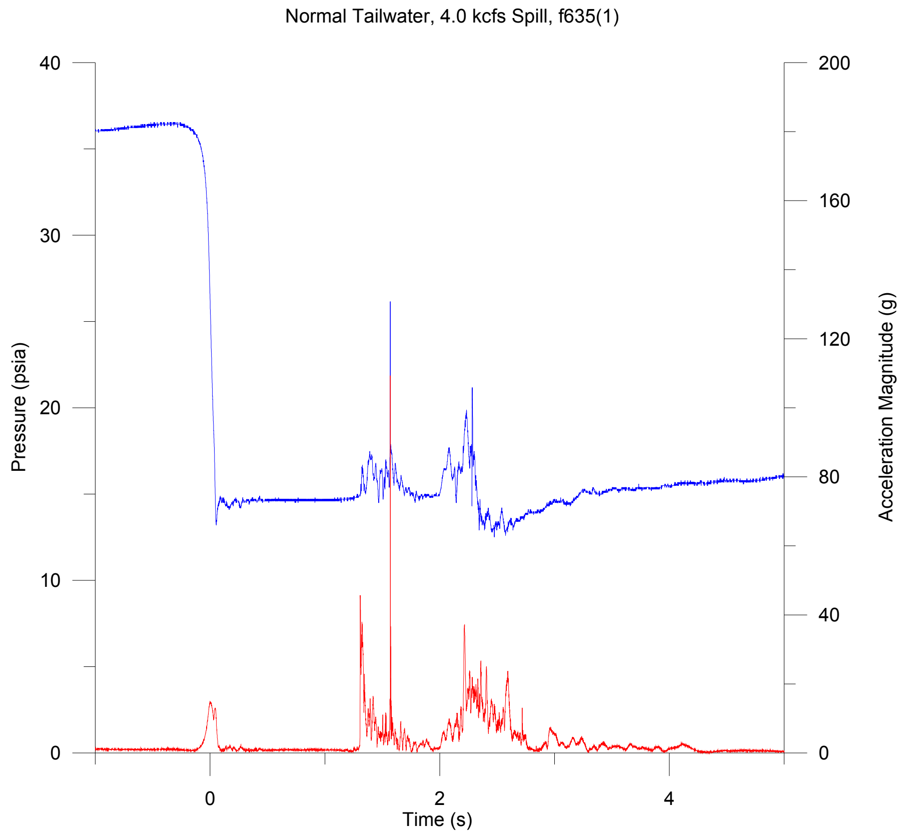


Normal Tailwater, 2.4 kcfs Spill, f901(14)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

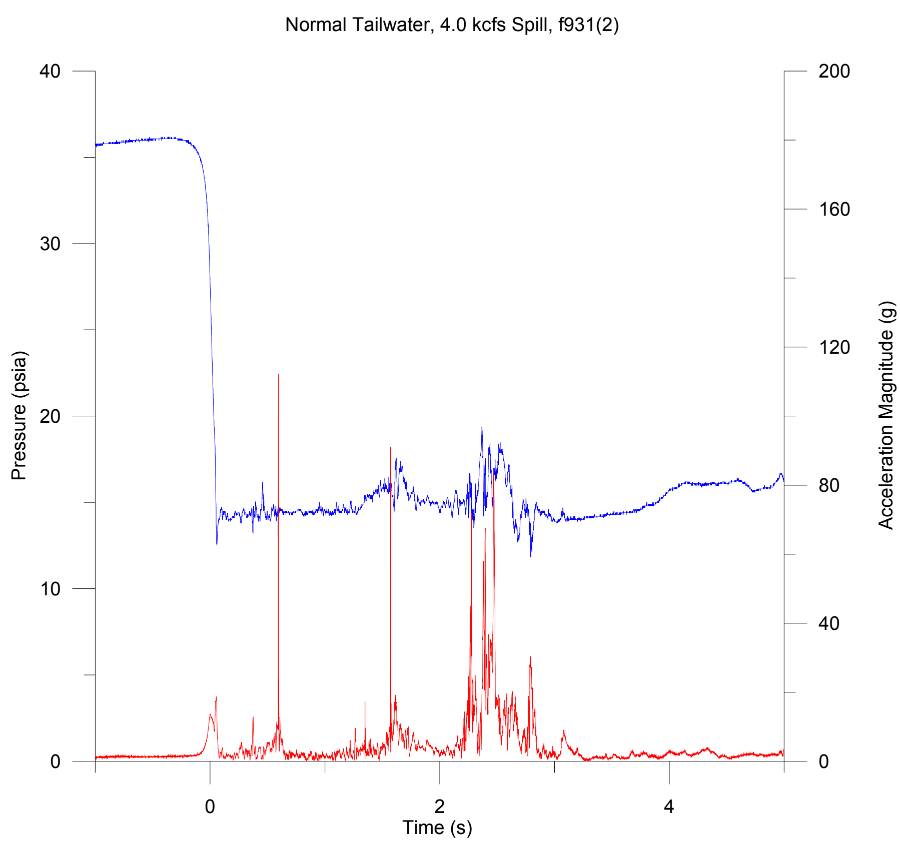

Normal Tailwater, 2.4 kcfs Spill, f927(15)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

John Day Dam Spillbay 20

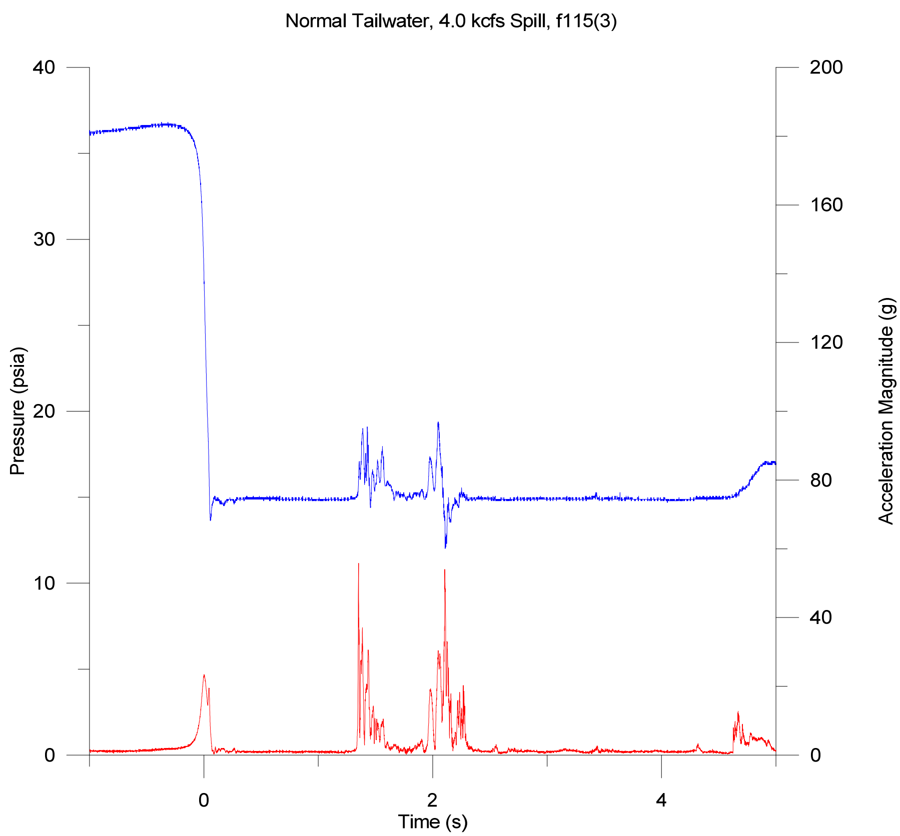
4.0-kcfs Discharge, Normal Tailwater



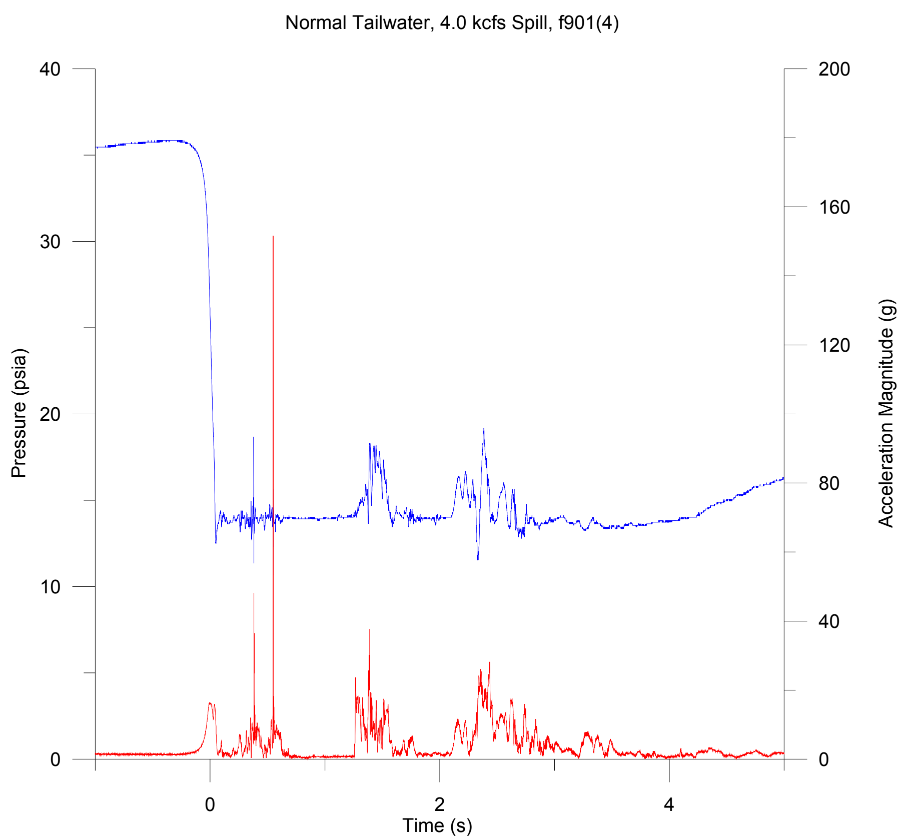
Normal Tailwater, 4.0 kcfs Spill, f635(1)
40
30
20
10
0
200
160
120
80
40
0
Pressure (psia)
Acceleration Magnitude (g)
0
2
4
Time (s)



Normal Tailwater, 4.0 kcfs Spill, f931(2)
40
30
20
10
0
200
160
120
80
40
0
Pressure (psia)
Acceleration Magnitude (g)
0
2
4
Time (s)

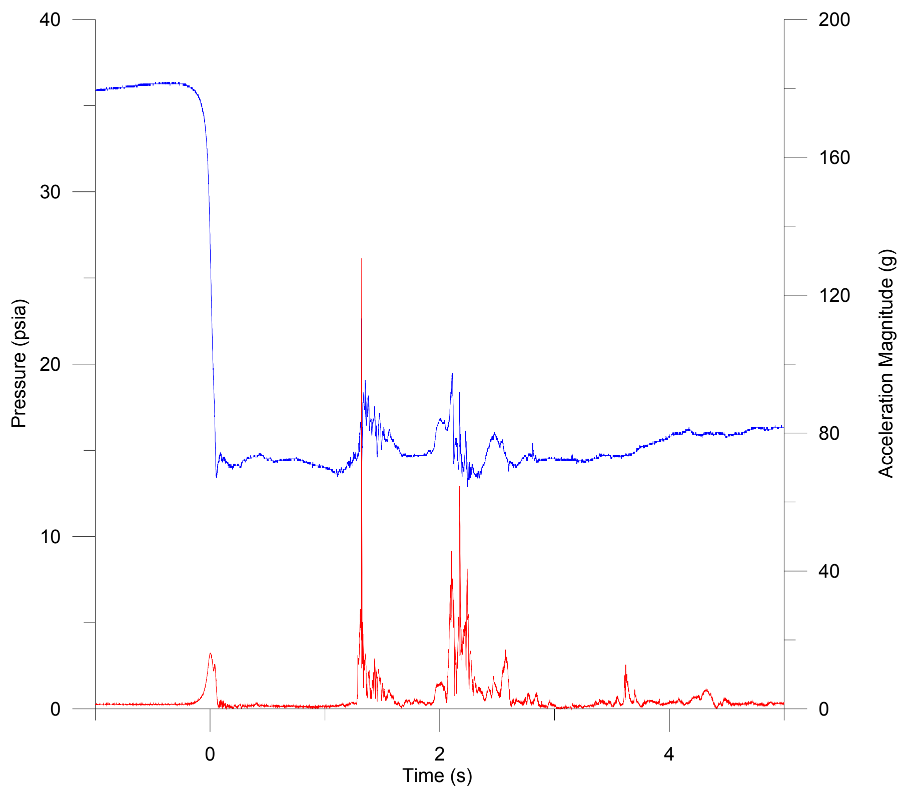


Normal Tailwater, 4.0 kcfs Spill, f115(3)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

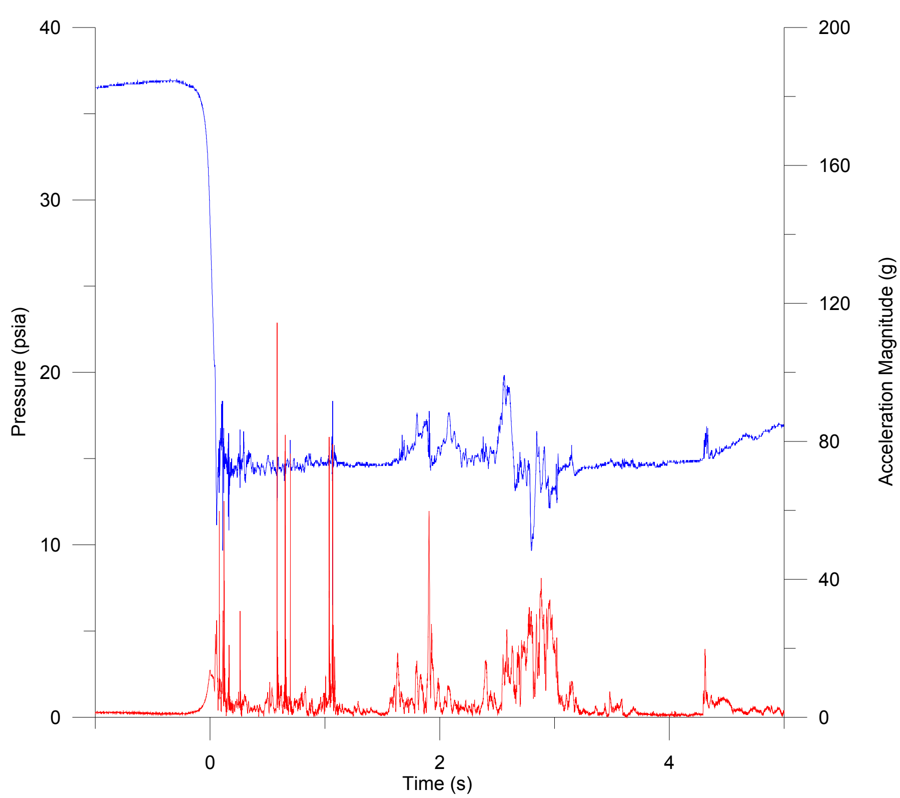


Normal Tailwater, 4.0 kcfs Spill, f901(4)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

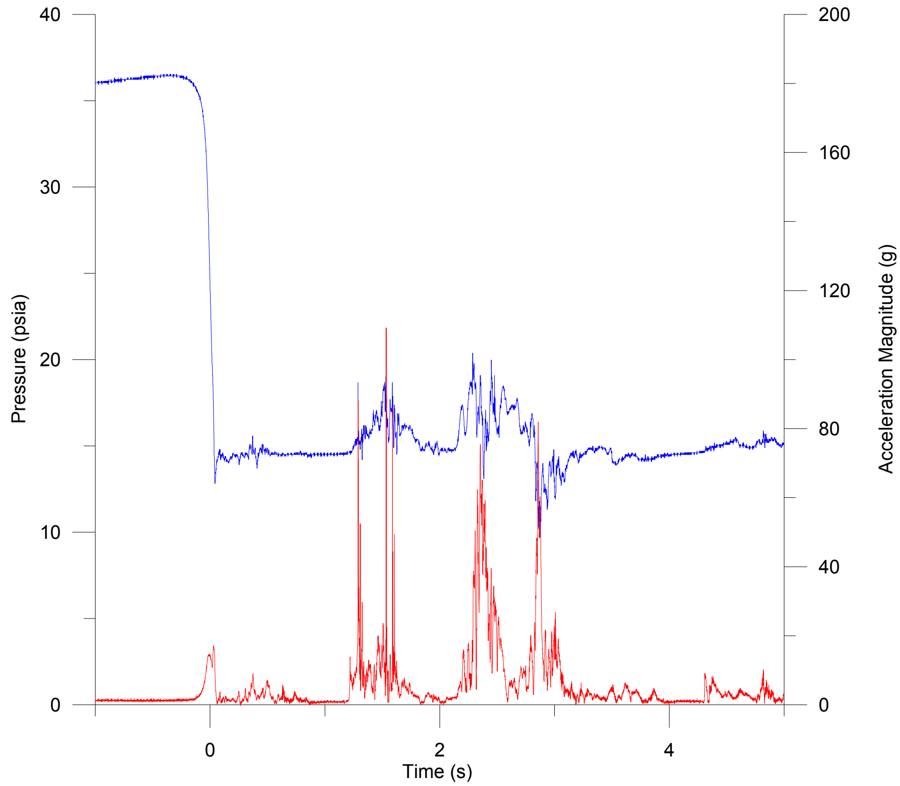
Normal Tailwater, 4.0 kcfs Spill, f930(5)



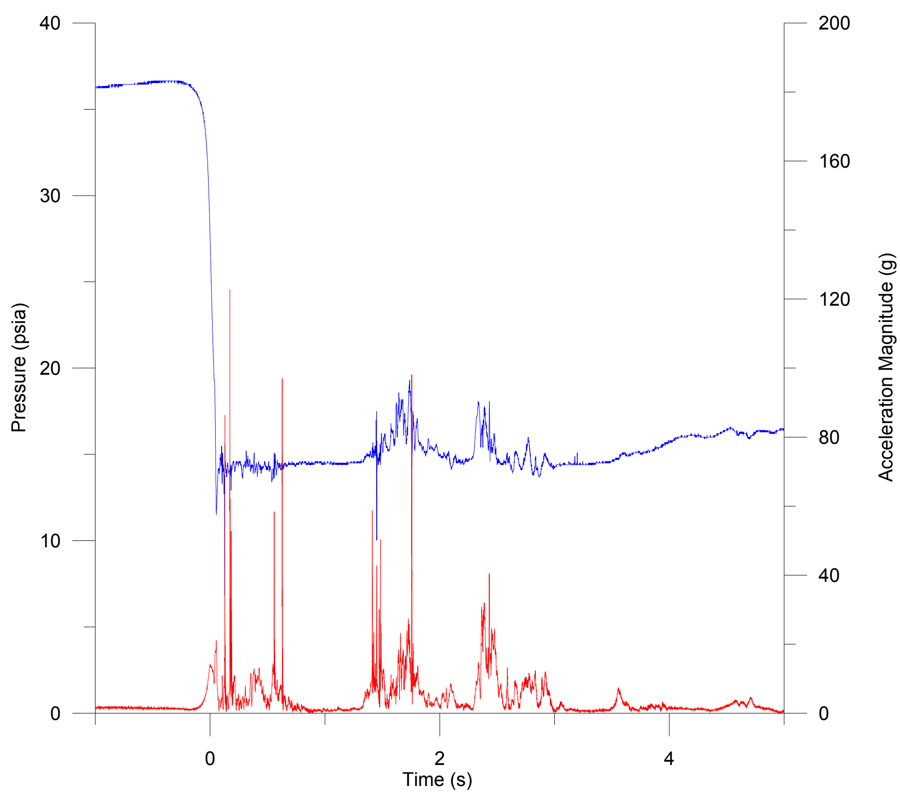
Normal Tailwater, 4.0 kcfs Spill, f640(6)

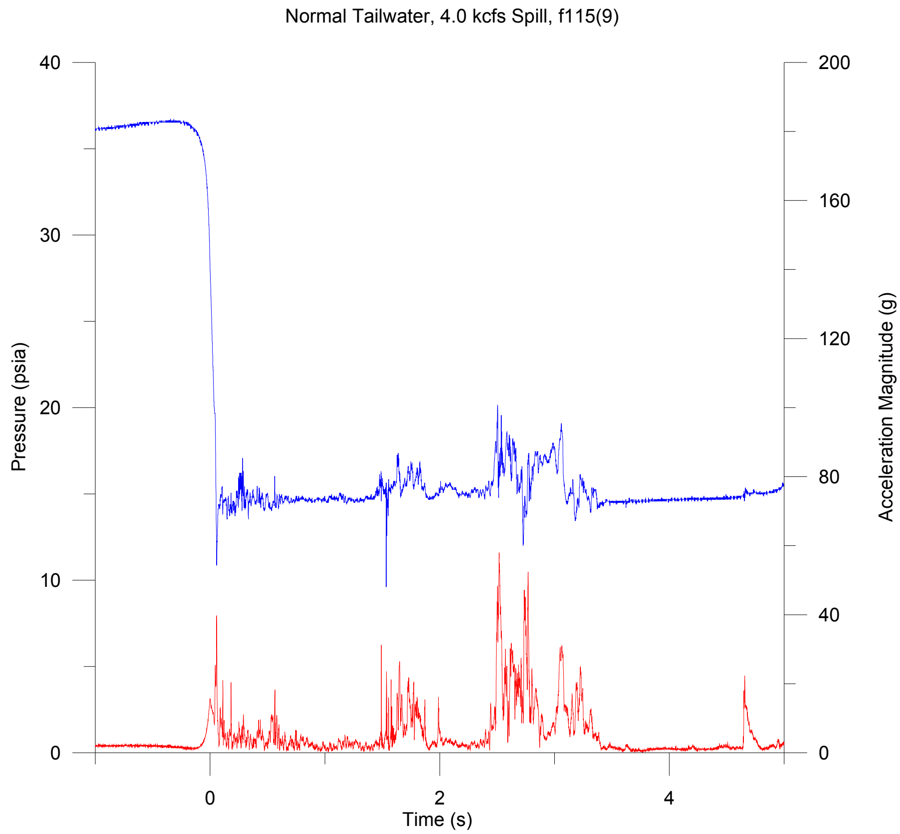


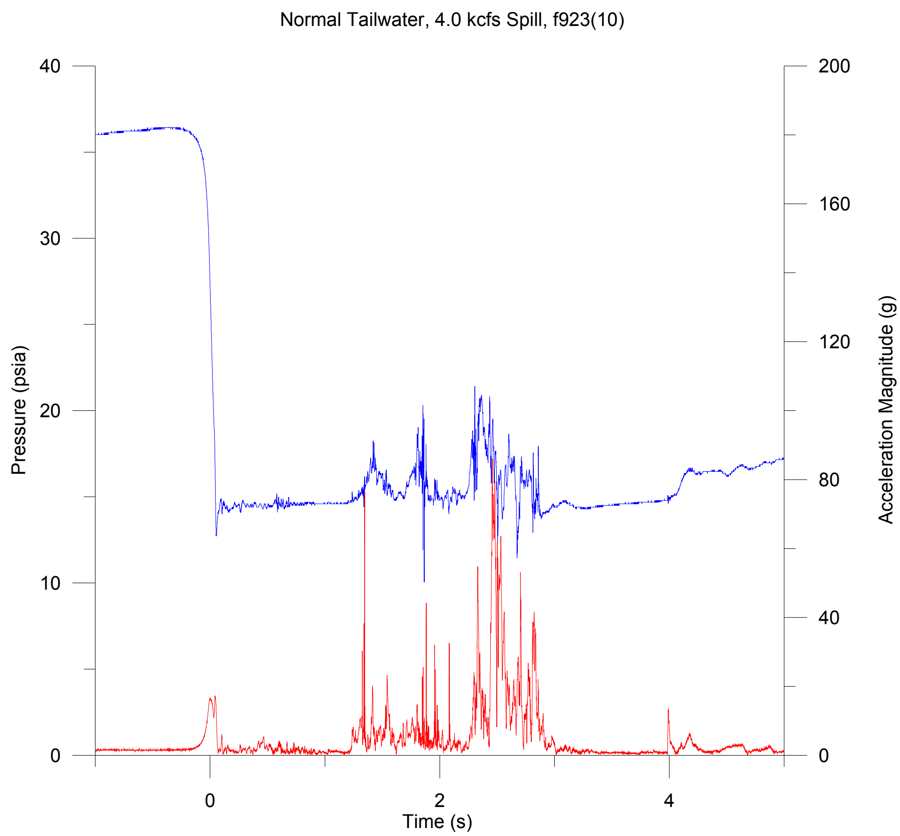
Normal Tailwater, 4.0 kcfs Spill, f635(7)

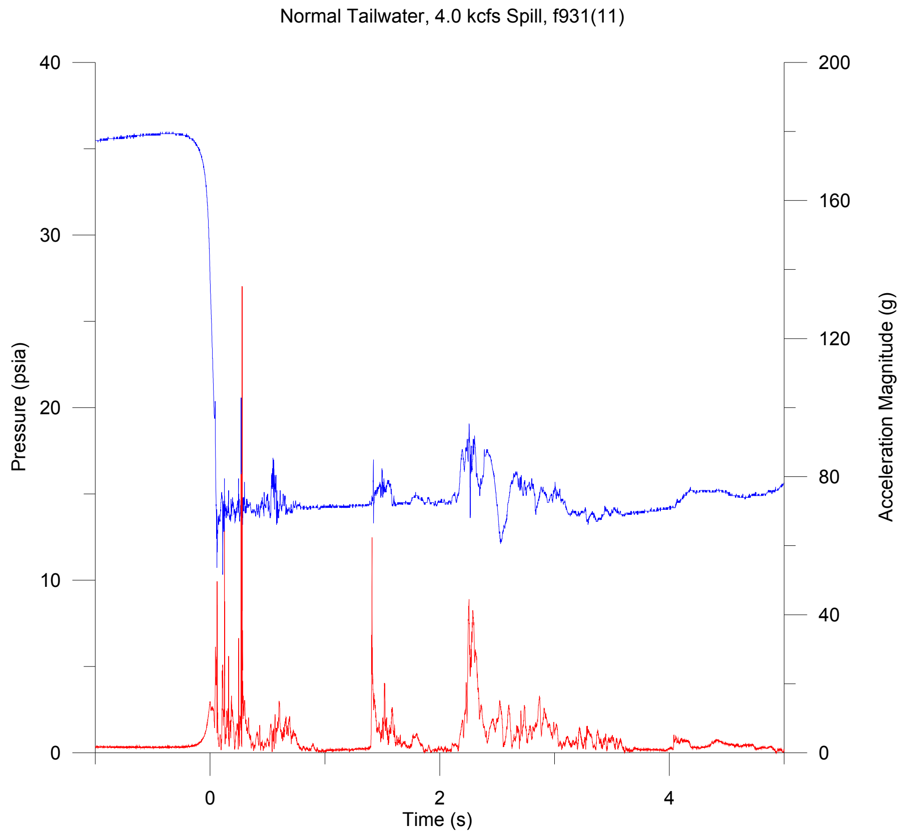


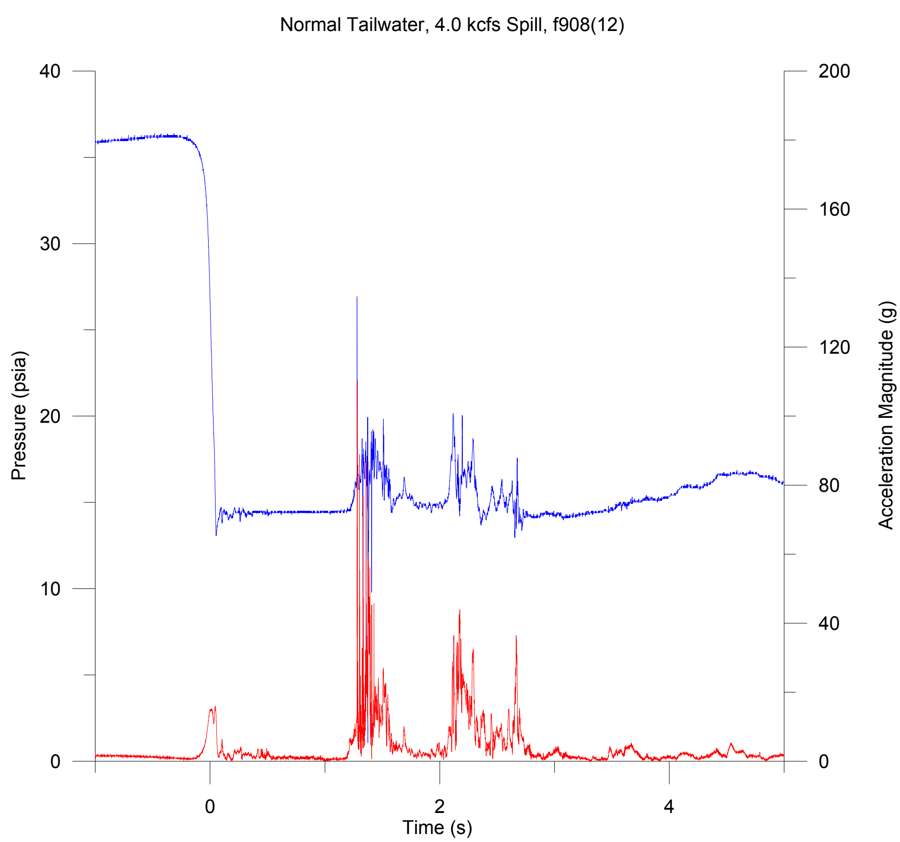
Normal Tailwater, 4.0 kcfs Spill, f664(8)

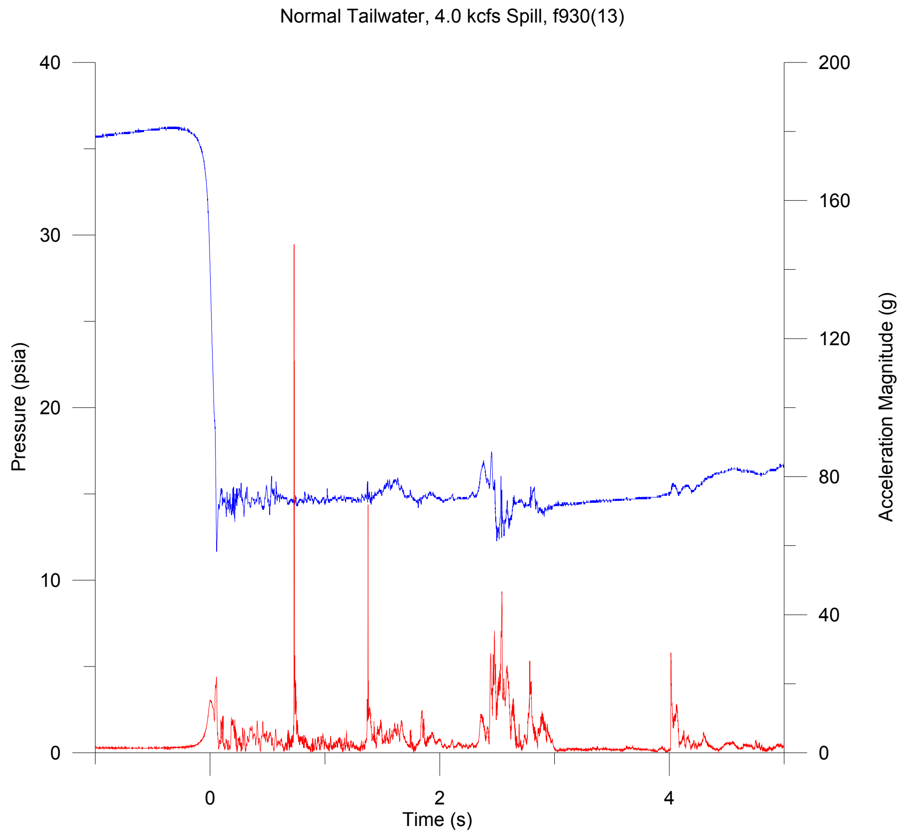


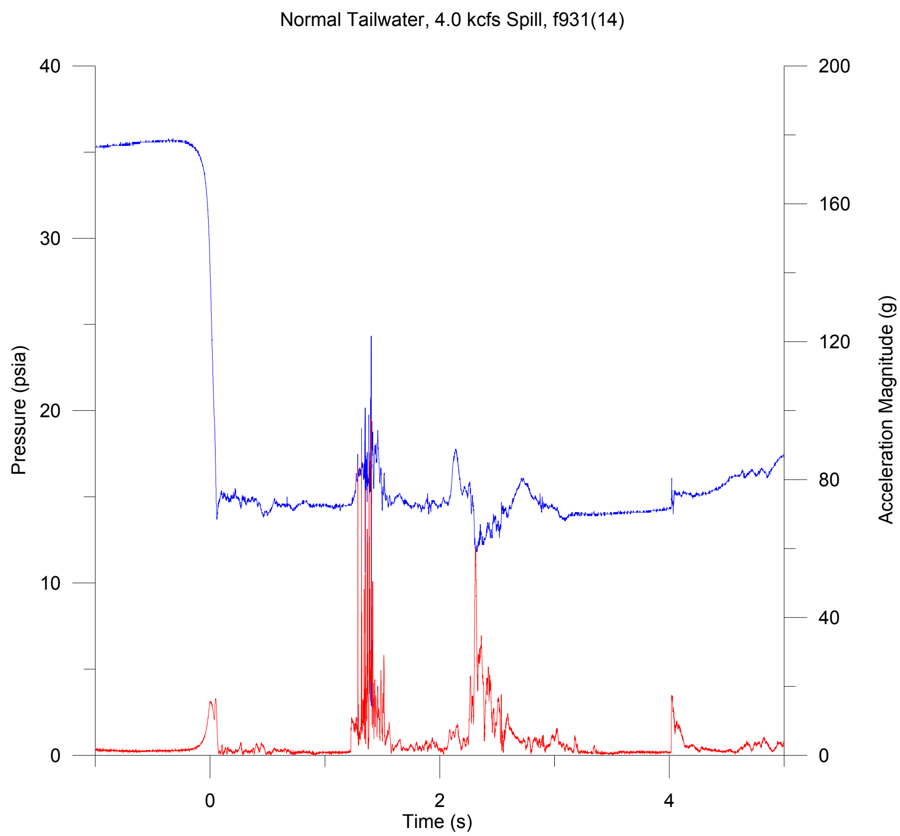

Normal Tailwater, 4.0 kcfs Spill, f115(9)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

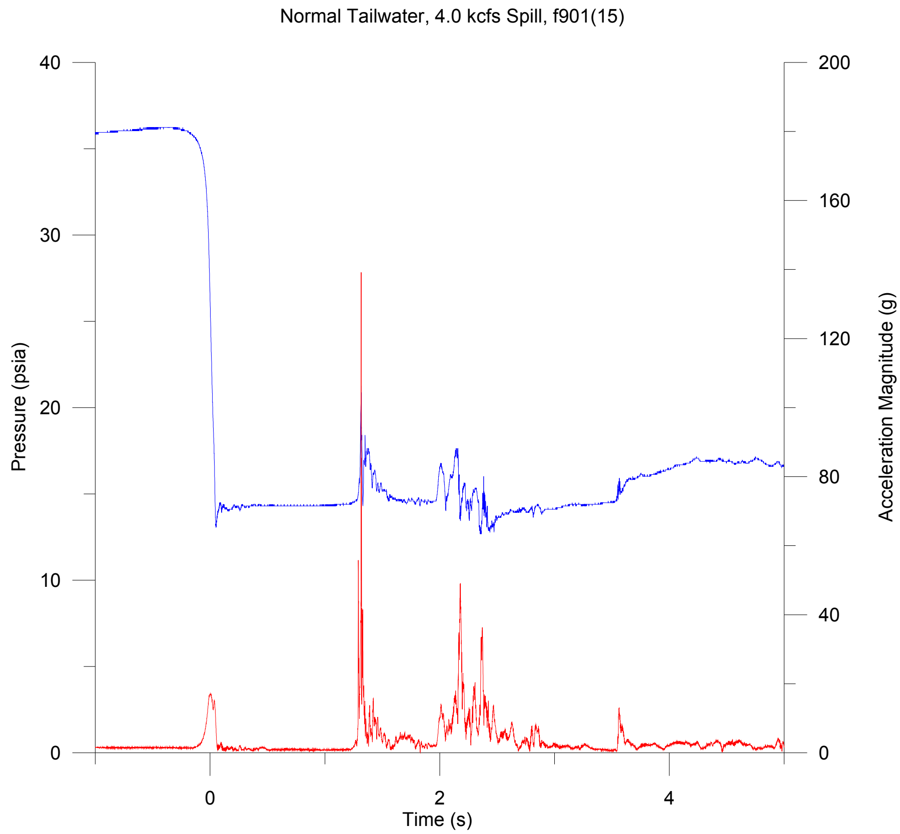

Normal Tailwater, 4.0 kcfs Spill, f923(10)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Normal Tailwater, 4.0 kcfs Spill, f931(11)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Normal Tailwater, 4.0 kcfs Spill, f908(12)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

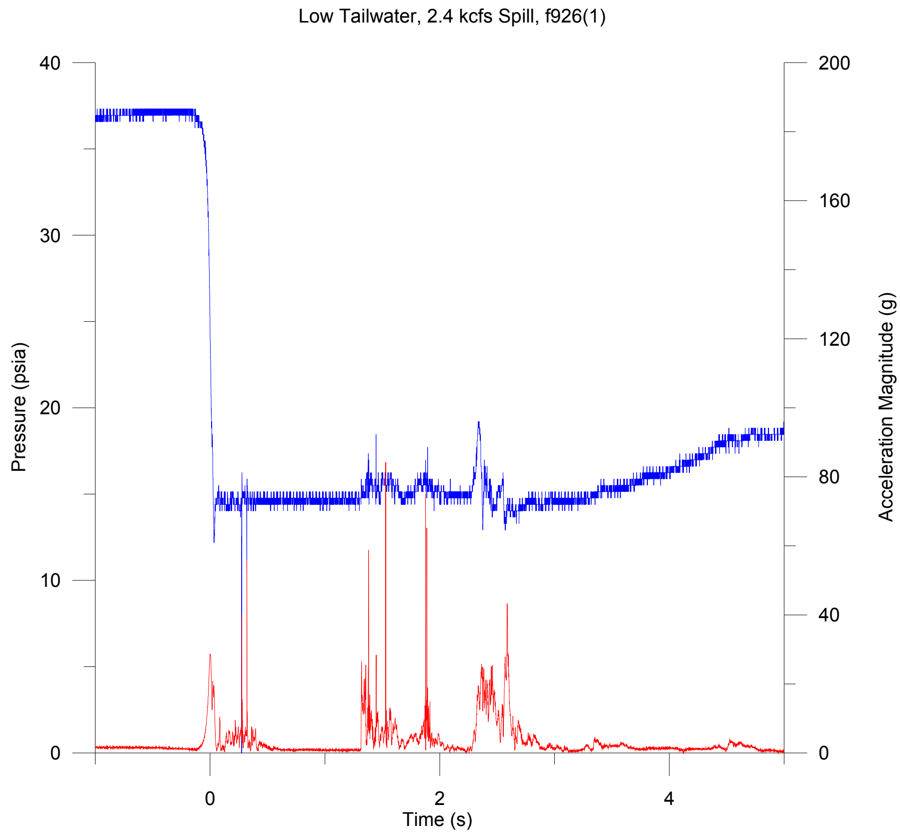

Normal Tailwater, 4.0 kcfs Spill, f930(13)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

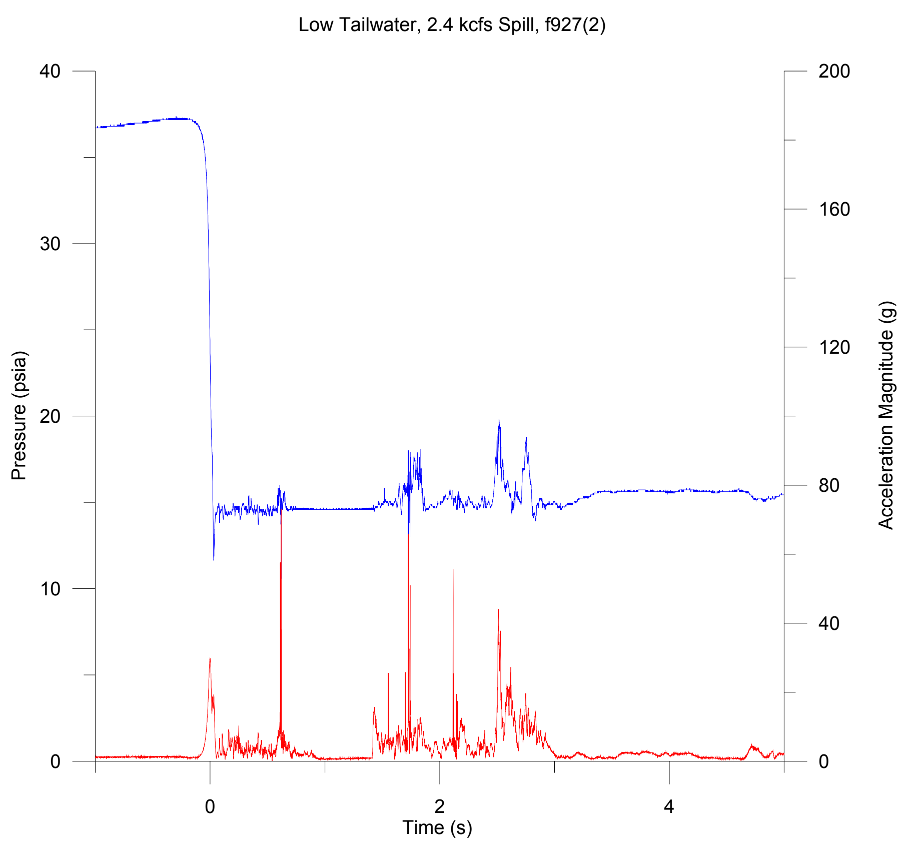

Normal Tailwater, 4.0 kcfs Spill, f931(14)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

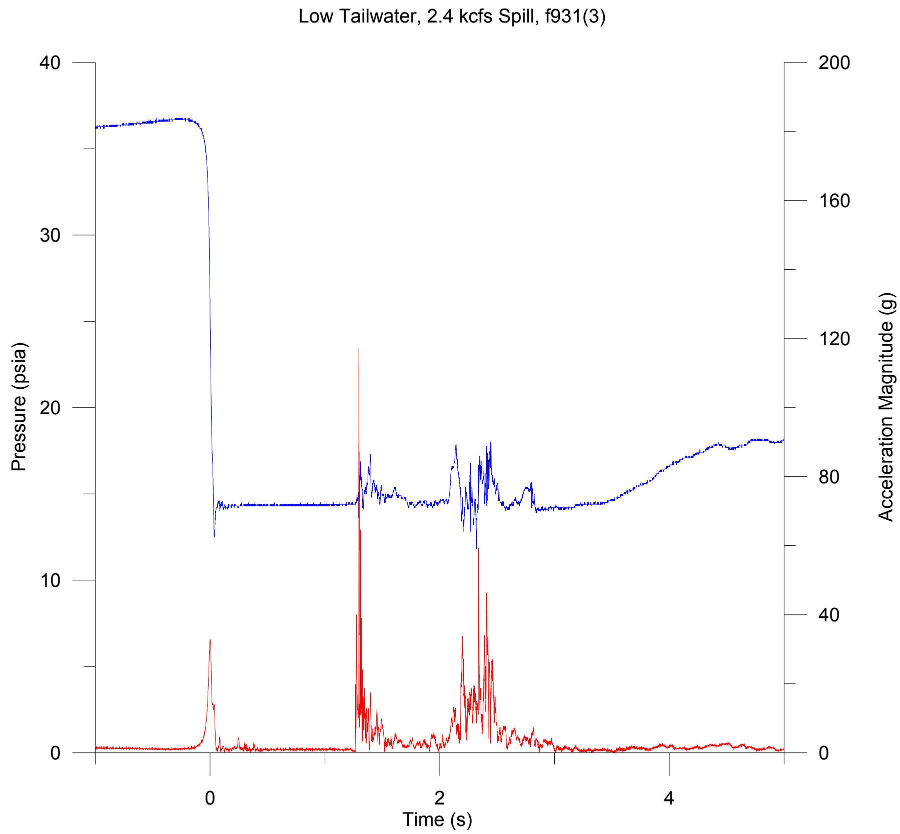

Normal Tailwater, 4.0 kcfs Spill, f901(15)
Pressure (psia)
40
30
20
10
0
Acceleration Magnitude (g)
200
160
120
80
40
0
0
2
4
Time (s)

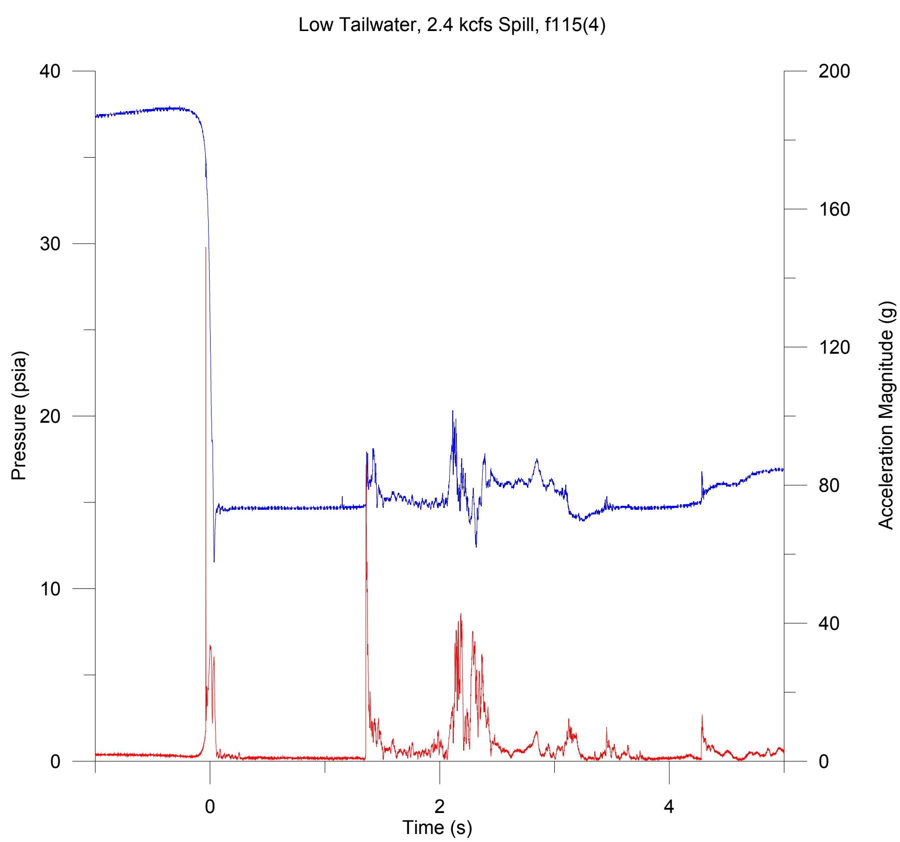
John Day Dam Spillbay 20

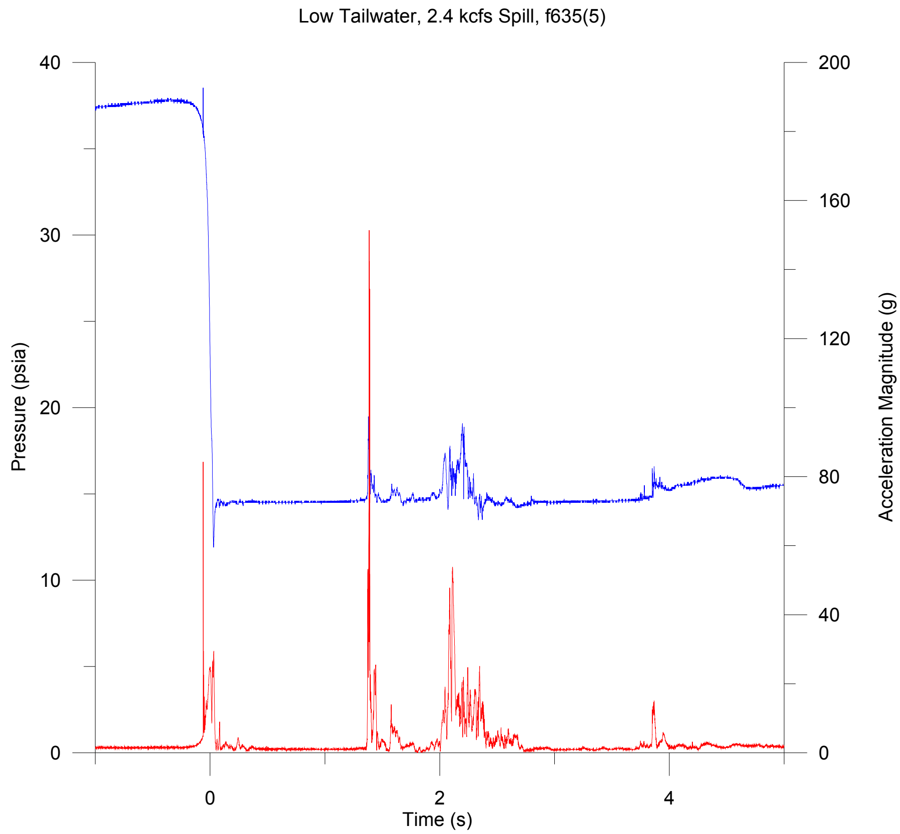
2.4-kcfs Discharge, Low Tailwater


Low Tailwater, 2.4 kcfs Spill, f926(1)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

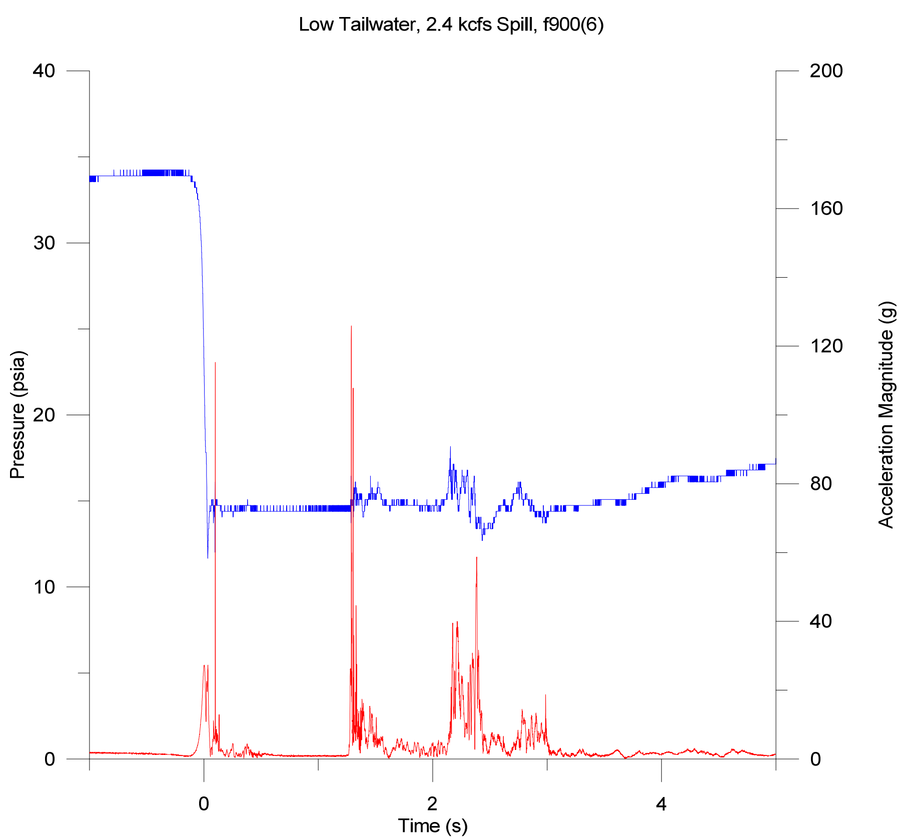

Low Tailwater, 2.4 kcfs Spill, f927(2)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Low Tailwater, 2.4 kcfs Spill, f931(3)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

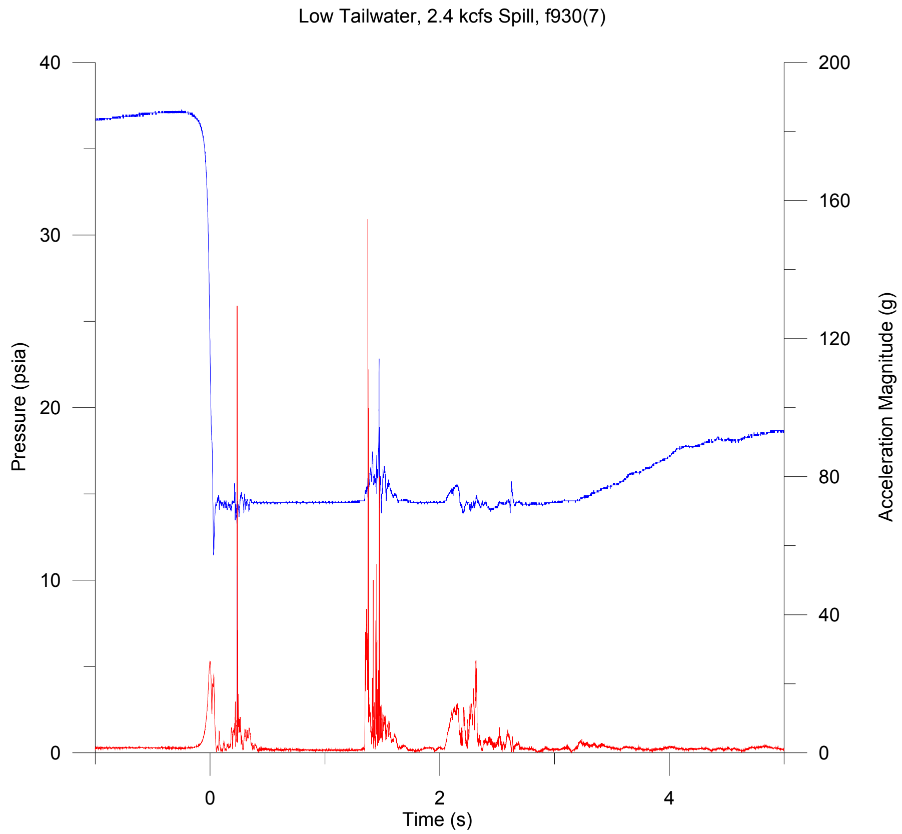

Low Tailwater, 2.4 kcfs Spill, f115(4)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

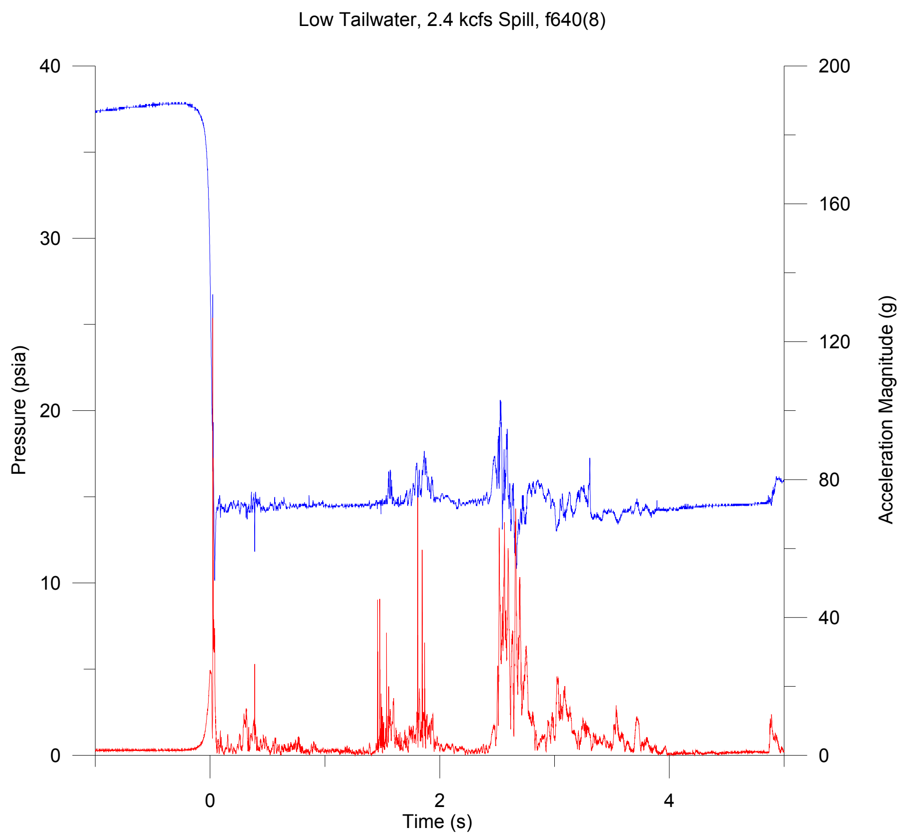


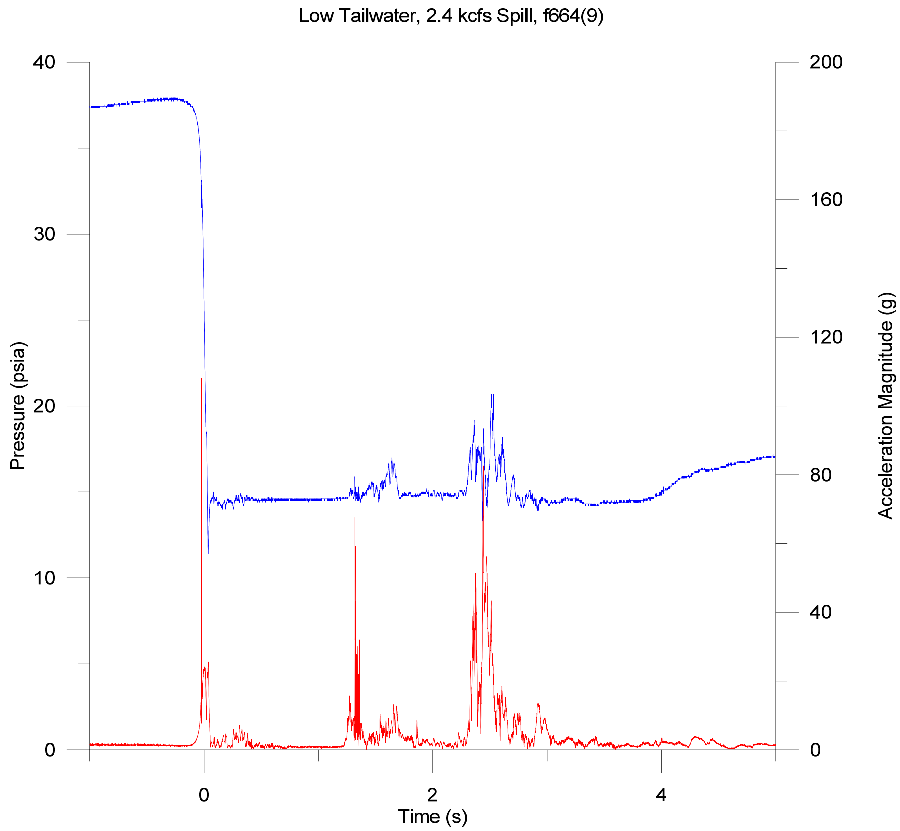
Low Tailwater, 2.4 kcfs Spill, f635(5)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

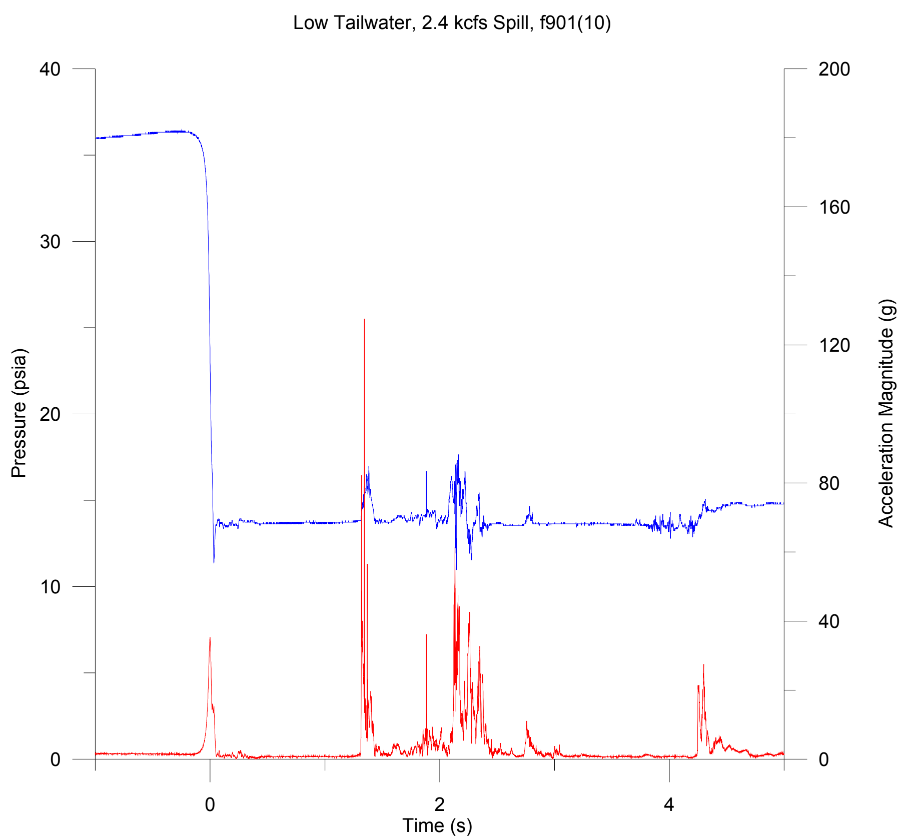


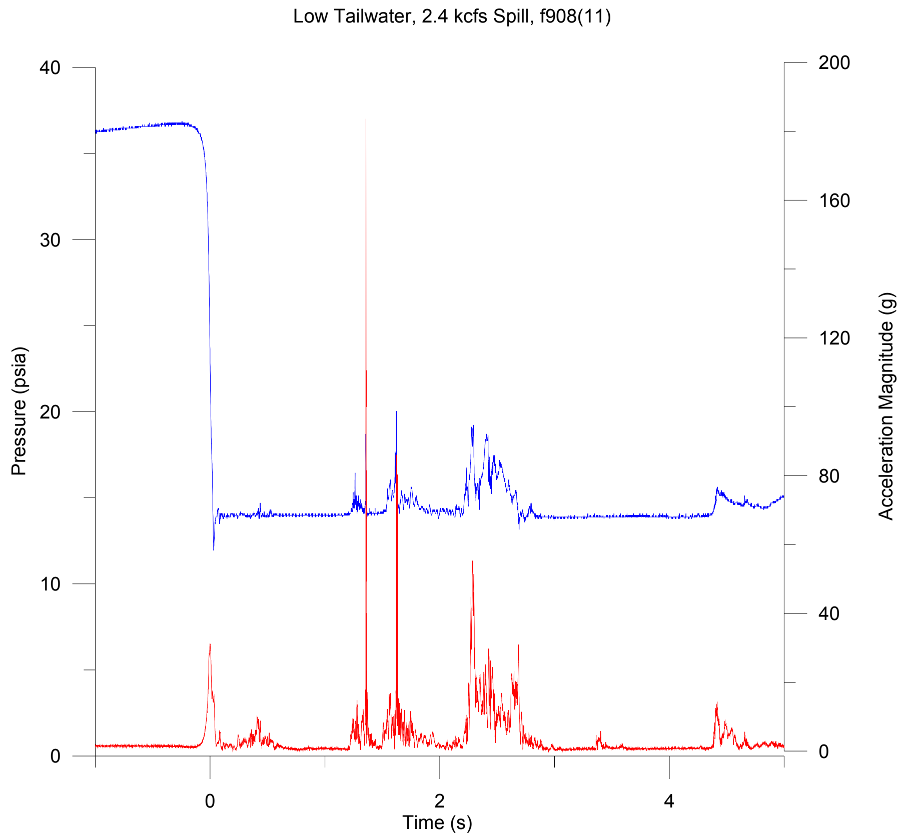
Low Tailwater, 2.4 kcfs Spill, f900(6)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4


Low Tailwater, 2.4 kcfs Spill, f930(7)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

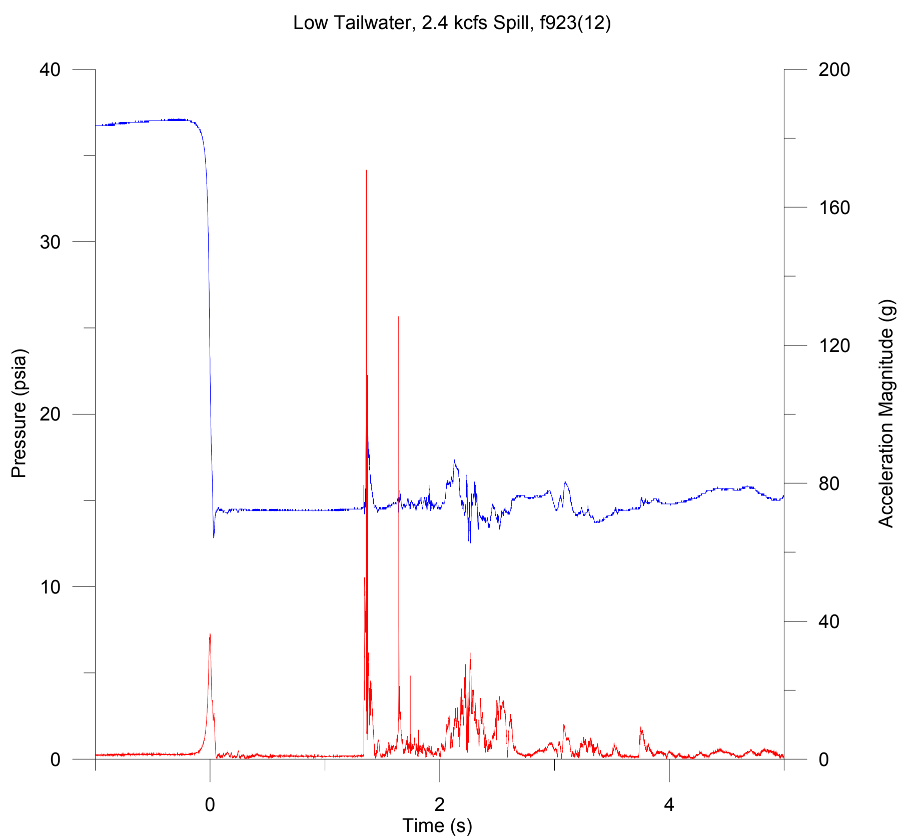

Low Tailwater, 2.4 kcfs Spill, f640(8)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Low Tailwater, 2.4 kcfs Spill, f664(9)
40
30
20
10
0
200
160
120
80
40
0
Pressure (psia)
Acceleration Magnitude (g)
0
2
4
Time (s)

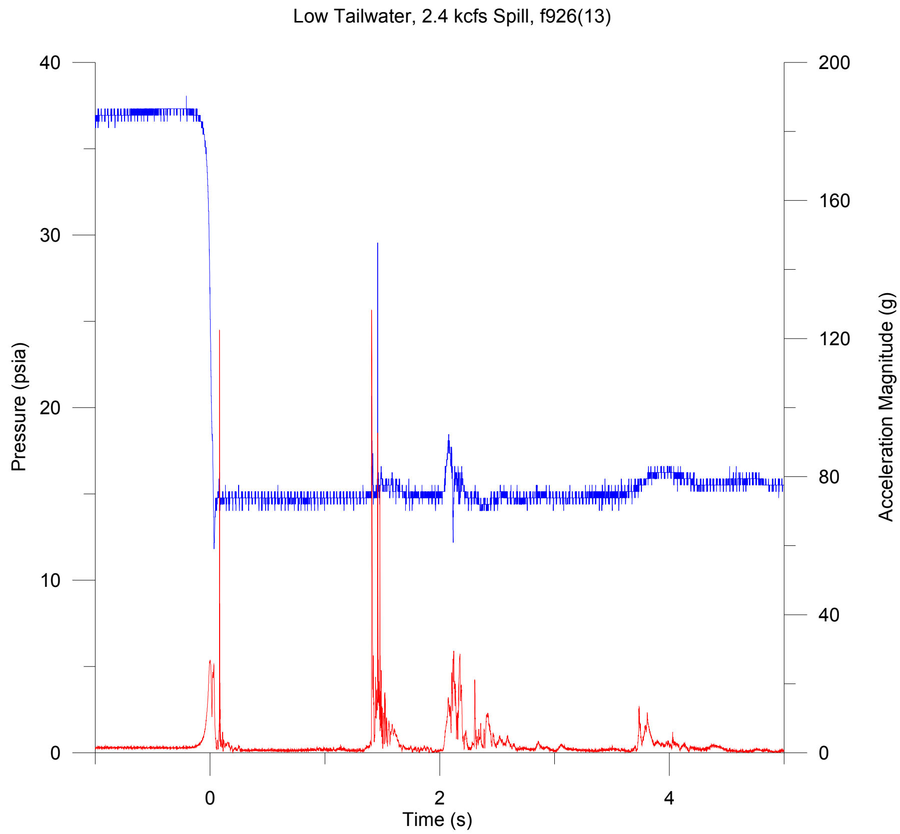

Low Tailwater, 2.4 kcfs Spill, f901(10)
40
30
20
10
0
200
160
120
80
40
0
Pressure (psia)
Acceleration Magnitude (g)
0
2
4
Time (s)

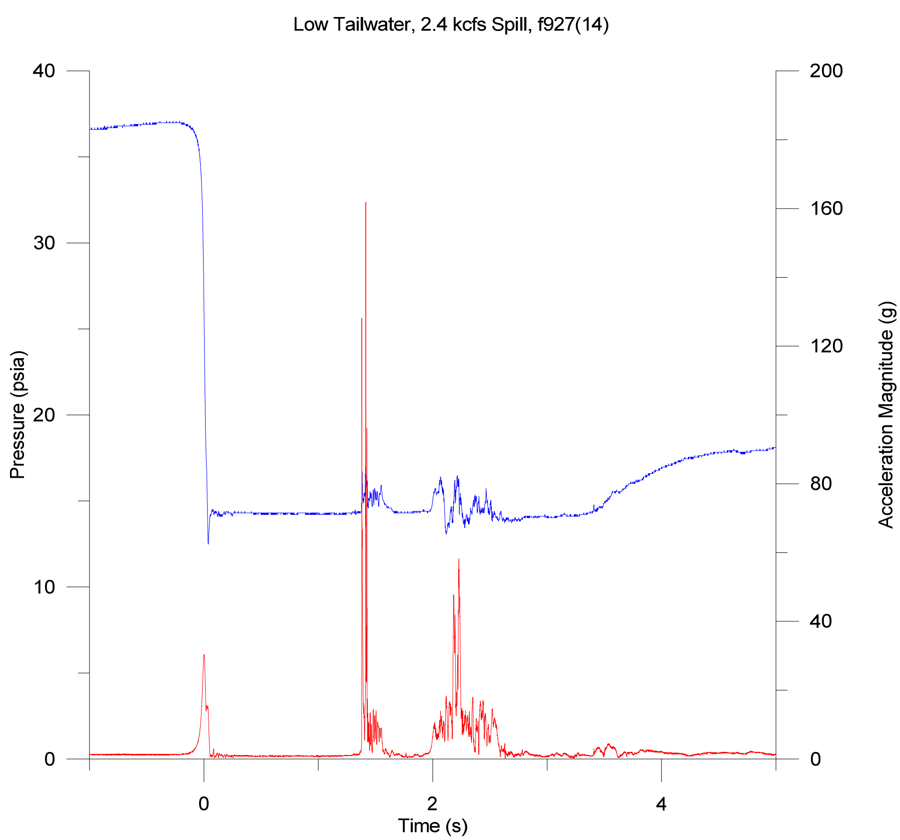


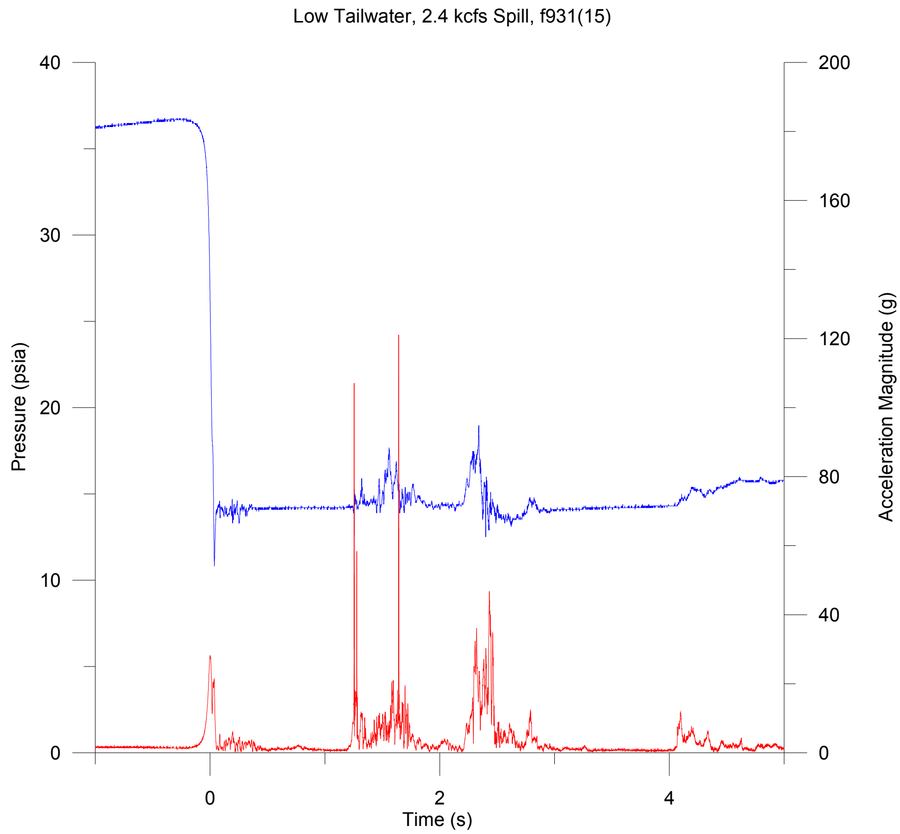
Low Tailwater, 2.4 kcfs Spill, f908(11)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4

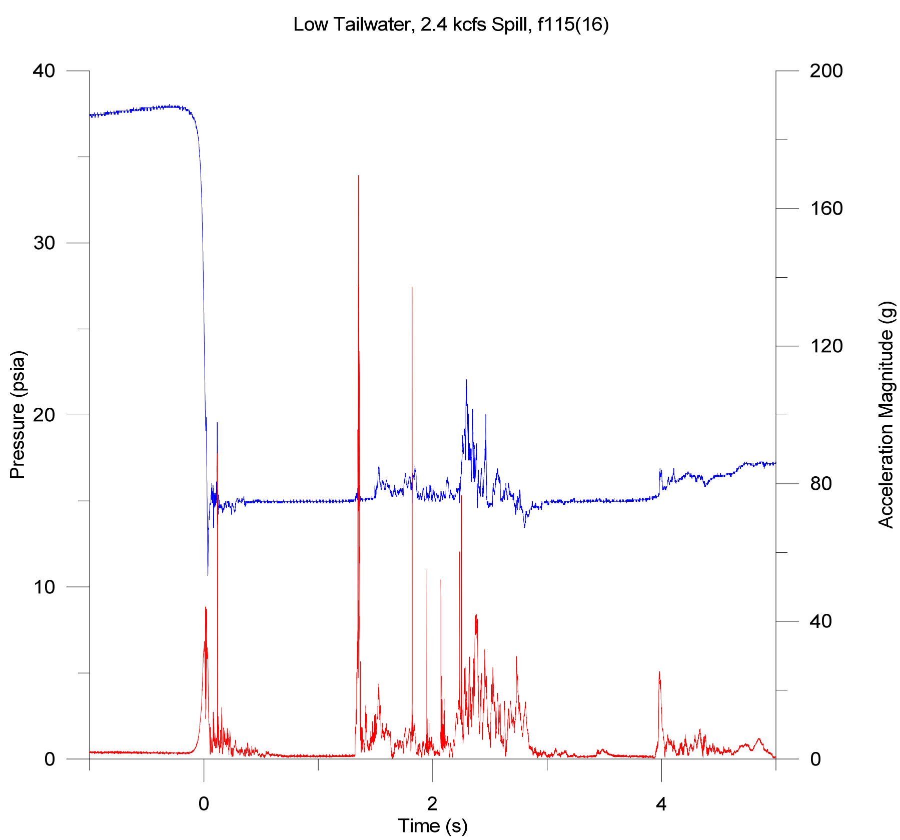


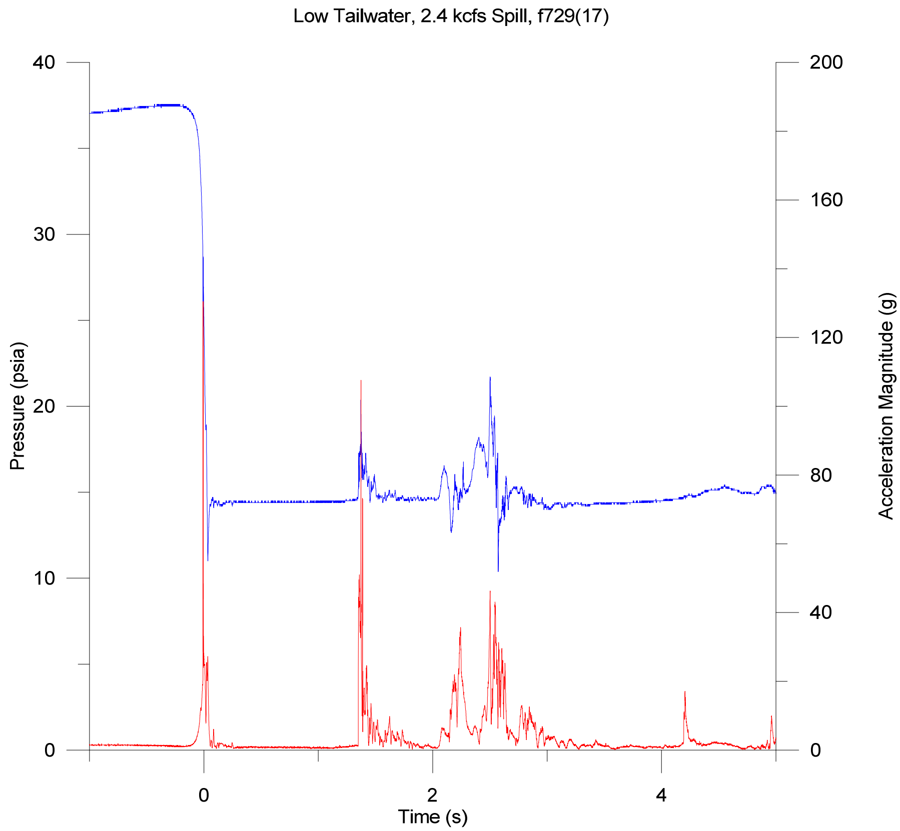
Low Tailwater, 2.4 kcfs Spill, f923(12)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
0
10
20
30
40
0
40
80
120
160
200
0
2
4


Low Tailwater, 2.4 kcfs Spill, f926(13)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Low Tailwater, 2.4 kcfs Spill, f927(14)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Low Tailwater, 2.4 kcfs Spill, f931(15)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4


Low Tailwater, 2.4 kcfs Spill, f115(16)
Pressure (psia)
Acceleration Magnitude (g)
Time (s)
40
30
20
10
0
200
160
120
80
40
0
0
2
4

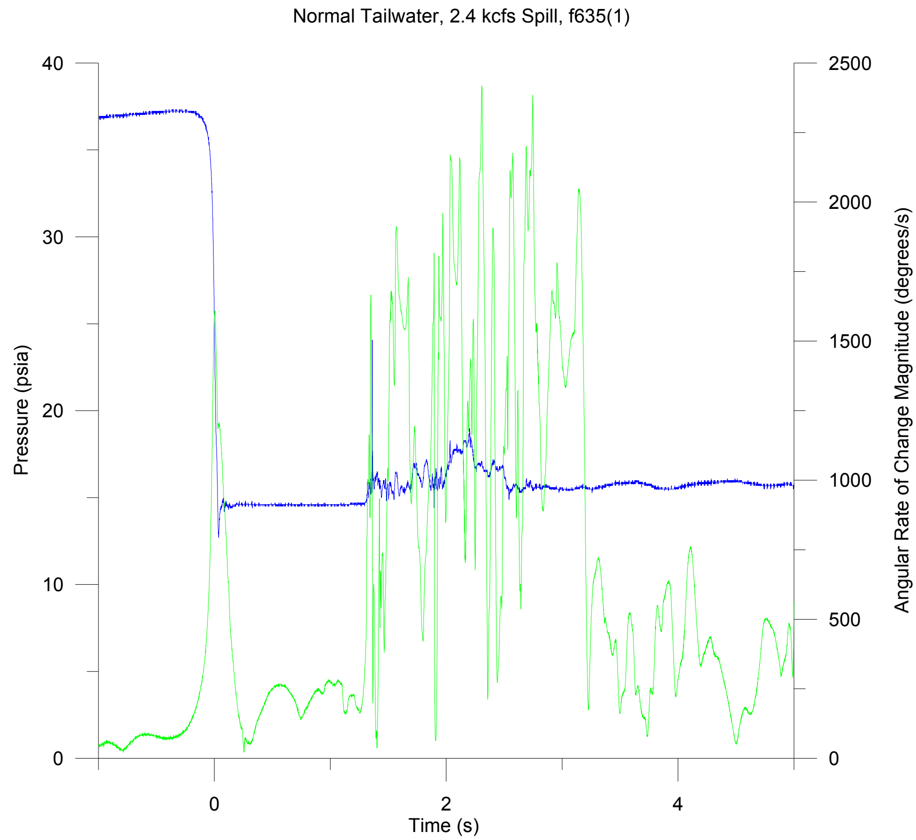

Low Tailwater, 2.4 kcfs Spill, f729(17)
Pressure (psia)
40
30
20
10
0
Acceleration Magnitude (g)
200
160
120
80
40
0
Time (s)
2
4

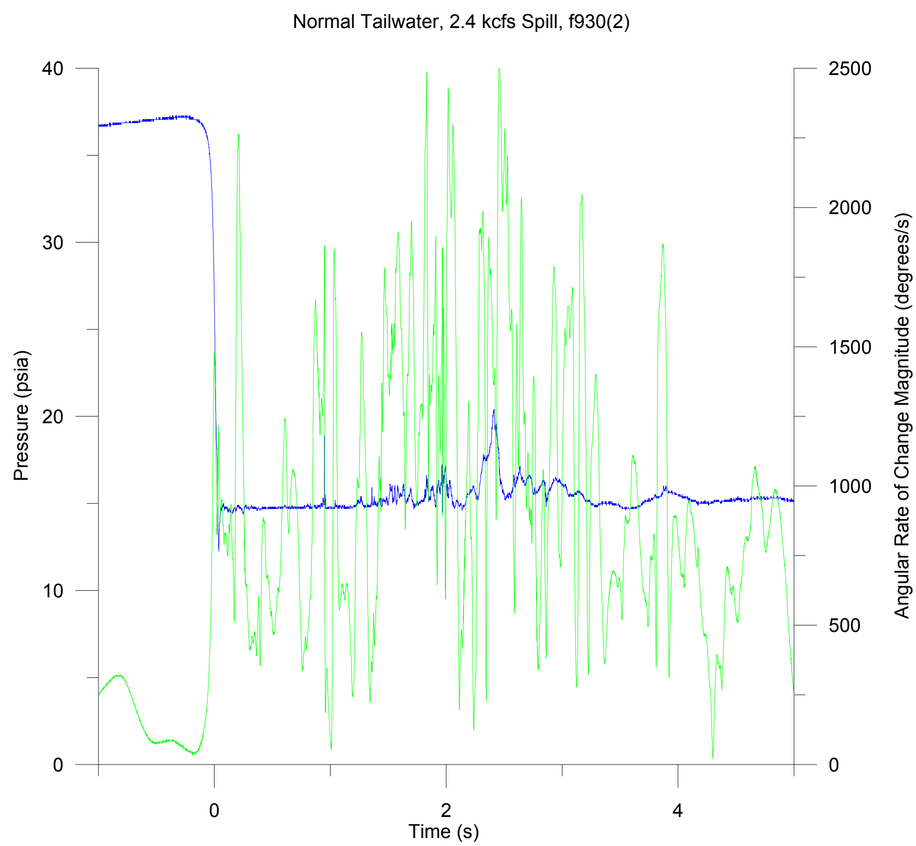
Appendix D

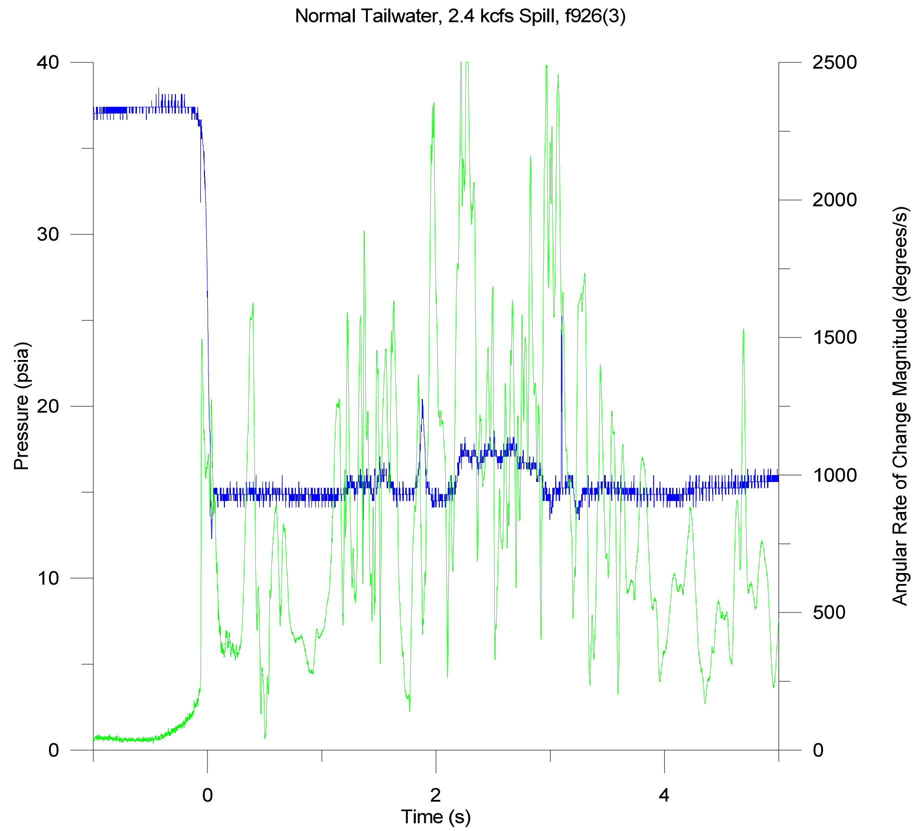
Pressure and Angular Rate-of-Change Magnitude Time Histories of Each Sensor Fish Release

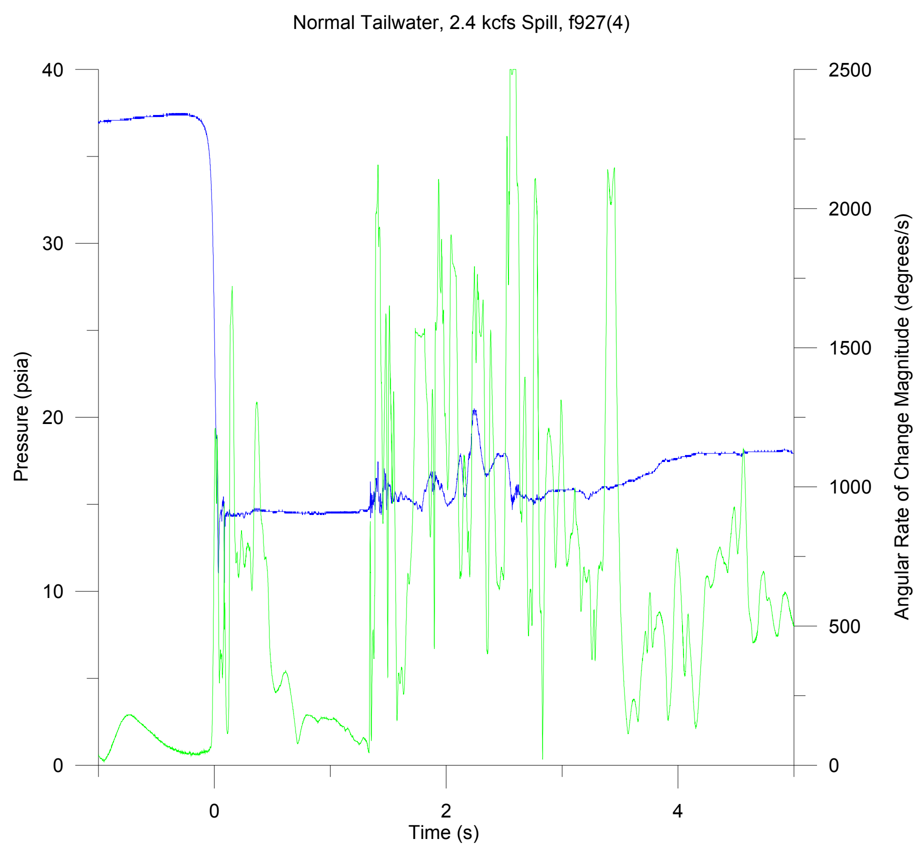
John Day Dam Spillbay 20

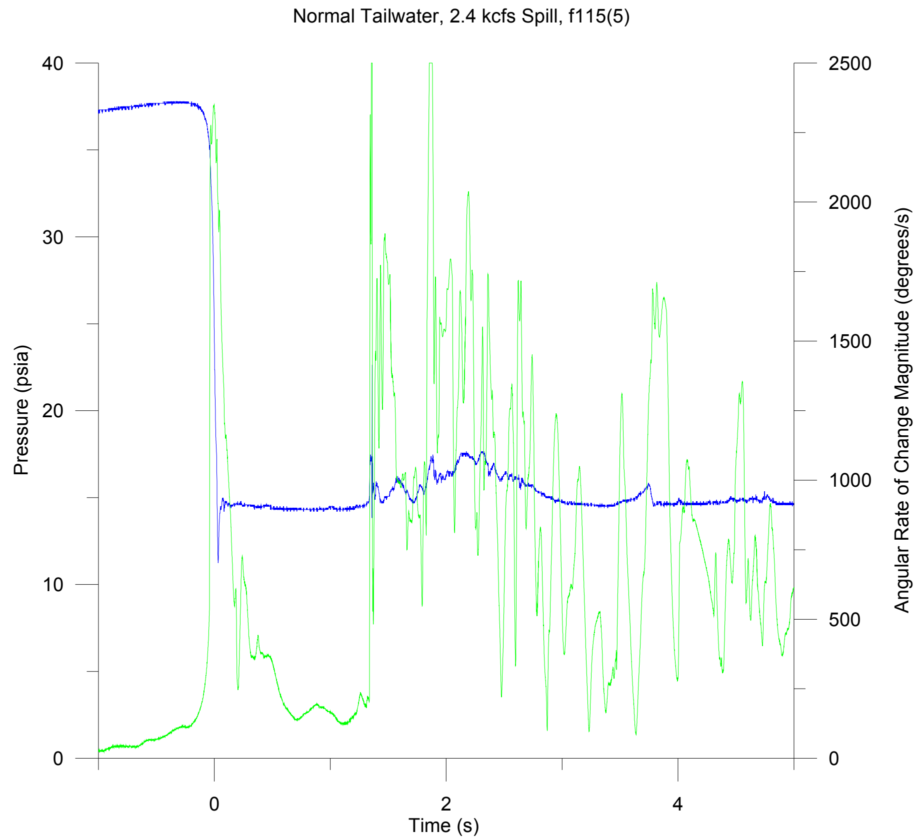
2.4-kcfs Discharge, Normal Tailwater

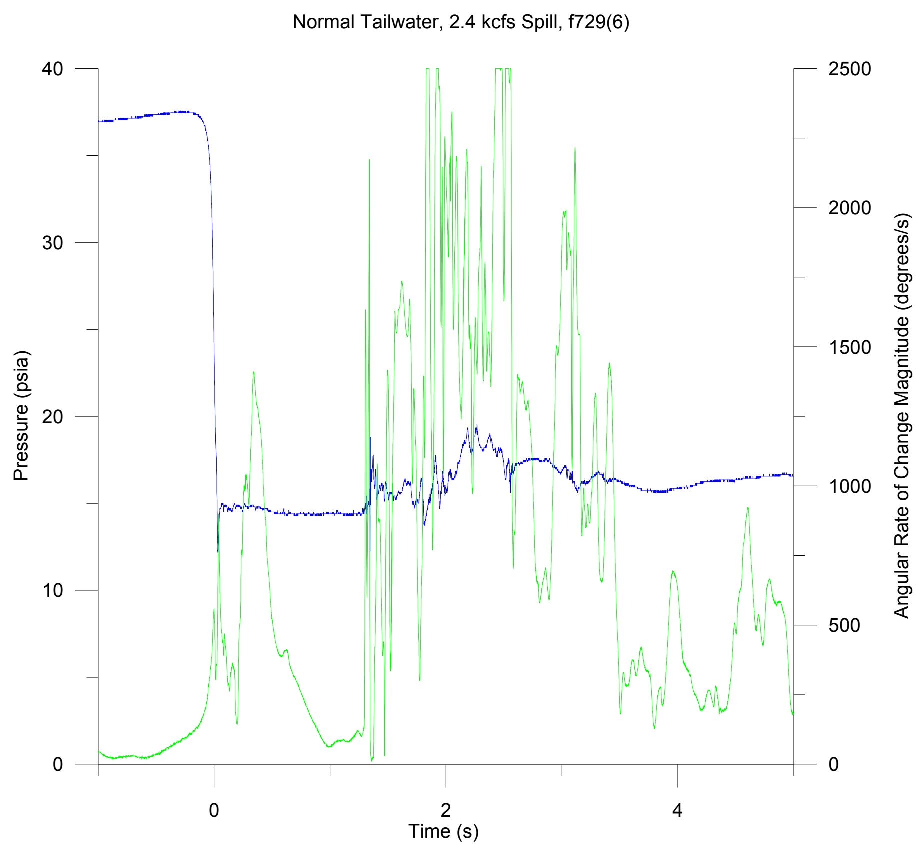

Normal Tailwater, 2.4 kcfs Spill, f635(1)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Normal Tailwater, 2.4 kcfs Spill, f930(2)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

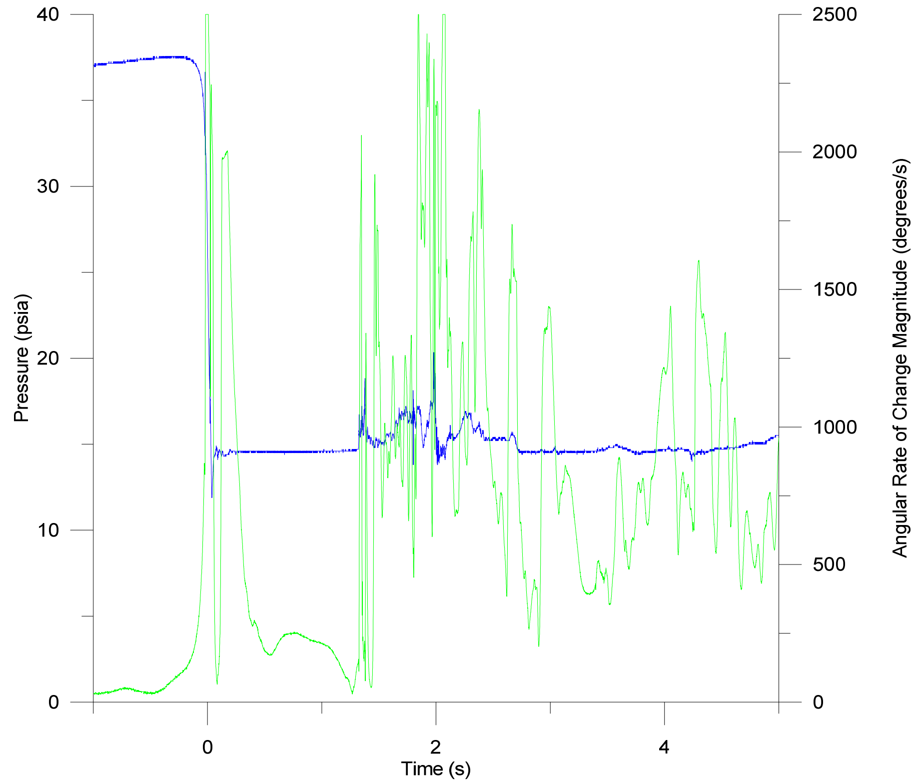

Normal Tailwater, 2.4 kcfs Spill, f926(3)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Normal Tailwater, 2.4 kcfs Spill, f927(4)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

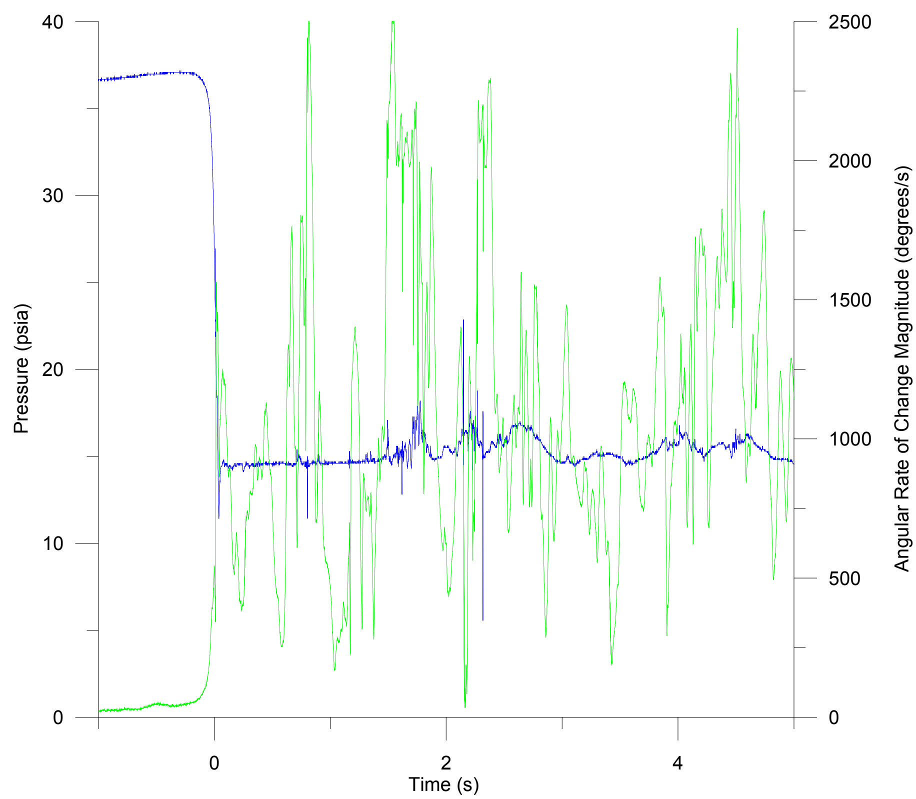

Normal Tailwater, 2.4 kcfs Spill, f115(5)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

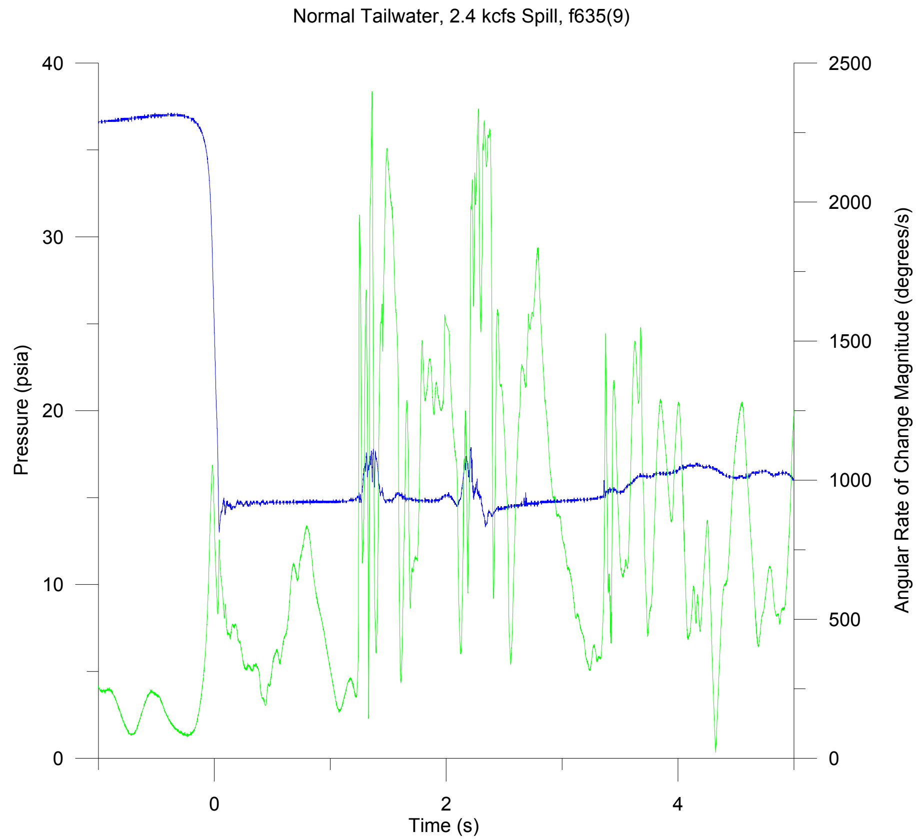

Normal Tailwater, 2.4 kcfs Spill, f729(6)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

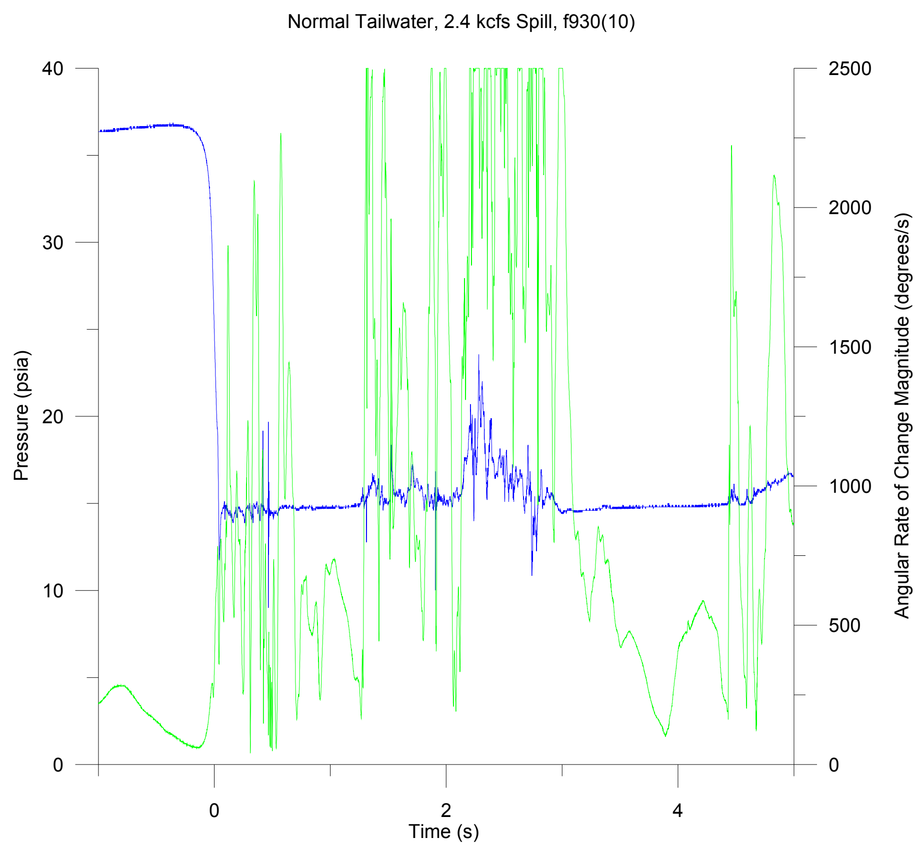
Normal Tailwater, 2.4 kcfs Spill, f117(7)

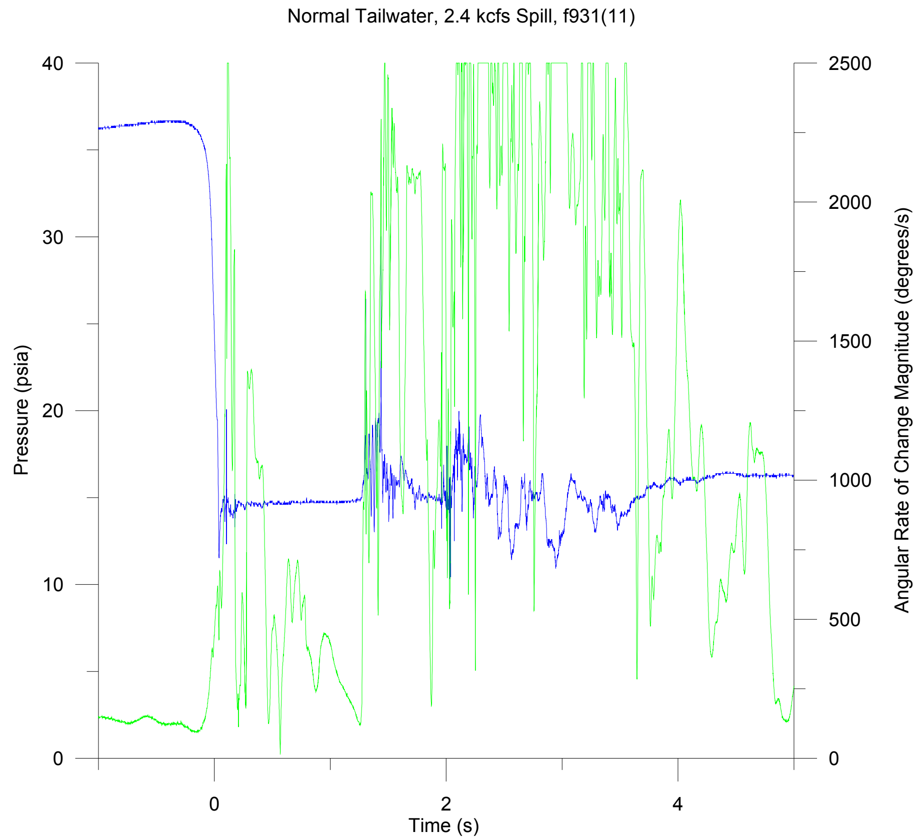


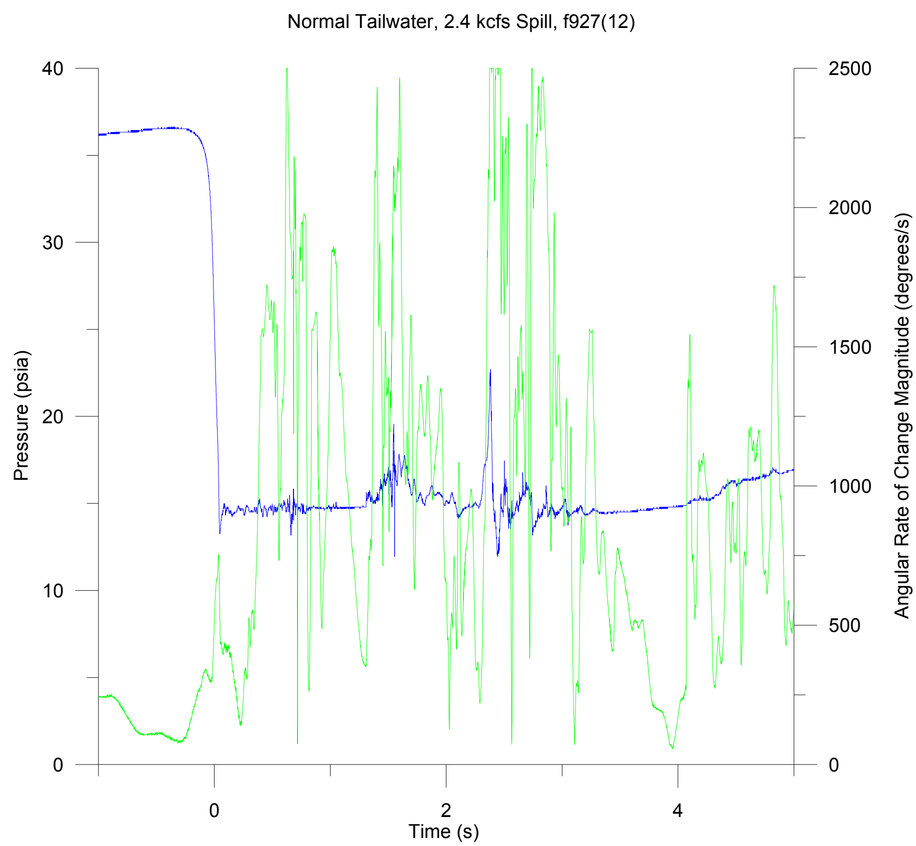
Normal Tailwater, 2.4 kcfs Spill, f931(8)

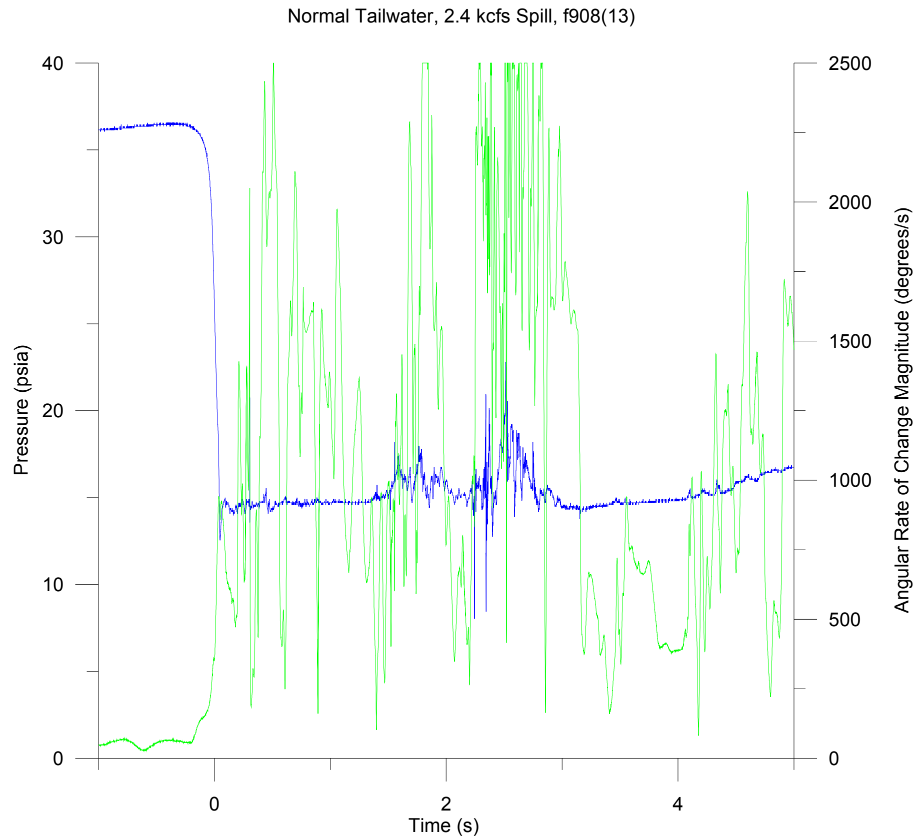



Normal Tailwater, 2.4 kcfs Spill, f635(9)
Pressure (psia)
40
30
20
10
0
Angular Rate of Change Magnitude (degrees/s)
2500
2000
1500
1000
500
0
0
2
4
Time (s)

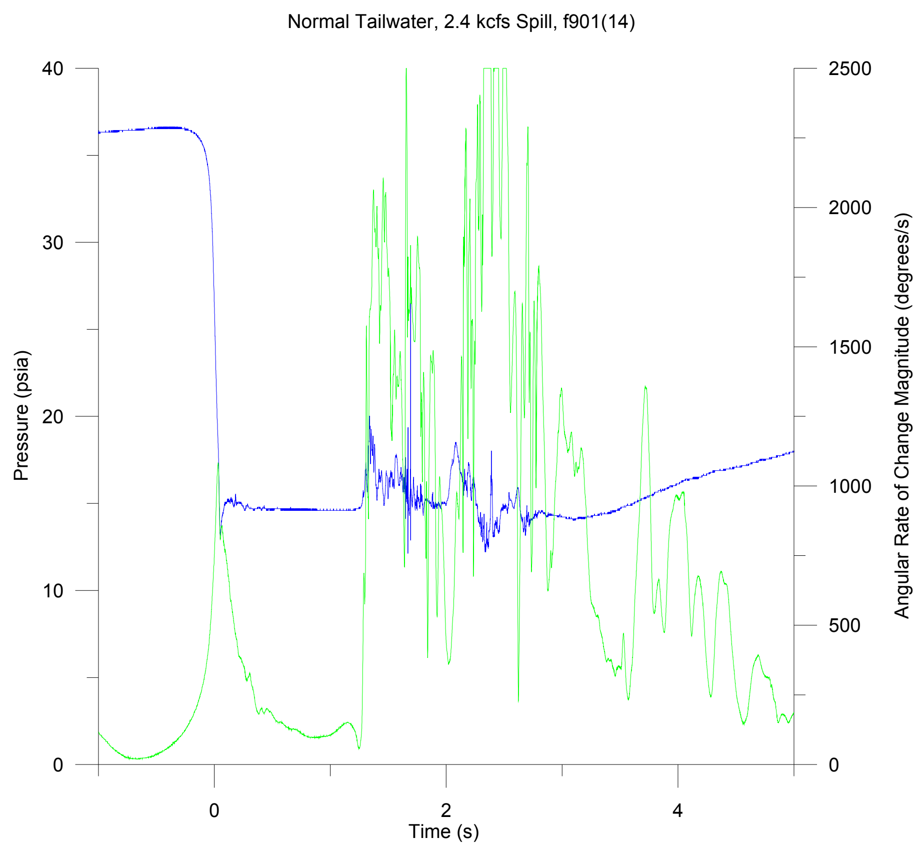

Normal Tailwater, 2.4 kcfs Spill, f930(10)
Pressure (psia)
40
30
20
10
0
Angular Rate of Change Magnitude (degrees/s)
2500
2000
1500
1000
500
0
0
2
4
Time (s)


Normal Tailwater, 2.4 kcfs Spill, f931(11)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
500
1000
1500
2000
2500
2
4

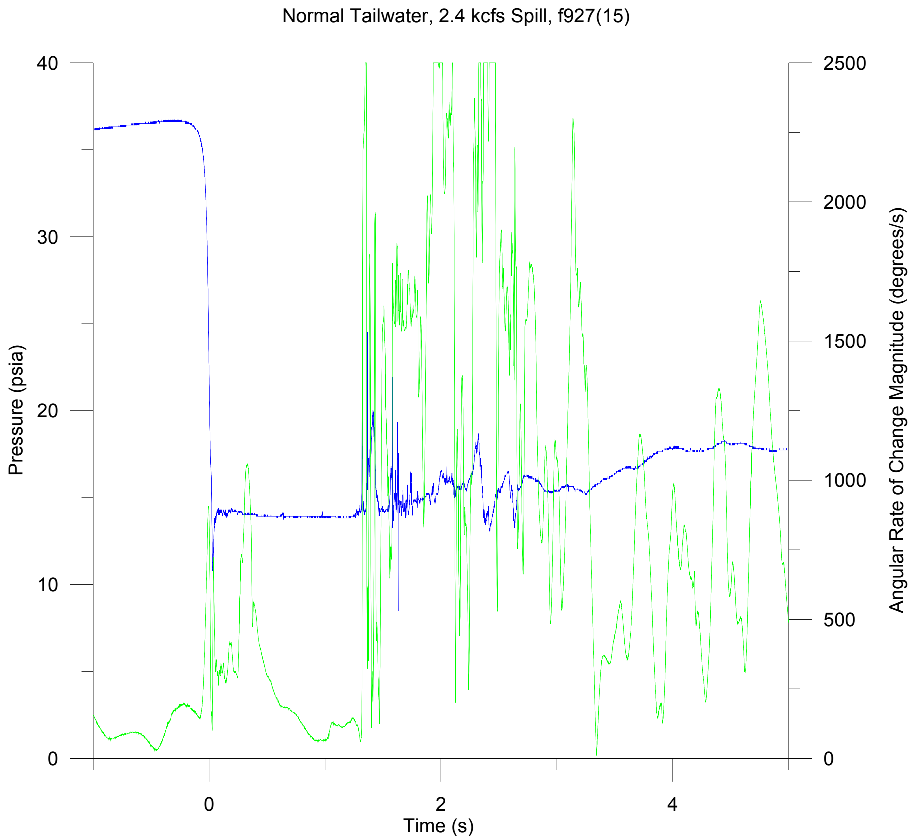

Normal Tailwater, 2.4 kcfs Spill, f927(12)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
500
1000
1500
2000
2500
2
4



Normal Tailwater, 2.4 kcfs Spill, f908(13)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4

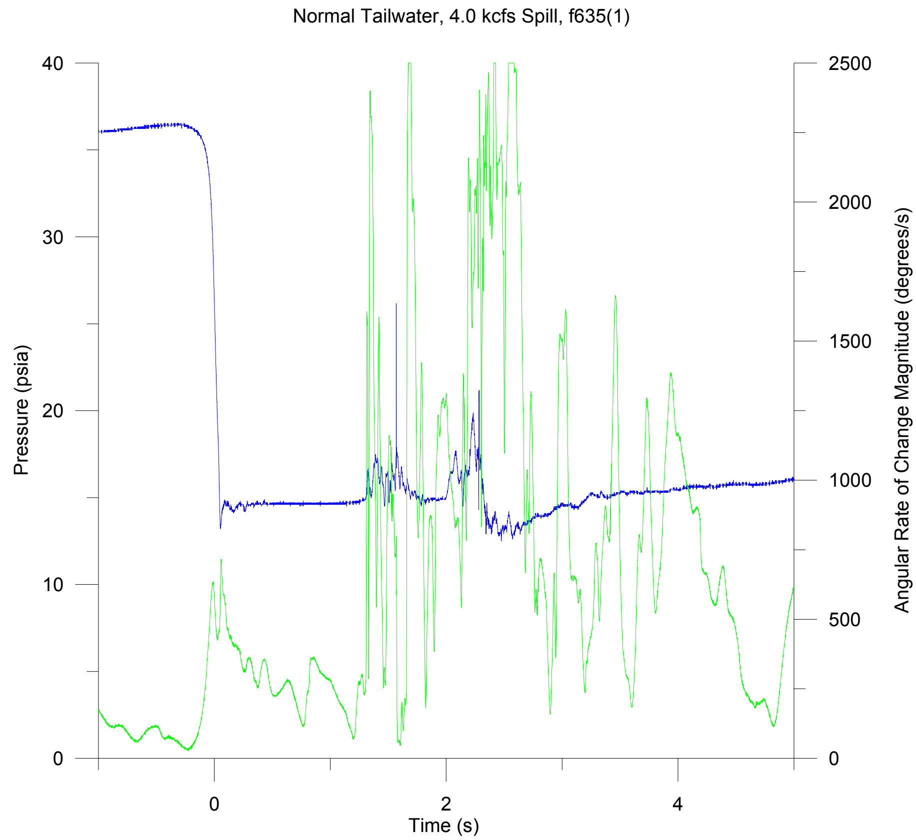


Normal Tailwater, 2.4 kcfs Spill, f901(14)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4

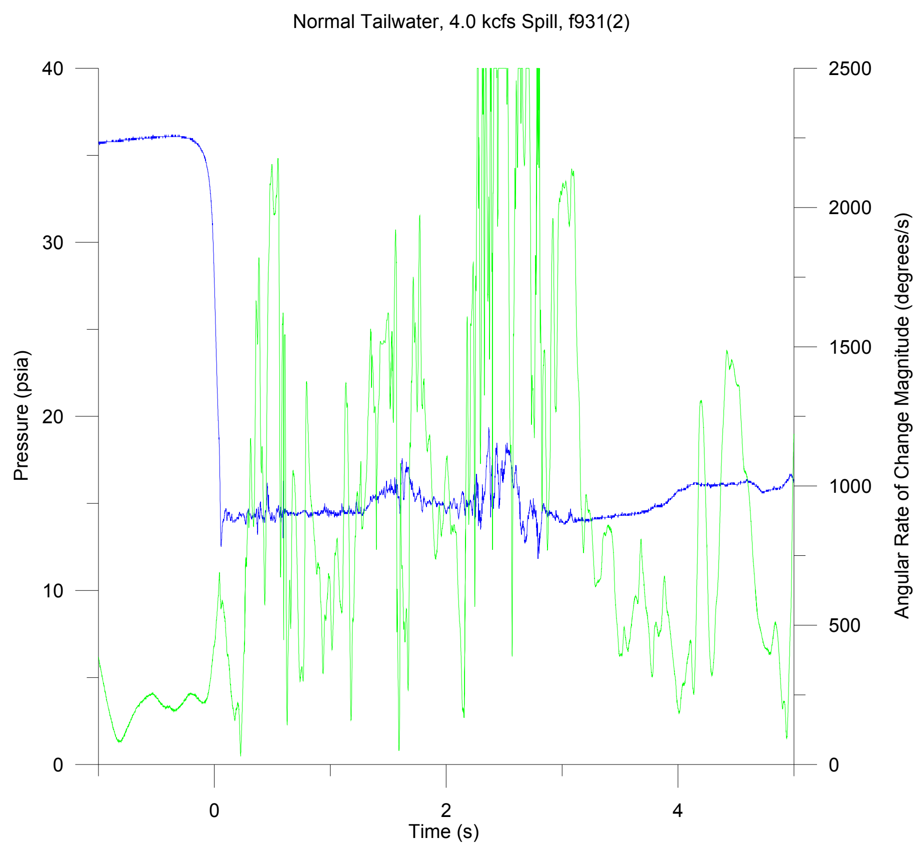

Normal Tailwater, 2.4 kcfs Spill, f927(15)
Pressure (psia)
40
30
20
10
0
Angular Rate of Change Magnitude (degrees/s)
2500
2000
1500
1000
500
0
Time (s)
0
2
4

John Day Dam Spillbay 20

4.0-kcfs Discharge, Normal Tailwater

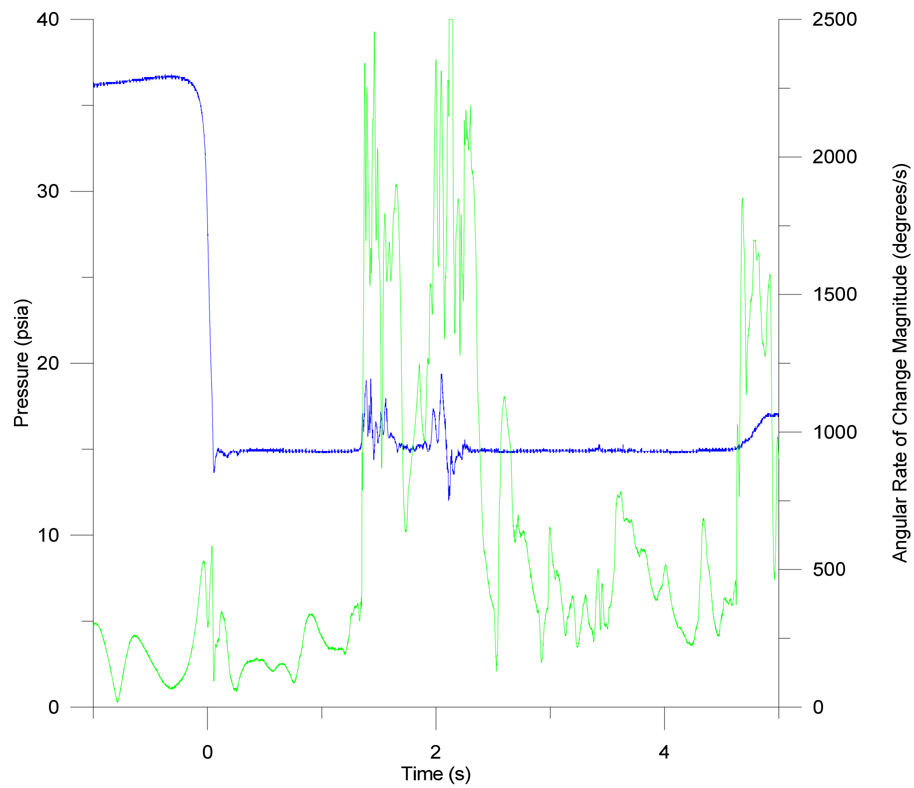


Normal Tailwater, 4.0 kcfs Spill, f635(1)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4

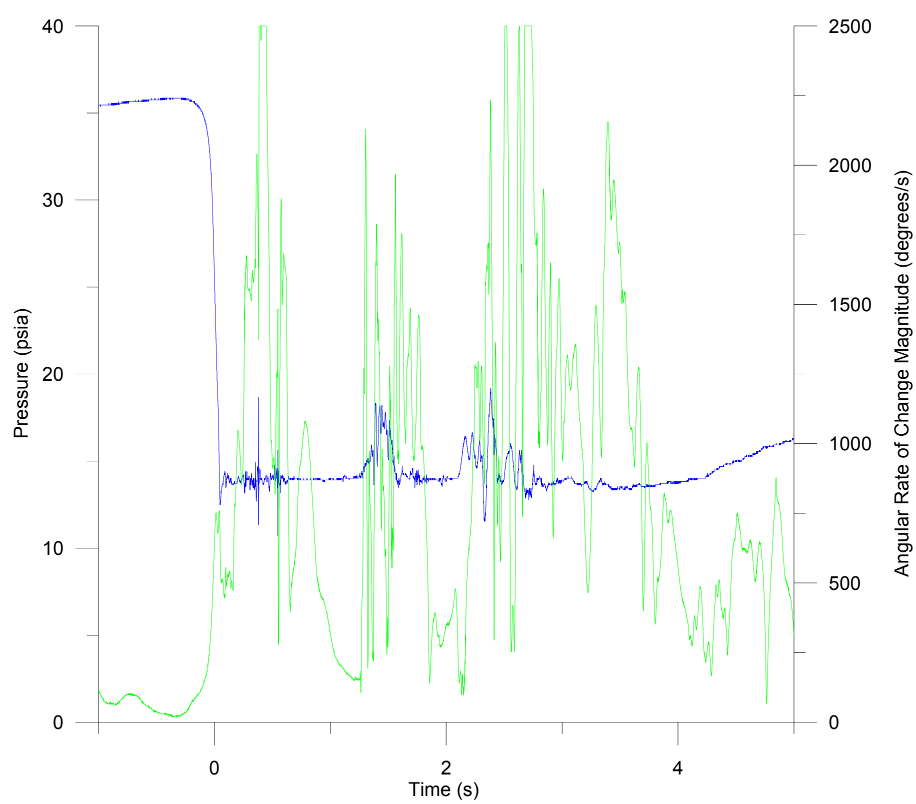


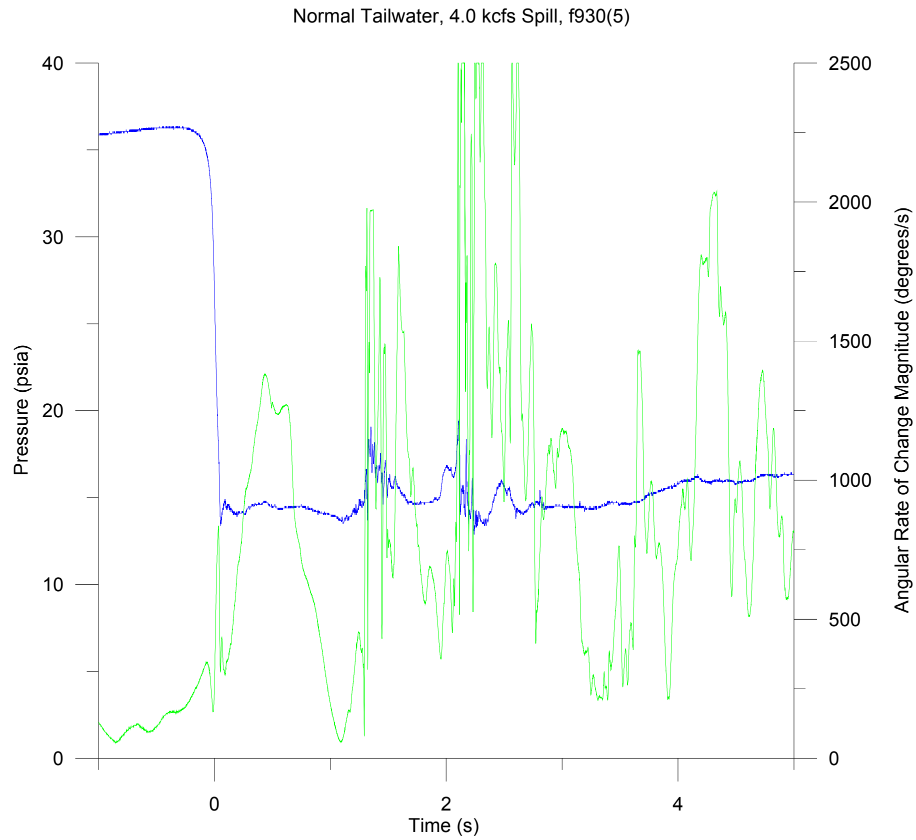
Normal Tailwater, 4.0 kcfs Spill, f931(2)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4

Normal Tailwater, 4.0 kcfs Spill, f115(3)

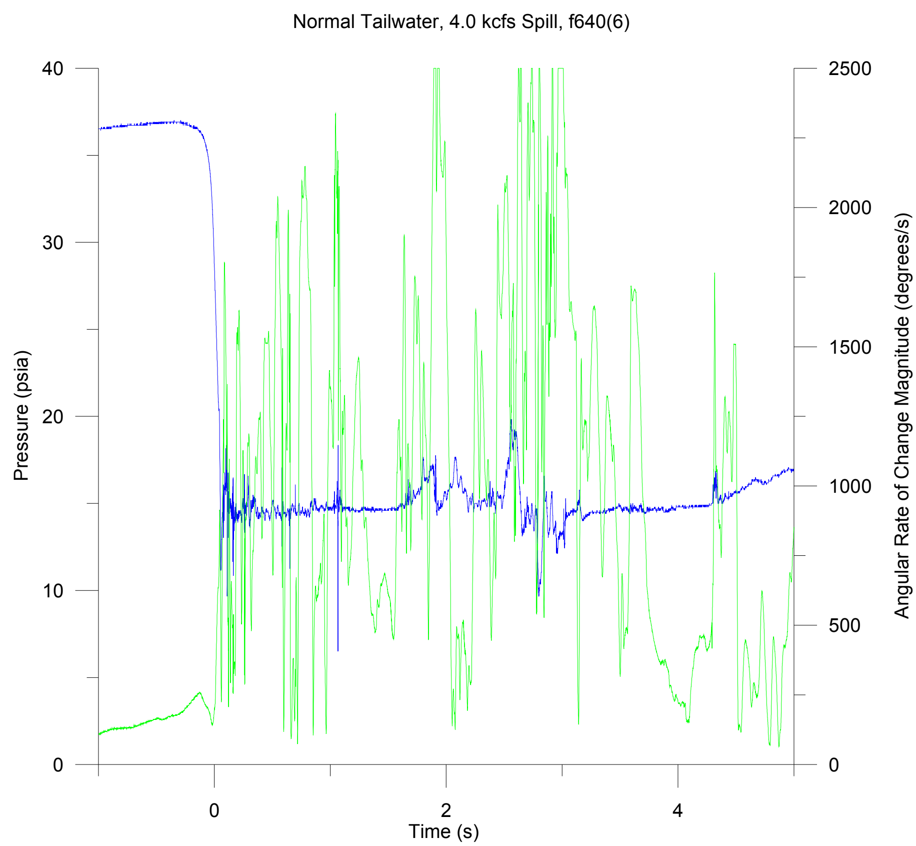


Normal Tailwater, 4.0 kcfs Spill, f901(4)

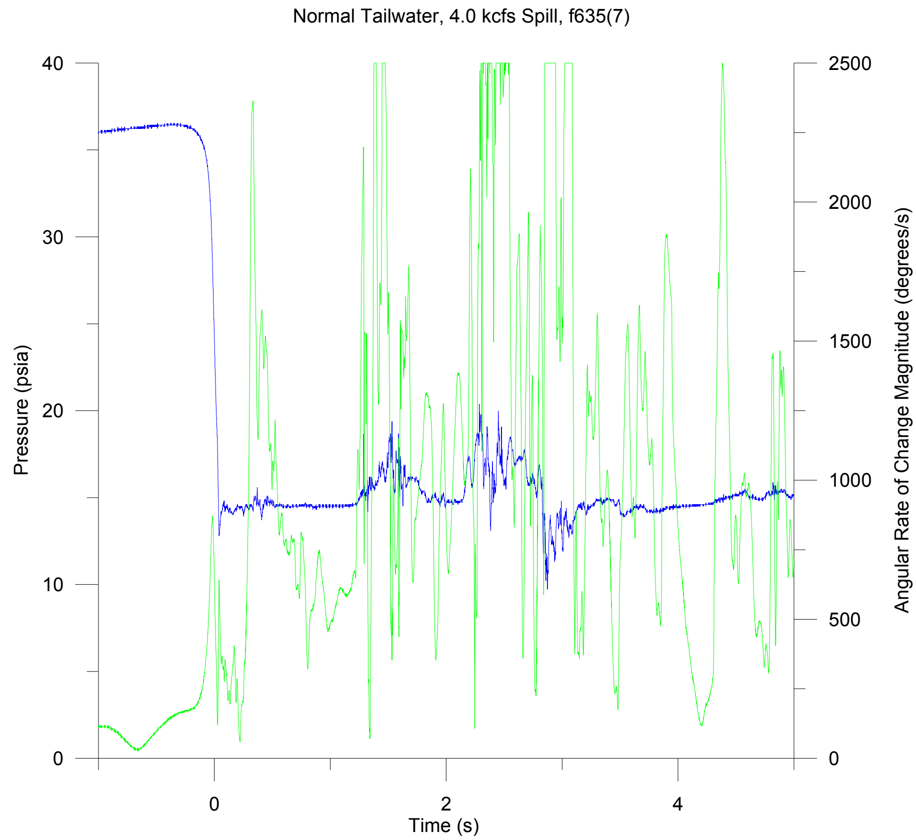


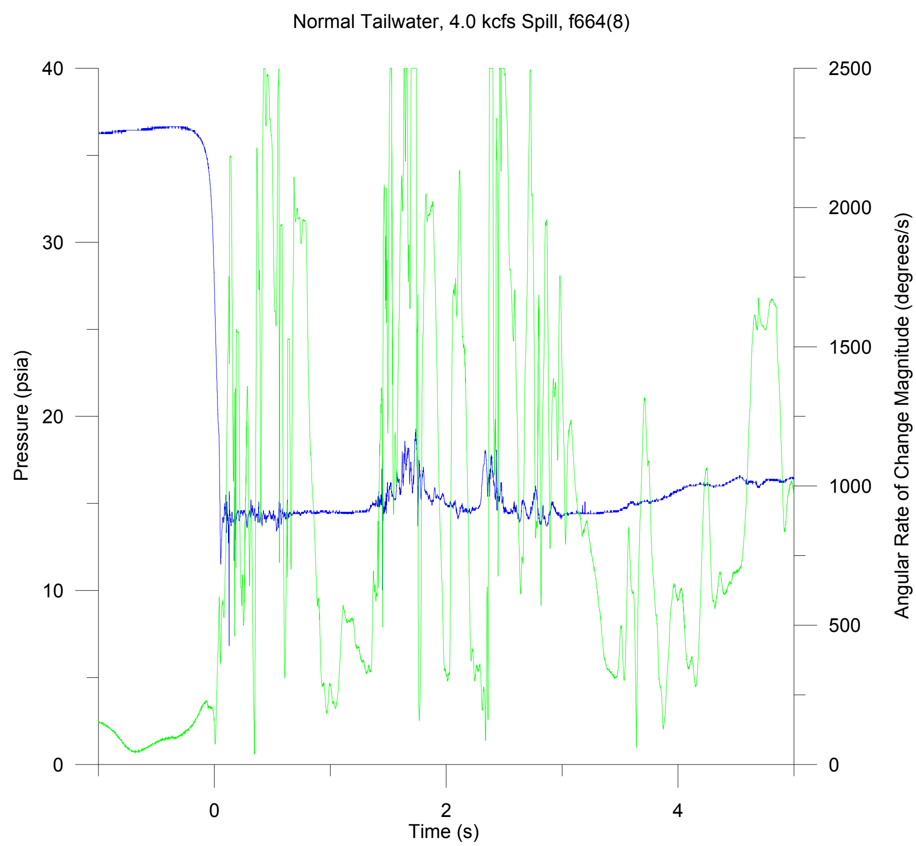


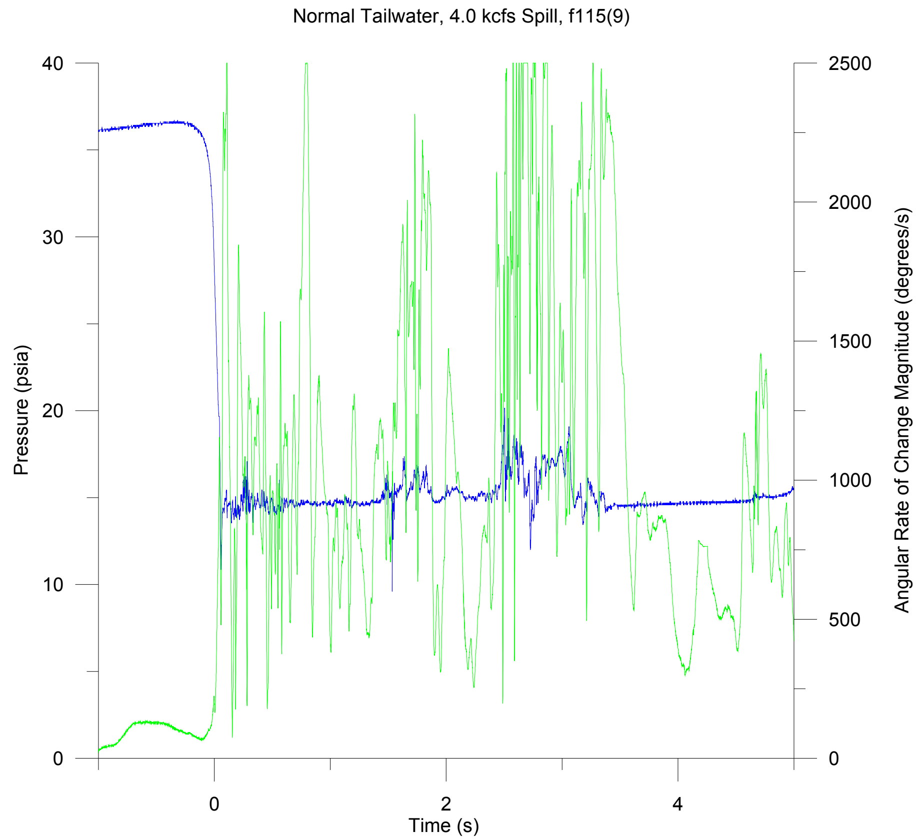
Normal Tailwater, 4.0 kcfs Spill, f930(5)
Pressure (psia)
0
10
20
30
40
Time (s)
0
2
4
Angular Rate of Change Magnitude (degrees/s)
0
500
1000
1500
2000
2500

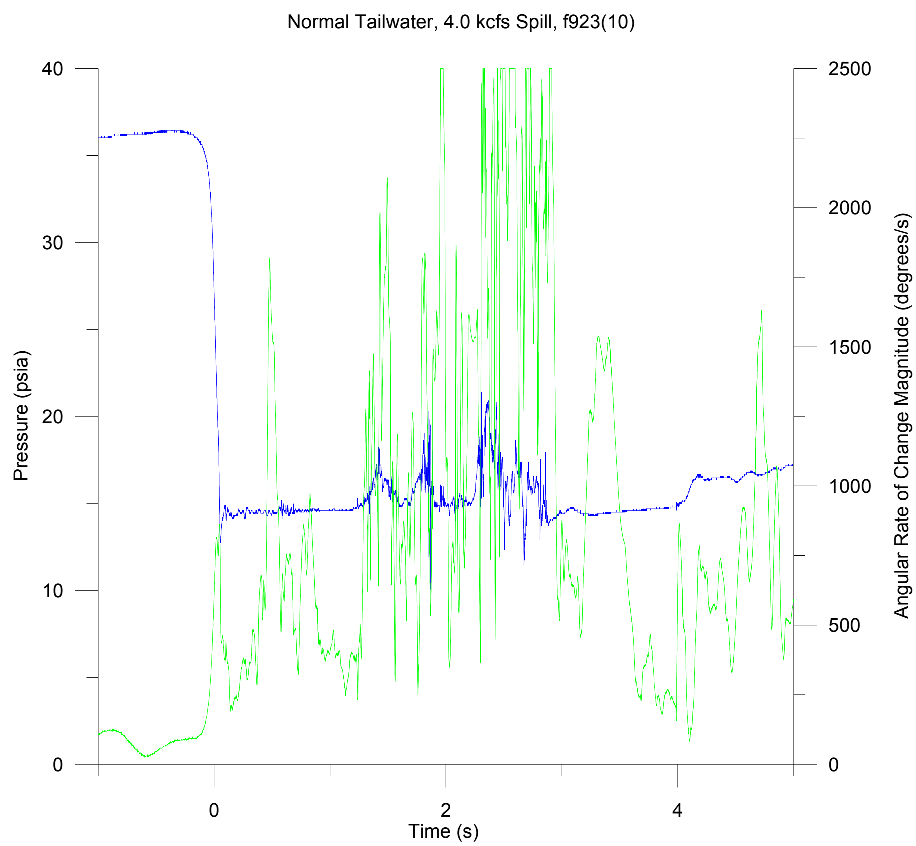


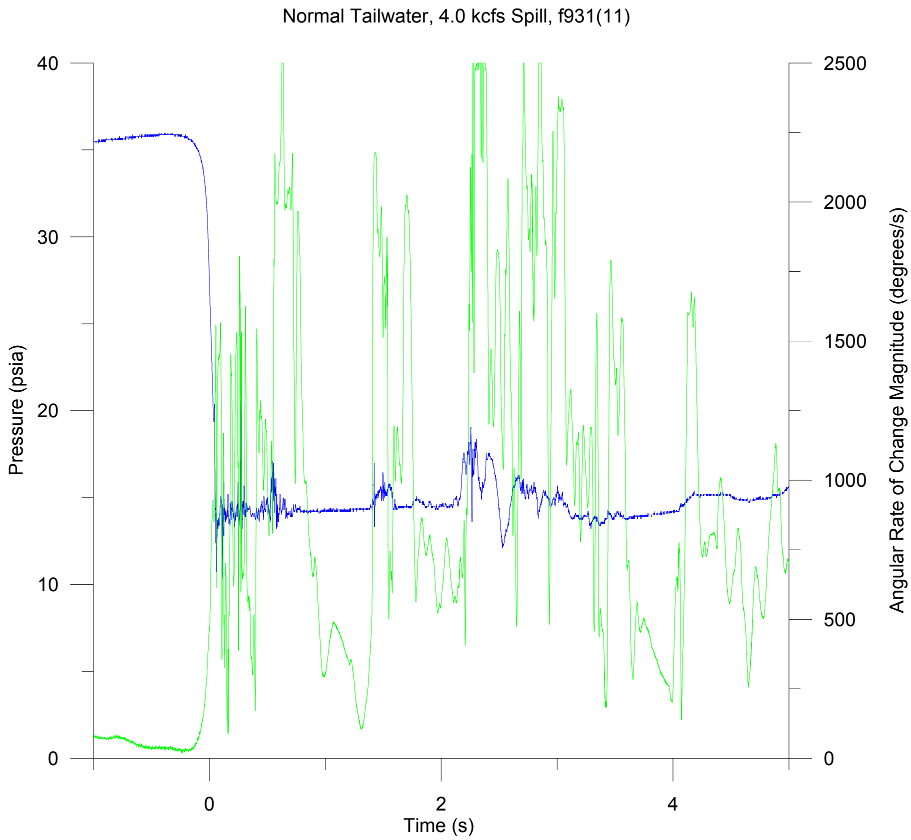
Normal Tailwater, 4.0 kcfs Spill, f640(6)
Pressure (psia)
0
10
20
30
40
Time (s)
0
2
4
Angular Rate of Change Magnitude (degrees/s)
0
500
1000
1500
2000
2500

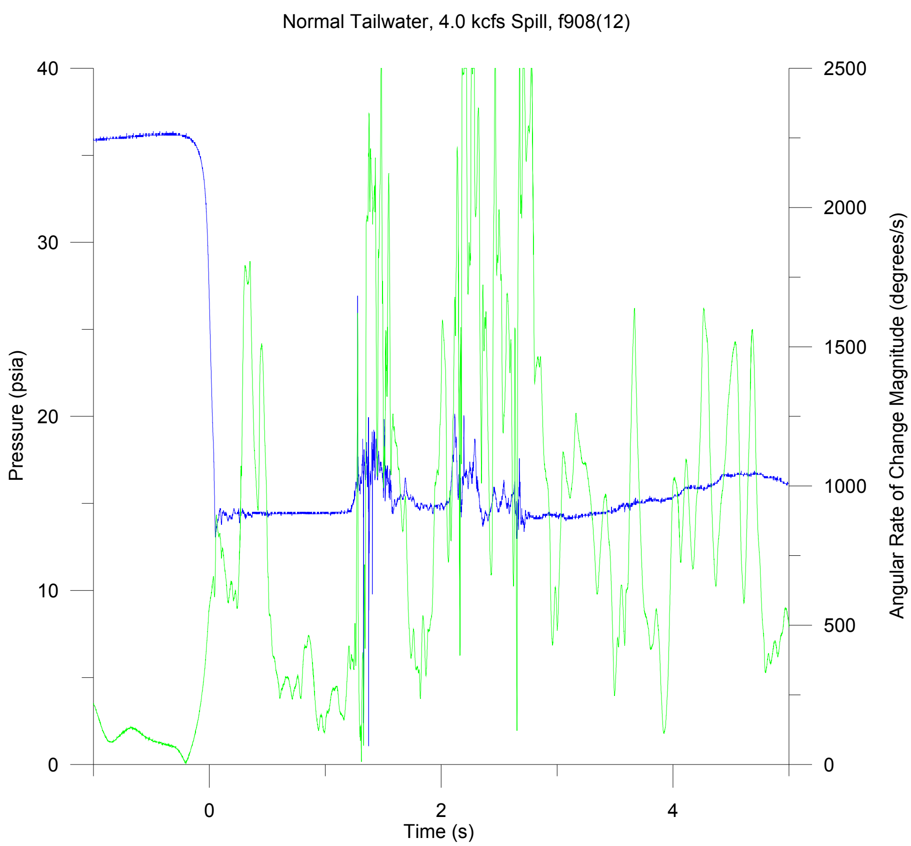

Normal Tailwater, 4.0 kcfs Spill, f635(7)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4

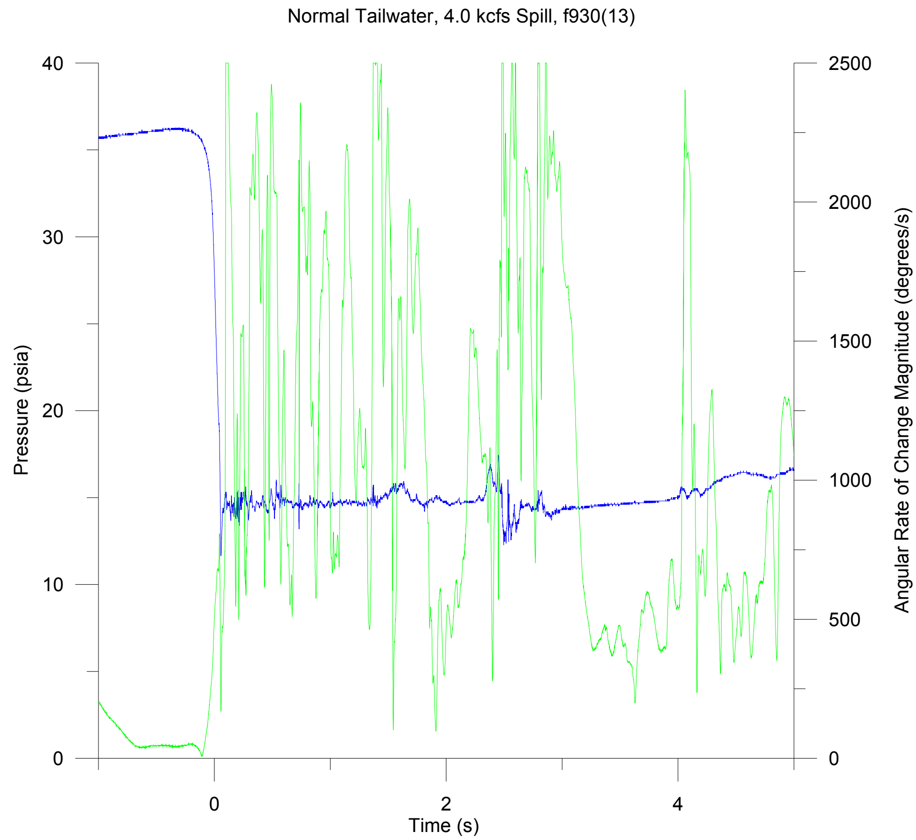

Normal Tailwater, 4.0 kcfs Spill, f664(8)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4

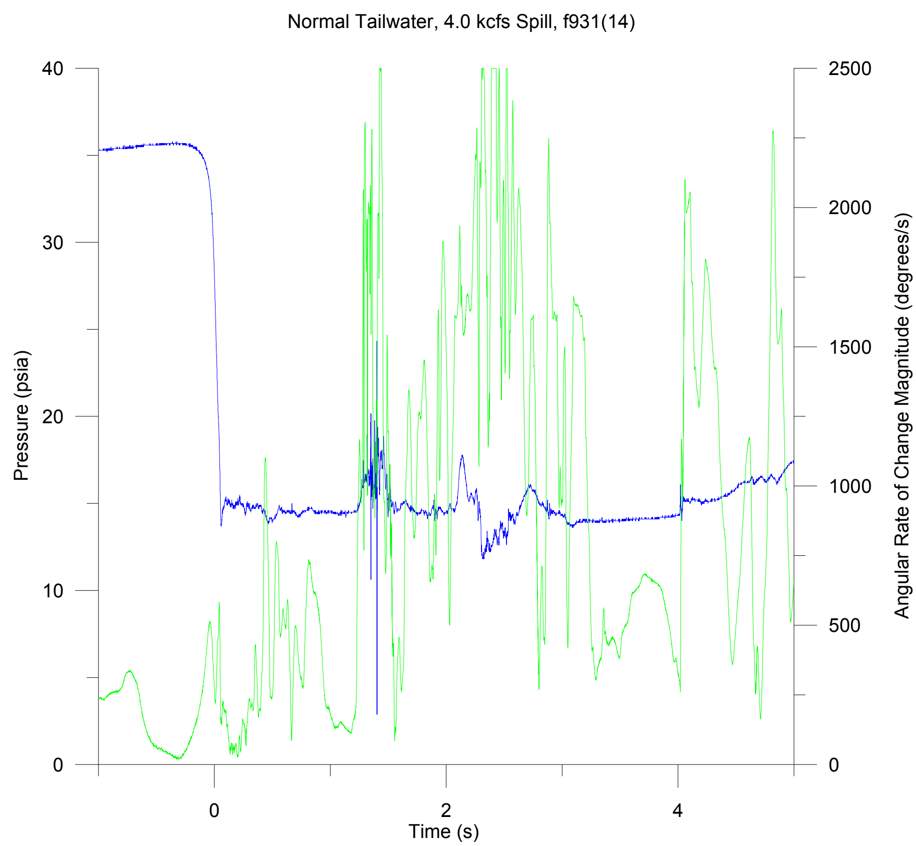

Normal Tailwater, 4.0 kcfs Spill, f115(9)
Pressure (psia)
0
10
20
30
40
Angular Rate of Change Magnitude (degrees/s)
0
500
1000
1500
2000
2500
Time (s)
0
2
4

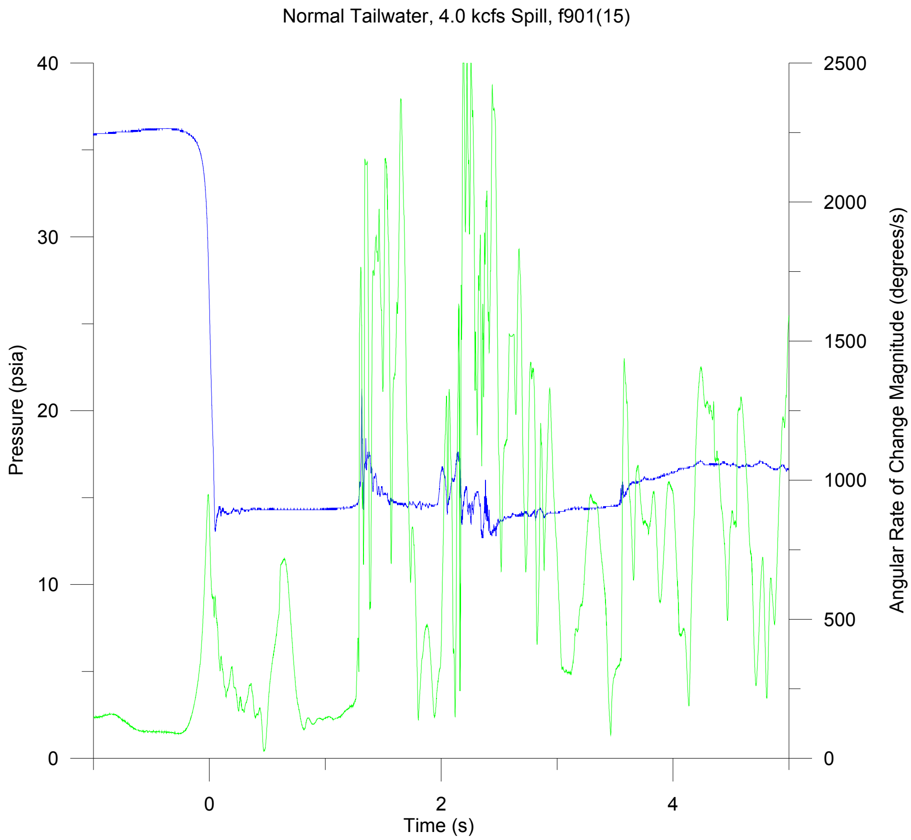

Normal Tailwater, 4.0 kcfs Spill, f923(10)
Pressure (psia)
0
10
20
30
40
Angular Rate of Change Magnitude (degrees/s)
0
500
1000
1500
2000
2500
Time (s)
0
2
4


Normal Tailwater, 4.0 kcfs Spill, f931(11)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
0
2
4


Normal Tailwater, 4.0 kcfs Spill, f908(12)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
0
2
4

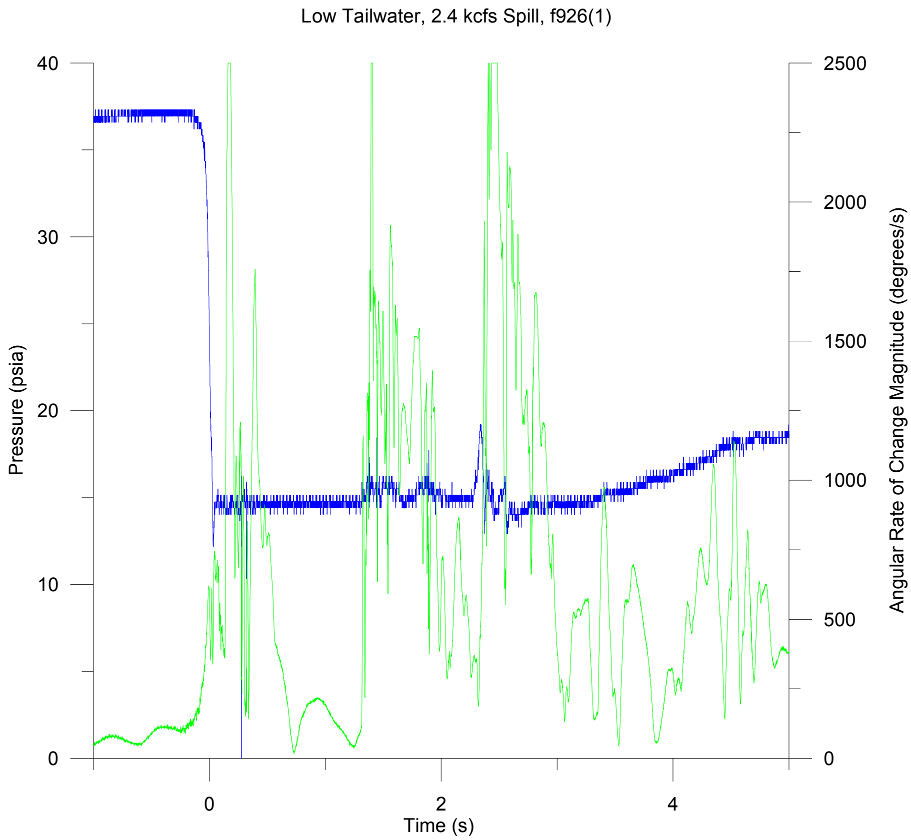

Normal Tailwater, 4.0 kcfs Spill, f930(13)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Normal Tailwater, 4.0 kcfs Spill, f931(14)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

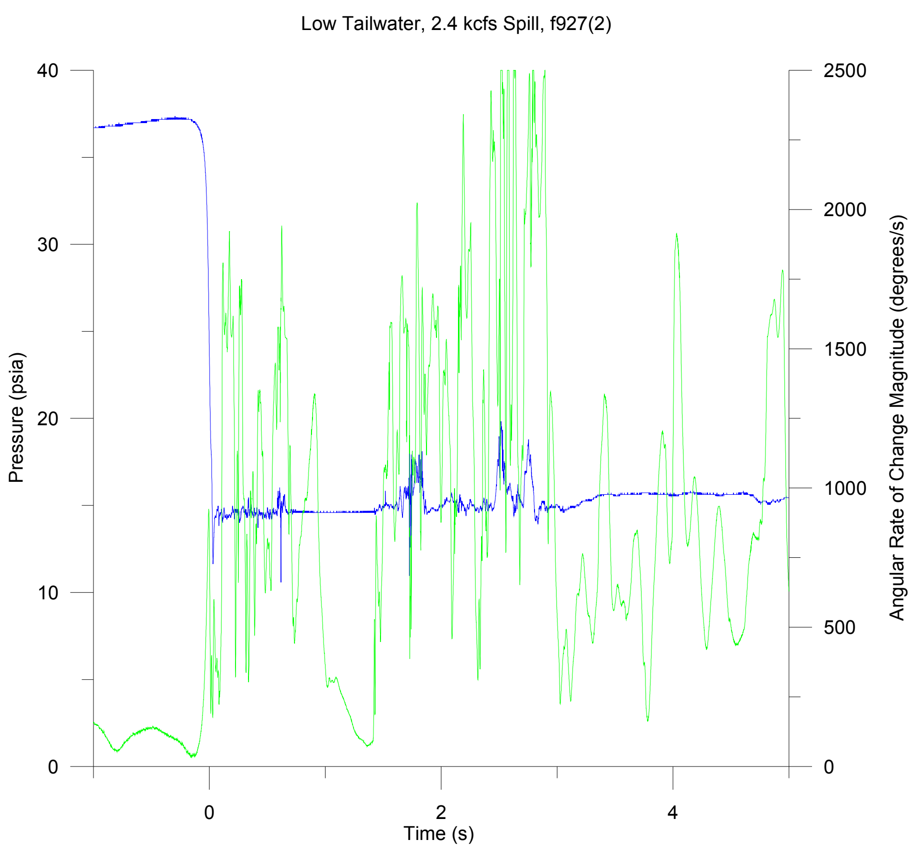

Normal Tailwater, 4.0 kcfs Spill, f901(15)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

John Day Dam Spillbay 20

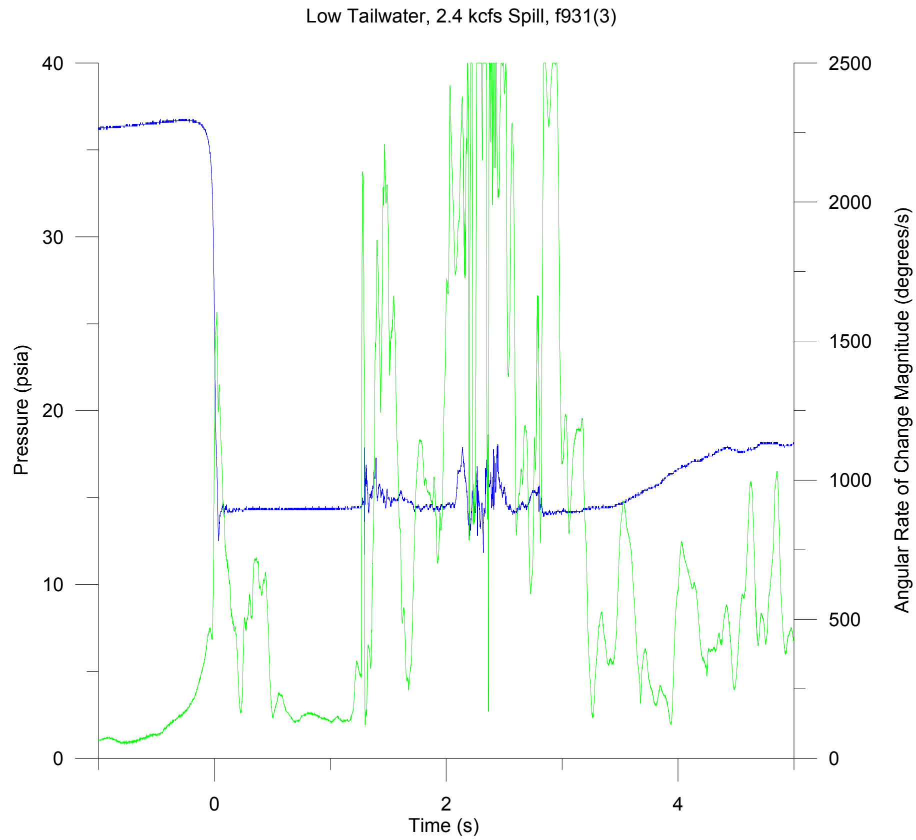
2.4-kcfs Discharge, Low Tailwater

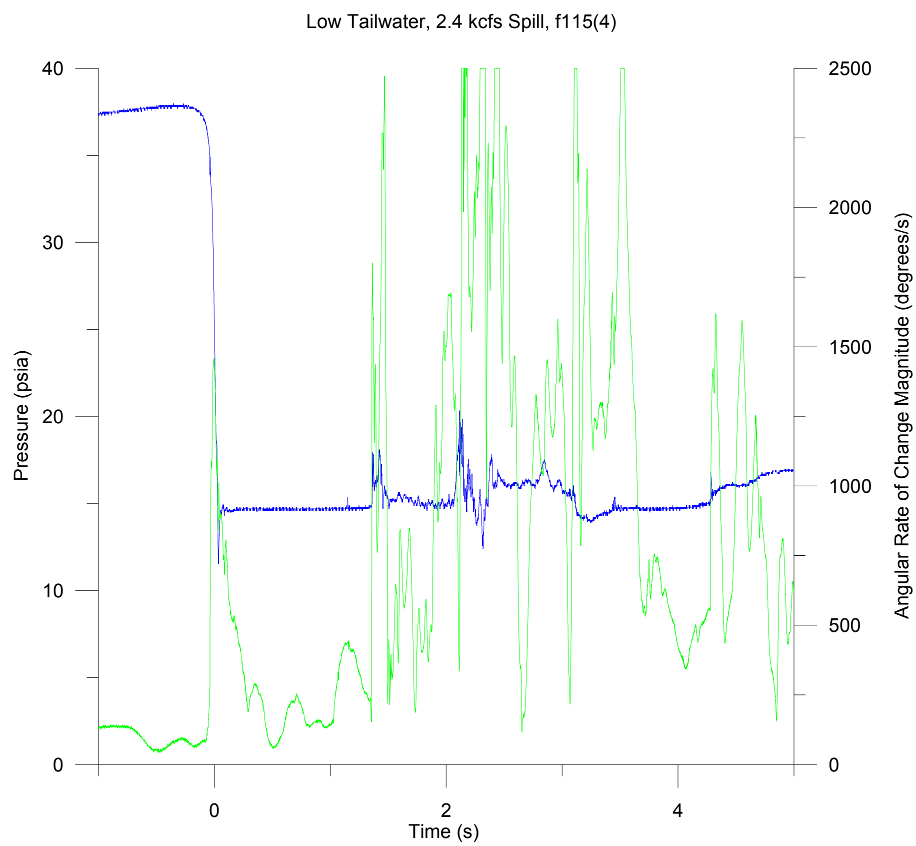


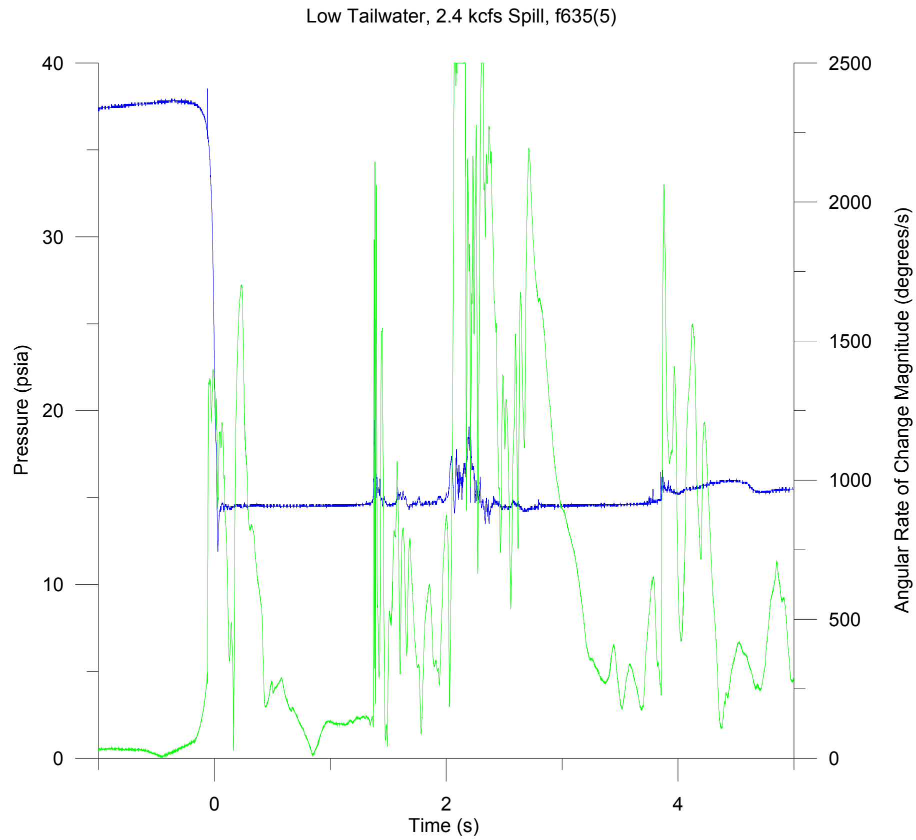
Low Tailwater, 2.4 kcfs Spill, f926(1)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

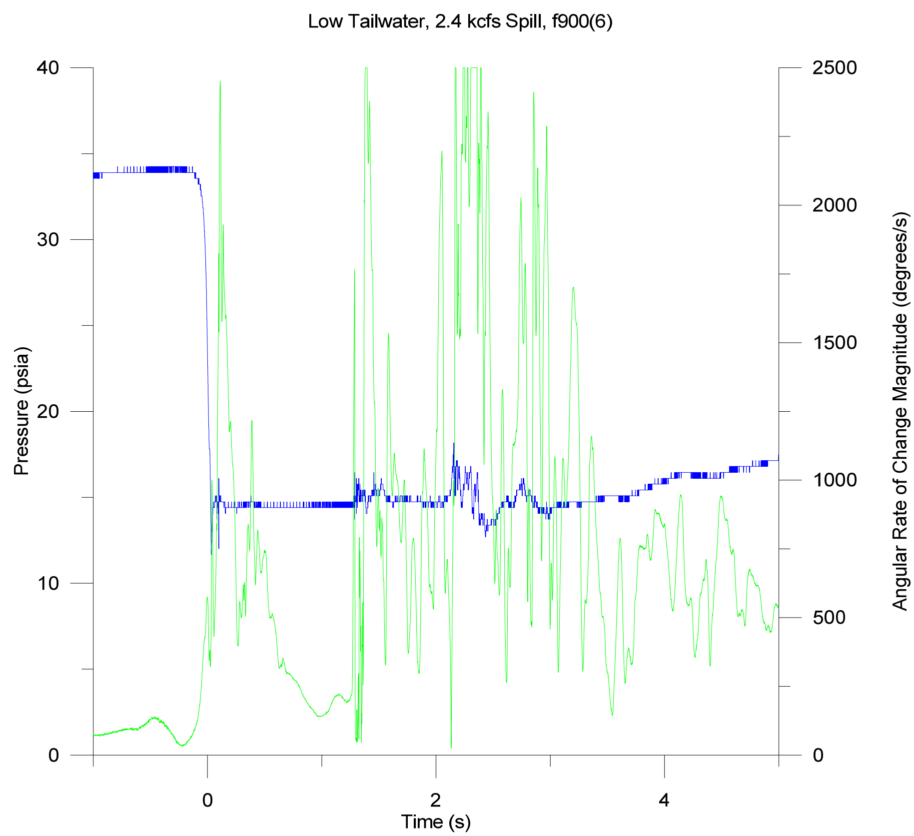


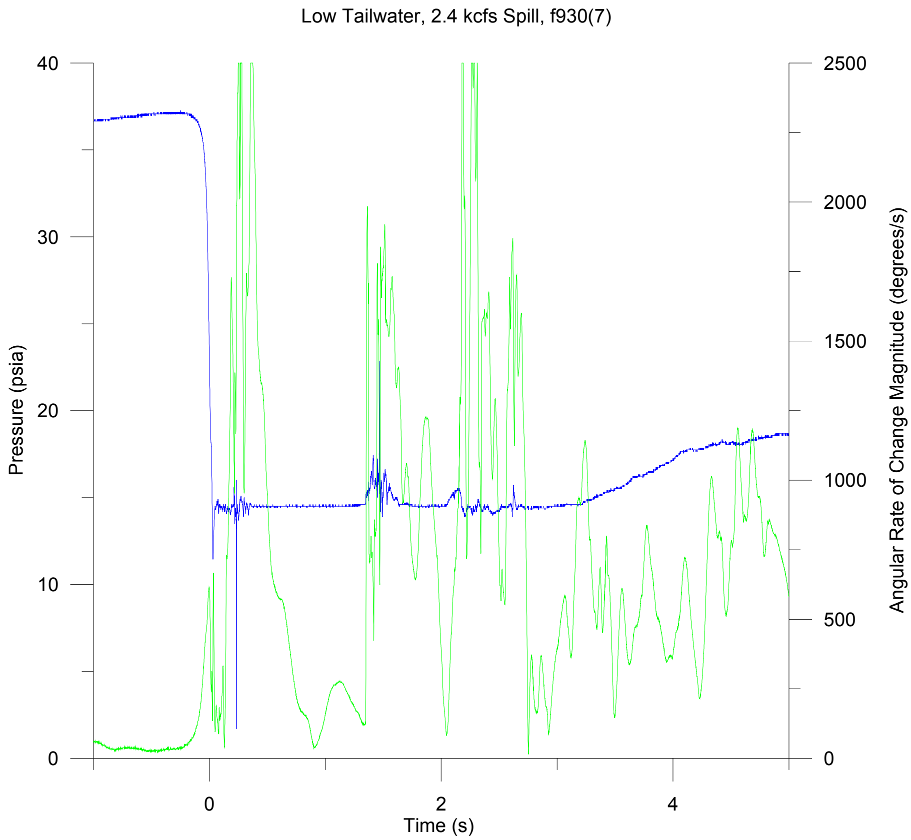
Low Tailwater, 2.4 kcfs Spill, f927(2)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4

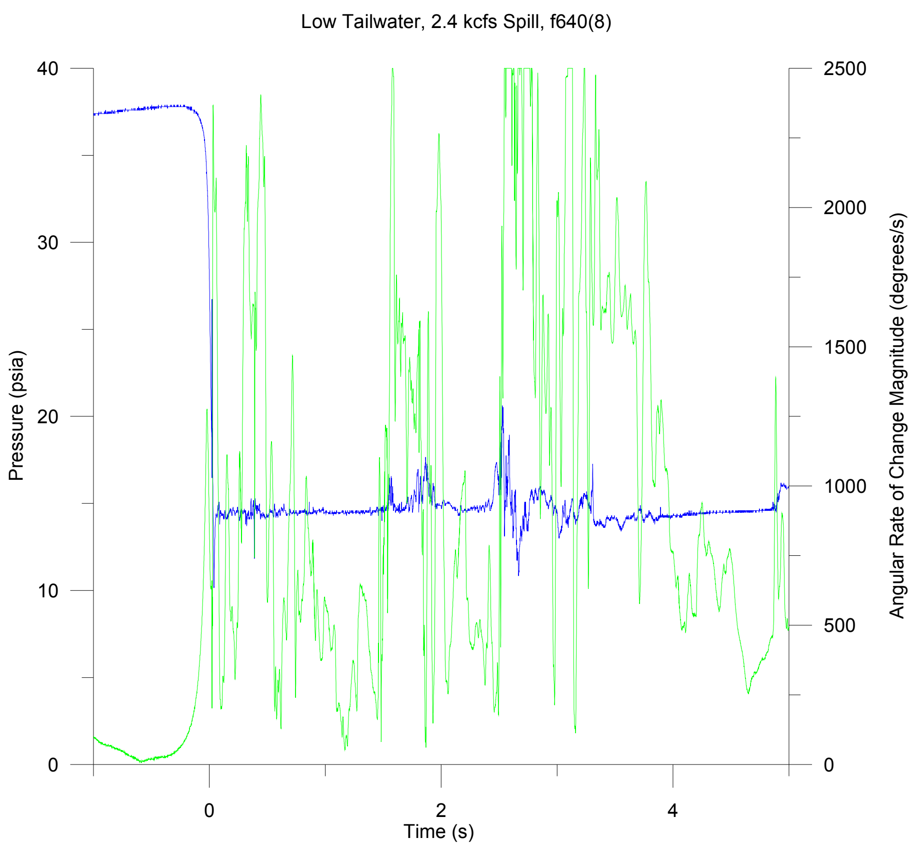

Low Tailwater, 2.4 kcfs Spill, f931(3)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Low Tailwater, 2.4 kcfs Spill, f115(4)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Low Tailwater, 2.4 kcfs Spill, f635(5)
Pressure (psia)
0
10
20
30
40
Angular Rate of Change Magnitude (degrees/s)
0
500
1000
1500
2000
2500
Time (s)
0
2
4


Low Tailwater, 2.4 kcfs Spill, f900(6)
Pressure (psia)
0
10
20
30
40
Angular Rate of Change Magnitude (degrees/s)
0
500
1000
1500
2000
2500
Time (s)
0
2
4


Low Tailwater, 2.4 kcfs Spill, f930(7)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
2
4


Low Tailwater, 2.4 kcfs Spill, f640(8)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
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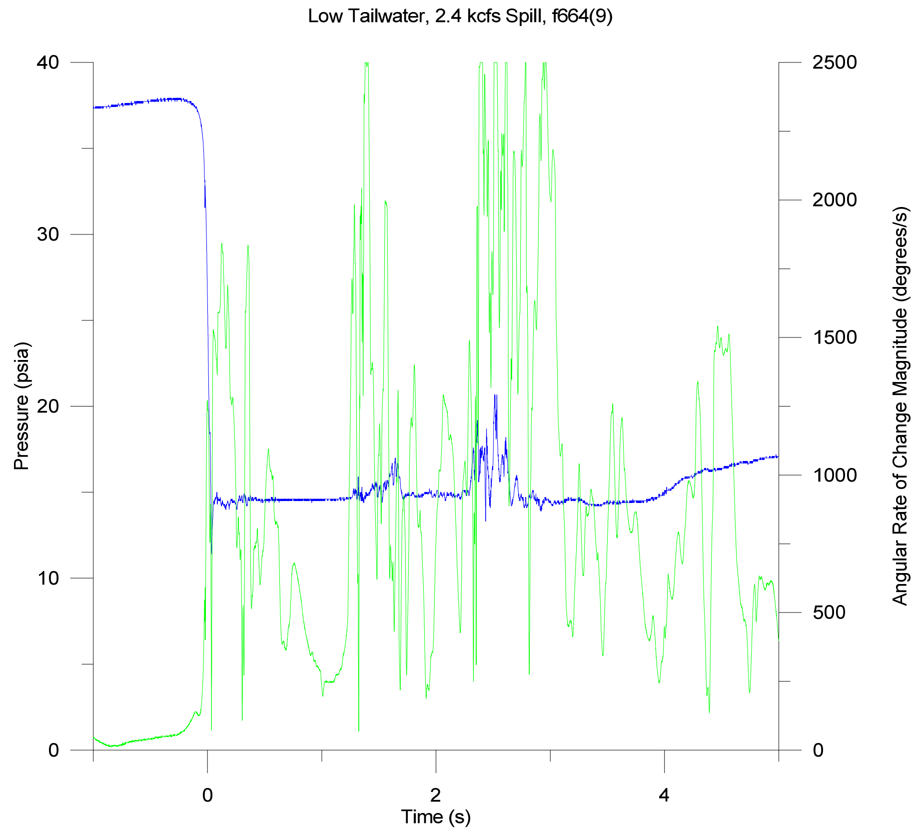
30
20
10
0
2500
2000
1500
1000
500
0
2
4


Low Tailwater, 2.4 kcfs Spill, f664(9)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
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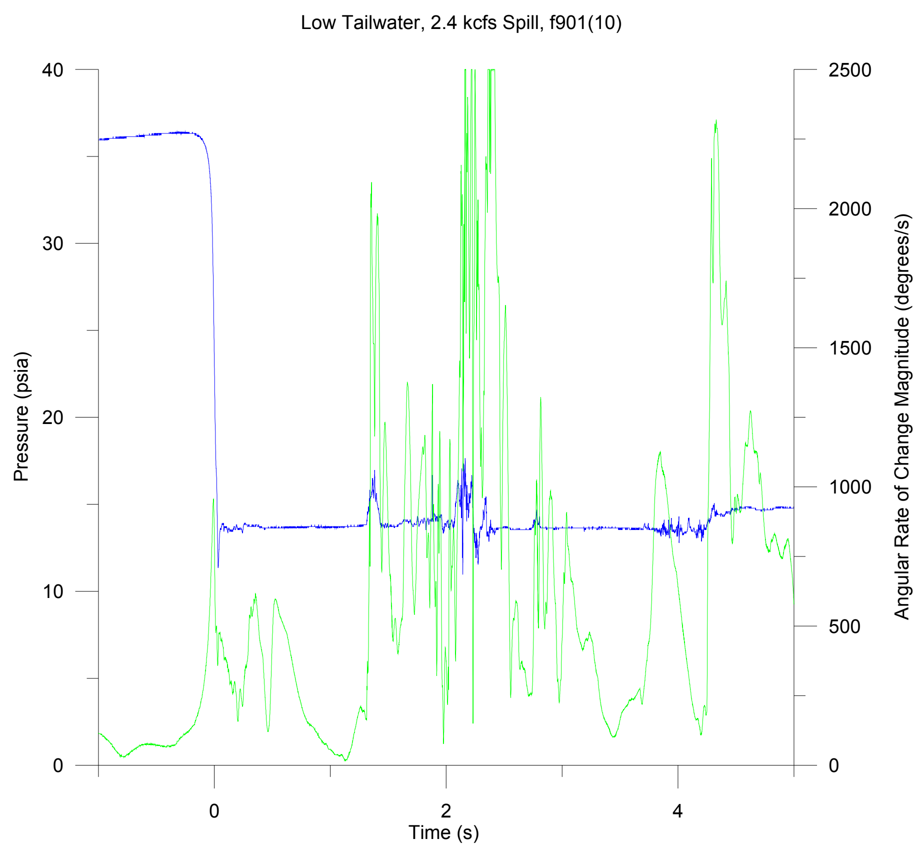
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Low Tailwater, 2.4 kcfs Spill, f901(10)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
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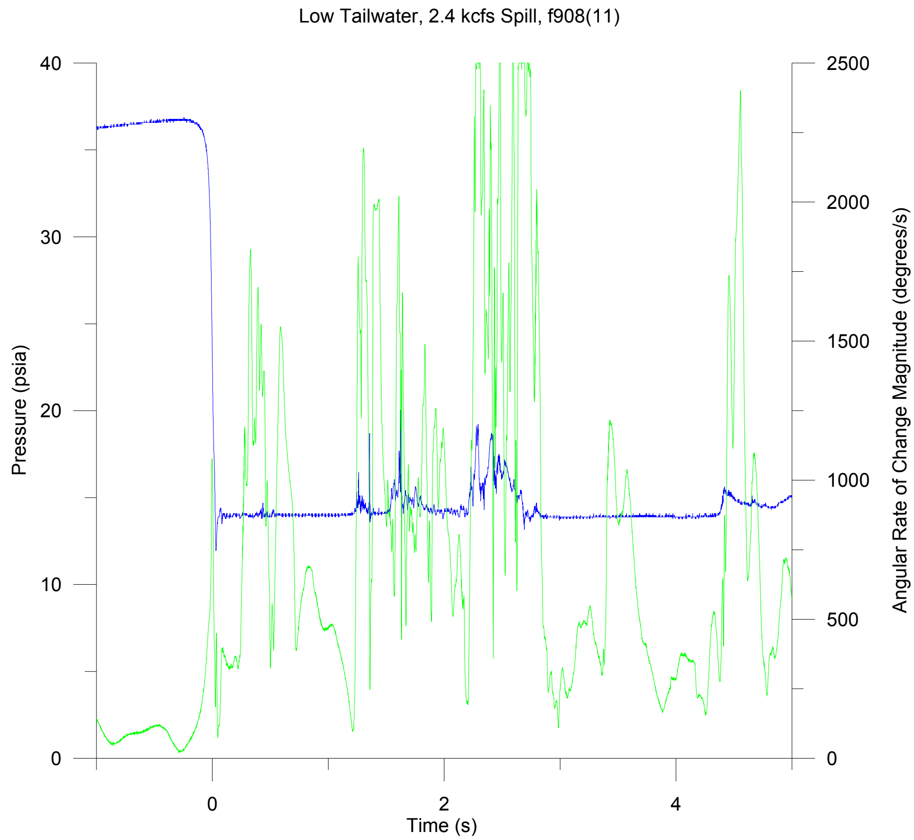
20
30
40
0
500
1000
1500
2000
2500
0
2
4



Low Tailwater, 2.4 kcfs Spill, f908(11)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
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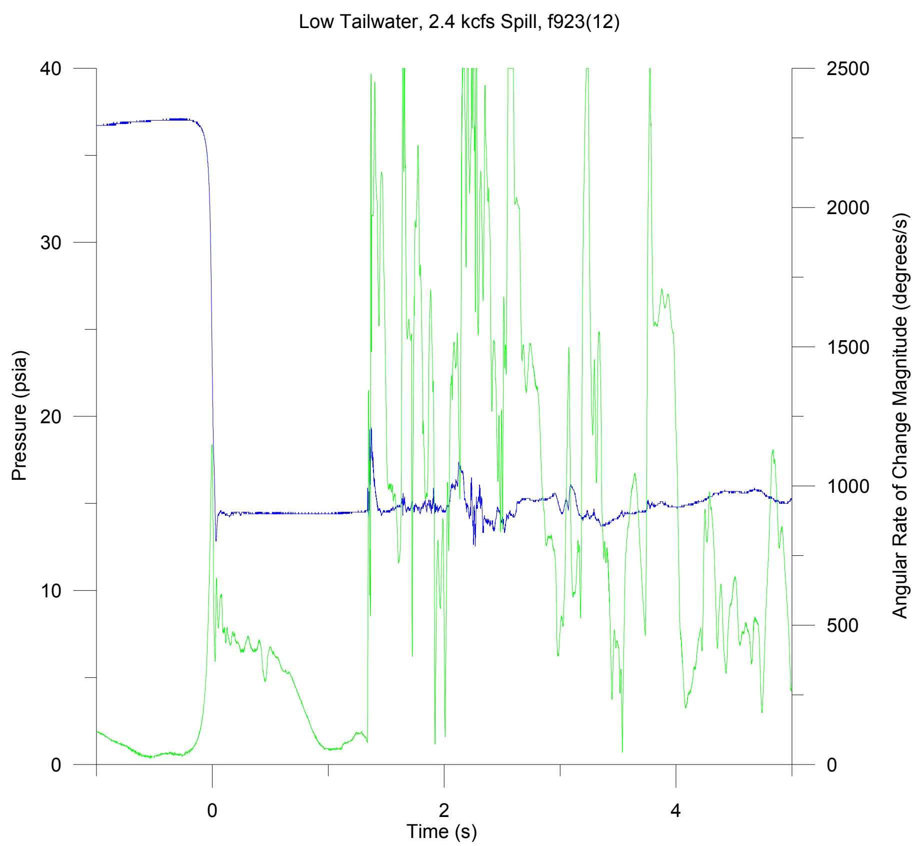
20
30
40
500
1000
1500
2000
2500
2
4



Low Tailwater, 2.4 kcfs Spill, f923(12)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
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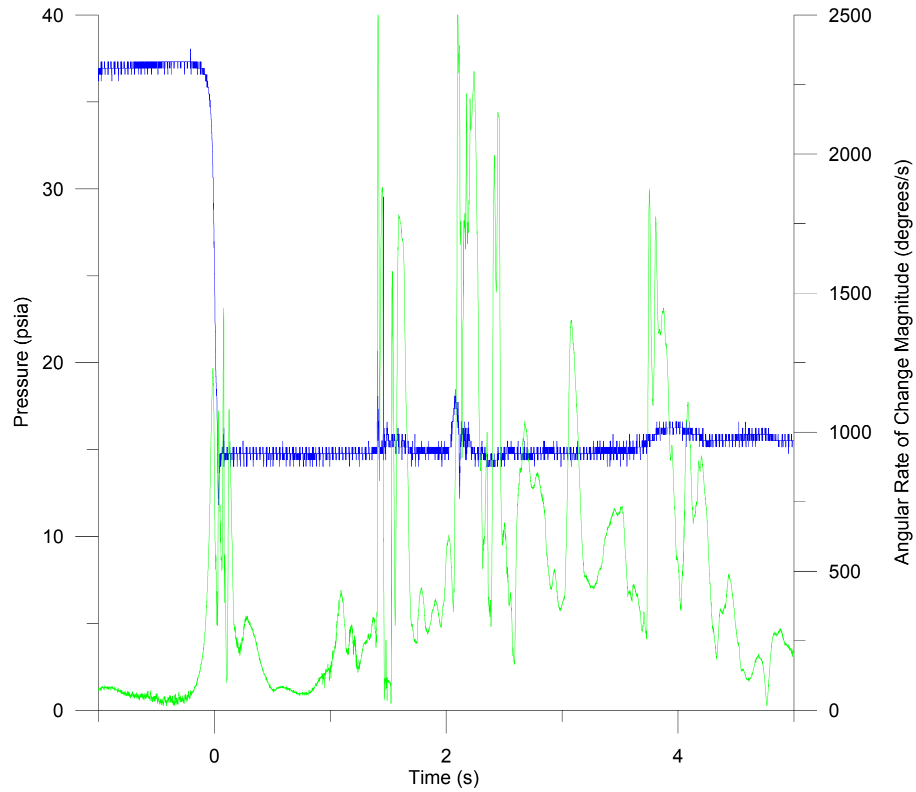
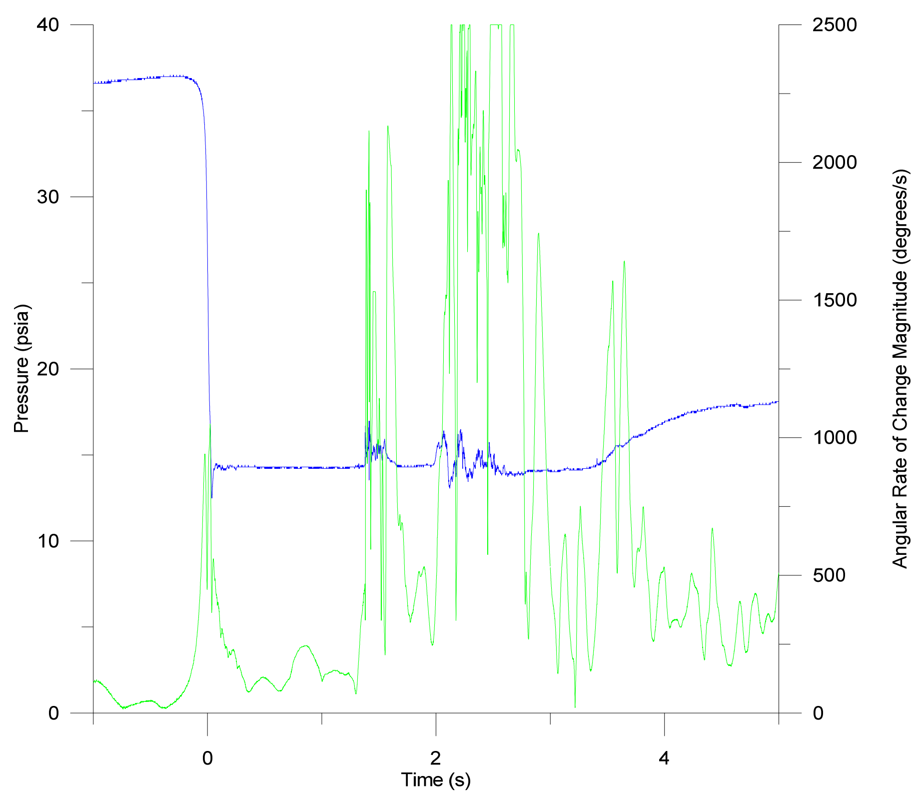
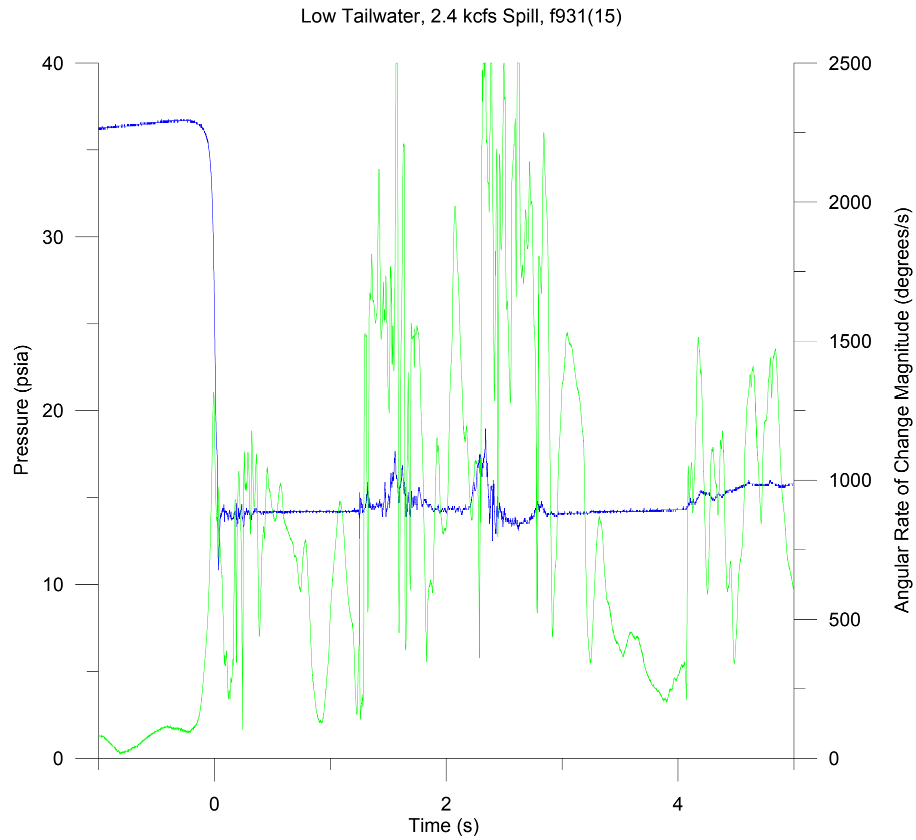
10
20
30
40
500
1000
1500
2000
2500
2
4

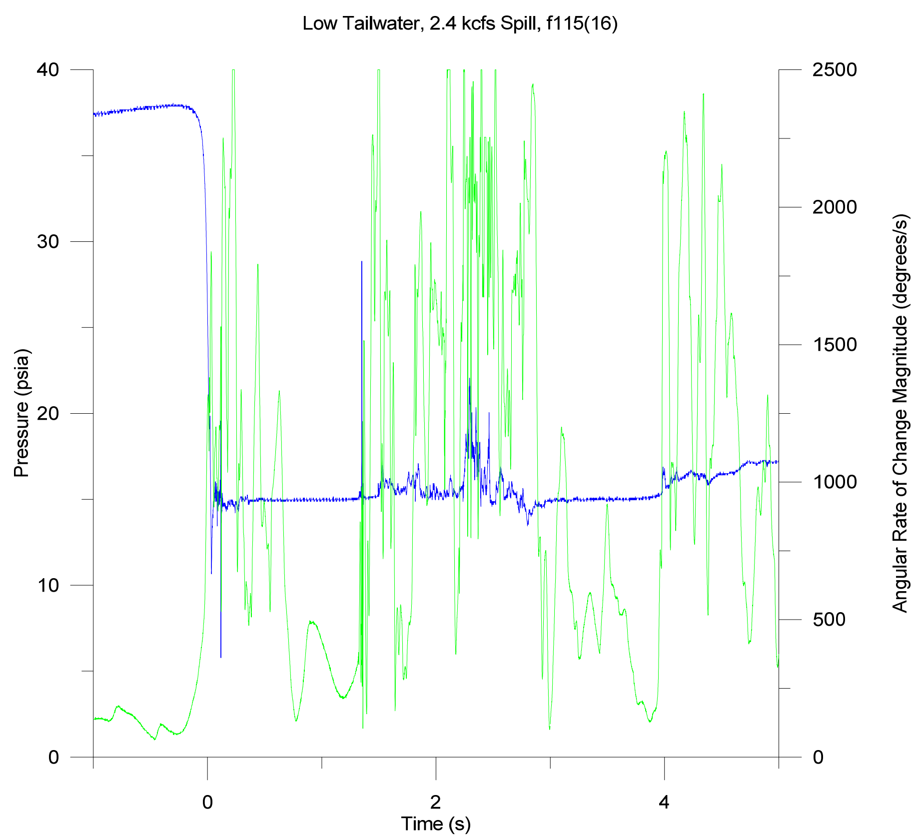
Low Tailwater, 2.4 kcfs Spill, f926(13)



Low Tailwater, 2.4 kcfs Spill, f927(14)




Low Tailwater, 2.4 kcfs Spill, f931(15)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
20
30
40
0
500
1000
1500
2000
2500
0
2
4


Low Tailwater, 2.4 kcfs Spill, f115(16)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
0
10
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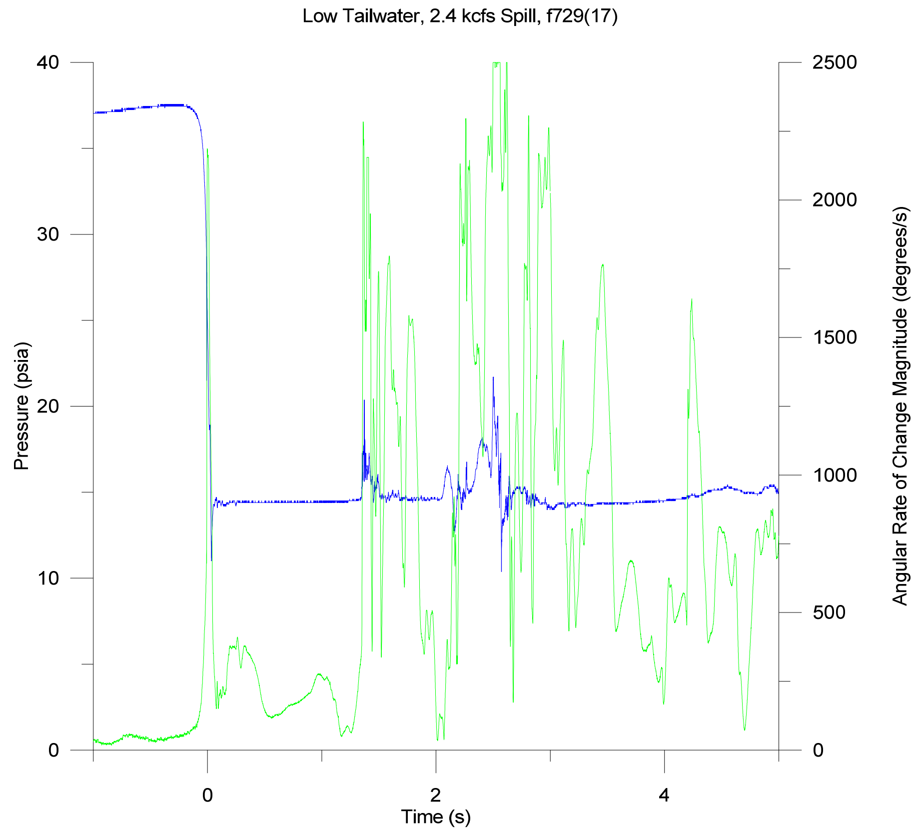
30
40
0
500
1000
1500
2000
2500
0
2
4



Low Tailwater, 2.4 kcfs Spill, f729(17)
Pressure (psia)
Angular Rate of Change Magnitude (degrees/s)
Time (s)
40
30
20
10
0
2500
2000
1500
1000
500
0
0
2
4

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